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Faculty of Civil Engineering
School of Civil Engineering

Curricular Plan 202x

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Executive Summary

This document presents the curriculum design for the Ingeniería Civil program at Universidad Nacional de Ingeniería (UNI) under the international standards and the global references of the *Body of Knowledge of Civil Engineering*. It synthesizes the disciplinary evolution of Ingeniería Civil from its scientific foundations to the demands for resilient, sustainable, and intelligent 21st-century infrastructure. The program adapts these global references to our regional context:

- Local and national requirements in construction, urban development, and infrastructure management.
- Institutional strengths in applied research, innovation in materials, construction methods, and project management.
- Emerging trends in digitalization, automation, and sustainability in Ingeniería Civil.

Contemporary Ingeniería Civil integrates the following domains:

- Basic Sciences and Engineering Fundamentals
- Traditional and Core Sciences (Structural, Geotechnical, Hydraulics, Transportation, Construction)
- Modern Trends (Digital Infrastructure, Sustainability, Resilience, Advanced Management, Technology)
- Soft Skills and Professional Ethics.

The pedagogical model is based on four pillars:

- **Technical Excellence**: Scientific foundations, structural design, soil mechanics, hydraulics, and construction technologies.
- **Digital Innovation**: BIM modeling, emerging technologies, and efficient project management.
- **Integral Sustainability**: Circular economy, resilient design, environmental impact, and responsible resource management.
- **Integral Human Formation**: Virtues, ethical awareness, public responsibility, and professional social commitment.

Universidad Nacional de Ingeniería (UNI), faithful to its identity, incorporates a solid foundation in basic sciences as a pillar, developing in students:

- Ability to discern ethical and social impacts of technical and design decisions.
- Sensitivity towards equity challenges, public safety, and community development through infrastructure.
- Commitment to integral human development and the common good, especially of vulnerable populations.
- Leadership based on values, professional integrity, and service to society.

This curriculum will produce professionals with:

- Ability to conceive, design, build, operate, and maintain complex infrastructure systems that are safe, functional, sustainable, and economical.
- Competencies to lead digital transformation in civil engineering projects with advanced methodologies and tools.
- Ability to integrate technical efficiency with environmental sustainability, social responsibility, and disaster resilience.
- Formation that enables them to practice their profession with technical excellence, moral rectitude, and a sense of public service.

The proposal incorporates continuous updating mechanisms, ensuring relevance in the face of technological evolution and alignment with international standards, while maintaining the distinctive mark of the formation that characterizes Universidad Nacional de Ingeniería (UNI).

Contents

Acknowledgments **xxv**

Acronyms **xxvii**

1 Introducción **1**
1.1 Basic definitions . . . 1
1.2 Occupational Field and Job Market . . . 2
1.3 Importance of the Program in Society . . . 3
1.4 Institutional Info . . . 4
1.4.1 Mission . . . 4
1.4.2 Vision . . . 4
1.5 Accreditation information . . . 4
1.5.1 Career Outcomes . . . 4
1.5.2 Educational objectives . . . 5
1.5.3 Learning Outcomes . . . 5
1.6 Profiles . . . 6
1.6.1 Applicant profile . . . 6
1.6.2 Graduate profile . . . 6
1.6.3 ProfessionalProfile . . . 6
1.6.4 Faculty profile . . . 7
1.7 Degrees and Titles . . . 7
1.8 Resources to teach . . . 7
1.9 Document Organization . . . 8

2 Body of knowledge of Civil Engineering **9**
2.1 Engineering Mechanics and Materials (EMM) . . . 10
2.1.1 EMM/Construction Materials Science (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 11
2.1.2 EMM/Mechanics of Materials and Structural Behavior (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 11
2.1.3 EMM/Concrete Technology and Advanced Cementitious Materials (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 12
2.1.4 EMM/Special Concretes and Concrete in Extreme Climates (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 13
2.1.5 EMM/Concrete Transport and Placement (Core Tier1: 1 hr, Core Tier2: 1 hr) 13
2.1.6 EMM/Statistical Quality Control of Concrete (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 14
2.1.7 EMM/Structural Metals, Alloys, and Corrosion Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 14
2.1.8 EMM/Polymeric, Composite, and Sustainable Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 15
2.1.9 EMM/Standardized Testing, Quality Control, and Failure Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 15
2.1.10 EMM/Traditional and Vernacular Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 16

2.1.11 EMM/Equilibrium of Particles and Rigid Bodies (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 16
2.1.12 EMM/Internal Forces in Trusses and Frames (Core Tier1: 1 hr, Core Tier2: 1 hr) 17
2.1.13 EMM/Geometric Properties of Areas and Friction (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 17
2.1.14 EMM/Kinematics of Rigid Bodies in Plane Motion (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 17
2.1.15 EMM/Kinetics of Rigid Bodies in Plane Motion (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 18
2.1.16 EMM/Introduction to Structural Vibrations (Core Tier1: 1 hr, Core Tier2: 1 hr) 18
2.2 Structural Analysis and Design (SAD) . . . 18
2.2.1 SAD/Structural Analysis I (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 19
2.2.2 SAD/Energy Methods for Structural Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 20
2.2.3 SAD/Force Method for Indeterminate Structures (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 20
2.2.4 SAD/Classical Displacement Methods (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 20
2.2.5 SAD/Matrix Structural Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 21
2.2.6 SAD/Seismology and Natural Hazards (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 21
2.2.7 SAD/Seismic Design Code and Structural Configuration Criteria (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 21
2.2.8 SAD/Structural Dynamics and Earthquake Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 22
2.2.9 SAD/Building Structural Analysis and Modeling Practicum (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 22
2.2.10 SAD/Reinforced Concrete Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 23
2.2.11 SAD/Design of Reinforced Concrete Stairs (Core Tier1: 1 hr, Core Tier2: 1 hr) 23
2.2.12 SAD/Seismic Detailing of Reinforced Concrete (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 24
2.2.13 SAD/Prestressed Concrete Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 24
2.2.14 SAD/Prestressed Concrete Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 24
2.2.15 SAD/Integrated Structural Design Project (Core Tier1: 1 hr, Core Tier2: 1 hr) 25
2.2.16 SAD/Design of Steel Members in Tension and Compression (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 25
2.2.17 SAD/Design of Steel Members in Flexure (Core Tier1: 1 hr, Core Tier2: 1 hr) 25
2.2.18 SAD/Steel Connections and Composite Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 26
2.2.19 SAD/Design Process for Low-Rise Buildings (Core Tier1: 1 hr, Core Tier2: 1 hr) 26
2.2.20 SAD/Masonry Structural Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 26
2.2.21 SAD/Timber and Light-Gauge Steel Framing Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 27
2.2.22 SAD/Adobe Structural Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 27
2.2.23 SAD/Bridge Superstructure Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 27
2.2.24 SAD/Bridge Substructure, Evaluation, and Special Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 28
2.2.25 SAD/Finite Element Methods in Structural Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 28
2.2.26 SAD/Nature and Characterization of Loads on Existing Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 29
2.2.27 SAD/Nonlinear Behavior of Structures (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 29
2.2.28 SAD/Structural Rehabilitation, Strengthening, and Retrofit (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 30
2.2.29 SAD/Industrial Structures: Chimneys and Tanks (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 30
2.2.30 SAD/Advanced Structural Analysis . . . 31
2.3 Geotechnical Engineering (GTE) . . . 31

2.3.1 GTE/Phase Relationships and Seepage (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 32
2.3.2 GTE/Shear Strength and Consolidation (Core Tier1: 1 hr, Core Tier2: 1 hr) . 32
2.3.3 GTE/Site Investigation and In-Situ Testing (Core Tier1: 1 hr, Core Tier2: 1 hr) 33
2.3.4 GTE/Bearing Capacity and Design (Core Tier1: 1 hr, Core Tier2: 1 hr) 34
2.3.5 GTE/Deep Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr) 34
2.3.6 GTE/Earth Retaining Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) 35
2.3.7 GTE/Slope Stability Analysis and Stabilization (Core Tier1: 1 hr, Core Tier2: 1 hr) 35
2.3.8 GTE/Geotechnical Earthquake Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) 36
2.3.9 GTE/Ground Improvement Techniques (Core Tier1: 1 hr, Core Tier2: 1 hr) . 36
2.3.10 GTE/Problematic Soils and Foundation-Soil Classification (Core Tier1: 1 hr, Core Tier2: 1 hr) 37
2.3.11 GTE/Geotechnical Numerical Modeling and Applications (Core Tier1: 1 hr, Core Tier2: 1 hr) 37
2.3.12 GTE/Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 38
2.3.13 GTE/Geotechnical Characterization for Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 38
2.3.14 GTE/Geotechnical Design of Embankment Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 38
2.3.15 GTE/Dam Instrumentation and Monitoring (Core Tier1: 1 hr, Core Tier2: 1 hr) 39
2.3.16 GTE/Construction of Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 39
2.3.17 GTE/Operation and Safety Management of Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 40
2.3.18 GTE/Geosynthetics for Geotechnical Engineering 40
2.4 General Geology (GGL) 40
2.4.1 GGL/Mineralogy (Core Tier1: 1 hr, Core Tier2: 1 hr) 41
2.4.2 GGL/Petrology and the Rock Cycle (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 41
2.4.3 GGL/Structural Geology (Core Tier1: 1 hr, Core Tier2: 1 hr) 42
2.4.4 GGL/Geomorphology, Weathering, and Erosion Processes (Core Tier1: 1 hr, Core Tier2: 1 hr) 42
2.4.5 GGL/Geologic Time, Stratigraphy, and Geologic Mapping (Core Tier1: 1 hr, Core Tier2: 1 hr) 43
2.4.6 GGL/Basic Surface and Groundwater Hydrology of Geologic Materials (Core Tier1: 1 hr, Core Tier2: 1 hr) 43
2.4.7 GGL/Applied Geology (Core Tier1: 1 hr, Core Tier2: 1 hr) 43
2.4.8 GGL/Rock Mass Characterization and Applied Rock and Soil Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr) 44
2.4.9 GGL/Engineering Geological and Geotechnical Mapping (Core Tier1: 1 hr, Core Tier2: 1 hr) 44
2.4.10 GGL/Soils and Rocks as Natural Resources for Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr) 45
2.4.11 GGL/Engineering Geology Applied to Roads and Canals (Core Tier1: 1 hr, Core Tier2: 1 hr) 45
2.4.12 GGL/Engineering Geology Applied to Bridges, Tunnels, and Dams (Core Tier1: 1 hr, Core Tier2: 1 hr) 45
2.4.13 GGL/Geological Hazards and Mass Movements (Core Tier1: 1 hr, Core Tier2: 1 hr) 46
2.5 Water Resources and Hydraulic Engineering (WRH) 46
2.5.1 WRH/Hydrologic Cycle and Water Balance (Core Tier1: 1 hr, Core Tier2: 1 hr) 47
2.5.2 WRH/Surface Hydrology and Watershed Modeling (Core Tier1: 1 hr, Core Tier2: 1 hr) 47
2.5.3 WRH/Flood Frequency Analysis and Climate Change (Core Tier1: 1 hr, Core Tier2: 1 hr) 47
2.5.4 WRH/Open Channel Flow and River Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr) 48

2.5.5 WRH/Pressurized Pipe Flow and Pump Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 48
2.5.6 WRH/Design of Hydraulic Structures (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 49
2.5.7 WRH/Urban Water Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) 49
2.5.8 WRH/Groundwater Hydrology (Core Tier1: 1 hr, Core Tier2: 1 hr) 50
2.5.9 WRH/Economic, Financial and Social Evaluation of Water Resources Projects (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 50
2.5.10 WRH/Sediment Transport in Alluvial Channels (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 51
2.5.11 WRH/Scour and Fluvial Morphology (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 51
2.5.12 WRH/River Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) 52
2.5.13 WRH/Agricultural Water Demand (Core Tier1: 1 hr, Core Tier2: 1 hr) 52
2.5.14 WRH/Irrigation Systems Design (Core Tier1: 1 hr, Core Tier2: 1 hr) 52
2.5.15 WRH/Coastal and Floodplain Engineering 53
2.6 Environmental Systems Engineering (ESE) 53
2.6.1 ESE/Water and Wastewater Treatment Process Design (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 54
2.6.2 ESE/Environmental Chemistry and Microbiology for Engineers (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 54
2.6.3 ESE/Air Quality and Pollution Control Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 55
2.6.4 ESE/Environmental Impact Assessment and Sustainability Metrics (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 56
2.6.5 ESE/Climate Adaptation Engineering for Water Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 56
2.6.6 ESE/Solid and Hazardous Waste Management 57
2.7 Construction Engineering and Management (CEM) 57
2.7.1 CEM/Construction Methods, Equipment, and Productivity (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 58
2.7.2 CEM/Project Planning, Scheduling, and Control (CPM, 4D/5D) (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 58
2.7.3 CEM/Construction Cost Estimating and Quantification (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 59
2.7.4 CEM/Construction Budgeting, Bidding, and Financial Control (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 59
2.7.5 CEM/Price Adjustment and Progress Valuations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 60
2.7.6 CEM/Construction Safety, Health, and Risk Management (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 60
2.7.7 CEM/Contracts, Specifications, and Construction Law (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 61
2.7.8 CEM/Lean Construction and Integrated Project Delivery (IPD) (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 61
2.7.9 CEM/Construction Layout and Staking of Works (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 62
2.7.10 CEM/Formwork Design and Shoring Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 62
2.7.11 CEM/Rebar Detailing, Fabrication, and Placement (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 63
2.7.12 CEM/Construction Site and Field Management (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 63
2.7.13 CEM/Integrated Quality, Environmental, and Safety Management Systems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 64
2.8 Digital Technologies in Civil Engineering (DTC) 64
2.8.1 DTC/Structural Health Monitoring (SHM) and Sensor Technologies (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 64

2.8.2 DTC/Building Information Modeling (BIM) for Digital Delivery and Asset Management (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 65
2.8.3 DTC/Artificial Intelligence and Machine Learning Applications in Civil Engineering . . . 66
2.8.4 DTC/Digital Twins for Infrastructure Lifecycle Management . . . 66
2.8.5 DTC/Geospatial Engineering . . . 67
2.8.6 DTC/Data Analytics, Visualization, and Informatics for Civil Systems . . . 67
2.8.7 DTC/Automation, Robotics, and Additive Manufacturing (3D Printing) in Construction . . . 68
2.9 Sustainable and Resilient Infrastructure (SRI) . . . 68
2.9.1 SRI/Foundational Sustainability Principles and Triple Bottom Line (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 69
2.9.2 SRI/Resource Efficiency and Circular Economy (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 69
2.9.3 SRI/Social, Economic, and Governance Dimensions of Sustainable Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 69
2.9.4 SRI/Resilient Design for Natural Hazards and Climate Change (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 70
2.9.5 SRI/Green Building Systems and Sustainable Urban Development (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 70
2.9.6 SRI/Life Cycle Assessment (LCA) and Embodied Carbon Accounting . . . 71
2.9.7 SRI/Nature-Based Solutions and Low-Impact Development . . . 71
2.9.8 SRI/Energy Infrastructure and Renewable Energy Integration . . . 72
2.10 Building Services Engineering (BSE) . . . 72
2.10.1 BSE/Water Supply System in Building Sanitary Installations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 73
2.10.2 BSE/Drainage System in Building Sanitary Installations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 73
2.10.3 BSE/Building Electrical Installations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 73
2.11 Professional Practice and Project Leadership (PPL) . . . 74
2.11.1 PPL/Engineering Ethics and Professional Responsibility (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 74
2.11.2 PPL/Written and Technical Communication (Core Tier1: 1 hr, Core Tier2: 1 hr) 75
2.11.3 PPL/Oral Presentation and Professional Communication (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 75
2.11.4 PPL/Digital and Collaborative Communication (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 75
2.11.5 PPL/Engineering Economics and Project Financing (PPPs) (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 76
2.11.6 PPL/Leadership, Team Dynamics, and Stakeholder Management (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 76
2.11.7 PPL/Engineering Licensure, Legal Liability, and Regulatory Frameworks (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 77
2.11.8 PPL/Global Engineering Practice and International Standards (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 77
2.11.9 PPL/Professional and Regulatory Context (Core Tier1: 1 hr, Core Tier2: 1 hr) 78
2.11.10 PPL/National Context of Existing Civil Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 78

3 Body of knowledge of Transportation Engineering 81
3.1 Pavement and Highway Engineering (TIE) . . . 82
3.1.1 TIE/Pavement Materials and Characterization (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 82
3.1.2 TIE/Pavement Design and Management (Core Tier1: 1 hr, Core Tier2: 1 hr) . 82
3.1.3 TIE/Pavement Condition Evaluation and Maintenance Planning (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 83

3.1.4 TIE/Road and Bridge Asset Management (Core Tier1: 1 hr, Core Tier2: 1 hr) 83
3.2 Geometric Design Engineering (GDE) . . . 84
3.2.1 GDE/Design Controls and Criteria . . . 84
3.2.2 GDE/Horizontal Alignment Design . . . 84
3.2.3 GDE/Vertical Alignment Design . . . 85
3.2.4 GDE/Cross-Section Elements and Roadside Design . . . 85
3.2.5 GDE/At-Grade Intersections and Interchanges . . . 86
3.2.6 GDE/Context-Sensitive and Multimodal Design . . . 86
3.3 Transportation Engineering (TRE) . . . 86
3.3.1 TRE/Transportation Planning and Economics . . . 87
3.3.2 TRE/Transportation Economics and Finance . . . 87
3.3.3 TRE/Freight Transportation and Logistics . . . 88
3.3.4 TRE/Public Transit Systems Planning . . . 88
3.4 Traffic Engineering (TFE) . . . 88
3.4.1 TFE/Traffic Flow Theory and Capacity Analysis . . . 88
3.4.2 TFE/Traffic Operations and Management . . . 89
3.4.3 TFE/Intelligent Transportation Systems and Connected Vehicles . . . 89
3.4.4 TFE/Road Safety Engineering . . . 90
3.4.5 TFE/Traffic Control Devices . . . 90
3.5 Airport Engineering (APE) . . . 90
3.5.1 APE/Airport Planning and Demand Forecasting . . . 91
3.5.2 APE/Airside Geometric Design . . . 91
3.5.3 APE/Airfield Pavement Design and Evaluation . . . 91
3.5.4 APE/Airfield Drainage, Lighting, and Visual Aids . . . 92
3.5.5 APE/Terminal and Landside Design . . . 92
3.5.6 APE/Airspace and Air Traffic Operations . . . 92
3.5.7 APE/Airport Safety, Security, and Regulation . . . 93
3.6 Railway Engineering (RWE) . . . 93
3.6.1 RWE/Railway Alignment Design . . . 93
3.6.2 RWE/Track Structure Design . . . 94
3.6.3 RWE/Railway Signaling and Train Control . . . 94
3.6.4 RWE/Railway Electrification . . . 94
3.6.5 RWE/Rolling Stock Fundamentals . . . 95
3.6.6 RWE/Railway Capacity and Operations . . . 95
3.6.7 RWE/Railway Station and Terminal Design . . . 95
3.7 Port Engineering (PTE) . . . 95
3.7.1 PTE/Port Planning . . . 96
3.7.2 PTE/Maritime Hydraulics for Ports . . . 96
3.7.3 PTE/Breakwater and Coastal Structures . . . 96
3.7.4 PTE/Berth and Quay Design . . . 97
3.7.5 PTE/Dredging and Bathymetry . . . 97
3.7.6 PTE/Cargo Handling and Yard Design . . . 97
3.7.7 PTE/Port Operations, Safety, and Environmental Management . . . 98
3.8 Topography (TOP) . . . 98
3.8.1 TOP/Surveying Fundamentals and Measurement Theory . . . 98
3.8.2 TOP/Planimetry . . . 98
3.8.3 TOP/Leveling and Vertical Control . . . 99
3.8.4 TOP/Total Stations and Theodolites . . . 99
3.8.5 TOP/GNSS Surveying . . . 99
3.8.6 TOP/Topographic Mapping and Digital Terrain Models . . . 100
3.8.7 TOP/Earthwork Volume Computations . . . 100
3.8.8 TOP/Construction Layout and Stakeout Surveying . . . 100
3.9 Geodesy (GEO) . . . 100
3.9.1 GEO/Geodetic Fundamentals and Reference Systems . . . 101
3.9.2 GEO/Geodetic Control Networks . . . 101
3.9.3 GEO/Physical Geodesy and the Gravity Field . . . 101

3.9.4 GEO/Satellite Geodesy and Precise Positioning . . . 102
3.10 Cartography (CAR) . . . 102
3.10.1 CAR/Map Projections and Coordinate Reference Systems . . . 102
3.10.2 CAR/Cartographic Design and Generalization . . . 103
3.10.3 CAR/Topographic and Thematic Cartography . . . 103
3.10.4 CAR/Cartographic Data Models and Standards . . . 103
3.11 Photogrammetry (FOT) . . . 104
3.11.1 FOT/Photogrammetric Fundamentals . . . 104
3.11.2 FOT/Aerial Triangulation and Georeferencing . . . 104
3.11.3 FOT/Digital Photogrammetric Products . . . 105
3.11.4 FOT/UAV and Close-Range Photogrammetry . . . 105
3.12 Geographic Information Systems (SIG) . . . 105
3.12.1 SIG/GIS Fundamentals and Data Models . . . 106
3.12.2 SIG/Spatial Analysis and Geoprocessing . . . 106
3.12.3 SIG/GIS Data Acquisition and Integration . . . 106
3.12.4 SIG/GIS Applications in Civil Engineering . . . 107
3.13 Remote Sensing (TLD) . . . 107
3.13.1 TLD/Remote Sensing Fundamentals . . . 107
3.13.2 TLD/Digital Image Processing . . . 107
3.13.3 TLD/Active Remote Sensing: LiDAR and Radar . . . 108
3.13.4 TLD/Remote Sensing Applications in Civil Engineering . . . 108
3.14 Transportation Systems Analysis and Modeling (TSA) . . . 109
3.14.1 TSA/Transportation Systems Fundamentals . . . 109
3.14.2 TSA/Transportation Network Modeling . . . 109
3.14.3 TSA/Transportation Simulation Methods . . . 109
3.14.4 TSA/Optimization for Transportation . . . 110
3.14.5 TSA/Data Analytics for Transportation . . . 110
3.15 Urban and Regional Transportation Planning (UTP) . . . 110
3.15.1 UTP/Land Use and Transportation Integration . . . 111
3.15.2 UTP/Regional Transportation Planning . . . 111
3.15.3 UTP/Transit-Oriented Development . . . 111
3.15.4 UTP/Active Transportation Planning . . . 112
3.15.5 UTP/Parking and Curb Space Management . . . 112
3.16 Transportation Policy, Law, and Governance (TPL) . . . 112
3.16.1 TPL/Transportation Policy Frameworks . . . 112
3.16.2 TPL/Transportation Law and Regulation . . . 113
3.16.3 TPL/Environmental Review and Permitting . . . 113
3.16.4 TPL/Transportation Equity and Accessibility . . . 113
3.16.5 TPL/Institutional Governance of Transportation . . . 114
3.17 Sustainable and Resilient Mobility (SMT) . . . 114
3.17.1 SMT/Transportation Emissions and Decarbonization . . . 114
3.17.2 SMT/Electrification and Alternative Fuels . . . 115
3.17.3 SMT/Climate Resilience of Transportation Infrastructure . . . 115
3.17.4 SMT/Noise and Air Quality Mitigation . . . 115
3.17.5 SMT/Life-Cycle Sustainability Assessment . . . 116
3.18 Transportation Project Management and Professional Practice (TPM) . . . 116
3.18.1 TPM/Transportation Project Delivery Methods . . . 116
3.18.2 TPM/Cost Estimating and Scheduling . . . 116
3.18.3 TPM/Construction Management for Transportation Projects . . . 117
3.18.4 TPM/Stakeholder Engagement . . . 117
3.18.5 TPM/Professional Ethics and Practice . . . 117

4 Body of knowledge of Engineering Science 119
4.1 Calculus and Analysis (CAN) . . . 120
4.1.1 CAN/Line Integrals and Vector Fields (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 120
4.1.2 CAN/Multiple Integrals (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 121
4.1.3 CAN/Multivariable Transformations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 121
4.1.4 CAN/Surface Integrals and Fundamental Theorems (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 121
4.1.5 CAN/Vector Functions of a Real Variable (Core Tier1: 1 hr, Core Tier2: 1 hr) 122
4.1.6 CAN/Limits and Continuity (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 122
4.1.7 CAN/Differential Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 122
4.1.8 CAN/Integral Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 122
4.1.9 CAN/Improper Integrals (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 123
4.1.10 CAN/Sequences, Series, and Power Series (Core Tier1: 1 hr, Core Tier2: 1 hr) 123
4.1.11 CAN/Applications of the Definite Integral (Core Tier1: 1 hr, Core Tier2: 1 hr) 123
4.1.12 CAN/Vectors and the Geometry of Space (Core Tier1: 1 hr, Core Tier2: 1 hr) 124
4.1.13 CAN/Quadric Surfaces (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 124
4.1.14 CAN/Parametric Equations and Polar Coordinates (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 124
4.1.15 CAN/Multivariable and Vector Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr) . 124
4.1.16 CAN/Complex Analysis and Conformal Mapping . . . 125
4.1.17 CAN/Harmonic Analysis and Fourier Series . . . 125
4.2 Algebra and Number Theory (ANT) . . . 125
4.2.1 ANT/Matrices and Systems of Linear Equations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 126
4.2.2 ANT/Vector Spaces and Linear Transformations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 126
4.2.3 ANT/Eigenvalues and Inner Product Spaces (Core Tier1: 1 hr, Core Tier2: 1 hr) 126
4.3 Mathematical Modeling and Simulation (MMS) . . . 126
4.3.1 MMS/First-Order Ordinary Differential Equations (ODEs) (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 127
4.3.2 MMS/Higher-Order Differential Equations and Systems (ODEs) (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 127
4.3.3 MMS/Partial Differential Equations (PDEs) (Core Tier1: 1 hr, Core Tier2: 1 hr) 127
4.3.4 MMS/Mathematical Fluid Dynamics (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 128
4.3.5 MMS/Asymptotic Analysis and Perturbation Methods (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 128
4.3.6 MMS/Dynamical Systems and Bifurcation Theory . . . 128
4.3.7 MMS/Control Theory and Optimal Control . . . 129
4.4 Probability and Statistics (PST) . . . 129
4.4.1 PST/Mathematical Statistics and Estimation Theory (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 129
4.4.2 PST/Time Series Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 130
4.4.3 PST/Probability Axioms and Random Variables . . . 130
4.4.4 PST/Stochastic Processes and Markov Chains . . . 130
4.5 Numerical and Scientific Analysis (NSA) . . . 131
4.5.1 NSA/Error Analysis and Floating Point Arithmetic (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 131
4.5.2 NSA/Numerical Linear Algebra (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 132
4.5.3 NSA/Numerical Solution of Nonlinear Equations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 132
4.5.4 NSA/Approximation Theory and Interpolation (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 132
4.5.5 NSA/Numerical Integration and Quadrature (Core Tier1: 1 hr, Core Tier2: 1 hr) 133
4.5.6 NSA/Numerical Methods for ODEs and PDEs (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 133
4.5.7 NSA/Finite Element Method (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 133

4.5.8 NSA/Optimization Algorithms (Core Tier1: 1 hr, Core Tier2: 1 hr) 134
4.5.9 NSA/Parallel and High-Performance Computing (Core Tier1: 1 hr, Core Tier2: 1 hr) 134
4.6 Mathematical Foundations of Data Science (FDS) 135
4.6.1 FDS/Information Theory and Entropy 135
4.7 Discrete Mathematics and Combinatorics (DMC) 135
4.7.1 DMC/Graph Theory (Core Tier1: 1 hr, Core Tier2: 1 hr) 135
4.8 Mathematical Biology and Life Sciences (MBL) 136
4.8.1 MBL/Population Dynamics (Core Tier1: 1 hr, Core Tier2: 1 hr) 136
4.9 Financial and Actuarial Mathematics (FAM) 136
4.9.1 FAM/Interest Theory and Time Value of Money (Core Tier1: 1 hr, Core Tier2: 1 hr) 136
4.10 Classical Mechanics (CME) 137
4.10.1 CME/Kinematics and Dynamics of Particles (Core Tier1: 1 hr, Core Tier2: 1 hr) 137
4.10.2 CME/Work, Energy, and Conservative Forces (Core Tier1: 1 hr, Core Tier2: 1 hr) 138
4.10.3 CME/Rotational Motion and Angular Momentum (Core Tier1: 1 hr, Core Tier2: 1 hr) 138
4.10.4 CME/Systems of Particles and Linear Momentum (Core Tier1: 1 hr, Core Tier2: 1 hr) 139
4.10.5 CME/Non-Inertial Reference Frames and Fictitious Forces (Core Tier1: 1 hr, Core Tier2: 1 hr) 139
4.10.6 CME/Lagrangian and Hamiltonian Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr) 139
4.10.7 CME/Continuum Mechanics Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr) 140
4.10.8 CME/Elasticity (Core Tier1: 1 hr, Core Tier2: 1 hr) 141
4.10.9 CME/Fluids: Hydrostatics, Hydrodynamics, and Viscosity (Core Tier1: 1 hr, Core Tier2: 1 hr) 141
4.10.10 CME/Vibrations and Waves (Core Tier1: 1 hr, Core Tier2: 1 hr) 141
4.10.11 CME/Theory of Small Oscillations and Coupled Oscillators (Core Tier1: 1 hr, Core Tier2: 1 hr) 142
4.10.12 CME/Transport Phenomena (Core Tier1: 1 hr, Core Tier2: 1 hr) 142
4.11 Electromagnetism (ELM) 143
4.11.1 ELM/Electrostatics: Electric Field and Gauss's Law (Core Tier1: 1 hr, Core Tier2: 1 hr) 143
4.11.2 ELM/Electric Potential and Poisson/Laplace Equations (Core Tier1: 1 hr, Core Tier2: 1 hr) 143
4.11.3 ELM/Electrostatic Energy and Dielectrics (Core Tier1: 1 hr, Core Tier2: 1 hr) 144
4.11.4 ELM/Magnetostatics: Biot-Savart and Ampere's Laws (Core Tier1: 1 hr, Core Tier2: 1 hr) 144
4.11.5 ELM/Magnetic Properties of Matter (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 144
4.11.6 ELM/Electrodynamics: Faraday's Law and Induction (Core Tier1: 1 hr, Core Tier2: 1 hr) 145
4.11.7 ELM/Electric Current, Circuits, and Kirchhoff's Laws (Core Tier1: 1 hr, Core Tier2: 1 hr) 145
4.11.8 ELM/Maxwell's Equations and Gauge Transformations 146
4.11.9 ELM/Electromagnetic Waves and Propagation in Media 146
4.12 Thermodynamics and Statistical Mechanics (TSM) 146
4.12.1 TSM/Laws of Thermodynamics and State Functions (Core Tier1: 1 hr, Core Tier2: 1 hr) 147
4.12.2 TSM/Kinetic Theory of Gases (Core Tier1: 1 hr, Core Tier2: 1 hr) 147
4.12.3 TSM/Heat Engines, Entropy, and the Second Law 147
4.13 Condensed Matter Physics (SSP) 148
4.13.1 SSP/Crystal Structures and Reciprocal Lattices 148
4.13.2 SSP/Free Electron Model and Band Theory of Solids 148
4.13.3 SSP/Semiconductors, Insulators, and Metals 149

4.14 General Chemistry (GCH) . . . 149
4.14.1 GCH/Matter and Energy (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 149
4.14.2 GCH/Basic Atomic Structure (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 150
4.14.3 GCH/Chemical Bonding (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 150
4.14.4 GCH/Stoichiometry (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 150
4.14.5 GCH/States of Matter (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 150
4.14.6 GCH/Environmental and Water Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr) 151
4.14.7 GCH/Polymers and Geosynthetics (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 151
4.14.8 GCH/Chemical Equilibrium (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 151
4.14.9 GCH/Ionic Equilibrium and Salt Hydrolysis (Core Tier1: 1 hr, Core Tier2: 1 hr) 151
4.14.10 GCH/Salts, Solubility, and Precipitation Equilibria (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 152
4.14.11 GCH/Electrochemistry and Electrolysis (Core Tier1: 1 hr, Core Tier2: 1 hr) . 152
4.14.12 GCH/Cement Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 152
4.15 Inorganic Chemistry (INC) . . . 152
4.15.1 INC/Solid State and Material Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr) . 152
4.15.2 INC/Atomic Structure and Periodicity . . . 153
4.16 Physical Chemistry (PHC) . . . 153
4.16.1 PHC/Chemical Thermodynamics and Equilibrium . . . 154
4.17 Materials Science and Nanotechnology (MSN) . . . 154
4.17.1 MSN/Synthesis of Nanomaterials and Nanofabrication . . . 154
4.17.2 MSN/Characterization of Materials (XRD, SEM, TEM) . . . 155
4.17.3 MSN/Energy Storage and Conversion Materials . . . 155
4.18 Probability Theory (PRO) . . . 156
4.18.1 PRO/Sample Spaces and Events (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 156
4.18.2 PRO/Probability Axioms and Properties (Core Tier1: 1 hr, Core Tier2: 1 hr) . 156
4.18.3 PRO/Conditional Probability and Independence (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 157
4.18.4 PRO/Discrete Random Variables and Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 157
4.18.5 PRO/Continuous Random Variables and Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 157
4.18.6 PRO/Joint, Marginal, and Conditional Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 158
4.18.7 PRO/Limit Theorems: LLN and CLT (Core Tier1: 1 hr, Core Tier2: 1 hr) . . 158
4.19 Descriptive Statistics and Data Analysis (DSC) . . . 158
4.19.1 DSC/Numerical Summaries: Location, Spread, and Shape (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 158
4.20 Statistical Inference (INF) . . . 159
4.20.1 INF/Point Estimation (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 159
4.20.2 INF/Interval Estimation and Confidence Intervals (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 159
4.20.3 INF/Hypothesis Testing Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 160
4.20.4 INF/Bayesian Inference (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 160
4.21 Regression and Statistical Models (REG) . . . 160
4.21.1 REG/Simple Linear Regression (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 161

5 Body of knowledge of Project Management 163
5.1 Project Management Principles (PR) . . . 163
5.1.1 PR/Stewardship . . . 164
5.1.2 PR/Create a Collaborative Project Team Environment . . . 164
5.1.3 PR/Effectively Engage with Stakeholders . . . 165
5.1.4 PR/Focus on Value . . . 165
5.1.5 PR/Recognize, Evaluate, and Respond to System Interactions . . . 165
5.1.6 PR/Demonstrate Leadership Behaviors . . . 166
5.1.7 PR/Tailor Based on Context . . . 166

5.1.8 PR/Build Quality into Processes and Deliverables . . . 167
5.1.9 PR/Navigate Complexity . . . 167
5.1.10 PR/Optimize Risk Responses . . . 167
5.1.11 PR/Embrace Adaptability and Resiliency . . . 168
5.1.12 PR/Enable Change to Achieve the Envisioned Future State . . . 168
5.2 Stakeholders (ST) . . . 168
5.2.1 ST/Stakeholder Identification and Analysis . . . 169
5.2.2 ST/Stakeholder Engagement Planning . . . 169
5.2.3 ST/Stakeholder Communication and Relationships . . . 169
5.2.4 ST/Managing Stakeholder Expectations . . . 170
5.2.5 ST/Stakeholder Influence and Power . . . 170
5.2.6 ST/Conflict and Negotiation with Stakeholders . . . 170
5.2.7 ST/Monitoring Stakeholder Engagement . . . 171
5.3 Team (TM) . . . 171
5.3.1 TM/Project Team Culture . . . 171
5.3.2 TM/Team Leadership Styles . . . 172
5.3.3 TM/Team Development and Performance . . . 172
5.3.4 TM/Motivation and Empowerment . . . 172
5.3.5 TM/Collaboration and Trust Building . . . 173
5.3.6 TM/Distributed and Virtual Teams . . . 173
5.3.7 TM/Ethics and Professional Conduct . . . 173
5.4 Development Approach and Life Cycle (DL) . . . 174
5.4.1 DL/Kickoff and Closure Activities (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 174
5.4.2 DL/Development Approach Selection . . . 174
5.4.3 DL/Predictive Approach . . . 175
5.4.4 DL/Adaptive Approach . . . 175
5.4.5 DL/Hybrid Approach . . . 175
5.4.6 DL/Project Phase Structure . . . 176
5.4.7 DL/Tailoring the Development Approach . . . 176
5.5 Planning (PL) . . . 176
5.5.1 PL/Planning Principles (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 177
5.5.2 PL/Scope and Requirements Planning (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 177
5.5.3 PL/Schedule Planning (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 177
5.5.4 PL/Cost and Budget Planning (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 178
5.5.5 PL/Resource Planning . . . 178
5.5.6 PL/Quality Planning . . . 178
5.5.7 PL/Risk and Uncertainty Planning . . . 179
5.5.8 PL/Communications and Stakeholder Engagement Planning . . . 179
5.5.9 PL/Procurement Planning . . . 179
5.5.10 PL/Integrated Project Planning . . . 180
5.6 Project Work (PW) . . . 180
5.6.1 PW/Managing Project Artifacts . . . 180
5.6.2 PW/Communication and Knowledge Management . . . 181
5.6.3 PW/Team Engagement During Execution . . . 181
5.6.4 PW/Stakeholder Engagement During Execution . . . 181
5.6.5 PW/Managing Physical Resources . . . 182
5.6.6 PW/Working with Procurements . . . 182
5.6.7 PW/Monitoring and Adapting Work . . . 182
5.7 Delivery (DV) . . . 183
5.7.1 DV/Value Definition and Delivery . . . 183
5.7.2 DV/Requirements and Scope Delivery . . . 183
5.7.3 DV/Quality Assurance and Delivery . . . 184
5.7.4 DV/Incremental and Iterative Delivery . . . 184
5.7.5 DV/Transition and Handover . . . 184
5.7.6 DV/Benefits Realization Management . . . 185
5.7.7 DV/Customer and User Satisfaction . . . 185

5.8 Measurement (MS) . . . 185
5.8.1 MS/Key Performance Indicators (Core Tier1: 1 hr, Core Tier2: 1 hr) . . . 185
5.8.2 MS/Dashboards and Information Radiators (Core Tier1: 1 hr, Core Tier2: 1 hr) 186
5.8.3 MS/Measurement Purpose and Approach . . . 186
5.8.4 MS/Earned Value and Schedule Performance . . . 186
5.8.5 MS/Forecasting and Trends . . . 187
5.8.6 MS/Stakeholder Performance Reporting . . . 187
5.8.7 MS/Lessons Learned and Knowledge Capture . . . 187
5.9 Uncertainty (UN) . . . 188
5.9.1 UN/Understanding Uncertainty and Risk . . . 188
5.9.2 UN/Risk Identification and Assessment . . . 188
5.9.3 UN/Threat and Opportunity Response . . . 189
5.9.4 UN/Ambiguity Management . . . 189
5.9.5 UN/Complexity Management . . . 190
5.9.6 UN/Volatility and Resilience Strategies . . . 190
5.9.7 UN/Monitoring and Adapting to Uncertainty . . . 190

6 Curricula 202x 191
6.1 Course Coding . . . 191
6.2 Estructura Curricular . . . 192
6.3 Topics distributed by course . . . 198
6.3.1 Civil Engineering topics/course . . . 198
6.3.2 Transportation Engineering topics/course . . . 211
6.3.3 Engineering Science topics/course . . . 215
6.3.4 Project Management topics/course . . . 222
6.4 Expected outcomes distributed by course . . . 225
6.5 Courses by Outcome . . . 229
6.5.1 Outcome: ABET-1) Identify, formulate, and solve complex engineering problems. 229
6.5.2 Outcome: ABET-2) Apply engineering design to produce solutions that meet specific needs. . . . 230
6.5.3 Outcome: ABET-3) Communicate effectively with diverse audiences. . . . 231
6.5.4 Outcome: ABET-4) Recognize ethical responsibilities and make informed judgments. . . . 231
6.5.5 Outcome: ABET-5) Function effectively in teams and exercise leadership. . . . 232
6.5.6 Outcome: ABET-6) Develop experiments, analyze data, and draw conclusions. 232
6.5.7 Outcome: ABET-7) Acquire and apply new knowledge using learning strategies. 233
6.6 Course distribution in the Career . . . 233
6.7 Departments . . . 235
6.7.1 Basic Sciences . . . 235
6.7.2 Construction . . . 235
6.7.3 Structures . . . 236
6.7.4 Hydraulics . . . 237
6.7.5 Geotechnical Engineering . . . 237
6.7.6 Basic Sciences . . . 238
6.8 Compatibility of the Career with International Standards . . . 239

7 Detailed content by course 245
First Semester . . . 245
MA100 Basic Mathematics (Mandatory) . . . 245
MA111 Calculus I (Mandatory) . . . 249
BCH101 Chemistry I (Mandatory) . . . 251
BME101 Learning Methodology Workshop (Mandatory) . . . 255
BRC101 Writing and Communication (Mandatory) . . . 260
BIC101 Introduction to Programming (Mandatory) . . . 262
BEC101 General Economics (Mandatory) . . . 266
Second Semester . . . 270

CE1G1 General Geology (Mandatory) . . . 270
CS100 Introduction to Computer Science (Mandatory) . . . 274
AI161 Applied AI (Mandatory) . . . 284
CB1E1 Technical Drawing & CAD (Mandatory) . . . 288
MA112 Calculus II (Mandatory) . . . 291
BFI101 General Physics (Mandatory) . . . 295
ID101 Technical and professional English I (Mandatory) . . . 300
BEF201 Ethics and Political Philosophy (Mandatory) . . . 303
Third Semester . . . 306
CE1M1 Statics (Mandatory) . . . 306
CB1E2 Engineering Drawing II (Mandatory) . . . 309
MA121 Linear Algebra I (Mandatory) . . . 312
MA210 Calculus III (Mandatory) . . . 314
BFI102 Physics II (Mandatory) . . . 317
ID102 Technical and professional English II (Mandatory) . . . 322
Fourth Semester . . . 326
CE1M2 Dynamics (Mandatory) . . . 326
CE2M1 Mechanics of Materials I (Mandatory) . . . 329
CE3M1 Concrete Technology (Mandatory) . . . 332
MA202 Numerical Methods (Mandatory) . . . 335
MA211 Calculus IV (Mandatory) . . . 340
STA251 Statistics and Probability (Mandatory) . . . 343
ID201 Technical and professional English III (Mandatory) . . . 348
Fifth Semester . . . 352
CE2M2 Mechanics of Materials II (Mandatory) . . . 352
ID202 Technical and professional English IV (Mandatory) . . . 355
Sixth Semester . . . 359
MA212 Ordinary Differential Equations (Mandatory) . . . 359
ID203 Technical and professional English V (Mandatory) . . . 362
Seventh Semester . . . 366
CE2C1 Materials Technology (Mandatory) . . . 366
CE2C2 Construction Technology I (Mandatory) . . . 371
CE2C6 Territorial Planning (Mandatory) . . . 374
CE2C8 Business Management in Construction I (Mandatory) . . . 377
CE2G1 Soil Mechanics I (Mandatory) . . . 381
CE2H1 Fluid Mechanics I (Mandatory) . . . 384
CE2S1 Structural Analysis I (Mandatory) . . . 391
CE2S2 Reinforced Concrete Design I (Mandatory) . . . 394
CE2S3 Steel Design (Mandatory) . . . 397
Eighth Semester . . . 400
CE2C3 Concrete Technology I (Mandatory) . . . 400
CE2C5 Construction Project Management (Mandatory) . . . 405
CE2C7 Business Organization and Management (Mandatory) . . . 408
CE2G2 Soil Mechanics II (Mandatory) . . . 413
CE3C2 Construction Technology II (Mandatory) . . . 417
CE3H1 Fluid Mechanics II (Mandatory) . . . 422
CE3S1 Structural Analysis II (Mandatory) . . . 425
CE3S5 Bridges and Structures (Mandatory) . . . 429
CE3S9 Prestressed Concrete (Mandatory) . . . 432
BMI201 Methodology of Engineering Research (Mandatory) . . . 435
Ninth Semester . . . 438
CE3C15 Professional Competencies Workshop (Mandatory) . . . 438
CE3C5 Costs and Budgeting (Mandatory) . . . 445
CE3C9 Integrated Construction Management (Mandatory) . . . 448
CE3G3 Applied Geology (Mandatory) . . . 453
CE3G4 Soil Mechanics Applied to Transportation Roads (Mandatory) . . . 458

CE3G5 Finite Elements Applied to Geotechnical Engineering (Mandatory) 461
CE3G6 Earth Dams (Mandatory) 464
CE3H2 General Hydrology (Mandatory) 469
CE3H3 Water Supply and Sewerage (Mandatory) 471
CE3H4 Water Resources (Mandatory) 481
CE3S11 Professional Competency Workshop - Structures (Mandatory) 487
CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (Mandatory) 494
CE3S8 Architecture and Structural Models (Mandatory) 497
CE402 Capstone project I (Mandatory) 504
BLW201 Law and Legislation (Mandatory) 506
Tenth Semester 512
CE3C11 Sanitary and Electrical Installations (Mandatory) 512
CE3G1 Soil Dynamics (Mandatory) 515
CE3G2 Soil Mechanics Applied to Foundations (Mandatory) 518
CE3G7 Professional Competencies Workshop - Geotechnical (Mandatory) 523
CE3H5 Introduction to Fluvial Hydraulics (Mandatory) 529
CE3H6 Irrigation Engineering (Mandatory) 533
CE3H7 Hydraulic and Hydrology Engineering Workshop (Mandatory) 537
CE3S10 Seismic Design of Civil Engineering Works (Mandatory) 540
CE3S12 Research Workshop (Mandatory) 544
CE3S2 Reinforced Concrete Design II (Mandatory) 549
CE3S6 Masonry, Adobe, and Timber (Mandatory) 554
CE3S7 Structural Rehabilitation and Retrofitting (Mandatory) 557
CE403 Capstone project II (Mandatory) 561
CE3C13 Project Planning and Control (Elective) 563
CE3C14 Sustainable and Resilient Infrastructure (Elective) 566

8 Professors & Courses **569**
Taught courses by professor 569
Professor assigned per course 569

9 Equivalences with Other Curriculum Plans **573**

10 Laboratories **575**

List of Figures

6.1 Course coding scheme. . . . 191
6.2 Credits by area by semester . . . 234
6.3 Distribution of courses by area considering credits. . . . 234
6.4 Distribution of credits by course levels. . . . 235
6.5 Basic Sciences . . . 236
6.6 Construction . . . 237
6.7 Structures . . . 238
6.8 Hydraulics . . . 239
6.9 Geotechnical Engineering . . . 240
6.10 Basic Sciences . . . 241

7.1 Connection Map. MA100 Basic Mathematics . . . 246
7.2 Connection Map. MA111 Calculus I . . . 249
7.3 Connection Map. BCH101 Chemistry I . . . 251
7.4 Connection Map. BME101 Learning Methodology Workshop . . . 255
7.5 Connection Map. BRC101 Writing and Communication . . . 260
7.6 Connection Map. BIC101 Introduction to Programming . . . 262
7.7 Connection Map. BEC101 General Economics . . . 266
7.8 Connection Map. CE1G1 General Geology . . . 270
7.9 Connection Map. CS100 Introduction to Computer Science . . . 274
7.10 Connection Map. AI161 Applied AI . . . 284
7.11 Connection Map. CB1E1 Technical Drawing & CAD . . . 288
7.12 Connection Map. MA112 Calculus II . . . 291
7.13 Connection Map. BFI101 General Physics . . . 295
7.14 Connection Map. ID101 Technical and professional English I . . . 300
7.15 Connection Map. BEF201 Ethics and Political Philosophy . . . 303
7.16 Connection Map. CE1M1 Statics . . . 306
7.17 Connection Map. CB1E2 Engineering Drawing II . . . 309
7.18 Connection Map. MA121 Linear Algebra I . . . 312
7.19 Connection Map. MA210 Calculus III . . . 314
7.20 Connection Map. BFI102 Physics II . . . 317
7.21 Connection Map. ID102 Technical and professional English II . . . 322
7.22 Connection Map. CE1M2 Dynamics . . . 326
7.23 Connection Map. CE2M1 Mechanics of Materials I . . . 329
7.24 Connection Map. CE3M1 Concrete Technology . . . 332
7.25 Connection Map. MA202 Numerical Methods . . . 335
7.26 Connection Map. MA211 Calculus IV . . . 340
7.27 Connection Map. STA251 Statistics and Probability . . . 343
7.28 Connection Map. ID201 Technical and professional English III . . . 348
7.29 Connection Map. CE2M2 Mechanics of Materials II . . . 352
7.30 Connection Map. ID202 Technical and professional English IV . . . 355
7.31 Connection Map. MA212 Ordinary Differential Equations . . . 359
7.32 Connection Map. ID203 Technical and professional English V . . . 362
7.33 Connection Map. CE2C1 Materials Technology . . . 366

7.34 Connection Map. CE2C2 Construction Technology I 371
7.35 Connection Map. CE2C6 Territorial Planning 374
7.36 Connection Map. CE2C8 Business Management in Construction I 377
7.37 Connection Map. CE2G1 Soil Mechanics I 381
7.38 Connection Map. CE2H1 Fluid Mechanics I 384
7.39 Connection Map. CE2S1 Structural Analysis I 391
7.40 Connection Map. CE2S2 Reinforced Concrete Design I 394
7.41 Connection Map. CE2S3 Steel Design 397
7.42 Connection Map. CE2C3 Concrete Technology I 400
7.43 Connection Map. CE2C5 Construction Project Management 405
7.44 Connection Map. CE2C7 Business Organization and Management 408
7.45 Connection Map. CE2G2 Soil Mechanics II 413
7.46 Connection Map. CE3C2 Construction Technology II 417
7.47 Connection Map. CE3H1 Fluid Mechanics II 422
7.48 Connection Map. CE3S1 Structural Analysis II 425
7.49 Connection Map. CE3S5 Bridges and Structures 429
7.50 Connection Map. CE3S9 Prestressed Concrete 432
7.51 Connection Map. BMI201 Methodology of Engineering Research 435
7.52 Connection Map. CE3C15 Professional Competencies Workshop 438
7.53 Connection Map. CE3C5 Costs and Budgeting 445
7.54 Connection Map. CE3C9 Integrated Construction Management 448
7.55 Connection Map. CE3G3 Applied Geology 453
7.56 Connection Map. CE3G4 Soil Mechanics Applied to Transportation Roads 458
7.57 Connection Map. CE3G5 Finite Elements Applied to Geotechnical Engineering 461
7.58 Connection Map. CE3G6 Earth Dams 464
7.59 Connection Map. CE3H2 General Hydrology 469
7.60 Connection Map. CE3H3 Water Supply and Sewerage 471
7.61 Connection Map. CE3H4 Water Resources 481
7.62 Connection Map. CE3S11 Professional Competency Workshop - Structures 487
7.63 Connection Map. CE3S4 Earthquake-Resistant Engineering and Disaster Prevention . 494
7.64 Connection Map. CE3S8 Architecture and Structural Models 497
7.65 Connection Map. CE402 Capstone project I 504
7.66 Connection Map. BLW201 Law and Legislation 506
7.67 Connection Map. CE3C11 Sanitary and Electrical Installations 512
7.68 Connection Map. CE3G1 Soil Dynamics 515
7.69 Connection Map. CE3G2 Soil Mechanics Applied to Foundations 518
7.70 Connection Map. CE3G7 Professional Competencies Workshop - Geotechnical 523
7.71 Connection Map. CE3H5 Introduction to Fluvial Hydraulics 529
7.72 Connection Map. CE3H6 Irrigation Engineering 533
7.73 Connection Map. CE3H7 Hydraulic and Hydrology Engineering Workshop 537
7.74 Connection Map. CE3S10 Seismic Design of Civil Engineering Works 540
7.75 Connection Map. CE3S12 Research Workshop 544
7.76 Connection Map. CE3S2 Reinforced Concrete Design II 549
7.77 Connection Map. CE3S6 Masonry, Adobe, and Timber 554
7.78 Connection Map. CE3S7 Structural Rehabilitation and Retrofitting 557
7.79 Connection Map. CE403 Capstone project II 561
7.80 Connection Map. CE3C13 Project Planning and Control 563
7.81 Connection Map. CE3C14 Sustainable and Resilient Infrastructure 566

List of Tables

2.1 List of KUs in the Engineering Mechanics and Materials area. 11
2.2 List of KUs in the Structural Analysis and Design area. 19
2.3 List of KUs in the Geotechnical Engineering area. 32
2.4 List of KUs in the General Geology area. 41
2.5 List of KUs in the Water Resources and Hydraulic Engineering area. 47
2.6 List of KUs in the Environmental Systems Engineering area. 54
2.7 List of KUs in the Construction Engineering and Management area. 58
2.8 List of KUs in the Digital Technologies in Civil Engineering area. 64
2.9 List of KUs in the Sustainable and Resilient Infrastructure area. 69
2.10 List of KUs in the Building Services Engineering area. 72
2.11 List of KUs in the Professional Practice and Project Leadership area. 74

3.1 List of KUs in the Pavement and Highway Engineering area. 82
3.2 List of KUs in the Geometric Design Engineering area. 84
3.3 List of KUs in the Transportation Engineering area. 87
3.4 List of KUs in the Traffic Engineering area. 88
3.5 List of KUs in the Airport Engineering area. 91
3.6 List of KUs in the Railway Engineering area. 93
3.7 List of KUs in the Port Engineering area. 96
3.8 List of KUs in the Topography area. 98
3.9 List of KUs in the Geodesy area. 100
3.10 List of KUs in the Cartography area. 102
3.11 List of KUs in the Photogrammetry area. 104
3.12 List of KUs in the Geographic Information Systems area. 105
3.13 List of KUs in the Remote Sensing area. 107
3.14 List of KUs in the Transportation Systems Analysis and Modeling area. 109
3.15 List of KUs in the Urban and Regional Transportation Planning area. 111
3.16 List of KUs in the Transportation Policy, Law, and Governance area. 112
3.17 List of KUs in the Sustainable and Resilient Mobility area. 114
3.18 List of KUs in the Transportation Project Management and Professional Practice area. 116

4.1 List of KUs in the Calculus and Analysis area. 120
4.2 List of KUs in the Algebra and Number Theory area. 126
4.3 List of KUs in the Mathematical Modeling and Simulation area. 127
4.4 List of KUs in the Probability and Statistics area. 129
4.5 List of KUs in the Numerical and Scientific Analysis area. 131
4.6 List of KUs in the Mathematical Foundations of Data Science area. 135
4.7 List of KUs in the Discrete Mathematics and Combinatorics area. 135
4.8 List of KUs in the Mathematical Biology and Life Sciences area. 136
4.9 List of KUs in the Financial and Actuarial Mathematics area. 136
4.10 List of KUs in the Classical Mechanics area. 137
4.11 List of KUs in the Electromagnetism area. 143
4.12 List of KUs in the Thermodynamics and Statistical Mechanics area. 146
4.13 List of KUs in the Condensed Matter Physics area. 148

4.14 List of KUs in the General Chemistry area. 149
4.15 List of KUs in the Inorganic Chemistry area. 152
4.16 List of KUs in the Physical Chemistry area. 153
4.17 List of KUs in the Materials Science and Nanotechnology area. 154
4.18 List of KUs in the Probability Theory area. 156
4.19 List of KUs in the Descriptive Statistics and Data Analysis area. 158
4.20 List of KUs in the Statistical Inference area. 159
4.21 List of KUs in the Regression and Statistical Models area. 160

5.1 List of KUs in the Project Management Principles area. 164
5.2 List of KUs in the Stakeholders area. 168
5.3 List of KUs in the Team area. 171
5.4 List of KUs in the Development Approach and Life Cycle area. 174
5.5 List of KUs in the Planning area. 176
5.6 List of KUs in the Project Work area. 180
5.7 List of KUs in the Delivery area. 183
5.8 List of KUs in the Measurement area. 185
5.9 List of KUs in the Uncertainty area. 188

6.1 Civil Engineering topics by course from 1st to 2nd Semester 198
6.2 Civil Engineering topics by course from 3rd to 5th Semester 199
6.3 Civil Engineering topics by course from 6th to 7th Semester 200
6.4 Civil Engineering topics by course 8th Semester (Part 1 of 2) 202
6.5 Civil Engineering topics by course 8th Semester (Part 2 of 2) 203
6.6 Civil Engineering topics by course 9th Semester (Part 1 of 3) 204
6.7 Civil Engineering topics by course 9th Semester (Part 2 of 3) 206
6.8 Civil Engineering topics by course 9th Semester (Part 3 of 3) 207
6.9 Civil Engineering topics by course 10th Semester (Part 1 of 3) 208
6.10 Civil Engineering topics by course 10th Semester (Part 2 of 3) 210
6.11 Civil Engineering topics by course 10th Semester (Part 3 of 3) 211
6.12 Transportation Engineering topics by course from 1st to 2nd Semester 211
6.13 Transportation Engineering topics by course from 3rd to 5th Semester 212
6.14 Transportation Engineering topics by course from 6th to 7th Semester 212
6.15 Transportation Engineering topics by course 8th Semester 212
6.16 Transportation Engineering topics by course 9th Semester 213
6.17 Transportation Engineering topics by course 10th Semester 213
6.18 Engineering Science topics by course from 1st to 2nd Semester (Part 1 of 2) 215
6.19 Engineering Science topics by course from 1st to 2nd Semester (Part 2 of 2) 216
6.20 Engineering Science topics by course from 3rd to 5th Semester (Part 1 of 2) 217
6.21 Engineering Science topics by course from 3rd to 5th Semester (Part 2 of 2) 219
6.22 Engineering Science topics by course from 6th to 7th Semester 220
6.23 Engineering Science topics by course 8th Semester 221
6.24 Engineering Science topics by course 9th Semester 221
6.25 Engineering Science topics by course 10th Semester 222
6.26 Project Management topics by course from 1st to 2nd Semester 222
6.27 Project Management topics by course from 3rd to 5th Semester 222
6.28 Project Management topics by course from 6th to 7th Semester 223
6.29 Project Management topics by course 8th Semester 223
6.30 Project Management topics by course 9th Semester 224
6.31 Project Management topics by course 10th Semester 224
6.32 Outcomes by course 1st to 2nd Semester 225
6.33 Outcomes by course 3rd to 5th Semester 226
6.34 Outcomes by course 6th to 7th Semester 226
6.35 Outcomes by course 8th Semester 227
6.36 Outcomes by course 9th Semester 227
6.37 Outcomes by course 10th Semester 228

6.38 Distribution of credits by area by semester 233

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This entire team assumed as a premise that the center of our effort is the academic and human education of the students, to shape them into agents of positive and disruptive change in society.

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Acronyms

.

Chapter 1

Introducción

Civil engineering has undergone fundamental and continuous development since the dawn of civilization, establishing itself as the indispensable pillar of humanity's material progress. This discipline is the engine behind the development of infrastructure, housing, transportation, sanitation, and energy, tangibly and permanently transforming our built environment and the quality of life in societies.

The practice of civil engineering has marked every era of history, from the earliest structures to contemporary megaprojects once considered unimaginable. The continuous evolution of its methods, materials, and technologies is transforming the conception, design, construction, and management of complex infrastructure. Its influence is decisive in sustainable urban development, water resources management, disaster resilience, transportation connectivity, and the safety of the buildings in which we live and work.

To understand the relevance and strategic importance of this discipline for our country's development, it is enough to mention that investment in infrastructure is a key indicator of economic growth and global competitiveness. The infrastructure built by civil engineers constitutes the physical foundation for all other productive and social activities.

While the core of the profession is clear and universal - the application of scientific and technical principles to create works that serve the public - academic training in this field may be presented under different emphases or names, such as Civil Engineering with a focus on Construction, Structures, Hydraulics, Transportation, and Geotechnical Engineering, among others. This diversity reflects the breadth and specialization within the discipline itself. However, it is fundamental that a central, solid, and shared body of knowledge exists to guarantee professional competence and public safety, regardless of the particular curricular emphasis.

Historically, civil engineering developed from military and civil construction practices, evolving into a formal scientific discipline during the Industrial Revolution. In modern universities, it consolidated as an independent branch of engineering, distinct from architecture and military engineering. Its academic recognition is based on a profound body of knowledge that integrates mathematics, physics, mechanics, geology, and materials science applied to real-world problems.

In Peru, infrastructure development is a national priority demanding highly skilled, ethical, and innovative civil engineering professionals. Higher education institutions face the challenge and responsibility of training these professionals to the highest international standards, responding to specific territorial challenges and aligning with global trends in sustainability, digitalization, and resilience.

The School of Ingeniería Civil recognizes this imperative need and assumes the commitment to lead this educational effort. It cannot remain on the sidelines of this imperative for excellence and updating, in which staying at the forefront is an obligation to effectively contribute to national development and societal well-being.

1.1 Basic definitions

Engineering, in its fundamental definition, is the reasoned application of knowledge from the basic sciences for the use and transformation of resources and forces of nature for the benefit of society.

According to the Statute of the College of Engineers of Peru (Art. 1.01), it is:

> the profession that applies with foundation and responsibility the scientific and technological knowledge achieved through the study of higher mathematics and natural sciences (physics, chemistry, biology), which transforms nature through productive processes for the benefit of humanity, to satisfy human needs, achieving the realization of an idea into reality.

The definition of Engineering establishes three essential pillars that characterize traditional engineering: a solid scientific base in continuous mathematics and natural sciences, the ability to transform nature through productive processes, and the realization of ideas into tangible and measurable realities.

An important conceptual distinction arises when contrasting the use of the term *ingeniero* in the Spanish language versus the English language.

In the Latin American context, *ingeniero* is a professional title conferred exclusively upon those who have completed regulated and accredited university education in engineering, under the supervision of professional bodies.

In contrast, in the Anglo-Saxon sphere, the word *engineer* frequently functions as a verb (*to engineer*) synonymous with *to make, to design, to create, to manufacture, to elaborate*, and as a noun denotes the job position held by a person, regardless of their specific academic degree.

This semantic difference generates confusion when importing job titles from English into the national professional context. Terms like *Process Engineer*, *QA Engineer*, *Cybersecurity Engineer*, *Artificial Intelligence Engineer* describe specific functions and activities within organizations, but they do not necessarily correspond to professionals qualified as engineers under traditional regulation.

In our country, the professional practice of engineering is linked to compliance with specific academic and legal requirements, and to active professional licensure, ensuring that those who call themselves engineers possess the required scientific-technological training to responsibly transform nature.

Therefore, it is essential to maintain clarity in the naming of engineering degree programs, ensuring they respond to the formal definition of Engineering just cited.

We must train professionals capable of applying higher mathematics and natural sciences in the transformation of nature, regardless of labor trends or Anglo-Saxon denominations that may generate ambiguity in professional identity.

1.2 Occupational Field and Job Market

Our graduate will be able to provide professional services in public and private companies and institutions that require their capabilities in the design, construction, operation, and management of infrastructure, including:

- National and international engineering consulting firms dedicated to the design of resilient and sustainable infrastructure.
- Construction companies and real estate developers executing building, transportation, hydraulic, and energy projects.
- Governmental and municipal entities responsible for urban planning, public infrastructure management, and technical regulation.
- Energy generation, transmission, and distribution companies, especially in renewable energy and green infrastructure projects.
- Organizations dedicated to water resources management, environmental sanitation, and pollution control.
- Logistics, transportation, and port, airport, and railway system operating companies.
- Firms specialized in risk assessment, environmental consulting, and technical infrastructure auditing.

Our graduate can perform in a globalized job market that increasingly values the integration of digital technologies (BIM, GIS, IoT) with the fundamental principles of civil engineering. Although market demand continues to require professionals capable of using conventional technical tools, our program forms solution creators who not only apply existing methodologies but develop innovative approaches to face the complex challenges of the 21st century: climate change, accelerated urbanization, resource scarcity, and demands for smart infrastructure.

Due to the education based on solid scientific principles and broad thinking, our professional is prepared to be an agent of transformation wherever they work. This same training allows them

to consider entrepreneurship in specialized consulting, development of infrastructure projects with a sustainable focus, or even the creation of technological startups (known as *Contech*) that develop digital solutions for the construction industry and asset management.

Considering the growing global demand for quality infrastructure, especially in emerging economies, our graduates have the opportunity to participate in international projects or to export high-value engineering services. Training in international standards (e.g., ABET) and global digital tools (BIM, parametric modeling) ensures they can compete in this scenario.

The job market for the contemporary civil engineer is extraordinarily broad and constantly evolving. Practically all productive and service sectors depend on adequate infrastructure, and the comprehensive training of our graduates—which combines technical fundamentals, sustainability, management, and digital technology—allows them to respond successfully to these demands. Our professionals will not only solve immediate technical problems but will propose innovations that drive the transition towards more efficient, resilient, and low-carbon infrastructure.

As the digitalization of the construction industry advances and the need to adapt infrastructure to climate change increases, so does the demand for professionals capable of integrating data analysis, advanced modeling, and circular economy principles into their projects. Our curriculum is designed to meet this demand both nationally and globally, with a medium and long-term vision.

The field for applied research and the development of technological solutions in civil engineering is vast and growing worldwide, ranging from advanced construction materials and structural rehabilitation techniques to intelligent monitoring systems and integrated asset lifecycle management models.

The innovative capacity and ethical focus of our graduate increase the probability of contributing with patents, technical publications, and best practice standards, thereby strengthening the infrastructure innovation ecosystem of our country and the region.

1.3 Importance of the Program in Society

One of the expected career paths for a professional in the field of Ingeniería Civil is to dedicate themselves to the design, construction, and management of resilient and sustainable infrastructure. In the context of national development, it is evident that countries aspiring to achieve first-world status have invested in cutting-edge infrastructure as a fundamental pillar. Thus, our graduates must be prepared to perform in the local, national, and globalized world we live in.

Our future professionals could also create companies capable of executing large-scale infrastructure projects, driving the country's competitiveness. This new profile is focused on generating innovative industry. If we are capable of planning and constructing infrastructure that meets international standards, we will also be in a position to attract new foreign investments. Such investments would generate more well-paid jobs and establish a solid foundation for sustainable economic growth. From this perspective, we can affirm that this program will be an engine that decisively drives the country's development with a strategic investment.

It is important to remember that the greatest innovations in modern infrastructure—such as smart cities, high-speed railways, sustainable water management systems, and energy-efficient buildings—are based on engineering principles and technologies that have been developed and refined in the academic and research world for decades. It is logical to think that academia should not limit itself to studying only the latest version of specific construction software or equipment, when the fundamental science and technology behind them have been known for a long time. For this same reason, it is rare in the world to see a university establish agreements with a multinational corporation to teach only their proprietary tools, because our mission is to generate that fundamental knowledge and innovation capacity **and not just know how to use existing tools**.

Nor should we forget that students entering today will graduate and enter the market in approximately 5 years, and in a world changing so rapidly, we cannot and should not teach them considering only the current market. Our professionals must be prepared to solve the infrastructure problems that will exist in 10 or 15 years—problems related to climate adaptation, population growth, resource scarcity, and digital integration—and that is only possible through a solid foundation in science, research, and broad thinking.

The development of strategic infrastructure is key for national integration and international competitiveness. Projects such as the construction of cross-country highways that connect the entire nation

not only reduce transportation times but also facilitate market access, stimulate regional development, and foster social cohesion. Similarly, the implementation of high-speed trains represents a qualitative leap in sustainable mobility, connecting major cities efficiently, safely, and with low environmental impact, which energizes local economies and improves the population's quality of life.

In the digital age, physical infrastructure is complemented by critical technological infrastructure. The development of high-performance and resilient data centers requires not only reliable energy and advanced cooling systems but also specialized civil infrastructure that ensures their physical security, fiber optic connectivity, and capacity to withstand natural disasters. These centers are the core of national and global connectivity, enabling the massive storage and processing of data that drives the digital economy, modern public services, and technological innovation across all sectors.

High-quality infrastructure is not merely a consequence of development; it is a prerequisite and a catalyst. It connects regions, facilitates trade, improves quality of life, ensures public safety, and enables the efficient provision of essential services. A country with first-world infrastructure attracts talent, fosters innovation, and positions itself as a reliable partner in the global economy. Therefore, training civil engineers with a global, sustainable, and technological vision is an investment in the very foundation of our nation's future prosperity and sovereignty.

1.4 Institutional Info

1.4.1 Mission

Based on the aforementioned, our mission is:

Train leading professionals in Civil Engineering, with strong competencies in science and technology; committed to the sustainable development of national infrastructure -roads, railways, bridges, water and sanitation systems, and buildings- with technical solvency and ethics, recognizing that this infrastructure is the indispensable foundation for a country's connectivity, economic competitiveness, and quality of life.

1.4.2 Vision

- We aspire to be a professional program accredited with international standards, recognized for the quality and competitiveness of its faculty and graduates.
- We aspire to be a program that stands out for the relevance and impact of its basic and applied research projects.
- We aspire to be a program that promotes technological and industrial development related to Ingeniería Civil at the international level, integrating its graduates into established industries or creating new companies in this field.
- We aspire to be a program that shares and disseminates knowledge with all sectors of society and contributes to solving the strategic challenges of our country.

1.5 Accreditation information

1.5.1 Career Outcomes

Upon completion of this program, graduates will have achieved the following outcomes:

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

ABET-3) An ability to communicate effectively with a range of audiences.

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

ABET-7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The competences and/or outcomes proposed in this curriculum correspond to the competences and/or outcomes proposed by ABET.

1.5.2 Educational objectives

Después de cinco años de egresado de la carrera profesional de Ingeniería Civil, nuestros profesionales deben ser capaces de:

1. Design, construct, and manage sustainable infrastructure that complies with technical and safety standards, exceeding sector expectations.
2. Lead multidisciplinary teams in complex projects using modern management and effective communication.
3. Implement innovative solutions integrating digital technologies and sustainability principles.
4. Communicate technical proposals and results clearly and precisely to diverse audiences.
5. Continuously adapt to new standards, technologies, and methodologies through lifelong learning.
6. Practice the profession with ethical, social, and environmental responsibility, prioritizing public welfare.
7. Contribute to professional advancement through participation in technical societies and development of best practices.

1.5.3 Learning Outcomes

Each KU within a KA lists both a set of topics and the learning outcomes that students must achieve regarding the specified topics. Learning outcomes are not of equal size and do not have a uniform allocation of curricular hours; topics with the same number of hours may have very different numbers of associated learning outcomes.

Each learning outcome has an associated level of mastery. In defining the different levels, we draw from other curricular approaches, especially Bloom's taxonomy, which has been well explored within Ingeniería Civil. In this document, Bloom's levels were not applied directly, partly because several of them are driven by pedagogical context, which would introduce too much plurality in a document of this type; and partly because we intend the mastery levels to be indicative and not impose theoretical restrictions on the users of this document.

We use three expected mastery levels, which are:

Level 1 Familiarity : The student **understands** basic concepts. Answers: **"What is this?"**

Level 2 Usage : The student **applies** concepts practically. Answers: **"How to use this?"**

Level 3 Assessment : The student **evaluates and justifies** approaches. Answers: **"Why this method?"**

For example, to assess mastery levels, let us consider the notion of material selection in engineering projects. At the "familiarity" level, a student is expected to know the types of available materials (metals, polymers, ceramics, composites), their general properties, and understand why this selection is crucial for the success of any project.

In order to demonstrate mastery at the "Usage" level, the student must be able to apply technical criteria to select materials in simple cases, using property tables, technical standards, and considering factors such as strength, cost, and availability.

At the "Assessment" level, the student would be required to analyze multiple material alternatives for a complex project, considering not only mechanical properties but also environmental impact, sustainability, life cycle, current regulations, and socioeconomic context, to select the optimal option while justifying their decision with a comprehensive and ethical approach.

1.6 Profiles

1.6.1 Applicant profile

The applicant to enter the Escuela Profesional de Ingeniería Civil at Universidad Nacional de Ingeniería (UNI) must have:
Knowledge of:

1. Fundamental concepts of mathematics (algebra, geometry, trigonometry, calculus).
2. Basic principles of physics and chemistry applicable to engineering.
3. Elementary notions of statistics for data analysis.
4. Socioeconomic and environmental context of their local and global environment.

Skills to:

1. Analyze complex problems, identify their components and cause-effect relationships.
2. Apply logical-mathematical reasoning to model and solve practical situations.
3. Interpret technical information, graphs, and quantitative data accurately.
4. Express technical ideas clearly and structured, both orally and in writing.
5. Work methodically and persistently in solving challenging problems.
6. Synthesize information from diverse sources and generate well-founded conclusions.
7. Adapt study and learning methods to technical and abstract content.
8. Collaborate effectively in work teams.

Attitudes of:

1. Genuine interest in the practical application of sciences to create technical solutions.
2. Willingness for active learning, experimentation, and innovation.
3. Responsibility towards the social, environmental, and ethical impact of technology.
4. Intellectual curiosity and openness to continuous and multidisciplinary learning.

1.6.2 Graduate profile

The graduate of the Civil Engineering Professional Program is able to:

1. Design, analyze, and dimension concrete, steel, and timber structures applying principles of solid mechanics, structural dynamics, and current codes (E.060, E.090, AISC) to ensure safety and serviceability.
2. Plan, schedule, and control infrastructure projects using modern methodologies (PMBOK, Lean Construction, BIM), optimizing resources, costs, and timelines across all lifecycle stages.
3. Evaluate mechanical properties and behavior of soils, rocks, and construction materials, designing shallow and deep foundations that guarantee stability under static and seismic loads.
4. Model and design water supply systems, urban drainage, sewer networks, and hydraulic structures, considering hydrological demands, water quality, and risk management.
5. Manage construction works, coordinating multidisciplinary teams, supervising quality, occupational safety, and compliance with technical and environmental specifications.
6. Apply transportation engineering principles in the design of roads, intersections, and traffic systems, optimizing vehicular flows and analyzing impacts on urban mobility.
7. Integrate sustainability criteria, circular economy, and climate change mitigation in the design of resilient infrastructure, evaluating environmental impact and carbon footprint.
8. Use specialized software (SAP2000, ETABS, AutoCAD Civil 3D, Revit, Plaxis) for structural modeling, geotechnical design, project management, and technical documentation.
9. Communicate technical proposals through construction drawings, design reports, calculation memoranda, and presentations to regulatory entities, clients, and communities.
10. Continue graduate studies in structures, geotechnics, project management, or sustainable engineering, leading innovation in critical infrastructure at the national level.

1.6.3 ProfessionalProfile

The professional in Ingeniería Civil has the following characteristics:

- Design concrete, steel, and timber structures applying current codes to ensure safety and serviceability.

- Plan and manage infrastructure projects using modern methodologies (PMBOK, BIM) optimizing resources and costs.
- Evaluate soil properties and design foundations that guarantee stability under static and seismic loads.
- Model water supply and drainage hydraulic systems, considering hydrological demands and risk management.
- Manage construction works, coordinating teams and supervising quality, safety and regulatory compliance.
- Apply transportation engineering in road design, intersections and urban traffic flow optimization.
- Integrate sustainability and circular economy criteria in resilient infrastructure evaluating environmental impact.
- Use specialized software (SAP2000, ETABS, Civil 3D, Revit) for structural modeling and project management.
- Communicate technical proposals through drawings, reports and presentations to regulatory entities and communities.
- Continue graduate studies in structures, geotechnics or project management leading innovation in infrastructure.

1.6.4 Faculty profile

The professor of the Ingeniería Civil program is a person who:

- Promotes holistic student formation through teaching, research, and extension, transmitting solid knowledge with clarity and simplicity.
- Fosters research and continuous learning so that students adapt to area advancements and seek the common good of individuals, organizations and society.
- In the particular case of the Universidad Nacional de Ingeniería (UNI), promote that research projects are aimed at solving the problems of the most vulnerable population.
- Pursues a PhD degree with full-time dedication, maintaining advanced academic training oriented towards international excellence.
- Publishes research in international events and high-impact indexed journals, contributing to knowledge advancement and staying updated.
- Establishes cooperation networks with international-level institutions, enriching the educational experience.
- Actively participates in student formation and integration into the academic community , promoting continuous rigor and academic excellence.

1.7 Degrees and Titles

Cumplida la aprobación de los créditos académicos propuestos en la malla curricular y luego de haber cumplido con los requisitos estipulados en el reglamento de grados y títulos de la carrera, el egresado recibirá:

Grado Académico: Bachiller en Ingeniería Civil y

Titulo Profesional: Ingeniería Civil

1.8 Resources to teach

A innovative professional must always stay up to date with the latest advances in their field. The latest developments in this discipline are not necessarily found in traditional books. We must use publications from indexed journals with worldwide circulation as a primary source of up-to-date knowledge.

For this reason, we rely on institutional subscriptions to specialized databases such as IEEE Xplore, Scopus, Web of Science and other professional societies relevant to each field of engineering. It is recommended that faculty use this material to discuss in class the trends, innovations and cutting-edge developments in all areas of the specialty.

Laboratory infrastructure must also be updated according to the technological progress specific to each discipline, and this implies constant renovations to ensure that students develop practical competencies aligned with current professional standards.

The physical resources regarding laboratories for each course are detailed in Chapter 10.

1.9 Document Organization

The remainder of this document is organized as follows: Chapter 1 defines and explains the field of action of the Ingeniería Civil, in addition to providing a very brief explanation of the different programs related to this discipline.

In Chapter 2, we present the Knowledge Areas of Civil Engineering, indicating the topics and learning objectives of each subject,

In Chapter 3, we present the Knowledge Areas of Transportation Engineering, indicating the topics and learning objectives of each subject,

In Chapter 4, we present the Knowledge Areas of Engineering Science, indicating the topics and learning objectives of each subject,

In Chapter 5, we present the Knowledge Areas of Project Management, indicating the topics and learning objectives of each subject,

Chapter 6 contains the distribution by semesters, by areas, by levels, graphical view of the curriculum, comparison with various international proposals, distribution of topics per course, as well as the distribution of skills per subject.

Chapter 7 contains detailed information for each of the courses, including the skills to which it contributes, bibliography per unit, as well as the minimum number of hours per unit.

In Chapter 8 we can observe a list of courses by professor and of professor by course.

In Chapter 9, the equivalence tables with other curricula are presented.

In Chapter 10, a suggestion of the laboratories required for teaching classes is presented, which could vary depending on the number of students.

Chapter 2

Body of knowledge of Civil Engineering

The 11 knowledge areas in Civil Engineering are:

2.1 Engineering Mechanics and Materials (EMM) (Pg.. 10)

- 2.1.1 Construction Materials Science (Pg.. 11)
- 2.1.2 Mechanics of Materials and Structural Behavior (Pg.. 11)
- 2.1.3 Concrete Technology and Advanced Cementitious Materials (Pg.. 12)
- 2.1.4 Special Concretes and Concrete in Extreme Climates (Pg.. 13)
- 2.1.5 Concrete Transport and Placement (Pg.. 13)
- 2.1.6 Statistical Quality Control of Concrete (Pg.. 14)
- 2.1.7 Structural Metals, Alloys, and Corrosion Engineering (Pg.. 14)
- 2.1.8 Polymeric, Composite, and Sustainable Construction Materials (Pg.. 15)
- 2.1.9 Standardized Testing, Quality Control, and Failure Analysis (Pg.. 15)
- 2.1.10 Traditional and Vernacular Construction Materials (Pg.. 16)
- 2.1.11 Equilibrium of Particles and Rigid Bodies (Pg.. 16)
- 2.1.12 Internal Forces in Trusses and Frames (Pg.. 17)
- 2.1.13 Geometric Properties of Areas and Friction (Pg.. 17)
- 2.1.14 Kinematics of Rigid Bodies in Plane Motion (Pg.. 17)
- 2.1.15 Kinetics of Rigid Bodies in Plane Motion (Pg.. 18)
- 2.1.16 Introduction to Structural Vibrations (Pg.. 18)

2.2 Structural Analysis and Design (SAD) (Pg.. 18)

- 2.2.1 Structural Analysis I (Pg.. 19)
- 2.2.2 Energy Methods for Structural Analysis (Pg.. 20)
- 2.2.3 Force Method for Indeterminate Structures (Pg.. 20)
- 2.2.4 Classical Displacement Methods (Pg.. 20)
- 2.2.5 Matrix Structural Analysis (Pg.. 21)
- 2.2.6 Seismology and Natural Hazards (Pg.. 21)
- 2.2.7 Seismic Design Code and Structural Configuration Criteria (Pg.. 21)
- 2.2.8 Structural Dynamics and Earthquake Engineering (Pg.. 22)
- 2.2.9 Building Structural Analysis and Modeling Practicum (Pg.. 22)
- 2.2.10 Reinforced Concrete Design (Pg.. 23)
- 2.2.11 Design of Reinforced Concrete Stairs (Pg.. 23)
- 2.2.12 Seismic Detailing of Reinforced Concrete (Pg.. 24)
- 2.2.13 Prestressed Concrete Analysis (Pg.. 24)
- 2.2.14 Prestressed Concrete Design (Pg.. 24)
- 2.2.15 Integrated Structural Design Project (Pg.. 25)
- 2.2.16 Design of Steel Members in Tension and Compression (Pg.. 25)
- 2.2.17 Design of Steel Members in Flexure (Pg.. 25)
- 2.2.18 Steel Connections and Composite Systems (Pg.. 26)
- 2.2.19 Design Process for Low-Rise Buildings (Pg.. 26)
- 2.2.20 Masonry Structural Design (Pg.. 26)
- 2.2.21 Timber and Light-Gauge Steel Framing Design (Pg.. 27)
- 2.2.22 Adobe Structural Design (Pg.. 27)
- 2.2.23 Bridge Superstructure Design (Pg.. 27)
- 2.2.24 Bridge Substructure, Evaluation, and Special Systems (Pg.. 28)
- 2.2.25 Finite Element Methods in Structural Engineering (Pg.. 28)
- 2.2.26 Nature and Characterization of Loads on Existing Infrastructure (Pg.. 29)
- 2.2.27 Nonlinear Behavior of Structures (Pg.. 29)
- 2.2.28 Structural Rehabilitation, Strengthening, and Retrofit (Pg.. 30)
- 2.2.29 Industrial Structures: Chimneys and Tanks (Pg.. 30)
- 2.2.30 Advanced Structural Analysis (Pg.. 31)

2.3 Geotechnical Engineering (GTE) (Pg.. 31)

- 2.3.1 Phase Relationships and Seepage (Pg.. 32)
- 2.3.2 Shear Strength and Consolidation (Pg.. 32)
- 2.3.3 Site Investigation and In-Situ Testing (Pg.. 33)
- 2.3.4 Bearing Capacity and Design (Pg.. 34)
- 2.3.5 Deep Foundations (Pg.. 34)
- 2.3.6 Earth Retaining Systems (Pg.. 35)
- 2.3.7 Slope Stability Analysis and Stabilization (Pg.. 35)
- 2.3.8 Geotechnical Earthquake Engineering (Pg.. 36)
- 2.3.9 Ground Improvement Techniques (Pg.. 36)
- 2.3.10 Problematic Soils and Foundation-Soil Classification (Pg.. 37)
- 2.3.11 Geotechnical Numerical Modeling and Applications (Pg.. 37)
- 2.3.12 Earth Dams (Pg.. 38)
- 2.3.13 Geotechnical Characterization for Earth Dams (Pg.. 38)
- 2.3.14 Geotechnical Design of Embankment Dams (Pg.. 38)
- 2.3.15 Dam Instrumentation and Monitoring (Pg.. 39)
- 2.3.16 Construction of Earth Dams (Pg.. 39)
- 2.3.17 Operation and Safety Management of Dams (Pg.. 40)
- 2.3.18 Geosynthetics for Geotechnical Engineering (Pg.. 40)

2.4 General Geology (GGL) (Pg.. 40)

- 2.4.1 Mineralogy (Pg.. 41)
- 2.4.2 Petrology and the Rock Cycle (Pg.. 41)
- 2.4.3 Structural Geology (Pg.. 42)
- 2.4.4 Geomorphology, Weathering, and Erosion Processes (Pg.. 42)
- 2.4.5 Geologic Time, Stratigraphy, and Geologic Mapping (Pg.. 43)
- 2.4.6 Basic Surface and Groundwater Hydrology of Geologic Materials (Pg.. 43)
- 2.4.7 Applied Geology (Pg.. 43)
- 2.4.8 Rock Mass Characterization and Applied Rock and Soil Mechanics (Pg.. 44)
- 2.4.9 Engineering Geological and Geotechnical Mapping (Pg.. 44)
- 2.4.10 Soils and Rocks as Natural Resources for Construction Materials (Pg.. 45)
- 2.4.11 Engineering Geology Applied to Roads and

Canals (Pg.. 45)
- 2.4.12 Engineering Geology Applied to Bridges, Tunnels, and Dams (Pg.. 45)
- 2.4.13 Geological Hazards and Mass Movements (Pg.. 46)

2.5 Water Resources and Hydraulic Engineering (WRH) (Pg.. 46)
- 2.5.1 Hydrologic Cycle and Water Balance (Pg.. 47)
- 2.5.2 Surface Hydrology and Watershed Modeling (Pg.. 47)
- 2.5.3 Flood Frequency Analysis and Climate Change (Pg.. 47)
- 2.5.4 Open Channel Flow and River Mechanics (Pg.. 48)
- 2.5.5 Pressurized Pipe Flow and Pump Systems (Pg.. 48)
- 2.5.6 Design of Hydraulic Structures (Pg.. 49)
- 2.5.7 Urban Water Systems (Pg.. 49)
- 2.5.8 Groundwater Hydrology (Pg.. 50)
- 2.5.9 Economic, Financial and Social Evaluation of Water Resources Projects (Pg.. 50)
- 2.5.10 Sediment Transport in Alluvial Channels (Pg.. 51)
- 2.5.11 Scour and Fluvial Morphology (Pg.. 51)
- 2.5.12 River Engineering (Pg.. 52)
- 2.5.13 Agricultural Water Demand (Pg.. 52)
- 2.5.14 Irrigation Systems Design (Pg.. 52)
- 2.5.15 Coastal and Floodplain Engineering (Pg.. 53)

2.6 Environmental Systems Engineering (ESE) (Pg.. 53)
- 2.6.1 Water and Wastewater Treatment Process Design (Pg.. 54)
- 2.6.2 Environmental Chemistry and Microbiology for Engineers (Pg.. 54)
- 2.6.3 Air Quality and Pollution Control Engineering (Pg.. 55)
- 2.6.4 Environmental Impact Assessment and Sustainability Metrics (Pg.. 56)
- 2.6.5 Climate Adaptation Engineering for Water Systems (Pg.. 56)
- 2.6.6 Solid and Hazardous Waste Management (Pg.. 57)

2.7 Construction Engineering and Management (CEM) (Pg.. 57)
- 2.7.1 Construction Methods, Equipment, and Productivity (Pg.. 58)
- 2.7.2 Project Planning, Scheduling, and Control (CPM, 4D/5D) (Pg.. 58)
- 2.7.3 Construction Cost Estimating and Quantification (Pg.. 59)
- 2.7.4 Construction Budgeting, Bidding, and Financial Control (Pg.. 59)
- 2.7.5 Price Adjustment and Progress Valuations (Pg.. 60)
- 2.7.6 Construction Safety, Health, and Risk Management (Pg.. 60)
- 2.7.7 Contracts, Specifications, and Construction Law (Pg.. 61)
- 2.7.8 Lean Construction and Integrated Project Delivery (IPD) (Pg.. 61)
- 2.7.9 Construction Layout and Staking of Works (Pg.. 62)
- 2.7.10 Formwork Design and Shoring Systems (Pg.. 62)
- 2.7.11 Rebar Detailing, Fabrication, and Placement (Pg.. 63)
- 2.7.12 Construction Site and Field Management (Pg.. 63)
- 2.7.13 Integrated Quality, Environmental, and Safety Management Systems (Pg.. 64)

2.8 Digital Technologies in Civil Engineering (DTC) (Pg.. 64)
- 2.8.1 Structural Health Monitoring (SHM) and Sensor Technologies (Pg.. 64)
- 2.8.2 Building Information Modeling (BIM) for Digital Delivery and Asset Management (Pg.. 65)
- 2.8.3 Artificial Intelligence and Machine Learning Applications in Civil Engineering (Pg.. 66)
- 2.8.4 Digital Twins for Infrastructure Lifecycle Management (Pg.. 66)
- 2.8.5 Geospatial Engineering (Pg.. 67)
- 2.8.6 Data Analytics, Visualization, and Informatics for Civil Systems (Pg.. 67)
- 2.8.7 Automation, Robotics, and Additive Manufacturing (3D Printing) in Construction (Pg.. 68)

2.9 Sustainable and Resilient Infrastructure (SRI) (Pg.. 68)
- 2.9.1 Foundational Sustainability Principles and Triple Bottom Line (Pg.. 69)
- 2.9.2 Resource Efficiency and Circular Economy (Pg.. 69)
- 2.9.3 Social, Economic, and Governance Dimensions of Sustainable Infrastructure (Pg.. 69)
- 2.9.4 Resilient Design for Natural Hazards and Climate Change (Pg.. 70)
- 2.9.5 Green Building Systems and Sustainable Urban Development (Pg.. 70)
- 2.9.6 Life Cycle Assessment (LCA) and Embodied Carbon Accounting (Pg.. 71)
- 2.9.7 Nature-Based Solutions and Low-Impact Development (Pg.. 71)
- 2.9.8 Energy Infrastructure and Renewable Energy Integration (Pg.. 72)

2.10 Building Services Engineering (BSE) (Pg.. 72)
- 2.10.1 Water Supply System in Building Sanitary Installations (Pg.. 73)
- 2.10.2 Drainage System in Building Sanitary Installations (Pg.. 73)
- 2.10.3 Building Electrical Installations (Pg.. 73)

2.11 Professional Practice and Project Leadership (PPL) (Pg.. 74)
- 2.11.1 Engineering Ethics and Professional Responsibility (Pg.. 74)
- 2.11.2 Written and Technical Communication (Pg.. 75)
- 2.11.3 Oral Presentation and Professional Communication (Pg.. 75)
- 2.11.4 Digital and Collaborative Communication (Pg.. 75)
- 2.11.5 Engineering Economics and Project Financing (PPPs) (Pg.. 76)
- 2.11.6 Leadership, Team Dynamics, and Stakeholder Management (Pg.. 76)
- 2.11.7 Engineering Licensure, Legal Liability, and Regulatory Frameworks (Pg.. 77)
- 2.11.8 Global Engineering Practice and International Standards (Pg.. 77)
- 2.11.9 Professional and Regulatory Context (Pg.. 78)
- 2.11.10 National Context of Existing Civil Infrastructure (Pg.. 78)

2.1 Engineering Mechanics and Materials (EMM)

This knowledge area covers the fundamental principles of mechanics, material science, and structural behavior essential for civil engineering design. It encompasses material properties, microstructure analysis, mechanical behavior under various loading conditions, and quality assurance methodologies.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.1.1 Construction Materials Science (Pg.. 11)	1	1
⭐ 2.1.2 Mechanics of Materials and Structural Behavior (Pg.. 11)	1	1
⭐ 2.1.3 Concrete Technology and Advanced Cementitious Materials (Pg.. 12)	1	1
⭐ 2.1.4 Special Concretes and Concrete in Extreme Climates (Pg.. 13)	1	1
⭐ 2.1.5 Concrete Transport and Placement (Pg.. 13)	1	1
⭐ 2.1.6 Statistical Quality Control of Concrete (Pg.. 14)	1	1
⭐ 2.1.7 Structural Metals, Alloys, and Corrosion Engineering (Pg.. 14)	1	1
⭐ 2.1.8 Polymeric, Composite, and Sustainable Construction Materials (Pg.. 15)	1	1
⭐ 2.1.9 Standardized Testing, Quality Control, and Failure Analysis (Pg.. 15)	1	1
⭐ 2.1.10 Traditional and Vernacular Construction Materials (Pg.. 16)	1	1
⭐ 2.1.11 Equilibrium of Particles and Rigid Bodies (Pg.. 16)	1	1
⭐ 2.1.12 Internal Forces in Trusses and Frames (Pg.. 17)	1	1
⭐ 2.1.13 Geometric Properties of Areas and Friction (Pg.. 17)	1	1
⭐ 2.1.14 Kinematics of Rigid Bodies in Plane Motion (Pg.. 17)	1	1
⭐ 2.1.15 Kinetics of Rigid Bodies in Plane Motion (Pg.. 18)	1	1
⭐ 2.1.16 Introduction to Structural Vibrations (Pg.. 18)	1	1

Table 2.1: List of KUs in the Engineering Mechanics and Materials area.

2.1.1 EMM/Construction Materials Science (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental understanding of construction material properties, microstructural characteristics, and durability performance under environmental and loading conditions.

Topics:

Core

- Physical and mechanical properties of construction materials including density, porosity, strength, and elasticity
- Microstructure and phase composition of construction materials
- Durability mechanisms including weathering, chemical attack, and environmental degradation
- Thermal and moisture properties of construction materials
- Crystalline and amorphous structures in construction materials
- Material selection criteria based on performance requirements
- Degradation mechanisms and service life prediction

Learning Outcomes:

Core:

1. Describe the fundamental physical and mechanical properties of major construction materials [Familiarity]
2. Analyze the relationship between microstructure and macroscopic properties of materials [Assessment]
3. Evaluate the durability performance of materials under specific environmental conditions [Usage]
4. Explain the effects of thermal and moisture variations on material behavior [Familiarity]
5. Select appropriate construction materials based on design specifications and performance criteria [Assessment]
6. Predict service life and degradation patterns of materials in various environments [Usage]

2.1.2 EMM/Mechanics of Materials and Structural Behavior (Core Tier1: 1 hr, Core Tier2: 1 hr)

Analysis of stress, strain, deformation, and failure modes in structural members under various loading conditions including axial, bending, torsion, and combined loads.

Topics:

Core

- Stress and strain concepts including normal, shear, and principal stresses
- Axial loading and deformation of members

- Torsion of circular and non-circular sections
- Bending stress and deflection in beams
- Shear stress distribution in beams
- Combined loading and stress transformation
- Buckling of columns and stability analysis
- Fatigue and fracture mechanics
- Elastic and plastic behavior of materials
- Energy methods for structural analysis

Learning Outcomes:
Core:

1. Define stress, strain, and their relationships through constitutive laws [Familiarity]
2. Calculate stresses and deformations in members under axial loading [Usage]
3. Determine torsional stresses and angles of twist in shafts [Usage]
4. Analyze bending stress distribution and deflection in beams [Assessment]
5. Compute shear stress distribution in beam cross-sections [Usage]
6. Apply stress transformation equations for combined loading conditions [Assessment]
7. Evaluate column stability and calculate critical buckling loads [Assessment]
8. Explain fatigue failure mechanisms and predict fatigue life [Familiarity]
9. Distinguish between elastic and plastic material behavior under loading [Usage]
10. Use energy methods to solve deflection and indeterminate structural problems [Usage]

2.1.3 EMM/Concrete Technology and Advanced Cementitious Materials (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of concrete mix design, fresh and hardened concrete properties, admixtures, special concretes, and emerging cementitious materials.
Topics:
Core

- Portland cement chemistry and hydration process
- Aggregates properties and grading requirements
- Mix design methodology for normal strength concrete
- Fresh concrete properties including workability, slump, and setting time
- Hardened concrete properties including strength, modulus, and shrinkage
- Chemical and mineral admixtures for concrete
- High-performance and high-strength concrete design
- Self-consolidating concrete and fiber-reinforced concrete
- Durability aspects including alkali-silica reaction, sulfate attack, and freeze-thaw
- Sustainable and low-carbon concrete technologies including supplementary cementitious materials such as fly ash, slag, and silica fume

Learning Outcomes:
Core:

1. Describe the chemistry of portland cement and the hydration process [Familiarity]
2. Evaluate aggregate quality and suitability for concrete production [Assessment]
3. Design concrete mixes for specified strength and workability requirements [Usage]
4. Test and interpret fresh concrete properties using standard procedures [Assessment]
5. Predict hardened concrete properties based on mix proportions and curing conditions [Usage]
6. Explain the function and effects of various concrete admixtures [Familiarity]
7. Formulate high-performance concrete mixes for demanding applications [Usage]
8. Select appropriate special concretes for specific construction scenarios [Assessment]
9. Incorporate supplementary cementitious materials to optimize concrete performance [Usage]
10. Analyze durability risks and specify protective measures for concrete structures [Assessment]
11. Compare environmental impacts and carbon footprints of different concrete formulations [Familiarity]

2.1.4 EMM/Special Concretes and Concrete in Extreme Climates (Core Tier1: 1 hr, Core Tier2: 1 hr)

Special concrete types for particular construction conditions, including hot-weather and cold-weather concrete, lightweight concrete, shotcrete, and high-durability concrete for aggressive environments.

Topics:

Core

- Hot-weather concrete: heat effects on hydration, retarding admixtures, and curing methods
- Cold-weather concrete: freeze protection, accelerating admixtures, and enclosure protection methods
- Structural lightweight concrete: materials, properties, and mix design
- Mass and heavyweight concrete: heat of hydration control and applications
- Shotcrete: mix design, application process, and quality control
- Concrete for underwater structures: antiwashout mixes and placement methods
- Pervious and architectural concrete: properties and applications

Learning Outcomes:

Core:

1. Identify the effects of hot and cold weather on fresh and hardened concrete properties [Familiarity]
2. Apply preventive and corrective measures for concrete production and placement in adverse weather conditions [Usage]
3. Select the appropriate special concrete type according to project functional and environmental requirements [Assessment]
4. Design lightweight concrete mixes meeting specified strength and density requirements [Usage]
5. Specify shotcrete mixing, transport, and placement procedures for tunnel and slope applications [Usage]
6. Evaluate the suitability of special concretes for extreme exposure conditions [Assessment]
7. Develop specifications for concrete in extreme temperature conditions following ACI 305 and ACI 306 standards [Usage]

2.1.5 EMM/Concrete Transport and Placement (Core Tier1: 1 hr, Core Tier2: 1 hr)

Methods for transporting, placing, consolidating, and finishing fresh concrete, including mixer trucks, pumps, and conveyor systems, with standardized procedures to ensure structural homogeneity and performance.

Topics:

Core

- Transit mixer transport: maximum delivery time, slump verification, and admissible conditions
- Concrete pumping: pumpable mix design, operating pressure, reach, and blockage prevention
- Placement methods: direct discharge, chutes, buckets, and crane placement
- Concrete consolidation: internal and external vibration, frequency, amplitude, and insertion depth
- Underwater concrete placement by tremie method and in restricted-access conditions
- Belt conveyor and pneumatic transport systems for large-volume concrete
- Concrete surface finishing: leveling, troweling, texturing, and immediate curing

Learning Outcomes:

Core:

1. Plan concrete transport considering delivery distance, setting time, and environmental conditions [Usage]
2. Execute standardized concrete placement procedures for different types of structural elements [Usage]
3. Apply correct vibration techniques to achieve uniform concrete consolidation [Usage]
4. Evaluate concrete placement quality and identify deficiencies such as segregation, honeycombs, and cold joints [Assessment]

5. Design pumpable concrete mixes for specific pumping height and distance conditions [Usage]
6. Specify placement methods for restricted-access structures or underwater placement conditions [Assessment]
7. Develop placement plans minimizing cold joints and ensuring concrete continuity in large structural elements [Usage]

2.1.6 EMM/Statistical Quality Control of Concrete (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of statistical methods for concrete production control and acceptance, including sampling, specimen preparation, compressive strength analysis, control charts, and conformance evaluation to ACI and equivalent standards.

Topics:

Core

- Sampling procedures and fresh concrete specimen preparation according to ASTM standards
- Compressive strength testing: procedure, minimum frequency, and testing conditions
- Basic statistics applied to concrete: mean, standard deviation, and coefficient of variation
- Concrete acceptance criteria according to ACI 318 and equivalent standards
- Statistical control charts ($\bar{X}$, R) for continuous monitoring of concrete production
- Non-conforming results analysis: investigation procedures, additional tests, and structural decisions
- Process capability indices (C_p, C_{pk}) and target mean strength adjustment

Learning Outcomes:

Core:

1. Apply standardized sampling and specimen fabrication procedures for concrete on site [Usage]
2. Interpret compressive strength test results and determine their validity [Assessment]
3. Calculate basic statistical parameters from series of concrete strength test results [Usage]
4. Evaluate concrete acceptance or rejection applying ACI 318 normative criteria [Assessment]
5. Construct statistical control charts for continuous monitoring of concrete production [Usage]
6. Diagnose causes of excessive variability and propose corrective actions in concrete production [Assessment]
7. Determine the target mean strength (f'_{cr}) considering the statistical variability of the production process [Usage]

2.1.7 EMM/Structural Metals, Alloys, and Corrosion Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Properties and behavior of structural metals including steel alloys, aluminum, metallurgical principles, and corrosion protection strategies.

Topics:

Core

- Steel composition, classification, and grade designations
- Mechanical properties of structural steel including yield strength and ductility
- Heat treatment processes and their effects on steel properties
- Weldability and connection behavior of structural metals
- Corrosion mechanisms in metallic structures
- High-strength and weathering steel applications
- Aluminum alloys and their structural applications
- Fatigue behavior and fracture toughness of metals
- Corrosion protection methods including coatings and cathodic protection
- Material selection for corrosive and high-temperature environments

Learning Outcomes:

Core:

1. Identify different steel grades and their appropriate structural applications [Familiarity]
2. Interpret stress-strain curves and determine mechanical properties of metals [Assessment]
3. Explain how heat treatment affects the microstructure and properties of steel [Familiarity]

4. Evaluate weldability of metals and specify appropriate welding procedures [Usage]
5. Describe the electrochemical basis of metallic corrosion [Familiarity]
6. Select high-strength or weathering steel for specific structural requirements [Usage]
7. Compare aluminum alloys with steel for lightweight structural applications [Assessment]
8. Analyze fatigue loading scenarios and predict service life of metal components [Assessment]
9. Design corrosion protection systems for metallic structures in aggressive environments [Usage]
10. Specify appropriate materials for structures exposed to extreme conditions [Assessment]

2.1.8 EMM/Polymeric, Composite, and Sustainable Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr)

Properties and applications of polymer-based materials, fiber-reinforced composites, bio-based materials, and sustainable alternatives in construction.

Topics:

Core

- Polymer chemistry and classification of construction polymers
- Mechanical and thermal behavior of polymeric materials
- Fiber-reinforced polymer composites and their structural applications
- Adhesives, sealants, and waterproofing materials
- Composite material mechanics and laminate theory
- FRP strengthening and rehabilitation of concrete and masonry structures
- Bio-based and recycled materials for sustainable construction
- Geopolymers and alternative binder systems
- Environmental degradation and long-term performance of polymers and composites

Learning Outcomes:

Core:

1. Classify polymers used in construction and describe their basic properties [Familiarity]
2. Characterize the mechanical and thermal behavior of polymeric materials [Assessment]
3. Apply fiber-reinforced polymers in structural design and retrofitting applications [Usage]
4. Select appropriate adhesives and sealants for specific construction applications [Familiarity]
5. Analyze composite laminates using classical lamination theory [Usage]
6. Design FRP strengthening systems for existing concrete or masonry structures [Assessment]
7. Evaluate the sustainability and life-cycle performance of bio-based construction materials [Assessment]
8. Compare geopolymer binders with traditional portland cement systems [Familiarity]
9. Predict long-term degradation of polymers and composites under environmental exposure [Usage]

2.1.9 EMM/Standardized Testing, Quality Control, and Failure Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Standard test methods for construction materials, quality assurance procedures, statistical quality control, and systematic failure investigation techniques.

Topics:

Core

- Standard test methods for material characterization and acceptance testing
- Sampling procedures and representative sample selection
- Quality control and quality assurance protocols in construction
- Statistical analysis of test data and acceptance criteria
- Non-destructive testing methods for materials and structures
- Advanced material characterization techniques including microscopy and spectroscopy
- Failure analysis methodology and root cause investigation
- Forensic engineering and distress evaluation
- Performance-based testing and specification approaches
- Certification, compliance, and third-party testing requirements

Learning Outcomes:
Core:

1. Perform standard material tests according to ASTM or equivalent specifications [Usage]
2. Develop appropriate sampling plans for construction material acceptance [Assessment]
3. Implement quality control procedures for construction materials and processes [Usage]
4. Analyze test data using statistical methods and establish acceptance criteria [Assessment]
5. Apply non-destructive testing techniques for in-situ material evaluation [Familiarity]
6. Utilize advanced characterization techniques to investigate material microstructure [Usage]
7. Conduct systematic failure analysis to determine root causes of material distress [Assessment]
8. Investigate structural failures using forensic engineering methodologies [Assessment]
9. Design performance-based test protocols for innovative materials [Usage]
10. Interpret certification requirements and coordinate third-party testing programs [Familiarity]

2.1.10 EMM/Traditional and Vernacular Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classification and properties of construction stone, and of vernacular construction materials -adobe, quincha, tapial, and bamboo- including their quality control testing.
Topics:
Core

- Construction stone: classification and properties
- Adobe as a construction material: fabrication and properties
- Quincha as a construction system: materials and technique
- Tapial (rammed earth) as a construction material: fabrication and properties
- Bamboo as a construction material: properties and structural applications
- Quality control testing for vernacular construction materials

Learning Outcomes:
Core:

1. Classify construction stone by its properties and applications [Familiarity]
2. Characterize the physical and mechanical properties of adobe, quincha, and tapial [Usage]
3. Evaluate the suitability of bamboo as a structural material in construction [Assessment]
4. Perform quality control tests on vernacular construction materials [Usage]
5. Recommend the use of an appropriate vernacular material based on a project's conditions [Assessment]

2.1.11 EMM/Equilibrium of Particles and Rigid Bodies (Core Tier1: 1 hr, Core Tier2: 1 hr)

Analysis of force systems in equilibrium for particles and rigid bodies in two and three dimensions, determination of support reactions, and equilibrium of flexible cables under concentrated and distributed loads.
Topics:
Core

- Equilibrium equations and free-body diagrams for particles and rigid bodies in two and three dimensions
- Flexible cables under concentrated and distributed loads

Learning Outcomes:
Core:

1. Apply equilibrium equations to determine support reactions in two- and three-dimensional rigid-body systems [Usage]
2. Determine cable tension and shape under concentrated and distributed loads [Usage]

2.1.12 EMM/Internal Forces in Trusses and Frames (Core Tier1: 1 hr, Core Tier2: 1 hr)

Determination of internal forces in trusses using the methods of joints and sections, in multi-member frames and machines, and in beams using shear-force and bending-moment diagrams.

Topics:

Core

- Truss analysis using the method of joints and the method of sections
- Free-body diagrams and internal-force analysis of multi-member frames and machines
- Internal forces in beams: shear-force and bending-moment diagrams

Learning Outcomes:

Core:

1. Analyze planar trusses using both the method of joints and the method of sections [Assessment]
2. Draw free-body diagrams for multi-member frames and machines and determine internal member forces [Usage]
3. Construct shear-force and bending-moment diagrams for beams under concentrated and distributed loads [Assessment]

2.1.13 EMM/Geometric Properties of Areas and Friction (Core Tier1: 1 hr, Core Tier2: 1 hr)

Determination of centroids and moments of inertia of composite areas, analysis of dry friction phenomena, and introduction to virtual work methods for equilibrium problems.

Topics:

Core

- Centroids and centers of gravity of composite areas and lines
- Moments of inertia of areas and the parallel-axis theorem
- Dry friction: laws of friction, wedges, and screws
- Virtual work and stability of equilibrium

Learning Outcomes:

Core:

1. Determine the geometric properties of complex cross-sections used in structural shapes [Usage]
2. Analyze equilibrium problems involving static friction forces [Assessment]
3. Apply friction principles to the analysis of wedges and screw mechanisms [Usage]
4. Evaluate the stability of equilibrium using virtual work principles [Familiarity]

2.1.14 EMM/Kinematics of Rigid Bodies in Plane Motion (Core Tier1: 1 hr, Core Tier2: 1 hr)

Kinematic analysis of rigid bodies in plane motion: translation, fixed-axis rotation, general plane motion, and the use of the instantaneous center of rotation to determine velocities and accelerations.

Topics:

Core

- Translation and rotation about a fixed axis
- General plane motion: relative velocity and acceleration, and the instantaneous center of rotation

Learning Outcomes:

Core:

1. Determine the velocity and acceleration of any point in a planar mechanism using the instantaneous center of rotation [Usage]
2. Explain the distinction between translation, fixed-axis rotation, and general plane motion [Familiarity]

2.1.15 EMM/Kinetics of Rigid Bodies in Plane Motion (Core Tier1: 1 hr, Core Tier2: 1 hr)

Kinetic analysis of rigid bodies in plane motion: equations of motion relating external forces to angular acceleration, and the principle of work and energy applied to rotational and translational kinetic energy.
Topics:
Core

- Equations of motion for a rigid body in plane motion
- Kinetic energy of a rigid body and the principle of work and energy

Learning Outcomes:
Core:

1. Apply the equations of motion to relate external forces to the angular acceleration of rigid bodies [Assessment]
2. Analyze rigid-body motion problems using the principle of work and energy [Usage]

2.1.16 EMM/Introduction to Structural Vibrations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamentals of free and forced vibration of single-degree-of-freedom systems, applied to the assessment of the dynamic behavior of simple structural models.
Topics:
Core

- Undamped free vibration of a single-degree-of-freedom system
- Simple pendulum and mass-spring models
- Natural frequency, period, and amplitude concepts
- Introduction to damped free vibration

Learning Outcomes:
Core:

1. Model simple structural systems as single-degree-of-freedom systems [Usage]
2. Calculate the natural frequency of a structure to avoid basic resonance phenomena [Assessment]
3. Describe the effect of damping on the free-vibration response of a structural system [Familiarity]
4. Interpret period and amplitude parameters from a structure's free-vibration response [Usage]

2.2 Structural Analysis and Design (SAD)

This knowledge area encompasses the analysis and design of structural systems, from fundamental principles of equilibrium and structural behavior to advanced computational methods and design of various structural materials and systems.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.2.1 Structural Analysis I (Pg.. 19)	1	1
⭐ 2.2.2 Energy Methods for Structural Analysis (Pg.. 20)	1	1
⭐ 2.2.3 Force Method for Indeterminate Structures (Pg.. 20)	1	1
⭐ 2.2.4 Classical Displacement Methods (Pg.. 20)	1	1
⭐ 2.2.5 Matrix Structural Analysis (Pg.. 21)	1	1
⭐ 2.2.6 Seismology and Natural Hazards (Pg.. 21)	1	1
⭐ 2.2.7 Seismic Design Code and Structural Configuration Criteria (Pg.. 21)	1	1
⭐ 2.2.8 Structural Dynamics and Earthquake Engineering (Pg.. 22)	1	1
⭐ 2.2.9 Building Structural Analysis and Modeling Practicum (Pg.. 22)	1	1
⭐ 2.2.10 Reinforced Concrete Design (Pg.. 23)	1	1
⭐ 2.2.11 Design of Reinforced Concrete Stairs (Pg.. 23)	1	1
⭐ 2.2.12 Seismic Detailing of Reinforced Concrete (Pg.. 24)	1	1
⭐ 2.2.13 Prestressed Concrete Analysis (Pg.. 24)	1	1
⭐ 2.2.14 Prestressed Concrete Design (Pg.. 24)	1	1
⭐ 2.2.15 Integrated Structural Design Project (Pg.. 25)	1	1
⭐ 2.2.16 Design of Steel Members in Tension and Compression (Pg.. 25)	1	1
⭐ 2.2.17 Design of Steel Members in Flexure (Pg.. 25)	1	1
⭐ 2.2.18 Steel Connections and Composite Systems (Pg.. 26)	1	1
⭐ 2.2.19 Design Process for Low-Rise Buildings (Pg.. 26)	1	1
⭐ 2.2.20 Masonry Structural Design (Pg.. 26)	1	1
⭐ 2.2.21 Timber and Light-Gauge Steel Framing Design (Pg.. 27)	1	1
⭐ 2.2.22 Adobe Structural Design (Pg.. 27)	1	1
⭐ 2.2.23 Bridge Superstructure Design (Pg.. 27)	1	1
⭐ 2.2.24 Bridge Substructure, Evaluation, and Special Systems (Pg.. 28)	1	1
⭐ 2.2.25 Finite Element Methods in Structural Engineering (Pg.. 28)	1	1
⭐ 2.2.26 Nature and Characterization of Loads on Existing Infrastructure (Pg.. 29)	1	1
⭐ 2.2.27 Nonlinear Behavior of Structures (Pg.. 29)	1	1
⭐ 2.2.28 Structural Rehabilitation, Strengthening, and Retrofit (Pg.. 30)	1	1
⭐ 2.2.29 Industrial Structures: Chimneys and Tanks (Pg.. 30)	1	1
2.2.30 Advanced Structural Analysis (Pg.. 31)	Elective	

Table 2.2: List of KUs in the Structural Analysis and Design area.

2.2.1 SAD/Structural Analysis I (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental analysis of statically determinate structures including trusses, beams, and frames, along with influence line construction for moving loads.

Topics:

Core

- Equilibrium equations and free body diagrams for structural systems
- Reactions and internal forces in determinate beams and frames
- Truss analysis using method of joints and method of sections
- Shear force and bending moment diagrams
- Cables and arches under concentrated and distributed loads
- Influence lines for beams and trusses
- Moving load analysis and envelope diagrams
- Three-dimensional truss and frame analysis
- Compound structures and classification of structural forms

Learning Outcomes:

Core:

1. Apply equilibrium equations to determine support reactions in determinate structures [Usage]
2. Calculate internal forces and moments at any section of beams and frames [Assessment]
3. Analyze planar trusses using both method of joints and method of sections [Usage]
4. Construct shear force and bending moment diagrams for various loading conditions [Assessment]

5. Determine internal forces in cables and arches under specified loads [Usage]
6. Develop influence lines for reactions and internal forces in determinate structures [Assessment]
7. Utilize influence lines to determine maximum effects from moving loads [Usage]
8. Analyze three-dimensional structural systems and determine spatial force components [Assessment]
9. Classify structures as determinate or indeterminate and identify stability conditions [Familiarity]

2.2.2 SAD/Energy Methods for Structural Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental energy principles for computing displacements and identifying the degree of indeterminacy in structural systems, forming the theoretical basis for the classical indeterminate analysis methods that follow.

Topics:

Core

- Indeterminacy and degree of freedom concepts
- Internal work of deformation and the principle of virtual work
- Castigliano's first theorem for the calculation of displacements
- Betti's and Maxwell's reciprocal theorems

Learning Outcomes:

Core:

1. Identify the degree of indeterminacy for structural systems [Assessment]
2. Apply the principle of virtual work to calculate internal deformation energy in structural systems [Usage]
3. Apply Castigliano's first theorem to determine displacements in indeterminate structures [Usage]
4. Verify the reciprocity of displacements and forces using Betti's and Maxwell's theorems [Assessment]

2.2.3 SAD/Force Method for Indeterminate Structures (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classical force (flexibility) method for analyzing statically indeterminate beams, frames, and arches, using redundant forces and compatibility conditions derived from energy principles.

Topics:

Core

- Force method and flexibility approach for indeterminate structures
- Principle of minimum work (Castigliano's second theorem) for the calculation of redundants
- Analysis of statically indeterminate arches
- Influence lines for indeterminate structures using Mueller-Breslau principle

Learning Outcomes:

Core:

1. Apply the force method to analyze indeterminate beams and frames [Usage]
2. Apply the principle of minimum work to calculate redundant forces in the force method [Usage]
3. Analyze statically indeterminate arches under combined loading [Assessment]
4. Construct influence lines for indeterminate structures qualitatively [Usage]

2.2.4 SAD/Classical Displacement Methods (Core Tier1: 1 hr, Core Tier2: 1 hr)

Displacement-based classical methods for analyzing indeterminate beams and frames, providing the conceptual bridge to the matrix stiffness formulation covered next.

Topics:

Core

- Slope-deflection method for continuous beams and frames
- Moment distribution method

Learning Outcomes:

Core:

1. Use slope-deflection equations to solve continuous beam and frame problems [Assessment]
2. Perform moment distribution analysis for indeterminate structures [Usage]

2.2.5 SAD/Matrix Structural Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Displacement method and stiffness approach
- Direct stiffness method and matrix formulation
- Coordinate transformations and assembly of global stiffness matrices

Learning Outcomes:
Core:

1. Implement the displacement method for structural analysis [Assessment]
2. Formulate structural problems using the direct stiffness method in matrix form [Usage]
3. Assemble global stiffness matrices and solve for nodal displacements [Assessment]

2.2.6 SAD/Seismology and Natural Hazards (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamentals of seismology and plate tectonics, regional seismicity of Peru, and the typology and management of natural disaster risk, as a conceptual foundation for earthquake-resistant engineering.
Topics:
Core

- Plate tectonics and earthquake generation mechanisms through fault rupture
- Seismic waves: types (P, S, surface) and their propagation
- Magnitude (seismic moment) and intensity (Modified Mercalli) scales
- Historical seismicity and subduction tectonic context of Peru
- Typology of natural disasters: seismic, volcanic, tsunami, and mass movement
- Disaster risk management: prevention, mitigation, preparedness, and response (SINAGERD framework)
- Seismological instrumentation: seismographs, accelerographs, and national monitoring networks

Learning Outcomes:
Core:

1. Explain plate tectonics and earthquake generation mechanisms through fault rupture [Familiarity]
2. Differentiate types of seismic waves and their effects on buildings [Usage]
3. Interpret and distinguish between earthquake magnitude and intensity scales [Usage]
4. Describe the historical seismicity and subduction context of Peru [Familiarity]
5. Classify the main types of natural disasters affecting Peruvian territory [Familiarity]
6. Analyze the disaster risk management framework for earthquake prevention and response [Assessment]

2.2.7 SAD/Seismic Design Code and Structural Configuration Criteria (Core Tier1: 1 hr, Core Tier2: 1 hr)

Structure and parameters of the Peruvian seismic design code (E.030), structural systems and their force reduction factor, and structural configuration and regularity criteria for earthquake-resistant building design.
Topics:
Core

- Scope and structure of the Peruvian seismic design code E.030
- Seismic hazard parameters: seismic zonation (Z), usage factor (U), and soil profile (S)
- Structural systems and seismic force reduction coefficient (R)
- Plan structural irregularities: torsional irregularity, re-entrant corners, and diaphragm discontinuity
- Vertical structural irregularities: soft story, weak story, and mass irregularity

- Structuring principles: symmetry, redundancy, hyperstaticity, and continuity
- Minimum base shear and inter-story drift limits

Learning Outcomes:

Core:

1. Explain the scope and structure of the Peruvian seismic design code E.030 [Familiarity]
2. Determine the seismic hazard parameters (Z, U, S) applicable to a given site [Usage]
3. Select the structural system and corresponding reduction coefficient R [Usage]
4. Classify the plan and vertical structural irregularities of a building [Assessment]
5. Apply structuring principles to propose a regular structural configuration [Usage]
6. Verify the minimum base shear and inter-story drift limits [Assessment]

2.2.8 SAD/Structural Dynamics and Earthquake Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Dynamic behavior of structures under time-varying loads, vibration analysis, earthquake ground motion characterization, and seismic design principles.

Topics:

Core

- Single-degree-of-freedom systems and free vibration
- Forced vibration and harmonic excitation
- Damping models and energy dissipation mechanisms
- Response spectrum analysis
- Earthquake ground motion characteristics and seismicity
- Multi-degree-of-freedom systems and modal analysis
- Time-history analysis and numerical integration methods
- Seismic design philosophy and capacity design principles
- Base isolation and energy dissipation devices
- Performance-based seismic design methodology

Learning Outcomes:

Core:

1. Analyze free vibration of single-degree-of-freedom systems and determine natural frequencies [Assessment]
2. Calculate structural response to harmonic and periodic loads [Usage]
3. Explain the role of damping in reducing dynamic response [Familiarity]
4. Apply response spectrum method for seismic analysis [Usage]
5. Interpret earthquake ground motion parameters and seismic hazard maps [Familiarity]
6. Perform modal analysis for multi-degree-of-freedom systems [Assessment]
7. Conduct time-history analysis using numerical integration techniques [Usage]
8. Design structures following capacity design and ductile detailing principles [Assessment]
9. Evaluate the effectiveness of base isolation and damping systems [Familiarity]
10. Implement performance-based seismic design procedures [Assessment]

2.2.9 SAD/Building Structural Analysis and Modeling Practicum (Core Tier1: 1 hr, Core Tier2: 1 hr)

Practical application of the stiffness method and seismic response-spectrum analysis to the software-based modeling and evaluation of real building structural systems, with presentation and discussion of results.

Topics:

Core

- Overview of case-study buildings: geometry, structural systems, and load paths
- Development of plane frame and truss models of real buildings using stiffness-method-based structural analysis software
- Application of static and seismic response-spectrum analysis to representative building case studies
- Presentation and peer discussion of structural analysis results and their design implications

- Definition of geometry, materials, sections, and boundary conditions for a three-dimensional building model in commercial structural analysis software (ETABS, Midas Gen)
- Assignment of gravity, seismic, and wind loads and their combinations to a three-dimensional building model
- Static and dynamic (modal) analysis of building models and interpretation of results, including story drifts, member forces, and vibration periods
- Verification of software-generated results against simplified hand calculations and code checks

Learning Outcomes:
Core:

1. Model real building structural systems for stiffness-method-based static and seismic analysis using structural analysis software [Usage]
2. Interpret and validate computer-generated analysis results against expected structural behavior [Assessment]
3. Present and defend structural analysis results and their design implications to peers [Usage]
4. Assign gravity, seismic, and wind loads and load combinations to a three-dimensional building model in commercial structural analysis software [Usage]
5. Interpret dynamic analysis results, including story drifts, member forces, and vibration periods [Assessment]
6. Verify software-generated results against simplified hand calculations [Assessment]

2.2.10 SAD/Reinforced Concrete Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of reinforced concrete members for flexure, shear, compression, and serviceability following limit state design philosophy.
Topics:
Core

- Design philosophy and limit state methodology for concrete structures
- Flexural design of rectangular and T-beams
- Shear and torsion design of concrete members
- Compression members and column design
- Slab design including one-way and two-way systems
- Development length and splicing of reinforcement
- Deflection control and serviceability requirements for concrete beams and slabs

Learning Outcomes:
Core:

1. Explain limit state design philosophy and load factor combinations [Familiarity]
2. Design reinforced concrete beams for flexure and check serviceability [Assessment]
3. Calculate shear and torsional reinforcement requirements [Usage]
4. Proportion columns for axial load and biaxial bending [Assessment]
5. Design one-way and two-way slab systems with appropriate reinforcement [Usage]
6. Determine development lengths and design lap splices for reinforcing bars [Assessment]
7. Control deflections and verify serviceability requirements through adequate member sizing and reinforcement [Usage]

2.2.11 SAD/Design of Reinforced Concrete Stairs (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of supported and cantilevered reinforced concrete staircases, including geometry of flights and landings, load distribution, and reinforcement detailing.
Topics:
Core

- Geometry of stair flights, landings, and waist slabs
- Load distribution and effective span for simply supported staircases
- Load distribution and effective span for cantilevered staircases
- Reinforcement detailing for stair flights, landings, and supports

Learning Outcomes:
Core:
1. Design a supported reinforced concrete staircase for gravity loads [Assessment]
2. Design a cantilevered reinforced concrete staircase for gravity loads [Assessment]
3. Detail reinforcement for stair flights, landings, and supports [Usage]

2.2.12 SAD/Seismic Detailing of Reinforced Concrete (Core Tier1: 1 hr, Core Tier2: 1 hr)

Beam-column joints, design of special structural walls, and special seismic detailing provisions for ductile reinforced concrete moment frames.
Topics:
Core
- Beam-column joints and moment-resisting frame connections
- Seismic detailing and ductile design of concrete structures
- Design of special reinforced concrete structural walls (shear walls) for seismic lateral force resistance
- Special seismic detailing provisions for reinforced concrete moment-resisting frames

Learning Outcomes:
Core:
1. Detail beam-column joints for moment transfer and shear resistance [Assessment]
2. Implement seismic detailing requirements for ductile concrete frames [Assessment]
3. Design special reinforced concrete structural walls for combined axial, flexural, and shear demands under seismic loading [Assessment]
4. Apply special seismic detailing provisions to reinforced concrete moment frame members and beam-column joints [Usage]

2.2.13 SAD/Prestressed Concrete Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Prestressing principles, elastic analysis of stresses under service loads, composite sections, and immediate and time-dependent prestress losses.
Topics:
Core
- Prestressed concrete principles and pre-tensioning methods
- Elastic analysis of stresses in prestressed concrete sections under service loads
- Composite prestressed concrete sections: precast members with cast-in-place topping
- Immediate and time-dependent losses of prestress

Learning Outcomes:
Core:
1. Apply prestressing principles to design pre-tensioned members [Usage]
2. Analyze stresses in prestressed concrete sections under service loads using elastic theory [Usage]
3. Design composite prestressed concrete sections combining precast members and cast-in-place concrete [Assessment]
4. Calculate immediate and time-dependent losses of prestress [Usage]

2.2.14 SAD/Prestressed Concrete Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Post-tensioned system design and tendon layout, deflection control, ultimate-limit-state flexural, shear, and torsion strength, and analysis of statically indeterminate prestressed structures.
Topics:
Core
- Post-tensioned concrete systems and tendon design
- Deflection control and serviceability requirements
- Flexural strength of prestressed concrete members at ultimate limit state
- Shear and torsion design of prestressed concrete members
- Statically indeterminate prestressed concrete structures, including secondary moments

Learning Outcomes:
Core:

1. Design post-tensioned slabs and beams including tendon layout [Assessment]
2. Control deflections through appropriate member sizing and reinforcement [Usage]
3. Design prestressed concrete members for flexural strength at the ultimate limit state [Assessment]
4. Design prestressed concrete members for shear and torsion strength [Assessment]
5. Analyze statically indeterminate prestressed concrete structures, including secondary moments [Assessment]

2.2.15 SAD/Integrated Structural Design Project (Core Tier1: 1 hr, Core Tier2: 1 hr)

Progressive development of a reinforced concrete structural design project integrating slabs, structural walls, and foundations, coordinating design decisions with architectural and geotechnical constraints, and culminating in technical design documentation.
Topics:
Core

- Progressive design exercise integrating slab, structural wall, and foundation design for a multi-story reinforced concrete building
- Coordination of structural design decisions with the architectural and geotechnical constraints of the project
- Structural design documentation, including calculation memoranda and design drawings

Learning Outcomes:
Core:

1. Develop a progressive, integrated structural design for a reinforced concrete building incorporating slabs, structural walls, and foundations [Assessment]
2. Apply course content cumulatively to solve realistic, open-ended design problems under code and site constraints [Assessment]
3. Prepare structural calculation documentation communicating design decisions [Usage]

2.2.16 SAD/Design of Steel Members in Tension and Compression (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of structural steel members subjected to pure axial tension and compression, including net area and block shear considerations and column buckling, using limit states design (LRFD/ASD).
Topics:
Core

- Tension member design and effective area considerations
- Compression member design and column buckling

Learning Outcomes:
Core:

1. Design tension members considering net area and block shear [Assessment]
2. Select appropriate column sections and check buckling capacity [Usage]

2.2.17 SAD/Design of Steel Members in Flexure (Core Tier1: 1 hr, Core Tier2: 1 hr)

Flexural design of steel beams, including lateral-torsional buckling, combined axial force and bending moment interaction (beam-columns), and plate girders with stiffeners.
Topics:
Core

- Flexural design of beams and lateral-torsional buckling
- Combined axial force and bending interaction
- Plate girders and web design

Learning Outcomes:
Core:

1. Proportion steel beams considering both local and lateral-torsional buckling [Assessment]
2. Evaluate beam-columns using interaction equations [Usage]
3. Design plate girders with consideration of web buckling and stiffeners [Assessment]

2.2.18 SAD/Steel Connections and Composite Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of bolted and welded steel connections, composite beams, seismic moment frames, and braced frame systems.
Topics:
Core

- Bolted connections design and failure modes
- Welded connections and design considerations
- Composite beams and shear connectors
- Moment-resisting frames and seismic provisions for steel structures
- Braced frames and concentrically braced frame design
- Connection design for special moment frames and prequalified connections

Learning Outcomes:
Core:

1. Design bolted connections for shear, tension, and combined loading [Assessment]
2. Specify welded connections and determine weld sizes [Usage]
3. Analyze composite beams and design shear stud connectors [Usage]
4. Design moment-resisting frames for seismic and wind loads [Assessment]
5. Proportion bracing members and connections in braced frame systems [Usage]
6. Detail prequalified moment connections according to seismic provisions [Assessment]

2.2.19 SAD/Design Process for Low-Rise Buildings (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design process for a low-rise building, from site and soil recognition and identification of the applicable regulatory framework, through selection of a structural system in masonry, adobe, or timber and its integration with the architectural layout of the project.
Topics:
Core

- Site and soil recognition, project requirements, and applicable regulatory framework (E.030, E.070, E.080, E.010)
- Criteria for selecting a structural system among masonry, adobe, and timber based on site conditions, materials availability, and seismic hazard
- Integration of the structural design with the architectural layout of a building project

Learning Outcomes:
Core:

1. Describe the design process of a low-rise building, identifying site conditions and the applicable Peruvian regulatory framework [Familiarity]
2. Select an appropriate structural system for a building project based on site conditions, materials, and seismic hazard [Usage]
3. Formulate the scope and requirements of a building project that integrates masonry, adobe, or timber systems [Assessment]

2.2.20 SAD/Masonry Structural Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design principles for unreinforced and reinforced masonry, including materials, detailing, and seismic provisions.
Topics:
Core

- Masonry materials, units, and mortar properties
- Unreinforced masonry wall design for compression and flexure
- Reinforced masonry design and detailing
- Seismic design of masonry and timber structures

Learning Outcomes:
Core:

1. Identify masonry unit types and specify appropriate mortar for applications [Familiarity]
2. Design unreinforced masonry walls for gravity and lateral loads [Assessment]
3. Proportion reinforced masonry elements and specify reinforcement details [Usage]
4. Implement seismic design provisions for masonry and timber buildings [Usage]

2.2.21 SAD/Timber and Light-Gauge Steel Framing Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Properties and design of sawn lumber, glued-laminated timber, and engineered wood elements and their connections, along with cold-formed steel members and light-gauge steel framing systems.
Topics:
Core

- Timber properties, grading, and design values
- Sawn lumber and glued-laminated timber design
- Timber connections including nails, bolts, and metal connectors
- Cold-formed steel members and sectional properties
- Light-gauge steel framing systems and design
- Engineered wood products including I-joists and structural composite lumber

Learning Outcomes:
Core:

1. Select timber species and grades based on structural requirements [Familiarity]
2. Design timber beams, columns, and combined loading members [Assessment]
3. Specify timber connections and calculate their capacity [Usage]
4. Calculate effective section properties for cold-formed steel members [Assessment]
5. Design light-gauge steel wall studs and floor joists [Usage]
6. Apply engineered wood products in floor and roof systems [Assessment]

2.2.22 SAD/Adobe Structural Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Adobe as a structural material: mechanical properties, wall design for gravity loads per Standard E.080, and seismic reinforcement techniques.
Topics:
Core

- Adobe as a structural material: mechanical properties and seismic behavior
- Adobe wall design for gravity loads and verification of thickness and slenderness per Standard E.080
- Seismic reinforcement techniques for adobe construction: meshes, geomeshes, and horizontal and vertical reinforcement

Learning Outcomes:
Core:

1. Characterize the mechanical properties of adobe and its seismic behavior [Familiarity]
2. Design adobe walls according to the thickness, slenderness, and geometric requirements of Standard E.080 [Assessment]
3. Specify seismic reinforcement techniques for new and existing adobe buildings [Usage]

2.2.23 SAD/Bridge Superstructure Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Types, loads, and design of bridge superstructures including concrete slab, steel girder, prestressed concrete, box girder, and truss systems.

Topics:
Core
- Bridge types, components, and structural systems
- Load models and load combinations for bridge design
- Concrete slab bridges and T-beam bridge design
- Steel girder bridges and composite bridge deck design
- Prestressed concrete girder bridges
- Box girder and curved bridge analysis
- Truss bridge design considerations for members under combined flexure and axial force

Learning Outcomes:
Core:
1. Classify bridge types and select appropriate systems for given site conditions [Familiarity]
2. Apply AASHTO load models and determine critical load combinations [Usage]
3. Design reinforced concrete slab bridges and T-beam superstructures [Assessment]
4. Proportion steel girders and design composite deck systems [Assessment]
5. Analyze and design prestressed concrete girder bridges [Assessment]
6. Model box girder bridges and analyze curved alignment effects [Usage]
7. Design truss bridge members subject to combined flexo-tension and flexo-compression [Usage]

2.2.24 SAD/Bridge Substructure, Evaluation, and Special Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of bridge substructures, cable-supported bridges, bridge evaluation, load rating, and seismic design.

Topics:
Core
- Substructure design including abutments and piers
- Cable-stayed and suspension bridge concepts
- Bearings, expansion joints, and bridge deck details
- Bridge load rating and evaluation procedures
- Seismic design of bridges and isolation systems

Learning Outcomes:
Core:
1. Design bridge abutments and piers for vertical and lateral loads [Usage]
2. Explain the structural behavior of cable-supported bridge systems [Familiarity]
3. Select and design bridge bearings and expansion joint systems [Assessment]
4. Perform load rating analysis for existing bridges [Usage]
5. Implement seismic design criteria for bridge structures [Assessment]

2.2.25 SAD/Finite Element Methods in Structural Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental theory and application of finite element analysis for structural problems including element formulation, modeling techniques, and result interpretation.

Topics:
Core
- Fundamentals of finite element theory and discretization
- Element types including truss, beam, and frame elements
- Stiffness matrix formulation and assembly
- Plane stress and plane strain elements
- Modeling techniques, boundary conditions, and mesh refinement
- Shell and plate elements
- Solid elements and three-dimensional analysis
- Nonlinear analysis including material and geometric nonlinearity
- Dynamic analysis using finite element methods
- Verification, validation, and error estimation in FEA

Learning Outcomes:
Core:

1. Explain the fundamental principles and assumptions of finite element analysis [Familiarity]
2. Formulate element stiffness matrices for basic element types [Usage]
3. Assemble global stiffness matrices and apply boundary conditions [Assessment]
4. Apply plane stress and plane strain elements to two-dimensional problems [Usage]
5. Develop appropriate finite element models with proper mesh density [Assessment]
6. Utilize shell and plate elements for thin-walled structure analysis [Usage]
7. Model complex three-dimensional structures using solid elements [Assessment]
8. Perform nonlinear finite element analysis for material and geometric effects [Usage]
9. Conduct dynamic finite element analysis including modal and time-history analysis [Assessment]
10. Validate finite element results and estimate discretization errors [Assessment]

2.2.26 SAD/Nature and Characterization of Loads on Existing Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr)

Characterization of the permanent, live, environmental, and deterioration-induced loads and load histories acting on existing civil infrastructure, as a basis for structural condition assessment and rehabilitation.
Topics:
Core

- Permanent (dead) and live load characterization for existing structures
- Environmental loads: wind, thermal, and differential settlement effects on infrastructure
- Deterioration-induced load effects: corrosion, creep, shrinkage, and fatigue
- Load history reconstruction and service load estimation for existing structures
- Overload and abnormal load events: impact, blast, and accidental actions
- Load combinations for structural assessment and rehabilitation design

Learning Outcomes:
Core:

1. Characterize the permanent and live loads applicable to existing civil infrastructure [Familiarity]
2. Determine environmental load effects, including wind, thermal, and differential settlement, on existing structures [Usage]
3. Identify deterioration-induced load effects such as corrosion, creep, shrinkage, and fatigue [Assessment]
4. Reconstruct the load history and estimate in-service loads for an existing structure [Usage]
5. Recognize overload and abnormal load events relevant to infrastructure assessment [Familiarity]
6. Establish load combinations appropriate for structural assessment and rehabilitation design [Assessment]

2.2.27 SAD/Nonlinear Behavior of Structures (Core Tier1: 1 hr, Core Tier2: 1 hr)

Material and geometric nonlinear behavior of structural components and systems, including hysteretic response, plastic hinge modeling, nonlinear static analysis, and displacement-based assessment methods used to evaluate the performance of existing structures.
Topics:
Core

- Material nonlinearity: stress-strain behavior of concrete and reinforcing steel beyond yield
- Geometric nonlinearity and P-delta effects in structural response
- Hysteretic behavior and energy dissipation of structural components under cyclic loading
- Plastic hinge formation, hinge length, and moment-curvature relationships
- Nonlinear static (pushover) analysis and capacity curve development
- Displacement ductility and curvature ductility demand
- Performance levels and acceptance criteria for structural and nonstructural components
- Displacement-based assessment methods for existing structures

Learning Outcomes:
Core:

1. Explain the material and geometric sources of nonlinear structural behavior [Familiarity]
2. Determine moment-curvature relationships and plastic hinge properties for structural members [Usage]
3. Perform nonlinear static (pushover) analysis to develop a structure's capacity curve [Usage]
4. Calculate displacement and curvature ductility demands for structural components [Assessment]
5. Evaluate structural and nonstructural performance levels against acceptance criteria [Assessment]
6. Apply displacement-based methods to assess the seismic performance of existing structures [Usage]

2.2.28 SAD/Structural Rehabilitation, Strengthening, and Retrofit (Core Tier1: 1 hr, Core Tier2: 1 hr)

Assessment, strengthening, and retrofit techniques for existing structures including seismic upgrade, structural health evaluation, and repair methodologies.

Topics:

Core

- Condition assessment and structural evaluation procedures
- Load rating and capacity evaluation of existing structures
- Concrete repair materials and techniques
- Strengthening techniques using external reinforcement
- FRP strengthening systems for flexure and shear
- Seismic retrofit strategies for buildings and bridges
- Steel jacketing and external post-tensioning
- Masonry rehabilitation and historic structure preservation
- Performance-based assessment and retrofit design
- Nondestructive evaluation and structural health monitoring

Learning Outcomes:

Core:

1. Conduct comprehensive condition assessments of existing structures [Assessment]
2. Evaluate load-carrying capacity of existing structural members [Usage]
3. Select appropriate concrete repair materials and application methods [Familiarity]
4. Design strengthening interventions using conventional techniques [Assessment]
5. Apply FRP systems for flexural and shear strengthening of concrete members [Usage]
6. Develop seismic retrofit strategies for deficient structures [Assessment]
7. Implement steel jacketing and external post-tensioning systems [Usage]
8. Rehabilitate masonry structures while preserving historic character [Assessment]
9. Perform performance-based assessment and design retrofit interventions [Usage]
10. Utilize nondestructive testing and monitoring technologies for damage assessment [Familiarity]

2.2.29 SAD/Industrial Structures: Chimneys and Tanks (Core Tier1: 1 hr, Core Tier2: 1 hr)

Seismic analysis and reinforced concrete design of special/industrial civil engineering structures – free-standing chimneys and liquid-storage tanks – including dynamic idealization, seismic force and pressure distribution, hydrodynamic effects on liquid-containing structures, and detailing according to ACI 307 and ACI 350.3.

Topics:

Core

- Dynamic idealization of a free-standing chimney as an equivalent cantilever stick model
- Seismic force and overturning moment distribution along the height of a chimney per ACI 307
- Flexural and shear design of reinforced concrete chimney shell sections under seismic loading
- Seismic reinforcement detailing for chimney shells, openings, and construction joints
- Housner's impulsive-convective two-mass model for the hydrodynamic seismic response of liquid-storage tanks

- Impulsive and convective (sloshing) hydrodynamic pressure distribution on tank walls and base per ACI 350.3
- Design of reinforced concrete tank walls and base slab for seismic-induced hydrodynamic pressures
- Sloshing wave height, freeboard requirements, and anchorage design for storage tanks

Learning Outcomes:
Core:

1. Explain the dynamic idealization of a free-standing chimney as an equivalent cantilever stick model for seismic analysis [Familiarity]
2. Determine the seismic force and overturning moment distribution along the height of a reinforced concrete chimney [Usage]
3. Design the reinforced concrete shell section of a chimney for flexure and shear under seismic loading [Assessment]
4. Detail seismic reinforcement for chimney shells, openings, and construction joints [Usage]
5. Explain Housner's impulsive-convective mass model for the hydrodynamic seismic response of liquid-storage tanks [Familiarity]
6. Determine impulsive and convective hydrodynamic pressure distributions on tank walls and base [Usage]
7. Design reinforced concrete tank walls and base slab for seismic-induced hydrodynamic pressures [Assessment]
8. Calculate sloshing wave height and freeboard requirements, and design anchorage for a storage tank [Usage]

2.2.30 SAD/Advanced Structural Analysis

Topics:
Core

- Plastic analysis and limit load design
- Second-order effects and geometric nonlinearity

Learning Outcomes:
Core:

1. Determine collapse loads using plastic analysis methods [Assessment]
2. Evaluate the significance of second-order effects in structural analysis [Familiarity]

2.3 Geotechnical Engineering (GTE)

This knowledge area covers the engineering behavior of earth materials, subsurface investigation, foundation design, earth retention systems, slope stability, and ground improvement techniques essential for safe and economical infrastructure development.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.3.1 Phase Relationships and Seepage (Pg.. 32)	1	1
⭐ 2.3.2 Shear Strength and Consolidation (Pg.. 32)	1	1
⭐ 2.3.3 Site Investigation and In-Situ Testing (Pg.. 33)	1	1
⭐ 2.3.4 Bearing Capacity and Design (Pg.. 34)	1	1
⭐ 2.3.5 Deep Foundations (Pg.. 34)	1	1
⭐ 2.3.6 Earth Retaining Systems (Pg.. 35)	1	1
⭐ 2.3.7 Slope Stability Analysis and Stabilization (Pg.. 35)	1	1
⭐ 2.3.8 Geotechnical Earthquake Engineering (Pg.. 36)	1	1
⭐ 2.3.9 Ground Improvement Techniques (Pg.. 36)	1	1
⭐ 2.3.10 Problematic Soils and Foundation-Soil Classification (Pg.. 37)	1	1
⭐ 2.3.11 Geotechnical Numerical Modeling and Applications (Pg.. 37)	1	1
⭐ 2.3.12 Earth Dams (Pg.. 38)	1	1
⭐ 2.3.13 Geotechnical Characterization for Earth Dams (Pg.. 38)	1	1
⭐ 2.3.14 Geotechnical Design of Embankment Dams (Pg.. 38)	1	1
⭐ 2.3.15 Dam Instrumentation and Monitoring (Pg.. 39)	1	1
⭐ 2.3.16 Construction of Earth Dams (Pg.. 39)	1	1
⭐ 2.3.17 Operation and Safety Management of Dams (Pg.. 40)	1	1
2.3.18 Geosynthetics for Geotechnical Engineering (Pg.. 40)	Elective	

Table 2.3: List of KUs in the Geotechnical Engineering area.

2.3.1 GTE/Phase Relationships and Seepage (Core Tier1: 1 hr, Core Tier2: 1 hr)

Phase relationships, index properties, classification systems, and compaction of soils; permeability, water flow through soils, the effective stress principle, and capillary phenomena.

Topics:

Core

- Phase relationships and index properties of soils
- Soil classification systems including USCS and AASHTO
- Particle size distribution and Atterberg limits
- Compaction theory and field control methods
- Permeability and Darcy's law
- Seepage analysis and flow nets
- Effective stress principle and pore water pressure
- Capillarity and soil suction
- Frost action and thermal properties of soils

Learning Outcomes:

Core:

1. Calculate phase relationships and derive index properties from laboratory data [Usage]
2. Classify soils according to USCS and AASHTO classification systems [Assessment]
3. Interpret particle size distribution curves and plasticity charts [Assessment]
4. Apply compaction theory to field construction control [Usage]
5. Determine soil permeability using laboratory and field methods [Assessment]
6. Construct flow nets and calculate seepage quantities [Usage]
7. Explain the effective stress principle and its engineering significance [Familiarity]
8. Analyze capillary rise and soil suction effects in partially saturated soils [Assessment]
9. Evaluate frost susceptibility and design frost protection measures [Familiarity]

2.3.2 GTE/Shear Strength and Consolidation (Core Tier1: 1 hr, Core Tier2: 1 hr)

Soil shear strength, the Mohr-Coulomb failure criterion, direct shear and triaxial testing, and critical-state and residual behavior; consolidation theory, settlement prediction, stress distribution in soil masses, secondary compression, and anisotropy.

Topics:
Core
- Shear strength of soils and Mohr-Coulomb failure criterion
- Direct shear and triaxial testing methods
- Drained and undrained shear strength behavior
- Consolidation theory and settlement analysis
- Time-rate of consolidation and degree of consolidation
- Stress distribution in soil masses using elastic theory
- Critical state soil mechanics concepts
- Residual shear strength and sensitivity of clays
- Secondary compression and creep behavior
- Anisotropy and stress path effects on soil behavior

Learning Outcomes:
Core:
1. Apply Mohr-Coulomb criterion to determine shear strength parameters [Familiarity]
2. Interpret direct shear and triaxial test results [Assessment]
3. Distinguish between drained and undrained loading conditions [Usage]
4. Calculate consolidation settlement using one-dimensional theory [Assessment]
5. Predict time-rate of settlement for consolidating soils [Usage]
6. Compute stress distribution beneath loaded areas using Boussinesq theory [Assessment]
7. Explain critical state concepts and their application to soil behavior [Familiarity]
8. Evaluate residual strength and sensitivity for slope stability problems [Assessment]
9. Estimate secondary compression for highly plastic soils [Usage]
10. Analyze the effects of stress paths and anisotropy on soil response [Familiarity]

2.3.3 GTE/Site Investigation and In-Situ Testing (Core Tier1: 1 hr, Core Tier2: 1 hr)

Subsurface investigation planning, drilling and sampling methods, laboratory testing programs, and geotechnical report preparation; in-situ testing -SPT, CPT, vane, and pressuremeter-, geophysical methods, groundwater monitoring, and borrow area investigation.
Topics:
Core
- Investigation planning and scope determination
- Boring methods and subsurface exploration techniques
- Sampling methods for disturbed and undisturbed samples
- Standard Penetration Test and correlations
- Laboratory testing program and test selection
- Cone Penetration Test and piezocone testing
- Vane shear test and pressuremeter testing
- Geophysical methods including seismic and resistivity surveys
- Groundwater monitoring and piezometer installation
- Report preparation and geotechnical data presentation
- In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment
- Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes:
Core:
1. Develop appropriate site investigation programs based on project requirements [Assessment]
2. Select appropriate boring and exploration methods for different soil conditions [Familiarity]
3. Specify sampling techniques to obtain quality samples for testing [Usage]
4. Interpret SPT data and apply empirical correlations for design parameters [Assessment]
5. Design laboratory testing programs for geotechnical projects [Usage]
6. Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment]
7. Apply vane shear and pressuremeter tests for soft clay characterization [Usage]
8. Utilize geophysical methods to complement traditional investigation techniques [Assessment]
9. Monitor groundwater conditions and interpret piezometric data [Usage]

10. Prepare comprehensive geotechnical investigation reports [Assessment]
11. Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage]
12. Characterize borrow areas for embankment fill material quantity and quality [Assessment]

2.3.4 GTE/Bearing Capacity and Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Bearing capacity theory, ultimate bearing capacity equations, settlement analysis, and allowable differential settlement; design of isolated footings, combined footings, mat foundations, and continuous footings, including eccentric loading and soil-structure interaction.

Topics:

Core

- Bearing capacity theory and failure mechanisms
- Ultimate bearing capacity equations for various conditions
- Settlement analysis using elastic and consolidation methods
- Isolated spread footing design
- Combined footings and strap footings
- Allowable bearing pressure and factor of safety selection
- Mat foundation analysis and design
- Eccentric and inclined loading effects
- Soil-structure interaction effects
- Differential settlement and tolerable limits
- Continuous (strip) footing design for basement and foundation walls

Learning Outcomes:

Core:

1. Explain bearing capacity failure mechanisms in shallow foundations [Familiarity]
2. Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment]
3. Predict total and differential settlements for shallow foundations [Usage]
4. Design isolated spread footings for gravity loads [Assessment]
5. Proportion combined and strap footings for column arrangements [Usage]
6. Determine allowable bearing pressures based on strength and settlement criteria [Assessment]
7. Analyze mat foundations using conventional and finite element methods [Assessment]
8. Evaluate bearing capacity under eccentric and inclined loading [Usage]
9. Consider soil-structure interaction in foundation design [Familiarity]
10. Assess differential settlement and apply tolerable settlement criteria [Assessment]
11. Design continuous strip footings for basement and foundation walls [Usage]

2.3.5 GTE/Deep Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of pile foundations and drilled shafts including axial and lateral capacity, group effects, and load testing.

Topics:

Core

- Pile types and installation methods
- Axial capacity of single piles in cohesive and cohesionless soils
- Lateral load capacity and p-y method
- Pile group behavior and group efficiency
- Drilled shaft design and construction considerations
- Negative skin friction and downdrag forces

Learning Outcomes:

Core:

1. Select appropriate pile types based on soil conditions and loading [Familiarity]
2. Calculate axial capacity of piles using static methods [Assessment]
3. Analyze laterally loaded piles using p-y curves [Usage]
4. Evaluate pile group capacity and settlement [Assessment]
5. Design drilled shaft foundations including shaft diameter and reinforcement [Usage]

6. Interpret pile load test results and verify design assumptions [Assessment]

2.3.6 GTE/Earth Retaining Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Earth pressure theory and design of retaining walls, anchored walls, and mechanically stabilized earth systems.

Topics:

Core

- Earth pressure theory including active and passive pressures
- Retaining wall types and selection criteria
- Load testing methods including static and dynamic tests
- Anchored walls and tied-back systems
- Mechanically stabilized earth walls and reinforced soil systems
- Basement and foundation wall design considering top-of-wall restraint conditions
- Counterfort and buttressed retaining wall design

Learning Outcomes:

Core:

1. Apply lateral earth pressure theories for retaining wall design [Assessment]
2. Design gravity and cantilever retaining walls [Usage]
3. Design anchored wall systems including ground anchor capacity [Assessment]
4. Proportion mechanically stabilized earth walls and select reinforcement [Usage]
5. Design basement and foundation walls considering top restraint, surcharge, and hydrostatic loads [Assessment]
6. Design counterfort retaining walls including stem, heel, toe, and counterfort elements [Usage]

2.3.7 GTE/Slope Stability Analysis and Stabilization (Core Tier1: 1 hr, Core Tier2: 1 hr)

Infinite slope analysis, the method of slices, failure surfaces, factor of safety, and stability charts; landslide types, seismic slope stability, stabilization methods, monitoring, and probabilistic analysis.

Topics:

Core

- Infinite slope analysis for simple geometries
- Method of slices and limit equilibrium analysis
- Circular and non-circular failure surfaces
- Factor of safety determination and acceptance criteria
- Stability charts and simplified methods
- Landslide types and failure mechanisms
- Seismic slope stability and pseudo-static analysis
- Stabilization methods including drainage and reinforcement
- Monitoring systems and early warning for unstable slopes
- Probabilistic slope stability analysis

Learning Outcomes:

Core:

1. Perform infinite slope stability analysis for uniform slopes [Assessment]
2. Apply method of slices to analyze slope stability [Usage]
3. Analyze slopes with circular and non-circular failure surfaces [Assessment]
4. Calculate factors of safety and interpret results [Usage]
5. Use stability charts for rapid slope evaluation [Assessment]
6. Identify landslide types and their characteristic features [Familiarity]
7. Evaluate seismic stability using pseudo-static methods [Usage]
8. Design slope stabilization measures for specific failure modes [Assessment]
9. Implement monitoring systems for potentially unstable slopes [Usage]
10. Conduct probabilistic stability analysis considering parameter uncertainty [Assessment]

2.3.8 GTE/Geotechnical Earthquake Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Single-degree-of-freedom dynamic systems, wave propagation in soil deposits, and site response to seismic ground motion; liquefaction susceptibility and potential evaluation, its effects on structures and infrastructure, and dynamic soil properties from laboratory and field testing; ground improvement for liquefaction mitigation, lateral spreading, seismic settlement, performance-based design, and machine foundation design under dynamic loads.

Topics:

Core

- Single-degree-of-freedom dynamic systems and one-dimensional wave propagation through soil deposits
- Site response and ground motion amplification
- Seismic hazard analysis and design ground motions
- Liquefaction susceptibility and triggering mechanisms
- Cyclic stress ratio and liquefaction evaluation procedures
- Effects of liquefaction on structures and infrastructure
- Dynamic soil properties and laboratory testing
- Design of foundations for vibrating machinery under dynamic loading
- Ground improvement methods for liquefaction mitigation
- Lateral spreading and flow failures
- Seismically induced settlement and bearing capacity
- Performance-based design for geotechnical earthquake engineering

Learning Outcomes:

Core:

1. Formulate single-degree-of-freedom models and one-dimensional wave-propagation equations to characterize seismic wave transmission through soil deposits [Usage]
2. Explain site response effects and ground motion characteristics [Familiarity]
3. Determine design ground motions for geotechnical seismic analysis [Assessment]
4. Evaluate liquefaction susceptibility using field investigation data [Usage]
5. Calculate cyclic stress ratios and assess liquefaction potential [Assessment]
6. Assess the consequences of liquefaction on foundations and structures [Familiarity]
7. Characterize dynamic soil properties from laboratory and field tests [Usage]
8. Proportion machine foundations considering dynamic soil-foundation stiffness, resonance avoidance, and permissible vibration amplitudes [Assessment]
9. Select and design ground improvement methods to mitigate liquefaction [Assessment]
10. Predict lateral spreading displacements and flow failure potential [Usage]
11. Analyze seismically induced settlement and reduced bearing capacity [Assessment]
12. Implement performance-based approaches for seismic geotechnical design [Assessment]

2.3.9 GTE/Ground Improvement Techniques (Core Tier1: 1 hr, Core Tier2: 1 hr)

Compaction methods, stone columns, preloading with vertical drains, deep mixing and jet grouting, and chemical stabilization.

Topics:

Core

- Compaction methods including dynamic and vibratory techniques
- Stone columns and vibro-replacement methods
- Preloading and vertical drains for soft ground treatment
- Deep mixing and jet grouting techniques
- Chemical stabilization and grouting methods

Learning Outcomes:

Core:

1. Select appropriate ground improvement methods for specific soil conditions [Familiarity]
2. Design stone column systems for settlement reduction [Assessment]
3. Calculate consolidation time reduction using vertical drains [Usage]

4. Identify geosynthetic types and their engineering applications [Familiarity]
5. Proportion reinforcement for mechanically stabilized earth structures [Assessment]

2.3.10 GTE/Problematic Soils and Foundation-Soil Classification (Core Tier1: 1 hr, Core Tier2: 1 hr)

Identification, engineering behavior, and foundation design implications of soils that pose special hazards -expansive, collapsible, and dispersive soils, and engineered fills- together with the foundation-soil classification and investigation criteria used under Peru's RNE Norma E.050.

Topics:

Core

- Types of foundation soils and site characterization from geologic maps and subsurface data
- Foundation-soil classification and investigation requirements under Peru's RNE Norma E.050
- Identification and mineralogy of expansive (swelling) soils
- Swell potential testing and foundation design measures for expansive soils
- Identification and behavior of collapsible (metastable) soils
- Identification and treatment of dispersive soils
- Specification and quality control of engineered fill for foundation support

Learning Outcomes:

Core:

1. Classify foundation soils using geologic maps and subsurface investigation data [Familiarity]
2. Apply Peru's RNE Norma E.050 criteria to classify foundation soils and define investigation requirements [Assessment]
3. Identify expansive soils from mineralogy and index test data [Usage]
4. Design foundations for expansive soils based on swell potential test results [Assessment]
5. Recognize collapsible and dispersive soil behavior from field and laboratory indicators [Familiarity]
6. Specify engineered fill requirements for foundation support [Usage]

2.3.11 GTE/Geotechnical Numerical Modeling and Applications (Core Tier1: 1 hr, Core Tier2: 1 hr)

Boundary conditions, staged construction, soil-structure interaction, and one-dimensional numerical models; two-dimensional numerical models, dynamic analysis, and soil constitutive models for nonlinear geotechnical analysis.

Topics:

Core

- Boundary conditions, initial stress state, and staged construction (excavation and fill sequencing) in geotechnical finite element models
- Soil-structure interaction modeling: interface elements and contact behavior between soil and structural elements
- One-dimensional numerical models for consolidation and axially loaded pile-soil interaction
- Two-dimensional plane-strain numerical models for excavations, embankments, and retaining structures
- Dynamic numerical analysis of seismic site response and soil-structure dynamic interaction
- Constitutive soil models: Mohr-Coulomb, Cam-Clay, and Hardening Soil Model for nonlinear geotechnical analysis

Learning Outcomes:

Core:

1. Explain the boundary conditions, initial stress state, and staged construction sequencing required for geotechnical finite element models [Familiarity]
2. Model soil-structure interaction using interface elements in a finite element mesh [Usage]
3. Formulate one-dimensional finite element models for consolidation and pile-soil interaction problems [Usage]
4. Develop two-dimensional plane-strain finite element models for excavation, embankment, and retaining-structure problems [Usage]

5. Analyze the dynamic response of geotechnical systems using numerical dynamic analysis [Assessment]
6. Select and apply appropriate constitutive soil models (Mohr-Coulomb, Cam-Clay, Hardening Soil Model) in nonlinear finite element analysis [Usage]

2.3.12 GTE/Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental concepts, function, typology, and zoning of earth and rockfill (embankment) dams within water resources infrastructure.

Topics:

Core

- Definition, function, and role of earth dams within water resources infrastructure
- Typology of embankment dams: homogeneous and zoned earthfill/rockfill dams, and selection criteria
- Dam zoning: core, shell, filters, drains, and transition zones
- Site selection factors and reservoir/dam-site feasibility considerations

Learning Outcomes:

Core:

1. Explain the function of earth dams and their role within water resources infrastructure [Familiarity]
2. Classify embankment dams by type and select an appropriate typology for given site and material conditions [Assessment]
3. Describe the zoning of an earth dam and the function of each zone (core, shell, filters, drains) [Familiarity]
4. Evaluate site selection factors governing dam type and location choice [Usage]

2.3.13 GTE/Geotechnical Characterization for Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Geotechnical characterization of foundation conditions and construction materials specific to embankment dam design, including borrow material suitability and dispersivity assessment.

Topics:

Core

- Foundation geotechnical characterization: rock and soil foundation conditions for embankment dams
- Characterization of borrow materials for core, shell, and filter zones
- Compaction and shear strength properties of compacted fill materials
- Permeability characterization of foundation and embankment materials
- Dispersive soil identification and erodibility assessment for core materials

Learning Outcomes:

Core:

1. Characterize foundation soil and rock conditions relevant to embankment dam design [Assessment]
2. Evaluate borrow material sources for suitability as core, shell, or filter material [Usage]
3. Determine compaction and shear strength properties of compacted embankment materials [Assessment]
4. Assess dispersive soil potential and erodibility of candidate core materials [Usage]

2.3.14 GTE/Geotechnical Design of Embankment Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Geotechnical design of embankment dams, including seepage analysis and control, filter and drain design, slope stability of dam faces, seismic considerations, and freeboard/settlement allowances.

Topics:

Core

- Seepage analysis through the embankment and foundation using flow nets and numerical methods
- Seepage control measures: core design, cutoff walls, and grout curtains
- Filter and drain design criteria to prevent internal erosion and piping
- Slope stability analysis of upstream and downstream dam faces under static and rapid drawdown conditions
- Seismic design considerations and deformation analysis for embankment dams
- Freeboard determination and settlement/camber allowance in embankment design

Learning Outcomes:

Core:

1. Analyze seepage through the embankment and foundation using flow nets or numerical seepage models [Assessment]
2. Design seepage control measures including impervious cores, cutoff walls, and grout curtains [Usage]
3. Design filter and drain zones according to piping and internal erosion criteria [Assessment]
4. Evaluate slope stability of dam faces under steady-state seepage, rapid drawdown, and end-of-construction conditions [Usage]
5. Incorporate seismic loading and deformation analysis into embankment dam design [Assessment]
6. Determine freeboard and settlement allowances for embankment design [Usage]

2.3.15 GTE/Dam Instrumentation and Monitoring (Core Tier1: 1 hr, Core Tier2: 1 hr)

Instrumentation systems and performance monitoring programs for embankment dams throughout construction and operation.

Topics:

Core

- Instrumentation planning: objectives, parameters to monitor, and instrument selection
- Piezometers and pore pressure measurement systems
- Settlement and deformation monitoring: surface markers, inclinometers, and extensometers
- Seepage flow monitoring using weirs and flow measurement devices
- Data acquisition, automation, and interpretation of monitoring records
- Threshold (alert/alarm) values and performance evaluation criteria

Learning Outcomes:

Core:

1. Plan an instrumentation program defining monitoring objectives and parameters [Usage]
2. Select and locate piezometers to monitor pore pressure within the embankment and foundation [Assessment]
3. Specify deformation monitoring instruments (markers, inclinometers, extensometers) for an embankment dam [Usage]
4. Monitor seepage flow and interpret trends against baseline conditions [Assessment]
5. Interpret monitoring data and establish threshold values for dam safety alerts [Usage]

2.3.16 GTE/Construction of Earth Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Construction methods, quality control, and foundation treatment for embankment dam construction.

Topics:

Core

- Foundation preparation and treatment: stripping, grouting, and cutoff trench excavation
- Placement and compaction of core, filter, and shell fill materials
- Field compaction quality control and acceptance testing
- Construction sequencing, staged construction, and river diversion during construction
- Construction-phase monitoring and as-built verification

Learning Outcomes:

Core:

1. Specify foundation treatment methods including cutoff trench excavation and grouting [Usage]

2. Control fill placement and compaction to meet design specifications [Assessment]
3. Verify compaction quality through field acceptance testing [Usage]
4. Sequence embankment construction considering staged construction and river diversion [Assessment]

2.3.17 GTE/Operation and Safety Management of Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Operational surveillance, risk assessment, and emergency planning for dam safety management throughout the dam's service life.

Topics:

Core

- Dam surveillance programs: visual inspection and periodic evaluation procedures
- Risk assessment and hazard classification of dams
- Emergency action plans and downstream hazard/inundation mapping
- Regulatory framework and dam safety programs (e.g., Peru's ANA dam safety regulations)
- Dam rehabilitation, decommissioning, and aging infrastructure management

Learning Outcomes:

Core:

1. Conduct dam surveillance inspections and evaluate performance indicators [Usage]
2. Classify dam hazard potential and assess associated risks [Assessment]
3. Develop an emergency action plan including downstream inundation mapping [Usage]
4. Apply regulatory dam safety requirements to an operating dam [Assessment]
5. Propose rehabilitation measures for aging or deficient dam infrastructure [Usage]

2.3.18 GTE/Geosynthetics for Geotechnical Engineering

Geosynthetic types, reinforced soil structure design, filtration and drainage systems, basal reinforcement, and long-term performance.

Topics:

Core

- Geosynthetic types and material properties
- Reinforcement functions and design of reinforced soil structures
- Geosynthetic design for filtration, drainage, and separation
- Basal reinforcement and geogrid design
- Long-term performance and durability of geosynthetics

Learning Outcomes:

Core:

1. Apply deep mixing and jet grouting for soil stabilization [Usage]
2. Specify chemical stabilization methods and grouting parameters [Assessment]
3. Design geosynthetic filtration and drainage systems [Usage]
4. Analyze basal reinforced embankments using limit equilibrium methods [Assessment]
5. Evaluate long-term durability and reduction factors for geosynthetics [Familiarity]

2.4 General Geology (GGL)

This knowledge area covers the fundamental Earth materials, processes, and structures relevant to civil engineering: minerals, rocks, geologic structures, surface processes, geologic time, and the descriptive fundamentals of site geological characterization, as a foundation for, and complement to, the applied geotechnical design content covered in GTE.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.4.1 Mineralogy (Pg.. 41)	1	1
⭐ 2.4.2 Petrology and the Rock Cycle (Pg.. 41)	1	1
⭐ 2.4.3 Structural Geology (Pg.. 42)	1	1
⭐ 2.4.4 Geomorphology, Weathering, and Erosion Processes (Pg.. 42)	1	1
⭐ 2.4.5 Geologic Time, Stratigraphy, and Geologic Mapping (Pg.. 43)	1	1
⭐ 2.4.6 Basic Surface and Groundwater Hydrology of Geologic Materials (Pg.. 43)	1	1
⭐ 2.4.7 Applied Geology (Pg.. 43)	1	1
⭐ 2.4.8 Rock Mass Characterization and Applied Rock and Soil Mechanics (Pg.. 44)	1	1
⭐ 2.4.9 Engineering Geological and Geotechnical Mapping (Pg.. 44)	1	1
⭐ 2.4.10 Soils and Rocks as Natural Resources for Construction Materials (Pg.. 45)	1	1
⭐ 2.4.11 Engineering Geology Applied to Roads and Canals (Pg.. 45)	1	1
⭐ 2.4.12 Engineering Geology Applied to Bridges, Tunnels, and Dams (Pg.. 45)	1	1
⭐ 2.4.13 Geological Hazards and Mass Movements (Pg.. 46)	1	1

Table 2.4: List of KUs in the General Geology area.

2.4.1 GGL/Mineralogy (Core Tier1: 1 hr, Core Tier2: 1 hr)

Study of the most common rock-forming minerals, their distinctive physical properties, and the practical mineral identification methods relevant to civil engineering.

Topics:

Core

- Crystal structure and habit of minerals
- Main groups of rock-forming minerals: silicates, carbonates, oxides, and sulfates
- Mohs hardness scale and scratch tests
- Cleavage, fracture, and other diagnostic physical properties
- Luster, color, and streak as identification criteria
- Basic chemical composition and reaction with dilute hydrochloric acid

Learning Outcomes:

Core:

1. Identify the most common rock-forming minerals using physical properties [Familiarity]
2. Apply the Mohs scale to determine the relative hardness of mineral samples [Usage]
3. Distinguish similar minerals through cleavage, fracture, and luster [Assessment]
4. Relate the mineral composition of a rock to its expected engineering behavior [Familiarity]
5. Perform simple field tests (scratch, acid, luster) for mineral identification [Usage]

2.4.2 GGL/Petrology and the Rock Cycle (Core Tier1: 1 hr, Core Tier2: 1 hr)

Formation processes, classification, and engineering properties of igneous, sedimentary, and metamorphic rocks, and their cyclic relationship within the rock cycle.

Topics:

Core

- Classification of intrusive and extrusive igneous rocks by texture and composition
- Sedimentary rock formation processes: erosion, transport, deposition, and lithification
- Classification of clastic, chemical, and biochemical sedimentary rocks
- Metamorphic processes: contact and regional metamorphism
- Classification of foliated and non-foliated metamorphic rocks
- The rock cycle and transformations between lithologic types
- Relevant engineering properties of rocks: strength, durability, and alterability

Learning Outcomes:

Core:

1. Classify hand samples of igneous rocks according to their texture and mineral composition [Assessment]

2. Explain the formation processes of sedimentary rocks and their engineering significance [Familiarity]
3. Recognize foliated and non-foliated metamorphic textures in hand samples [Usage]
4. Trace the pathways of the rock cycle among the three lithologic groups [Familiarity]
5. Qualitatively evaluate the suitability of a rock type for use as a construction or foundation material [Assessment]

2.4.3 GGL/Structural Geology (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of stress and strain in the Earth's crust, and the identification and interpretation of geologic structures -folds, faults, and joints- relevant to rock mass stability analysis and infrastructure site selection.

Topics:

Core

- Stress and strain concepts in rocks
- Fold types: anticlines, synclines, and their geometric elements
- Fault types: normal, reverse, and strike-slip
- Joint sets and their influence on rock mass strength
- Measurement and interpretation of strike and dip
- Unconformities and their significance in geologic history
- Influence of geologic structures on slope and excavation stability

Learning Outcomes:

Core:

1. Differentiate folds, faults, and joints based on their geometric features [Familiarity]
2. Measure the strike and dip of geologic planes using a geologic (Brunton-type) compass [Usage]
3. Interpret the orientation of structural discontinuities relative to an excavation or slope [Assessment]
4. Assess the influence of joint sets on the stability of a rock mass [Assessment]
5. Recognize unconformities and relate them to regional geologic history [Familiarity]

2.4.4 GGL/Geomorphology, Weathering, and Erosion Processes (Core Tier1: 1 hr, Core Tier2: 1 hr)

Physical, chemical, and biological weathering processes of Earth materials, resulting landforms, and surface erosion processes relevant to evaluating site conditions in civil engineering projects.

Topics:

Core

- Physical weathering: thermal fragmentation, frost wedging, and unloading
- Chemical weathering: hydrolysis, oxidation, and dissolution
- Biological weathering and bioerosion
- Residual soil formation from in-situ weathering
- Main landforms: valleys, terraces, alluvial fans, and debris cones
- Water and wind erosion processes and mass wasting processes

Learning Outcomes:

Core:

1. Distinguish physical, chemical, and biological weathering types present at an outcrop [Familiarity]
2. Relate the degree of weathering of a rock to the expected quality of a rock mass [Usage]
3. Identify landforms and their geomorphological origin [Familiarity]
4. Evaluate the susceptibility of a slope to erosion and mass wasting processes [Assessment]
5. Apply weathering grade classification criteria to estimate the durability of rock materials in slopes [Usage]

2.4.5 GGL/Geologic Time, Stratigraphy, and Geologic Mapping (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of stratigraphy and relative geochronology, and the fundamental techniques for reading and interpreting geologic maps, stratigraphic columns, and geologic cross-sections.

Topics:

Core

- The geologic time scale and the magnitude of deep time
- Principles of relative dating: superposition, original horizontality, and cross-cutting relationships
- Construction and interpretation of stratigraphic columns
- Symbology and conventions of geologic maps
- Construction of geologic cross-sections from maps
- Stratigraphic discontinuities and their expression on geologic maps
- Basic field geologic mapping techniques

Learning Outcomes:

Core:

1. Explain the principles of relative dating to establish stratigraphic sequences [Familiarity]
2. Read and interpret standard geologic maps, including their symbology and legend [Usage]
3. Construct a geologic cross-section from a geologic map and strike/dip data [Assessment]
4. Correlate stratigraphic units between columns from different localities [Assessment]
5. Apply basic field geologic mapping techniques for a simple survey [Usage]

2.4.6 GGL/Basic Surface and Groundwater Hydrology of Geologic Materials (Core Tier1: 1 hr, Core Tier2: 1 hr)

Introductory concepts on the occurrence and movement of surface and groundwater in relation to geologic materials -porosity, permeability, water table, and springs- as a descriptive foundation prior to applied engineering hydrology and hydrogeology.

Topics:

Core

- Porosity and permeability of soils and rocks
- Water table concept and the unsaturated zone
- Basic concepts of aquifer, aquitard, and aquiclude
- Springs, seeps, and their relationship to the geologic context
- Surface drainage patterns and their relationship to lithology and structure
- Water-rock interaction and its influence on weathering

Learning Outcomes:

Core:

1. Differentiate the concepts of porosity and permeability for different geologic materials [Familiarity]
2. Describe the position of the water table and its seasonal variation at a given site [Familiarity]
3. Relate the occurrence of springs and seeps to the local geologic and hydrogeologic context [Usage]
4. Identify surface drainage patterns characteristic of different geologic conditions [Assessment]
5. Explain conceptually the water-rock interaction and its role in chemical weathering [Familiarity]

2.4.7 GGL/Applied Geology (Core Tier1: 1 hr, Core Tier2: 1 hr)

Introduction to the application of general geology to the preliminary characterization of sites for civil engineering works, including field geologic reconnaissance, descriptive rock mass classification, and identification of geologic hazards, as a descriptive preamble to applied geotechnical investigation.

Topics:

Core

- Preliminary geologic site reconnaissance
- Qualitative description of rock masses: degree of fracturing and weathering
- Types of geologic hazards: landslides, rockfalls, seismic and volcanic activity

- Use of aerial photographs and remote sensing imagery in geologic reconnaissance
- Basic elements of a preliminary geologic site report
- Use of field tools: geologic compass, GPS, hand lens, and rock hammer
- Influence of geologic conditions on infrastructure site selection

Learning Outcomes:
Core:

1. Conduct a preliminary geologic reconnaissance of a site of interest for civil engineering [Usage]
2. Qualitatively describe the degree of fracturing and weathering of a rock mass [Assessment]
3. Recognize the main types of geologic hazards that can affect an infrastructure project [Familiarity]
4. Use basic field tools to gather geologic information [Usage]
5. Prepare a preliminary geologic site report with basic recommendations for further studies [Assessment]

2.4.8 GGL/Rock Mass Characterization and Applied Rock and Soil Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Field characterization of rock mass discontinuities and quality, standard rock mass classification systems, and the influence of geological origin and weathering on the engineering behavior of rocks and soils, as a link between descriptive geology and applied rock and soil mechanics.
Topics:
Core

- Characterization of rock mass discontinuities: orientation, spacing, persistence, roughness, aperture, and infill
- Rock Quality Designation (RQD) and geotechnical core logging
- Rock mass classification systems: RMR, Q-system, and GSI
- Estimation of rock mass strength and deformability using the Hoek-Brown criterion
- Influence of weathering grade on rock mass mechanical behavior
- Influence of geological origin -residual versus transported- on soil engineering properties

Learning Outcomes:
Core:

1. Characterize rock mass discontinuities from field or core data [Usage]
2. Determine RQD and classify rock mass quality using RMR, Q, and GSI systems [Assessment]
3. Estimate rock mass strength and deformability parameters using the Hoek-Brown criterion [Assessment]
4. Relate weathering grade to expected rock mass mechanical behavior [Familiarity]
5. Relate the geological origin of a soil to its expected engineering properties [Usage]

2.4.9 GGL/Engineering Geological and Geotechnical Mapping (Core Tier1: 1 hr, Core Tier2: 1 hr)

Purpose, types, and preparation of engineering geological and geotechnical maps for infrastructure planning and geotechnical hazard zonation, extending basic geologic map reading into maps prepared specifically for engineering decision-making.
Topics:
Core

- Types and purposes of engineering geological and geotechnical maps
- Geotechnical zonation and microzonation mapping for urban and infrastructure planning
- Specialized symbology and legends for engineering geological maps
- Use of GIS and remote sensing tools in geotechnical mapping

Learning Outcomes:
Core:

1. Distinguish the types and purposes of engineering geological and geotechnical maps [Familiarity]
2. Prepare a basic geotechnical zonation map for a project area [Usage]
3. Apply GIS tools to compile and present geotechnical mapping information [Usage]

2.4.10 GGL/Soils and Rocks as Natural Resources for Construction Materials (Core Tier1: 1 hr, Core Tier2: 1 hr)

Geological evaluation of soils and rocks as natural resources for construction: aggregate and quarry sources, dimension stone, and basic quality control criteria for their use in civil engineering works.

Topics:

Core

- Geological sources and quality evaluation of aggregates for concrete and construction
- Site selection and geological evaluation of quarries and borrow pits
- Dimension stone and other rock and soil resources used in construction
- Basic quality control criteria and tests for construction material sources

Learning Outcomes:

Core:

1. Evaluate geological sources of aggregates and construction materials for quality and suitability [Usage]
2. Select and assess quarry and borrow-pit sites based on geological criteria [Assessment]
3. Apply basic quality control criteria to construction material sources [Familiarity]

2.4.11 GGL/Engineering Geology Applied to Roads and Canals (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of engineering geology to the siting, design, and construction of linear infrastructure -roads and canals- including alignment selection, cut-slope stability, and embankment foundation conditions.

Topics:

Core

- Geological considerations for highway and road alignment selection
- Geological and hydrogeological conditions for canal siting and seepage control
- Structural geological controls on cut-slope stability along transportation corridors
- Geological and geotechnical conditions for road and canal embankment foundations
- Engineering geological mapping and hazard identification along linear infrastructure corridors

Learning Outcomes:

Core:

1. Evaluate geological conditions to support road and canal alignment selection [Assessment]
2. Assess seepage and foundation conditions for canal design based on geological survey [Usage]
3. Analyze structural geological controls on cut-slope stability along a transportation corridor [Assessment]
4. Prepare an engineering geological map identifying hazards along a linear infrastructure corridor [Usage]

2.4.12 GGL/Engineering Geology Applied to Bridges, Tunnels, and Dams (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of engineering geology to the site selection and geological characterization of major infrastructure works -bridges, tunnels, and dams- across the phases of a project, from reconnaissance through design.

Topics:

Core

- Engineering geological studies required at each phase of an infrastructure project: reconnaissance, feasibility, design, and construction
- Geological and rock mass considerations for tunnel alignment, excavation method, and support selection
- Geological siting and foundation and abutment characterization for dams
- Reservoir geology: seepage, landslide-induced impoundment hazards, and sedimentation sources
- Geological considerations for bridge site selection and pier and abutment foundation conditions

- Comparative geological criteria for selecting sites and alignments among infrastructure alternatives

Learning Outcomes:
Core:

1. Identify the engineering geological studies required at each phase of an infrastructure project [Familiarity]
2. Evaluate rock mass conditions relevant to tunnel excavation method and support selection [Assessment]
3. Characterize the geological suitability of a site for dam foundations and abutments [Assessment]
4. Assess reservoir-related geological hazards including landslide-induced impoundment risk [Usage]
5. Evaluate geological conditions relevant to bridge foundation siting [Usage]

2.4.13 GGL/Geological Hazards and Mass Movements (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classification, recognition, and hazard/susceptibility assessment of mass movements and other geological hazards relevant to civil infrastructure, extending the basic hazard-type awareness introduced in GGL.EngineeringGeologyBasics into systematic hazard classification, mapping, and mitigation.
Topics:
Core

- Classification of mass movements: falls, topples, slides, flows, and lateral spreads
- Triggering and controlling factors of mass movements: geological, hydrological, and seismic
- Field recognition of landslide morphology and indicators of active or past instability
- Geological hazards from seismic and volcanic activity relevant to civil infrastructure
- Geological hazard susceptibility mapping and risk zonation
- Overview of structural and non-structural mitigation measures for geological hazards

Learning Outcomes:
Core:

1. Classify mass movements according to their mechanism and material type [Assessment]
2. Identify triggering and controlling factors of mass movements at a given site [Familiarity]
3. Recognize field indicators of landslide morphology and slope instability [Usage]
4. Prepare a geological hazard susceptibility map for a project area [Assessment]
5. Propose mitigation measures appropriate to a specific type of geological hazard [Usage]

2.5 Water Resources and Hydraulic Engineering (WRH)

This knowledge area encompasses the analysis, design, and management of water resources systems, hydraulic structures, and water distribution networks for sustainable water supply, flood control, and environmental protection.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.5.1 Hydrologic Cycle and Water Balance (Pg.. 47)	1	1
⭐ 2.5.2 Surface Hydrology and Watershed Modeling (Pg.. 47)	1	1
⭐ 2.5.3 Flood Frequency Analysis and Climate Change (Pg.. 47)	1	1
⭐ 2.5.4 Open Channel Flow and River Mechanics (Pg.. 48)	1	1
⭐ 2.5.5 Pressurized Pipe Flow and Pump Systems (Pg.. 48)	1	1
⭐ 2.5.6 Design of Hydraulic Structures (Pg.. 49)	1	1
⭐ 2.5.7 Urban Water Systems (Pg.. 49)	1	1
⭐ 2.5.8 Groundwater Hydrology (Pg.. 50)	1	1
⭐ 2.5.9 Economic, Financial and Social Evaluation of Water Resources Projects (Pg.. 50)	1	1
⭐ 2.5.10 Sediment Transport in Alluvial Channels (Pg.. 51)	1	1
⭐ 2.5.11 Scour and Fluvial Morphology (Pg.. 51)	1	1
⭐ 2.5.12 River Engineering (Pg.. 52)	1	1
⭐ 2.5.13 Agricultural Water Demand (Pg.. 52)	1	1
⭐ 2.5.14 Irrigation Systems Design (Pg.. 52)	1	1
2.5.15 Coastal and Floodplain Engineering (Pg.. 53)	Elective	

Table 2.5: List of KUs in the Water Resources and Hydraulic Engineering area.

2.5.1 WRH/Hydrologic Cycle and Water Balance (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Hydrologic cycle and water balance concepts
- Precipitation measurement and analysis
- Evaporation and evapotranspiration estimation
- Infiltration theory and rainfall-runoff processes

Learning Outcomes:
Core:

1. Explain the hydrologic cycle and quantify water balance components [Familiarity]
2. Analyze precipitation data and develop depth-area-duration relationships [Assessment]
3. Estimate evaporation and evapotranspiration using empirical methods [Usage]
4. Apply infiltration models to estimate runoff from rainfall events [Assessment]

2.5.2 WRH/Surface Hydrology and Watershed Modeling (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Hydrograph analysis and unit hydrograph method
- Watershed modeling and hydrologic simulation
- Streamflow measurement and gauging techniques

Learning Outcomes:
Core:

1. Derive unit hydrographs and synthesize runoff hydrographs [Usage]
2. Develop watershed models using software tools for hydrologic simulation [Usage]
3. Conduct streamflow measurements and interpret flow duration curves [Assessment]

2.5.3 WRH/Flood Frequency Analysis and Climate Change (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Flood frequency analysis and design storms
- Hydrologic routing methods for channels and reservoirs
- Climate change impacts on hydrologic systems

Learning Outcomes:

Core:

1. Perform flood frequency analysis using statistical methods [Assessment]
2. Route flood hydrographs through channels and reservoirs [Usage]
3. Evaluate climate change impacts on watershed hydrology and design implications [Assessment]

2.5.4 WRH/Open Channel Flow and River Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of flow in open channels, channel hydraulics, uniform and gradually varied flow, and river engineering applications.

Topics:

Core

- Channel flow classification and hydraulic elements
- Energy and momentum principles in open channels
- Uniform flow and Manning's equation
- Critical flow and specific energy concepts
- Gradually varied flow profiles
- Hydraulic jump and rapidly varied flow
- Channel design for stable conveyance
- Sediment transport in open channels
- River morphology and channel stability
- Scour analysis and protection measures

Learning Outcomes:

Core:

1. Classify open channel flow regimes and calculate hydraulic elements [Familiarity]
2. Apply energy and momentum equations to solve channel flow problems [Assessment]
3. Calculate normal depth and discharge using Manning's equation [Usage]
4. Determine critical depth and analyze specific energy relationships [Assessment]
5. Compute gradually varied flow profiles using standard methods [Usage]
6. Analyze hydraulic jumps and calculate energy dissipation [Assessment]
7. Design stable channels with appropriate cross-sections and linings [Usage]
8. Estimate sediment transport rates in alluvial channels [Assessment]
9. Evaluate river channel stability and bank erosion potential [Familiarity]
10. Predict scour depths at hydraulic structures and design protection [Assessment]

2.5.5 WRH/Pressurized Pipe Flow and Pump Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Analysis and design of pressurized pipe networks, pump selection and system curves, water hammer, and pipeline design.

Topics:

Core

- Pipe flow fundamentals and Darcy-Weisbach equation
- Minor losses and pipe system analysis
- Pipe network analysis methods
- Pump characteristics and system curves
- Pump selection and installation requirements
- Water hammer and surge analysis
- Pipeline design and material selection
- Variable speed pumps and energy efficiency
- Network modeling and optimization
- Valve selection and hydraulic control systems

Learning Outcomes:
Core:

1. Calculate head losses in pipe systems using friction equations [Assessment]
2. Determine total head loss including minor losses in complex piping [Usage]
3. Analyze pipe networks using Hardy Cross or equivalent methods [Assessment]
4. Construct pump characteristic curves and system head curves [Usage]
5. Select appropriate pumps based on operating point and efficiency [Assessment]
6. Evaluate water hammer effects and design surge protection [Usage]
7. Design pipelines considering hydraulic, structural, and economic factors [Assessment]
8. Apply variable speed drives for pump system optimization [Usage]
9. Optimize water distribution networks using modeling software [Assessment]
10. Specify valves and control systems for pipeline operations [Usage]

2.5.6 WRH/Design of Hydraulic Structures (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of dams, spillways, weirs, gates, stilling basins, and other hydraulic control and conveyance structures.
Topics:
Core

- Dam types and selection criteria
- Spillway hydraulics and design
- Weir and gate flow equations
- Energy dissipation and stilling basin design
- Culvert hydraulics and design
- Dam safety analysis and risk assessment
- Outlet works and control structures
- Fish passage facilities and environmental hydraulics
- Cavitation analysis and prevention
- Physical hydraulic modeling and scale effects

Learning Outcomes:
Core:

1. Classify dam types and select appropriate configurations for site conditions [Familiarity]
2. Design spillways for flood discharge capacity [Assessment]
3. Calculate discharge over weirs and through gates [Usage]
4. Proportion energy dissipation structures and stilling basins [Assessment]
5. Analyze culvert hydraulics for inlet and outlet control [Usage]
6. Perform dam safety evaluations and hazard classification [Assessment]
7. Design outlet works including intake structures and conduits [Usage]
8. Incorporate fish passage requirements in hydraulic structure design [Assessment]
9. Evaluate cavitation potential and design preventive measures [Usage]
10. Interpret physical model results and apply scale corrections [Assessment]

2.5.7 WRH/Urban Water Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design and analysis of urban water supply distribution systems, stormwater management, and urban drainage infrastructure.
Topics:
Core

- Water demand estimation and distribution system design
- Distribution network analysis and modeling
- Water quality considerations in distribution systems
- Stormwater runoff estimation using rational method
- Storm sewer design and hydraulic analysis
- Urban drainage best management practices
- Advanced water distribution system modeling
- Detention and retention facility design

- Green infrastructure and low impact development
- Combined sewer systems and overflow control

Learning Outcomes:

Core:

1. Estimate water demands and design distribution system capacity [Assessment]
2. Analyze distribution networks for pressure and flow adequacy [Usage]
3. Address water quality issues including disinfection and corrosion [Familiarity]
4. Calculate stormwater runoff using the rational method [Assessment]
5. Design storm sewer systems following hydraulic grade line principles [Usage]
6. Implement stormwater best management practices for runoff control [Assessment]
7. Develop advanced water distribution models for system optimization [Usage]
8. Proportion detention and retention basins for peak flow reduction [Assessment]
9. Apply green infrastructure techniques for sustainable stormwater management [Usage]
10. Evaluate combined sewer overflow issues and design control measures [Assessment]

2.5.8 WRH/Groundwater Hydrology (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of groundwater flow, well hydraulics, aquifer assessment and modeling, and groundwater-surface water interaction for water resources development.

Topics:

Core

- Aquifer types: confined, unconfined, and semi-confined
- Darcy's law applied to groundwater flow and hydraulic conductivity
- Well hydraulics: Theis and Thiem equations for transient and steady-state flow
- Pumping tests and estimation of hydrogeologic parameters (transmissivity, storativity)
- Numerical modeling of groundwater flow and aquifer water balance
- Groundwater-surface water interaction and conjunctive use of resources
- Groundwater quality and basic contaminant transport
- Design and construction of water supply wells
- Sustainable aquifer management and prevention of overexploitation

Learning Outcomes:

Core:

1. Classify aquifer types and describe their hydraulic boundary conditions [Familiarity]
2. Apply Darcy's law to calculate groundwater flow rates and velocities [Usage]
3. Solve the Theis and Thiem equations to determine drawdown in pumping wells [Assessment]
4. Estimate hydrogeologic parameters from pumping test data [Usage]
5. Model the water balance of an aquifer and evaluate exploitation scenarios [Assessment]
6. Design a water supply well accounting for aquifer characteristics [Usage]
7. Evaluate the sustainability of aquifer exploitation and propose management measures [Assessment]

2.5.9 WRH/Economic, Financial and Social Evaluation of Water Resources Projects (Core Tier1: 1 hr, Core Tier2: 1 hr)

Economic, financial, and social evaluation methodologies for selecting among water resources project alternatives, including profitability indicators, sensitivity analysis, and financing mechanisms.

Topics:

Core

- Economic evaluation indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost ratio
- Selecting among project alternatives by comparing economic indicators
- Sensitivity analysis to variations in costs, benefits, and discount rate
- Funding sources and financial structuring of water projects
- User payment capacity and tariff schemes
- Cost allocation among beneficiaries in multipurpose projects
- Social evaluation of projects: exchange theory and shadow prices

- Distributional impacts and equity in project social evaluation

Learning Outcomes:

Core:

1. Calculate NPV, IRR, and Benefit-Cost ratio for a water resources project [Usage]
2. Select among project alternatives based on compared economic indicators [Assessment]
3. Perform a sensitivity analysis of project profitability to changes in key variables [Usage]
4. Evaluate funding sources and tariff schemes based on user payment capacity [Assessment]
5. Allocate costs among beneficiaries in a multipurpose project [Usage]
6. Apply social evaluation principles to estimate a project's net benefit to society [Assessment]

2.5.10 WRH/Sediment Transport in Alluvial Channels (Core Tier1: 1 hr, Core Tier2: 1 hr)

Watershed erosion, sediment properties, flow resistance and incipient motion in alluvial channels, and methods for measuring and computing bed load, suspended load, and total sediment transport.

Topics:

Core

- Watershed erosion and sediment yield
- Physical properties of sediment: size, shape, density, and fall velocity
- Flow in sand and gravel channels and associated bedforms
- Flow resistance in alluvial channels
- Incipient motion condition and design of erodible channels
- Fundamentals and techniques for measuring sediment transport
- Bed load sediment transport
- Suspended load sediment transport
- Sediment entry into intakes and diversion structures
- Total sediment load transport formulas

Learning Outcomes:

Core:

1. Explain watershed erosion processes and their relation to sediment yield [Familiarity]
2. Classify sediments by their physical properties and estimate their fall velocity [Usage]
3. Determine the incipient motion condition for a given alluvial channel [Assessment]
4. Calculate flow resistance in an alluvial channel accounting for bedforms [Usage]
5. Estimate bed load and suspended load transport rates using standard formulas [Assessment]
6. Apply total sediment load formulas to an alluvial channel design problem [Usage]
7. Evaluate sediment entry into an intake and propose exclusion measures [Assessment]

2.5.11 WRH/Scour and Fluvial Morphology (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamentals and computation of general and local scour, long-term bed elevation changes, fluvial cycles and processes, alluvial channel geometry and stability, and the Lane balance for the qualitative analysis of channel response.

Topics:

Core

- Scour fundamentals and long-term bed elevation changes
- Computation of general scour
- Local scour from contractions, bends, and confluences
- Local scour at bridge piers and abutments
- Fluvial morphology cycles and processes
- Shape, geometry, and stability of alluvial channels
- Lane balance: qualitative channel response and modeling
- Interaction between highway infrastructure and natural streams

Learning Outcomes:

Core:

1. Calculate the general scour depth in a channel reach [Assessment]
2. Determine local scour from contraction and at bridge piers and abutments [Usage]

3. Analyze long-term bed elevation changes in a fluvial reach [Assessment]
4. Describe the cycles and processes governing alluvial channel morphology [Familiarity]
5. Apply the Lane balance to predict the qualitative response of a channel to changes in its variables [Usage]
6. Evaluate interaction problems between highway infrastructure and natural streams [Assessment]

2.5.12 WRH/River Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of channel stabilization and bank protection structures, reservoir sedimentation management, and the fundamentals of river navigation.

Topics:

Core

- Channel stabilization: design criteria and examples
- Control structures for riverbank protection
- Design of riprap, gabions, and protective filters
- Practical design considerations for river protection works
- Reservoir sedimentation and dead storage volume
- Trap efficiency and management of reservoir sedimentation
- Analytical fundamentals of river navigation
- River navigation paradigms and port conditioning

Learning Outcomes:

Core:

1. Design a channel stabilization structure for a given reach [Usage]
2. Select and size bank protection structures (riprap, gabions, filters) [Assessment]
3. Apply practical design considerations to a conceptual river protection case [Usage]
4. Estimate the dead storage volume and useful life of a reservoir due to sedimentation [Assessment]
5. Evaluate the sediment trap efficiency of a reservoir and propose management measures [Usage]
6. Explain the analytical fundamentals of river navigation and its port conditioning [Familiarity]

2.5.13 WRH/Agricultural Water Demand (Core Tier1: 1 hr, Core Tier2: 1 hr)

Soil-water-plant relationships, estimation of evapotranspiration and agricultural water demand, and supply-and-demand analysis for irrigation project planning.

Topics:

Core

- Soil-water-plant relationships and soil water availability
- Estimation of reference and crop evapotranspiration
- Crop water requirement and crop coefficients
- Water supply-and-demand balance for an irrigation project
- Irrigation scheduling and cropping calendars
- Irrigation efficiency at the field, conveyance, and system level

Learning Outcomes:

Core:

1. Explain the soil-water-plant relationship and its effect on water availability for crops [Familiarity]
2. Calculate reference and crop evapotranspiration using standard methods [Usage]
3. Estimate a crop's water requirement throughout its growth cycle [Assessment]
4. Develop the water supply-and-demand balance for an irrigation project [Usage]
5. Design an irrigation schedule accounting for the cropping calendar [Assessment]
6. Evaluate the irrigation efficiency of a system and propose improvements [Usage]

2.5.14 WRH/Irrigation Systems Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of intake works (headworks, desanders) and gravity and pressurized irrigation systems, including the agronomic and hydraulic design of drip irrigation.

Topics:

Core

- Types of irrigation intake works
- Headworks design
- Desander design
- Other structures of the irrigation conveyance and distribution system
- Design of gravity irrigation systems
- Design of pressurized (technified) irrigation systems
- Agronomic design of drip irrigation
- Hydraulic design of drip irrigation: laterals, distribution lines, and emitters

Learning Outcomes:
Core:

1. Select the appropriate intake work type for the conditions of an irrigation project [Usage]
2. Design a headworks structure and its associated desander [Assessment]
3. Design a gravity irrigation system for a given field [Usage]
4. Compare pressurized irrigation alternatives against gravity irrigation [Assessment]
5. Perform the agronomic design of a drip irrigation system [Usage]
6. Hydraulically design the lateral and distribution lines of a drip irrigation system [Assessment]

2.5.15 WRH/Coastal and Floodplain Engineering

Analysis and design for coastal protection, wave mechanics, floodplain management, and flood risk assessment.
Topics:
Core

- Wave mechanics and coastal processes
- Coastal structures and shoreline protection
- Floodplain delineation and hydraulic modeling
- Flood risk assessment and hazard mapping
- Levee and floodwall design
- Storm surge modeling and coastal flooding
- Beach nourishment and dune stabilization
- Floodplain management and NFIP regulations
- Flood warning systems and emergency planning
- Climate change adaptation for coastal and flood infrastructure

Learning Outcomes:
Core:

1. Explain wave mechanics and coastal sediment transport processes [Familiarity]
2. Design coastal protection structures including breakwaters and revetments [Assessment]
3. Delineate floodplains using hydraulic modeling techniques [Usage]
4. Conduct flood risk assessments and develop hazard maps [Assessment]
5. Proportion levees and floodwalls for flood protection [Usage]
6. Model storm surge and coastal flood inundation [Assessment]
7. Plan beach nourishment projects and dune restoration [Usage]
8. Apply floodplain management principles and NFIP requirements [Familiarity]
9. Develop flood warning systems and emergency response plans [Assessment]
10. Incorporate climate change projections in coastal and flood infrastructure design [Usage]

2.6 Environmental Systems Engineering (ESE)

This knowledge area covers the principles and applications of environmental engineering for the protection of public health and natural ecosystems. It focuses on the design of systems for water supply, wastewater treatment, air pollution control, solid waste management, and environmental impact assessment within a sustainable and resilient framework.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.6.1 Water and Wastewater Treatment Process Design (Pg.. 54)	1	1
⭐ 2.6.2 Environmental Chemistry and Microbiology for Engineers (Pg.. 54)	1	1
⭐ 2.6.3 Air Quality and Pollution Control Engineering (Pg.. 55)	1	1
⭐ 2.6.4 Environmental Impact Assessment and Sustainability Metrics (Pg.. 56)	1	1
⭐ 2.6.5 Climate Adaptation Engineering for Water Systems (Pg.. 56)	1	1
2.6.6 Solid and Hazardous Waste Management (Pg.. 57)	Elective	

Table 2.6: List of KUs in the Environmental Systems Engineering area.

2.6.1 ESE/Water and Wastewater Treatment Process Design (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles, design, and operation of physical, chemical, and biological unit processes for the treatment of potable water and municipal/industrial wastewater to meet quality standards and regulatory requirements.

Topics:

Core

- Water quality parameters and regulatory standards for drinking water and wastewater effluent
- Physical treatment processes: screening, sedimentation, flotation, and filtration
- Chemical treatment processes: coagulation, flocculation, disinfection, and pH adjustment
- Biological treatment principles: suspended growth (activated sludge) and attached growth (trickling filters) systems
- Process selection and design criteria based on source water or wastewater characteristics
- Advanced treatment processes: membrane filtration, advanced oxidation, and nutrient removal (N&P)
- Sludge and biosolids handling, treatment, and disposal methods
- Plant layout, hydraulic profile, and pumping system design
- Industrial wastewater pretreatment and specific contaminant removal strategies
- Process control, monitoring, and troubleshooting in treatment plants

Learning Outcomes:

Core:

1. Identify key water quality parameters and their significance for human health and the environment [Familiarity]
2. Select appropriate physical and chemical unit processes for a given water or wastewater treatment objective [Assessment]
3. Design fundamental components of water treatment plants, such as rapid mix basins, flocculators, and sedimentation tanks [Usage]
4. Explain the biological mechanisms and operational parameters of activated sludge systems [Familiarity]
5. Size primary and secondary treatment units based on flow rates and pollutant loading [Assessment]
6. Design advanced treatment trains for water reuse or stringent nutrient discharge limits [Usage]
7. Evaluate sludge management alternatives and select appropriate thickening/dewatering methods [Assessment]
8. Develop hydraulic profiles and pump specifications for treatment plant layouts [Usage]
9. Propose pretreatment strategies for specific industrial wastewater streams [Assessment]
10. Implement basic process control strategies to optimize treatment plant performance [Usage]

2.6.2 ESE/Environmental Chemistry and Microbiology for Engineers (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of chemical and microbiological principles to understand and solve environmental engineering problems, including reaction kinetics, equilibrium, nutrient cycles, and the role of microorganisms in natural and engineered systems.

Topics:
Core

- Aquatic chemistry principles: acidity, alkalinity, hardness, and buffer capacity
- Chemical equilibria and kinetics relevant to environmental processes
- Microbial metabolism, growth, and classification in environmental contexts
- Biogeochemical cycles of carbon, nitrogen, phosphorus, and sulfur
- Water quality indicators and standard analytical methods
- Colloid and surface chemistry for contaminant fate and transport
- Toxicology and risk assessment of environmental contaminants
- Molecular biology tools for environmental engineering applications
- Fate and transport modeling of pollutants in engineered and natural systems

Learning Outcomes:
Core:

1. Calculate pH, buffer intensity, and chemical speciation in aquatic systems [Usage]
2. Explain the role of key microbial groups in wastewater treatment and biogeochemical cycling [Familiarity]
3. Apply mass balance and reaction kinetics to environmental systems [Assessment]
4. Describe the major steps and environmental significance of the nitrogen and phosphorus cycles [Familiarity]
5. Interpret water quality data from standard analytical reports [Usage]
6. Analyze the role of colloidal and interfacial processes in contaminant removal [Assessment]
7. Define key toxicological parameters and concepts used in environmental risk assessment [Familiarity]
8. Evaluate the application of molecular techniques for monitoring engineered biological systems [Assessment]
9. Model the fate and transport of a conservative pollutant in a simple environmental compartment [Usage]

2.6.3 ESE/Air Quality and Pollution Control Engineering (Core Tier1: 1 hr, Core Tier2: 1 hr)

Sources, effects, monitoring, and control of air pollutants; atmospheric dispersion modeling; and design of engineering systems to reduce emissions from stationary and mobile sources.
Topics:
Core

- Atmospheric structure, composition, and basic meteorology
- Pollutant types, sources, and health/environmental effects
- Monitoring techniques and ambient air quality standards
- Dispersion modeling fundamentals and Gaussian plume model
- Control technologies for particulate matter: cyclones, baghouses, and ESPs
- Gaseous pollutant control: absorption, adsorption, and catalytic systems
- Mobile source emissions and control strategies
- Indoor air quality and ventilation
- Climate change and greenhouse gas mitigation engineering

Learning Outcomes:
Core:

1. Describe the major classes of air pollutants, their sources, and impacts [Familiarity]
2. Apply the Gaussian plume model to estimate ground-level concentrations from a point source [Usage]
3. Select appropriate particulate control devices based on particle size distribution and efficiency requirements [Assessment]
4. Interpret ambient air quality monitoring data relative to regulatory standards [Familiarity]
5. Design a basic absorption tower for removing a gaseous pollutant from a flue gas stream [Assessment]
6. Explain the engineering approaches for controlling emissions from mobile sources [Familiarity]

7. Evaluate indoor air quality parameters and propose mitigation measures for a building [Assessment]
8. Propose engineering strategies for reducing greenhouse gas emissions from an industrial facility [Usage]

2.6.4 ESE/Environmental Impact Assessment and Sustainability Metrics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Systematic process for identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken; and the use of sustainability indicators and life-cycle thinking in engineering decision-making.

Topics:

Core

- EIA process: screening, scoping, impact analysis, mitigation, and public participation
- Impact prediction methods for air, water, soil, noise, and ecological systems
- Mitigation hierarchy and design of environmental management plans
- Legal and institutional frameworks for EIA
- Sustainability concepts and the triple bottom line (environment, economy, society)
- Cumulative impact assessment and strategic environmental assessment (SEA)
- Social impact assessment and stakeholder engagement methods
- Sustainability metrics and indicator frameworks (e.g., SDGs, Envision)
- Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes:

Core:

1. Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity]
2. Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage]
3. Develop mitigation measures for identified significant environmental impacts [Assessment]
4. Explain the legal requirements and purpose of EIA in the project approval process [Familiarity]
5. Apply the triple bottom line framework to evaluate a simple engineering project [Assessment]
6. Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment]
7. Design a stakeholder engagement plan for a controversial development project [Usage]
8. Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment]
9. Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

2.6.5 ESE/Climate Adaptation Engineering for Water Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Engineering approaches to assess vulnerability and enhance the resilience of water infrastructure (supply, drainage, coastal) to climate change impacts, including changing precipitation patterns, sea-level rise, and extreme weather events.

Topics:

Core

- Climate science fundamentals and downscaling of global climate model projections
- Hydrologic impacts of climate change: precipitation intensity, drought, and snowmelt
- Vulnerability and risk assessment frameworks for water infrastructure
- Water supply system adaptation: source diversification and demand management
- Stormwater system adaptation for increased intensity rainfall
- Coastal adaptation strategies: managed retreat, protective structures, and nature-based solutions
- Decision-making under uncertainty and adaptive management pathways
- Infrastructure design standards and codes under non-stationary climate conditions

- Economic appraisal of adaptation options and financing mechanisms

Learning Outcomes:

Core:

1. Interpret downscaled climate projections for key hydrologic variables [Familiarity]
2. Assess the vulnerability of a water supply system to projected changes in drought frequency [Assessment]
3. Redesign a stormwater culvert for increased design rainfall intensity based on climate projections [Usage]
4. Describe adaptation strategies for managing urban water demand under water scarcity [Familiarity]
5. Compare hard and soft (nature-based) engineering options for coastal flood protection [Assessment]
6. Develop an adaptive management plan for a reservoir facing uncertain future inflow regimes [Usage]
7. Propose revisions to infrastructure design standards to incorporate climate resilience [Assessment]
8. Conduct a cost-benefit analysis for a portfolio of water infrastructure adaptation measures [Usage]

2.6.6 ESE/Solid and Hazardous Waste Management

Generation, characterization, collection, treatment, and final disposal of municipal solid waste and hazardous materials, with emphasis on engineering design, regulatory frameworks, and sustainable practices.

Topics:

Core

- Waste generation rates, characterization, and composition analysis
- Collection systems, transfer stations, and transportation logistics
- Landfill design: site selection, liner systems, leachate management, and gas collection
- Waste processing and material recovery facilities (MRFs)
- Hazardous waste identification, classification, and regulatory definitions
- Thermal treatment technologies: incineration, pyrolysis, and gasification
- Biological treatment: composting and anaerobic digestion
- Remediation technologies for contaminated sites
- Integrated solid waste management planning and life-cycle assessment

Learning Outcomes:

Core:

1. Estimate waste generation rates and characterize waste streams for a community [Assessment]
2. Design the layout and key components of a municipal solid waste landfill [Usage]
3. Explain the function and components of a material recovery facility (MRF) [Familiarity]
4. Identify and classify hazardous wastes according to regulatory criteria [Familiarity]
5. Plan collection routes and specify transfer station requirements [Usage]
6. Compare thermal treatment technologies based on energy recovery and environmental impacts [Assessment]
7. Design a composting or anaerobic digestion system for organic waste [Usage]
8. Select appropriate remediation technologies for a given contaminated site scenario [Assessment]
9. Develop an integrated waste management plan with source reduction and recycling targets [Usage]

2.7 Construction Engineering and Management (CEM)

This knowledge area covers the principles and practices required to plan, design, construct, operate, and maintain the built environment. It integrates engineering fundamentals with business and management skills to deliver construction projects safely, on time, within budget, and to specified quality standards.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.7.1 Construction Methods, Equipment, and Productivity (Pg.. 58)	1	1
⭐ 2.7.2 Project Planning, Scheduling, and Control (CPM, 4D/5D) (Pg.. 58)	1	1
⭐ 2.7.3 Construction Cost Estimating and Quantification (Pg.. 59)	1	1
⭐ 2.7.4 Construction Budgeting, Bidding, and Financial Control (Pg.. 59)	1	1
⭐ 2.7.5 Price Adjustment and Progress Valuations (Pg.. 60)	1	1
⭐ 2.7.6 Construction Safety, Health, and Risk Management (Pg.. 60)	1	1
⭐ 2.7.7 Contracts, Specifications, and Construction Law (Pg.. 61)	1	1
⭐ 2.7.8 Lean Construction and Integrated Project Delivery (IPD) (Pg.. 61)	1	1
⭐ 2.7.9 Construction Layout and Staking of Works (Pg.. 62)	1	1
⭐ 2.7.10 Formwork Design and Shoring Systems (Pg.. 62)	1	1
⭐ 2.7.11 Rebar Detailing, Fabrication, and Placement (Pg.. 63)	1	1
⭐ 2.7.12 Construction Site and Field Management (Pg.. 63)	1	1
⭐ 2.7.13 Integrated Quality, Environmental, and Safety Management Systems (Pg.. 64)	1	1

Table 2.7: List of KUs in the Construction Engineering and Management area.

2.7.1 CEM/Construction Methods, Equipment, and Productivity (Core Tier1: 1 hr, Core Tier2: 1 hr)

Selection and application of construction methods, technologies, and heavy equipment for earthwork, concrete, steel, and building systems; includes productivity analysis, crew balance, and equipment economics.

Topics:

Core

- Earthwork operations: excavation, hauling, compaction, and mass diagrams
- Concrete construction: formwork, placing, finishing, and curing
- Steel erection, connection, and safety procedures
- Construction equipment types, capabilities, and selection criteria
- Productivity measurement, cycle time analysis, and crew balancing
- Heavy civil construction methods for tunnels, dams, and bridges
- Equipment economics: ownership vs. rental, depreciation, and operating cost
- Trenchless technologies and deep excavation support systems
- Automation and robotics in construction operations

Learning Outcomes:

Core:

1. Select appropriate construction equipment for common earthwork and material handling tasks [Usage]
2. Design basic formwork and shoring for a concrete slab or wall [Assessment]
3. Explain the sequence and safety considerations for steel erection [Familiarity]
4. Calculate productivity rates and cycle times for equipment operations [Usage]
5. Balance a construction crew to optimize productivity for a given task [Assessment]
6. Compare construction methods for a heavy civil project like a cut-and-cover tunnel [Assessment]
7. Analyze the economic life and hourly cost of a piece of construction equipment [Usage]
8. Describe the applications and limitations of trenchless construction technologies [Familiarity]
9. Evaluate the potential for automation to improve safety and productivity on a construction site [Assessment]

2.7.2 CEM/Project Planning, Scheduling, and Control (CPM, 4D/5D) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Development and management of project schedules using network-based techniques (CPM, PERT), resource leveling, cost-loading, and advanced visualization methods (4D/5D BIM) for project control and performance measurement.

Topics:
Core
- Work breakdown structure (WBS) development and activity definition
- Network diagramming: activity-on-node (AON) and precedence diagramming method (PDM)
- Critical Path Method (CPM) for schedule calculation: forward/backward pass, floats
- Resource allocation, loading, and leveling techniques
- Schedule updating, monitoring, and control using earned value management (EVM)
- Program Evaluation and Review Technique (PERT) for schedule risk analysis
- Line of balance (LOB) scheduling for repetitive projects
- 4D scheduling (time + 3D model) for visualization and clash detection
- 5D scheduling (time + cost + 3D model) for integrated cost control

Learning Outcomes:
Core:
1. Develop a Work Breakdown Structure (WBS) for a medium-scale construction project [Usage]
2. Construct a CPM network diagram and calculate the critical path and activity floats [Assessment]
3. Perform resource leveling on a simple project schedule to minimize resource fluctuations [Usage]
4. Monitor project progress using schedule variance (SV) and cost variance (CV) from earned value data [Assessment]
5. Apply PERT to estimate project duration probabilities and identify schedule risks [Assessment]
6. Create a Line of Balance (LOB) schedule for a repetitive housing project [Usage]
7. Generate a 4D simulation to visualize the construction sequence and identify spatial conflicts [Usage]
8. Integrate cost data with a 3D model to perform a 5D analysis for budget tracking [Assessment]

2.7.3 CEM/Construction Cost Estimating and Quantification (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles and techniques for preparing accurate cost estimates at various project stages, from conceptual to detailed; includes quantity takeoff from drawings and digital models, unit-price components, parametric and probabilistic estimating techniques, and life-cycle cost analysis.
Topics:
Core
- Estimating types: conceptual, preliminary, and detailed
- Quantity takeoff methods from drawings and digital models
- Pricing components: labor, material, equipment, and overhead
- Parametric and probabilistic estimating techniques
- Life-cycle cost analysis for building systems

Learning Outcomes:
Core:
1. Perform a detailed quantity takeoff for concrete, formwork, and reinforcement from construction drawings [Usage]
2. Prepare a unit price estimate for a defined work package [Assessment]
3. Apply parametric models to develop a conceptual cost estimate for a building [Assessment]
4. Conduct a life-cycle cost analysis to compare two alternative building envelope systems [Usage]

2.7.4 CEM/Construction Budgeting, Bidding, and Financial Control (Core Tier1: 1 hr, Core Tier2: 1 hr)

Bid preparation and analysis processes, cash flow forecasting and management, value engineering and constructability analysis, and financial statements and performance metrics for the financial control of construction projects and firms.
Topics:
Core
- Bid preparation, submission, and analysis processes
- Cash flow forecasting and management for construction projects

- Value engineering and constructability analysis
- Financial statements and performance metrics for construction firms

Learning Outcomes:

Core:

1. Explain the components and typical markup structure of a competitive bid [Familiarity]
2. Develop a monthly cash flow forecast for a construction project [Usage]
3. Perform a value engineering workshop to identify cost-saving alternatives without sacrificing function [Assessment]
4. Interpret key financial ratios for assessing a construction company's health [Familiarity]

2.7.5 CEM/Price Adjustment and Progress Valuations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Mechanisms for adjusting contract prices to reflect cost escalation during construction execution, and for certifying and paying work actually performed: polynomial price-adjustment formulas indexed to official unit-cost indices, and monthly progress valuations as the basis for progress payments.

Topics:

Core

- Polynomial price-adjustment formula: structure, incidence coefficients (coeficientes de incidencia), and representative unit-cost components
- Official unified construction cost indices: publication cycle, sourcing, and application to the adjustment formula
- Monthly progress valuations: measurement of completed quantities and certification for payment
- Advance payments and retentions: calculation and amortization schedule within progress valuations
- Disputed price-adjustment and valuation calculations: common sources of disagreement and resolution mechanisms

Learning Outcomes:

Core:

1. Calculate the adjusted contract price for a work item using a polynomial price-adjustment formula and official cost indices [Usage]
2. Prepare a monthly progress valuation certifying completed quantities for payment [Usage]
3. Explain the role of advance payments and retentions in a progress-payment schedule [Familiarity]
4. Resolve a disputed price-adjustment calculation by correctly applying index-based escalation rules [Assessment]

2.7.6 CEM/Construction Safety, Health, and Risk Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Identification, assessment, and control of safety, health, and environmental risks on construction sites; implementation of safety programs, regulatory compliance (OSHA), and proactive risk management strategies.

Topics:

Core

- Safety management systems and the role of safety culture
- Common construction hazards: falls, struck-by, electrocution, caught-in/between
- Occupational Safety and Health Administration (OSHA) regulations and compliance
- Risk identification and assessment techniques (e.g., JSA, checklists)
- Hierarchy of controls: elimination, substitution, engineering, administrative, PPE
- Occupational health: silica, noise, ergonomics, and industrial hygiene
- Emergency response planning and incident investigation
- Insurance and bonding principles for construction risk transfer
- Proactive safety leading indicators and predictive analytics

Learning Outcomes:

Core:

1. Identify the "Fatal Four" construction hazards and basic OSHA requirements for each [Familiarity]
2. Conduct a Job Safety Analysis (JSA) for a common construction task [Assessment]
3. Develop a site-specific safety plan for a given project scenario [Usage]
4. Apply the hierarchy of controls to mitigate an identified safety risk [Familiarity]
5. Evaluate occupational health exposures (e.g., noise, dust) and recommend monitoring strategies [Assessment]
6. Create an emergency response plan for a construction site [Usage]
7. Explain the purpose and types of insurance (e.g., CGL, workers' comp) in construction risk management [Familiarity]
8. Propose leading safety indicators to track and predict site safety performance [Assessment]

2.7.7 CEM/Contracts, Specifications, and Construction Law (Core Tier1: 1 hr, Core Tier2: 1 hr)

Legal principles and documentation governing construction projects, including contract types, procurement methods, specification writing, change orders, claims, dispute resolution, and professional liability.

Topics:

Core

- Contract types: lump sum, unit price, cost-plus, and design-build
- Procurement methods and bidding strategies
- Project specifications: MasterFormat, performance vs. prescriptive
- General conditions of contract and key clauses (e.g., AIA, FIDIC)
- Change orders, extra work, and variation procedures
- Claims management: delay, disruption, and acceleration
- Dispute resolution: negotiation, mediation, arbitration, litigation
- Professional liability, negligence, and standard of care
- Ethical dilemmas and professional conduct in construction

Learning Outcomes:

Core:

1. Compare the risk allocation between owner and contractor in different contract types [Familiarity]
2. Select an appropriate procurement method for a given project delivery model [Assessment]
3. Write a clear, unambiguous technical specification for a construction material [Usage]
4. Explain the purpose of key clauses in standard general conditions of contract [Familiarity]
5. Process a hypothetical change order, documenting cost and time impacts [Usage]
6. Analyze a simple delay claim and determine entitlement and damages [Assessment]
7. Recommend an appropriate dispute resolution method for a given conflict scenario [Assessment]
8. Define the engineer's standard of care and potential liabilities for design errors [Familiarity]
9. Resolve an ethical dilemma related to bidding practices or site safety reporting [Assessment]

2.7.8 CEM/Lean Construction and Integrated Project Delivery (IPD) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of lean production principles to construction to minimize waste and maximize value; and collaborative project delivery models (IPD) that align stakeholder interests through shared risk and reward.

Topics:

Core

- Lean thinking principles: value, value stream, flow, pull, perfection
- Identification and elimination of the eight wastes in construction
- Last Planner System (LPS) for production planning and control
- Visual management tools: 5S, Kanban, and Andon
- Integrated Project Delivery (IPD) principles and multi-party agreements
- Target Value Delivery (TVD) and Set-Based Design

- Collaboration technologies and Big Room co-location
- Performance measurement: Percent Plan Complete (PPC), Takt time
- Culture change and implementation strategies for lean transformation

Learning Outcomes:

Core:

1. Define the seven (or eight) types of waste (Muda) in a construction context [Familiarity]
2. Apply the Last Planner System to develop a reliable weekly work plan [Usage]
3. Identify opportunities to apply visual management (5S) on a construction site [Assessment]
4. Explain how Integrated Project Delivery (IPD) aligns goals and shares risk among project stakeholders [Familiarity]
5. Use Target Value Delivery principles to guide design decisions within a cost target [Assessment]
6. Facilitate a collaborative pull planning session with multiple trades [Usage]
7. Calculate and interpret Percent Plan Complete (PPC) as a lean performance metric [Assessment]
8. Develop a basic implementation plan for introducing lean practices to a project team [Assessment]

2.7.9 CEM/Construction Layout and Staking of Works (Core Tier1: 1 hr, Core Tier2: 1 hr)

Transfer of design geometry to the field for construction execution; establishment and preservation of horizontal and vertical control, and staking of axes, levels, and elevations for foundations and structures using conventional and satellite-based instruments.

Topics:

Core

- Establishment and preservation of horizontal and vertical control points
- Staking of building axes, column lines, and reference offsets
- Transfer of design elevations and benchmarks to excavation and formwork
- Layout instruments: total station, automatic/digital level, and GNSS/GPS receivers

Learning Outcomes:

Core:

1. Establish horizontal and vertical control points for a building site using a total station [Usage]
2. Stake out building axes and column locations from a foundation layout plan [Usage]
3. Explain the appropriate use of GNSS/GPS receivers for construction layout tasks [Familiarity]

2.7.10 CEM/Formwork Design and Shoring Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design, selection, and erection of formwork and falsework/shoring systems for cast-in-place concrete construction; includes formwork pressure calculations, system selection for walls, columns, and slabs, shoring and reshoring, and safe stripping and removal practices.

Topics:

Core

- Lateral pressure of fresh concrete on formwork and design loads
- Formwork systems for walls and columns: panel, ganged, and slip forms
- Formwork systems for slabs and beams: conventional, flying, and table forms
- Formwork materials: wood, plywood, engineered forms, and modular metal systems
- Shoring and falsework design: post shores, scaffold shoring, and heavy-duty shoring towers
- Reshoring and backshoring procedures for multistory construction
- Formwork removal and stripping time criteria based on concrete strength gain
- Safety considerations in formwork and shoring erection and dismantling

Learning Outcomes:

Core:

1. Calculate the lateral pressure of fresh concrete on wall formwork for a given pour rate [Assessment]
2. Design wall or column formwork, including sheathing, studs, and ties, for a specified pressure [Assessment]

3. Select an appropriate slab formwork system for a given floor plan and cycle time [Usage]
4. Design a shoring system, including post shore spacing and load path, for an elevated slab [Assessment]
5. Plan a reshoring sequence for a multistory concrete building [Usage]
6. Determine the minimum stripping time for formwork based on concrete strength development [Assessment]

2.7.11 CEM/Rebar Detailing, Fabrication, and Placement (Core Tier1: 1 hr, Core Tier2: 1 hr)

Field and fabrication practices for reinforcing steel: interpretation of structural drawings and bar bending schedules, bar bending and cutting, splicing methods, placement and tying, cover and spacing tolerances, and quality control inspection of reinforcement prior to concrete placement.

Topics:

Core

- Interpretation of structural drawings and bar bending schedules (BBS)
- Bar bending and cutting to standard hooks, bends, and fabrication tolerances
- Splicing methods: lap splices, mechanical couplers, and welded splices
- Placement, support (chairs/spacers), and tying of reinforcing bars
- Concrete cover and bar spacing tolerances for durability and structural performance
- Site quality control and inspection of reinforcement prior to concrete pour

Learning Outcomes:

Core:

1. Interpret a bar bending schedule and structural drawing to fabricate reinforcing bars [Usage]
2. Select an appropriate splicing method for a given bar size and location [Assessment]
3. Place and tie reinforcing steel to meet specified cover and spacing tolerances [Usage]
4. Inspect a completed reinforcement placement for compliance before authorizing concrete pour [Assessment]

2.7.12 CEM/Construction Site and Field Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Day-to-day management and execution of construction site operations, including mobilization, field supervision, subcontractor and trade coordination, progress reporting, materials tracking, quality control during execution, and project closeout.

Topics:

Core

- Site mobilization: temporary facilities, access, utilities, and site organization
- Field supervision and daily site operations management
- Subcontractor and trade coordination and sequencing
- Progress reporting, documentation, and site coordination meetings
- Materials management: procurement tracking, delivery, and storage
- Quality control and inspection during construction execution
- Stakeholder communication and conflict resolution on site
- Project closeout: punch lists, commissioning, and turnover

Learning Outcomes:

Core:

1. Develop a site mobilization plan including temporary facilities and access logistics [Usage]
2. Supervise daily site operations and resolve field-level execution issues [Assessment]
3. Coordinate subcontractor and trade sequencing to avoid schedule conflicts [Usage]
4. Prepare a progress report and lead a site coordination meeting [Usage]
5. Track material procurement, delivery, and on-site storage for a work package [Assessment]
6. Conduct a quality control inspection during a construction execution phase [Assessment]
7. Resolve a stakeholder conflict arising during site execution [Familiarity]
8. Manage project closeout activities, including punch lists and turnover [Usage]

2.7.13 CEM/Integrated Quality, Environmental, and Safety Management Systems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Integration of quality (ISO 9001), environmental (ISO 14001), and occupational health and safety (ISO 45001) management systems into a single, coordinated management framework for a construction project. Covers the common high-level structure shared by the three standards, integrated policies and documentation, and integrated (multi-standard) auditing.

Topics:

Core

- Common high-level structure (Annex SL) shared by ISO 9001, 14001, and 45001: aligned clauses for context, leadership, planning, support, operation, performance evaluation, and improvement
- Integrated management policy and objectives spanning quality, environmental, and OH&S goals; a single integrated management manual and shared documented information
- Integrated internal and external audit programs covering multiple standards in a single audit cycle: combined checklists, joint findings, and non-conformance tracking
- Synergies between the three systems (shared risk-based thinking, PDCA cycle, documented information) versus potential conflicts (competing priorities, resource allocation), and approaches to resolve them

Learning Outcomes:

Core:

1. Explain the common high-level structure shared by ISO 9001, 14001, and 45001 and how it enables management system integration [Familiarity]
2. Design an integrated audit checklist covering quality, environmental, and occupational health and safety requirements for a construction site [Usage]
3. Evaluate the effectiveness of an integrated management system on a construction project, identifying synergies and unresolved conflicts between its component systems [Assessment]

2.8 Digital Technologies in Civil Engineering (DTC)

This knowledge area encompasses the transformative digital tools, methodologies, and data-driven processes that are reshaping the planning, design, construction, operation, and management of civil infrastructure. It focuses on the integration of computational intelligence, sensing, automation, and information modeling to create smarter, more efficient, and resilient built environments.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.8.1 Structural Health Monitoring (SHM) and Sensor Technologies (Pg.. 64)	1	1
⭐ 2.8.2 Building Information Modeling (BIM) for Digital Delivery and Asset Management (Pg.. 65)	1	1
2.8.3 Artificial Intelligence and Machine Learning Applications in Civil Engineering (Pg.. 66)	Elective	
2.8.4 Digital Twins for Infrastructure Lifecycle Management (Pg.. 66)	Elective	
2.8.5 Geospatial Engineering (Pg.. 67)	Elective	
2.8.6 Data Analytics, Visualization, and Informatics for Civil Systems (Pg.. 67)	Elective	
2.8.7 Automation, Robotics, and Additive Manufacturing (3D Printing) in Construction (Pg.. 68)	Elective	

Table 2.8: List of KUs in the Digital Technologies in Civil Engineering area.

2.8.1 DTC/Structural Health Monitoring (SHM) and Sensor Technologies (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles, technologies, and data analysis methods for continuously or periodically monitoring the condition and performance of civil infrastructure using networks of sensors to detect damage, assess safety, and inform maintenance.

Topics:
Core
- SHM objectives, paradigms, and lifecycle cost-benefit analysis
- Sensor types: strain gauges, accelerometers, tiltmeters, fiber optics, piezoelectrics
- Data acquisition systems, signal conditioning, and sampling theory
- Wireless sensor networks (WSN) and IoT communication protocols
- Vibration-based damage detection and modal analysis
- Advanced sensing: distributed fiber optics, computer vision, and radar interferometry
- Data management, cloud storage, and cybersecurity for SHM systems
- Statistical pattern recognition and anomaly detection algorithms
- Decision-support systems for maintenance planning based on SHM data

Learning Outcomes:
Core:
1. List the primary objectives and potential benefits of a Structural Health Monitoring (SHM) system [Familiarity]
2. Select appropriate sensor types for monitoring specific structural responses (strain, vibration, deflection) [Assessment]
3. Design the layout of a basic sensor network for a simply supported beam or a bridge pier [Usage]
4. Explain the advantages and challenges of wireless sensor networks over wired systems [Familiarity]
5. Perform a basic modal analysis on a set of acceleration data to identify natural frequencies [Usage]
6. Compare advanced sensing technologies for detecting crack propagation or settlement [Assessment]
7. Develop a data management plan for a long-term SHM project, considering cloud storage [Usage]
8. Apply a simple statistical control chart to identify anomalies in time-series sensor data [Assessment]
9. Propose a maintenance action based on the output of a SHM-based decision-support system [Usage]

2.8.2 DTC/Building Information Modeling (BIM) for Digital Delivery and Asset Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Comprehensive methodology for creating and managing digital representations of physical and functional characteristics of facilities (BIM), supporting collaboration, decision-making, and information management across the project lifecycle from conception to demolition.
Topics:
Core
- BIM concepts: dimensions (3D, 4D, 5D, 6D, 7D), LOD, and LOIN
- BIM authoring tools and parametric modeling techniques
- Model coordination, clash detection, and interference checking
- Collaboration platforms, Common Data Environments (CDE), and BIM execution plans
- BIM-based analysis: quantity takeoff, energy simulation, and structural analysis
- Digital twins and the connection between BIM and operational data
- Interoperability standards: IFC, COBie, and openBIM
- Asset information models (AIM) and BIM for facilities management (FM)
- Regulatory submission and automated code compliance checking

Learning Outcomes:
Core:
1. Define the different dimensions of BIM (3D-7D) and their associated information [Familiarity]
2. Create a basic 3D parametric model of a structural framing system using BIM software [Usage]
3. Perform a clash detection analysis between architectural and structural models [Assessment]
4. Outline the key components of a BIM Execution Plan (BEP) [Familiarity]
5. Extract a material quantity takeoff schedule from a BIM model [Usage]
6. Explain the relationship between a BIM model and a digital twin for an asset [Familiarity]
7. Export a BIM model using the IFC format to ensure interoperability [Usage]

8. Develop an Asset Information Model (AIM) deliverable for handover to a facility manager [Assessment]
9. Evaluate the potential of automated rule-checking for building code compliance [Assessment]

2.8.3 DTC/Artificial Intelligence and Machine Learning Applications in Civil Engineering

Fundamental concepts and applications of artificial intelligence (AI) and machine learning (ML) for solving complex civil engineering problems, including predictive analytics, pattern recognition, optimization, and automated decision support.

Topics:

Core

- AI fundamentals: supervised, unsupervised, and reinforcement learning
- Data preparation, feature engineering, and model training workflows
- Predictive models for infrastructure performance and deterioration
- Computer vision applications for construction progress monitoring and defect detection
- Optimization algorithms for design, scheduling, and resource allocation
- Natural language processing (NLP) for analyzing construction documents and reports
- Generative AI for design exploration and automated code checking
- Explainable AI (XAI) and ethical considerations in algorithmic decision-making
- Edge computing and embedded AI for real-time structural monitoring

Learning Outcomes:

Core:

1. Distinguish between major types of machine learning (supervised, unsupervised, reinforcement) [Familiarity]
2. Prepare a dataset for training a simple ML model, handling missing values and scaling [Usage]
3. Develop a basic regression model to predict a concrete property from mix parameters [Assessment]
4. Describe how computer vision can be used for automated site inspection [Familiarity]
5. Apply NLP techniques to extract key information from a set of inspection reports [Assessment]
6. Utilize a generative AI tool to explore conceptual design alternatives for a site layout [Usage]
7. Explain the importance of explainable AI and bias mitigation in engineering applications [Familiarity]
8. Design a concept for an edge-AI system to monitor vibration in real-time on a bridge [Assessment]

2.8.4 DTC/Digital Twins for Infrastructure Lifecycle Management

Creation, updating, and utilization of dynamic digital replicas of physical assets that are synchronized with real-time data from sensors and other sources to simulate, predict, and optimize performance throughout the asset's lifecycle.

Topics:

Core

- Digital twin definition, components, and levels of integration
- Real-time data integration from IoT sensors and operational systems
- Physics-based and data-driven simulation models within the twin
- Interactive visualization, dashboards, and augmented reality (AR) interfaces
- Predictive maintenance and remaining useful life forecasting
- Federated digital twins for city-scale or network-level infrastructure
- Autonomous control and closed-loop optimization of infrastructure systems
- Business models and value proposition for digital twin implementation
- Cybersecurity and data governance for critical digital twin systems

Learning Outcomes:

Core:

1. Describe the core components and data flows of a digital twin for a bridge or building [Familiarity]

2. Connect a simple sensor data stream to a visualization dashboard for a digital twin mock-up [Usage]
3. Use a simulation model within a digital twin to predict structural response under a load scenario [Assessment]
4. Explain how predictive maintenance strategies are enhanced by digital twin technology [Familiarity]
5. Conceptualize a federated digital twin for managing an urban water distribution network [Assessment]
6. Design a closed-loop control logic for optimizing energy use in a building digital twin [Assessment]
7. Analyze the potential return on investment (ROI) for implementing a digital twin on a large project [Familiarity]
8. Develop a cybersecurity risk assessment for a critical infrastructure digital twin [Assessment]

2.8.5 DTC/Geospatial Engineering

Acquisition, processing, analysis, and visualization of spatial data using Geographic Information Systems (GIS), remote sensing (satellite, aerial), and Light Detection and Ranging (LiDAR) for site analysis, planning, mapping, and monitoring in civil engineering projects.

Topics:

Core

- GIS fundamentals: spatial data models, coordinate systems, and projections
- Remote sensing platforms and image characteristics (resolution, spectral bands)
- LiDAR technology: principles, point clouds, and digital elevation models (DEM)
- Spatial analysis: overlay, buffering, network analysis, and suitability modeling
- Cartography and map production for engineering communication
- Image processing and classification for land use/cover mapping
- Change detection and time-series analysis for monitoring
- Integration of BIM and GIS (GeoBIM) for infrastructure planning
- WebGIS and mobile GIS applications for field data collection

Learning Outcomes:

Core:

1. Perform a coordinate transformation and reprojection of spatial data [Usage]
2. Compare the applications of optical satellite imagery, aerial photography, and LiDAR [Familiarity]
3. Process a LiDAR point cloud to generate a Digital Terrain Model (DTM) [Assessment]
4. Conduct a site suitability analysis for a new road alignment using GIS overlay operations [Usage]
5. Create an effective thematic map for an engineering report [Assessment]
6. Classify land cover from a satellite image using a supervised classification method [Usage]
7. Quantify urban sprawl or deforestation from multi-temporal satellite imagery [Assessment]
8. Integrate a building footprint from a BIM model into a GIS for solar exposure analysis [Usage]
9. Design a mobile GIS data collection form for a field survey [Usage]

2.8.6 DTC/Data Analytics, Visualization, and Informatics for Civil Systems

Methods for managing, analyzing, interpreting, and communicating large, complex datasets generated throughout the infrastructure lifecycle to extract insights, support decisions, and improve outcomes.

Topics:

Core

- Data types and sources in civil engineering: structured, unstructured, streaming
- Data wrangling, cleaning, and transformation techniques
- Exploratory data analysis (EDA) and descriptive statistics
- Data visualization principles and tools (dashboards, graphs, charts)
- Database fundamentals (SQL, NoSQL) for engineering data management
- Big data platforms and distributed computing concepts (e.g., Hadoop, Spark)
- Spatial statistics and geostatistical analysis

- Information theory and data quality assessment
- Data storytelling and communication for technical and non-technical audiences

Learning Outcomes:
Core:

1. Clean and structure a messy dataset from a construction cost database [Usage]
2. Perform exploratory data analysis to identify trends and outliers in sensor data [Assessment]
3. Create effective visualizations (histograms, scatter plots, time series) to communicate data insights [Usage]
4. Write basic SQL queries to extract and filter data from a relational database [Familiarity]
5. Describe the architecture of a big data platform and its relevance to infrastructure analytics [Familiarity]
6. Apply kriging or another geostatistical method to interpolate soil property data across a site [Assessment]
7. Evaluate the quality and fitness-for-purpose of a given dataset for a specific analysis [Assessment]
8. Develop a data-driven narrative to present the findings of an infrastructure performance study to stakeholders [Usage]

2.8.7 DTC/Automation, Robotics, and Additive Manufacturing (3D Printing) in Construction

Application of automated systems, robotic platforms, and additive manufacturing (3D printing) technologies to perform construction tasks, aiming to increase productivity, safety, precision, and enable new design possibilities.

Topics:
Core

- Automation fundamentals: degrees of automation, control systems, and robotic kinematics
- Robotic systems for material handling, assembly, and inspection
- Additive manufacturing processes for construction: extrusion, powder bonding
- Materials for robotic fabrication and 3D printing (concrete, polymers, composites)
- Path planning and simulation for construction robots
- Swarm robotics and collaborative multi-robot systems
- Unmanned Aerial Vehicles (UAVs/drones) for surveying, inspection, and delivery
- Wearable robotics (exoskeletons) for worker assist and safety
- Digital fabrication and robotic assembly of complex structures

Learning Outcomes:
Core:

1. Classify different levels of automation applicable to construction tasks [Familiarity]
2. Select an appropriate robotic system or additive manufacturing process for a given construction application [Assessment]
3. Explain the challenges and opportunities of 3D printing with concrete [Familiarity]
4. Simulate a simple robotic path for placing bricks or spraying insulation [Usage]
5. Design a concept for a swarm of drones to collaboratively map a construction site [Assessment]
6. Describe the safety and productivity benefits of exoskeletons for construction workers [Familiarity]
7. Plan a digital fabrication workflow for a non-standard architectural component [Assessment]
8. Evaluate the economic and scheduling impact of introducing robotics on a construction project [Assessment]

2.9 Sustainable and Resilient Infrastructure (SRI)

This knowledge area integrates the principles of sustainability, resilience, and climate adaptation into the lifecycle of civil infrastructure. It focuses on designing, constructing, and managing systems that meet present needs without compromising the ability of future generations to meet their own, while withstanding and recovering from natural and anthropogenic shocks and stresses.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.9.1 Foundational Sustainability Principles and Triple Bottom Line (Pg.. 69)	1	1
⭐ 2.9.2 Resource Efficiency and Circular Economy (Pg.. 69)	1	1
⭐ 2.9.3 Social, Economic, and Governance Dimensions of Sustainable Infrastructure (Pg.. 69)	1	1
⭐ 2.9.4 Resilient Design for Natural Hazards and Climate Change (Pg.. 70)	1	1
⭐ 2.9.5 Green Building Systems and Sustainable Urban Development (Pg.. 70)	1	1
2.9.6 Life Cycle Assessment (LCA) and Embodied Carbon Accounting (Pg.. 71)	Elective	
2.9.7 Nature-Based Solutions and Low-Impact Development (Pg.. 71)	Elective	
2.9.8 Energy Infrastructure and Renewable Energy Integration (Pg.. 72)	Elective	

Table 2.9: List of KUs in the Sustainable and Resilient Infrastructure area.

2.9.1 SRI/Foundational Sustainability Principles and Triple Bottom Line (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Triple bottom line (TBL) framework and sustainability metrics
- Life-cycle thinking and stage-gate analysis for infrastructure projects
- Regenerative design and net-positive impact goals

Learning Outcomes:
Core:

1. Define the three pillars of the triple bottom line and give an infrastructure-related example for each [Familiarity]
2. Apply life-cycle thinking to compare the long-term impacts of two alternative paving materials [Assessment]
3. Develop a project goal for achieving a net-positive environmental impact [Assessment]

2.9.2 SRI/Resource Efficiency and Circular Economy (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Resource efficiency: energy, water, and material consumption minimization
- Circular economy principles: reduce, reuse, recycle, recover (R4)
- Sustainable procurement and supply chain management

Learning Outcomes:
Core:

1. Calculate the embodied energy or water footprint of a simple structural component [Usage]
2. Explain how circular economy principles can be applied to construction and demolition waste [Familiarity]

2.9.3 SRI/Social, Economic, and Governance Dimensions of Sustainable Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr)

Topics:
Core

- Social sustainability: equity, accessibility, and community well-being
- Economic sustainability: life-cycle costing and total cost of ownership
- Policy frameworks and green rating systems (e.g., Envision, LEED for Infrastructure)

Learning Outcomes:
Core:

1. Evaluate the social equity implications of a proposed transportation project [Assessment]

2. Perform a life-cycle cost analysis to justify a higher initial investment in a durable material [Usage]
3. Use a green infrastructure rating system checklist to assess a project's sustainability performance [Familiarity]

2.9.4 SRI/Resilient Design for Natural Hazards and Climate Change (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design strategies and engineering solutions to enhance the ability of infrastructure systems to anticipate, absorb, adapt to, and recover from acute shocks (e.g., earthquakes, floods) and chronic stresses (e.g., sea-level rise, temperature increase) in a timely and efficient manner.

Topics:

Core

- Resilience concepts: robustness, redundancy, resourcefulness, rapid recovery
- Hazard identification and probabilistic risk assessment
- Multi-hazard design approaches and trade-offs
- Climate change projections and their translation into design parameters
- Structural resilience: performance-based design and damage-control technologies
- System-of-systems resilience for interconnected infrastructure networks
- Adaptive capacity and flexible design for uncertain futures
- Community resilience and social dimensions of infrastructure recovery
- Financing resilience: benefit-cost analysis and innovative funding mechanisms

Learning Outcomes:

Core:

1. Describe the four key properties (4Rs) of a resilient system [Familiarity]
2. Perform a qualitative risk assessment for a site exposed to multiple natural hazards [Assessment]
3. Incorporate projected sea-level rise or increased precipitation into the design basis for a coastal or drainage structure [Usage]
4. Explain how base isolation or damping devices enhance structural resilience [Familiarity]
5. Analyze the cascading failures in interconnected water and power networks after an earthquake [Assessment]
6. Design a flexible foundation system that can be adapted for future increased loads [Usage]
7. Evaluate the role of social capital and community preparedness in post-disaster recovery [Assessment]
8. Conduct a benefit-cost analysis for a proposed infrastructure resilience upgrade [Usage]

2.9.5 SRI/Green Building Systems and Sustainable Urban Development (Core Tier1: 1 hr, Core Tier2: 1 hr)

Integrated design of high-performance buildings and sustainable urban forms that minimize environmental impact, optimize resource use, and enhance human health and well-being, considering energy, water, materials, indoor environmental quality, and site ecology.

Topics:

Core

- High-performance building envelopes and passive design strategies
- Energy modeling, efficient HVAC systems, and on-site renewable generation
- Water efficiency: low-flow fixtures, rainwater harvesting, and greywater reuse
- Indoor environmental quality (IEQ): thermal comfort, daylighting, and air quality
- Sustainable site design: stormwater management, heat island reduction, habitat preservation
- Net-zero energy and water building design
- Smart building technologies and IoT for operational optimization
- Urban sustainability: transit-oriented development, density, and mixed-use planning
- Green building certification systems: LEED, BREEAM, Living Building Challenge

Learning Outcomes:

Core:

1. Design a building section illustrating key passive heating and cooling strategies [Assessment]

2. Size a rainwater harvesting system for a given roof area and demand [Usage]
3. Explain the key parameters affecting indoor air quality and thermal comfort [Familiarity]
4. Develop a site plan that minimizes impervious surfaces and incorporates green infrastructure [Usage]
5. Model a building's energy use to demonstrate a path to net-zero energy [Assessment]
6. Describe how a building automation system can optimize energy and water use [Familiarity]
7. Plan a transit-oriented development (TOD) node for reduced vehicle dependence [Assessment]
8. Prepare documentation for a project targeting a specific level of LEED certification [Usage]

2.9.6 SRI/Life Cycle Assessment (LCA) and Embodied Carbon Accounting

Methodology for quantifying the environmental impacts of a product, process, or system throughout its entire life cycle, from raw material extraction to end-of-life disposal, with a specific focus on calculating and reducing embodied carbon in construction materials and assemblies.

Topics:

Core

- LCA methodology: goal definition, inventory analysis, impact assessment, interpretation
- Life cycle inventory (LCI) data sources and databases (e.g., Ecoinvent)
- Impact assessment categories: global warming potential, acidification, eutrophication
- Embodied carbon: definitions, calculation methods, and benchmarks
- LCA software tools and their application to building and infrastructure systems
- Whole-building LCA and integration with BIM
- Dynamic LCA and temporal considerations in impact assessment
- Carbon sequestration in bio-based materials and concrete
- Policy drivers: carbon budgets, regulations, and carbon pricing

Learning Outcomes:

Core:

1. Outline the four main phases of a standard Life Cycle Assessment (LCA) [Familiarity]
2. Compile a life cycle inventory for a concrete mix using a standard database [Usage]
3. Calculate the global warming potential (embodied carbon) of a defined structural element [Assessment]
4. Interpret the results of a comparative LCA for two competing design options [Familiarity]
5. Use a simplified LCA software tool to model a small building assembly [Usage]
6. Conduct a whole-building LCA using BIM-integrated tools [Assessment]
7. Explain the importance of time horizon and dynamic factors in carbon accounting [Familiarity]
8. Quantify the potential carbon storage benefit of using mass timber instead of concrete [Assessment]
9. Analyze how a carbon tax would affect the material selection for a project [Assessment]

2.9.7 SRI/Nature-Based Solutions and Low-Impact Development

Use of natural processes and ecosystems (e.g., wetlands, green roofs, permeable pavements) to manage water, reduce pollution, mitigate urban heat, enhance biodiversity, and provide other infrastructure services, often in combination with conventional engineered systems.

Topics:

Core

- Nature-based Solutions (NbS) concepts, typology, and co-benefits
- Low-Impact Development (LID) principles and site-scale techniques
- Green infrastructure for stormwater: bioswales, rain gardens, constructed wetlands
- Blue-green infrastructure: restoring urban streams and daylighting rivers
- Soil restoration and urban greening for heat mitigation and carbon sequestration
- Ecological engineering and habitat creation
- Hybrid grey-green systems and their performance quantification
- Community engagement and social acceptance of NbS
- Policy and planning frameworks for mainstreaming NbS at city scale

Learning Outcomes:
Core:

1. Define Nature-Based Solutions and list three key benefits beyond water management [Familiarity]
2. Design a bioswale or rain garden for treating runoff from a small parking lot [Usage]
3. Compare the cost and performance of a green roof vs. a conventional roof for stormwater retention [Assessment]
4. Explain the concept of "daylighting" a stream and its urban benefits [Familiarity]
5. Design a multi-functional green space that provides both flood storage and habitat [Assessment]
6. Quantify the runoff reduction and peak flow attenuation of a proposed green infrastructure plan [Assessment]
7. Develop a public engagement strategy for a proposed urban wetland restoration project [Familiarity]
8. Integrate NbS into a municipal stormwater master plan [Assessment]

2.9.8 SRI/Energy Infrastructure and Renewable Energy Integration

Planning, design, and assessment of energy systems for buildings and communities, with emphasis on energy efficiency, renewable energy sources (solar, wind, geothermal), energy storage, microgrids, and the role of civil infrastructure in enabling the energy transition.
Topics:
Core

- Energy systems fundamentals: demand, supply, conversion, and distribution
- Renewable energy technologies: solar PV, solar thermal, wind, geothermal heat pumps
- Energy efficiency in buildings and industrial processes
- Energy storage technologies: batteries, pumped hydro, thermal storage
- Grid integration of distributed energy resources and smart grids
- Microgrid design for resilience and community energy independence
- Civil infrastructure's role: building-integrated PV, wind turbine foundations, geothermal wells
- Life-cycle energy analysis of renewable energy projects
- Policy, economics, and financing of renewable energy infrastructure

Learning Outcomes:
Core:

1. Describe the operating principles and typical applications of three major renewable energy technologies [Familiarity]
2. Calculate the potential annual energy generation from a rooftop PV array [Usage]
3. Audit a simple building to identify key opportunities for energy efficiency improvements [Assessment]
4. Explain the function of energy storage in balancing variable renewable generation [Familiarity]
5. Design a conceptual microgrid for a university campus to enhance energy resilience [Assessment]
6. Evaluate the structural and geotechnical considerations for siting a utility-scale wind turbine [Assessment]
7. Perform a simple life-cycle energy analysis for a solar farm [Usage]
8. Analyze the impact of a feed-in tariff on the financial viability of a residential solar project [Familiarity]

2.10 Building Services Engineering (BSE)

This knowledge area covers the design of sanitary and electrical installations inside a building: water supply, wastewater evacuation, and the sizing and protection of residential electrical installations.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.10.1 Water Supply System in Building Sanitary Installations (Pg.. 73)	1	1
⭐ 2.10.2 Drainage System in Building Sanitary Installations (Pg.. 73)	1	1
⭐ 2.10.3 Building Electrical Installations (Pg.. 73)	1	1

Table 2.10: List of KUs in the Building Services Engineering area.

2.10.1 BSE/Water Supply System in Building Sanitary Installations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Importance and scope of sanitary installations, and design of a building's cold and hot water system, including demand allowance, pressures, pipe sizing, cisterns, elevated tanks, and pumping systems.

Topics:

Core

- Importance and scope of sanitary installations in a building
- Cold water system design: demand allowance, pressures, and pipe sizing
- Hot water system design and other building water uses
- Cisterns, elevated tanks, and water pumping systems

Learning Outcomes:

Core:

1. Explain the importance and scope of sanitary installations in a building [Familiarity]
2. Design a building's cold and hot water system, determining demand allowance, pressures, and pipe sizing [Usage]
3. Size cisterns, elevated tanks, and water pumping systems for a building [Assessment]

2.10.2 BSE/Drainage System in Building Sanitary Installations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of a building's wastewater and stormwater drainage system, including sanitary venting systems and traps for odor control.

Topics:

Core

- Wastewater drainage system design
- Building stormwater drainage system design
- Sanitary venting systems and traps for odor control

Learning Outcomes:

Core:

1. Design a building's wastewater and stormwater drainage system [Usage]
2. Apply sanitary venting and odor control criteria to the design of a drainage system [Assessment]

2.10.3 BSE/Building Electrical Installations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Design of residential electrical installations: determination of installed power and maximum demand, lighting, grounding, and electricity tariffs.

Topics:

Core

- Importance and scope of electrical installations in a building
- Determination of installed power per applicable standards
- Maximum demand calculation and demand factors
- Design of branch circuits and feeders
- Basic lighting design concepts for buildings
- Grounding systems
- Electricity tariffs and service billing

Learning Outcomes:

Core:

1. Explain the importance of electrical installations in a building [Familiarity]
2. Determine the installed power of a building per current standards [Usage]
3. Calculate the maximum demand of a building applying the corresponding demand factors [Assessment]
4. Design the branch circuits and feeders of a residential electrical installation [Usage]
5. Apply lighting and grounding concepts to the design of an electrical installation [Assessment]

2.11 Professional Practice and Project Leadership (PPL)

This knowledge area encompasses the non-technical skills, ethical frameworks, and professional responsibilities essential for the successful practice of civil engineering. It focuses on communication, teamwork, leadership, project economics, legal aspects, licensure, and the engineer's role in a global society, preparing graduates to lead projects and serve the public interest responsibly.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 2.11.1 Engineering Ethics and Professional Responsibility (Pg.. 74)	1	1
⭐ 2.11.2 Written and Technical Communication (Pg.. 75)	1	1
⭐ 2.11.3 Oral Presentation and Professional Communication (Pg.. 75)	1	1
⭐ 2.11.4 Digital and Collaborative Communication (Pg.. 75)	1	1
⭐ 2.11.5 Engineering Economics and Project Financing (PPPs) (Pg.. 76)	1	1
⭐ 2.11.6 Leadership, Team Dynamics, and Stakeholder Management (Pg.. 76)	1	1
⭐ 2.11.7 Engineering Licensure, Legal Liability, and Regulatory Frameworks (Pg.. 77)	1	1
⭐ 2.11.8 Global Engineering Practice and International Standards (Pg.. 77)	1	1
⭐ 2.11.9 Professional and Regulatory Context (Pg.. 78)	1	1
⭐ 2.11.10 National Context of Existing Civil Infrastructure (Pg.. 78)	1	1

Table 2.11: List of KUs in the Professional Practice and Project Leadership area.

2.11.1 PPL/Engineering Ethics and Professional Responsibility (Core Tier1: 1 hr, Core Tier2: 1 hr)

Moral principles, ethical theories, and professional codes of conduct that guide engineering practice. It involves recognizing ethical dilemmas, analyzing stakeholders' interests, and making decisions that prioritize public safety, health, and welfare while maintaining integrity and honesty.

Topics:

Core

- Ethical theories: utilitarianism, duty ethics, virtue ethics
- Professional codes of conduct (e.g., ASCE, NSPE) and their fundamental canons
- Engineer's paramount responsibility to public safety, health, and welfare
- Ethical dilemmas in practice: conflicts of interest, whistleblowing, gift-giving
- Ethical decision-making frameworks and case study analysis
- Global engineering ethics and cross-cultural challenges
- Ethical obligations for sustainable development and environmental stewardship
- Ethical implications of emerging technologies (AI, automation, data privacy)
- Ethical conduct in dispute resolution and litigation

Learning Outcomes:

Core:

1. Explain the primary tenets of the engineer's code of ethics [Familiarity]
2. Apply an ethical decision-making framework to a hypothetical engineering scenario [Assessment]
3. Identify conflicts of interest and other common ethical pitfalls in project work [Familiarity]
4. Analyze a historical engineering failure case from an ethical perspective [Assessment]
5. Evaluate the ethical dimensions of a project with significant social or environmental impacts in a different cultural context [Assessment]
6. Articulate the ethical argument for incorporating sustainability into all engineering work [Familiarity]
7. Discuss the ethical responsibilities related to data collection and use in smart infrastructure projects [Assessment]
8. Describe the role of ethics in alternative dispute resolution processes [Familiarity]

2.11.2 PPL/Written and Technical Communication (Core Tier1: 1 hr, Core Tier2: 1 hr)

Written communication of technical content for engineering audiences, covering audience analysis, technical report writing, and visual communication through graphs, diagrams, and slides.

Topics:

Core

- Audience analysis and adaptation of technical content
- Written communication: technical reports, memos, emails, and specifications
- Visual communication: graphs, charts, diagrams, and effective slide design

Learning Outcomes:

Core:

1. Write a clear, concise, and well-organized technical report on a laboratory experiment or design project [Usage]
2. Create effective graphs and diagrams to present engineering data [Assessment]

2.11.3 PPL/Oral Presentation and Professional Communication (Core Tier1: 1 hr, Core Tier2: 1 hr)

Oral delivery of technical information and professional proposal writing, including presentation structure and delivery techniques, proposal development, and executive summaries for non-technical stakeholders.

Topics:

Core

- Oral presentations: structure, delivery techniques, and handling Q&A
- Proposal writing: technical approach, management plan, and cost estimating
- Executive summaries and communicating with non-technical stakeholders

Learning Outcomes:

Core:

1. Deliver a structured oral presentation on a technical topic using appropriate visual aids [Usage]
2. Outline the key sections of a competitive engineering proposal [Familiarity]
3. Develop an executive summary that conveys key project findings to a senior management audience [Usage]

2.11.4 PPL/Digital and Collaborative Communication (Core Tier1: 1 hr, Core Tier2: 1 hr)

Digital and collaborative communication practices for engineering teams, covering collaborative document management, digital and social-media communication, and persuasive negotiation techniques.

Topics:

Core

- Collaborative writing and document management in team settings
- Digital communication: web content, social media guidelines for engineers
- Persuasive communication and negotiation techniques

Learning Outcomes:

Core:

1. Manage a collaborative document (e.g., on Google Docs or SharePoint) for a team project [Assessment]
2. Explain the professional risks and opportunities associated with engineers using social media [Familiarity]
3. Employ basic negotiation tactics to resolve a simulated conflict over project scope [Usage]

2.11.5 PPL/Engineering Economics and Project Financing (PPPs) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Application of economic principles and analysis techniques to evaluate and compare engineering project alternatives. Includes time value of money, cost estimation, feasibility studies, life-cycle costing, and an introduction to public-private partnership (PPP) models for infrastructure financing.

Topics:

Core

- Time value of money: present worth, future worth, annual worth calculations
- Comparison of project alternatives: present worth, rate of return, benefit-cost analysis
- Depreciation methods and tax considerations in engineering economics
- Project feasibility studies and break-even analysis
- Risk and uncertainty in economic analysis: sensitivity and scenario analysis
- Life-cycle costing for infrastructure assets
- Project financing models: debt, equity, and public-private partnerships (PPPs)
- Valuation of intangible benefits and costs in public projects
- Real options analysis for flexible project planning

Learning Outcomes:

Core:

1. Calculate present worth, future worth, and annual worth for a series of cash flows [Usage]
2. Compare two mutually exclusive project alternatives using present worth analysis [Assessment]
3. Apply straight-line and MACRS depreciation methods to a capital asset [Usage]
4. Conduct a basic sensitivity analysis on the key variables of a project's economic model [Assessment]
5. Perform a life-cycle cost analysis for a bridge, considering initial construction, maintenance, and end-of-life costs [Usage]
6. Compare the risk allocation in a Design-Bid-Build project versus a Public-Private Partnership (PPP) [Familiarity]
7. Monetize the societal benefits (e.g., reduced travel time) of a transportation project for a benefit-cost analysis [Assessment]
8. Explain how real options analysis can add value to the planning of a multi-phase infrastructure project [Familiarity]

2.11.6 PPL/Leadership, Team Dynamics, and Stakeholder Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Development of leadership skills, understanding of team dynamics, and strategies for effective collaboration and conflict resolution in multidisciplinary project teams. Includes identification and management of diverse stakeholder interests throughout the project lifecycle.

Topics:

Core

- Leadership styles, traits, and the difference between leadership and management
- Team dynamics: forming, storming, norming, performing stages and roles
- Conflict resolution strategies and negotiation
- Stakeholder identification, analysis, and engagement planning
- Motivation theories and their application to engineering teams
- Cultural intelligence and leading diverse, global teams
- Change management and leading organizational transformation
- Emotional intelligence and its role in effective leadership
- Ethical leadership and creating an ethical organizational culture

Learning Outcomes:

Core:

1. Describe different leadership styles and identify situations where each might be effective [Familiarity]
2. Diagnose the stage of development of a project team and propose appropriate interventions [Assessment]

3. Resolve a simulated interpersonal conflict within a project team using a structured approach [Usage]
4. Develop a stakeholder engagement plan for a project with community opposition [Assessment]
5. Adapt communication and leadership approach when working with a team from a different cultural background [Assessment]
6. Explain the key steps in a change management process for implementing a new technology [Familiarity]
7. Evaluate one's own emotional intelligence and identify areas for development [Assessment]
8. Model ethical leadership behavior in a team-based project simulation [Usage]

2.11.7 PPL/Engineering Licensure, Legal Liability, and Regulatory Frameworks (Core Tier1: 1 hr, Core Tier2: 1 hr)

Process and requirements for obtaining professional engineering licensure (PE). Understanding of legal principles affecting engineering practice, including tort law, contracts, liability, standard of care, and the regulatory environment for infrastructure projects.

Topics:

Core

- Professional licensure process: EIT/FE exam, experience requirements, PE exam
- Legal fundamentals: torts (negligence), contracts, and intellectual property
- Professional liability, errors and omissions, and standard of care
- Regulatory framework for design and construction (building codes, environmental regulations)
- Risk management strategies: insurance, indemnification, limitation of liability
- International licensure and mutual recognition agreements
- Forensic engineering and expert witness testimony
- Government contracting and the Federal Acquisition Regulation (FAR)
- Compliance programs and ethics training for engineering firms

Learning Outcomes:

Core:

1. Outline the typical steps and requirements to become a licensed Professional Engineer (PE) [Familiarity]
2. Define the legal concepts of negligence, standard of care, and breach of contract in an engineering context [Familiarity]
3. Analyze a case to determine if an engineer's actions met the professional standard of care [Assessment]
4. Identify the key regulatory permits required for a typical land development project [Familiarity]
5. Explain the purpose of professional liability insurance and common policy exclusions [Familiarity]
6. Compare the licensure requirements in two different countries [Familiarity]
7. Prepare an outline for an expert witness report on a technical failure [Assessment]
8. Describe the unique challenges and rules of government contracting for engineering services [Familiarity]
9. Design a simple ethics and compliance training module for an engineering consultancy [Assessment]

2.11.8 PPL/Global Engineering Practice and International Standards (Core Tier1: 1 hr, Core Tier2: 1 hr)

Practice of engineering in an international context, including awareness of cultural differences, global project delivery models, international standards (ISO, FIDIC), supply chain logistics, and the role of engineering in addressing global challenges such as sustainable development and climate change.

Topics:

Core

- Globalization of engineering: drivers, opportunities, and challenges
- Cultural dimensions and their impact on communication, negotiation, and project management

- International standards organizations (ISO) and their role in harmonization
- FIDIC contract conditions and international project delivery
- Global challenges: UN Sustainable Development Goals (SDGs) and the engineer's role
- Global supply chain management and logistics for construction
- Expatriate assignments and working in multinational teams
- Risk management for international projects: political, currency, force majeure
- Technology transfer and capacity building in developing regions

Learning Outcomes:

Core:

1. Describe how cultural differences can affect team dynamics and project outcomes on international projects [Familiarity]
2. Use a cultural dimensions framework to analyze a cross-cultural misunderstanding in a project case study [Assessment]
3. Identify key ISO standards relevant to quality management (ISO 9001) and environmental management (ISO 14001) in engineering [Familiarity]
4. Explain the structure and key principles of FIDIC Red and Yellow Books [Familiarity]
5. Map the objectives of a civil engineering project to relevant UN Sustainable Development Goals (SDGs) [Assessment]
6. Develop a risk register for an international joint venture project, identifying political and currency risks [Assessment]
7. Outline the key considerations for an engineer accepting a long-term assignment in a foreign country [Familiarity]
8. Design a technology transfer plan for implementing a new water treatment process in a developing community [Assessment]

2.11.9 PPL/Professional and Regulatory Context (Core Tier1: 1 hr, Core Tier2: 1 hr)

Overview of the principal categories of civil engineering works – buildings, transportation and hydraulic infrastructure, and special/industrial structures – and the professional, regulatory, and public-safety context that governs their planning and design in Peru, with emphasis on the elevated risk profile of special/industrial structures such as chimneys and liquid-storage tanks.

Topics:

Core

- Typology of civil engineering works: buildings, transportation and hydraulic infrastructure, and special/industrial structures (chimneys, tanks, silos)
- Peruvian regulatory framework (Reglamento Nacional de Edificaciones) and applicable international standards (ACI, ASCE) for special/industrial structures
- Professional responsibility and public-safety risk considerations specific to special/industrial structures under seismic hazard
- Design process and stakeholders involved in a special/industrial structures project: owner, design engineer, and regulatory authority

Learning Outcomes:

Core:

1. Classify civil engineering works by typology and identify the regulatory framework applicable to special/industrial structures [Familiarity]
2. Explain the professional responsibility and public-safety risk considerations specific to the design of special/industrial structures [Familiarity]
3. Describe the design process and the stakeholders involved in a special/industrial structures project [Usage]

2.11.10 PPL/National Context of Existing Civil Infrastructure (Core Tier1: 1 hr, Core Tier2: 1 hr)

Overview of the inventory and condition of Peru's existing civil infrastructure – buildings, bridges, and lifelines – the causes and consequences of infrastructure deficiency, and the economic, risk-

management, and regulatory context that governs the decision to rehabilitate versus replace deficient existing structures.

Topics:

Core

- Overview of Peru's existing civil infrastructure inventory and condition: buildings, bridges, and lifelines
- Causes and consequences of infrastructure deficiency: aging, inadequate maintenance, unregulated construction, and seismic vulnerability
- Economic, social, and risk-management implications of infrastructure rehabilitation versus replacement
- Institutional and regulatory framework for the rehabilitation of existing structures in Peru

Learning Outcomes:

Core:

1. Describe the condition and typology of Peru's existing civil infrastructure [Familiarity]
2. Explain the causes and consequences of infrastructure deficiency in the Peruvian context [Familiarity]
3. Discuss the economic and risk-management criteria used to decide between rehabilitation and replacement of existing infrastructure [Usage]

Chapter 3

Body of knowledge of Transportation Engineering

The 18 knowledge areas in Transportation Engineering are:

3.1 Pavement and Highway Engineering (TIE) (Pg.. 82)
- 3.1.1 Pavement Materials and Characterization (Pg.. 82)
- 3.1.2 Pavement Design and Management (Pg.. 82)
- 3.1.3 Pavement Condition Evaluation and Maintenance Planning (Pg.. 83)
- 3.1.4 Road and Bridge Asset Management (Pg.. 83)

3.2 Geometric Design Engineering (GDE) (Pg.. 84)
- 3.2.1 Design Controls and Criteria (Pg.. 84)
- 3.2.2 Horizontal Alignment Design (Pg.. 84)
- 3.2.3 Vertical Alignment Design (Pg.. 85)
- 3.2.4 Cross-Section Elements and Roadside Design (Pg.. 85)
- 3.2.5 At-Grade Intersections and Interchanges (Pg.. 86)
- 3.2.6 Context-Sensitive and Multimodal Design (Pg.. 86)

3.3 Transportation Engineering (TRE) (Pg.. 86)
- 3.3.1 Transportation Planning and Economics (Pg.. 87)
- 3.3.2 Transportation Economics and Finance (Pg.. 87)
- 3.3.3 Freight Transportation and Logistics (Pg.. 88)
- 3.3.4 Public Transit Systems Planning (Pg.. 88)

3.4 Traffic Engineering (TFE) (Pg.. 88)
- 3.4.1 Traffic Flow Theory and Capacity Analysis (Pg.. 88)
- 3.4.2 Traffic Operations and Management (Pg.. 89)
- 3.4.3 Intelligent Transportation Systems and Connected Vehicles (Pg.. 89)
- 3.4.4 Road Safety Engineering (Pg.. 90)
- 3.4.5 Traffic Control Devices (Pg.. 90)

3.5 Airport Engineering (APE) (Pg.. 90)
- 3.5.1 Airport Planning and Demand Forecasting (Pg.. 91)
- 3.5.2 Airside Geometric Design (Pg.. 91)
- 3.5.3 Airfield Pavement Design and Evaluation (Pg.. 91)
- 3.5.4 Airfield Drainage, Lighting, and Visual Aids (Pg.. 92)
- 3.5.5 Terminal and Landside Design (Pg.. 92)
- 3.5.6 Airspace and Air Traffic Operations (Pg.. 92)
- 3.5.7 Airport Safety, Security, and Regulation (Pg.. 93)

3.6 Railway Engineering (RWE) (Pg.. 93)
- 3.6.1 Railway Alignment Design (Pg.. 93)
- 3.6.2 Track Structure Design (Pg.. 94)
- 3.6.3 Railway Signaling and Train Control (Pg.. 94)
- 3.6.4 Railway Electrification (Pg.. 94)
- 3.6.5 Rolling Stock Fundamentals (Pg.. 95)
- 3.6.6 Railway Capacity and Operations (Pg.. 95)
- 3.6.7 Railway Station and Terminal Design (Pg.. 95)

3.7 Port Engineering (PTE) (Pg.. 95)
- 3.7.1 Port Planning (Pg.. 96)
- 3.7.2 Maritime Hydraulics for Ports (Pg.. 96)
- 3.7.3 Breakwater and Coastal Structures (Pg.. 96)
- 3.7.4 Berth and Quay Design (Pg.. 97)
- 3.7.5 Dredging and Bathymetry (Pg.. 97)
- 3.7.6 Cargo Handling and Yard Design (Pg.. 97)
- 3.7.7 Port Operations, Safety, and Environmental Management (Pg.. 98)

3.8 Topography (TOP) (Pg.. 98)
- 3.8.1 Surveying Fundamentals and Measurement Theory (Pg.. 98)
- 3.8.2 Planimetry (Pg.. 98)
- 3.8.3 Leveling and Vertical Control (Pg.. 99)
- 3.8.4 Total Stations and Theodolites (Pg.. 99)
- 3.8.5 GNSS Surveying (Pg.. 99)
- 3.8.6 Topographic Mapping and Digital Terrain Models (Pg.. 100)
- 3.8.7 Earthwork Volume Computations (Pg.. 100)
- 3.8.8 Construction Layout and Stakeout Surveying (Pg.. 100)

3.9 Geodesy (GEO) (Pg.. 100)
- 3.9.1 Geodetic Fundamentals and Reference Systems (Pg.. 101)
- 3.9.2 Geodetic Control Networks (Pg.. 101)
- 3.9.3 Physical Geodesy and the Gravity Field (Pg.. 101)
- 3.9.4 Satellite Geodesy and Precise Positioning (Pg.. 102)

3.10 Cartography (CAR) (Pg.. 102)
- 3.10.1 Map Projections and Coordinate Reference Systems (Pg.. 102)
- 3.10.2 Cartographic Design and Generalization (Pg.. 103)
- 3.10.3 Topographic and Thematic Cartography (Pg.. 103)
- 3.10.4 Cartographic Data Models and Standards (Pg.. 103)

3.11 Photogrammetry (FOT) (Pg.. 104)
- 3.11.1 Photogrammetric Fundamentals (Pg.. 104)
- 3.11.2 Aerial Triangulation and Georeferencing (Pg.. 104)
- 3.11.3 Digital Photogrammetric Products (Pg.. 105)
- 3.11.4 UAV and Close-Range Photogrammetry (Pg.. 105)

3.12 Geographic Information Systems (SIG) (Pg.. 105)
- 3.12.1 GIS Fundamentals and Data Models (Pg.. 106)
- 3.12.2 Spatial Analysis and Geoprocessing (Pg.. 106)
- 3.12.3 GIS Data Acquisition and Integration (Pg.. 106)
- 3.12.4 GIS Applications in Civil Engineering (Pg.. 107)

3.13 Remote Sensing (TLD) (Pg.. 107)
- 3.13.1 Remote Sensing Fundamentals (Pg.. 107)
- 3.13.2 Digital Image Processing (Pg.. 107)
- 3.13.3 Active Remote Sensing: LiDAR and Radar (Pg.. 108)
- 3.13.4 Remote Sensing Applications in Civil Engineering (Pg.. 108)

3.14 Transportation Systems Analysis and Modeling (TSA) (Pg.. 109)
- 3.14.1 Transportation Systems Fundamentals (Pg.. 109)
- 3.14.2 Transportation Network Modeling (Pg.. 109)
- 3.14.3 Transportation Simulation Methods (Pg.. 109)

- 3.14.4 Optimization for Transportation (Pg.. 110)
- 3.14.5 Data Analytics for Transportation (Pg.. 110)

3.15 Urban and Regional Transportation Planning (UTP) (Pg.. 110)

- 3.15.1 Land Use and Transportation Integration (Pg.. 111)
- 3.15.2 Regional Transportation Planning (Pg.. 111)
- 3.15.3 Transit-Oriented Development (Pg.. 111)
- 3.15.4 Active Transportation Planning (Pg.. 112)
- 3.15.5 Parking and Curb Space Management (Pg.. 112)

3.16 Transportation Policy, Law, and Governance (TPL) (Pg.. 112)

- 3.16.1 Transportation Policy Frameworks (Pg.. 112)
- 3.16.2 Transportation Law and Regulation (Pg.. 113)
- 3.16.3 Environmental Review and Permitting (Pg.. 113)
- 3.16.4 Transportation Equity and Accessibility (Pg.. 113)
- 3.16.5 Institutional Governance of Transportation (Pg.. 114)

3.17 Sustainable and Resilient Mobility (SMT) (Pg.. 114)

- 3.17.1 Transportation Emissions and Decarbonization (Pg.. 114)
- 3.17.2 Electrification and Alternative Fuels (Pg.. 115)
- 3.17.3 Climate Resilience of Transportation Infrastructure (Pg.. 115)
- 3.17.4 Noise and Air Quality Mitigation (Pg.. 115)
- 3.17.5 Life-Cycle Sustainability Assessment (Pg.. 116)

3.18 Transportation Project Management and Professional Practice (TPM) (Pg.. 116)

- 3.18.1 Transportation Project Delivery Methods (Pg.. 116)
- 3.18.2 Cost Estimating and Scheduling (Pg.. 116)
- 3.18.3 Construction Management for Transportation Projects (Pg.. 117)
- 3.18.4 Stakeholder Engagement (Pg.. 117)
- 3.18.5 Professional Ethics and Practice (Pg.. 117)

3.1 Pavement and Highway Engineering (TIE)

This knowledge area encompasses pavement materials characterization, design, evaluation, and management, and road and bridge asset management.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 3.1.1 Pavement Materials and Characterization (Pg.. 82)	1	1
⭐ 3.1.2 Pavement Design and Management (Pg.. 82)	1	1
⭐ 3.1.3 Pavement Condition Evaluation and Maintenance Planning (Pg.. 83)	1	1
⭐ 3.1.4 Road and Bridge Asset Management (Pg.. 83)	1	1

Table 3.1: List of KUs in the Pavement and Highway Engineering area.

3.1.1 TIE/Pavement Materials and Characterization (Core Tier1: 1 hr, Core Tier2: 1 hr)

Pavement types, asphalt and aggregate properties, subgrade characterization, and sustainable pavement technologies.

Topics:

Core

- Pavement types and structural components
- Asphalt binder and mixture properties
- Aggregate properties and gradation requirements
- Subgrade characterization and stabilization
- Sustainable pavement technologies and recycling

Learning Outcomes:

Core:

1. Identify pavement types and describe their structural functions [Familiarity]
2. Characterize asphalt binders and design asphalt mixtures [Assessment]
3. Evaluate aggregate quality for pavement applications [Usage]
4. Assess subgrade strength and specify stabilization treatments [Assessment]
5. Incorporate sustainable practices and recycled materials in pavement design [Familiarity]

3.1.2 TIE/Pavement Design and Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Traffic load and design parameter determination, flexible and rigid pavement design, mechanistic-empirical methods, performance prediction, rehabilitation, and pavement management systems.

Topics:

Core

- Traffic load characterization and equivalent single axle load (ESAL) computation
- Design reliability, serviceability, and drainage/environmental factors in pavement design
- Flexible pavement design using empirical methods

- Rigid pavement design and joint systems
- Mechanistic-empirical pavement design methods
- Pavement performance prediction and distress mechanisms
- Rehabilitation strategies and overlay design
- Pavement management systems and life-cycle cost analysis

Learning Outcomes:

Core:

1. Compute the design equivalent single axle load (ESAL) from traffic composition and growth projections [Usage]
2. Determine design reliability, serviceability, and drainage/environmental parameters for flexible and rigid pavement design [Assessment]
3. Design flexible pavements using AASHTO or equivalent methods [Assessment]
4. Proportion rigid pavement thickness and design joint spacing [Usage]
5. Apply mechanistic-empirical methods for pavement design [Usage]
6. Predict pavement performance and identify distress mechanisms [Assessment]
7. Select appropriate rehabilitation strategies and design overlays [Usage]
8. Implement pavement management systems and perform life-cycle analysis [Assessment]

3.1.3 TIE/Pavement Condition Evaluation and Maintenance Planning (Core Tier1: 1 hr, Core Tier2: 1 hr)

Surface distress and roughness evaluation, structural evaluation using deflection testing, remaining service life estimation, and maintenance and rehabilitation decision-making for in-service pavements.

Topics:

Core

- Visual distress surveys and pavement condition index (PCI) computation
- Pavement roughness measurement and the international roughness index (IRI)
- Structural evaluation using deflection testing (falling weight deflectometer, Benkelman beam)
- Backcalculation of pavement layer moduli and structural capacity assessment
- Remaining service life estimation and rehabilitation treatment selection
- Maintenance and rehabilitation program planning and scheduling

Learning Outcomes:

Core:

1. Conduct visual distress surveys and compute the pavement condition index (PCI) [Usage]
2. Explain pavement roughness measurement methods and interpret the international roughness index [Familiarity]
3. Perform structural evaluation of in-service pavements using deflection testing methods [Usage]
4. Backcalculate pavement layer moduli from deflection basin data [Assessment]
5. Estimate the remaining service life of a pavement and select an appropriate treatment [Assessment]
6. Develop maintenance and rehabilitation program plans and schedules [Usage]

3.1.4 TIE/Road and Bridge Asset Management (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles and methods for inventorying, inspecting, assessing the condition of, and prioritizing preservation for road and bridge networks throughout their life cycle.

Topics:

Core

- Inventory, inspection, and condition assessment of roads and bridges
- Condition indices, deterioration models, and prioritization criteria for maintenance and rehabilitation programs
- Life-cycle cost analysis and budgeting for road and bridge network preservation

Learning Outcomes:

Core:

1. Describe the fundamentals of an infrastructure asset management system for roads and bridges [Familiarity]
2. Apply condition indices and prioritization criteria to plan maintenance and rehabilitation actions for a road or bridge network [Usage]
3. Analyze life-cycle cost to budget preservation programs for road and bridge infrastructure [Assessment]

3.2 Geometric Design Engineering (GDE)

This knowledge area covers the geometric design of highways, streets, and intersections: design controls and criteria, horizontal and vertical alignment, cross-section and roadside design, at-grade intersections and interchanges, and context-sensitive, multimodal design practice.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.2.1 Design Controls and Criteria (Pg.. 84)	Elective	
3.2.2 Horizontal Alignment Design (Pg.. 84)	Elective	
3.2.3 Vertical Alignment Design (Pg.. 85)	Elective	
3.2.4 Cross-Section Elements and Roadside Design (Pg.. 85)	Elective	
3.2.5 At-Grade Intersections and Interchanges (Pg.. 86)	Elective	
3.2.6 Context-Sensitive and Multimodal Design (Pg.. 86)	Elective	

Table 3.2: List of KUs in the Geometric Design Engineering area.

3.2.1 GDE/Design Controls and Criteria

Design vehicle and driver performance characteristics, functional classification and design domain, design speed selection, and the design exception process that together govern every subsequent geometric design decision.

Topics:

Core

- Design vehicle types and turning template characteristics
- Driver performance characteristics: perception-reaction time and eye/object height
- Functional classification of highways and streets and its relation to design criteria
- Design speed selection and its relationship to operating speed
- Design domain concept and flexible design criteria ranges
- Design exception process for substandard criteria

Learning Outcomes:

Core:

1. Select an appropriate design vehicle and apply its turning template to a layout [Familiarity]
2. Apply driver performance parameters (perception-reaction time, eye/object height) in design computations [Usage]
3. Determine the functional classification of a facility and the design criteria it implies [Assessment]
4. Select a design speed consistent with context, function, and operating speed expectations [Assessment]
5. Explain the design domain concept and its use in flexible design [Familiarity]
6. Document a design exception for a criterion that cannot be met [Usage]

3.2.2 GDE/Horizontal Alignment Design

Design of horizontal curves and their transitions, superelevation, and the sight-distance and comfort criteria that govern safe horizontal alignment.

Topics:

Core

- Simple circular curve geometry and layout
- Spiral transition curves and their application

- Superelevation design, rates, and runoff/transition lengths
- Side friction factors and minimum radius determination
- Horizontal sight distance and sight obstructions on curves
- Compound and reverse curve design considerations

Learning Outcomes:
Core:

1. Design simple circular horizontal curves for a given design speed [Usage]
2. Apply spiral transition curves where required by design speed and curvature [Assessment]
3. Design superelevation rates and transition/runoff lengths for a horizontal curve [Assessment]
4. Determine minimum curve radius from side friction and superelevation limits [Usage]
5. Verify horizontal sight distance and identify sight obstructions along a curve [Assessment]
6. Evaluate compound and reverse curve layouts against design guidance [Familiarity]

3.2.3 GDE/Vertical Alignment Design

Design of grades and vertical curves, and the stopping, passing, and vertical-clearance criteria that determine safe and comfortable vertical alignment.
Topics:
Core

- Maximum and minimum grade control and critical length of grade
- Crest vertical curve design for stopping sight distance
- Sag vertical curve design for headlight and comfort criteria
- Stopping sight distance computation and application
- Passing sight distance on two-lane highways
- Vertical clearance requirements at structures and underpasses

Learning Outcomes:
Core:

1. Apply grade control criteria including critical length of grade for trucks [Assessment]
2. Design crest vertical curves satisfying stopping sight distance [Assessment]
3. Design sag vertical curves satisfying headlight and comfort criteria [Assessment]
4. Compute stopping sight distance for a given design speed and grade [Usage]
5. Determine passing sight distance requirements on two-lane highways [Usage]
6. Verify vertical clearance at structures against design standards [Familiarity]

3.2.4 GDE/Cross-Section Elements and Roadside Design

Design of travel lanes, shoulders, medians, and other cross-section elements, and the roadside design, clear-zone, and barrier criteria that protect errant vehicles.
Topics:
Core

- Lane and shoulder width selection by functional class and context
- Median types, widths, and median barrier warrants
- Cross slope, superelevation transition, and drainage considerations
- Clear zone width determination and roadside hazard rating
- Roadside barrier selection, placement, and end treatments
- Sidewalk, bike lane, and buffer cross-section design

Learning Outcomes:
Core:

1. Select lane and shoulder widths appropriate to functional class and context [Usage]
2. Determine median type, width, and barrier warrant for a given facility [Assessment]
3. Explain cross slope and drainage requirements in cross-section design [Familiarity]
4. Determine clear zone width from roadside hazard rating and design speed [Assessment]
5. Select and place roadside barriers and end treatments [Usage]
6. Design sidewalk, bike lane, and buffer cross-sections for a complete street [Assessment]

3.2.5 GDE/At-Grade Intersections and Interchanges

Geometric design of at-grade intersection channelization and turning lanes, and the selection and ramp/weaving design of grade-separated interchanges.
Topics:
Core

- At-grade intersection types and alignment/skew considerations
- Channelization and turning lane design (left/right turn lanes)
- Intersection sight distance and approach sight triangles
- Interchange types and selection criteria (diamond, cloverleaf, directional)
- Ramp geometric design and gore area treatment
- Weaving section geometry and auxiliary lane design

Learning Outcomes:
Core:

1. Select an at-grade intersection type and alignment appropriate to approach conditions [Assessment]
2. Design channelization and turning lanes for an at-grade intersection [Usage]
3. Verify intersection sight distance against approach sight triangle criteria [Usage]
4. Select an interchange type appropriate to traffic, right-of-way, and terrain constraints [Assessment]
5. Design ramp geometry and gore area treatments [Usage]
6. Analyze weaving section geometry and auxiliary lane requirements [Assessment]

3.2.6 GDE/Context-Sensitive and Multimodal Design

Context-sensitive design practice and complete-streets principles for balancing multimodal users, together with the three-dimensional coordination of horizontal and vertical alignment.
Topics:
Core

- Context-sensitive design process and stakeholder-based criteria flexibility
- Complete streets principles and multimodal accommodation
- Traffic calming elements for urban and residential streets
- Three-dimensional coordination of horizontal and vertical alignment
- Aesthetic and environmental considerations in geometric design
- Access management and driveway spacing criteria

Learning Outcomes:
Core:

1. Explain the context-sensitive design process and when design flexibility is appropriate [Familiarity]
2. Apply complete streets principles to accommodate multiple travel modes [Usage]
3. Select traffic calming elements appropriate to an urban or residential context [Assessment]
4. Coordinate horizontal and vertical alignment for a three-dimensionally consistent design [Assessment]
5. Consider aesthetic and environmental factors in geometric design decisions [Familiarity]
6. Apply access management criteria to driveway and intersection spacing [Usage]

3.3 Transportation Engineering (TRE)

This knowledge area encompasses transportation planning, demand forecasting, economic appraisal and financing, freight and logistics, and public transit systems planning.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.3.1 Transportation Planning and Economics (Pg.. 87)	Elective	
3.3.2 Transportation Economics and Finance (Pg.. 87)	Elective	
3.3.3 Freight Transportation and Logistics (Pg.. 88)	Elective	
3.3.4 Public Transit Systems Planning (Pg.. 88)	Elective	

Table 3.3: List of KUs in the Transportation Engineering area.

3.3.1 TRE/Transportation Planning and Economics

Principles of transportation planning, demand forecasting, project evaluation, and economic analysis of transportation investments.

Topics:

Core

- Transportation planning process and institutional framework
- Travel demand modeling and forecasting methods
- Four-step travel demand model
- Data collection methods for transportation planning
- Economic evaluation and benefit-cost analysis
- Activity-based modeling and advanced forecasting techniques
- Multimodal transportation planning and integration
- Sustainable transportation and environmental considerations
- Public participation and stakeholder engagement
- Performance measures and system monitoring

Learning Outcomes:

Core:

1. Explain the transportation planning process and institutional relationships [Familiarity]
2. Apply travel demand forecasting methods to predict future travel patterns [Assessment]
3. Implement the four-step travel demand model for regional analysis [Usage]
4. Design data collection programs for transportation studies [Assessment]
5. Conduct benefit-cost analysis for transportation projects [Usage]
6. Utilize activity-based models for advanced travel demand analysis [Assessment]
7. Develop integrated multimodal transportation plans [Usage]
8. Incorporate sustainability principles into transportation planning [Assessment]
9. Facilitate public participation processes in transportation planning [Familiarity]
10. Establish performance measures and monitoring systems for transportation networks [Assessment]

3.3.2 TRE/Transportation Economics and Finance

Economic appraisal methods for transportation projects, infrastructure financing and public-private partnerships, and road pricing and funding mechanisms.

Topics:

Core

- Economic appraisal methods for transportation projects (NPV, IRR, benefit-cost ratio)
- Transportation infrastructure financing and public-private partnerships
- Road pricing, congestion pricing, and value capture mechanisms
- Transit subsidies and funding mechanisms

Learning Outcomes:

Core:

1. Appraise a transportation project using NPV, IRR, and benefit-cost ratio methods [Usage]
2. Describe infrastructure financing mechanisms, including public-private partnerships [Familiarity]
3. Evaluate road pricing and value capture mechanisms for a transportation corridor [Assessment]
4. Explain transit subsidy structures and funding mechanisms [Familiarity]

3.3.3 TRE/Freight Transportation and Logistics

Freight demand modeling, supply chain and logistics network design, intermodal freight terminals, and urban freight distribution.

Topics:

Core

- Freight demand modeling and commodity flow analysis
- Freight supply chain and logistics network design
- Intermodal freight terminals and transfer facilities
- Urban freight distribution and last-mile delivery

Learning Outcomes:

Core:

1. Model freight demand and commodity flows for a region [Usage]
2. Design a logistics network for freight supply chains [Usage]
3. Describe the role of intermodal freight terminals in a logistics network [Familiarity]
4. Propose urban freight distribution strategies to reduce last-mile delivery impacts [Assessment]

3.3.4 TRE/Public Transit Systems Planning

Transit route and network planning, transit mode selection and service design, fare policy and integration, and transit accessibility.

Topics:

Core

- Public transit route and network planning
- Transit mode selection (bus, BRT, light rail, metro) and service design
- Fare policy and multimodal fare integration
- Transit accessibility and first/last-mile connections

Learning Outcomes:

Core:

1. Plan a transit route and network for a given service area [Usage]
2. Select an appropriate transit mode and design its service characteristics [Assessment]
3. Describe fare policy options and multimodal fare integration approaches [Familiarity]
4. Improve transit accessibility through first/last-mile connection strategies [Usage]

3.4 Traffic Engineering (TFE)

This knowledge area encompasses traffic flow theory and capacity analysis, traffic operations and management, intelligent transportation systems, and road safety engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.4.1 Traffic Flow Theory and Capacity Analysis (Pg.. 88)	Elective	
3.4.2 Traffic Operations and Management (Pg.. 89)	Elective	
3.4.3 Intelligent Transportation Systems and Connected Vehicles (Pg.. 89)	Elective	
3.4.4 Road Safety Engineering (Pg.. 90)	Elective	
3.4.5 Traffic Control Devices (Pg.. 90)	Elective	

Table 3.4: List of KUs in the Traffic Engineering area.

3.4.1 TFE/Traffic Flow Theory and Capacity Analysis

Traffic flow fundamentals, highway capacity analysis, level of service, traffic control devices, signal design, and intersection analysis.

Topics:

Core

- Traffic flow characteristics and fundamental relationships
- Highway capacity analysis using HCM methodology

- Level of service concepts and analysis procedures
- Traffic control devices and MUTCD standards
- Signal timing and phasing design
- Intersection capacity and delay analysis

Learning Outcomes:

Core:

1. Explain traffic flow theory and fundamental traffic stream parameters [Familiarity]
2. Perform highway capacity analysis for various facility types [Assessment]
3. Determine level of service for transportation facilities [Usage]
4. Apply MUTCD standards for traffic control device design and placement [Assessment]
5. Design signal timing plans for isolated intersections [Usage]
6. Analyze intersection capacity and calculate control delay [Assessment]

3.4.2 TFE/Traffic Operations and Management

Arterial signal coordination, freeway operations, traffic simulation, incident management, and roundabout design.

Topics:

Core

- Arterial analysis and signal coordination
- Freeway operations and bottleneck analysis
- Traffic simulation and microsimulation modeling
- Incident management and traffic management centers
- Roundabout design and capacity analysis

Learning Outcomes:

Core:

1. Develop coordinated signal systems for arterial corridors [Usage]
2. Evaluate freeway performance and identify operational bottlenecks [Assessment]
3. Utilize traffic simulation models for complex operational analysis [Usage]
4. Implement incident management strategies and traffic management operations [Assessment]
5. Design roundabouts and analyze their operational performance [Usage]

3.4.3 TFE/Intelligent Transportation Systems and Connected Vehicles

Technologies and applications of intelligent transportation systems, connected and autonomous vehicles, and smart mobility solutions.

Topics:

Core

- ITS architecture and system components
- Traffic detection and surveillance technologies
- Advanced traffic management systems
- Traveler information systems and real-time data
- Connected vehicle technologies and V2X communication
- Autonomous vehicle systems and infrastructure requirements
- Adaptive signal control and traffic-responsive systems
- Electronic toll collection and congestion pricing
- Transit signal priority and bus rapid transit systems
- Data analytics and artificial intelligence in transportation

Learning Outcomes:

Core:

1. Explain ITS architecture and identify system components [Familiarity]
2. Select appropriate traffic detection technologies for specific applications [Assessment]
3. Design advanced traffic management system deployments [Usage]
4. Implement traveler information systems and dissemination strategies [Assessment]
5. Describe connected vehicle technologies and communication protocols [Familiarity]
6. Evaluate infrastructure requirements for autonomous vehicle deployment [Assessment]

7. Apply adaptive signal control algorithms for traffic optimization [Usage]
8. Analyze electronic toll collection systems and pricing strategies [Assessment]
9. Integrate transit signal priority in multimodal networks [Usage]
10. Utilize data analytics and AI for transportation system optimization [Assessment]

3.4.4 TFE/Road Safety Engineering

Crash data analysis and high-risk location identification, road safety audits, the Vision Zero safe systems approach, and pedestrian and bicycle safety countermeasures.

Topics:

Core

- Crash data analysis and identification of high-risk locations
- Road safety audits and systematic safety reviews
- Vision Zero and the safe systems approach to street design
- Pedestrian and bicycle safety countermeasures

Learning Outcomes:

Core:

1. Analyze crash data to identify high-risk locations and contributing factors [Assessment]
2. Conduct a road safety audit for a roadway or intersection [Usage]
3. Explain the Vision Zero safe systems approach to street design [Familiarity]
4. Recommend pedestrian and bicycle safety countermeasures for a given location [Usage]

3.4.5 TFE/Traffic Control Devices

Classification, design, and placement of traffic signs and pavement markings, and the warrant analysis, phasing, detection, and equipment decisions behind traffic signal installations.

Topics:

Core

- Classification and design of regulatory, warning, and guide signs
- Sign placement, sizing, and retroreflectivity standards
- Pavement marking types, materials, and placement standards
- Traffic signal warrant analysis and justification studies
- Signal phasing, sequencing, and vehicle/pedestrian detection design
- Signal equipment, controllers, and maintenance considerations

Learning Outcomes:

Core:

1. Classify traffic signs according to national/MUTCD-equivalent standards and select the appropriate sign for a given condition [Familiarity]
2. Specify sign placement, size, and retroreflectivity per design standards [Usage]
3. Design a pavement marking plan for a given roadway section [Assessment]
4. Conduct a signal warrant analysis to justify installing a traffic signal [Assessment]
5. Design signal phasing and detection layouts for an intersection [Usage]
6. Evaluate signal equipment and controller requirements for an installation [Familiarity]

3.5 Airport Engineering (APE)

This knowledge area encompasses the planning, geometric and pavement design, operations, and regulatory compliance of airports, from system-level master planning through airside, landside, and safety management.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.5.1 Airport Planning and Demand Forecasting (Pg.. 91)	Elective	
3.5.2 Airside Geometric Design (Pg.. 91)	Elective	
3.5.3 Airfield Pavement Design and Evaluation (Pg.. 91)	Elective	
3.5.4 Airfield Drainage, Lighting, and Visual Aids (Pg.. 92)	Elective	
3.5.5 Terminal and Landside Design (Pg.. 92)	Elective	
3.5.6 Airspace and Air Traffic Operations (Pg.. 92)	Elective	
3.5.7 Airport Safety, Security, and Regulation (Pg.. 93)	Elective	

Table 3.5: List of KUs in the Airport Engineering area.

3.5.1 APE/Airport Planning and Demand Forecasting

Airport master planning process, site selection, integration within regional airport systems, aviation demand forecasting, and airport capacity analysis.

Topics:

Core

- Airport master planning process and site selection
- Airport system planning within the regional and national context
- Aviation demand forecasting methods
- Airport capacity analysis and level of service

Learning Outcomes:

Core:

1. Describe the airport master planning process and site selection criteria [Familiarity]
2. Integrate an airport within a regional airport system plan [Usage]
3. Forecast aviation demand using established methods [Usage]
4. Conduct airport capacity analysis and evaluate level of service [Assessment]

3.5.2 APE/Airside Geometric Design

Aerodrome reference code classification, runway orientation, geometric design of runways and taxiways, safety area separations, and apron layout.

Topics:

Core

- Aerodrome reference code and airport reference code (ARC) classification
- Runway orientation analysis and wind rose evaluation
- Runway and taxiway geometric design standards
- Safety area separations, runway/taxiway strips, and obstacle-free zones
- Apron and aircraft holding bay geometric design

Learning Outcomes:

Core:

1. Classify an aerodrome according to its reference code [Familiarity]
2. Determine runway orientation from wind rose analysis [Usage]
3. Design runway and taxiway geometry following FAA/ICAO standards [Assessment]
4. Verify required safety area separations and obstacle-free zones [Assessment]
5. Lay out aprons and aircraft holding bays [Usage]

3.5.3 APE/Airfield Pavement Design and Evaluation

Flexible and rigid airfield pavement design, layered elastic and finite element design methods, pavement and aircraft classification numbers, and pavement evaluation and strengthening.

Topics:

Core

- Flexible and rigid airfield pavement design methods
- Layered elastic design using the FAA FAARFIELD method
- Pavement classification number (PCN) and aircraft classification number (ACN)

- Airfield pavement evaluation and strengthening overlay design

Learning Outcomes:

Core:

1. Design flexible and rigid airfield pavements for specified aircraft loading [Assessment]
2. Apply the FAA FAARFIELD method to size airfield pavement layers [Usage]
3. Compute pavement and aircraft classification numbers (PCN/ACN) [Usage]
4. Evaluate in-service airfield pavement condition and design strengthening overlays [Assessment]

3.5.4 APE/Airfield Drainage, Lighting, and Visual Aids

Airfield surface and subsurface drainage design, airfield lighting systems and visual aids, pavement marking and signage standards, and siting constraints for navigational aids.

Topics:

Core

- Airfield surface and subsurface drainage design
- Airfield lighting systems and visual aids
- Pavement marking and signage standards
- Siting constraints imposed by navigational aids

Learning Outcomes:

Core:

1. Design airfield surface and subsurface drainage systems [Usage]
2. Describe airfield lighting systems and visual aid requirements [Familiarity]
3. Apply pavement marking and signage standards [Usage]
4. Explain siting constraints imposed by navigational aids [Familiarity]

3.5.5 APE/Terminal and Landside Design

Passenger terminal sizing and level-of-service standards, landside access and curbside design, parking facility planning, and air cargo terminal design.

Topics:

Core

- Passenger terminal sizing and level-of-service standards
- Landside access, curbside, and ground transportation design
- Parking facility planning and sizing
- Air cargo terminal design

Learning Outcomes:

Core:

1. Size a passenger terminal using level-of-service standards [Usage]
2. Design landside access and curbside facilities [Usage]
3. Plan parking facilities to meet projected demand [Usage]
4. Describe the functional requirements of an air cargo terminal [Familiarity]

3.5.6 APE/Airspace and Air Traffic Operations

Fundamentals of airspace structure and procedure design, air traffic control fundamentals, airport and airspace capacity and delay analysis, and simulation tools.

Topics:

Core

- Airspace structure and basic procedure design
- Air traffic control fundamentals and separation standards
- Airport and airspace capacity and delay analysis
- Airfield and airspace simulation tools

Learning Outcomes:

Core:

1. Explain airspace structure and basic procedure design [Familiarity]
2. Describe air traffic control fundamentals and separation standards [Familiarity]

3. Analyze airport and airspace capacity and delay [Assessment]
4. Utilize simulation tools to evaluate airfield and airspace performance [Usage]

3.5.7 APE/Airport Safety, Security, and Regulation

Regulatory compliance under ICAO Annex 14 and FAA Part 139, safety management systems, wildlife hazard management, aviation security fundamentals, and airport environmental management.

Topics:

Core

- ICAO Annex 14 and FAA Part 139 regulatory compliance
- Safety management systems (SMS)
- Wildlife hazard management
- Aviation security (AVSEC) fundamentals
- Airport environmental management (noise and emissions)

Learning Outcomes:

Core:

1. Explain ICAO Annex 14 and FAA Part 139 regulatory requirements [Familiarity]
2. Implement a safety management system (SMS) framework [Usage]
3. Develop a wildlife hazard management plan [Usage]
4. Describe aviation security (AVSEC) fundamentals [Familiarity]
5. Assess airport environmental impacts related to noise and emissions [Assessment]

3.6 Railway Engineering (RWE)

This knowledge area encompasses the alignment, track structure, signaling, electrification, rolling stock fundamentals, capacity, and station design of railway systems.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.6.1 Railway Alignment Design (Pg.. 93)	Elective	
3.6.2 Track Structure Design (Pg.. 94)	Elective	
3.6.3 Railway Signaling and Train Control (Pg.. 94)	Elective	
3.6.4 Railway Electrification (Pg.. 94)	Elective	
3.6.5 Rolling Stock Fundamentals (Pg.. 95)	Elective	
3.6.6 Railway Capacity and Operations (Pg.. 95)	Elective	
3.6.7 Railway Station and Terminal Design (Pg.. 95)	Elective	

Table 3.6: List of KUs in the Railway Engineering area.

3.6.1 RWE/Railway Alignment Design

Horizontal and vertical alignment design for railway track, superelevation and transition curves, track gauge and kinematic envelope, and alignment design criteria by service type.

Topics:

Core

- Horizontal alignment and curve design for railway track
- Vertical alignment and grade design for railway track
- Superelevation (cant) and transition curve design
- Track gauge and kinematic envelope (clearance) standards
- Alignment design criteria by service type (freight, passenger, high-speed)

Learning Outcomes:

Core:

1. Design horizontal alignment and curves for a railway track [Usage]
2. Determine vertical alignment and grades for a railway track [Usage]
3. Compute superelevation and transition curve lengths for a design speed [Assessment]
4. Describe track gauge standards and kinematic envelope requirements [Familiarity]

5. Select alignment design criteria appropriate to the service type [Usage]

3.6.2 RWE/Track Structure Design

Track superstructure components, railway subgrade and trackbed design, rail jointing and continuous welded rail, and track drainage.

Topics:

Core

- Track superstructure components: rail, sleepers, and ballast
- Railway subgrade and trackbed design
- Rail jointing methods and continuous welded rail
- Track drainage design

Learning Outcomes:

Core:

1. Identify track superstructure components and describe their functions [Familiarity]
2. Design the railway subgrade and trackbed for expected loading [Usage]
3. Explain rail jointing methods and continuous welded rail behavior [Familiarity]
4. Develop a track drainage design [Usage]

3.6.3 RWE/Railway Signaling and Train Control

Fundamentals of railway signaling systems, interlocking principles, automatic train protection and control, and fixed-block and moving-block operation.

Topics:

Core

- Fundamental railway signaling systems
- Interlocking principles for safe train movements
- Automatic train protection and control (ATP/ATC) fundamentals
- Fixed-block and moving-block operating systems

Learning Outcomes:

Core:

1. Describe fundamental railway signaling systems [Familiarity]
2. Explain interlocking principles for safe train movements [Familiarity]
3. Summarize automatic train protection and control fundamentals [Familiarity]
4. Compare fixed-block and moving-block operating principles and their effect on capacity [Assessment]

3.6.4 RWE/Railway Electrification

Fundamentals of overhead catenary and third-rail electrification systems, traction substations, and power supply arrangements for railways.

Topics:

Core

- Overhead catenary system fundamentals
- Third-rail electrification systems
- Traction substations
- Power supply arrangements and voltage standards

Learning Outcomes:

Core:

1. Describe overhead catenary system components and function [Familiarity]
2. Explain third-rail electrification and its application constraints [Familiarity]
3. Outline the role of traction substations in a railway power system [Familiarity]
4. Identify power supply arrangements and applicable voltage standards [Familiarity]

3.6.5 RWE/Rolling Stock Fundamentals

Wheel-rail interaction, loading and kinematic gauges, basic vehicle dynamics, and rolling stock types.
Topics:
Core

- Wheel-rail interaction and contact mechanics fundamentals
- Loading gauge and kinematic envelope
- Basic vehicle dynamics: hunting, stability, and ride quality
- Rolling stock types for freight, passenger, and transit service

Learning Outcomes:
Core:

1. Explain wheel-rail interaction and contact mechanics fundamentals [Familiarity]
2. Apply loading gauge constraints to infrastructure clearance design [Usage]
3. Describe basic vehicle dynamics phenomena affecting ride quality and stability [Familiarity]
4. Classify rolling stock types by service and operating requirements [Familiarity]

3.6.6 RWE/Railway Capacity and Operations

Railway line and network capacity analysis, timetabling methods, operations planning, and train dispatching.
Topics:
Core

- Railway line and network capacity analysis
- Timetabling methods and conflict resolution
- Operations planning for freight and passenger service
- Train dispatching and control center operations

Learning Outcomes:
Core:

1. Analyze railway line and network capacity [Assessment]
2. Develop a conflict-free railway timetable [Usage]
3. Plan freight and passenger railway operations [Usage]
4. Describe train dispatching and control center functions [Familiarity]

3.6.7 RWE/Railway Station and Terminal Design

Passenger station and platform design, freight terminal and yard design, and accessibility and multimodal integration at railway facilities.
Topics:
Core

- Passenger station design fundamentals
- Platform design, clearances, and passenger flow
- Freight terminal and yard design
- Accessibility and multimodal integration at railway facilities

Learning Outcomes:
Core:

1. Design a passenger railway station for projected demand [Usage]
2. Size platforms and clearances for projected passenger flow [Usage]
3. Describe freight terminal and yard design principles [Familiarity]
4. Integrate accessibility and multimodal connections into a railway station design [Usage]

3.7 Port Engineering (PTE)

This knowledge area encompasses the planning, maritime hydraulics, coastal and berthing structures, dredging, cargo handling, and operations and safety of port facilities.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.7.1 Port Planning (Pg.. 96)	Elective	
3.7.2 Maritime Hydraulics for Ports (Pg.. 96)	Elective	
3.7.3 Breakwater and Coastal Structures (Pg.. 96)	Elective	
3.7.4 Berth and Quay Design (Pg.. 97)	Elective	
3.7.5 Dredging and Bathymetry (Pg.. 97)	Elective	
3.7.6 Cargo Handling and Yard Design (Pg.. 97)	Elective	
3.7.7 Port Operations, Safety, and Environmental Management (Pg.. 98)	Elective	

Table 3.7: List of KUs in the Port Engineering area.

3.7.1 PTE/Port Planning

Port master planning, site selection, port system planning, and cargo and vessel traffic demand forecasting.

Topics:

Core

- Port master planning process
- Site selection criteria for port development
- Port system planning within national and regional logistics networks
- Cargo and vessel traffic demand forecasting

Learning Outcomes:

Core:

1. Develop a port master plan [Usage]
2. Evaluate candidate sites for port development [Assessment]
3. Describe how a port fits within a national or regional logistics network [Familiarity]
4. Forecast cargo and vessel traffic demand [Usage]

3.7.2 PTE/Maritime Hydraulics for Ports

Wave analysis, tide and current characterization, harbor agitation and resonance, and design metocean conditions for port facilities.

Topics:

Core

- Wave generation, propagation, and transformation analysis
- Tide and current characterization for port design
- Harbor agitation and resonance (seiche) analysis
- Design metocean conditions and return-period selection

Learning Outcomes:

Core:

1. Analyze wave generation, propagation, and transformation at a port site [Usage]
2. Characterize tides and currents relevant to port design [Familiarity]
3. Assess harbor agitation and resonance risk for a proposed layout [Assessment]
4. Select design metocean conditions for a given return period [Usage]

3.7.3 PTE/Breakwater and Coastal Structures

Breakwater design, revetments and shore protection, armor layer stability, and rubble-mound versus vertical breakwater selection.

Topics:

Core

- Breakwater design fundamentals
- Revetments and shore protection works
- Armor layer stability and unit sizing
- Rubble-mound versus vertical breakwater selection

Learning Outcomes:
Core:
1. Design a breakwater cross-section for specified wave conditions [Usage]
2. Describe revetment and shore protection alternatives [Familiarity]
3. Size armor layer units for hydraulic stability [Usage]
4. Select between rubble-mound and vertical breakwater types for a given site [Assessment]

3.7.4 PTE/Berth and Quay Design

Quay wall design, berth dimensioning, mooring systems, and fender system selection and design.
Topics:
Core
- Quay wall design (gravity, sheet pile, and piled structures)
- Berth dimensioning for design vessel classes
- Mooring systems and bollard layout
- Fender system selection and energy absorption design

Learning Outcomes:
Core:
1. Design a quay wall for specified soil and loading conditions [Assessment]
2. Dimension a berth for a design vessel class [Usage]
3. Lay out a mooring system and bollard arrangement [Usage]
4. Specify a fender system based on berthing energy absorption requirements [Assessment]

3.7.5 PTE/Dredging and Bathymetry

Access channel design, dredging methods, disposal of dredged material, and bathymetric survey principles.
Topics:
Core
- Access channel and turning basin design
- Dredging equipment and methods selection
- Disposal and beneficial reuse of dredged material
- Bathymetric survey principles and data processing

Learning Outcomes:
Core:
1. Design an access channel and turning basin for a design vessel [Usage]
2. Select appropriate dredging equipment and methods for given site conditions [Assessment]
3. Evaluate disposal and beneficial reuse options for dredged material [Familiarity]
4. Process bathymetric survey data to support channel design [Usage]

3.7.6 PTE/Cargo Handling and Yard Design

Cargo handling equipment selection, container and bulk cargo yard layout, and container terminal design.
Topics:
Core
- Cargo handling equipment (ship-to-shore cranes, yard cranes, conveyors)
- Yard layout and storage capacity planning
- Container terminal design and throughput sizing
- Bulk and break-bulk cargo facility design

Learning Outcomes:
Core:
1. Select cargo handling equipment appropriate to a given cargo type [Familiarity]
2. Plan yard layout and storage capacity for projected throughput [Usage]
3. Size a container terminal for projected throughput [Usage]
4. Describe design requirements for bulk and break-bulk cargo facilities [Familiarity]

3.7.7 PTE/Port Operations, Safety, and Environmental Management

Terminal capacity and throughput analysis, intermodal integration with logistics chains, ISPS Code security requirements, and port environmental management.

Topics:

Core

- Terminal capacity and throughput analysis
- Intermodal integration with inland logistics chains
- Port facility security under the ISPS Code
- Port environmental management and sustainability

Learning Outcomes:

Core:

1. Analyze terminal capacity and throughput [Assessment]
2. Describe intermodal integration with inland logistics chains [Familiarity]
3. Explain port facility security requirements under the ISPS Code [Familiarity]
4. Assess port environmental management and sustainability practices [Assessment]

3.8 Topography (TOP)

This knowledge area covers the fundamental ground-based measurement and positioning techniques civil engineers use to characterize terrain, establish horizontal and vertical control, and set out construction works: measurement theory, planimetry, leveling, surveying instruments, GNSS positioning, topographic mapping, earthwork computations, and construction layout.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.8.1 Surveying Fundamentals and Measurement Theory (Pg.. 98)	Elective	
3.8.2 Planimetry (Pg.. 98)	Elective	
3.8.3 Leveling and Vertical Control (Pg.. 99)	Elective	
3.8.4 Total Stations and Theodolites (Pg.. 99)	Elective	
3.8.5 GNSS Surveying (Pg.. 99)	Elective	
3.8.6 Topographic Mapping and Digital Terrain Models (Pg.. 100)	Elective	
3.8.7 Earthwork Volume Computations (Pg.. 100)	Elective	
3.8.8 Construction Layout and Stakeout Surveying (Pg.. 100)	Elective	

Table 3.8: List of KUs in the Topography area.

3.8.1 TOP/Surveying Fundamentals and Measurement Theory

The role of surveying in civil engineering practice, the distinction between geodetic and plane surveying, and the theory of measurement error that underlies every subsequent surveying technique.

Topics:

Core

- Surveying's role in civil engineering: geodetic vs. plane surveying, and horizontal and vertical control
- Sources and types of measurement error; precision, accuracy, and significant figures
- Units and coordinate systems used in surveying: UTM, local grids, and datums

Learning Outcomes:

Core:

1. Distinguish between geodetic and plane surveying and identify which applies to a given civil engineering project [Familiarity]
2. Propagate and evaluate measurement error in a computed surveying quantity [Usage]

3.8.2 TOP/Planimetry

Horizontal measurement and computation: distance and angle measurement methods and the traverse computations used to establish horizontal control.

Topics:
Core
- Distance measurement methods: taping and electronic distance measurement, and reduction to horizontal
- Horizontal and vertical angle measurement and angular adjustment
- Traverse computation: latitudes, departures, closure, and coordinate adjustment

Learning Outcomes:
Core:
1. Compute traverse closure and adjust traverse coordinates using an accepted method (e.g. the compass rule) [Usage]
2. Determine the coordinates of unknown points from field angle and distance observations [Assessment]

3.8.3 TOP/Leveling and Vertical Control

Methods for determining elevation differences and establishing vertical control, and their application to producing the profiles and cross-sections used in linear infrastructure design.
Topics:
Core
- Differential leveling: benchmarks, backsight/foresight readings, and level circuits
- Trigonometric leveling for indirect elevation determination
- Profile and cross-section leveling for linear infrastructure design

Learning Outcomes:
Core:
1. Perform a differential leveling circuit and compute elevations with error closure within tolerance [Usage]
2. Generate a longitudinal profile and cross-sections from field leveling data [Usage]

3.8.4 TOP/Total Stations and Theodolites

Operation of the electronic surveying instruments used to collect field measurements, and the sources of instrumental error inherent to them.
Topics:
Core
- Total station and theodolite setup, orientation, and field operation
- Electronic distance measurement (EDM) principles and error sources

Learning Outcomes:
Core:
1. Operate a total station to collect horizontal and vertical field measurements [Usage]
2. Explain the sources of instrumental error in total station measurements and how to minimize them [Familiarity]

3.8.5 TOP/GNSS Surveying

Satellite-based positioning methods used in modern surveying practice, from underlying principles through the coordinate transformations needed to use GNSS data on a local project.
Topics:
Core
- GNSS positioning principles: satellite constellations, signals, and error sources
- Static and Real-Time Kinematic (RTK) GNSS surveying methods
- Coordinate reference systems and datum transformations for GNSS data

Learning Outcomes:
Core:
1. Compare static and RTK GNSS surveying methods and identify which fits a given accuracy requirement [Familiarity]
2. Transform GNSS-derived coordinates between reference datums for use in a local project [Usage]

3.8.6 TOP/Topographic Mapping and Digital Terrain Models

Representation of terrain relief and production of topographic maps and digital terrain models from field or GNSS survey data, the direct output of the measurement techniques covered earlier in this knowledge area.

Topics:

Core

- Contour representation and interpretation of terrain relief
- Digital Terrain Model (DTM) generation from field or GNSS survey data
- Topographic map production and cartographic conventions

Learning Outcomes:

Core:

1. Generate a contour map from field survey data [Usage]
2. Build a digital terrain model (DTM) from a point-based topographic survey [Assessment]

3.8.7 TOP/Earthwork Volume Computations

Computation of cut and fill volumes and their use in planning the earthwork balance and haul distances of a linear infrastructure project.

Topics:

Core

- Cut and fill volume computation methods: average end area and prismoidal
- Mass-haul diagrams for earthwork balance and haul distance planning

Learning Outcomes:

Core:

1. Calculate cut and fill volumes for a linear earthwork project from cross-section data [Usage]
2. Construct a mass-haul diagram to plan earthwork balance and haul distances [Usage]

3.8.8 TOP/Construction Layout and Stakeout Surveying

Application of the surveying techniques covered throughout this knowledge area to setting out civil works in the field and verifying as-built geometry against the design.

Topics:

Core

- Stakeout methods for horizontal and vertical alignment of civil works
- As-built survey verification against design geometry

Learning Outcomes:

Core:

1. Stake out a horizontal alignment (e.g. a road centerline or building corner) from design coordinates [Usage]
2. Verify as-built construction geometry against design specifications using survey data [Assessment]

3.9 Geodesy (GEO)

This knowledge area covers the science of measuring and representing the Earth's shape, orientation, and gravity field: geodetic reference systems and datums, control network design and adjustment, physical geodesy, and satellite-based precise positioning.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.9.1 Geodetic Fundamentals and Reference Systems (Pg.. 101)	Elective	
3.9.2 Geodetic Control Networks (Pg.. 101)	Elective	
3.9.3 Physical Geodesy and the Gravity Field (Pg.. 101)	Elective	
3.9.4 Satellite Geodesy and Precise Positioning (Pg.. 102)	Elective	

Table 3.9: List of KUs in the Geodesy area.

3.9.1 GEO/Geodetic Fundamentals and Reference Systems

Earth shape models, geodetic datums, and the coordinate and reference-frame systems that underlie every geodetic measurement.

Topics:

Core

- Earth shape models: the reference ellipsoid and the geoid
- Horizontal geodetic datums and their realization
- Vertical geodetic datums and height reference surfaces
- Global reference frames (ITRF, WGS84) and their realization and maintenance
- Geodetic, geocentric, and projected coordinate systems and conversions between them

Learning Outcomes:

Core:

1. Distinguish the reference ellipsoid from the geoid and explain their respective roles [Familiarity]
2. Select an appropriate horizontal and vertical datum for a given project [Usage]
3. Transform coordinates between global reference frames (e.g. ITRF realizations) [Assessment]
4. Convert coordinates between geodetic, geocentric, and projected coordinate systems [Usage]
5. Explain how a geodetic datum is realized and maintained over time [Familiarity]

3.9.2 GEO/Geodetic Control Networks

Design, adjustment, and accuracy classification of the horizontal and vertical control networks that densify a country's national geodetic framework.

Topics:

Core

- Geodetic control network design: configuration, redundancy, and point selection
- Least-squares network adjustment and error ellipse interpretation
- National geodetic control networks and their institutional maintenance (e.g. Peru's IGN network)
- Control network densification for local and project-level surveys
- Geodetic accuracy standards and classification of control points

Learning Outcomes:

Core:

1. Design a geodetic control network with appropriate configuration and redundancy [Usage]
2. Adjust a geodetic network by least squares and interpret the resulting error ellipses [Assessment]
3. Describe the structure and maintenance of a national geodetic control network [Familiarity]
4. Densify a national control network for a local or project-level survey [Usage]
5. Classify a control point against its applicable geodetic accuracy standard [Assessment]

3.9.3 GEO/Physical Geodesy and the Gravity Field

The Earth's gravity field, geoid determination from gravimetric data, and the distinction between orthometric and ellipsoidal height systems that this field makes necessary.

Topics:

Core

- Gravity field fundamentals and normal gravity formulas
- Geoid models and geoid undulation determination
- Gravimetric surveying methods and instrumentation
- Orthometric versus ellipsoidal height systems and the role of the geoid in converting between them
- Application of geoid undulation to obtain orthometric heights from GNSS data

Learning Outcomes:

Core:

1. Explain the Earth's gravity field and the normal gravity formula [Familiarity]
2. Apply a geoid model to determine geoid undulation at a point [Usage]
3. Conduct a gravimetric survey and process the resulting data [Assessment]
4. Distinguish orthometric from ellipsoidal heights and explain when each is used [Familiarity]

5. Convert ellipsoidal heights from GNSS to orthometric heights using a geoid model [Usage]

3.9.4 GEO/Satellite Geodesy and Precise Positioning

Satellite orbit fundamentals and the precise GNSS positioning techniques -static baseline processing and precise point positioning- used to carry out a geodetic-grade GNSS campaign.

Topics:

Core

- GNSS geodetic positioning: static baseline processing for control-quality accuracy
- Satellite orbit fundamentals and broadcast versus precise ephemerides
- Precise Point Positioning (PPP) principles and applications
- Planning and execution of a geodetic-grade GNSS observation campaign
- GNSS error sources affecting geodetic-grade positioning and their mitigation

Learning Outcomes:

Core:

1. Process static GNSS baselines to achieve control-quality positioning accuracy [Usage]
2. Explain satellite orbit fundamentals and the difference between broadcast and precise ephemerides [Familiarity]
3. Apply Precise Point Positioning to a geodetic observation [Assessment]
4. Plan a geodetic-grade GNSS observation campaign [Usage]
5. Mitigate GNSS error sources affecting geodetic-grade positioning [Assessment]

3.10 Cartography (CAR)

This knowledge area covers the science and design of map production: map projections and coordinate reference systems, cartographic design and generalization, topographic and thematic mapping, and the data models and standards behind digital map products.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.10.1 Map Projections and Coordinate Reference Systems (Pg.. 102)	Elective	
3.10.2 Cartographic Design and Generalization (Pg.. 103)	Elective	
3.10.3 Topographic and Thematic Cartography (Pg.. 103)	Elective	
3.10.4 Cartographic Data Models and Standards (Pg.. 103)	Elective	

Table 3.10: List of KUs in the Cartography area.

3.10.1 CAR/Map Projections and Coordinate Reference Systems

Map projection theory and distortion, the UTM system and local grids, and the criteria for selecting a projection for regional or national mapping.

Topics:

Core

- Map projection theory: developable surfaces and projection families
- The Universal Transverse Mercator (UTM) system and zone conventions
- Projection distortion: conformality, equal-area, and equidistant properties
- Local and national grid systems derived from a base projection
- Criteria for selecting a map projection for a given mapping purpose and extent

Learning Outcomes:

Core:

1. Explain map projection theory and the trade-offs among projection families [Familiarity]
2. Apply the UTM system's zone conventions to a mapping project [Usage]
3. Evaluate the distortion characteristics of a given projection for a mapping task [Assessment]
4. Derive a local grid system from a national base projection [Usage]
5. Select a map projection appropriate to a given purpose and geographic extent [Assessment]

3.10.2 CAR/Cartographic Design and Generalization

Principles of map composition and symbolization, cartographic generalization across scales, and the use of color and visual hierarchy in effective map design.

Topics:

Core

- Map composition elements: title, legend, scale, north arrow, and layout
- Symbolization of point, line, and area features
- Cartographic generalization: simplification, selection, and exaggeration across scales
- Map scale selection and its relationship to feature detail and generalization
- Color theory and visual hierarchy in map design

Learning Outcomes:

Core:

1. Compose a map layout with appropriate title, legend, scale, and north arrow elements [Usage]
2. Design symbolization for point, line, and area features on a map [Assessment]
3. Generalize map content appropriately for a target scale [Assessment]
4. Select an appropriate map scale for a given purpose and level of detail [Familiarity]
5. Apply color theory and visual hierarchy principles to improve map readability [Usage]

3.10.3 CAR/Topographic and Thematic Cartography

Conventions of topographic map series production, the main thematic map types, and the digital production workflows and accuracy standards behind modern map products.

Topics:

Core

- Topographic map series conventions and national mapping grids (e.g. Peru's Carta Nacional)
- Thematic map types: choropleth, isoline, dot-density, and proportional symbol maps
- Digital cartographic production workflows
- Map accuracy standards and positional accuracy testing
- Cartographic metadata documentation

Learning Outcomes:

Core:

1. Explain topographic map series conventions and national mapping grid systems [Familiarity]
2. Select an appropriate thematic map type for a given dataset and message [Usage]
3. Produce a digital cartographic product following a defined production workflow [Usage]
4. Test a map product against an applicable positional accuracy standard [Assessment]
5. Document the metadata of a cartographic product [Familiarity]

3.10.4 CAR/Cartographic Data Models and Standards

Vector and raster data models underlying digital maps, national mapping standards, web mapping/tile services, and the data interoperability and quality control practices that support them.

Topics:

Core

- Vector and raster data models for cartographic products
- National mapping standards and spatial data infrastructure (e.g. Peru's IDEP)
- Web mapping services and tile-based map delivery standards
- Data interoperability standards for exchanging cartographic data
- Quality control procedures for cartographic data production

Learning Outcomes:

Core:

1. Distinguish vector from raster data models and identify when each is appropriate for a cartographic product [Familiarity]
2. Apply a national mapping standard or spatial data infrastructure specification to a mapping project [Usage]
3. Publish a cartographic product as a web map or tile service [Usage]
4. Verify data interoperability when exchanging cartographic data between systems [Assessment]

5. Perform quality control on a cartographic data production workflow [Assessment]

3.11 Photogrammetry (FOT)

This knowledge area covers the extraction of geometric measurements from photographic and digital imagery: photogrammetric fundamentals, aerial triangulation and georeferencing, digital photogrammetric products, and UAV and close-range photogrammetry.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.11.1 Photogrammetric Fundamentals (Pg.. 104)	Elective	
3.11.2 Aerial Triangulation and Georeferencing (Pg.. 104)	Elective	
3.11.3 Digital Photogrammetric Products (Pg.. 105)	Elective	
3.11.4 UAV and Close-Range Photogrammetry (Pg.. 105)	Elective	

Table 3.11: List of KUs in the Photogrammetry area.

3.11.1 FOT/Photogrammetric Fundamentals

Camera geometry and the image-formation model, stereoscopic vision, and the flight and scale planning that precede any photogrammetric acquisition.

Topics:

Core

- Camera geometry: focal length, principal point, and lens distortion
- The central projection image-formation model
- Stereoscopic vision and parallax measurement
- Flight planning: overlap, flying height, and strip layout
- Image scale determination and its relationship to flying height and focal length

Learning Outcomes:

Core:

1. Explain camera geometry and the central projection image-formation model [Familiarity]
2. Measure parallax on a stereo pair to determine relative elevation [Usage]
3. Plan an aerial photography flight with appropriate overlap and flying height [Assessment]
4. Compute image scale from flying height and camera focal length [Usage]
5. Identify lens distortion effects and their correction [Familiarity]

3.11.2 FOT/Aerial Triangulation and Georeferencing

Interior and exterior orientation of photogrammetric imagery, ground control point selection, and the bundle-adjustment aerial triangulation process that ties images together geometrically.

Topics:

Core

- Ground control point selection, measurement, and distribution
- Interior orientation and camera calibration parameters
- Exterior orientation and camera position/attitude determination
- Bundle adjustment for simultaneous multi-image orientation
- Aerial triangulation workflow for large image blocks

Learning Outcomes:

Core:

1. Select and distribute ground control points for a photogrammetric project [Usage]
2. Explain interior orientation and the role of camera calibration parameters [Familiarity]
3. Determine exterior orientation parameters for an acquired image [Assessment]
4. Perform a bundle adjustment over a block of overlapping images [Assessment]
5. Execute an aerial triangulation workflow for a large image block [Usage]

3.11.3 FOT/Digital Photogrammetric Products

Production of digital elevation/surface models, orthophotos, and dense point clouds (including structure-from-motion workflows) from oriented photogrammetric imagery, and the assessment of their accuracy.
Topics:
Core

- Digital Elevation/Surface Model (DEM/DSM) generation from stereo imagery
- Orthophoto production and mosaicking
- Dense point cloud generation from photogrammetric image matching
- Structure-from-Motion (SfM) workflows for unordered image sets
- Accuracy assessment of digital photogrammetric products against ground truth

Learning Outcomes:
Core:

1. Generate a digital elevation/surface model from stereo imagery [Usage]
2. Produce and mosaic an orthophoto from oriented imagery [Assessment]
3. Generate a dense point cloud from photogrammetric image matching [Usage]
4. Apply a Structure-from-Motion workflow to an unordered image set [Assessment]
5. Evaluate the accuracy of a digital photogrammetric product against ground truth [Assessment]

3.11.4 FOT/UAV and Close-Range Photogrammetry

Mission planning, sensors, and processing workflows for drone-based and close-range photogrammetric acquisition, together with the regulatory considerations governing UAV flight.
Topics:
Core

- UAV mission planning: flight paths, overlap, and ground sample distance
- UAV sensors and payloads for photogrammetric acquisition
- Close-range photogrammetry applications (e.g. facade/structure documentation)
- Regulatory considerations for UAV survey operations
- End-to-end UAV photogrammetric processing workflows

Learning Outcomes:
Core:

1. Plan a UAV photogrammetric mission with appropriate overlap and ground sample distance [Usage]
2. Select UAV sensors and payloads appropriate to a photogrammetric task [Familiarity]
3. Apply close-range photogrammetric techniques to document a structure [Assessment]
4. Comply with applicable UAV survey operation regulations [Familiarity]
5. Execute an end-to-end UAV photogrammetric processing workflow [Usage]

3.12 Geographic Information Systems (SIG)

This knowledge area covers the capture, storage, analysis, and application of spatial data in a geographic information system: GIS data models, spatial analysis and geoprocessing, data acquisition and integration, and GIS applications in civil engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.12.1 GIS Fundamentals and Data Models (Pg.. 106)	Elective	
3.12.2 Spatial Analysis and Geoprocessing (Pg.. 106)	Elective	
3.12.3 GIS Data Acquisition and Integration (Pg.. 106)	Elective	
3.12.4 GIS Applications in Civil Engineering (Pg.. 107)	Elective	

Table 3.12: List of KUs in the Geographic Information Systems area.

3.12.1 SIG/GIS Fundamentals and Data Models

Vector and raster spatial data models, spatial database structure, coordinate reference system handling, and attribute data management within a GIS.

Topics:

Core

- Vector data model: points, lines, and polygons, and topology
- Raster data model: cell size, resolution, and raster-vector tradeoffs
- Spatial database structure and spatial indexing
- Coordinate reference system handling and on-the-fly reprojection in a GIS
- Attribute data management and relational joins

Learning Outcomes:

Core:

1. Distinguish vector from raster data models and select the appropriate one for a given dataset [Familiarity]
2. Build a topologically correct vector dataset in a GIS [Usage]
3. Design a spatial database schema for a GIS project [Assessment]
4. Manage coordinate reference systems and reprojection within a GIS project [Usage]
5. Join attribute data to spatial features using relational joins [Usage]

3.12.2 SIG/Spatial Analysis and Geoprocessing

Overlay, proximity, network, and terrain analysis geoprocessing operations, and the spatial interpolation methods used to generate continuous surfaces from sample data.

Topics:

Core

- Overlay analysis: intersection, union, and spatial join operations
- Buffer and proximity analysis
- Network analysis: shortest path, service areas, and allocation
- Terrain analysis from a raster DEM: slope, aspect, and watershed delineation
- Spatial interpolation methods for generating continuous surfaces from sample data

Learning Outcomes:

Core:

1. Perform overlay analysis to combine multiple spatial datasets [Usage]
2. Conduct a buffer/proximity analysis for a siting or impact study [Assessment]
3. Solve a network analysis problem (shortest path, service area, or allocation) [Usage]
4. Derive slope, aspect, and watershed boundaries from a raster DEM [Assessment]
5. Interpolate a continuous surface from point sample data [Usage]

3.12.3 SIG/GIS Data Acquisition and Integration

Methods for capturing and integrating field, GNSS, and remote sensing data into a GIS, and the data quality and metadata practices required for reliable spatial analysis.

Topics:

Core

- Field data capture methods: digitizing, heads-up capture, and mobile GIS
- Integration of GNSS-collected data into a GIS
- Integration of remote sensing imagery and derived products into a GIS
- Data quality standards: positional accuracy, completeness, and lineage
- Spatial data metadata documentation standards

Learning Outcomes:

Core:

1. Capture field data into a GIS using digitizing or mobile GIS tools [Usage]
2. Integrate GNSS-collected data into a GIS dataset [Assessment]
3. Integrate remote sensing-derived products into a GIS analysis [Usage]
4. Evaluate a spatial dataset against applicable data quality standards [Assessment]
5. Document a spatial dataset's metadata following a recognized standard [Familiarity]

3.12.4 SIG/GIS Applications in Civil Engineering

Application of GIS to infrastructure asset mapping, land use and environmental analysis, web GIS and spatial data infrastructure, and GIS-based decision support for civil engineering projects.
Topics:
Core

- Infrastructure asset mapping and inventory in a GIS
- Land use and environmental analysis using GIS
- Web GIS and spatial data infrastructure (SDI) for data sharing
- GIS-based decision support and multi-criteria site selection
- Design of a GIS project workflow from data acquisition to final product

Learning Outcomes:
Core:

1. Build an infrastructure asset inventory in a GIS [Usage]
2. Analyze land use or environmental conditions using GIS layers [Assessment]
3. Publish a dataset through a web GIS or spatial data infrastructure [Usage]
4. Support a site-selection decision using GIS-based multi-criteria analysis [Assessment]
5. Design an end-to-end GIS project workflow for a civil engineering application [Assessment]

3.13 Remote Sensing (TLD)

This knowledge area covers the acquisition and interpretation of information about the Earth's surface from satellite, airborne, and UAV sensors: remote sensing fundamentals, digital image processing, active sensing (LiDAR and radar), and remote sensing applications in civil engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.13.1 Remote Sensing Fundamentals (Pg.. 107)	Elective	
3.13.2 Digital Image Processing (Pg.. 107)	Elective	
3.13.3 Active Remote Sensing: LiDAR and Radar (Pg.. 108)	Elective	
3.13.4 Remote Sensing Applications in Civil Engineering (Pg.. 108)	Elective	

Table 3.13: List of KUs in the Remote Sensing area.

3.13.1 TLD/Remote Sensing Fundamentals

The electromagnetic spectrum and its interaction with Earth surface materials, passive and active sensor types, the resolution concepts that characterize a sensor, and the platforms that carry them.
Topics:
Core

- The electromagnetic spectrum and spectral signatures of Earth surface materials
- Passive versus active sensor types
- Spatial, spectral, temporal, and radiometric resolution concepts
- Satellite, airborne, and UAV remote sensing platforms
- Atmospheric effects on remotely sensed signals

Learning Outcomes:
Core:

1. Explain the electromagnetic spectrum and the spectral signature concept [Familiarity]
2. Distinguish passive from active remote sensing and identify example sensors of each [Familiarity]
3. Select a sensor and platform based on required spatial, spectral, and temporal resolution [Usage]
4. Describe the remote sensing platforms available for a given application [Familiarity]
5. Account for atmospheric effects when interpreting remotely sensed data [Assessment]

3.13.2 TLD/Digital Image Processing

Radiometric and geometric preprocessing of remotely sensed imagery, image enhancement, derived spectral indices, and the image classification techniques used to extract thematic information.

Topics:
Core
- Radiometric correction of remotely sensed imagery
- Geometric correction and orthorectification of imagery
- Image enhancement techniques: contrast stretching and filtering
- Spectral band combinations and indices (e.g. NDVI)
- Supervised and unsupervised image classification

Learning Outcomes:
Core:
1. Apply radiometric correction to a remotely sensed image [Usage]
2. Orthorectify imagery using ground control and a terrain model [Assessment]
3. Enhance an image using contrast stretching and spatial filtering [Usage]
4. Compute spectral indices (e.g. NDVI) from multispectral imagery [Assessment]
5. Classify an image into thematic categories using supervised or unsupervised methods [Assessment]

3.13.3 TLD/Active Remote Sensing: LiDAR and Radar

Operating principles and derived products of LiDAR and synthetic aperture radar, including the InSAR techniques used for ground deformation monitoring.
Topics:
Core
- LiDAR operating principles: ranging, scanning, and point density
- LiDAR-derived products: classified point clouds, DEMs, and canopy models
- Synthetic Aperture Radar (SAR) fundamentals
- Interferometric SAR (InSAR) for ground deformation monitoring
- Point cloud processing and feature extraction from active sensors

Learning Outcomes:
Core:
1. Explain LiDAR operating principles and the factors governing point density [Familiarity]
2. Derive a classified point cloud, DEM, or canopy model from LiDAR data [Usage]
3. Describe Synthetic Aperture Radar fundamentals and its advantages over optical sensing [Familiarity]
4. Monitor ground deformation using InSAR time-series analysis [Assessment]
5. Process and extract features from a point cloud acquired by an active sensor [Usage]

3.13.4 TLD/Remote Sensing Applications in Civil Engineering

Application of remote sensing to land cover and change detection, environmental and hazard monitoring, infrastructure monitoring, and its integration with GIS for engineering decision-making.
Topics:
Core
- Land cover classification and multi-temporal change detection
- Environmental and natural hazard monitoring using remote sensing
- Infrastructure condition and deformation monitoring using remote sensing
- Integration of remote sensing products with GIS for analysis and decision-making
- End-to-end remote sensing application workflows for an engineering project

Learning Outcomes:
Core:
1. Classify land cover and detect multi-temporal change from a satellite image series [Usage]
2. Monitor an environmental or natural hazard condition using remote sensing data [Assessment]
3. Monitor infrastructure condition or deformation using remote sensing techniques [Usage]
4. Integrate remote sensing products into a GIS-based engineering analysis [Assessment]
5. Design an end-to-end remote sensing application workflow for an engineering project [Assessment]

3.14 Transportation Systems Analysis and Modeling (TSA)

This knowledge area encompasses the systems-engineering foundations of transportation, network modeling, simulation methods, optimization techniques, and data analytics applied to transportation problems.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.14.1 Transportation Systems Fundamentals (Pg.. 109)	Elective	
3.14.2 Transportation Network Modeling (Pg.. 109)	Elective	
3.14.3 Transportation Simulation Methods (Pg.. 109)	Elective	
3.14.4 Optimization for Transportation (Pg.. 110)	Elective	
3.14.5 Data Analytics for Transportation (Pg.. 110)	Elective	

Table 3.14: List of KUs in the Transportation Systems Analysis and Modeling area.

3.14.1 TSA/Transportation Systems Fundamentals

Transportation modes and network characteristics, the systems-engineering approach to transportation problems, stakeholders and institutional actors, and performance measurement.

Topics:

Core

- Transportation modes and network characteristics
- Systems-engineering approach to transportation problems
- Stakeholders and institutional actors in transportation systems
- Performance measures and level-of-service concepts for transportation systems

Learning Outcomes:

Core:

1. Describe transportation modes and their network characteristics [Familiarity]
2. Explain the systems-engineering approach applied to transportation problems [Familiarity]
3. Identify stakeholders and institutional actors relevant to a transportation system [Familiarity]
4. Apply performance measures to evaluate a transportation system [Usage]

3.14.2 TSA/Transportation Network Modeling

Graph-based representation of transportation networks, shortest-path and routing algorithms, traffic assignment models, and network connectivity and accessibility measures.

Topics:

Core

- Graph-based representation of transportation networks
- Shortest-path and routing algorithms
- Traffic assignment models (user equilibrium, system optimum)
- Network connectivity and accessibility measures

Learning Outcomes:

Core:

1. Represent a transportation network using graph-based data structures [Usage]
2. Compute shortest paths and routes within a transportation network [Usage]
3. Apply traffic assignment models to estimate link flows [Assessment]
4. Evaluate network connectivity and accessibility [Assessment]

3.14.3 TSA/Transportation Simulation Methods

Microscopic, macroscopic, and mesoscopic simulation fundamentals, simulation model calibration and validation, and scenario analysis using simulation outputs.

Topics:

Core

- Microsimulation fundamentals for traffic and transit systems

- Macroscopic and mesoscopic simulation fundamentals
- Simulation model calibration and validation
- Scenario analysis using simulation outputs

Learning Outcomes:
Core:

1. Describe the fundamentals of microscopic traffic and transit simulation [Familiarity]
2. Explain macroscopic and mesoscopic simulation approaches [Familiarity]
3. Calibrate and validate a simulation model against field data [Usage]
4. Conduct scenario analysis using simulation outputs [Usage]

3.14.4 TSA/Optimization for Transportation

Vehicle routing and scheduling optimization, transportation network design optimization, resource allocation and facility location, and heuristic solution methods.
Topics:
Core

- Vehicle routing and scheduling optimization
- Transportation network design optimization
- Resource allocation and facility location optimization
- Heuristic and metaheuristic solution methods

Learning Outcomes:
Core:

1. Formulate a vehicle routing or scheduling problem as an optimization model [Usage]
2. Solve a transportation network design optimization problem [Usage]
3. Apply resource allocation and facility location methods to a transportation problem [Assessment]
4. Describe heuristic and metaheuristic methods for large-scale transportation optimization [Familiarity]

3.14.5 TSA/Data Analytics for Transportation

Big data sources for transportation, GIS applications, machine learning applications, and data visualization for transportation performance monitoring.
Topics:
Core

- Big data sources for transportation (GPS, sensors, mobile, probe vehicles)
- GIS applications in transportation analysis
- Machine learning applications in transportation
- Data visualization and dashboards for transportation performance

Learning Outcomes:
Core:

1. Identify big data sources available for transportation analysis [Familiarity]
2. Apply GIS tools to analyze transportation data [Usage]
3. Describe machine learning applications in transportation [Familiarity]
4. Develop data visualizations and dashboards for transportation performance monitoring [Usage]

3.15 Urban and Regional Transportation Planning (UTP)

This knowledge area encompasses the integration of land use and transportation, regional transportation planning, transit-oriented development, active transportation planning, and parking and curb management.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.15.1 Land Use and Transportation Integration (Pg.. 111)	Elective	
3.15.2 Regional Transportation Planning (Pg.. 111)	Elective	
3.15.3 Transit-Oriented Development (Pg.. 111)	Elective	
3.15.4 Active Transportation Planning (Pg.. 112)	Elective	
3.15.5 Parking and Curb Space Management (Pg.. 112)	Elective	

Table 3.15: List of KUs in the Urban and Regional Transportation Planning area.

3.15.1 UTP/Land Use and Transportation Integration

The land use-transportation feedback cycle, density and accessibility relationships, corridor-level coordination, and growth management strategies linked to transportation investment.

Topics:

Core

- Land use-transportation feedback cycle
- Density, mix, and accessibility relationships
- Corridor-level land use and transportation coordination
- Growth management strategies linked to transportation investment

Learning Outcomes:

Core:

1. Explain the land use-transportation feedback cycle [Familiarity]
2. Describe the relationship between density, land use mix, and accessibility [Familiarity]
3. Develop a coordinated land use and transportation plan for a corridor [Usage]
4. Outline growth management strategies linked to transportation investment [Familiarity]

3.15.2 UTP/Regional Transportation Planning

The metropolitan planning process, long-range transportation plans, regional travel demand forecasting, and funding and programming.

Topics:

Core

- Metropolitan planning organization (MPO) process
- Long-range transportation plan development
- Regional travel demand forecasting
- Funding and capital improvement programming

Learning Outcomes:

Core:

1. Describe the metropolitan planning organization process [Familiarity]
2. Develop a long-range transportation plan [Usage]
3. Apply regional travel demand forecasting methods [Usage]
4. Program transportation investments into a capital improvement program [Usage]

3.15.3 UTP/Transit-Oriented Development

Transit-oriented development principles, station area planning, density and mix standards, and first/last-mile connections.

Topics:

Core

- Transit-oriented development principles
- Station area planning
- Density and land use mix standards for TOD
- First- and last-mile connections

Learning Outcomes:

Core:

1. Explain transit-oriented development principles [Familiarity]

2. Design a station area plan [Usage]
3. Apply density and land use mix standards for a TOD project [Usage]
4. Integrate first- and last-mile connections into a station area plan [Usage]

3.15.4 UTP/Active Transportation Planning

Pedestrian network planning, bicycle network planning, multi-use trail design, and Safe Routes to School/Transit programs.

Topics:

Core

- Pedestrian network planning
- Bicycle network planning
- Multi-use trail design
- Safe Routes to School/Transit programs

Learning Outcomes:

Core:

1. Plan a pedestrian network for an urban area [Usage]
2. Design a bicycle network and its facilities [Usage]
3. Describe multi-use trail design principles [Familiarity]
4. Develop a Safe Routes to School or Transit program [Usage]

3.15.5 UTP/Parking and Curb Space Management

Parking demand analysis, parking policy and pricing, curb space allocation, and loading/transportation network company (TNC) management.

Topics:

Core

- Parking demand analysis
- Parking policy and pricing strategies
- Curb space allocation among competing uses
- Loading zone and transportation network company (TNC) pick-up/drop-off management

Learning Outcomes:

Core:

1. Conduct a parking demand analysis [Usage]
2. Describe parking policy and pricing strategies [Familiarity]
3. Allocate curb space among competing uses [Usage]
4. Explain loading zone and TNC pick-up/drop-off management strategies [Familiarity]

3.16 Transportation Policy, Law, and Governance (TPL)

This knowledge area encompasses transportation policy frameworks, transportation law and regulation, environmental review and permitting, equity and accessibility, and institutional governance.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.16.1 Transportation Policy Frameworks (Pg.. 112)	Elective	
3.16.2 Transportation Law and Regulation (Pg.. 113)	Elective	
3.16.3 Environmental Review and Permitting (Pg.. 113)	Elective	
3.16.4 Transportation Equity and Accessibility (Pg.. 113)	Elective	
3.16.5 Institutional Governance of Transportation (Pg.. 114)	Elective	

Table 3.16: List of KUs in the Transportation Policy, Law, and Governance area.

3.16.1 TPL/Transportation Policy Frameworks

National transportation policy, policy instruments, performance-based planning, and international policy frameworks.

Topics:
Core
- National transportation policy frameworks
- Policy instruments: regulation, pricing, investment, information
- Performance-based planning and programming
- International transportation policy frameworks

Learning Outcomes:
Core:
1. Describe a national transportation policy framework [Familiarity]
2. Explain the main categories of transportation policy instruments [Familiarity]
3. Apply performance-based planning principles to a transportation program [Usage]
4. Compare international transportation policy frameworks [Familiarity]

3.16.2 TPL/Transportation Law and Regulation

The regulatory framework governing transportation, vehicle and operator regulation, concessions and public-private partnership law, and liability and insurance.
Topics:
Core
- Regulatory framework governing transportation infrastructure and services
- Vehicle and operator regulation
- Concessions and public-private partnership law
- Liability and insurance in transportation projects and operations

Learning Outcomes:
Core:
1. Describe the regulatory framework governing transportation infrastructure and services [Familiarity]
2. Explain vehicle and operator regulation requirements [Familiarity]
3. Analyze a concession or public-private partnership contract [Usage]
4. Outline liability and insurance considerations for a transportation project [Familiarity]

3.16.3 TPL/Environmental Review and Permitting

Environmental impact assessment, the permitting process, mitigation planning, and public consultation for transportation projects.
Topics:
Core
- Environmental impact assessment for transportation projects
- Permitting process and requirements
- Environmental mitigation planning
- Public consultation processes

Learning Outcomes:
Core:
1. Conduct an environmental impact assessment for a transportation project [Usage]
2. Describe the permitting process and its requirements [Familiarity]
3. Develop an environmental mitigation plan [Usage]
4. Facilitate a public consultation process for a transportation project [Usage]

3.16.4 TPL/Transportation Equity and Accessibility

Transportation equity frameworks, accessibility analysis, assessment of impacts on disadvantaged communities, and universal design standards.
Topics:
Core
- Transportation equity frameworks
- Accessibility analysis methods

- Assessment of transportation impacts on disadvantaged communities
- Universal design standards for transportation facilities

Learning Outcomes:

Core:

1. Explain transportation equity frameworks [Familiarity]
2. Conduct an accessibility analysis for a transportation project [Usage]
3. Assess transportation impacts on disadvantaged communities [Assessment]
4. Apply universal design standards to a transportation facility [Usage]

3.16.5 TPL/Institutional Governance of Transportation

Multilevel governance, institutional arrangements, interagency coordination, and performance accountability for transportation systems.

Topics:

Core

- Multilevel governance of transportation systems
- Institutional arrangements for transportation agencies
- Interagency coordination mechanisms
- Performance accountability frameworks

Learning Outcomes:

Core:

1. Describe multilevel governance of transportation systems [Familiarity]
2. Explain institutional arrangements for transportation agencies [Familiarity]
3. Coordinate interagency efforts on a transportation program [Usage]
4. Develop a performance accountability framework for a transportation agency [Usage]

3.17 Sustainable and Resilient Mobility (SMT)

This knowledge area encompasses transportation emissions and decarbonization, electrification and alternative fuels, climate resilience of transportation infrastructure, noise and air quality mitigation, and life-cycle sustainability assessment.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.17.1 Transportation Emissions and Decarbonization (Pg.. 114)	Elective	
3.17.2 Electrification and Alternative Fuels (Pg.. 115)	Elective	
3.17.3 Climate Resilience of Transportation Infrastructure (Pg.. 115)	Elective	
3.17.4 Noise and Air Quality Mitigation (Pg.. 115)	Elective	
3.17.5 Life-Cycle Sustainability Assessment (Pg.. 116)	Elective	

Table 3.17: List of KUs in the Sustainable and Resilient Mobility area.

3.17.1 SMT/Transportation Emissions and Decarbonization

Greenhouse gas inventory methods, decarbonization strategies, modal shift for emissions reduction, and carbon pricing mechanisms.

Topics:

Core

- Greenhouse gas inventory methods for the transportation sector
- Decarbonization strategies for transportation systems
- Modal shift strategies for emissions reduction
- Carbon pricing mechanisms applied to transportation

Learning Outcomes:

Core:

1. Conduct a greenhouse gas inventory for a transportation system [Usage]
2. Describe decarbonization strategies for transportation systems [Familiarity]

3. Evaluate the emissions-reduction impact of a modal shift strategy [Assessment]
4. Explain carbon pricing mechanisms applied to transportation [Familiarity]

3.17.2 SMT/Electrification and Alternative Fuels

Electric vehicle charging infrastructure planning, alternative fuel technologies, fleet electrification strategies, and charging demand forecasting.

Topics:

Core

- Electric vehicle charging infrastructure planning
- Alternative fuel technologies (hydrogen, biofuels, natural gas)
- Fleet electrification strategies
- Charging demand forecasting

Learning Outcomes:

Core:

1. Plan electric vehicle charging infrastructure for a service area [Usage]
2. Describe alternative fuel technologies for transportation [Familiarity]
3. Develop a fleet electrification strategy [Usage]
4. Forecast charging demand for a planning horizon [Usage]

3.17.3 SMT/Climate Resilience of Transportation Infrastructure

Climate risk assessment, adaptation strategies, resilient design standards, and disaster recovery planning for transportation infrastructure.

Topics:

Core

- Climate risk assessment for transportation infrastructure
- Climate adaptation strategies
- Resilient design standards for transportation infrastructure
- Disaster recovery planning for transportation systems

Learning Outcomes:

Core:

1. Conduct a climate risk assessment for a transportation asset [Usage]
2. Describe climate adaptation strategies for transportation infrastructure [Familiarity]
3. Apply resilient design standards to a transportation project [Usage]
4. Develop a disaster recovery plan for a transportation system [Usage]

3.17.4 SMT/Noise and Air Quality Mitigation

Noise impact assessment, air quality impact assessment, mitigation measures, and monitoring program design for transportation facilities.

Topics:

Core

- Noise impact assessment for transportation facilities
- Air quality impact assessment
- Noise and air quality mitigation measures
- Monitoring program design

Learning Outcomes:

Core:

1. Conduct a noise impact assessment for a transportation facility [Usage]
2. Assess the air quality impacts of a transportation project [Assessment]
3. Select appropriate noise and air quality mitigation measures [Usage]
4. Design a noise or air quality monitoring program [Usage]

3.17.5 SMT/Life-Cycle Sustainability Assessment

Life-cycle assessment methods, embodied carbon of materials, infrastructure sustainability rating systems, and incorporating the cost of carbon into decision-making.

Topics:

Core

- Life-cycle assessment methods for transportation infrastructure
- Embodied carbon of transportation construction materials
- Infrastructure sustainability rating systems (Envision, Greenroads)
- Incorporating the cost of carbon into project decision-making

Learning Outcomes:

Core:

1. Describe life-cycle assessment methods for transportation infrastructure [Familiarity]
2. Compute the embodied carbon of transportation construction materials [Usage]
3. Explain how infrastructure sustainability rating systems evaluate a project [Familiarity]
4. Incorporate the cost of carbon into transportation project decision-making [Usage]

3.18 Transportation Project Management and Professional Practice (TPM)

This knowledge area encompasses project delivery methods, cost estimating and scheduling, construction management for transportation projects, stakeholder engagement, and professional ethics and practice.

Knowledge Area (KA)	Core Tier1	Core Tier2
3.18.1 Transportation Project Delivery Methods (Pg.. 116)	Elective	
3.18.2 Cost Estimating and Scheduling (Pg.. 116)	Elective	
3.18.3 Construction Management for Transportation Projects (Pg.. 117)	Elective	
3.18.4 Stakeholder Engagement (Pg.. 117)	Elective	
3.18.5 Professional Ethics and Practice (Pg.. 117)	Elective	

Table 3.18: List of KUs in the Transportation Project Management and Professional Practice area.

3.18.1 TPM/Transportation Project Delivery Methods

Selection among project delivery methods, public-private partnerships, procurement strategies, and contract types and risk allocation.

Topics:

Core

- Selection among delivery methods (design-bid-build, design-build, CM/GC)
- Public-private partnership structures
- Procurement strategies for transportation projects
- Contract types and risk allocation

Learning Outcomes:

Core:

1. Select an appropriate project delivery method for a transportation project [Usage]
2. Describe public-private partnership structures for transportation infrastructure [Familiarity]
3. Explain procurement strategies for transportation projects [Familiarity]
4. Allocate risk appropriately across contract types [Usage]

3.18.2 TPM/Cost Estimating and Scheduling

Conceptual and detailed cost estimating, critical-path-method schedule development, and contingency and risk-based estimating.

Topics:

Core

- Conceptual cost estimating
- Detailed cost estimating
- Critical path method (CPM) schedule development
- Contingency and risk-based estimating

Learning Outcomes:

Core:

1. Develop a conceptual cost estimate for a transportation project [Usage]
2. Prepare a detailed cost estimate for a transportation project [Usage]
3. Construct a critical-path-method schedule for a transportation project [Usage]
4. Apply contingency and risk-based estimating methods [Usage]

3.18.3 TPM/Construction Management for Transportation Projects

Construction phase management, traffic control during construction, quality assurance and quality control, and construction claims.

Topics:

Core

- Construction phase management
- Work-zone traffic control during construction
- Quality assurance and quality control (QA/QC)
- Construction claims and dispute resolution

Learning Outcomes:

Core:

1. Describe construction phase management for a transportation project [Familiarity]
2. Design a work-zone traffic control plan [Usage]
3. Apply quality assurance and quality control procedures [Usage]
4. Explain common causes of construction claims and dispute resolution approaches [Familiarity]

3.18.4 TPM/Stakeholder Engagement

Public involvement planning, communication strategies, conflict resolution, and multidisciplinary team coordination for transportation projects.

Topics:

Core

- Public involvement planning
- Communication strategies for transportation projects
- Conflict resolution techniques
- Multidisciplinary team coordination

Learning Outcomes:

Core:

1. Develop a public involvement plan for a transportation project [Usage]
2. Describe communication strategies for transportation projects [Familiarity]
3. Apply conflict resolution techniques among project stakeholders [Usage]
4. Coordinate a multidisciplinary project team [Usage]

3.18.5 TPM/Professional Ethics and Practice

Codes of professional ethics, licensure and certification, professional liability, and continuing professional development.

Topics:

Core

- Professional code of ethics
- Licensure and certification requirements
- Professional liability
- Continuing professional development

Learning Outcomes:
Core:

1. Explain the professional code of ethics applicable to transportation engineering practice [Familiarity]
2. Describe licensure and certification requirements for transportation engineers [Familiarity]
3. Outline professional liability considerations in transportation engineering practice [Familiarity]
4. Plan a continuing professional development path [Usage]

Chapter 4

Body of knowledge of Engineering Science

The 21 knowledge areas in Engineering Science are:

4.1 Calculus and Analysis (CAN) (Pg.. 120)
- 4.1.1 Line Integrals and Vector Fields (Pg.. 120)
- 4.1.2 Multiple Integrals (Pg.. 121)
- 4.1.3 Multivariable Transformations (Pg.. 121)
- 4.1.4 Surface Integrals and Fundamental Theorems (Pg.. 121)
- 4.1.5 Vector Functions of a Real Variable (Pg.. 122)
- 4.1.6 Limits and Continuity (Pg.. 122)
- 4.1.7 Differential Calculus (Pg.. 122)
- 4.1.8 Integral Calculus (Pg.. 122)
- 4.1.9 Improper Integrals (Pg.. 123)
- 4.1.10 Sequences, Series, and Power Series (Pg.. 123)
- 4.1.11 Applications of the Definite Integral (Pg.. 123)
- 4.1.12 Vectors and the Geometry of Space (Pg.. 124)
- 4.1.13 Quadric Surfaces (Pg.. 124)
- 4.1.14 Parametric Equations and Polar Coordinates (Pg.. 124)
- 4.1.15 Multivariable and Vector Calculus (Pg.. 124)
- 4.1.16 Complex Analysis and Conformal Mapping (Pg.. 125)
- 4.1.17 Harmonic Analysis and Fourier Series (Pg.. 125)

4.2 Algebra and Number Theory (ANT) (Pg.. 125)
- 4.2.1 Matrices and Systems of Linear Equations (Pg.. 126)
- 4.2.2 Vector Spaces and Linear Transformations (Pg.. 126)
- 4.2.3 Eigenvalues and Inner Product Spaces (Pg.. 126)

4.3 Mathematical Modeling and Simulation (MMS) (Pg.. 126)
- 4.3.1 First-Order Ordinary Differential Equations (ODEs) (Pg.. 127)
- 4.3.2 Higher-Order Differential Equations and Systems (ODEs) (Pg.. 127)
- 4.3.3 Partial Differential Equations (PDEs) (Pg.. 127)
- 4.3.4 Mathematical Fluid Dynamics (Pg.. 128)
- 4.3.5 Asymptotic Analysis and Perturbation Methods (Pg.. 128)
- 4.3.6 Dynamical Systems and Bifurcation Theory (Pg.. 128)
- 4.3.7 Control Theory and Optimal Control (Pg.. 129)

4.4 Probability and Statistics (PST) (Pg.. 129)
- 4.4.1 Mathematical Statistics and Estimation Theory (Pg.. 129)
- 4.4.2 Time Series Analysis (Pg.. 130)
- 4.4.3 Probability Axioms and Random Variables (Pg.. 130)
- 4.4.4 Stochastic Processes and Markov Chains (Pg.. 130)

4.5 Numerical and Scientific Analysis (NSA) (Pg.. 131)
- 4.5.1 Error Analysis and Floating Point Arithmetic (Pg.. 131)
- 4.5.2 Numerical Linear Algebra (Pg.. 132)
- 4.5.3 Numerical Solution of Nonlinear Equations (Pg.. 132)
- 4.5.4 Approximation Theory and Interpolation (Pg.. 132)
- 4.5.5 Numerical Integration and Quadrature (Pg.. 133)
- 4.5.6 Numerical Methods for ODEs and PDEs (Pg.. 133)
- 4.5.7 Finite Element Method (Pg.. 133)
- 4.5.8 Optimization Algorithms (Pg.. 134)
- 4.5.9 Parallel and High-Performance Computing (Pg.. 134)

4.6 Mathematical Foundations of Data Science (FDS) (Pg.. 135)
- 4.6.1 Information Theory and Entropy (Pg.. 135)

4.7 Discrete Mathematics and Combinatorics (DMC) (Pg.. 135)
- 4.7.1 Graph Theory (Pg.. 135)

4.8 Mathematical Biology and Life Sciences (MBL) (Pg.. 136)
- 4.8.1 Population Dynamics (Pg.. 136)

4.9 Financial and Actuarial Mathematics (FAM) (Pg.. 136)
- 4.9.1 Interest Theory and Time Value of Money (Pg.. 136)

4.10 Classical Mechanics (CME) (Pg.. 137)
- 4.10.1 Kinematics and Dynamics of Particles (Pg.. 137)
- 4.10.2 Work, Energy, and Conservative Forces (Pg.. 138)
- 4.10.3 Rotational Motion and Angular Momentum (Pg.. 138)
- 4.10.4 Systems of Particles and Linear Momentum (Pg.. 139)
- 4.10.5 Non-Inertial Reference Frames and Fictitious Forces (Pg.. 139)
- 4.10.6 Lagrangian and Hamiltonian Mechanics (Pg.. 139)
- 4.10.7 Continuum Mechanics Foundations (Pg.. 140)
- 4.10.8 Elasticity (Pg.. 141)
- 4.10.9 Fluids: Hydrostatics, Hydrodynamics, and Viscosity (Pg.. 141)
- 4.10.10 Vibrations and Waves (Pg.. 141)
- 4.10.11 Theory of Small Oscillations and Coupled Oscillators (Pg.. 142)
- 4.10.12 Transport Phenomena (Pg.. 142)

4.11 Electromagnetism (ELM) (Pg.. 143)
- 4.11.1 Electrostatics: Electric Field and Gauss's Law (Pg.. 143)
- 4.11.2 Electric Potential and Poisson/Laplace Equations (Pg.. 143)
- 4.11.3 Electrostatic Energy and Dielectrics (Pg.. 144)
- 4.11.4 Magnetostatics: Biot-Savart and Ampere's Laws (Pg.. 144)
- 4.11.5 Magnetic Properties of Matter (Pg.. 144)
- 4.11.6 Electrodynamics: Faraday's Law and Induction (Pg.. 145)
- 4.11.7 Electric Current, Circuits, and Kirchhoff's Laws (Pg.. 145)
- 4.11.8 Maxwell's Equations and Gauge Transformations (Pg.. 146)
- 4.11.9 Electromagnetic Waves and Propagation in Media (Pg.. 146)

4.12 Thermodynamics and Statistical Mechanics (TSM) (Pg.. 146)

- 4.12.1 Laws of Thermodynamics and State Functions (Pg.. 147)
- 4.12.2 Kinetic Theory of Gases (Pg.. 147)
- 4.12.3 Heat Engines, Entropy, and the Second Law (Pg.. 147)

4.13 Condensed Matter Physics (SSP) (Pg.. 148)
- 4.13.1 Crystal Structures and Reciprocal Lattices (Pg.. 148)
- 4.13.2 Free Electron Model and Band Theory of Solids (Pg.. 148)
- 4.13.3 Semiconductors, Insulators, and Metals (Pg.. 149)

4.14 General Chemistry (GCH) (Pg.. 149)
- 4.14.1 Matter and Energy (Pg.. 149)
- 4.14.2 Basic Atomic Structure (Pg.. 150)
- 4.14.3 Chemical Bonding (Pg.. 150)
- 4.14.4 Stoichiometry (Pg.. 150)
- 4.14.5 States of Matter (Pg.. 150)
- 4.14.6 Environmental and Water Chemistry (Pg.. 151)
- 4.14.7 Polymers and Geosynthetics (Pg.. 151)
- 4.14.8 Chemical Equilibrium (Pg.. 151)
- 4.14.9 Ionic Equilibrium and Salt Hydrolysis (Pg.. 151)
- 4.14.10 Salts, Solubility, and Precipitation Equilibria (Pg.. 152)
- 4.14.11 Electrochemistry and Electrolysis (Pg.. 152)
- 4.14.12 Cement Chemistry (Pg.. 152)

4.15 Inorganic Chemistry (INC) (Pg.. 152)
- 4.15.1 Solid State and Material Chemistry (Pg.. 152)
- 4.15.2 Atomic Structure and Periodicity (Pg.. 153)

4.16 Physical Chemistry (PHC) (Pg.. 153)
- 4.16.1 Chemical Thermodynamics and Equilibrium (Pg.. 154)

4.17 Materials Science and Nanotechnology (MSN) (Pg.. 154)
- 4.17.1 Synthesis of Nanomaterials and Nanofabrication (Pg.. 154)
- 4.17.2 Characterization of Materials (XRD, SEM, TEM) (Pg.. 155)
- 4.17.3 Energy Storage and Conversion Materials (Pg.. 155)

4.18 Probability Theory (PRO) (Pg.. 156)
- 4.18.1 Sample Spaces and Events (Pg.. 156)
- 4.18.2 Probability Axioms and Properties (Pg.. 156)
- 4.18.3 Conditional Probability and Independence (Pg.. 157)
- 4.18.4 Discrete Random Variables and Distributions (Pg.. 157)
- 4.18.5 Continuous Random Variables and Distributions (Pg.. 157)
- 4.18.6 Joint, Marginal, and Conditional Distributions (Pg.. 158)
- 4.18.7 Limit Theorems: LLN and CLT (Pg.. 158)

4.19 Descriptive Statistics and Data Analysis (DSC) (Pg.. 158)
- 4.19.1 Numerical Summaries: Location, Spread, and Shape (Pg.. 158)

4.20 Statistical Inference (INF) (Pg.. 159)
- 4.20.1 Point Estimation (Pg.. 159)
- 4.20.2 Interval Estimation and Confidence Intervals (Pg.. 159)
- 4.20.3 Hypothesis Testing Foundations (Pg.. 160)
- 4.20.4 Bayesian Inference (Pg.. 160)

4.21 Regression and Statistical Models (REG) (Pg.. 160)
- 4.21.1 Simple Linear Regression (Pg.. 161)

4.1 Calculus and Analysis (CAN)

This area covers the fundamental study of change, limits, and the rigorous properties of functions. It spans from basic differentiation and integration to advanced measure theory and functional spaces, providing the essential toolkit for all mathematical modeling.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.1.1 Line Integrals and Vector Fields (Pg.. 120)	1	1
⭐ 4.1.2 Multiple Integrals (Pg.. 121)	1	1
⭐ 4.1.3 Multivariable Transformations (Pg.. 121)	1	1
⭐ 4.1.4 Surface Integrals and Fundamental Theorems (Pg.. 121)	1	1
⭐ 4.1.5 Vector Functions of a Real Variable (Pg.. 122)	1	1
⭐ 4.1.6 Limits and Continuity (Pg.. 122)	1	1
⭐ 4.1.7 Differential Calculus (Pg.. 122)	1	1
⭐ 4.1.8 Integral Calculus (Pg.. 122)	1	1
⭐ 4.1.9 Improper Integrals (Pg.. 123)	1	1
⭐ 4.1.10 Sequences, Series, and Power Series (Pg.. 123)	1	1
⭐ 4.1.11 Applications of the Definite Integral (Pg.. 123)	1	1
⭐ 4.1.12 Vectors and the Geometry of Space (Pg.. 124)	1	1
⭐ 4.1.13 Quadric Surfaces (Pg.. 124)	1	1
⭐ 4.1.14 Parametric Equations and Polar Coordinates (Pg.. 124)	1	1
⭐ 4.1.15 Multivariable and Vector Calculus (Pg.. 124)	1	1
4.1.16 Complex Analysis and Conformal Mapping (Pg.. 125)	Elective	
4.1.17 Harmonic Analysis and Fourier Series (Pg.. 125)	Elective	

Table 4.1: List of KUs in the Calculus and Analysis area.

4.1.1 CAN/Line Integrals and Vector Fields (Core Tier1: 1 hr, Core Tier2: 1 hr)

Scalar and vector line integrals, conservative fields, potential functions, path independence, and Green's Theorem.

Topics:

Core

- Vector fields: definition, visualization, divergence, and curl
- Line integrals of scalar functions: arc length and mass
- Line integrals of vector fields: work and circulation
- Conservative fields, potential functions, and path independence
- Green's Theorem and its applications in the plane

Learning Outcomes:

Core:

1. Compute scalar and vector line integrals over oriented curves [Usage]
2. Determine whether a vector field is conservative and construct its potential function [Usage]
3. Apply Green's Theorem to evaluate line integrals via double integrals [Assessment]

4.1.2 CAN/Multiple Integrals (Core Tier1: 1 hr, Core Tier2: 1 hr)

Integration of functions of several variables: double and triple integrals in Cartesian, polar, cylindrical, and spherical coordinates, with applications.

Topics:

Core

- Double integrals over rectangles and general regions; iterated integrals (Fubini's theorem)
- Double integrals in polar coordinates and change-of-variables formula
- Triple integrals in Cartesian coordinates and applications to volume and mass
- Triple integrals in cylindrical and spherical coordinates
- Applications: area, volume, centers of mass, and moments of inertia

Learning Outcomes:

Core:

1. Evaluate double and triple integrals over general regions using iterated integrals [Usage]
2. Apply coordinate changes in polar, cylindrical, and spherical systems to simplify multiple integrals [Usage]
3. Compute areas, volumes, and centers of mass using multiple integrals [Assessment]

4.1.3 CAN/Multivariable Transformations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Vector functions of vector variables: differentiability, the Jacobian matrix, change of variables, and the inverse and implicit function theorems.

Topics:

Core

- Transformations from $\mathbb{R}^n$ to $\mathbb{R}^m$ and their differentiability
- Jacobian matrix and Jacobian determinant
- Change of variables in polar, cylindrical, and spherical coordinates
- Inverse function theorem
- Implicit function theorem in multivariable contexts

Learning Outcomes:

Core:

1. Describe transformations between coordinate systems using the Jacobian matrix [Familiarity]
2. Compute the Jacobian and apply change of variables to evaluate multiple integrals [Usage]
3. Apply the inverse and implicit function theorems to analyze local invertibility [Assessment]

4.1.4 CAN/Surface Integrals and Fundamental Theorems (Core Tier1: 1 hr, Core Tier2: 1 hr)

Parametric surfaces, scalar and flux surface integrals, curl, divergence, and the fundamental theorems of Stokes and Gauss.

Topics:

Core

- Parametric surfaces, tangent plane, and surface area
- Surface integrals of scalar functions
- Flux integrals: surface integrals of vector fields

- Stokes' Theorem: relation between line integrals and surface integrals
- Divergence Theorem (Gauss): relation between flux and volume integral

Learning Outcomes:

Core:

1. Parametrize surfaces and evaluate scalar and flux surface integrals [Usage]
2. Apply Stokes' and Divergence Theorems to reduce complex integrals [Assessment]
3. Relate local differential properties (curl, divergence) to global behavior via integral theorems [Assessment]

4.1.5 CAN/Vector Functions of a Real Variable (Core Tier1: 1 hr, Core Tier2: 1 hr)

Space curves as vector functions of a real variable, including differential geometry of curves: Frenet frame, curvature, and torsion.

Topics:

Core

- Definition, domain, and range of vector functions of a real variable
- Limits, continuity, and derivatives of vector functions
- Arc length and natural parametrization of a curve
- Tangent, normal, and binormal vectors; moving Frenet frame
- Curvature, torsion, and Frenet-Serret formulas

Learning Outcomes:

Core:

1. Identify limits, continuity, and derivatives of vector functions of a real variable [Familiarity]
2. Compute tangent, normal, and binormal vectors and reparametrize a curve by arc length [Usage]
3. Calculate curvature and torsion using the Frenet-Serret formulas [Assessment]

4.1.6 CAN/Limits and Continuity (Core Tier1: 1 hr, Core Tier2: 1 hr)

Limits and continuity of single-variable functions, the foundation for rigorously studying change in engineering systems.

Topics:

Core

- Limits and continuity of single-variable functions

Learning Outcomes:

Core:

1. Interpret the concept of limit and continuity of a function and its relevance to modeling the behavior of engineering systems near a point [Familiarity]

4.1.7 CAN/Differential Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr)

Derivatives and rules of differentiation, with applications to engineering design and optimization.

Topics:

Core

- Derivatives and rules of differentiation

Learning Outcomes:

Core:

1. Apply differentiation rules to find rates of change and optimize engineering design parameters [Usage]
2. Formulate and solve optimization problems for engineering systems using differential calculus [Assessment]

4.1.8 CAN/Integral Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr)

The Fundamental Theorem of Calculus, integration techniques, and their applications to engineering problems.

Topics:
Core
- The Fundamental Theorem of Calculus
- Integration techniques including substitution and parts
- Engineering applications of integration: areas, volumes, centroids, and moments of inertia

Learning Outcomes:
Core:
1. State and explain the Fundamental Theorem of Calculus [Familiarity]
2. Calculate definite integrals arising from engineering problems such as work, fluid pressure, and heat transfer [Usage]

4.1.9 CAN/Improper Integrals (Core Tier1: 1 hr, Core Tier2: 1 hr)

Integrals over unbounded intervals or of unbounded functions, and the convergence criteria engineers use to determine whether such quantities (e.g. total impulse, accumulated decay) are finite.
Topics:
Core
- Improper integrals over unbounded intervals
- Improper integrals of unbounded (discontinuous) integrands
- Convergence criteria and comparison tests for improper integrals

Learning Outcomes:
Core:
1. Determine whether an improper integral arising from an engineering model converges, using comparison and other convergence tests [Assessment]
2. Evaluate an improper integral by taking the appropriate limit, when it converges [Usage]

4.1.10 CAN/Sequences, Series, and Power Series (Core Tier1: 1 hr, Core Tier2: 1 hr)

Convergence of infinite sequences and series and the power-series (Taylor/Maclaurin) approximations engineers use to model, linearize, and numerically evaluate functions.
Topics:
Core
- Sequences and series: convergence tests (ratio, root, comparison, integral)
- Power series, radius of convergence, and Taylor/Maclaurin series
- Engineering use of Taylor polynomials for linearization and numerical approximation

Learning Outcomes:
Core:
1. Determine convergence of a power series and construct a Taylor series for a standard engineering function [Assessment]
2. Apply a Taylor polynomial to approximate or linearize an engineering function [Usage]

4.1.11 CAN/Applications of the Definite Integral (Core Tier1: 1 hr, Core Tier2: 1 hr)

Geometric and physical applications of the definite integral: areas, volumes of revolution, arc length, and work, as engineering computations built on integral calculus.
Topics:
Core
- Area between curves by integrating with respect to x or y
- Volume of solids of revolution by the disk and washer method
- Volume of solids of revolution by the cylindrical shell method
- Work via integration (springs, pumping fluids, cables)

Elective
- Moments and centroid of a plane region or solid

Learning Outcomes:
Core:
1. Calculate the volume of a solid of revolution using the disk, washer, or cylindrical shell method [Usage]
2. Calculate the work done by a variable force using integration [Usage]

4.1.12 CAN/Vectors and the Geometry of Space (Core Tier1: 1 hr, Core Tier2: 1 hr)

Vectors in three-dimensional space, the dot and cross products, and their application to lines and planes, the basis of vector analysis in statics and dynamics.
Topics:
Core
- Dot and cross products: definition, properties, and geometric interpretation
- Equations of lines and planes in space

Learning Outcomes:
Core:
1. Compute the dot and cross products of vectors to solve engineering force and moment problems [Usage]
2. Determine equations of lines and planes in space from the geometric data of an engineering problem [Usage]

4.1.13 CAN/Quadric Surfaces (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classification of quadric surfaces, used to describe component geometries and surfaces in engineering modeling.
Topics:
Core
- Classification of quadrics (ellipsoids, paraboloids, hyperboloids) from their general equation

Learning Outcomes:
Core:
1. Classify a quadric surface and identify its geometry for engineering component modeling [Usage]

4.1.14 CAN/Parametric Equations and Polar Coordinates (Core Tier1: 1 hr, Core Tier2: 1 hr)

Parametric curves and polar coordinates, used to describe trajectories and geometries in kinematics and engineering design.
Topics:
Core
- Parametric curves and their calculus, applied to trajectories in kinematics
- Polar coordinates and their conversion to Cartesian coordinates

Learning Outcomes:
Core:
1. Calculate the velocity and acceleration of a trajectory described parametrically [Usage]
2. Convert between polar and Cartesian coordinates when modeling engineering geometries [Usage]

4.1.15 CAN/Multivariable and Vector Calculus (Core Tier1: 1 hr, Core Tier2: 1 hr)

Calculus of functions of several variables, focusing on partial derivatives, multiple integrals, and vector field theorems essential for field analysis in engineering.
Topics:
Core
- Partial derivatives and the gradient vector
- Multiple integrals in Cartesian, cylindrical, and spherical coordinate systems

- Vector fields and line and surface integrals
- Integral theorems: Green, Stokes, and the Divergence Theorem
- Applications to flux, circulation, and conservative fields in engineering contexts

Learning Outcomes:

Core:

1. Compute gradients and directional derivatives for scalar fields describing physical quantities [Usage]
2. Evaluate double and triple integrals for volumes, masses, and centroids of engineering objects [Usage]
3. Apply Stokes' and Gauss's Divergence Theorems to relate field integrals in electromagnetism and fluid mechanics [Assessment]
4. Determine whether a vector force field is conservative and compute the potential function [Assessment]

4.1.16 CAN/Complex Analysis and Conformal Mapping

Study of functions of a complex variable, analyticity, contour integration, and geometric transformations with applications to potential theory and signal analysis.

Topics:

Core

- Holomorphic functions and Cauchy-Riemann equations
- Contour integration and the Residue Theorem
- Conformal mapping and its applications in potential flow and heat conduction
- Connection between complex analysis and Laplace transforms in circuit analysis

Learning Outcomes:

Core:

1. Evaluate real definite integrals using the Residue Theorem [Usage]
2. Apply conformal mapping to transform boundary value problems in potential flow analysis [Assessment]
3. Explain the analyticity conditions relevant to engineering potential theory [Familiarity]
4. Determine if a complex function is analytic using the Cauchy-Riemann equations [Usage]

4.1.17 CAN/Harmonic Analysis and Fourier Series

Representation of periodic and aperiodic engineering signals as superpositions of sinusoidal components using Fourier series and transforms.

Topics:

Core

- Fourier series representation of periodic functions
- The Fourier transform and its properties in signal and system analysis
- Introduction to wavelet theory for non-stationary signal analysis
- Spectral analysis of engineering signals and filtering concepts

Learning Outcomes:

Core:

1. Decompose periodic signals into their Fourier components and interpret the frequency spectrum [Usage]
2. Apply the Fourier transform to analyze linear time-invariant engineering systems [Usage]
3. Design frequency-domain filters using Fourier analysis to remove noise from engineering signals [Assessment]
4. Explain the conditions for convergence of Fourier series and their practical implications [Familiarity]

4.2 Algebra and Number Theory (ANT)

Structural properties of mathematical systems including linear systems, abstract algebraic structures, and properties of integers.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.2.1 Matrices and Systems of Linear Equations (Pg.. 126)	1	1
⭐ 4.2.2 Vector Spaces and Linear Transformations (Pg.. 126)	1	1
⭐ 4.2.3 Eigenvalues and Inner Product Spaces (Pg.. 126)	1	1

Table 4.2: List of KUs in the Algebra and Number Theory area.

4.2.1 ANT/Matrices and Systems of Linear Equations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Matrix factorization and solution of engineering linear systems via LU, QR, Cholesky, and SVD decompositions.

Topics:

Core

- LU, QR, and Cholesky factorizations for solving engineering linear systems
- Singular Value Decomposition (SVD) and least squares solutions

Learning Outcomes:

Core:

1. Solve systems of linear equations arising in structural, circuit, and fluid engineering problems [Usage]
2. Apply the SVD to solve over-determined systems in data fitting and signal processing [Usage]

4.2.2 ANT/Vector Spaces and Linear Transformations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Vector spaces and linear transformations with applications to engineering coordinate changes.

Topics:

Core

- Vector spaces, subspaces, bases, and dimension
- Linear transformations and their matrix representations in coordinate changes

Learning Outcomes:

Core:

1. Formulate and interpret coordinate system transformations for engineering geometry problems [Assessment]

4.2.3 ANT/Eigenvalues and Inner Product Spaces (Core Tier1: 1 hr, Core Tier2: 1 hr)

Eigenvalues, diagonalization, and inner product spaces with applications to modal analysis of structures.

Topics:

Core

- Eigenvalues, eigenvectors, and diagonalization with applications to vibration and stability
- Inner product spaces, orthogonality, and the Gram-Schmidt process

Learning Outcomes:

Core:

1. Perform eigenvalue decomposition on symmetric matrices for modal analysis of mechanical structures [Assessment]

4.3 Mathematical Modeling and Simulation (MMS)

This area bridges theoretical mathematics and real-world engineering applications. It focuses on formulating, analyzing, and simulating mathematical representations of physical systems using differential equations, dynamical systems theory, and control theory.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.3.1 First-Order Ordinary Differential Equations (ODEs) (Pg.. 127)	1	1
⭐ 4.3.2 Higher-Order Differential Equations and Systems (ODEs) (Pg.. 127)	1	1
⭐ 4.3.3 Partial Differential Equations (PDEs) (Pg.. 127)	1	1
⭐ 4.3.4 Mathematical Fluid Dynamics (Pg.. 128)	1	1
⭐ 4.3.5 Asymptotic Analysis and Perturbation Methods (Pg.. 128)	1	1
4.3.6 Dynamical Systems and Bifurcation Theory (Pg.. 128)	Elective	
4.3.7 Control Theory and Optimal Control (Pg.. 129)	Elective	

Table 4.3: List of KUs in the Mathematical Modeling and Simulation area.

4.3.1 MMS/First-Order Ordinary Differential Equations (ODEs) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Methods for solving and analyzing first-order ordinary differential equations, fundamental to modeling simple engineering systems.

Topics:

Core

- First-order equations: separable, linear, and exact forms

Learning Outcomes:

Core:

1. Solve linear first-order ODEs using integrating factors [Usage]

4.3.2 MMS/Higher-Order Differential Equations and Systems (ODEs) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Methods for solving and analyzing linear higher-order differential equations, systems of ODEs, and the Laplace transform, fundamental to mechanical, electrical, and thermal engineering systems.

Topics:

Core

- Linear higher-order equations with constant coefficients
- Systems of first-order linear ODEs and state-space formulation
- Laplace transform method for solving engineering ODEs with initial conditions
- Modeling of mass-spring-damper, RLC circuits, and heat conduction with ODEs

Learning Outcomes:

Core:

1. Apply the Laplace transform method to solve linear engineering ODEs with initial conditions [Usage]
2. Model a damped mechanical oscillator or RLC circuit as a second-order linear ODE [Usage]
3. Analyze the stability and transient response of engineering systems described by systems of ODEs [Assessment]
4. Formulate state-space representations for multi-variable engineering dynamic systems [Usage]

4.3.3 MMS/Partial Differential Equations (PDEs) (Core Tier1: 1 hr, Core Tier2: 1 hr)

Equations involving multiple independent variables essential for describing heat transfer, structural vibration, wave propagation, and potential fields in engineering.

Topics:

Core

- Separation of variables for heat and wave equations in engineering geometries
- Laplace transform methods applied to initial-boundary value problems
- Classification of PDEs: elliptic, parabolic, and hyperbolic types and their physical significance
- Formulation and physical interpretation of boundary conditions in engineering problems

Non Core

- Green's functions and boundary value problems for advanced engineering analysis

Learning Outcomes:

Core:

1. Apply separation of variables to solve the 1D heat conduction and wave equations [Usage]
2. Classify a given PDE and select the appropriate analytical or numerical solution approach [Assessment]
3. Formulate boundary conditions for a heat transfer or stress analysis problem [Assessment]
4. Derive the governing PDE for steady-state heat conduction using Fourier's law [Usage]

4.3.4 MMS/Mathematical Fluid Dynamics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Continuum mechanics, Euler and Navier-Stokes equations, vorticity, potential flow, and turbulence modeling.

Topics:

Non Core

- Continuum hypothesis, material derivative, and the Reynolds transport theorem
- Euler equations for inviscid flow: conservation form, vorticity, and potential flow
- Navier-Stokes equations: derivation, exact solutions, and dimensional analysis
- Boundary layer theory: Prandtl equations and the Blasius solution
- Turbulence: Reynolds averaging, the k-ε model, and direct numerical simulation

Learning Outcomes:

NonCore:

1. Derive the Navier-Stokes equations from conservation principles and identify each term's physical meaning [Familiarity]
2. Analyze inviscid flows using the Euler equations and apply Bernoulli's principle [Usage]
3. Apply boundary layer theory to estimate drag on a flat plate and compare with the Blasius solution [Assessment]

4.3.5 MMS/Asymptotic Analysis and Perturbation Methods (Core Tier1: 1 hr, Core Tier2: 1 hr)

Asymptotic expansions, regular and singular perturbation theory, boundary layers, and multiple scales, for engineering models with a small parameter.

Topics:

Non Core

- Asymptotic expansions and the Landau order symbols (O, o, $\sim$)
- Regular perturbation theory for algebraic equations and ODEs
- Singular perturbation theory and matched asymptotic expansions (boundary layers)
- Method of multiple scales and the WKB approximation

Learning Outcomes:

NonCore:

1. Construct a regular perturbation expansion for an ODE with a small parameter [Familiarity]
2. Apply matched asymptotic expansions to solve singular perturbation problems with boundary layers [Usage]

4.3.6 MMS/Dynamical Systems and Bifurcation Theory

Long-term behavior of engineering systems modeled as autonomous differential equations, focusing on stability, limit cycles, and parameter-dependent behavior.

Topics:

Core

- Phase portraits and linearization of nonlinear engineering systems
- Stability of equilibrium points via eigenvalue analysis and Lyapunov methods
- Limit cycles and self-sustained oscillations in mechanical and electrical systems

Non Core

- Bifurcation analysis and parameter sensitivity in engineering systems

Learning Outcomes:
Core:
1. Sketch phase portraits for two-dimensional nonlinear engineering systems [Usage]
2. Classify the stability of equilibrium points for a linearized engineering system [Assessment]
3. Apply Lyapunov's direct method to assess stability of a nonlinear control system [Usage]

NonCore:
4. Identify bifurcation points and predict system behavior changes under varying engineering parameters [Assessment]

4.3.7 MMS/Control Theory and Optimal Control

Mathematical framework for designing feedback systems to regulate the dynamic behavior of engineering processes and machines.
Topics:
Core
- Feedback control, PID controllers, and closed-loop stability analysis
- Transfer functions, frequency response, and Bode diagrams
- State-space representation, controllability, and observability
- Root locus technique and frequency-domain design methods

Non Core
- Pontryagin's Maximum Principle for optimal engineering control

Learning Outcomes:
Core:
1. Design a PID controller for a given engineering plant and assess closed-loop stability [Usage]
2. Evaluate the controllability and observability of a state-space model [Assessment]
3. Construct Bode diagrams and use frequency-domain criteria for stability assessment [Usage]
4. Analyze the root locus of a feedback system to determine gain settings for desired transient response [Assessment]

4.4 Probability and Statistics (PST)

This area covers the mathematical modeling of uncertainty and the analysis of engineering data. It ranges from the axiomatic foundations of probability to statistical inference methods essential for quality control, reliability engineering, and data-driven design.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.4.1 Mathematical Statistics and Estimation Theory (Pg.. 129)	1	1
⭐ 4.4.2 Time Series Analysis (Pg.. 130)	1	1
4.4.3 Probability Axioms and Random Variables (Pg.. 130)	Elective	
4.4.4 Stochastic Processes and Markov Chains (Pg.. 130)	Elective	

Table 4.4: List of KUs in the Probability and Statistics area.

4.4.1 PST/Mathematical Statistics and Estimation Theory (Core Tier1: 1 hr, Core Tier2: 1 hr)

Rigorous methods for estimating population parameters from sample data in engineering experiments and quality control.
Topics:
Core
- Point estimation: Method of Moments and Maximum Likelihood Estimation
- Construction and interpretation of confidence intervals in engineering tests
- Hypothesis testing for engineering quality control and process validation
- Linear and nonlinear regression for engineering data fitting
- Introduction to Design of Experiments (DoE) for engineering optimization

Learning Outcomes:
Core:
1. Derive Maximum Likelihood Estimators for parameters of engineering failure models [Usage]
2. Verify the statistical significance of engineering test results using hypothesis testing [Assessment]
3. Construct confidence intervals for key process parameters from experimental data [Usage]
4. Apply linear regression to model and predict engineering performance from measured data [Assessment]

4.4.2 PST/Time Series Analysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Stationary processes, ARMA models, spectral analysis, state-space models, and forecasting.
Topics:
Core
- Stationarity, autocovariance function, and the autocorrelation function (ACF)
- ARMA models: identification, estimation (Yule-Walker, MLE), and diagnostics
- Spectral density, the periodogram, and Wiener-Khinchin theorem
- State-space models and the Kalman filter
- ARIMA models, seasonal adjustment, and multi-step forecasting

Learning Outcomes:
Core:
1. Identify stationarity and determine the order of an ARMA model from ACF and PACF plots [Familiarity]
2. Fit ARIMA models to time series data, validate residuals, and produce forecasts [Usage]
3. Apply the Kalman filter to estimate hidden states in a linear Gaussian state-space model [Assessment]

4.4.3 PST/Probability Axioms and Random Variables

Foundations of probability theory including sample spaces, probability measures, and random variables with engineering applications in reliability and uncertainty quantification.
Topics:
Core
- Sample spaces, events, and the Kolmogorov axioms
- Discrete and continuous random variables and their distribution functions
- Expectation, variance, and moments of engineering random variables
- Common engineering distributions: Normal, Exponential, Poisson, and Weibull
- Joint distributions, covariance, and multivariate normal distribution

Learning Outcomes:
Core:
1. Calculate probabilities for discrete and continuous distributions relevant to reliability engineering [Usage]
2. Compute the mean, variance, and standard deviation of random variables describing engineering quantities [Usage]
3. Evaluate the probability density function for transformed random variables and apply it to failure analysis [Assessment]
4. Model multivariate engineering uncertainties using joint probability distributions [Usage]

4.4.4 PST/Stochastic Processes and Markov Chains

Models for engineering systems that evolve randomly over time, including queuing, reliability, and signal noise models.
Topics:
Core
- Discrete-time Markov chains, transition matrices, and steady-state analysis
- Poisson processes and their application in reliability and queuing engineering
- Stationarity and ergodicity in engineering random signals

Non Core

- Brownian motion and its application in vibration and financial engineering

Learning Outcomes:

Core:

1. Compute stationary distributions for Markov chain models of engineering system states [Assessment]
2. Model arrival processes in queuing systems using the Poisson distribution [Usage]
3. Explain the concept of power spectral density for stationary random engineering signals [Familiarity]

NonCore:

4. Simulate a simple Brownian motion model and interpret its variance growth over time [Usage]

4.5 Numerical and Scientific Analysis (NSA)

This area focuses on computational algorithms for obtaining numerical solutions to mathematical problems arising in engineering. It covers error analysis, numerical linear algebra, and methods for solving differential equations by discretization.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.5.1 Error Analysis and Floating Point Arithmetic (Pg.. 131)	1	1
⭐ 4.5.2 Numerical Linear Algebra (Pg.. 132)	1	1
⭐ 4.5.3 Numerical Solution of Nonlinear Equations (Pg.. 132)	1	1
⭐ 4.5.4 Approximation Theory and Interpolation (Pg.. 132)	1	1
⭐ 4.5.5 Numerical Integration and Quadrature (Pg.. 133)	1	1
⭐ 4.5.6 Numerical Methods for ODEs and PDEs (Pg.. 133)	1	1
⭐ 4.5.7 Finite Element Method (Pg.. 133)	1	1
⭐ 4.5.8 Optimization Algorithms (Pg.. 134)	1	1
⭐ 4.5.9 Parallel and High-Performance Computing (Pg.. 134)	1	1

Table 4.5: List of KUs in the Numerical and Scientific Analysis area.

4.5.1 NSA/Error Analysis and Floating Point Arithmetic (Core Tier1: 1 hr, Core Tier2: 1 hr)

Study of how numerical errors originate and propagate in engineering computations, and strategies to control them.

Topics:

Core

- Floating point representation and round-off errors in engineering software
- Conditioning of engineering problems and stability of numerical algorithms
- Truncation error in series approximations and finite difference stencils
- Error propagation through chains of computations in engineering simulations

Learning Outcomes:

Core:

1. Explain the sources and consequences of round-off and truncation errors in engineering computations [Familiarity]
2. Calculate the condition number of a linear system and interpret its effect on solution accuracy [Assessment]
3. Estimate the propagation of measurement uncertainties through an engineering calculation chain [Usage]
4. Select numerical methods with appropriate stability properties for engineering simulation requirements [Assessment]

4.5.2 NSA/Numerical Linear Algebra (Core Tier1: 1 hr, Core Tier2: 1 hr)

Efficient numerical algorithms for solving large linear systems and eigenvalue problems arising in structural, fluid, and electromagnetic engineering.

Topics:

Core

- LU and QR decompositions for solving engineering linear systems
- Iterative solvers: Jacobi, Gauss-Seidel, and Conjugate Gradient for large sparse systems
- Singular Value Decomposition (SVD) for data fitting and model reduction
- Sparse matrix storage formats and efficient solvers for large engineering FEM/FVM systems

Learning Outcomes:

Core:

1. Solve engineering linear systems using LU decomposition with partial pivoting [Usage]
2. Analyze the convergence rate of iterative solvers applied to engineering stiffness matrices [Assessment]
3. Implement a Conjugate Gradient solver for a large symmetric positive-definite engineering system [Usage]
4. Apply SVD to compress a structural mode shape dataset and assess the approximation quality [Assessment]

4.5.3 NSA/Numerical Solution of Nonlinear Equations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Iterative methods for approximating roots of engineering nonlinear equations and analysis of their convergence.

Topics:

Core

- Bracketing methods: bisection and false position
- Newton-Raphson method and the secant method
- Order of convergence and stopping criteria in iterative methods

Learning Outcomes:

Core:

1. Explain the basis and convergence guarantees of the bisection and false position methods [Familiarity]
2. Apply the Newton-Raphson and secant methods to approximate roots of engineering equations [Usage]
3. Compare the convergence order of different iterative methods and select the most appropriate one for a given problem [Assessment]

4.5.4 NSA/Approximation Theory and Interpolation (Core Tier1: 1 hr, Core Tier2: 1 hr)

Polynomial and spline interpolation, best approximation, Chebyshev polynomials, and rational approximation.

Topics:

Core

- Polynomial interpolation: Lagrange, Newton divided differences, and Runge's phenomenon
- Spline interpolation: cubic splines, B-splines, and piecewise polynomial methods
- Best approximation in normed spaces: Chebyshev (minimax) and least squares
- Chebyshev polynomials: properties, orthogonality, and spectral convergence
- Trigonometric approximation and the fast Fourier transform (FFT)

Learning Outcomes:

Core:

1. Explain Runge's phenomenon and justify the choice of Chebyshev nodes to mitigate it [Familiarity]

2. Construct cubic spline and Chebyshev interpolants for given data and estimate the interpolation error [Usage]
3. Apply the FFT to efficiently compute trigonometric approximations of a sampled function [Assessment]

4.5.5 NSA/Numerical Integration and Quadrature (Core Tier1: 1 hr, Core Tier2: 1 hr)

Quadrature rules, adaptive integration, Gaussian quadrature, and multi-dimensional integration.
Topics:
Core
- Newton-Cotes rules: trapezoidal, Simpson's, and composite rules; error analysis
- Adaptive quadrature and automatic error control
- Gaussian quadrature: optimal nodes and weights, orthogonal polynomial connection
- Numerical treatment of improper and singular integrals
- Monte Carlo integration and quasi-Monte Carlo methods for high-dimensional integrals

Learning Outcomes:
Core:
1. Derive the error formula for composite Simpson's rule and identify its order of accuracy [Familiarity]
2. Select and apply an appropriate quadrature rule (Gaussian, adaptive) based on integrand regularity [Usage]
3. Apply Monte Carlo integration to estimate high-dimensional integrals and quantify the statistical error [Assessment]

4.5.6 NSA/Numerical Methods for ODEs and PDEs (Core Tier1: 1 hr, Core Tier2: 1 hr)

Solving differential equations that govern engineering systems through time-stepping and spatial discretization methods.
Topics:
Core
- Runge-Kutta methods and adaptive time-stepping for engineering ODE problems
- Stability analysis and stiffness in engineering ODE integrators
- Finite difference discretization of engineering PDEs (heat equation, Laplace equation)

Non Core
- Finite element and shooting methods for engineering boundary value problems

Learning Outcomes:
Core:
1. Implement a fourth-order Runge-Kutta integrator for a mechanical vibration problem [Usage]
2. Determine the region of absolute stability for an explicit time-stepping scheme [Assessment]
3. Discretize the 2D heat equation using finite differences and set up the resulting linear system [Usage]

NonCore:
4. Compare finite difference and finite element approaches for solving an engineering PDE [Assessment]

4.5.7 NSA/Finite Element Method (Core Tier1: 1 hr, Core Tier2: 1 hr)

Variational formulation, Galerkin methods, finite element spaces, error estimates, and applications to elliptic PDEs.
Topics:
Core
- Weak (variational) formulation of boundary value problems and Sobolev spaces
- Galerkin method: finite-dimensional approximation spaces and the stiffness matrix
- Triangular and quadrilateral finite element spaces: Lagrange elements and conformity

- A priori error estimates: Céa's lemma and interpolation error bounds

Non Core

- A posteriori error estimates and adaptive mesh refinement

Learning Outcomes:

Core:

1. Derive the weak formulation of an elliptic BVP and show its equivalence to the strong form [Familiarity]
2. Assemble the global stiffness matrix and load vector for a linear finite element discretization [Usage]
3. Estimate the H^1 error of a finite element solution using Céa's lemma and interpolation theory [Assessment]

4.5.8 NSA/Optimization Algorithms (Core Tier1: 1 hr, Core Tier2: 1 hr)

Gradient methods, Newton and quasi-Newton methods, constrained optimization, and convex optimization algorithms.

Topics:

Core

- Gradient descent and line search methods: Armijo-Wolfe conditions and convergence rates
- Newton's method and quasi-Newton methods (BFGS, L-BFGS)
- Constrained optimization: KKT conditions, penalty methods, and sequential quadratic programming
- Convex optimization algorithms: interior-point methods and the alternating direction method of multipliers (ADMM)
- Stochastic gradient descent (SGD), variance reduction, and Adam optimizer

Learning Outcomes:

Core:

1. Explain the convergence guarantees of gradient descent for smooth convex functions [Familiarity]
2. Apply Newton and quasi-Newton methods to unconstrained optimization problems [Usage]
3. Formulate a constrained optimization problem as a KKT system and apply an interior-point method [Assessment]

4.5.9 NSA/Parallel and High-Performance Computing (Core Tier1: 1 hr, Core Tier2: 1 hr)

Parallel architectures, performance models, parallel algorithms for linear algebra, and GPU computing.

Topics:

Core

- Parallel architectures: shared memory (OpenMP), distributed memory (MPI), and GPU (CUDA)
- Performance models: Amdahl's law, roofline model, and communication complexity
- Parallel algorithms for dense and sparse linear algebra (ScaLAPACK, PETSc)
- Domain decomposition and parallel PDE solvers

Non Core

- Automatic differentiation (forward and reverse mode) and its role in scientific ML

Learning Outcomes:

Core:

1. Explain Amdahl's law and identify the bottlenecks limiting parallel speedup in a given algorithm [Familiarity]
2. Implement a parallel linear algebra routine using MPI or OpenMP and measure parallel efficiency [Usage]

NonCore:

3. Apply automatic differentiation to compute gradients of complex scientific functions for optimization [Assessment]

4.6 Mathematical Foundations of Data Science (FDS)

This area provides the formal mathematical underpinnings for extracting knowledge from engineering data, combining information theory, optimization, and statistical learning relevant to sensor systems, communication, and data-driven engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
4.6.1 Information Theory and Entropy (Pg.. 135)	Elective	

Table 4.6: List of KUs in the Mathematical Foundations of Data Science area.

4.6.1 FDS/Information Theory and Entropy

Quantifying information, redundancy, and uncertainty in engineering signals and communication systems.

Topics:

Core

- Shannon entropy and mutual information for engineering data sources
- Kullback-Leibler divergence and relative entropy in model comparison
- Channel capacity and the Shannon-Hartley theorem for communication systems
- Lossless compression bounds and Huffman coding for engineering data

Learning Outcomes:

Core:

1. Calculate the entropy of discrete probability distributions representing engineering sensor outputs [Usage]
2. Minimize cross-entropy loss as a design objective in sensor classification tasks [Assessment]
3. Explain the concept of channel capacity and its significance in engineering communication system design [Familiarity]
4. Apply information-theoretic measures to evaluate the quality of engineering data streams [Usage]

4.7 Discrete Mathematics and Combinatorics (DMC)

This area covers the mathematics of finite and countable structures, including combinatorial enumeration, graph theory, discrete optimization, and the logical foundations of mathematics. It underpins theoretical computer science, operations research, and modern data science.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.7.1 Graph Theory (Pg.. 135)	1	1

Table 4.7: List of KUs in the Discrete Mathematics and Combinatorics area.

4.7.1 DMC/Graph Theory (Core Tier1: 1 hr, Core Tier2: 1 hr)

Structure and properties of graphs: connectivity, colorings, matchings, planarity, and spectral graph theory.

Topics:

Core

- Graphs: definitions, isomorphism, degree sequences, trees, and spanning trees
- Connectivity, Menger's theorem, and network flows (max-flow min-cut)
- Matchings (Hall's theorem), graph colorings, and the chromatic polynomial
- Planar graphs, Euler's formula, Kuratowski's theorem, and the four-color theorem
- Adjacency and Laplacian matrices, eigenvalues, and expander graphs

Learning Outcomes:

Core:

1. Identify structural properties of graphs (connectivity, planarity, bipartiteness) and apply Euler's formula [Familiarity]
2. Apply Hall's marriage theorem and network flow algorithms to matching and routing problems [Usage]
3. Analyze a graph's spectrum to bound its chromatic number and connectivity properties [Assessment]

4.8 Mathematical Biology and Life Sciences (MBL)

This area covers the application of mathematical methods to biological systems, spanning population dynamics, epidemiology, systems biology, bioinformatics, and computational neuroscience, with emphasis on models grounded in modern experimental data.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.8.1 Population Dynamics (Pg.. 136)	1	1

Table 4.8: List of KUs in the Mathematical Biology and Life Sciences area.

4.8.1 MBL/Population Dynamics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Mathematical models of single and interacting populations: logistic growth, Lotka-Volterra systems, spatial ecology, and evolutionary dynamics.

Topics:

Core

- Exponential and logistic growth models; carrying capacity and the Allee effect
- Lotka-Volterra predator-prey and competition models; equilibria and stability analysis
- Age-structured models: Leslie matrices and the Euler-Lotka equation
- Reaction-diffusion models and traveling waves in spatial ecology (Fisher-KPP equation)
- Evolutionary dynamics: replicator equations, game theory, and the Price equation

Learning Outcomes:

Core:

1. Analyze the stability of equilibria in Lotka-Volterra systems using linearization and phase portraits [Familiarity]
2. Construct age-structured population models using Leslie matrices and compute long-term growth rates [Usage]
3. Apply reaction-diffusion theory to model the spatial spread of an invasive species using the Fisher-KPP equation [Assessment]

4.9 Financial and Actuarial Mathematics (FAM)

This area covers the mathematical foundations of finance and actuarial science, from interest theory and arbitrage pricing to stochastic models for derivatives, risk measurement, actuarial life tables, and computational methods in quantitative finance.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.9.1 Interest Theory and Time Value of Money (Pg.. 136)	1	1

Table 4.9: List of KUs in the Financial and Actuarial Mathematics area.

4.9.1 FAM/Interest Theory and Time Value of Money (Core Tier1: 1 hr, Core Tier2: 1 hr)

Time value of money, compound interest, annuities, yield curves, bond pricing, and immunization strategies.

Topics:
Core
- Compound interest: accumulation functions, effective and nominal rates, and force of interest
- Annuities-immediate and annuities-due: present and accumulated values, perpetuities
- Bond pricing: price-yield relationship, duration, convexity, and amortization schedules
- Yield curves: spot rates, forward rates, and bootstrap methods for term structure
- Portfolio immunization: Redington's conditions and cash-flow matching

Learning Outcomes:
Core:
1. Compute the present value and accumulated value of annuities under various interest rate assumptions [Familiarity]
2. Price bonds using the price-yield relationship and calculate duration and convexity for interest rate sensitivity [Usage]
3. Construct a portfolio satisfying Redington's immunization conditions against parallel yield curve shifts [Assessment]

4.10 Classical Mechanics (CME)

Classical Mechanics provides the foundational principles governing the motion of macroscopic objects, from particles to rigid bodies and continuous media. It encompasses Newtonian dynamics, conservation laws, Lagrangian and Hamiltonian formalisms, oscillatory systems, and celestial mechanics.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.10.1 Kinematics and Dynamics of Particles (Pg.. 137)	1	1
⭐ 4.10.2 Work, Energy, and Conservative Forces (Pg.. 138)	1	1
⭐ 4.10.3 Rotational Motion and Angular Momentum (Pg.. 138)	1	1
⭐ 4.10.4 Systems of Particles and Linear Momentum (Pg.. 139)	1	1
⭐ 4.10.5 Non-Inertial Reference Frames and Fictitious Forces (Pg.. 139)	1	1
⭐ 4.10.6 Lagrangian and Hamiltonian Mechanics (Pg.. 139)	1	1
⭐ 4.10.7 Continuum Mechanics Foundations (Pg.. 140)	1	1
⭐ 4.10.8 Elasticity (Pg.. 141)	1	1
⭐ 4.10.9 Fluids: Hydrostatics, Hydrodynamics, and Viscosity (Pg.. 141)	1	1
⭐ 4.10.10 Vibrations and Waves (Pg.. 141)	1	1
⭐ 4.10.11 Theory of Small Oscillations and Coupled Oscillators (Pg.. 142)	1	1
⭐ 4.10.12 Transport Phenomena (Pg.. 142)	1	1

Table 4.10: List of KUs in the Classical Mechanics area.

4.10.1 CME/Kinematics and Dynamics of Particles (Core Tier1: 1 hr, Core Tier2: 1 hr)

Mathematical description of motion and the study of forces that cause or modify motion for point particles, forming the basis of mechanical and structural engineering analysis.
Topics:
Core
- Vector description of position, velocity, and acceleration in Cartesian, polar, and spherical coordinates
- Newton's three laws of motion and inertial reference frames
- Formulation and solution of equations of motion for constant and variable forces
- Static and kinetic friction forces, including angle of repose
- Numerical integration of equations of motion for engineering dynamics problems

Learning Outcomes:
Core:
1. Formulate the equations of motion for a particle in one, two, and three dimensions given a force law [Usage]

2. Identify all forces acting on a particle and draw a correct free-body diagram [Familiarity]
3. Calculate the terminal velocity of an object falling through a fluid with drag resistance [Assessment]
4. Implement a numerical algorithm to simulate the dynamics of an engineering mechanical system [Usage]
5. Construct and interpret phase space diagrams for simple engineering oscillatory systems [Assessment]

4.10.2 CME/Work, Energy, and Conservative Forces (Core Tier1: 1 hr, Core Tier2: 1 hr)

Energy concepts in mechanics: work-energy theorem, kinetic and potential energy, conservation of mechanical energy, and properties of conservative force fields.

Topics:

Core

- Definition of work as a line integral $W = \int \vec{F} \cdot d\vec{r}$
- Work-energy theorem: $W_{total} = \Delta K$
- Potential energy function and the force relation $\vec{F} = -\nabla U$
- Conservation of total mechanical energy $E = K + U$
- Energy diagrams, turning points, and equilibrium stability
- Work done by non-conservative forces and energy dissipation in engineering systems

Learning Outcomes:

Core:

1. Calculate the work done by a force along a specified engineering path [Usage]
2. Apply conservation of mechanical energy to solve for speeds and positions in engineering dynamics [Usage]
3. Analyze an energy diagram to identify equilibrium positions and stability [Assessment]
4. Estimate energy dissipated by friction and damping forces in mechanical engineering systems [Assessment]

4.10.3 CME/Rotational Motion and Angular Momentum (Core Tier1: 1 hr, Core Tier2: 1 hr)

Rotational kinematics and dynamics, torque, moment of inertia, rotational energy, and conservation of angular momentum for engineering machines and structures.

Topics:

Core

- Rotational kinematics: angular displacement, velocity, and acceleration
- Torque: $\vec{\tau} = \vec{r} \times \vec{F}$ and its computation
- Moment of inertia $I = \sum m_i r_i^2$ and the parallel axis theorem
- Rotational kinetic energy: $K_{rot} = \frac{1}{2} I \omega^2$
- Conservation of angular momentum in engineering machines and rotating structures
- Rolling without slipping dynamics and applications to wheels and shafts

Learning Outcomes:

Core:

1. Calculate torque about a given axis for an engineering power transmission system [Usage]
2. Determine the moment of inertia for machine components such as rods, disks, and shafts [Usage]
3. Apply conservation of angular momentum to analyze speed changes in rotating engineering systems [Assessment]
4. Analyze combined translational and rotational motion in wheeled engineering systems [Assessment]

4.10.4 CME/Systems of Particles and Linear Momentum (Core Tier1: 1 hr, Core Tier2: 1 hr)

Dynamics of multi-particle systems: center of mass motion, linear momentum conservation, and collision mechanics relevant to structural impacts and machinery.

Topics:

Core

- Definition and computation of center of mass for particle systems and distributed bodies
- Linear momentum of a particle and system: $\vec{P} = M\vec{V}_{CM}$
- Conservation of linear momentum for isolated engineering systems
- Two-body collisions: elastic, inelastic, and the coefficient of restitution
- Variable mass systems such as rockets and conveyor belts

Learning Outcomes:

Core:

1. Locate the center of mass for discrete particle systems and distributed engineering objects [Usage]
2. Apply conservation of linear momentum to analyze impact and collision problems [Usage]
3. Classify collisions as elastic or inelastic and determine energy loss [Familiarity]
4. Solve variable-mass system equations to determine velocity gain in propulsion problems [Usage]

4.10.5 CME/Non-Inertial Reference Frames and Fictitious Forces (Core Tier1: 1 hr, Core Tier2: 1 hr)

Physics in accelerating reference frames: centrifugal, Coriolis, and Euler forces, with applications to Earth's rotation.

Topics:

Core

- Transformations between inertial and accelerating reference frames
- Centrifugal force defined as $F_{cent} = -m\vec{\omega} \times (\vec{\omega} \times \vec{r}')$
- Coriolis force defined as $F_{Cor} = -2m\vec{\omega} \times \vec{v}'$
- Euler force for non-constant rotation: $F_{Euler} = -m\frac{d\vec{\omega}}{dt} \times \vec{r}'$
- Effective gravity on the rotating Earth: $g_{eff} = g - \vec{\omega} \times (\vec{\omega} \times \vec{R})$
- Foucault pendulum as a demonstration of the Earth's rotation
- Coriolis effect on global weather patterns and ocean currents

Elective

- Larmor precession in magnetic fields viewed as a rotating frame effect
- Tidal forces as differential gravitational effects in co-rotating frames
- Connection to General Relativity's equivalence principle

Learning Outcomes:

Core:

1. Transform Newton's second law to a uniformly rotating reference frame [Usage]
2. Calculate centrifugal and Coriolis forces for given positions and velocities in a rotating frame [Usage]
3. Predict the deflection direction of projectiles due to the Earth's rotation through the Coriolis effect [Assessment]
4. Explain the precession of a Foucault pendulum in terms of the Earth's rotation [Familiarity]
5. Compute effective gravitational acceleration at different latitudes on Earth [Usage]

Elective:

6. Analyze Larmor precession using the concept of rotating reference frames [Assessment]
7. Compare tidal forces to centrifugal forces in co-rotating systems [Assessment]

4.10.6 CME/Lagrangian and Hamiltonian Mechanics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Advanced formulations of mechanics: principle of least action, Lagrangian formulation, Hamiltonian mechanics, and canonical transformations.

Topics:
Core

- Principle of least action and Hamilton's principle of stationary action
- Lagrangian definition: $L = T - V$ for conservative systems
- Euler-Lagrange equations of motion: $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) = \frac{\partial L}{\partial q_i}$
- Generalized coordinates and the treatment of holonomic constraints
- Cyclic coordinates and the associated conservation laws
- Legendre transform from the Lagrangian to the Hamiltonian: $H = \sum p_i \dot{q}_i - L$
- Hamilton's equations: $\dot{q}_i = \frac{\partial H}{\partial p_i}$ and $\dot{p}_i = -\frac{\partial H}{\partial q_i}$

Elective

- Poisson brackets: $\{f, g\} = \sum \left(\frac{\partial f}{\partial q_i}\frac{\partial g}{\partial p_i} - \frac{\partial f}{\partial p_i}\frac{\partial g}{\partial q_i}\right)$
- Canonical transformations and their generating functions
- Action-angle variables for periodic Hamiltonian systems

Learning Outcomes:
Core:

1. Construct the Lagrangian for simple mechanical systems in appropriate generalized coordinates [Usage]
2. Derive equations of motion from the Euler-Lagrange equations [Usage]
3. Identify cyclic coordinates and their associated conserved quantities in a given Lagrangian [Assessment]
4. Formulate the Hamiltonian from a given Lagrangian system [Usage]
5. Solve Hamilton's equations for simple systems such as the harmonic oscillator [Usage]

Elective:

6. Compute Poisson brackets for pairs of dynamical variables [Usage]
7. Apply canonical transformations to simplify the description of Hamiltonian systems [Usage]

4.10.7 CME/Continuum Mechanics Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr)

Introduction to continuous media: stress and strain tensors, elasticity, fluid mechanics, and conservation laws.
Topics:
Elective

- Continuum hypothesis and the definition of density fields
- Stress tensor σ_{ij} and the concept of force per unit area
- Strain tensor ϵ_{ij} as a measure of local deformation
- Hooke's law for isotropic materials: $\sigma_{ij} = \lambda \epsilon_{kk} \delta_{ij} + 2\mu \epsilon_{ij}$
- Navier-Stokes equation for viscous fluids: $\rho\left(\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v}\right) = -\nabla p + \mu \nabla^2 \vec{v} + \vec{f}$
- Bernoulli's principle for inviscid and incompressible fluid flow
- Conservation of mass and the continuity equation: $\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$
- Conservation of momentum expressed in continuum mechanics form
- Wave propagation in elastic media including P-waves and S-waves
- Viscosity and the rheology of non-Newtonian fluids

Learning Outcomes:
Elective:

1. Interpret the physical meaning of the components of the stress tensor [Familiarity]
2. Calculate strain tensor components for simple deformations [Usage]
3. Apply Hooke's law to relate stress and strain for isotropic elastic materials [Usage]
4. Simplify the Navier-Stokes equation for special cases such as steady or inviscid flow [Usage]
5. Apply Bernoulli's principle to calculate pressure variations in fluid flow [Usage]
6. Derive the continuity equation from the principle of mass conservation [Usage]
7. Analyze different wave propagation modes in elastic solids [Assessment]

4.10.8 CME/Elasticity (Core Tier1: 1 hr, Core Tier2: 1 hr)

Elastic properties of solids under axial, shear, and volumetric load: stress, strain, and scalar elastic moduli.

Topics:

Core

- Definition of stress (force/area) and strain ($\Delta L/L$)
- Young's modulus and Hooke's law for longitudinal strain: $\sigma = E\epsilon$
- Shear modulus (rigidity) and shear strain
- Bulk modulus (compressibility) and volumetric strain
- Elastic limit, plastic region, and fracture point on the stress-strain diagram

Elective

- Elastic energy stored in a deformed material

Learning Outcomes:

Core:

1. Apply the scalar Hooke's law to calculate the deformation of a rod under axial load [Usage]
2. Calculate Young's, shear, or bulk modulus from experimental stress-strain data [Usage]
3. Identify the elastic region, elastic limit, and fracture point on a stress-strain curve [Familiarity]

Elective:

4. Calculate the elastic potential energy stored in a deformed spring or rod [Usage]

4.10.9 CME/Fluids: Hydrostatics, Hydrodynamics, and Viscosity (Core Tier1: 1 hr, Core Tier2: 1 hr)

Statics and dynamics of incompressible fluids: pressure, buoyancy, the continuity and Bernoulli equations, and an introduction to viscous flow.

Topics:

Core

- Density, pressure, and its variation with depth in a fluid at rest: $p = p_0 + \rho gh$
- Pascal's principle and its applications (hydraulic press)
- Archimedes' principle, buoyant force, and flotation
- Pressure measurement with manometers and barometers
- Continuity equation for incompressible flow: $A_1 v_1 = A_2 v_2$
- Bernoulli's equation and energy conservation in ideal flow
- Applications: Venturi tube, Torricelli's theorem, Pitot tube

Elective

- Viscosity and Poiseuille's law for laminar flow in pipes
- Reynolds number and the transition to turbulent flow
- Stokes' law for the drag force on a sphere in a viscous fluid

Learning Outcomes:

Core:

1. Calculate the pressure at a point in a fluid at rest given depth and density [Usage]
2. Apply Archimedes' principle to determine whether an object floats, sinks, or remains in equilibrium [Usage]
3. Apply the continuity and Bernoulli equations to solve flow problems in pipes of varying cross-section [Usage]
4. Interpret manometer and barometer readings to determine absolute and gauge pressures [Assessment]

Elective:

5. Apply Poiseuille's law to calculate the flow rate of a viscous fluid in a cylindrical tube [Usage]
6. Estimate the Reynolds number of a flow and predict whether it is laminar or turbulent [Assessment]

4.10.10 CME/Vibrations and Waves (Core Tier1: 1 hr, Core Tier2: 1 hr)

Simple harmonic motion, damped and forced oscillations, and the propagation, superposition, and resonance of mechanical waves.

Topics:
Core
- Simple harmonic motion (SHM): equation of motion, position, velocity, and acceleration
- Oscillating systems: spring-mass and simple/physical pendulum
- Energy in simple harmonic motion
- Damped and forced oscillations; introduction to resonance
- Transverse and longitudinal waves; propagation speed
- Wave equation and speed of a wave on a taut string: $v = \sqrt{T/\mu}$
- Superposition principle and standing waves
- Sound waves, intensity, and sound intensity level (decibels)

Elective
- Doppler effect for sound waves
- Beats and interference of waves of nearby frequencies

Learning Outcomes:
Core:
1. Derive the equation of motion and the period of a spring-mass system and a simple pendulum [Usage]
2. Calculate the kinetic, potential, and total energy of a simple harmonic oscillator at any instant [Usage]
3. Analyze the amplitude response of a forced oscillator near the resonance frequency [Assessment]
4. Calculate the propagation speed of a wave on a string from the tension and linear density [Usage]
5. Determine the frequencies and wavelengths of the normal modes of a standing wave on a fixed string [Usage]
6. Calculate the sound intensity level in decibels from the intensity of a sound wave [Usage]

Elective:
7. Apply the Doppler effect formula for a moving source and/or observer [Usage]

4.10.11 CME/Theory of Small Oscillations and Coupled Oscillators (Core Tier1: 1 hr, Core Tier2: 1 hr)

Small oscillations about equilibrium: normal modes, eigenfrequencies, damping, forcing, and coupled systems, extending single-oscillator SHM to engineering systems with several degrees of freedom.
Topics:
Non Core
- Small oscillation approximation via Taylor expansion about a stable equilibrium
- Coupled oscillators and the formulation of equations of motion in matrix form
- Normal modes and eigenfrequencies derived from the eigenvalue problem
- Damped oscillators: underdamped, critically damped, and overdamped regimes

Learning Outcomes:
NonCore:
1. Linearize equations of motion about a stable equilibrium point [Usage]
2. Find normal mode frequencies and eigenvectors for systems of Two coupled oscillators [Usage]

4.10.12 CME/Transport Phenomena (Core Tier1: 1 hr, Core Tier2: 1 hr)

Introduction to transport phenomena in continuous media: heat conduction and mass diffusion as gradient-driven flux processes.
Topics:
Core
- Heat conduction and Fourier's law: $\vec{q} = -k\nabla T$
- Thermal conductivity of materials and thermal resistance in composite walls
- Molecular diffusion and Fick's first law: $\vec{J} = -D\nabla C$

Elective
- Analogy between heat, mass, and momentum transport (Prandtl and Schmidt numbers)

Learning Outcomes:
Core:

1. Apply Fourier's law to calculate the heat flux through a plane or composite wall [Usage]
2. Apply Fick's first law to calculate the diffusive flux of a species in a concentration gradient [Usage]

Elective:

3. Identify mathematical analogies between heat, mass, and momentum transport processes [Familiarity]

4.11 Electromagnetism (ELM)

Electromagnetism studies the behavior of electric charges at rest and in motion, the properties of electric and magnetic fields, and their interaction as described by Maxwell's equations. It covers electrostatics, magnetostatics, electrodynamics, and the propagation of electromagnetic waves in vacuum and matter.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.11.1 Electrostatics: Electric Field and Gauss's Law (Pg.. 143)	1	1
⭐ 4.11.2 Electric Potential and Poisson/Laplace Equations (Pg.. 143)	1	1
⭐ 4.11.3 Electrostatic Energy and Dielectrics (Pg.. 144)	1	1
⭐ 4.11.4 Magnetostatics: Biot-Savart and Ampere's Laws (Pg.. 144)	1	1
⭐ 4.11.5 Magnetic Properties of Matter (Pg.. 144)	1	1
⭐ 4.11.6 Electrodynamics: Faraday's Law and Induction (Pg.. 145)	1	1
⭐ 4.11.7 Electric Current, Circuits, and Kirchhoff's Laws (Pg.. 145)	1	1
4.11.8 Maxwell's Equations and Gauge Transformations (Pg.. 146)	Elective	
4.11.9 Electromagnetic Waves and Propagation in Media (Pg.. 146)	Elective	

Table 4.11: List of KUs in the Electromagnetism area.

4.11.1 ELM/Electrostatics: Electric Field and Gauss's Law (Core Tier1: 1 hr, Core Tier2: 1 hr)

Analysis of stationary charges, the vector nature of the electric field, and the application of Gauss's Law to symmetric engineering configurations.

Topics:

Core

- Coulomb's law for point charges and the principle of linear superposition
- The electric field vector $\vec{E}$ for discrete and continuous charge distributions
- Gauss's Law in integral form and its relation to enclosed charge
- Differential form of Gauss's Law: $\nabla \cdot \vec{E} = \rho/\epsilon_0$
- Applications of Gauss's Law to spherical and cylindrical symmetry
- The Divergence Theorem applied to electrostatic fields

Learning Outcomes:

Core:

1. Calculate the electrostatic force on a charge distribution using superposition [Usage]
2. Apply Gauss's Law to find the electric field for systems with high symmetry [Usage]
3. Evaluate the electric flux through surfaces of engineering interest [Assessment]
4. Determine volume charge density from a given expression of the electric field [Usage]

4.11.2 ELM/Electric Potential and Poisson/Laplace Equations (Core Tier1: 1 hr, Core Tier2: 1 hr)

The scalar potential formulation of electrostatics and the solution of boundary value problems relevant to capacitor and electrode design.

Topics:

Core

- Definition of the scalar potential V and $\vec{E} = -\nabla V$

- Calculating potential for continuous charge distributions
- Poisson's equation $\nabla^2 V = -\rho/\epsilon_0$ and Laplace's equation
- Solution of Laplace's equation via separation of variables for engineering geometries
- The method of images for computing fields near conducting boundaries

Learning Outcomes:

Core:

1. Compute the electrostatic potential energy of a charge configuration [Usage]
2. Derive the electric field vector from a given scalar potential [Usage]
3. Solve Laplace's equation for a practical engineering geometry with specified boundary conditions [Assessment]
4. Apply the method of images to engineering problems involving grounded conductors [Usage]

4.11.3 ELM/Electrostatic Energy and Dielectrics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Energy storage in electric fields, capacitor design, and the macroscopic behavior of dielectric materials used in electrical engineering.

Topics:

Core

- Energy density in the electric field: $u = \frac{1}{2}\epsilon_0 E^2$
- Capacitance $C = Q/V$ for standard engineering geometries
- The displacement vector $\vec{D}$ and Gauss's Law in dielectric materials
- Linear dielectrics, susceptibility, and relative permittivity ϵ_r
- Boundary conditions for $\vec{E}$ and $\vec{D}$ at material interfaces

Learning Outcomes:

Core:

1. Calculate the capacitance of parallel-plate and coaxial capacitors filled with dielectrics [Usage]
2. Evaluate bound charge distributions in polarized dielectric materials [Assessment]
3. Solve for electric fields on both sides of a dielectric interface using boundary conditions [Usage]
4. Analyze the force on a dielectric slab in a partially inserted capacitor [Assessment]

4.11.4 ELM/Magnetostatics: Biot-Savart and Ampere's Laws (Core Tier1: 1 hr, Core Tier2: 1 hr)

The physics of steady currents, magnetic field generation, and forces on moving charges, forming the basis of motor and transformer design.

Topics:

Core

- Lorentz force law: $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
- Magnetic force on current-carrying wires and loops
- Biot-Savart Law for the magnetic field of a current element
- Ampere's Law in integral form for high-symmetry engineering configurations
- The magnetic vector potential $\vec{A}$ and $\vec{B} = \nabla \times \vec{A}$

Learning Outcomes:

Core:

1. Calculate the magnetic field of solenoids and toroids using Ampere's Law [Usage]
2. Compute the magnetic field on the axis of a current loop using the Biot-Savart Law [Usage]
3. Verify that a given magnetic field satisfies $\nabla \cdot \vec{B} = 0$ [Assessment]
4. Analyze the torque on a current loop in a non-uniform magnetic field [Assessment]

4.11.5 ELM/Magnetic Properties of Matter (Core Tier1: 1 hr, Core Tier2: 1 hr)

Magnetization of materials, bound currents, and the classification of magnetic media relevant to transformer core and permanent magnet design.

Topics:

Core

- The magnetization vector $\vec{M}$ as magnetic dipole moment per unit volume
- The magnetic field intensity $\vec{H}$ and Ampere's Law in matter
- Physical principles of diamagnetism, paramagnetism, and ferromagnetism
- Ferromagnetic domains and the hysteresis loop for engineering material selection
- Linear magnetic media and magnetic permeability μ

Learning Outcomes:
Core:

1. Find bound current distributions for magnetized engineering materials [Usage]
2. Classify materials as diamagnetic, paramagnetic, or ferromagnetic for engineering application suitability [Assessment]
3. Analyze energy loss per cycle from a ferromagnetic hysteresis loop for transformer core selection [Assessment]

4.11.6 ELM/Electrodynamics: Faraday's Law and Induction (Core Tier1: 1 hr, Core Tier2: 1 hr)

Time-dependent magnetic fields and electromagnetic induction, foundational to generators, transformers, and electric motors.
Topics:
Core

- Faraday's Law of induction and Lenz's Law
- Self-inductance L and the back-EMF in engineering inductors
- Mutual inductance M and transformer principles
- Energy stored in the magnetic field of inductors
- Eddy currents, magnetic braking, and core loss in electrical machines

Learning Outcomes:
Core:

1. Calculate the induced EMF in a rotating coil and relate it to generator operation [Usage]
2. Apply Lenz's Law to determine the direction of induced currents in engineering scenarios [Assessment]
3. Compute the magnetic energy stored in a solenoid or toroidal inductor [Usage]
4. Evaluate mutual inductance between coupled coils for transformer design [Assessment]

4.11.7 ELM/Electric Current, Circuits, and Kirchhoff's Laws (Core Tier1: 1 hr, Core Tier2: 1 hr)

Study of electric charge flow, resistance, and DC circuit analysis using Kirchhoff's laws, foundational to all electrical engineering.
Topics:
Core

- Definition of current, current density, and the continuity equation
- Ohm's law, resistivity, and temperature dependence of resistance
- Kirchhoff's Current Law (KCL) for circuit node analysis
- Kirchhoff's Voltage Law (KVL) for circuit loop analysis
- Series and parallel circuit simplification and equivalent resistance
- RC and RL circuit transients and engineering time constants

Learning Outcomes:
Core:

1. Apply KCL and KVL to solve multi-loop DC engineering circuits [Usage]
2. Calculate power dissipated in resistive circuit elements [Assessment]
3. Analyze the transient response of RC and RL circuits and determine the time constant [Usage]
4. Design a resistor network to meet specified voltage division or current distribution requirements [Assessment]

4.11.8 ELM/Maxwell's Equations and Gauge Transformations

The unified set of equations governing all classical electromagnetic phenomena and the energy/momentum carried by electromagnetic fields.
Topics:
Core

- Maxwell's displacement current and its role in completing Ampere's Law
- The complete set of four Maxwell's equations in integral and differential forms
- Poynting's theorem and energy conservation in electromagnetic fields
- The Poynting vector $\vec{S} = \vec{E} \times \vec{H}$ as energy flux density
- Gauge invariance and the formulation of potentials in engineering electrodynamics

Learning Outcomes:
Core:

1. Calculate the displacement current in engineering capacitor circuits [Usage]
2. State all four Maxwell equations and identify their physical content [Familiarity]
3. Analyze the energy flow and power dissipation in engineering resistive and reactive components [Assessment]
4. Compute the radiation pressure exerted by an electromagnetic wave on a reflective engineering surface [Usage]

4.11.9 ELM/Electromagnetic Waves and Propagation in Media

The propagation of electromagnetic waves in vacuum, dielectrics, and conductors, fundamental to antenna design, wireless communications, and photonics.
Topics:
Core

- Derivation of the electromagnetic wave equation from Maxwell's equations
- Monochromatic plane wave solutions and their polarization states
- Energy density, intensity, and momentum of plane waves
- Wave propagation in conducting media and the skin depth δ for shielding design
- Reflection and refraction at interfaces for optical and RF engineering

Learning Outcomes:
Core:

1. Derive the dispersion relation and relate the wave speed to medium properties [Usage]
2. Determine the polarization state of a wave from its field vector components [Assessment]
3. Analyze how skin depth varies with frequency and select shielding materials accordingly [Assessment]
4. Apply Fresnel equations to calculate transmission and reflection at material interfaces [Usage]

4.12 Thermodynamics and Statistical Mechanics (TSM)

Thermodynamics and Statistical Mechanics bridge microscopic properties of matter and macroscopic engineering observables. This area covers the laws of energy transfer, entropy, equilibrium states, and heat engine cycles essential for energy systems and thermal engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.12.1 Laws of Thermodynamics and State Functions (Pg.. 147)	1	1
⭐ 4.12.2 Kinetic Theory of Gases (Pg.. 147)	1	1
4.12.3 Heat Engines, Entropy, and the Second Law (Pg.. 147)	Elective	

Table 4.12: List of KUs in the Thermodynamics and Statistical Mechanics area.

4.12.1 TSM/Laws of Thermodynamics and State Functions (Core Tier1: 1 hr, Core Tier2: 1 hr)

Fundamental principles governing energy, heat, and work in engineering thermodynamic systems, and the mathematical definition of state variables.

Topics:

Core

- Zeroth Law of Thermodynamics and temperature equilibrium
- First Law of Thermodynamics: $dU = dQ - dW$ for engineering systems
- Enthalpy $H = U + PV$ and its role in flow processes and chemical reactions
- Heat capacities C_V and C_P and their engineering measurement and application
- Adiabatic processes and isentropic flow conditions in turbomachinery

Learning Outcomes:

Core:

1. Calculate work done by a gas during isothermal and adiabatic expansions in engineering cycles [Usage]
2. Evaluate internal energy changes and apply the First Law to engineering thermodynamic processes [Assessment]
3. Apply Mayer's relation to determine heat capacity ratios for engineering working fluids [Usage]
4. Analyze isentropic flow conditions in engineering nozzles and turbines [Assessment]

4.12.2 TSM/Kinetic Theory of Gases (Core Tier1: 1 hr, Core Tier2: 1 hr)

Microscopic model of gases relating molecular motion to macroscopic engineering properties such as pressure, temperature, and transport coefficients.

Topics:

Core

- Derivation of macroscopic pressure from molecular momentum transfer
- Maxwell-Boltzmann speed distribution and its engineering implications
- Equipartition theorem and degrees of freedom for monatomic and polyatomic gases
- Mean free path and its relevance to gas flow and vacuum engineering
- Transport phenomena: viscosity, thermal conductivity, and diffusion in engineering gases

Learning Outcomes:

Core:

1. Compute the rms and average molecular velocities for engineering working gases [Usage]
2. Interpret the Maxwell-Boltzmann distribution and its temperature dependence for engineering applications [Assessment]
3. Calculate mean free path and relate it to viscosity in gas-dynamics engineering problems [Usage]
4. Estimate thermal conductivity and viscosity of a gas from kinetic theory for engineering design [Assessment]

4.12.3 TSM/Heat Engines, Entropy, and the Second Law

Thermal efficiency limits, entropy generation, and the thermodynamic constraints governing engineering heat engines and refrigeration cycles.

Topics:

Core

- Kelvin-Planck and Clausius statements of the Second Law and their engineering implications
- The Carnot cycle and maximum efficiency $\eta = 1 - T_c/T_h$
- Clausius inequality and the thermodynamic definition of entropy
- Analysis of engineering cycles (Rankine, Brayton, Refrigeration) using T-S diagrams
- Boltzmann's entropy formula $S = k_B \ln \Omega$ and its engineering interpretation

Learning Outcomes:

Core:

1. Calculate the maximum thermal efficiency of an engineering heat engine operating between two temperatures [Usage]

2. Evaluate entropy generation in irreversible engineering processes such as heat transfer across a finite temperature difference [Assessment]
3. Analyze the thermodynamic performance of Rankine and Brayton cycles using T-S diagrams [Usage]
4. Compute entropy changes from microscopic state counts for simple engineering systems [Usage]

4.13 Condensed Matter Physics (SSP)

Condensed Matter Physics investigates the macroscopic and microscopic properties of matter in its solid and liquid phases. It explores how collective interactions between atoms lead to emergent phenomena such as electrical conductivity, magnetism, and semiconductor behavior, directly relevant to materials engineering.

Knowledge Area (KA)	Core Tier1	Core Tier2
4.13.1 Crystal Structures and Reciprocal Lattices (Pg.. 148)	Elective	
4.13.2 Free Electron Model and Band Theory of Solids (Pg.. 148)	Elective	
4.13.3 Semiconductors, Insulators, and Metals (Pg.. 149)	Elective	

Table 4.13: List of KUs in the Condensed Matter Physics area.

4.13.1 SSP/Crystal Structures and Reciprocal Lattices

The mathematical description of periodic atomic arrangements in real and momentum space, forming the structural basis for materials engineering and diffraction analysis.

Topics:

Core

- The 14 Bravais lattices and point group symmetries in engineering materials
- Unit cells, Wigner-Seitz cells, and the basis of atoms in common engineering materials
- Miller indices for crystal planes and directions in structural materials
- The First Brillouin Zone and its significance for electronic and phonon properties
- Atomic packing fractions and coordination numbers for SC, BCC, FCC, and HCP structures

Learning Outcomes:

Core:

1. Determine reciprocal lattice vectors for FCC and BCC engineering metal crystals [Usage]
2. Calculate the atomic packing factor for common engineering crystal structures [Assessment]
3. Explain the use of Miller indices to identify slip planes and fracture planes in engineering metals [Familiarity]
4. Identify rotational and translational symmetries relevant to engineering material texture analysis [Usage]

4.13.2 SSP/Free Electron Model and Band Theory of Solids

The behavior of electrons in periodic potentials, explaining electrical conduction, band gaps, and the electronic properties of engineering solids.

Topics:

Core

- The Drude model: electrical conductivity, drift velocity, and Hall effect in engineering metals
- The Sommerfeld model: Fermi energy, Fermi surface, and density of states
- Bloch's Theorem for electron wavefunctions in periodic crystal potentials
- The Kronig-Penney model and the emergence of energy band gaps
- The tight-binding approximation and band structure of engineering materials

Learning Outcomes:

Core:

1. Calculate the Fermi energy and Fermi temperature for common engineering metals [Usage]

2. Explain the origin of energy band gaps in crystalline solids and their engineering significance [Familiarity]
3. Evaluate the effective mass of charge carriers from a given $E(k)$ dispersion relation [Assessment]
4. Apply band theory to predict the electrical properties of engineering metal alloys and semiconductors [Usage]

4.13.3 SSP/Semiconductors, Insulators, and Metals

Classification of engineering solids based on electronic band structure, carrier density, and doping, foundational to microelectronics and photovoltaics.

Topics:

Core

- Intrinsic semiconductors: carrier concentration and the law of mass action
- Extrinsic semiconductors: n-type and p-type doping and Fermi level shift
- The p-n junction: depletion region, built-in potential, and diode operation
- Carrier mobility, resistivity, and their temperature dependence in engineering semiconductors
- Direct and indirect bandgap semiconductors and their use in LEDs and solar cells

Learning Outcomes:

Core:

1. Determine intrinsic carrier concentration of silicon at room temperature [Usage]
2. Analyze how doping shifts the Fermi level and modifies carrier density in engineering semiconductors [Assessment]
3. Design a p-n junction with specified breakdown voltage for a power electronics application [Usage]
4. Select between direct and indirect bandgap semiconductors for LED versus solar cell applications [Assessment]

4.14 General Chemistry (GCH)

This area covers general chemistry fundamentals: the nature of matter and energy, basic atomic structure, chemical bonding, stoichiometry, and states of matter, needed as a foundation for engineering disciplines.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.14.1 Matter and Energy (Pg.. 149)	1	1
⭐ 4.14.2 Basic Atomic Structure (Pg.. 150)	1	1
⭐ 4.14.3 Chemical Bonding (Pg.. 150)	1	1
⭐ 4.14.4 Stoichiometry (Pg.. 150)	1	1
⭐ 4.14.5 States of Matter (Pg.. 150)	1	1
⭐ 4.14.6 Environmental and Water Chemistry (Pg.. 151)	1	1
⭐ 4.14.7 Polymers and Geosynthetics (Pg.. 151)	1	1
⭐ 4.14.8 Chemical Equilibrium (Pg.. 151)	1	1
⭐ 4.14.9 Ionic Equilibrium and Salt Hydrolysis (Pg.. 151)	1	1
⭐ 4.14.10 Salts, Solubility, and Precipitation Equilibria (Pg.. 152)	1	1
⭐ 4.14.11 Electrochemistry and Electrolysis (Pg.. 152)	1	1
⭐ 4.14.12 Cement Chemistry (Pg.. 152)	1	1

Table 4.14: List of KUs in the General Chemistry area.

4.14.1 GCH/Matter and Energy (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classification of matter, the scientific method, and the unit system used in engineering chemistry.

Topics:

Core

- Classification of matter: elements, compounds, and mixtures

- The scientific method and the international system of units

Learning Outcomes:

Core:

1. Describe the properties of matter and energy and classify a given substance [Familiarity]
2. Perform unit conversions in engineering chemistry problems [Usage]

4.14.2 GCH/Basic Atomic Structure (Core Tier1: 1 hr, Core Tier2: 1 hr)

Structure of the atom, atomic number and isotopes, and electron configuration at an introductory level.

Topics:

Core

- Structure of the atom, atomic number, mass number, and isotopes
- Quantum model of the atom and electron configuration

Learning Outcomes:

Core:

1. Describe the structure of the atom and its subatomic particles [Familiarity]
2. Determine the electron configuration of an atom and relate it to its chemical properties [Usage]

4.14.3 GCH/Chemical Bonding (Core Tier1: 1 hr, Core Tier2: 1 hr)

Types of chemical bonding and their relationship to molecular geometry and substance properties, foundational for engineering material selection.

Topics:

Core

- Ionic, covalent, and metallic bonding
- Molecular geometry and its relationship to substance properties

Learning Outcomes:

Core:

1. Describe the different types of chemical bonding [Familiarity]
2. Predict molecular geometry and relate bond type to material properties [Assessment]

4.14.4 GCH/Stoichiometry (Core Tier1: 1 hr, Core Tier2: 1 hr)

Quantitative calculations of chemical reactions: molar mass, equation balancing, limiting reagent, and yield, essential in engineering processes.

Topics:

Core

- Molar mass, the mole concept, and balancing chemical equations
- Stoichiometric calculations, limiting reagent, and percent yield

Learning Outcomes:

Core:

1. Calculate the molar mass of a compound and balance chemical equations [Usage]
2. Determine the amount of reactants and products in an engineering process using stoichiometric calculations [Assessment]

4.14.5 GCH/States of Matter (Core Tier1: 1 hr, Core Tier2: 1 hr)

Properties of gases, liquids, and solids, phase changes, and ideal gas laws applied to engineering systems.

Topics:

Core

- Properties of gases, liquids, and solids, and phase changes
- Ideal gas laws and phase diagrams

Learning Outcomes:

Core:

1. Describe the properties of the different states of matter and their phase changes [Familiarity]
2. Apply ideal gas laws to engineering problems [Usage]

4.14.6 GCH/Environmental and Water Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr)

Water quality as a resource and environmental pollutants relevant to the design of sanitary and environmental infrastructure.

Topics:

Core

- Water quality parameters (pH, hardness, dissolved oxygen, BOD) for infrastructure design
- Fundamentals of water treatment and major air and water pollutants

Learning Outcomes:

Core:

1. Interpret water quality parameters for the design of treatment systems [Usage]
2. Identify pollutants relevant to sanitary and environmental infrastructure projects [Familiarity]

4.14.7 GCH/Polymers and Geosynthetics (Core Tier1: 1 hr, Core Tier2: 1 hr)

Classification of polymers and geosynthetics used in civil engineering works.

Topics:

Core

- Classification of polymers: thermoplastics, thermosets, and elastomers
- Geosynthetics: geotextiles, geomembranes, and geogrids, and their applications in civil works

Learning Outcomes:

Core:

1. Classify a polymer by its structure and thermal behavior [Usage]
2. Select the appropriate geosynthetic for a given civil engineering application [Usage]

4.14.8 GCH/Chemical Equilibrium (Core Tier1: 1 hr, Core Tier2: 1 hr)

The equilibrium constant and Le Chatelier's principle applied to engineering processes.

Topics:

Core

- The equilibrium constant K_c and its relation to stoichiometry
- Le Chatelier's principle and its effect on industrial chemical processes

Learning Outcomes:

Core:

1. Write the equilibrium constant expression for a reaction of engineering interest [Usage]
2. Predict the shift of a chemical equilibrium in an engineering process [Assessment]

4.14.9 GCH/Ionic Equilibrium and Salt Hydrolysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

pH, acid-base equilibrium, and salt hydrolysis relevant to water quality control and concrete.

Topics:

Core

- Calculating the pH of strong and weak acids and bases
- Salt hydrolysis and its effect on the pH of water and soils

Learning Outcomes:

Core:

1. Calculate the pH of solutions relevant to environmental quality control [Usage]
2. Predict the effect of salt hydrolysis on the pH of water and soils [Assessment]

4.14.10 GCH/Salts, Solubility, and Precipitation Equilibria (Core Tier1: 1 hr, Core Tier2: 1 hr)

The solubility product applied to predicting scaling and precipitates in engineering systems.
Topics:
Core
- The solubility product K_{sp} and predicting precipitation

Learning Outcomes:
Core:
1. Predict the formation of precipitates or scale in engineering water systems [Usage]

4.14.11 GCH/Electrochemistry and Electrolysis (Core Tier1: 1 hr, Core Tier2: 1 hr)

Redox reactions and electrochemistry applied to the corrosion of metals and reinforced concrete.
Topics:
Core
- Redox reactions, galvanic cells, and electrode potentials
- Electrochemical corrosion of metals and of reinforcing steel in reinforced concrete, and protection methods

Learning Outcomes:
Core:
1. Calculate the potential of a galvanic cell and predict the spontaneity of a redox reaction [Usage]
2. Analyze corrosion conditions in engineering structures and propose protection methods [Assessment]

4.14.12 GCH/Cement Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr)

Composition of Portland cement and its hydration reactions, the chemical basis of concrete design.
Topics:
Core
- Chemical composition of Portland cement and its main compounds
- Cement hydration reactions and their relation to concrete strength development

Learning Outcomes:
Core:
1. Describe the chemical composition of Portland cement [Familiarity]
2. Explain the relationship between cement hydration and concrete strength development [Usage]

4.15 Inorganic Chemistry (INC)

This knowledge area covers the fundamental principles of inorganic chemistry including atomic structure, coordination chemistry, main group and transition metal chemistry, organometallic chemistry, and solid-state materials. It emphasizes bonding theories, reaction mechanisms, and applications in catalysis and materials science.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.15.1 Solid State and Material Chemistry (Pg.. 152)	1	1
4.15.2 Atomic Structure and Periodicity (Pg.. 153)	Elective	

Table 4.15: List of KUs in the Inorganic Chemistry area.

4.15.1 INC/Solid State and Material Chemistry (Core Tier1: 1 hr, Core Tier2: 1 hr)

Principles of solid-state chemistry including crystal structures, bonding in engineering solids, defect chemistry, electronic properties, and synthesis methods for inorganic materials.

Topics:
Core
- Crystal systems, Bravais lattices, and Miller indices for engineering materials
- X-ray diffraction for crystal structure determination and phase identification
- Ionic compounds: crystal structures and lattice energies
- Metallic and covalent network solids: bonding and engineering properties
- Point defects, vacancies, interstitials, and non-stoichiometry in engineering solids
- Band theory and the electronic properties of engineering conductors, semiconductors, and insulators
- Synthesis methods for engineering inorganic materials: solid-state reactions, sol-gel, and CVD

Learning Outcomes:
Core:
1. Identify crystal systems and describe symmetry operations in engineering solid materials [Familiarity]
2. Interpret X-ray diffraction patterns to identify crystal phases and determine unit cell parameters [Usage]
3. Calculate lattice energies using Born-Haber cycles for engineering ionic compounds [Usage]
4. Explain how point defects control diffusion, conductivity, and corrosion in engineering materials [Assessment]
5. Apply band theory to predict and engineer the electrical properties of solid materials [Assessment]
6. Select synthesis methods appropriate for producing specific engineering inorganic materials [Usage]

4.15.2 INC/Atomic Structure and Periodicity

Fundamental concepts of atomic structure, electron configuration, periodic trends, and the relationship between electronic structure and chemical properties of engineering materials.
Topics:
Core
- Quantum numbers and atomic orbitals
- Electron configuration and the Aufbau principle
- Periodic trends: atomic radius, ionization energy, and electronegativity
- Effective nuclear charge and shielding effects relevant to material selection
- Spin-orbit coupling and magnetic properties of engineering materials

Learning Outcomes:
Core:
1. Describe quantum numbers and their role in defining atomic orbitals of engineering elements [Familiarity]
2. Write electron configurations for atoms and ions commonly encountered in engineering materials [Usage]
3. Predict periodic trends in atomic properties and relate them to material engineering performance [Assessment]
4. Interpret magnetic properties of engineering alloys using spin-orbit coupling considerations [Usage]

4.16 Physical Chemistry (PHC)

This knowledge area covers the application of physics principles to chemical systems. It includes chemical thermodynamics, statistical mechanics, quantum chemistry, molecular kinetics, and surface phenomena.

Knowledge Area (KA)	Core Tier1	Core Tier2
4.16.1 Chemical Thermodynamics and Equilibrium (Pg.. 154)	Elective	

Table 4.16: List of KUs in the Physical Chemistry area.

4.16.1 PHC/Chemical Thermodynamics and Equilibrium

Application of the laws of thermodynamics to chemical engineering systems: state functions, chemical potential, phase equilibria, and reaction equilibrium.
Topics:
Core

- Laws of thermodynamics applied to chemical engineering processes
- State functions: enthalpy, entropy, and Gibbs free energy in chemical process engineering
- Chemical potential and fugacity in engineering fluid systems and mixtures
- Phase equilibrium in multicomponent engineering systems and phase diagrams
- Chemical reaction equilibrium: equilibrium constants and temperature dependence
- Non-ideal solutions, activity coefficients, and their role in chemical process design

Learning Outcomes:
Core:

1. Explain the Second Law of Thermodynamics in terms of entropy and spontaneity of engineering chemical processes [Familiarity]
2. Calculate Gibbs free energy changes to determine whether engineering chemical reactions are spontaneous [Usage]
3. Apply chemical potential to derive equilibrium conditions for engineering multiphase systems [Assessment]
4. Interpret binary phase diagrams for engineering alloys and mixtures [Usage]
5. Predict the behavior of engineering gas mixtures and solutions using non-ideality models [Assessment]

4.17 Materials Science and Nanotechnology (MSN)

This knowledge area explores the synthesis, characterization, and application of advanced materials at the macro, micro, and nano scales. It covers nanofabrication techniques, advanced characterization tools, and the development of functional materials for energy and smart engineering applications.

Knowledge Area (KA)	Core Tier1	Core Tier2
4.17.1 Synthesis of Nanomaterials and Nanofabrication (Pg.. 154)	Elective	
4.17.2 Characterization of Materials (XRD, SEM, TEM) (Pg.. 155)	Elective	
4.17.3 Energy Storage and Conversion Materials (Pg.. 155)	Elective	

Table 4.17: List of KUs in the Materials Science and Nanotechnology area.

4.17.1 MSN/Synthesis of Nanomaterials and Nanofabrication

Bottom-up and top-down approaches for producing engineering nanomaterials, including chemical vapor deposition, sol-gel processes, and lithography.
Topics:
Core

- Bottom-up synthesis: sol-gel, self-assembly, and chemical bath deposition for engineering nanomaterials
- Top-down nanofabrication: photolithography, electron-beam lithography, and milling
- Physical and chemical vapor deposition (PVD and CVD) for engineering thin film production
- Thermodynamics and kinetics of nucleation and crystal growth at the nanoscale
- Surface functionalization and stabilization of engineering nanoparticles

Learning Outcomes:
Core:

1. Describe the fundamental differences between bottom-up and top-down nanofabrication routes [Familiarity]

2. Synthesize nanoparticles using wet-chemical methods and characterize their size distribution [Usage]
3. Evaluate the suitability of CVD versus PVD for producing high-purity engineering thin films [Assessment]
4. Optimize reaction conditions to control the size and morphology of engineering nanostructures [Usage]

4.17.2 MSN/Characterization of Materials (XRD, SEM, TEM)

Advanced analytical techniques for probing the structural, morphological, and elemental properties of engineering materials.

Topics:

Core

- X-ray diffraction (XRD) for crystal structure determination and phase identification in engineering materials
- Scanning electron microscopy (SEM) for surface morphology and failure analysis
- Transmission electron microscopy (TEM) for internal structure and defect imaging in engineering materials
- Energy-dispersive X-ray spectroscopy (EDS) for elemental composition mapping
- Atomic force microscopy (AFM) for surface roughness and nanomechanical property measurement

Learning Outcomes:

Core:

1. Explain Bragg's Law and its application in identifying phases in engineering material XRD patterns [Familiarity]
2. Interpret SEM micrographs to assess surface morphology and fracture modes in engineering materials [Usage]
3. Analyze TEM images to identify dislocations, grain boundaries, and phases in engineering alloys [Assessment]
4. Perform elemental quantification using EDS to verify composition of engineering multi-component materials [Usage]

4.17.3 MSN/Energy Storage and Conversion Materials

Chemistry and physics of materials used in batteries, supercapacitors, fuel cells, and photovoltaic devices for engineering energy systems.

Topics:

Core

- Lithium-ion batteries: electrode materials, electrolytes, and degradation mechanisms
- Photovoltaic materials: silicon-based, perovskite, and third-generation solar cells
- Supercapacitors: electric double-layer and pseudocapacitive materials for power engineering
- Fuel cell components: proton exchange membranes and electrocatalysts for energy engineering
- Solid-state hydrogen storage materials for engineering energy carrier systems

Learning Outcomes:

Core:

1. Describe charge-discharge mechanisms in lithium-ion batteries and relate them to engineering performance [Familiarity]
2. Evaluate the advantages and stability challenges of perovskite solar cells for engineering deployment [Assessment]
3. Design electrode architectures for enhanced supercapacitor energy density in engineering power systems [Usage]
4. Analyze the efficiency and durability of electrocatalysts for hydrogen and oxygen reactions in fuel cells [Assessment]

4.18 Probability Theory (PRO)

This knowledge area covers the mathematical foundations of probability, including sample spaces, random variables, probability distributions, joint distributions, moments, transformations, and the fundamental limit theorems. It provides the theoretical basis for all of statistical inference and modeling.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.18.1 Sample Spaces and Events (Pg.. 156)	1	1
⭐ 4.18.2 Probability Axioms and Properties (Pg.. 156)	1	1
⭐ 4.18.3 Conditional Probability and Independence (Pg.. 157)	1	1
⭐ 4.18.4 Discrete Random Variables and Distributions (Pg.. 157)	1	1
⭐ 4.18.5 Continuous Random Variables and Distributions (Pg.. 157)	1	1
⭐ 4.18.6 Joint, Marginal, and Conditional Distributions (Pg.. 158)	1	1
⭐ 4.18.7 Limit Theorems: LLN and CLT (Pg.. 158)	1	1

Table 4.18: List of KUs in the Probability Theory area.

4.18.1 PRO/Sample Spaces and Events (Core Tier1: 1 hr, Core Tier2: 1 hr)

Formal definition of random experiments, sample spaces, and events. Covers set-theoretic operations on events and the construction of sigma-algebras as the foundation of probability theory.
Topics:
Core

- Random experiments, outcomes, and sample spaces: finite, countable, and uncountable
- Set-theoretic operations on events: union, intersection, complement, and De Morgan's laws
- Sigma-algebras and measurable spaces as the foundation for rigorous probability
- Borel sets and the Borel sigma-algebra on the real line

Learning Outcomes:
Core:

1. Define sample spaces, events, and sigma-algebras for a given random experiment [Familiarity]
2. Apply set-theoretic operations to compute probabilities of compound events [Usage]
3. Construct appropriate sigma-algebras for measurable spaces arising in statistical problems [Assessment]

4.18.2 PRO/Probability Axioms and Properties (Core Tier1: 1 hr, Core Tier2: 1 hr)

Kolmogorov's axioms of probability and derived properties. Covers classical, frequentist, and subjective interpretations of probability and their implications.
Topics:
Core

- Kolmogorov's three axioms of probability and their consequences
- Derived properties: complement rule, addition rule, monotonicity, and continuity of probability
- Classical, frequentist, and subjective (Bayesian) interpretations of probability
- Counting methods: permutations, combinations, and the multiplication principle

Learning Outcomes:
Core:

1. State Kolmogorov's axioms and derive fundamental probability properties [Familiarity]
2. Calculate probabilities of events using the addition rule and complement rule [Usage]
3. Apply counting methods to compute probabilities in finite sample spaces [Usage]

4.18.3 PRO/Conditional Probability and Independence (Core Tier1: 1 hr, Core Tier2: 1 hr)

Conditional probability, the multiplication rule, the law of total probability, Bayes' theorem, and the concept of independence between events and collections of events.

Topics:

Core

- Definition and interpretation of conditional probability P(A|B) and its properties
- Bayes' theorem and the law of total probability: derivation and applications
- Independence of events: pairwise and mutual independence
- Conditional independence and its role in probabilistic graphical models

Learning Outcomes:

Core:

1. Explain conditional probability and independence and their relationship [Familiarity]
2. Apply Bayes' theorem and the law of total probability to solve probability problems [Usage]
3. Analyze whether events are independent or conditionally independent in a given probability model [Assessment]

4.18.4 PRO/Discrete Random Variables and Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr)

Random variables as measurable functions, probability mass functions, cumulative distribution functions, and the most important discrete probability distributions.

Topics:

Core

- Probability mass functions (PMF) and cumulative distribution functions (CDF) for discrete random variables
- Key discrete distributions: Bernoulli, Binomial, Geometric, Negative Binomial, Poisson, Hypergeometric
- Properties of discrete distributions: mean, variance, skewness, and kurtosis
- Poisson approximation to the Binomial and limiting distribution arguments

Learning Outcomes:

Core:

1. Identify and describe the key discrete probability distributions and their parameters [Familiarity]
2. Calculate probabilities, means, and variances using PMFs of standard discrete distributions [Usage]
3. Select an appropriate discrete distribution to model a given random phenomenon and justify the choice [Assessment]

4.18.5 PRO/Continuous Random Variables and Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr)

Probability density functions, CDFs, and the most important continuous probability distributions used in statistical theory and practice.

Topics:

Core

- Probability density functions (PDF) and CDFs for continuous random variables
- Key continuous distributions: Uniform, Normal, Exponential, Gamma, Beta, Chi-squared, t, F
- The Normal distribution: properties, standard normal, and its central role in statistical inference
- The exponential family of distributions: canonical form and sufficient statistics

Learning Outcomes:

Core:

1. Describe the properties and parameters of key continuous probability distributions [Familiarity]
2. Calculate probabilities and quantiles for standard continuous distributions [Usage]

3. Identify distributions belonging to the exponential family and derive their sufficient statistics [Assessment]

4.18.6 PRO/Joint, Marginal, and Conditional Distributions (Core Tier1: 1 hr, Core Tier2: 1 hr)

Joint distributions of multiple random variables, marginal and conditional distributions, covariance, correlation, and the bivariate normal distribution.

Topics:

Core

- Joint PMFs and PDFs for two or more random variables
- Marginal and conditional distributions derived from joint distributions
- Covariance, correlation, and their properties; independence implies zero covariance (converse not always true)
- The bivariate normal distribution and its conditional distributions

Learning Outcomes:

Core:

1. Derive marginal and conditional distributions from a given joint distribution [Usage]
2. Calculate covariance and correlation between two random variables [Usage]
3. Analyze the conditional structure of the bivariate normal distribution [Assessment]

4.18.7 PRO/Limit Theorems: LLN and CLT (Core Tier1: 1 hr, Core Tier2: 1 hr)

The laws of large numbers and the central limit theorem as the mathematical justification for statistical estimation and inference procedures based on large samples.

Topics:

Core

- Weak law of large numbers: convergence in probability and its implications for estimation
- Central limit theorem: statement, conditions, and role in justifying normal approximations
- Applications of the CLT: normal approximation to the binomial and sampling distributions
- Strong law of large numbers: almost sure convergence
- The delta method: asymptotic distribution of smooth functions of estimators

Learning Outcomes:

Core:

1. State the LLN and CLT and explain the conditions under which they hold [Familiarity]
2. Apply the CLT to derive normal approximations and sampling distributions [Usage]
3. Apply the delta method to derive asymptotic distributions of nonlinear estimators [Assessment]

4.19 Descriptive Statistics and Data Analysis (DSC)

This knowledge area covers methods for summarizing, visualizing, and exploring data. It includes numerical and graphical summaries, exploratory data analysis, data quality assessment, and communication of statistical findings.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.19.1 Numerical Summaries: Location, Spread, and Shape (Pg.. 158)	1	1

Table 4.19: List of KUs in the Descriptive Statistics and Data Analysis area.

4.19.1 DSC/Numerical Summaries: Location, Spread, and Shape (Core Tier1: 1 hr, Core Tier2: 1 hr)

Measures of central tendency, dispersion, and distributional shape. Includes robust alternatives and the interpretation of numerical summaries in context.

Topics:

Core

- Measures of location: mean, median, mode, trimmed mean, and weighted mean
- Measures of spread: variance, standard deviation, IQR, MAD, and range
- Measures of shape: skewness and kurtosis; quantiles and percentiles
- Robust summary statistics: resistance to outliers and heavy-tailed distributions

Learning Outcomes:

Core:

1. Calculate and interpret measures of location, spread, and shape for a univariate dataset [Usage]
2. Select appropriate summary statistics based on the distributional properties of the data [Usage]
3. Compare classical and robust summary statistics and justify the choice for a given dataset [Assessment]

4.20 Statistical Inference (INF)

This knowledge area covers the foundations and methods of statistical inference: point and interval estimation, hypothesis testing, likelihood theory, Bayesian inference, nonparametric methods, multiple testing, and large-sample theory. It is the core of classical and modern statistics.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.20.1 Point Estimation (Pg.. 159)	1	1
⭐ 4.20.2 Interval Estimation and Confidence Intervals (Pg.. 159)	1	1
⭐ 4.20.3 Hypothesis Testing Foundations (Pg.. 160)	1	1
⭐ 4.20.4 Bayesian Inference (Pg.. 160)	1	1

Table 4.20: List of KUs in the Statistical Inference area.

4.20.1 INF/Point Estimation (Core Tier1: 1 hr, Core Tier2: 1 hr)

Methods for estimating unknown parameters from data. Covers desirable properties of estimators, method of moments, maximum likelihood estimation, and the Cramer-Rao lower bound.

Topics:

Core

- Desirable properties: unbiasedness, consistency, efficiency, and sufficiency
- Method of moments estimation: derivation and asymptotic properties
- Maximum likelihood estimation: derivation, properties, and invariance principle
- Cramer-Rao lower bound and the concept of Fisher information

Learning Outcomes:

Core:

1. Describe the key properties of estimators and explain the trade-offs between them [Familiarity]
2. Derive method of moments and MLE estimators for standard distributions [Usage]
3. Evaluate the efficiency of an estimator using the Cramer-Rao lower bound [Assessment]

4.20.2 INF/Interval Estimation and Confidence Intervals (Core Tier1: 1 hr, Core Tier2: 1 hr)

Construction and interpretation of confidence intervals. Covers pivotal quantity method, large-sample intervals, and the relationship between confidence intervals and hypothesis tests.

Topics:

Core

- Constructing confidence intervals using pivotal quantities and exact distributions
- Correct interpretation of confidence intervals: coverage probability and common misconceptions
- Large-sample confidence intervals based on asymptotic normality
- Duality between confidence intervals and hypothesis tests

Learning Outcomes:

Core:

1. Construct confidence intervals for means, proportions, and variances using exact and large-sample methods [Usage]
2. Interpret confidence intervals correctly and identify common misinterpretations [Usage]
3. Explain the duality between confidence intervals and hypothesis tests and use it to draw inferences [Assessment]

4.20.3 INF/Hypothesis Testing Foundations (Core Tier1: 1 hr, Core Tier2: 1 hr)

The Neyman-Pearson framework for hypothesis testing: null and alternative hypotheses, Type I and II errors, power, p-values, and the most powerful tests.

Topics:

Core

- Neyman-Pearson framework: null/alternative hypotheses, rejection regions, Type I and II errors
- p-values: definition, correct interpretation, and common misuse; power and sample size
- Common parametric tests: z-test, t-test, F-test, chi-squared test
- Neyman-Pearson lemma and uniformly most powerful tests

Learning Outcomes:

Core:

1. Explain the logic of hypothesis testing, Type I and II errors, and the meaning of a p-value [Familiarity]
2. Apply standard parametric tests and interpret the results in context [Usage]
3. Derive the most powerful test for a simple hypothesis using the Neyman-Pearson lemma [Assessment]

4.20.4 INF/Bayesian Inference (Core Tier1: 1 hr, Core Tier2: 1 hr)

The Bayesian approach to statistical inference: prior distributions, likelihood, posterior distributions, credible intervals, and Bayesian decision theory.

Topics:

Core

- Bayesian framework: prior, likelihood, posterior, and the role of Bayes' theorem
- Prior distributions: informative, non-informative, and conjugate priors
- Posterior inference: point estimates, credible intervals, and posterior predictive distributions
- Bayesian model comparison: Bayes factors and posterior model probabilities

Learning Outcomes:

Core:

1. Explain the Bayesian approach to inference and contrast it with the frequentist approach [Familiarity]
2. Derive the posterior distribution for standard conjugate models [Usage]
3. Apply Bayes factors to compare statistical models and interpret the evidence [Assessment]

4.21 Regression and Statistical Models (REG)

This knowledge area covers the construction, estimation, interpretation, and validation of statistical models for relationships between variables. It spans simple and multiple linear regression, generalized linear models, nonparametric regression, mixed models, and causal inference.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 4.21.1 Simple Linear Regression (Pg.. 161)	1	1

Table 4.21: List of KUs in the Regression and Statistical Models area.

4.21.1 REG/Simple Linear Regression (Core Tier1: 1 hr, Core Tier2: 1 hr)

The simple linear regression model: least squares estimation, inference for coefficients, model fit, and the assumptions of the classical linear model.

Topics:

Core

- Ordinary least squares estimation: derivation of coefficients and their properties
- Inference for regression coefficients: t-tests, confidence intervals, and p-values
- Coefficient of determination R-squared and analysis of variance decomposition
- Gauss-Markov theorem: BLUE property of OLS under classical assumptions

Learning Outcomes:

Core:

1. Fit a simple linear regression model and interpret the estimated coefficients [Usage]
2. Conduct hypothesis tests and construct confidence intervals for regression parameters [Usage]
3. Verify the Gauss-Markov assumptions and assess their consequences when violated [Assessment]

Chapter 5

Body of knowledge of Project Management

The 9 knowledge areas in Project Management are:

5.1 Project Management Principles (PR) (Pg.. 163)
- 5.1.1 Stewardship (Pg.. 164)
- 5.1.2 Create a Collaborative Project Team Environment (Pg.. 164)
- 5.1.3 Effectively Engage with Stakeholders (Pg.. 165)
- 5.1.4 Focus on Value (Pg.. 165)
- 5.1.5 Recognize, Evaluate, and Respond to System Interactions (Pg.. 165)
- 5.1.6 Demonstrate Leadership Behaviors (Pg.. 166)
- 5.1.7 Tailor Based on Context (Pg.. 166)
- 5.1.8 Build Quality into Processes and Deliverables (Pg.. 167)
- 5.1.9 Navigate Complexity (Pg.. 167)
- 5.1.10 Optimize Risk Responses (Pg.. 167)
- 5.1.11 Embrace Adaptability and Resiliency (Pg.. 168)
- 5.1.12 Enable Change to Achieve the Envisioned Future State (Pg.. 168)

5.2 Stakeholders (ST) (Pg.. 168)
- 5.2.1 Stakeholder Identification and Analysis (Pg.. 169)
- 5.2.2 Stakeholder Engagement Planning (Pg.. 169)
- 5.2.3 Stakeholder Communication and Relationships (Pg.. 169)
- 5.2.4 Managing Stakeholder Expectations (Pg.. 170)
- 5.2.5 Stakeholder Influence and Power (Pg.. 170)
- 5.2.6 Conflict and Negotiation with Stakeholders (Pg.. 170)
- 5.2.7 Monitoring Stakeholder Engagement (Pg.. 171)

5.3 Team (TM) (Pg.. 171)
- 5.3.1 Project Team Culture (Pg.. 171)
- 5.3.2 Team Leadership Styles (Pg.. 172)
- 5.3.3 Team Development and Performance (Pg.. 172)
- 5.3.4 Motivation and Empowerment (Pg.. 172)
- 5.3.5 Collaboration and Trust Building (Pg.. 173)
- 5.3.6 Distributed and Virtual Teams (Pg.. 173)
- 5.3.7 Ethics and Professional Conduct (Pg.. 173)

5.4 Development Approach and Life Cycle (DL) (Pg.. 174)
- 5.4.1 Kickoff and Closure Activities (Pg.. 174)
- 5.4.2 Development Approach Selection (Pg.. 174)
- 5.4.3 Predictive Approach (Pg.. 175)
- 5.4.4 Adaptive Approach (Pg.. 175)
- 5.4.5 Hybrid Approach (Pg.. 175)
- 5.4.6 Project Phase Structure (Pg.. 176)
- 5.4.7 Tailoring the Development Approach (Pg.. 176)

5.5 Planning (PL) (Pg.. 176)
- 5.5.1 Planning Principles (Pg.. 177)
- 5.5.2 Scope and Requirements Planning (Pg.. 177)
- 5.5.3 Schedule Planning (Pg.. 177)
- 5.5.4 Cost and Budget Planning (Pg.. 178)
- 5.5.5 Resource Planning (Pg.. 178)
- 5.5.6 Quality Planning (Pg.. 178)
- 5.5.7 Risk and Uncertainty Planning (Pg.. 179)
- 5.5.8 Communications and Stakeholder Engagement Planning (Pg.. 179)
- 5.5.9 Procurement Planning (Pg.. 179)
- 5.5.10 Integrated Project Planning (Pg.. 180)

5.6 Project Work (PW) (Pg.. 180)
- 5.6.1 Managing Project Artifacts (Pg.. 180)
- 5.6.2 Communication and Knowledge Management (Pg.. 181)
- 5.6.3 Team Engagement During Execution (Pg.. 181)
- 5.6.4 Stakeholder Engagement During Execution (Pg.. 181)
- 5.6.5 Managing Physical Resources (Pg.. 182)
- 5.6.6 Working with Procurements (Pg.. 182)
- 5.6.7 Monitoring and Adapting Work (Pg.. 182)

5.7 Delivery (DV) (Pg.. 183)
- 5.7.1 Value Definition and Delivery (Pg.. 183)
- 5.7.2 Requirements and Scope Delivery (Pg.. 183)
- 5.7.3 Quality Assurance and Delivery (Pg.. 184)
- 5.7.4 Incremental and Iterative Delivery (Pg.. 184)
- 5.7.5 Transition and Handover (Pg.. 184)
- 5.7.6 Benefits Realization Management (Pg.. 185)
- 5.7.7 Customer and User Satisfaction (Pg.. 185)

5.8 Measurement (MS) (Pg.. 185)
- 5.8.1 Key Performance Indicators (Pg.. 185)
- 5.8.2 Dashboards and Information Radiators (Pg.. 186)
- 5.8.3 Measurement Purpose and Approach (Pg.. 186)
- 5.8.4 Earned Value and Schedule Performance (Pg.. 186)
- 5.8.5 Forecasting and Trends (Pg.. 187)
- 5.8.6 Stakeholder Performance Reporting (Pg.. 187)
- 5.8.7 Lessons Learned and Knowledge Capture (Pg.. 187)

5.9 Uncertainty (UN) (Pg.. 188)
- 5.9.1 Understanding Uncertainty and Risk (Pg.. 188)
- 5.9.2 Risk Identification and Assessment (Pg.. 188)
- 5.9.3 Threat and Opportunity Response (Pg.. 189)
- 5.9.4 Ambiguity Management (Pg.. 189)
- 5.9.5 Complexity Management (Pg.. 190)
- 5.9.6 Volatility and Resilience Strategies (Pg.. 190)
- 5.9.7 Monitoring and Adapting to Uncertainty (Pg.. 190)

5.1 Project Management Principles (PR)

This knowledge area covers the twelve foundational principles introduced in PMBoK 7th edition (2021). These principles are not prescriptive rules but guiding behaviors and values that practitioners

use to navigate project decisions. They provide the ethical and professional foundation for all project management performance domains.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.1.1 Stewardship (Pg.. 164)	Elective	
5.1.2 Create a Collaborative Project Team Environment (Pg.. 164)	Elective	
5.1.3 Effectively Engage with Stakeholders (Pg.. 165)	Elective	
5.1.4 Focus on Value (Pg.. 165)	Elective	
5.1.5 Recognize, Evaluate, and Respond to System Interactions (Pg.. 165)	Elective	
5.1.6 Demonstrate Leadership Behaviors (Pg.. 166)	Elective	
5.1.7 Tailor Based on Context (Pg.. 166)	Elective	
5.1.8 Build Quality into Processes and Deliverables (Pg.. 167)	Elective	
5.1.9 Navigate Complexity (Pg.. 167)	Elective	
5.1.10 Optimize Risk Responses (Pg.. 167)	Elective	
5.1.11 Embrace Adaptability and Resiliency (Pg.. 168)	Elective	
5.1.12 Enable Change to Achieve the Envisioned Future State (Pg.. 168)	Elective	

Table 5.1: List of KUs in the Project Management Principles area.

5.1.1 PR/Stewardship

Being a diligent, respectful, and caring steward. Project practitioners act as stewards of the organization, project team, stakeholders, and the broader environment, balancing organizational and external factors in a responsible and ethical manner.

Topics:

Core

- Responsible and ethical conduct as a foundation of stewardship
- Acting as a steward of organizational resources: financial, human, material, and intellectual
- Stewardship of the external environment: sustainability, community impact, and societal responsibility
- Transparency, accountability, and honest reporting as stewardship behaviors
- Long-term thinking: balancing immediate project needs with long-term organizational and societal outcomes

Learning Outcomes:

Core:

1. Describe the concept of stewardship and its application to project management responsibilities [Familiarity]
2. Apply stewardship principles to make responsible resource and ethical decisions in a project context [Usage]
3. Evaluate project decisions from the perspective of stewardship toward the organization, stakeholders, and society [Assessment]

5.1.2 PR/Create a Collaborative Project Team Environment

Building a team environment characterized by shared ownership, mutual respect, and collaborative decision-making. This principle emphasizes that project outcomes emerge from collective team effort rather than individual heroics.

Topics:

Core

- Shared ownership of project goals and outcomes within the team
- Psychological safety: creating an environment where team members can contribute ideas and raise concerns without fear
- Collaborative decision-making and inclusive participation
- Clarity of roles, responsibilities, and accountabilities within the team
- Leveraging diversity and inclusion for team creativity and problem-solving

Learning Outcomes:
Core:
1. Explain how a collaborative team environment contributes to project success [Familiarity]
2. Foster shared ownership and psychological safety within a project team [Usage]
3. Design practices that promote inclusion and collaborative decision-making in a project team [Assessment]

5.1.3 PR/Effectively Engage with Stakeholders

Proactively engaging with stakeholders to understand their needs, interests, and concerns, and involving them in project decisions. Effective stakeholder engagement increases the likelihood of delivering value and achieving project success.
Topics:
Core
- Proactive stakeholder engagement throughout the project life cycle
- Understanding stakeholder interests, needs, expectations, and potential impact
- Two-way communication and feedback loops with stakeholders
- Adapting engagement strategies to evolving stakeholder needs and project context

Learning Outcomes:
Core:
1. Describe the importance of proactive stakeholder engagement as a project management principle [Familiarity]
2. Apply stakeholder engagement strategies that promote two-way communication and shared understanding [Usage]
3. Evaluate the effectiveness of stakeholder engagement approaches and propose improvements [Assessment]

5.1.4 PR/Focus on Value

Continually evaluating and adjusting project alignment with business outcomes and intended benefits. Value is the ultimate indicator of project success, and it may be defined differently by different stakeholders throughout the project.
Topics:
Core
- Defining value: tangible and intangible benefits, business outcomes, and stakeholder satisfaction
- Aligning project work continuously with the intended value and business case
- Benefits realization: ensuring delivered outcomes translate into actual organizational value
- Distinguishing between delivering scope and delivering value
- Strategies for early and incremental value delivery

Learning Outcomes:
Core:
1. Define value in the context of a project and identify how it differs across stakeholders [Familiarity]
2. Align project decisions and trade-offs with the intended value and business outcomes [Usage]
3. Evaluate whether a project's current trajectory is delivering the expected value and propose adjustments [Assessment]

5.1.5 PR/Recognize, Evaluate, and Respond to System Interactions

Understanding projects as components of a larger system with interdependencies, feedback loops, and emergent behaviors. Systems thinking helps project practitioners anticipate second-order effects and make better decisions.
Topics:
Core
- Systems thinking foundations: interdependencies, feedback loops, and emergent behaviors

- The project as a system embedded within organizational and environmental systems
- Anticipating second-order effects of project decisions on the broader system
- Systems mapping: visualizing interdependencies and influence relationships

Learning Outcomes:
Core:

1. Explain how systems thinking applies to project management decision-making [Familiarity]
2. Analyze a project situation using systems thinking to identify interdependencies and potential second-order effects [Usage]
3. Apply systems mapping to visualize the relationships between a project and its organizational environment [Assessment]

5.1.6 PR/Demonstrate Leadership Behaviors

Demonstrating and adapting leadership behaviors to support individual and team needs. Effective leadership in project management is not tied to a formal role - anyone on the project team can and should demonstrate leadership.
Topics:
Core

- Distinction between leadership and management in project contexts
- Adaptive leadership: adjusting style to context, team maturity, and situational needs
- Servant leadership: prioritizing team needs and removing obstacles to performance
- Key leadership behaviors: vision, influence, empathy, integrity, and decisiveness
- Shared and distributed leadership: empowering team members to lead within their domain

Learning Outcomes:
Core:

1. Describe the key leadership behaviors expected of project practitioners regardless of their role [Familiarity]
2. Demonstrate adaptive leadership behaviors appropriate to a given project team situation [Usage]
3. Evaluate the leadership climate of a project team and propose interventions to strengthen it [Assessment]

5.1.7 PR/Tailor Based on Context

Adapting the project approach, governance, and processes to fit the specific context of the project. Tailoring recognizes that no single methodology fits all projects, and that effective practitioners select and adapt their approach deliberately.
Topics:
Core

- The concept of tailoring: adapting frameworks, methods, and processes to context
- Factors that influence tailoring: project size, complexity, uncertainty, team maturity, and organizational culture
- Tailoring governance structures: approval levels, reporting requirements, and decision authorities
- Tailoring the life cycle and development approach to project-specific needs
- Continuously reassessing and adjusting tailoring decisions as the project evolves

Learning Outcomes:
Core:

1. Explain the purpose of tailoring and why a one-size-fits-all approach is insufficient in project management [Familiarity]
2. Apply tailoring criteria to select an appropriate project approach for a given project context [Usage]
3. Design a tailored project governance structure appropriate to a specific project's complexity and risk profile [Assessment]

5.1.8 PR/Build Quality into Processes and Deliverables

Maintaining focus on quality throughout the project by embedding quality into processes and deliverables rather than inspecting quality after the fact. Quality is defined by meeting requirements and fitness for purpose as perceived by stakeholders.

Topics:

Core

- Defining quality: meeting requirements, fitness for purpose, and stakeholder satisfaction
- Building quality in: prevention over inspection, shift-left testing, and continuous improvement
- Quality in processes: consistent execution, repeatability, and process improvement
- Balancing the cost of quality with the cost of poor quality

Learning Outcomes:

Core:

1. Describe the principle of building quality into project processes and deliverables [Familiarity]
2. Apply quality-by-design practices to embed quality checkpoints throughout the project life cycle [Usage]
3. Evaluate the trade-off between quality investment and the cost of poor quality in a project scenario [Assessment]

5.1.9 PR/Navigate Complexity

Using knowledge, experience, and learning to navigate complexity throughout the project. Complexity arises from human behavior, system interactions, and uncertainty, and cannot be eliminated but must be managed adaptively.

Topics:

Core

- Defining complexity: distinction from complicatedness, sources of complexity in projects
- Cynefin framework: simple, complicated, complex, and chaotic domains
- Indicators of project complexity: interdependencies, ambiguity, uncertainty, and innovation
- Strategies for navigating complexity: iterative approaches, experimentation, and emergent solutions
- Building team and organizational resilience to manage ongoing complexity

Learning Outcomes:

Core:

1. Describe the nature and sources of complexity in project environments [Familiarity]
2. Apply the Cynefin framework to classify a project situation and select an appropriate response approach [Usage]
3. Develop strategies for navigating a specific complex project situation [Assessment]

5.1.10 PR/Optimize Risk Responses

Constantly evaluating exposure to both threats and opportunities, and optimizing risk responses to maximize positive outcomes and minimize negative impacts. Risk optimization is an ongoing activity, not a one-time planning step.

Topics:

Core

- Viewing risk as both threat and opportunity: balanced risk mindset
- Continuous risk assessment throughout the project life cycle
- Optimizing risk responses: proportionality, cost-effectiveness, and timeliness
- Building a risk-aware culture: open communication about risks at all levels

Learning Outcomes:

Core:

1. Explain the principle of optimizing risk responses including both threats and opportunities [Familiarity]
2. Apply continuous risk assessment practices to identify and respond to emerging risks [Usage]
3. Evaluate the proportionality and cost-effectiveness of a set of risk responses [Assessment]

5.1.11 PR/Embrace Adaptability and Resiliency

Building adaptability and resiliency into the project and team to absorb the impacts of change and disruption. Adaptable teams respond effectively to changing requirements, unexpected events, and emerging information.

Topics:

Core

- Adaptability: the ability to respond effectively to changes in the project environment
- Resiliency: the capacity to absorb disruption and recover without loss of function
- Building change readiness in teams: flexible mindset, skills versatility, and open communication
- Organizational resilience and its relationship to project adaptability

Learning Outcomes:

Core:

1. Distinguish between adaptability and resiliency and explain their importance in project management [Familiarity]
2. Apply practices that build team adaptability and change readiness in a project environment [Usage]
3. Design a resilience strategy for a project team operating in a highly volatile environment [Assessment]

5.1.12 PR/Enable Change to Achieve the Envisioned Future State

Preparing those affected by the project for the transition from current state to future state. Projects create change, and enabling that change requires structured change management integrated with project delivery.

Topics:

Core

- Change management foundations: current state, transition state, and future state
- Assessing and building stakeholder readiness for organizational change
- Understanding and managing resistance to change in project-driven transformations
- Change management models: Kotter 8-step, ADKAR, and Prosci
- Embedding and sustaining change after project completion

Learning Outcomes:

Core:

1. Describe the role of change management as an integral part of project delivery [Familiarity]
2. Apply a change management model to plan and execute a project-driven organizational transition [Usage]
3. Evaluate stakeholder readiness for change and design interventions to reduce resistance [Assessment]

5.2 Stakeholders (ST)

This performance domain covers the activities and functions associated with stakeholders throughout the project. Effective stakeholder engagement requires understanding who stakeholders are, what they need, and how to involve them to maximize project value and minimize resistance.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.2.1 Stakeholder Identification and Analysis (Pg.. 169)	Elective	
5.2.2 Stakeholder Engagement Planning (Pg.. 169)	Elective	
5.2.3 Stakeholder Communication and Relationships (Pg.. 169)	Elective	
5.2.4 Managing Stakeholder Expectations (Pg.. 170)	Elective	
5.2.5 Stakeholder Influence and Power (Pg.. 170)	Elective	
5.2.6 Conflict and Negotiation with Stakeholders (Pg.. 170)	Elective	
5.2.7 Monitoring Stakeholder Engagement (Pg.. 171)	Elective	

Table 5.2: List of KUs in the Stakeholders area.

5.2.1 ST/Stakeholder Identification and Analysis

Identifying all individuals, groups, and organizations that could impact or be impacted by the project, and analyzing their interests, power, and engagement levels.

Topics:

Core

- Stakeholder identification techniques: brainstorming, organizational charts, expert interviews
- Stakeholder register: capturing identification, assessment, and classification data
- Power/interest grid and salience model for stakeholder prioritization
- Monitoring changes in the stakeholder landscape throughout the project

Learning Outcomes:

Core:

1. Identify and document project stakeholders using structured identification and analysis techniques [Usage]
2. Classify and prioritize stakeholders using a power/interest grid [Usage]
3. Monitor changes in the stakeholder landscape and update the stakeholder register accordingly [Assessment]

5.2.2 ST/Stakeholder Engagement Planning

Developing strategies and actions to promote productive stakeholder involvement based on analysis of their needs, interests, and current engagement levels.

Topics:

Core

- Engagement assessment matrix: current vs. desired engagement levels
- Tailored engagement strategies for different stakeholder profiles and engagement levels
- Integrating stakeholder engagement planning with the communications management approach
- Reviewing and updating the engagement plan at key project milestones and phase transitions

Learning Outcomes:

Core:

1. Develop a stakeholder engagement plan with tailored strategies for each key stakeholder group [Usage]
2. Integrate stakeholder engagement planning with communications and change management approaches [Assessment]
3. Evaluate the adequacy of a stakeholder engagement plan against project complexity and stakeholder diversity [Assessment]

5.2.3 ST/Stakeholder Communication and Relationships

Building and maintaining productive relationships with stakeholders through consistent, targeted communication. Covers active listening, feedback mechanisms, and trust-building.

Topics:

Core

- Active listening and empathy as foundations of stakeholder relationship-building
- Feedback mechanisms: soliciting, processing, and acting on stakeholder feedback
- Building and maintaining trust with diverse stakeholder groups
- Building stakeholder relationships in virtual and distributed environments

Learning Outcomes:

Core:

1. Apply active listening and feedback techniques to strengthen stakeholder relationships [Usage]
2. Design a relationship management approach for a complex multi-stakeholder project environment [Assessment]
3. Evaluate the effectiveness of stakeholder communication strategies and recommend improvements [Assessment]

5.2.4 ST/Managing Stakeholder Expectations

Aligning stakeholder expectations with project scope, constraints, and intended value. Proactively managing expectations prevents misalignment, reduces conflict, and builds stakeholder satisfaction.
Topics:
Core

- Aligning stakeholder expectations with project reality: scope, timeline, and value boundaries
- Proactive expectation setting: communicating early and clearly about constraints and trade-offs
- Identifying and closing expectation gaps through negotiation and re-scoping
- Documenting agreed expectations in the project charter, scope baseline, and meeting records

Learning Outcomes:
Core:

1. Align stakeholder expectations with project scope and constraints through proactive communication [Usage]
2. Resolve stakeholder expectation gaps through structured negotiation and trade-off analysis [Assessment]
3. Design a proactive expectation management approach for a project with diverse and conflicting stakeholder needs [Assessment]

5.2.5 ST/Stakeholder Influence and Power

Understanding and navigating stakeholder power, politics, and influence to advance project objectives. Includes ethical use of influence and managing political dynamics.
Topics:
Core

- Power dynamics in projects: formal authority, expert power, referent power, and resource control
- Navigating organizational politics to advance project objectives ethically
- Influencing without formal authority: coalition building, persuasion, and negotiation
- Building strategic alliances and sponsor relationships to advance project objectives

Learning Outcomes:
Core:

1. Identify different sources of stakeholder power and their implications for project management [Familiarity]
2. Apply ethical influence strategies to gain stakeholder support without formal authority [Assessment]
3. Evaluate the ethical boundaries of influence strategies in a specific stakeholder and organizational context [Assessment]

5.2.6 ST/Conflict and Negotiation with Stakeholders

Identifying, addressing, and resolving stakeholder conflicts constructively. Covers negotiation strategies and escalation paths for stakeholder disputes.
Topics:
Core

- Sources of stakeholder conflict: competing interests, resource scarcity, and communication failures
- Conflict resolution strategies: collaborate, compromise, accommodate, avoid, compete
- Principled negotiation: interests vs. positions, BATNA, and win-win framing
- Escalation paths and governance structures for unresolved stakeholder conflicts

Learning Outcomes:
Core:

1. Apply conflict resolution strategies to address a stakeholder dispute in a project scenario [Usage]
2. Negotiate a stakeholder agreement using principled negotiation techniques [Usage]
3. Design an escalation path for managing unresolved stakeholder conflicts [Assessment]

5.2.7 ST/Monitoring Stakeholder Engagement

Continuously monitoring the effectiveness of stakeholder engagement and adjusting strategies as the project evolves. Covers engagement metrics, feedback analysis, and adaptive response.
Topics:
Core

- Metrics for measuring stakeholder engagement effectiveness: participation rates, feedback scores, sentiment
- Periodic review of stakeholder engagement: updating the engagement assessment matrix
- Early warning signals of stakeholder disengagement or resistance
- Corrective actions for declining engagement: re-engagement workshops, escalation, and plan revision

Learning Outcomes:
Core:

1. Monitor stakeholder engagement using defined metrics and update engagement strategies [Usage]
2. Identify early signals of stakeholder disengagement and propose proactive responses [Assessment]
3. Evaluate the overall effectiveness of the stakeholder engagement approach and recommend adaptive changes [Assessment]

5.3 Team (TM)

This performance domain covers the activities and functions associated with the people responsible for producing project outcomes. It emphasizes leadership, team culture, skill development, and creating an environment where the team can perform at its best.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.3.1 Project Team Culture (Pg.. 171)	Elective	
5.3.2 Team Leadership Styles (Pg.. 172)	Elective	
5.3.3 Team Development and Performance (Pg.. 172)	Elective	
5.3.4 Motivation and Empowerment (Pg.. 172)	Elective	
5.3.5 Collaboration and Trust Building (Pg.. 173)	Elective	
5.3.6 Distributed and Virtual Teams (Pg.. 173)	Elective	
5.3.7 Ethics and Professional Conduct (Pg.. 173)	Elective	

Table 5.3: List of KUs in the Team area.

5.3.1 TM/Project Team Culture

Establishing and sustaining a healthy team culture characterized by trust, transparency, and shared values. Culture shapes how teams make decisions, resolve conflicts, and respond to adversity.
Topics:
Core

- Defining team culture: shared values, norms, behaviors, and communication patterns
- Psychological safety: enabling open dialogue, experimentation, and honest feedback
- Building trust and transparency as foundations of high-performing team culture
- Relationship between team culture and project performance outcomes

Learning Outcomes:
Core:

1. Describe the elements of a healthy project team culture and their impact on performance [Familiarity]
2. Apply practices that build psychological safety and trust within a project team [Usage]
3. Evaluate the current culture of a project team and propose targeted improvements [Assessment]

5.3.2 TM/Team Leadership Styles

Understanding and applying different leadership styles to meet the needs of the team and the project context. PMBoK 7th edition emphasizes servant leadership and situational adaptation.

Topics:

Core

- Servant leadership: removing obstacles, supporting team members, and enabling performance
- Situational leadership: matching leadership style to team member competence and commitment
- Transformational leadership: inspiring change, innovation, and team growth
- Distributed leadership: sharing leadership responsibilities across the team

Learning Outcomes:

Core:

1. Compare servant, situational, and transformational leadership styles and their applicability [Familiarity]
2. Apply situational leadership principles to a team member development scenario [Usage]
3. Select the most appropriate leadership approach for a given team and project context [Assessment]

5.3.3 TM/Team Development and Performance

Building team competencies, cohesion, and performance over the project life cycle. Covers team formation stages, performance indicators, and continuous development.

Topics:

Core

- Tuckman team development stages: forming, storming, norming, performing, adjourning
- Team performance indicators: velocity, quality of output, collaboration metrics
- Continuous team development: coaching, mentoring, and skill-building activities
- Characteristics and practices of high-performing project teams

Learning Outcomes:

Core:

1. Apply team development strategies appropriate to each stage of team formation [Usage]
2. Design a team development plan targeting high performance outcomes [Assessment]
3. Evaluate the current performance stage of a project team and select appropriate interventions to accelerate progression [Assessment]

5.3.4 TM/Motivation and Empowerment

Understanding what motivates team members and creating conditions for intrinsic motivation, autonomy, and ownership. Empowered teams make better decisions and deliver more value.

Topics:

Core

- Motivation theories: Maslow, Herzberg, self-determination theory, and Drive (Pink)
- Intrinsic motivation: autonomy, mastery, and purpose as drivers of team performance
- Empowerment practices: delegating decision-making, providing autonomy, and trusting team judgment
- Recognition and rewards: designing systems that reinforce desired team behaviors

Learning Outcomes:

Core:

1. Explain the key motivation theories and their application to project team management [Familiarity]
2. Apply empowerment practices to increase team autonomy and ownership of project outcomes [Usage]
3. Design a recognition and reward system aligned with intrinsic motivation principles [Assessment]

5.3.5 TM/Collaboration and Trust Building

Creating conditions for effective team collaboration through trust, clear agreements, and shared working practices. Covers team charters, collaboration tools, and conflict prevention.

Topics:

Core

- Team charter: defining working agreements, norms, communication expectations, and decision rights
- Collaboration tools and practices: shared workspaces, visual management, and daily stand-ups
- Trust models: competence-based and character-based trust in team relationships
- Proactive conflict prevention through clear agreements and early communication

Learning Outcomes:

Core:

1. Develop a team charter that establishes working agreements and collaboration norms [Usage]
2. Evaluate the level of trust and collaboration in a project team and propose targeted interventions [Assessment]
3. Design a conflict prevention strategy based on clear team agreements and proactive communication practices [Assessment]

5.3.6 TM/Distributed and Virtual Teams

Managing teams that are geographically distributed or operate virtually. Covers communication challenges, cultural differences, tools, and leadership practices for virtual environments.

Topics:

Core

- Challenges of virtual teams: communication lag, isolation, cultural differences, and time zones
- Digital collaboration tools for virtual teams: video conferencing, async communication, and shared workspaces
- Cultural intelligence (CQ): understanding and adapting to cultural differences in global teams
- Leadership practices specific to virtual and distributed team environments

Learning Outcomes:

Core:

1. Describe the unique challenges of managing distributed and virtual project teams [Familiarity]
2. Apply cultural intelligence and virtual collaboration practices to manage a distributed team [Usage]
3. Design a virtual team management approach that addresses communication, culture, and performance [Assessment]

5.3.7 TM/Ethics and Professional Conduct

Upholding ethical standards and professional conduct within the project team. Covers PMI's Code of Ethics, handling ethical dilemmas, and fostering an ethical team environment.

Topics:

Core

- PMI Code of Ethics: responsibility, respect, fairness, and honesty
- Recognizing and resolving ethical dilemmas in project team and stakeholder contexts
- Creating an inclusive, respectful, and psychologically safe team environment
- Ethical leadership: modeling integrity and accountability as a project leader

Learning Outcomes:

Core:

1. Describe the PMI Code of Ethics and its application to project team behavior [Familiarity]
2. Resolve an ethical dilemma in a project team context using principled reasoning [Usage]
3. Evaluate the ethical climate of a project team and propose leadership actions to strengthen it [Assessment]

5.4 Development Approach and Life Cycle (DL)

This performance domain covers the activities and functions associated with selecting, defining, and managing the development approach and the project life cycle. PMBoK 7th edition treats the choice of development approach as a deliberate, context-driven decision rather than a default.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 5.4.1 Kickoff and Closure Activities (Pg.. 174)	1	1
5.4.2 Development Approach Selection (Pg.. 174)	Elective	
5.4.3 Predictive Approach (Pg.. 175)	Elective	
5.4.4 Adaptive Approach (Pg.. 175)	Elective	
5.4.5 Hybrid Approach (Pg.. 175)	Elective	
5.4.6 Project Phase Structure (Pg.. 176)	Elective	
5.4.7 Tailoring the Development Approach (Pg.. 176)	Elective	

Table 5.4: List of KUs in the Development Approach and Life Cycle area.

5.4.1 DL/Kickoff and Closure Activities (Core Tier1: 1 hr, Core Tier2: 1 hr)

Key activities at the start and end of the project and its phases. Covers project kickoff, phase transitions, and formal closure activities.

Topics:

Core

- Project kickoff: aligning team and stakeholders on objectives, approach, and working agreements
- Phase transition activities: reviews, approvals, and handoffs between phases
- Project closure: final deliverable acceptance, lessons learned, and team release
- Integrating lessons learned from closure into organizational knowledge assets

Learning Outcomes:

Core:

1. Conduct an effective project kickoff that aligns team and stakeholders on goals and approach [Usage]
2. Execute project closure activities including final acceptance and lessons learned archiving [Usage]
3. Design a comprehensive project closure checklist ensuring all administrative, contractual, and knowledge capture obligations are met [Assessment]

5.4.2 DL/Development Approach Selection

Selecting the most appropriate development approach - predictive, adaptive, or hybrid - based on project characteristics, organizational factors, and stakeholder needs.

Topics:

Core

- Overview of development approaches: predictive, iterative, incremental, adaptive, and hybrid
- Selection criteria: degree of uncertainty, rate of change, stakeholder involvement, and team capability
- Organizational factors influencing approach selection: culture, standards, and governance
- Evolving and adjusting the development approach as the project progresses

Learning Outcomes:

Core:

1. Select an appropriate development approach for a project based on defined selection criteria [Usage]
2. Justify the selected development approach given organizational and project-specific factors [Assessment]
3. Evaluate the alignment between a chosen development approach and the project's uncertainty level, team capability, and stakeholder engagement requirements [Assessment]

5.4.3 DL/Predictive Approach

Understanding when and how to apply a predictive (plan-driven) approach. Covers sequential phases, detailed upfront planning, and change management in predictive environments.

Topics:

Core

- Characteristics of predictive approach: sequential phases, fixed scope, and detailed upfront planning
- Conditions favoring predictive approach: stable requirements, low uncertainty, regulatory constraints
- Managing change in predictive environments: formal change control and baseline management
- Limitations of predictive approach in complex and uncertain environments

Learning Outcomes:

Core:

1. Describe the characteristics and appropriate use cases of a predictive development approach [Familiarity]
2. Apply predictive approach practices to plan and manage a project with stable requirements [Usage]
3. Evaluate when a predictive approach is or is not suitable for a given project context [Assessment]

5.4.4 DL/Adaptive Approach

Understanding when and how to apply adaptive (agile) approaches. Covers iterative and incremental delivery, backlog management, and empirical process control.

Topics:

Core

- Characteristics of adaptive approach: iterative delivery, evolving requirements, and empirical control
- Scrum and Kanban as representative adaptive frameworks
- Product backlog management: prioritization, refinement, and sprint planning
- Scaling adaptive approaches for large teams: SAFe, LeSS, and disciplined agile

Learning Outcomes:

Core:

1. Describe the characteristics and appropriate use cases of adaptive development approaches [Familiarity]
2. Apply adaptive approach practices including backlog management and iterative delivery [Usage]
3. Select an appropriate scaling framework for an adaptive approach in a large-team context [Assessment]

5.4.5 DL/Hybrid Approach

Combining predictive and adaptive elements to create a tailored development approach. Hybrid approaches acknowledge that few projects are purely predictive or purely adaptive.

Topics:

Core

- Rationale for hybrid approaches: mixing predictive stability with adaptive flexibility
- Common hybrid patterns: predictive planning with agile delivery, rolling wave with fixed milestones
- Governance challenges in hybrid approaches: reporting, metrics, and decision authority
- Managing the transition between predictive and adaptive phases within a hybrid life cycle

Learning Outcomes:

Core:

1. Design a hybrid approach combining predictive and adaptive elements for a given project context [Usage]
2. Evaluate the governance implications of a hybrid development approach [Assessment]
3. Justify the selection of a hybrid approach over a purely predictive or purely adaptive alternative [Assessment]

5.4.6 DL/Project Phase Structure

Defining the phase structure of the project life cycle, including phase sequencing, gate reviews, and the relationship between phases and the development approach.
Topics:
Core

- Defining project phases: sequential, overlapping, and iterative phase structures
- Phase gate reviews: decision criteria, governance, and go/no-go decisions
- Aligning phase structure with the selected development approach
- Defining exit criteria and deliverable acceptance standards for each project phase

Learning Outcomes:
Core:

1. Define an appropriate phase structure and gate review criteria for a given project [Usage]
2. Align the project phase structure with the selected development approach [Assessment]
3. Design a phase gate framework with clear entry and exit criteria appropriate to the project's risk profile [Assessment]

5.4.7 DL/Tailoring the Development Approach

Systematically tailoring the development approach and life cycle to the specific needs of the project. Tailoring is a deliberate, ongoing activity that balances organizational standards with project context.
Topics:
Core

- Tailoring process: assess context, select approach, customize, and continuously adjust
- Constraints on tailoring: regulatory requirements, organizational standards, and customer expectations
- Documenting tailoring decisions and rationale for governance and audit purposes
- Reviewing and refining tailoring decisions at project milestones based on performance evidence

Learning Outcomes:
Core:

1. Apply a tailoring process to customize the development approach for a specific project [Usage]
2. Justify tailoring decisions within organizational and regulatory constraints [Assessment]
3. Evaluate the effectiveness of tailoring decisions at project milestones and propose refinements [Assessment]

5.5 Planning (PL)

This performance domain covers the activities and functions associated with the initial, ongoing, and evolving organization and coordination necessary for delivering project outcomes. PMBoK 7th edition treats planning as an ongoing activity adapted to the development approach, not a one-time upfront exercise.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 5.5.1 Planning Principles (Pg.. 177)	1	1
⭐ 5.5.2 Scope and Requirements Planning (Pg.. 177)	1	1
⭐ 5.5.3 Schedule Planning (Pg.. 177)	1	1
⭐ 5.5.4 Cost and Budget Planning (Pg.. 178)	1	1
5.5.5 Resource Planning (Pg.. 178)	Elective	
5.5.6 Quality Planning (Pg.. 178)	Elective	
5.5.7 Risk and Uncertainty Planning (Pg.. 179)	Elective	
5.5.8 Communications and Stakeholder Engagement Planning (Pg.. 179)	Elective	
5.5.9 Procurement Planning (Pg.. 179)	Elective	
5.5.10 Integrated Project Planning (Pg.. 180)	Elective	

Table 5.5: List of KUs in the Planning area.

5.5.1 PL/Planning Principles (Core Tier1: 1 hr, Core Tier2: 1 hr)

Foundational principles for planning in PMBoK 7th edition: planning is iterative, just-enough, and adapted to the development approach and uncertainty level.

Topics:

Core

- Planning as an ongoing and iterative activity throughout the project life cycle
- Just-enough planning: balancing detail with flexibility based on uncertainty
- Relationship between planning depth and the selected development approach
- Adaptive planning: rolling wave, progressive elaboration, and iterative refinement

Learning Outcomes:

Core:

1. Describe the principles of iterative and just-enough planning in PMBoK 7th edition [Familiarity]
2. Apply adaptive planning principles to a project with high uncertainty and evolving requirements [Assessment]
3. Evaluate whether a project's planning approach provides sufficient detail and flexibility for its uncertainty level [Assessment]

5.5.2 PL/Scope and Requirements Planning (Core Tier1: 1 hr, Core Tier2: 1 hr)

Defining and planning the scope of the project and product, including requirements elicitation, documentation, and traceability across all development approaches.

Topics:

Core

- Requirements elicitation techniques across predictive and adaptive approaches
- Scope definition: project scope statement vs. product backlog depending on approach
- Requirements traceability: linking requirements to outcomes across all approaches
- Scope decomposition: WBS for predictive, backlog structuring for adaptive

Learning Outcomes:

Core:

1. Define project and product scope using techniques appropriate to the selected development approach [Usage]
2. Compare scope planning approaches in predictive and adaptive development contexts [Assessment]
3. Design a requirements traceability approach ensuring all deliverables are linked to stated stakeholder needs [Assessment]

5.5.3 PL/Schedule Planning (Core Tier1: 1 hr, Core Tier2: 1 hr)

Estimating, sequencing, and scheduling project activities. Covers both traditional scheduling (CPM, Gantt) and adaptive scheduling (sprint planning, release planning).

Topics:

Core

- Activity estimation techniques: analogous, parametric, three-point, and story points
- Schedule development: critical path for predictive, sprint and release planning for adaptive
- Building schedule flexibility: buffers, contingency, and iteration capacity
- Schedule baseline in predictive vs. release roadmap in adaptive: comparison and use

Learning Outcomes:

Core:

1. Develop a project schedule appropriate to the selected development approach [Usage]
2. Compare scheduling practices in predictive and adaptive project environments [Assessment]
3. Evaluate a project schedule for realism, buffer adequacy, and alignment with scope and resource constraints [Assessment]

5.5.4 PL/Cost and Budget Planning (Core Tier1: 1 hr, Core Tier2: 1 hr)

Estimating costs and establishing the project budget. Covers cost estimation techniques, budget structures, and contingency across development approaches.

Topics:

Core

- Cost estimation techniques: analogous, parametric, bottom-up, and three-point
- Budget structure: cost baseline, contingency reserves, and management reserves
- Cost planning in adaptive environments: fixed-capacity budgeting and cost per iteration
- Establishing and maintaining the cost performance baseline and managing reserve drawdown

Learning Outcomes:

Core:

1. Estimate project costs and develop a budget using appropriate techniques [Usage]
2. Adapt cost planning practices for adaptive and hybrid project environments [Assessment]
3. Evaluate the adequacy of a project budget including contingency and management reserves [Assessment]

5.5.5 PL/Resource Planning

Identifying, estimating, and planning for the human and physical resources needed to deliver project outcomes.

Topics:

Core

- Identifying required roles, skills, and physical resources for project delivery
- Resource estimation: effort estimation, capacity planning, and resource calendars
- Managing resource constraints: availability gaps, skill shortages, and procurement needs
- Resource leveling and smoothing: optimizing resource allocation across the project schedule

Learning Outcomes:

Core:

1. Develop a resource plan identifying required roles, skills, and quantities for project delivery [Usage]
2. Identify and resolve resource constraint issues in a project plan [Assessment]
3. Optimize resource allocation across the project schedule using leveling and smoothing techniques [Assessment]

5.5.6 PL/Quality Planning

Defining quality standards, metrics, and approaches for ensuring that project deliverables meet stakeholder expectations across all development approaches.

Topics:

Core

- Selecting applicable quality standards and metrics for the project and product
- Quality approach: testing strategy, definition of done, and acceptance criteria
- Quality planning in adaptive environments: continuous testing, automated QA, and done criteria
- Cost of conformance vs. cost of non-conformance: planning the right investment in quality

Learning Outcomes:

Core:

1. Define quality standards and acceptance criteria for a project's deliverables [Usage]
2. Design a quality approach appropriate for an adaptive or hybrid project environment [Assessment]
3. Evaluate the trade-off between quality investment and the risk of non-conformance in a project context [Assessment]

5.5.7 PL/Risk and Uncertainty Planning

Planning for risks and uncertainty as an integral part of the overall project plan. Covers risk identification, response planning, and uncertainty management across development approaches.
Topics:
Core

- Risk planning process: identification, qualitative assessment, response planning, and monitoring
- Planning for uncertainty: contingency reserves, timeboxes, and spike solutions
- Risk planning in adaptive environments: risk-adjusted backlog prioritization and iterative risk review
- Maintaining and updating the risk register throughout the project life cycle

Learning Outcomes:
Core:

1. Develop a risk management plan with identified risks and planned responses [Usage]
2. Adapt risk planning practices for adaptive project environments [Assessment]
3. Evaluate the comprehensiveness and adequacy of a risk management plan for a given project context [Assessment]

5.5.8 PL/Communications and Stakeholder Engagement Planning

Planning how information will flow to and from stakeholders throughout the project. Integrates communications and stakeholder engagement into a coherent plan.
Topics:
Core

- Communications plan: information needs, methods, frequency, and responsible parties
- Integrating stakeholder engagement strategies with the communications plan
- Information radiators and visual management tools for transparent project communication
- Communication channel analysis: determining the right medium, frequency, and audience for each communication

Learning Outcomes:
Core:

1. Develop an integrated communications and stakeholder engagement plan [Usage]
2. Implement information radiators and visual management practices for project transparency [Usage]
3. Design a communications plan that addresses the specific needs of diverse stakeholder groups across the project life cycle [Assessment]

5.5.9 PL/Procurement Planning

Planning for the acquisition of external products, services, or results. Covers make-or-buy decisions, contract type selection, and procurement strategy.
Topics:
Core

- Make-or-buy analysis: determining what to acquire externally and why
- Procurement strategy: contract types, vendor selection approach, and risk allocation
- Procurement considerations in adaptive projects: flexible contracts and vendor collaboration
- Vendor selection criteria: capability, cost, reliability, risk, and strategic fit

Learning Outcomes:
Core:

1. Develop a procurement plan including make-or-buy analysis and contract type selection [Usage]
2. Adapt procurement planning practices for adaptive and hybrid development contexts [Assessment]
3. Evaluate vendor proposals against defined selection criteria to support procurement decision-making [Assessment]

5.5.10 PL/Integrated Project Planning

Bringing together all planning elements into a coherent, integrated project plan. Covers the relationship between plan components, baselines, and the project management plan as a living document.
Topics:
Core

- Integrating subsidiary plans into a coherent project management plan
- The project plan as a living document: ongoing updates and rebaselines
- Baseline management: establishing, maintaining, and updating project baselines
- Differences in integrated planning artifacts across predictive, adaptive, and hybrid approaches

Learning Outcomes:
Core:

1. Develop an integrated project management plan combining all planning elements [Usage]
2. Compare integrated planning artifacts across predictive, adaptive, and hybrid approaches [Assessment]
3. Evaluate the internal consistency of an integrated project plan and identify gaps or conflicts among its subsidiary components [Assessment]

5.6 Project Work (PW)

This performance domain covers the activities and functions associated with establishing project processes, managing physical resources, and fostering a learning environment. It encompasses the day-to-day management of the work needed to keep the project progressing.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.6.1 Managing Project Artifacts (Pg.. 180)	Elective	
5.6.2 Communication and Knowledge Management (Pg.. 181)	Elective	
5.6.3 Team Engagement During Execution (Pg.. 181)	Elective	
5.6.4 Stakeholder Engagement During Execution (Pg.. 181)	Elective	
5.6.5 Managing Physical Resources (Pg.. 182)	Elective	
5.6.6 Working with Procurements (Pg.. 182)	Elective	
5.6.7 Monitoring and Adapting Work (Pg.. 182)	Elective	

Table 5.6: List of KUs in the Project Work area.

5.6.1 PW/Managing Project Artifacts

Creating, maintaining, and controlling project artifacts throughout the project life cycle. Covers configuration management, version control, and artifact accessibility.
Topics:
Core

- Project artifact types: plans, logs, registers, reports, agreements, and deliverables
- Configuration management: version control, change tracking, and artifact integrity
- Ensuring artifact accessibility and traceability across the project team and stakeholders
- Artifact retention and archiving policies aligned with organizational and regulatory requirements

Learning Outcomes:
Core:

1. Apply configuration management practices to maintain project artifact integrity [Usage]
2. Design an artifact management approach ensuring accessibility and traceability [Assessment]
3. Evaluate the artifact management system of a project for completeness, version control, and compliance [Assessment]

5.6.2 PW/Communication and Knowledge Management

Managing information flow and organizational knowledge during project execution. Covers lessons learned, knowledge transfer, and information distribution.

Topics:

Core

- Distributing project information to stakeholders according to the communications plan
- Capturing and sharing project knowledge: lessons learned, retrospectives, and knowledge repositories
- Contributing to organizational learning through systematic knowledge transfer
- Identifying and overcoming communication barriers: noise, filtering, cultural differences, and information overload

Learning Outcomes:

Core:

1. Execute the communications plan to distribute information effectively to project stakeholders [Usage]
2. Design a knowledge management approach that supports organizational learning throughout the project [Assessment]
3. Evaluate the effectiveness of project communication and identify improvements to reduce barriers and information gaps [Assessment]

5.6.3 PW/Team Engagement During Execution

Keeping the team engaged, motivated, and productive during project execution. Covers daily management practices, performance feedback, and maintaining team well-being.

Topics:

Core

- Daily management practices: stand-ups, task boards, and flow management
- Providing timely, constructive performance feedback to team members
- Monitoring and maintaining team well-being and sustainable pace
- Identifying and removing impediments that block team productivity and flow

Learning Outcomes:

Core:

1. Apply daily management practices to maintain team focus and productivity during execution [Usage]
2. Monitor team well-being indicators and take corrective action to maintain sustainable performance [Assessment]
3. Design an impediment management process that rapidly surfaces and resolves blockers during project execution [Assessment]

5.6.4 PW/Stakeholder Engagement During Execution

Actively engaging stakeholders during project execution to maintain alignment, address issues, and incorporate feedback into the work.

Topics:

Core

- Maintaining ongoing stakeholder engagement: check-ins, demos, and feedback loops
- Identifying, logging, and resolving stakeholder issues during execution
- Handling stakeholder-driven change requests during execution
- Tracking stakeholder satisfaction levels during execution and responding to declining engagement

Learning Outcomes:

Core:

1. Maintain active stakeholder engagement through regular touchpoints and feedback mechanisms [Usage]
2. Manage stakeholder-driven changes during execution while protecting project value delivery [Assessment]

3. Evaluate the effectiveness of stakeholder engagement during execution and recommend adjustments to the engagement approach [Assessment]

5.6.5 PW/Managing Physical Resources

Managing the physical resources required for project execution, including materials, equipment, facilities, and infrastructure.

Topics:

Core

- Acquiring and mobilizing physical resources according to the resource plan
- Monitoring physical resource utilization and addressing shortages or waste
- Optimizing physical resource usage to minimize cost and environmental impact
- Documenting physical resource usage, issues, and handover for audit and lessons learned

Learning Outcomes:

Core:

1. Monitor physical resource utilization and take corrective action for deviations [Usage]
2. Optimize physical resource management to reduce waste and improve efficiency [Assessment]
3. Design a physical resource management plan that addresses acquisition, utilization tracking, and responsible disposal [Assessment]

5.6.6 PW/Working with Procurements

Managing procurement activities during project execution, including vendor management, contract administration, and procurement performance monitoring.

Topics:

Core

- Day-to-day vendor management: communication, performance tracking, and issue resolution
- Contract administration during execution: change orders, compliance monitoring, and payments
- Building collaborative vendor relationships to support project value delivery
- Procurement closeout: final acceptance, release of obligations, and vendor performance assessment

Learning Outcomes:

Core:

1. Manage vendor performance and contract compliance during project execution [Usage]
2. Build a collaborative vendor relationship strategy that supports project outcomes [Assessment]
3. Evaluate vendor performance against contractual obligations and determine appropriate corrective or closeout actions [Assessment]

5.6.7 PW/Monitoring and Adapting Work

Continuously monitoring project work and adapting plans, priorities, and processes in response to performance data, emerging risks, and changing conditions.

Topics:

Core

- Monitoring work performance: progress tracking, burndown/burnup charts, and status reports
- Adapting work plans and priorities in response to performance data and new information
- Embedding continuous improvement practices: retrospectives, process reviews, and kaizen
- Distinguishing corrective actions (address current deviations) from preventive actions (avoid future issues)

Learning Outcomes:

Core:

1. Monitor project work progress and identify deviations requiring corrective action [Usage]
2. Implement continuous improvement practices to increase team and process effectiveness [Assessment]

3. Evaluate the adequacy of corrective and adaptive actions taken in response to project performance deviations [Assessment]

5.7 Delivery (DV)

This performance domain covers the activities and functions associated with delivering project outcomes that produce intended value. Delivery is about more than completing scope - it is about ensuring that what is delivered actually realizes the expected benefits.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.7.1 Value Definition and Delivery (Pg.. 183)	Elective	
5.7.2 Requirements and Scope Delivery (Pg.. 183)	Elective	
5.7.3 Quality Assurance and Delivery (Pg.. 184)	Elective	
5.7.4 Incremental and Iterative Delivery (Pg.. 184)	Elective	
5.7.5 Transition and Handover (Pg.. 184)	Elective	
5.7.6 Benefits Realization Management (Pg.. 185)	Elective	
5.7.7 Customer and User Satisfaction (Pg.. 185)	Elective	

Table 5.7: List of KUs in the Delivery area.

5.7.1 DV/Value Definition and Delivery

Defining value clearly at the start and continuously ensuring that project outputs are aligned with delivering that value. Value may be financial, social, or experiential.

Topics:

Core

- Defining project value: financial return, social impact, customer satisfaction, and strategic advancement
- Continuously aligning deliverables with defined value throughout the project
- Prioritizing features and deliverables by value contribution
- Validating delivered value with stakeholders and customers throughout the project

Learning Outcomes:

Core:

1. Define project value in terms meaningful to key stakeholders and align deliverables accordingly [Usage]
2. Prioritize project deliverables based on their relative value contribution [Assessment]
3. Evaluate whether delivered project outputs have achieved the defined value and propose corrective actions if gaps exist [Assessment]

5.7.2 DV/Requirements and Scope Delivery

Ensuring project deliverables meet defined requirements and scope, and that scope is managed to protect value delivery.

Topics:

Core

- Verifying that deliverables meet defined requirements and acceptance criteria
- Controlling scope to prevent scope creep and protect value delivery
- Making trade-off decisions between scope and value when constraints emerge
- Formal scope validation with stakeholders: reviews, sign-offs, and acceptance documentation

Learning Outcomes:

Core:

1. Verify project deliverables against requirements and acceptance criteria [Usage]
2. Make principled scope trade-off decisions to protect project value delivery [Assessment]
3. Design a scope validation process that ensures stakeholder acceptance at each delivery milestone [Assessment]

5.7.3 DV/Quality Assurance and Delivery

Ensuring deliverables meet quality standards through ongoing quality assurance and control activities embedded in the delivery process.

Topics:

Core

- Embedding quality into the delivery process: definition of done, acceptance criteria, and continuous testing
- Defect prevention strategies: root cause analysis, process improvement, and shift-left testing
- Tracking quality metrics across deliverables to detect trends and drive improvement
- Quality audits: reviewing adherence to quality processes and identifying systemic improvement opportunities

Learning Outcomes:

Core:

1. Apply quality assurance practices to ensure deliverables meet defined quality standards [Usage]
2. Analyze delivery quality metrics to identify improvement opportunities [Assessment]
3. Design a quality audit framework that continuously validates process adherence and delivery quality [Assessment]

5.7.4 DV/Incremental and Iterative Delivery

Delivering value in increments or iterations to provide early benefits, incorporate feedback, and reduce risk. Covers sprint reviews, minimum viable products, and release planning.

Topics:

Core

- Incremental delivery: releasing usable portions of the product to provide early value
- Iterative delivery: refining and improving deliverables based on feedback across iterations
- Minimum viable product (MVP) and minimum viable feature (MVF) for early value delivery
- Release planning: scheduling increments for maximum business value

Learning Outcomes:

Core:

1. Plan and execute incremental and iterative deliveries to provide early and continuous value [Usage]
2. Design a release plan that maximizes business value across delivery increments [Assessment]
3. Evaluate the results of a delivery iteration and use feedback to adjust the scope and priorities for subsequent increments [Assessment]

5.7.5 DV/Transition and Handover

Managing the transition of project deliverables into operations or to end users. Covers readiness assessment, knowledge transfer, and organizational change support.

Topics:

Core

- Readiness assessment: evaluating organizational and user readiness to receive deliverables
- Knowledge transfer to operations: documentation, training, and support arrangements
- Supporting organizational change management during the handover phase
- Producing comprehensive handover documentation: user manuals, operational guides, and support agreements

Learning Outcomes:

Core:

1. Plan a transition and handover process ensuring operational readiness [Usage]
2. Design change management support activities to enable successful adoption of project deliverables [Assessment]
3. Evaluate organizational and user readiness for handover and identify actions needed to close readiness gaps [Assessment]

5.7.6 DV/Benefits Realization Management

Ensuring that the benefits identified in the business case are actually realized after project completion. Covers benefits tracking, ownership, and post-project review.

Topics:

Core

- Identifying and documenting expected benefits in the business case and benefits register
- Assigning benefits ownership to operational stakeholders beyond project closure
- Tracking benefits realization post-project: metrics, timelines, and reporting
- Maintaining a benefits register linked to the business case throughout and after the project

Learning Outcomes:

Core:

1. Develop a benefits realization plan with defined metrics and ownership assignments [Usage]
2. Evaluate the extent to which project benefits have been realized after project completion [Assessment]
3. Design a post-project benefits tracking mechanism with clear ownership, timelines, and reporting thresholds [Assessment]

5.7.7 DV/Customer and User Satisfaction

Ensuring that project deliverables satisfy end users and customers. Covers user acceptance, satisfaction measurement, and feedback integration into delivery.

Topics:

Core

- User acceptance testing (UAT): validating deliverables with end users
- Measuring customer and user satisfaction: surveys, NPS, and feedback sessions
- Integrating customer and user feedback into ongoing delivery decisions
- Tracking satisfaction trends over time and using data to improve the delivery approach

Learning Outcomes:

Core:

1. Conduct user acceptance testing and document satisfaction outcomes [Usage]
2. Integrate customer feedback into delivery decisions to maximize user satisfaction [Assessment]
3. Evaluate customer and user satisfaction trends and propose delivery adjustments to close satisfaction gaps [Assessment]

5.8 Measurement (MS)

This performance domain covers the activities and functions associated with assessing project performance and taking appropriate actions to maintain acceptable performance. Measurement in PMBoK 7th edition goes beyond EVM to encompass a broader set of value-focused metrics.

Knowledge Area (KA)	Core Tier1	Core Tier2
⭐ 5.8.1 Key Performance Indicators (Pg.. 185)	1	1
⭐ 5.8.2 Dashboards and Information Radiators (Pg.. 186)	1	1
5.8.3 Measurement Purpose and Approach (Pg.. 186)	Elective	
5.8.4 Earned Value and Schedule Performance (Pg.. 186)	Elective	
5.8.5 Forecasting and Trends (Pg.. 187)	Elective	
5.8.6 Stakeholder Performance Reporting (Pg.. 187)	Elective	
5.8.7 Lessons Learned and Knowledge Capture (Pg.. 187)	Elective	

Table 5.8: List of KUs in the Measurement area.

5.8.1 MS/Key Performance Indicators (Core Tier1: 1 hr, Core Tier2: 1 hr)

Defining, selecting, and using key performance indicators (KPIs) to track project health across scope, schedule, cost, quality, and value dimensions.

Topics:
Core
- Selecting KPIs: relevance to project objectives, measurability, and actionability
- Balanced metric sets: leading and lagging indicators, outcome and output metrics
- Setting KPI thresholds and alert levels for triggering corrective action
- Reviewing and adapting the KPI set as the project evolves and stakeholder priorities shift

Learning Outcomes:
Core:
1. Define a balanced KPI set for monitoring a project across multiple performance dimensions [Usage]
2. Evaluate a given set of KPIs for balance, relevance, and potential for metric dysfunction [Assessment]
3. Design a KPI review cycle that keeps performance metrics aligned with evolving project objectives [Assessment]

5.8.2 MS/Dashboards and Information Radiators (Core Tier1: 1 hr, Core Tier2: 1 hr)

Using visual management tools to make project performance visible to the team and stakeholders. Covers dashboards, kanban boards, burndown charts, and physical information radiators.
Topics:
Core
- Designing effective project dashboards: key metrics, visual clarity, and stakeholder relevance
- Information radiators: physical and digital tools for continuous team transparency
- Real-time dashboards: automated data feeds and live project status visualization
- Maintaining and evolving dashboards as the project progresses and information needs change

Learning Outcomes:
Core:
1. Design a project performance dashboard with relevant KPIs for team and stakeholder use [Usage]
2. Implement information radiators that provide real-time project transparency to the team [Assessment]
3. Evaluate the effectiveness of a dashboard in communicating project health and recommend improvements [Assessment]

5.8.3 MS/Measurement Purpose and Approach

Understanding why and how to measure project performance. Covers the purpose of measurement, the risk of metric dysfunction, and principles for selecting meaningful measures.
Topics:
Core
- Purpose of measurement: informing decisions, detecting issues, and demonstrating value
- Principles of effective measurement: meaningful, actionable, and timely metrics
- Metric dysfunction: gaming, Goodhart's Law, and the dangers of measuring the wrong things
- Selecting measurement approach based on project type, development approach, and stakeholder needs

Learning Outcomes:
Core:
1. Describe the purpose and principles of effective project performance measurement [Familiarity]
2. Identify the risk of metric dysfunction and select measures that drive the right behaviors [Usage]
3. Design a measurement approach appropriate to the project type and stakeholder needs [Assessment]

5.8.4 MS/Earned Value and Schedule Performance

Using Earned Value Management (EVM) and schedule performance indicators to measure project cost and schedule health. Covers EVM metrics, SPI, CPI, and forecasting.

Topics:
Core
- EVM metrics: PV, EV, AC, CV, SV, CPI, SPI
- EVM forecasting: EAC, ETC, VAC, and TCPI
- Applying earned value concepts in adaptive environments: velocity, burndown, and throughput
- Interpreting EVM trends over time to forecast project completion and identify systemic issues

Learning Outcomes:
Core:
1. Calculate and interpret EVM metrics to assess project cost and schedule performance [Usage]
2. Adapt EVM concepts for use in adaptive project environments [Assessment]
3. Use EVM data to forecast project completion cost and schedule and evaluate the accuracy of those forecasts [Assessment]

5.8.5 MS/Forecasting and Trends

Using current performance data to forecast future project outcomes. Covers trend analysis, forecasting techniques, and the use of forecasts for proactive management.
Topics:
Core
- Trend analysis: identifying performance patterns to predict future outcomes
- Forecasting techniques: EAC formulas, regression analysis, and expert judgment
- Using forecasts proactively to prevent problems rather than react to them
- Communicating forecast uncertainty: confidence intervals, scenario ranges, and assumptions

Learning Outcomes:
Core:
1. Apply trend analysis and forecasting techniques to predict project completion outcomes [Usage]
2. Use forecasting data to make proactive project management decisions [Assessment]
3. Evaluate the reliability of project forecasts by examining underlying assumptions and comparing against actual results [Assessment]

5.8.6 MS/Stakeholder Performance Reporting

Communicating project performance to stakeholders in a format and frequency appropriate to their needs. Covers report design, tailoring, and information transparency.
Topics:
Core
- Designing performance reports: content, format, and frequency tailored to stakeholder needs
- Transparent reporting: honest and complete performance communication including bad news
- Executive-level reporting: summarizing project health for senior stakeholders
- Exception reporting: focusing reporting effort on deviations, risks, and decisions rather than routine status

Learning Outcomes:
Core:
1. Prepare a project performance report tailored to a specific stakeholder audience [Usage]
2. Design an executive reporting structure that provides meaningful project health information [Assessment]
3. Evaluate a project reporting system for transparency, accuracy, and stakeholder relevance [Assessment]

5.8.7 MS/Lessons Learned and Knowledge Capture

Systematically capturing, documenting, and disseminating lessons learned throughout and after the project. Covers retrospectives, after-action reviews, and organizational knowledge assets.
Topics:
Core

- Lessons learned process: capture, analysis, documentation, and dissemination
- Retrospectives and after-action reviews: structured team reflection for continuous improvement

- Contributing lessons learned to organizational knowledge repositories and process assets
- Timing and frequency of lessons learned: ongoing capture vs. phase-end reviews vs. project closure

Learning Outcomes:
Core:

1. Conduct a lessons learned session and document findings for team and organizational use [Usage]
2. Integrate lessons learned into organizational knowledge assets to support future projects [Assessment]
3. Design a lessons learned program that captures insights continuously rather than only at project closure [Assessment]

5.9 Uncertainty (UN)

This performance domain covers the activities and functions associated with risk and uncertainty throughout the project. PMBoK 7th edition broadens the traditional risk focus to include ambiguity, complexity, and volatility as distinct forms of uncertainty requiring different management approaches.

Knowledge Area (KA)	Core Tier1	Core Tier2
5.9.1 Understanding Uncertainty and Risk (Pg.. 188)	Elective	
5.9.2 Risk Identification and Assessment (Pg.. 188)	Elective	
5.9.3 Threat and Opportunity Response (Pg.. 189)	Elective	
5.9.4 Ambiguity Management (Pg.. 189)	Elective	
5.9.5 Complexity Management (Pg.. 190)	Elective	
5.9.6 Volatility and Resilience Strategies (Pg.. 190)	Elective	
5.9.7 Monitoring and Adapting to Uncertainty (Pg.. 190)	Elective	

Table 5.9: List of KUs in the Uncertainty area.

5.9.1 UN/Understanding Uncertainty and Risk

Distinguishing between uncertainty, risk, ambiguity, complexity, and volatility, and understanding how each requires different management strategies.
Topics:
Core

- Distinction between uncertainty (unknown probabilities) and risk (known probabilities and impacts)
- VUCA framework: volatility, uncertainty, complexity, and ambiguity in project environments
- Developing a balanced risk mindset: embracing opportunity while managing threats
- Assessing the uncertainty profile of a project: sources and types of uncertainty

Learning Outcomes:
Core:

1. Distinguish between risk, uncertainty, ambiguity, complexity, and volatility in project contexts [Familiarity]
2. Assess the uncertainty profile of a project and identify dominant uncertainty types [Assessment]
3. Select management strategies that are appropriate to the dominant type of uncertainty in a given project [Assessment]

5.9.2 UN/Risk Identification and Assessment

Identifying individual and overall project risks and assessing their probability, impact, and urgency using both qualitative and quantitative methods.

Topics:
Core

- Risk identification techniques: brainstorming, interviews, checklists, SWOT, and assumption analysis
- Qualitative risk assessment: probability-impact matrix and risk prioritization
- Quantitative risk assessment: EMV, Monte Carlo simulation, and sensitivity analysis
- Assessing overall project risk beyond individual risks: portfolio-level risk view and risk thresholds

Learning Outcomes:
Core:

1. Identify and prioritize project risks using qualitative assessment techniques [Usage]
2. Apply quantitative assessment techniques to measure overall project risk exposure [Assessment]
3. Evaluate the completeness of a risk register and recommend additional identification or assessment activities [Assessment]

5.9.3 UN/Threat and Opportunity Response

Planning and implementing responses to both threats and opportunities. PMBoK 7th emphasizes optimizing risk responses - not just mitigating threats but actively exploiting opportunities.
Topics:
Core

- Threat response strategies: avoid, transfer, mitigate, accept
- Opportunity response strategies: exploit, share, enhance, accept
- Optimizing responses: selecting cost-effective and proportional actions
- Managing residual and secondary risks created by responses

Learning Outcomes:
Core:

1. Select and justify risk response strategies for a set of prioritized threats and opportunities [Usage]
2. Evaluate the cost-effectiveness and secondary risk implications of planned responses [Assessment]
3. Design a balanced risk response plan that addresses both threats and opportunities proportionally [Assessment]

5.9.4 UN/Ambiguity Management

Managing ambiguity - situations where the problem or solution is unclear. Covers techniques for reducing ambiguity and making progress under unclear conditions.
Topics:
Core

- Types of ambiguity: conceptual (unclear problem), directional (unclear goal), temporal (unclear timing)
- Techniques for reducing ambiguity: experiments, prototypes, proof-of-concept, and stakeholder alignment
- Making progress under ambiguity: iterative discovery, timeboxing, and decision staging
- Assessing the ambiguity tolerance of the team and stakeholders and calibrating planning accordingly

Learning Outcomes:
Core:

1. Describe the different types of ambiguity and their impact on project planning [Familiarity]
2. Apply ambiguity reduction techniques to clarify project objectives and solution direction [Usage]
3. Design an approach for making productive progress when project goals or solutions remain unclear [Assessment]

5.9.5 UN/Complexity Management

Recognizing and navigating project complexity arising from system interdependencies, human behavior, and emergent dynamics. Covers complexity assessment and adaptive management strategies.
Topics:
Core

- Assessing project complexity: interdependency mapping, stakeholder diversity, and technical novelty
- Strategies for managing complexity: decomposition, incremental delivery, and expert facilitation
- Managing emergent behavior in complex projects: sense-and-respond and adaptive governance
- Ongoing monitoring of complexity indicators and escalating governance as complexity increases

Learning Outcomes:
Core:

1. Assess the complexity profile of a project and identify the primary complexity drivers [Usage]
2. Design adaptive management strategies for a project with high complexity [Assessment]
3. Evaluate the effectiveness of complexity management strategies and propose refinements as project conditions evolve [Assessment]

5.9.6 UN/Volatility and Resilience Strategies

Managing volatility - frequent and unpredictable changes in the project environment. Covers resilience-building strategies, rapid response capabilities, and organizational agility.
Topics:
Core

- Characteristics of volatile environments: rapid change, unpredictability, and short planning horizons
- Building project resilience: flexible planning, reserve capacity, and adaptive teams
- Rapid response mechanisms: decision escalation paths and pre-authorized response plans
- Early warning indicators of increasing volatility and triggers for activating resilience measures

Learning Outcomes:
Core:

1. Describe the characteristics of volatile project environments and their management challenges [Familiarity]
2. Apply resilience-building strategies to prepare a project team for high-volatility conditions [Usage]
3. Design rapid response mechanisms for a project operating in a volatile environment [Assessment]

5.9.7 UN/Monitoring and Adapting to Uncertainty

Continuously monitoring the uncertainty landscape and adapting project approach, plans, and responses as new information emerges throughout the project.
Topics:
Core

- Monitoring uncertainty: early warning indicators, trigger conditions, and horizon scanning
- Adapting plans and approaches in response to changing uncertainty conditions
- Learning and improving under uncertainty: experimental mindset and fast feedback loops
- Communicating uncertainty status to stakeholders: risk-adjusted forecasts and uncertainty heat maps

Learning Outcomes:
Core:

1. Monitor the uncertainty landscape using early warning indicators and trigger conditions [Usage]
2. Adapt project plans and approaches in response to emerging uncertainty [Usage]
3. Apply an experimental mindset and fast feedback loops to learn and improve under uncertainty [Assessment]

Chapter 6

Curricula 202x

6.1 Course Coding

Courses are classified into 4 levels:

- **Introductory** Code 1.. example: CS100
- **Intermediate** Code 2.. example: MA200
- **Advanced** Code 3.. example: IS370
- **Capstone Project** Code 4.. example: CS403

The courses are encoded under the scheme shown in Figure 6.1.

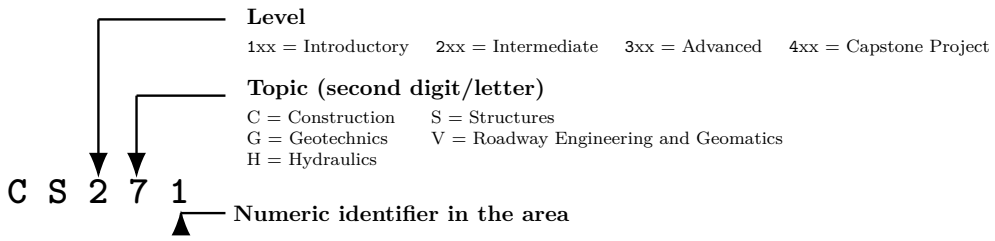

Figure 6.1: Course coding scheme.

The course type is determined by the initial letters. The possible codes for these types are:

1. **CE** Computer Engineering (CE),
2. **CS** Computer Science (CS);
3. **AI** Artificial Intelligence (AI);
4. **CB** Basic Sciences (Physics, Biology);
5. **MA** Mathematics (MA);
6. **STA** Statistics (STA);
7. **BFI** Physic Sciences
8. **BCH** Chemical Sciences (CH);
9. **ID** Languages Area.
10. **BEF** Ethics and Political Philosophy
11. **BME** Learning Methodology
12. **BRC** Writing and Communication
13. **BLW** Law and Legislation
14. **BMI** Research Methodology in Engineering
15. **BIC** Introduction to Computing
16. **BEC** General Economics

At the same time, and according to current university law, courses are classified into:

- General studies
- Specific
- Specialization

6.2 Estructura Curricular

La relación de cursos se muestra a continuación:

TH = Theory Hours, PR = Practice Hours, CR = Credits, T = Type of Course.

M = Mandatory, E = Elective.

Primer Semestre							
Código	**Curso**	**Área**	**HT**	**HP**	**CR**	**T**	**Requisitos**
MA100	Basic Mathematics (Pág 245)	General Estudies	3	4	5	O	
MA111	Calculus I (Pág 249)	General Estudies	3	4	5	O	
BCH101	Chemistry I (Pág 251)	General Estudies	3	2	5	O	
BME101	Learning Methodology Workshop (Pág 255)	General Estudies	2	2	2	O	
BRC101	Writing and Communication (Pág 260)	General Estudies	2	2	2	O	
BIC101	Introduction to Programming (Pág 262)	General Estudies	3	4	5	O	
BEC101	General Economics (Pág 266)	Specific	2	2	3	O	
					12		

Segundo Semestre							
Código	**Curso**	**Área**	**HT**	**HP**	**CR**	**T**	**Requisitos**
CE1G1	General Geology (Pág 270)	General Estudies	3	2	3	O	
CS100	Introduction to Computer Science (Pág 274)	General Estudies	2	2	3	O	
AI161	Applied AI (Pág 284)	Specific	2	4	4	O	BIC101 (1er Sem)
CB1E1	Technical Drawing & CAD (Pág 288)	General Estudies	4	2	3	O	
MA112	Calculus II (Pág 291)	General Estudies	3	4	5	O	MA111 (1er Sem)
BFI101	General Physics (Pág 295)	General Estudies	3	4	5	O	MA111 (1er Sem)
ID101	Technical and professional English I (Pág 300)	General Estudies	1	2	2	O	
BEF201	Ethics and Political Philosophy (Pág 303)	General Estudies	1	2	2	O	
					14		

Tercer Semestre

Código	Curso	Área	HT	HP	CR	T	Requisitos
CE1M1	Statics (Pág 306)	Specialization	4	4	4	O	BFI101 (2do Sem)
CB1E2	Engineering Drawing II (Pág 309)	General Estudies	3	2	4	O	CB1E1 (2do Sem)
MA121	Linear Algebra I (Pág 312)	General Estudies	3	4	5	O	MA100 (1er Sem)
MA210	Calculus III (Pág 314)	General Estudies	3	2	4	O	MA112 (2do Sem)
BFI102	Physics II (Pág 317)	General Estudies	4	2	5	O	BFI101 (2do Sem)
ID102	Technical and professional English II (Pág 322)	General Estudies	1	2	2	O	ID101 (2do Sem)
					2		

Cuarto Semestre

Código	Curso	Área	HT	HP	CR	T	Requisitos
CE1M2	Dynamics (Pág 326)	Specialization	4	4	4	O	CE1M1 (3er Sem), BFI102 (3er Sem)
CE2M1	Mechanics of Materials I (Pág 329)	Specialization	4	4	5	O	CE1M1 (3er Sem), MA210 (3er Sem)
CE3M1	Concrete Technology (Pág 332)	Specialization	4	4	4	O	BCH101 (1er Sem)
MA202	Numerical Methods (Pág 335)	General Estudies	2	2	3	O	MA121 (3er Sem), BIC101 (1er Sem)
MA211	Calculus IV (Pág 340)	General Estudies	3	4	5	O	MA210 (3er Sem), MA121 (3er Sem)
STA251	Statistics and Probability (Pág 343)	General Estudies	1	4	3	O	MA112 (2do Sem)
ID201	Technical and professional English III (Pág 348)	General Estudies	1	2	2	O	ID102 (3er Sem)
					8		

Quinto Semestre

Código	Curso	Área	HT	HP	CR	T	Requisitos
CE2M2	Mechanics of Materials II (Pág 352)	Specialization	4	4	4	O	CE2M1 (4to Sem)
ID202	Technical and professional English IV (Pág 355)	General Estudies	1	2	2	O	ID201 (4to Sem)
					2		

Sexto Semestre

Código	Curso	Área	HT	HP	CR	T	Requisitos
MA212	Ordinary Differential Equations (Pág 359)	Specific	4	4	6	O	MA211 (4to Sem)
ID203	Technical and professional English V (Pág 362)	General Estudies	1	2	2	O	ID202 (5to Sem)
					2		

Séptimo Semestre

Código	Curso	Área	HT	HP	CR	T	Requisitos
CE2C1	Materials Technology (Pág 366)	Specific	3	2	4	O	CE3M1 (4to Sem)
CE2C2	Construction Technology I (Pág 371)	Specific	2	1	3	O	CE3M1 (4to Sem)
CE2C6	Territorial Planning (Pág 374)	Specific	2	2	3	O	CE1G1 (2do Sem)
CE2C8	Business Management in Construction I (Pág 377)	Specific	4	2	3	O	BEC101 (1er Sem)
CE2G1	Soil Mechanics I (Pág 381)	Specific	3	2	4	O	CE1G1 (2do Sem), CE2M1 (4to Sem)
CE2H1	Fluid Mechanics I (Pág 384)	Specific	4	2	5	O	CE1M1 (3er Sem), CE1M2 (4to Sem), MA211 (4to Sem)
CE2S1	Structural Analysis I (Pág 391)	Specific	4	2	5	O	CE2M2 (5to Sem)
CE2S2	Reinforced Concrete Design I (Pág 394)	Specific	4	2	5	O	CE2M2 (5to Sem)
CE2S3	Steel Design (Pág 397)	Specific	4	2	5	O	CE2M2 (5to Sem)
					0		

Octavo Semestre							
Código	**Curso**	**Área**	**HT**	**HP**	**CR**	**T**	**Requisitos**
CE2C3	Concrete Technology I (Pág 400)	Specific	3	2	4	O	CE2C1 (7mo Sem), CE2M2 (5to Sem)
CE2C5	Construction Project Management (Pág 405)	Specific	4	2	3	O	CE2C2 (7mo Sem)
CE2C7	Business Organization and Management (Pág 408)	Specific	2	2	3	O	CE2C8 (7mo Sem)
CE2G2	Soil Mechanics II (Pág 413)	Specific	3	2	4	O	CE2G1 (7mo Sem)
CE3C2	Construction Technology II (Pág 417)	Specific	3	2	4	O	CE2C2 (7mo Sem)
CE3H1	Fluid Mechanics II (Pág 422)	Specific	2	4	4	O	CE2H1 (7mo Sem)
CE3S1	Structural Analysis II (Pág 425)	Specific	2	4	4	O	CE2S1 (7mo Sem)
CE3S5	Bridges and Structures (Pág 429)	Specific	2	2	3	O	CE2S1 (7mo Sem), CE2S2 (7mo Sem)
CE3S9	Prestressed Concrete (Pág 432)	Specific	2	2	3	O	CE2S2 (7mo Sem)
BMI201	Methodology of Engineering Research (Pág 435)	Specialization	4	4	4	O	150Cr
					4		

Noveno Semestre							
Código	**Curso**	**Área**	**HT**	**HP**	**CR**	**T**	**Requisitos**
CE3C15	Professional Competencies Workshop (Pág 438)	Specific	4	2	3	O	CE3C9 (9no Sem)
CE3C5	Costs and Budgeting (Pág 445)	Specific	4	2	3	O	CE2C2 (7mo Sem)
CE3C9	Integrated Construction Management (Pág 448)	Specific	4	2	3	O	CE3C2 (8vo Sem)
CE3G3	Applied Geology (Pág 453)	Specific	3	2	4	O	CE2G2 (8vo Sem)
CE3G4	Soil Mechanics Applied to Transportation Roads (Pág 458)	Specific			3	O	CE2G2 (8vo Sem)
CE3G5	Finite Elements Applied to Geotechnical Engineering (Pág 461)	Specific	4		4	O	CE2G2 (8vo Sem), CE2H1 (7mo Sem)
CE3G6	Earth Dams (Pág 464)	Specific	4		4	O	CE2G2 (8vo Sem), CE2H1 (7mo Sem)
CE3H2	General Hydrology (Pág 469)	Specific	2	2	3	O	CE3H1 (8vo Sem)
CE3H3	Water Supply and Sewerage (Pág 471)	Specific	4	2	4	O	CE3H1 (8vo Sem)
CE3H4	Water Resources (Pág 481)	Specific	2	4	4	O	CE3H1 (8vo Sem)
CE3S11	Professional Competency Workshop - Structures (Pág 487)	Specific	1	4	3	O	CE3S1 (8vo Sem)
CE3S4	Earthquake-Resistant Engineering and Disaster Prevention (Pág 494)	Specific	4	2	4	O	CE2S1 (7mo Sem), CE2S2 (7mo Sem)
CE3S8	Architecture and Structural Models (Pág 497)	Specific	2	4	3	O	CE2S1 (7mo Sem)
CE402	Capstone project I (Pág 504)	Specialization	4	4	4	O	BMI201 (8vo Sem)
BLW201	Law and Legislation (Pág 506)	Specific	1	1	4	O	
					8		

Décimo Semestre								
	Código	**Curso**	**Área**	**HT**	**HP**	**CR**	**T**	**Requisitos**
	CE3C11	Sanitary and Electrical Installations (Pág 512)	Specific	4	2	3	O	CE3H1 (8vo Sem)
	CE3G1	Soil Dynamics (Pág 515)	Specific	3		3	O	CE2G2 (8vo Sem)
	CE3G2	Soil Mechanics Applied to Foundations (Pág 518)	Specific	3	2	4	O	CE2G2 (8vo Sem)
	CE3G7	Professional Competencies Workshop - Geotechnical (Pág 523)	Specific			3	O	CE3G3 (9no Sem)
	CE3H5	Introduction to Fluvial Hydraulics (Pág 529)	Specific	2	4	4	O	CE3H1 (8vo Sem)
	CE3H6	Irrigation Engineering (Pág 533)	Specific	2	4	4	O	CE3H4 (9no Sem)
	CE3H7	Hydraulic and Hydrology Engineering Workshop (Pág 537)	Specific			3	O	CE3H1 (8vo Sem)
	CE3S10	Seismic Design of Civil Engineering Works (Pág 540)	Specific	2	4	4	O	CE3S4 (9no Sem)
	CE3S12	Research Workshop (Pág 544)	Specific	2	4	3	O	BMI201 (8vo Sem)
	CE3S2	Reinforced Concrete Design II (Pág 549)	Specific	4	2	4	O	CE2S2 (7mo Sem)
	CE3S6	Masonry, Adobe, and Timber (Pág 554)	Specific	2	4	3	O	CE3S4 (9no Sem)
	CE3S7	Structural Rehabilitation and Retrofitting (Pág 557)	Specific	4	2	3	O	CE3S4 (9no Sem)
	CE403	Capstone project II (Pág 561)	Specialization	4	4	4	O	CE402 (9no Sem)
Elective	CE3C13	Project Planning and Control (Pág 563)	Specific	2	2	4	E	CE3C5 (9no Sem)
	CE3C14	Sustainable and Resilient Infrastructure (Pág 566)	Specific	2	1	3	E	CE2C1 (7mo Sem), CE2C2 (7mo Sem)
						4		

Total de créditos de la carrera: 56 .

6.3 Topics distributed by course

6.3.1 Civil Engineering topics/course

		First Sem							Second Sem								.
	Knowledge Units of Civil Engineering **Courses →**	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201	Total
⭐	GGL/Mineralogy (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
⭐	GGL/Petrology and the Rock Cycle (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
⭐	GGL/Structural Geology (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
⭐	GGL/Geomorphology, Weathering, and Erosion Processes (1 hour Core-Tier1, 1 hour Core-Tier2)								4								4
⭐	GGL/Geologic Time, Stratigraphy, and Geologic Mapping (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
⭐	GGL/Basic Surface and Groundwater Hydrology of Geologic Materials (1 hour Core-Tier1, 1 hour Core-Tier2)								4								4
⭐	GGL/Applied Geology (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
⭐	PPL/Written and Technical Communication (1 hour Core-Tier1, 1 hour Core-Tier2)				2	19											21
⭐	PPL/Oral Presentation and Professional Communication (1 hour Core-Tier1, 1 hour Core-Tier2)				1	19											20
⭐	PPL/Digital and Collaborative Communication (1 hour Core-Tier1, 1 hour Core-Tier2)				1	18											19
⭐	PPL/Leadership, Team Dynamics, and Stakeholder Management (1 hour Core-Tier1, 1 hour Core-Tier2)				4												4
	Total	0	0	0	8	56	0	0	38	0	0	0	0	0	0	0	

Table 6.1: Civil Engineering topics by course from 1st to 2nd Semester

		Third Sem						Fourth Sem							Fifth Sem		.
	Knowledge Units of Civil Engineering **Courses →**	CE1M1	CB1E2	MA121	MA210	BFI102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202	Total
★	EMM/Mechanics of Materials and Structural Behavior (1 hour Core-Tier1, 1 hour Core-Tier2)								24								24
★	EMM/Concrete Technology and Advanced Cementitious Materials (1 hour Core-Tier1, 1 hour Core-Tier2)									24							24
★	EMM/Concrete Transport and Placement (1 hour Core-Tier1, 1 hour Core-Tier2)									20							20
★	EMM/Statistical Quality Control of Concrete (1 hour Core-Tier1, 1 hour Core-Tier2)									20							20
★	EMM/Equilibrium of Particles and Rigid Bodies (1 hour Core-Tier1, 1 hour Core-Tier2)	8															8
★	EMM/Internal Forces in Trusses and Frames (1 hour Core-Tier1, 1 hour Core-Tier2)	12															12
★	EMM/Geometric Properties of Areas and Friction (1 hour Core-Tier1, 1 hour Core-Tier2)	12															12
★	EMM/Kinematics of Rigid Bodies in Plane Motion (1 hour Core-Tier1, 1 hour Core-Tier2)							10									10
★	EMM/Kinetics of Rigid Bodies in Plane Motion (1 hour Core-Tier1, 1 hour Core-Tier2)							10									10
★	EMM/Introduction to Structural Vibrations (1 hour Core-Tier1, 1 hour Core-Tier2)							12									12
★	DTC/Building Information Modeling (BIM) for Digital Delivery and Asset Management (1 hour Core-Tier1, 1 hour Core-Tier2)		16														16
	Total	32	16	0	0	0	0	32	24	64	0	0	0	0	0	0	

Table 6.2: Civil Engineering topics by course from 3rd to 5th Semester

		Sixth Sem		Seventh Sem									.
	Knowledge Units of Civil Engineering **Courses →**	MA212	ID203	CE2C1	CE2C2	CE2C6	CE2C8	CE2G1	CE2H1	CE2S1	CE2S2	CE2S3	Total
★	EMM/Construction Materials Science (1 hour Core-Tier1, 1 hour Core-Tier2)			10									10
★	EMM/Mechanics of Materials and Structural Behavior (1 hour Core-Tier1, 1 hour Core-Tier2)								13				13
★	EMM/Concrete Technology and Advanced Cementitious Materials (1 hour Core-Tier1, 1 hour Core-Tier2)			14									14
★	EMM/Structural Metals, Alloys, and Corrosion Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)			5									5
★	EMM/Polymeric, Composite, and Sustainable Construction Materials (1 hour Core-Tier1, 1 hour Core-Tier2)			4									4
★	EMM/Standardized Testing, Quality Control, and Failure Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)			5									5
★	EMM/Traditional and Vernacular Construction Materials (1 hour Core-Tier1, 1 hour Core-Tier2)			18									18
★	SAD/Energy Methods for Structural Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)									36			36
★	SAD/Force Method for Indeterminate Structures (1 hour Core-Tier1, 1 hour Core-Tier2)									36			36
★	SAD/Classical Displacement Methods (1 hour Core-Tier1, 1 hour Core-Tier2)									18			18
★	SAD/Reinforced Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)										68		68
★	SAD/Design of Reinforced Concrete Stairs (1 hour Core-Tier1, 1 hour Core-Tier2)										6		6
★	SAD/Design of Steel Members in Tension and Compression (1 hour Core-Tier1, 1 hour Core-Tier2)											19	19
★	SAD/Design of Steel Members in Flexure (1 hour Core-Tier1, 1 hour Core-Tier2)											29	29
★	SAD/Steel Connections and Composite Systems (1 hour Core-Tier1, 1 hour Core-Tier2)											36	36
★	SAD/Masonry Structural Design (1 hour Core-Tier1, 1 hour Core-Tier2)			4									4
★	SAD/Timber and Light-Gauge Steel Framing Design (1 hour Core-Tier1, 1 hour Core-Tier2)			6									6
★	GTE/Phase Relationships and Seepage (1 hour Core-Tier1, 1 hour Core-Tier2)							66					66
★	GTE/Site Investigation and In-Situ Testing (1 hour Core-Tier1, 1 hour Core-Tier2)							4					4
★	GTE/Bearing Capacity and Design (1 hour Core-Tier1, 1 hour Core-Tier2)										10		10
★	WRH/Pressurized Pipe Flow and Pump Systems (1 hour Core-Tier1, 1 hour Core-Tier2)								8				8
★	WRH/Design of Hydraulic Structures (1 hour Core-Tier1, 1 hour Core-Tier2)								6				6
★	CEM/Construction Methods, Equipment, and Productivity (1 hour Core-Tier1, 1 hour Core-Tier2)				38								38
★	CEM/Construction Safety, Health, and Risk Management (1 hour Core-Tier1, 1				4								4

Eighth Sem .

Knowledge Units of Civil Engineering — Courses →	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BMI201	Total
EMM/Construction Materials Science (1 hour Core-Tier1, 1 hour Core-Tier2)	12										12
EMM/Concrete Technology and Advanced Cementitious Materials (1 hour Core-Tier1, 1 hour Core-Tier2)	25										25
EMM/Special Concretes and Concrete in Extreme Climates (1 hour Core-Tier1, 1 hour Core-Tier2)	6										6
EMM/Concrete Transport and Placement (1 hour Core-Tier1, 1 hour Core-Tier2)	4										4
EMM/Statistical Quality Control of Concrete (1 hour Core-Tier1, 1 hour Core-Tier2)	3										3
EMM/Polymeric, Composite, and Sustainable Construction Materials (1 hour Core-Tier1, 1 hour Core-Tier2)	4										4
SAD/Matrix Structural Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)							38				38
SAD/Structural Dynamics and Earthquake Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)							14				14
SAD/Building Structural Analysis and Modeling Practicum (1 hour Core-Tier1, 1 hour Core-Tier2)							12				12
SAD/Reinforced Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)					6						6
SAD/Seismic Detailing of Reinforced Concrete (1 hour Core-Tier1, 1 hour Core-Tier2)									16		16
SAD/Prestressed Concrete Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)									16		16
SAD/Prestressed Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)									20		20
SAD/Masonry Structural Design (1 hour Core-Tier1, 1 hour Core-Tier2)					6						6
SAD/Bridge Superstructure Design (1 hour Core-Tier1, 1 hour Core-Tier2)								36			36
SAD/Bridge Substructure, Evaluation, and Special Systems (1 hour Core-Tier1, 1 hour Core-Tier2)								4			4
SAD/Finite Element Methods in Structural Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)							20				20
SAD/Structural Rehabilitation, Strengthening, and Retrofit (1 hour Core-Tier1, 1 hour Core-Tier2)	3										3
GTE/Shear Strength and Consolidation (1 hour Core-Tier1, 1 hour Core-Tier2)				30	6						36
GTE/Bearing Capacity and Design (1 hour Core-Tier1, 1 hour Core-Tier2)				10	3						13
GTE/Deep Foundations (1 hour Core-Tier1, 1 hour Core-Tier2)				10	3						13
GTE/Earth Retaining Systems (1 hour Core-Tier1, 1 hour Core-Tier2)				10							10
GTE/Slope Stability Analysis and Stabilization (1 hour Core-Tier1, 1 hour Core-Tier2)				10							10
WRH/Open Channel Flow and River Mechanics (1 hour Core-Tier1, 1 hour Core-Tier2)						30					30
WRH/Pressurized Pipe Flow and Pump Systems (1 hour Core-Tier1, 1 hour Core-Tier2)						42					42
WRH/Design of Hydraulic Structures (1 hour Core-Tier1, 1 hour Core-Tier2)						12					12

Table 6.4: Civil Engineering topics by course 8th Semester (Part 1 of 2)

Eighth Sem

Knowledge Units of Civil Engineering — Courses →	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BM1201	Total
CEM/Construction Methods, Equipment, and Productivity (1 hour Core-Tier1, 1 hour Core-Tier2)					20						20
CEM/Project Planning, Scheduling, and Control (CPM, 4D/5D) (1 hour Core-Tier1, 1 hour Core-Tier2)		42									42
CEM/Construction Cost Estimating and Quantification (1 hour Core-Tier1, 1 hour Core-Tier2)		10									10
CEM/Construction Budgeting, Bidding, and Financial Control (1 hour Core-Tier1, 1 hour Core-Tier2)		8									8
CEM/Construction Layout and Staking of Works (1 hour Core-Tier1, 1 hour Core-Tier2)					6						6
CEM/Formwork Design and Shoring Systems (1 hour Core-Tier1, 1 hour Core-Tier2)					14						14
CEM/Rebar Detailing, Fabrication, and Placement (1 hour Core-Tier1, 1 hour Core-Tier2)					10						10
CEM/Construction Site and Field Management (1 hour Core-Tier1, 1 hour Core-Tier2)		24									24
Total	57	84	0	70	74	84	84	40	52	0	

Table 6.5: Civil Engineering topics by course 8th Semester (Part 2 of 2)

		Ninth Sem															.
	Knowledge Units of Civil Engineering **Courses →**	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
★	EMM/Construction Materials Science (1 hour Core-Tier1, 1 hour Core-Tier2)									6							6
★	EMM/Mechanics of Materials and Structural Behavior (1 hour Core-Tier1, 1 hour Core-Tier2)									6		10					16
★	EMM/Standardized Testing, Quality Control, and Failure Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)	6								4		6					16
★	SAD/Structural Analysis I (1 hour Core-Tier1, 1 hour Core-Tier2)													8			8
★	SAD/Seismology and Natural Hazards (1 hour Core-Tier1, 1 hour Core-Tier2)												17				17
★	SAD/Seismic Design Code and Structural Configuration Criteria (1 hour Core-Tier1, 1 hour Core-Tier2)											10	11				21
★	SAD/Structural Dynamics and Earthquake Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)											10	56				66
★	SAD/Reinforced Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)											10					10
★	SAD/Seismic Detailing of Reinforced Concrete (1 hour Core-Tier1, 1 hour Core-Tier2)											3					3
★	SAD/Prestressed Concrete Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)											3					3
★	SAD/Prestressed Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)											4					4
★	GTE/Site Investigation and In-Situ Testing (1 hour Core-Tier1, 1 hour Core-Tier2)				5			6		4							15
★	GTE/Geotechnical Numerical Modeling and Applications (1 hour Core-Tier1, 1 hour Core-Tier2)						50										50
★	GTE/Earth Dams (1 hour Core-Tier1, 1 hour Core-Tier2)							4									4
★	GTE/Geotechnical Characterization for Earth Dams (1 hour Core-Tier1, 1 hour Core-Tier2)							6									6
★	GTE/Geotechnical Design of Embankment Dams (1 hour Core-Tier1, 1 hour Core-Tier2)							12									12
★	GTE/Dam Instrumentation and Monitoring (1 hour Core-Tier1, 1 hour Core-Tier2)							12									12
★	GTE/Construction of Earth Dams (1 hour Core-Tier1, 1 hour Core-Tier2)							8									8
★	GTE/Operation and Safety Management of Dams (1 hour Core-Tier1, 1 hour Core-Tier2)							8									8
★	GGL/Rock Mass Characterization and Applied Rock and Soil Mechanics (1 hour Core-Tier1, 1 hour Core-Tier2)				10												10

	Knowledge Units of Civil Engineering — Courses →	Ninth Sem															.
		CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
★	WRH/Surface Hydrology and Watershed Modeling (1 hour Core-Tier1, 1 hour Core-Tier2)								17	2	9						28
★	WRH/Flood Frequency Analysis and Climate Change (1 hour Core-Tier1, 1 hour Core-Tier2)								17	2	8						27
★	WRH/Open Channel Flow and River Mechanics (1 hour Core-Tier1, 1 hour Core-Tier2)									8							8
★	WRH/Pressurized Pipe Flow and Pump Systems (1 hour Core-Tier1, 1 hour Core-Tier2)									6							6
★	WRH/Design of Hydraulic Structures (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
★	WRH/Urban Water Systems (1 hour Core-Tier1, 1 hour Core-Tier2)									8							8
★	WRH/Groundwater Hydrology (1 hour Core-Tier1, 1 hour Core-Tier2)										8						8
★	WRH/Economic, Financial and Social Evaluation of Water Resources Projects (1 hour Core-Tier1, 1 hour Core-Tier2)										12						12
★	ESE/Water and Wastewater Treatment Process Design (1 hour Core-Tier1, 1 hour Core-Tier2)									8							8
★	ESE/Environmental Chemistry and Microbiology for Engineers (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
★	ESE/Air Quality and Pollution Control Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)			12													12
★	ESE/Environmental Impact Assessment and Sustainability Metrics (1 hour Core-Tier1, 1 hour Core-Tier2)	6		12						4	3						25
★	ESE/Climate Adaptation Engineering for Water Systems (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
★	CEM/Construction Methods, Equipment, and Productivity (1 hour Core-Tier1, 1 hour Core-Tier2)	6															6
★	CEM/Project Planning, Scheduling, and Control (CPM, 4D/5D) (1 hour Core-Tier1, 1 hour Core-Tier2)	6															6
★	CEM/Construction Cost Estimating and Quantification (1 hour Core-Tier1, 1 hour Core-Tier2)		54														54
★	CEM/Construction Budgeting, Bidding, and Financial Control (1 hour Core-Tier1, 1 hour Core-Tier2)	6	44														50
★	CEM/Price Adjustment and Progress Valuations (1 hour Core-Tier1, 1 hour Core-Tier2)		32														32
★	CEM/Construction Safety, Health, and Risk Management (1 hour Core-Tier1, 1 hour Core-Tier2)	6		24													30
★	CEM/Contracts, Specifications, and Construction Law (1	6															6

		Ninth Sem															
	Knowledge Units of Civil Engineering **Courses →**	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
⭐	PPL/Engineering Ethics and Professional Responsibility (1 hour Core-Tier1, 1 hour Core-Tier2)											4					4
⭐	PPL/Written and Technical Communication (1 hour Core-Tier1, 1 hour Core-Tier2)													2			2
⭐	PPL/Oral Presentation and Professional Communication (1 hour Core-Tier1, 1 hour Core-Tier2)													1			1
⭐	PPL/Digital and Collaborative Communication (1 hour Core-Tier1, 1 hour Core-Tier2)													1			1
⭐	PPL/Engineering Economics and Project Financing (PPPs) (1 hour Core-Tier1, 1 hour Core-Tier2)	6															6
⭐	PPL/Engineering Licensure, Legal Liability, and Regulatory Frameworks (1 hour Core-Tier1, 1 hour Core-Tier2)													4			4
⭐	PPL/Global Engineering Practice and International Standards (1 hour Core-Tier1, 1 hour Core-Tier2)													4			4
	Total	54	130	64	70	0	50	56	56	76	51	70	84	60	0	0	

Table 6.8: Civil Engineering topics by course 9th Semester (Part 3 of 3)

Tenth Sem

Knowledge Units of Civil Engineering — Courses →	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14	Total
SAD/Seismology and Natural Hazards (1 hour Core-Tier1, 1 hour Core-Tier2)								6								6
SAD/Seismic Design Code and Structural Configuration Criteria (1 hour Core-Tier1, 1 hour Core-Tier2)								6				4				10
SAD/Structural Dynamics and Earthquake Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)								12								12
SAD/Building Structural Analysis and Modeling Practicum (1 hour Core-Tier1, 1 hour Core-Tier2)										4						4
SAD/Reinforced Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)										18						18
SAD/Seismic Detailing of Reinforced Concrete (1 hour Core-Tier1, 1 hour Core-Tier2)										7						7
SAD/Prestressed Concrete Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)										7						7
SAD/Prestressed Concrete Design (1 hour Core-Tier1, 1 hour Core-Tier2)										8						8
SAD/Integrated Structural Design Project (1 hour Core-Tier1, 1 hour Core-Tier2)										12						12
SAD/Design Process for Low-Rise Buildings (1 hour Core-Tier1, 1 hour Core-Tier2)											12					12
SAD/Masonry Structural Design (1 hour Core-Tier1, 1 hour Core-Tier2)											22					22
SAD/Timber and Light-Gauge Steel Framing Design (1 hour Core-Tier1, 1 hour Core-Tier2)											33					33
SAD/Adobe Structural Design (1 hour Core-Tier1, 1 hour Core-Tier2)											17					17
SAD/Nature and Characterization of Loads on Existing Infrastructure (1 hour Core-Tier1, 1 hour Core-Tier2)												10				10
SAD/Nonlinear Behavior of Structures (1 hour Core-Tier1, 1 hour Core-Tier2)												18				18
SAD/Structural Rehabilitation, Strengthening, and Retrofit (1 hour Core-Tier1, 1 hour Core-Tier2)												50				50
SAD/Industrial Structures: Chimneys and Tanks (1 hour Core-Tier1, 1 hour Core-Tier2)								48								48
GTE/Shear Strength and Consolidation (1 hour Core-Tier1, 1 hour Core-Tier2)				6												6
GTE/Site Investigation and In-Situ Testing (1 hour Core-Tier1, 1 hour Core-Tier2)				9												9
GTE/Bearing Capacity and Design (1 hour Core-Tier1, 1			26	9						26						61

Tenth Sem

Knowledge Units of Civil Engineering — Courses →	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14	Total
GTE/Earth Dams (1 hour Core-Tier1, 1 hour Core-Tier2)				4												4
GTE/Geotechnical Characterization for Earth Dams (1 hour Core-Tier1, 1 hour Core-Tier2)				5												5
GTE/Geotechnical Design of Embankment Dams (1 hour Core-Tier1, 1 hour Core-Tier2)				9												9
WRH/Hydrologic Cycle and Water Balance (1 hour Core-Tier1, 1 hour Core-Tier2)							5									5
WRH/Surface Hydrology and Watershed Modeling (1 hour Core-Tier1, 1 hour Core-Tier2)							4									4
WRH/Flood Frequency Analysis and Climate Change (1 hour Core-Tier1, 1 hour Core-Tier2)							3									3
WRH/Open Channel Flow and River Mechanics (1 hour Core-Tier1, 1 hour Core-Tier2)					8	9										17
WRH/Design of Hydraulic Structures (1 hour Core-Tier1, 1 hour Core-Tier2)					2	12	66									80
WRH/Economic, Financial and Social Evaluation of Water Resources Projects (1 hour Core-Tier1, 1 hour Core-Tier2)						9										9
WRH/Sediment Transport in Alluvial Channels (1 hour Core-Tier1, 1 hour Core-Tier2)					22											22
WRH/Scour and Fluvial Morphology (1 hour Core-Tier1, 1 hour Core-Tier2)					26											26
WRH/River Engineering (1 hour Core-Tier1, 1 hour Core-Tier2)					24											24
WRH/Agricultural Water Demand (1 hour Core-Tier1, 1 hour Core-Tier2)						12										12
WRH/Irrigation Systems Design (1 hour Core-Tier1, 1 hour Core-Tier2)						33										33
ESE/Environmental Impact Assessment and Sustainability Metrics (1 hour Core-Tier1, 1 hour Core-Tier2)						3										3
CEM/Project Planning, Scheduling, and Control (CPM, 4D/5D) (1 hour Core-Tier1, 1 hour Core-Tier2)														16		16
CEM/Lean Construction and Integrated Project Delivery (IPD) (1 hour Core-Tier1, 1 hour Core-Tier2)														12		12
SRI/Foundational Sustainability Principles and Triple Bottom Line (1 hour Core-Tier1, 1 hour Core-Tier2)															15	15
SRI/Resource Efficiency and Circular Economy (1 hour Core-Tier1, 1 hour Core-Tier2)															15	15
SRI/Social, Economic, and Governance Dimensions of Sustainable Infrastructure (1 hour Core-Tier1, 1 hour Core-															16	16

		Tenth Sem															.
	Knowledge Units of Civil Engineering **Courses →**	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14	Total
⭐	PPL/Digital and Collaborative Communication (1 hour Core-Tier1, 1 hour Core-Tier2)									2							2
⭐	PPL/Leadership, Team Dynamics, and Stakeholder Management (1 hour Core-Tier1, 1 hour Core-Tier2)														12		12
⭐	PPL/Professional and Regulatory Context (1 hour Core-Tier1, 1 hour Core-Tier2)								12								12
⭐	PPL/National Context of Existing Civil Infrastructure (1 hour Core-Tier1, 1 hour Core-Tier2)												2				2
	Total	56	42	70	84	82	78	78	84	12	108	84	84	0	40	46	

Table 6.11: Civil Engineering topics by course 10th Semester (Part 3 of 3)

6.3.2 Transportation Engineering topics/course

	First Sem							Second Sem								.
Knowledge Units of Transportation Engineering Courses →	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201	Total
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6.12: Transportation Engineering topics by course from 1st to 2nd Semester

Third Sem								Fourth Sem								Fifth Sem				Total
Knowledge Units of Transportation EngineeringCourses →	CE1M1	CB1E2	MA121	MA210	BF1102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202					
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					

Table 6.13: Transportation Engineering topics by course from 3rd to 5th Semester

Sixth Sem								Seventh Sem								Total
Knowledge Units of Transportation Engineering Courses →	MA212	ID203	CE2C1	CE2C2	CE2C6	CE2C8	CE2G1	CE2H1	CE2S1	CE2S2	CE2S3					
Total	0	0	0	0	0	0	0	0	0	0	0					

Table 6.14: Transportation Engineering topics by course from 6th to 7th Semester

Eighth Sem												Total
Knowledge Units of Transportation Engineering Courses →	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BM1201		
TIE/Road and Bridge Asset Management (1 hour Core-Tier1, 1 hour Core-Tier2)	0	0	0	0	0	0	0	2	0	0		2
Total	0	0	0	0	0	0	0	2	0	0		2

Table 6.15: Transportation Engineering topics by course 8th Semester

	Ninth Sem															.
Knowledge Units of Transportation Engineering Courses →	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
⭐ TIE/Pavement Materials and Characterization (1 hour Core-Tier1, 1 hour Core-Tier2)					6											6
⭐ TIE/Pavement Design and Management (1 hour Core-Tier1, 1 hour Core-Tier2)					14											14
⭐ TIE/Pavement Condition Evaluation and Maintenance Planning (1 hour Core-Tier1, 1 hour Core-Tier2)					10											10
Total	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	

Table 6.16: Transportation Engineering topics by course 9th Semester

	Tenth Sem															.
Knowledge Units of Transportation Engineering Courses →	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14	Total
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6.17: Transportation Engineering topics by course 10th Semester

6.3.3 Engineering Science topics/course

Knowledge Units of Engineering Science — Courses →	First Sem							Second Sem								.
	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201	Total
★ CAN/Vector Functions of a Real Variable (1 hour Core-Tier1, 1 hour Core-Tier2)												10				10
★ CAN/Limits and Continuity (1 hour Core-Tier1, 1 hour Core-Tier2)		20														20
★ CAN/Differential Calculus (1 hour Core-Tier1, 1 hour Core-Tier2)		20														20
★ CAN/Integral Calculus (1 hour Core-Tier1, 1 hour Core-Tier2)		10										14				24
★ CAN/Improper Integrals (1 hour Core-Tier1, 1 hour Core-Tier2)												6				6
★ CAN/Sequences, Series, and Power Series (1 hour Core-Tier1, 1 hour Core-Tier2)												14				14
★ CAN/Applications of the Definite Integral (1 hour Core-Tier1, 1 hour Core-Tier2)												16				16
★ CAN/Vectors and the Geometry of Space (1 hour Core-Tier1, 1 hour Core-Tier2)												6				6
★ CAN/Quadric Surfaces (1 hour Core-Tier1, 1 hour Core-Tier2)												6				6
★ CAN/Parametric Equations and Polar Coordinates (1 hour Core-Tier1, 1 hour Core-Tier2)												12				12
★ CME/Kinematics and Dynamics of Particles (1 hour Core-Tier1, 1 hour Core-Tier2)													22			22
★ CME/Work, Energy, and Conservative Forces (1 hour Core-Tier1, 1 hour Core-Tier2)													12			12
★ CME/Rotational Motion and Angular Momentum (1 hour Core-Tier1, 1 hour Core-Tier2)													12			12
★ CME/Systems of Particles and Linear Momentum (1 hour Core-Tier1, 1 hour Core-Tier2)													8			8
★ CME/Elasticity (1 hour Core-Tier1, 1 hour Core-Tier2)													2			2
★ CME/Fluids: Hydrostatics, Hydrodynamics, and Viscosity (1 hour Core-Tier1, 1 hour Core-Tier2)													10			10
★ CME/Vibrations and Waves (1 hour Core-Tier1, 1 hour Core-Tier2)													14			14
★ CME/Transport Phenomena (1 hour Core-Tier1, 1 hour Core-Tier2)													4			4

		First Sem							Second Sem								
	Knowledge Units of Engineering Science **Courses →**	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201	Total
★	GCH/Polymers and Geosynthetics (1 hour Core-Tier1, 1 hour Core-Tier2)			4													4
★	GCH/Chemical Equilibrium (1 hour Core-Tier1, 1 hour Core-Tier2)			4													4
★	GCH/Ionic Equilibrium and Salt Hydrolysis (1 hour Core-Tier1, 1 hour Core-Tier2)			12													12
★	GCH/Salts, Solubility, and Precipitation Equilibria (1 hour Core-Tier1, 1 hour Core-Tier2)			6													6
★	GCH/Electrochemistry and Electrolysis (1 hour Core-Tier1, 1 hour Core-Tier2)			8													8
★	GCH/Cement Chemistry (1 hour Core-Tier1, 1 hour Core-Tier2)			4													4
	Total	0	50	90	0	0	0	0	0	0	0	0	84	84	0	0	

Table 6.19: Engineering Science topics by course from 1st to 2nd Semester (Part 2 of 2)

		Third Sem						Fourth Sem							Fifth Sem		.
	Knowledge Units of Engineering Science Courses →	CE1M1	CB1E2	MA121	MA210	BFI102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202	Total
★	CAN/Line Integrals and Vector Fields (1 hour Core-Tier1, 1 hour Core-Tier2)				18												18
★	CAN/Multiple Integrals (1 hour Core-Tier1, 1 hour Core-Tier2)				12												12
★	CAN/Surface Integrals and Fundamental Theorems (1 hour Core-Tier1, 1 hour Core-Tier2)				16												16
★	CAN/Multivariable and Vector Calculus (1 hour Core-Tier1, 1 hour Core-Tier2)				22												22
★	ANT/Matrices and Systems of Linear Equations (1 hour Core-Tier1, 1 hour Core-Tier2)			28													28
★	ANT/Vector Spaces and Linear Transformations (1 hour Core-Tier1, 1 hour Core-Tier2)			22													22
★	ANT/Eigenvalues and Inner Product Spaces (1 hour Core-Tier1, 1 hour Core-Tier2)			20													20
★	MMS/First-Order Ordinary Differential Equations (ODEs) (1 hour Core-Tier1, 1 hour Core-Tier2)				16							30					46
★	MMS/Higher-Order Differential Equations and Systems (ODEs) (1 hour Core-Tier1, 1 hour Core-Tier2)											20					20
★	MMS/Partial Differential Equations (PDEs) (1 hour Core-Tier1, 1 hour Core-Tier2)											16					16
★	MMS/Asymptotic Analysis and Perturbation Methods (1 hour Core-Tier1, 1 hour Core-Tier2)											4					4
★	PST/Time Series Analysis (1 hour Core-Tier1, 1 hour Core-Tier2)										2						2
★	NSA/Error Analysis and Floating Point Arithmetic (1 hour Core-Tier1, 1 hour Core-Tier2)										6						6
★	NSA/Numerical Linear Algebra (1 hour Core-Tier1, 1 hour Core-Tier2)										12						12
★	NSA/Numerical Solution of Nonlinear Equations (1 hour Core-Tier1, 1 hour Core-Tier2)										10						10
★	NSA/Approximation Theory and Interpolation (1 hour Core-Tier1, 1 hour Core-Tier2)										10						10
★	NSA/Numerical Integration and Quadrature (1 hour Core-Tier1, 1 hour Core-Tier2)										10						10
★	NSA/Numerical Methods for ODEs and PDEs (1 hour Core-Tier1, 1 hour Core-Tier2)										12						12
★	NSA/Finite Element Method (1 hour Core-Tier1, 1 hour Core-Tier2)										8						8

		Third Sem						Fourth Sem							Fifth Sem		.
	Knowledge Units of Engineering Science Courses →	CE1M1	CB1E2	MA121	MA210	BFI102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202	Total
★	ELM/Electrostatic Energy and Dielectrics (1 hour Core-Tier1, 1 hour Core-Tier2)					6											6
★	ELM/Magnetostatics: Biot-Savart and Ampere's Laws (1 hour Core-Tier1, 1 hour Core-Tier2)					7											7
★	ELM/Magnetic Properties of Matter (1 hour Core-Tier1, 1 hour Core-Tier2)					7											7
★	ELM/Electrodynamics: Faraday's Law and Induction (1 hour Core-Tier1, 1 hour Core-Tier2)					6											6
★	ELM/Electric Current, Circuits, and Kirchhoff's Laws (1 hour Core-Tier1, 1 hour Core-Tier2)					4											4
★	PRO/Sample Spaces and Events (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Probability Axioms and Properties (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Conditional Probability and Independence (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Discrete Random Variables and Distributions (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Continuous Random Variables and Distributions (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Joint, Marginal, and Conditional Distributions (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	PRO/Limit Theorems: LLN and CLT (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	DSC/Numerical Summaries: Location, Spread, and Shape (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	INF/Point Estimation (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	INF/Interval Estimation and Confidence Intervals (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	INF/Hypothesis Testing Foundations (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	INF/Bayesian Inference (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
★	REG/Simple Linear Regression (1 hour Core-Tier1, 1 hour Core-Tier2)												4				4
	Total	0	0	70	84	84	0	0	0	0	82	70	52	0	0	0	

Knowledge Units of Engineering Science / Courses →	MA212	ID203	CE2C1	CE2C2	CE2C6	CE2C8	CE2G1	CE2H1	CE2S1	CE2S2	CE2S3	Total
	Sixth Sem		Seventh Sem									
★ MMS/First-Order Ordinary Differential Equations (ODEs) (1 hour Core-Tier1, 1 hour Core-Tier2)	20							4				24
★ MMS/Higher-Order Differential Equations and Systems (ODEs) (1 hour Core-Tier1, 1 hour Core-Tier2)	40											40
★ MMS/Mathematical Fluid Dynamics (1 hour Core-Tier1, 1 hour Core-Tier2)								6				6
★ NSA/Numerical Methods for ODEs and PDEs (1 hour Core-Tier1, 1 hour Core-Tier2)	36							8				44
★ NSA/Finite Element Method (1 hour Core-Tier1, 1 hour Core-Tier2)								6				6
★ CME/Kinematics and Dynamics of Particles (1 hour Core-Tier1, 1 hour Core-Tier2)								6				6
★ CME/Non-Inertial Reference Frames and Fictitious Forces (1 hour Core-Tier1, 1 hour Core-Tier2)								21				21
★ CME/Lagrangian and Hamiltonian Mechanics (1 hour Core-Tier1, 1 hour Core-Tier2)								21				21
★ CME/Continuum Mechanics Foundations (1 hour Core-Tier1, 1 hour Core-Tier2)								8				8
★ TSM/Laws of Thermodynamics and State Functions (1 hour Core-Tier1, 1 hour Core-Tier2)								4				4
★ TSM/Kinetic Theory of Gases (1 hour Core-Tier1, 1 hour Core-Tier2)								4				4
Total	96	0	0	0	0	0	0	88	0	0	0	

Table 6.22: Engineering Science topics by course from 6th to 7th Semester

		Eighth Sem										
Knowledge Units of Engineering Science	**Courses →**	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BMI201	Total
Total		0	0	0	0	0	0	0	0	0	0	

Table 6.23: Engineering Science topics by course 8th Semester

		Ninth Sem															
Knowledge Units of Engineering Science	**Courses →**	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
PST/Mathematical Statistics and Estimation Theory (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
NSA/Finite Element Method (1 hour Core-Tier1, 1 hour Core-Tier2)						6										6
NSA/Optimization Algorithms (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
DMC/Graph Theory (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
MBL/Population Dynamics (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
FAM/Interest Theory and Time Value of Money (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
INC/Solid State and Material Chemistry (1 hour Core-Tier1, 1 hour Core-Tier2)									4							4
Total		0	0	0	0	0	6	0	0	24	0	0	0	0	0	0	

Table 6.24: Engineering Science topics by course 9th Semester

Tenth Sem																
Knowledge Units of Engineering Science	Courses →	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14
Total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.25: Engineering Science topics by course 10th Semester

6.3.4 Project Management topics/course

First Sem																
Knowledge Units of Project Management	Courses →	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201
Total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.26: Project Management topics by course from 1st to 2nd Semester

Third Sem								Fourth Sem								Fifth Sem		
Knowledge Units of Project Management	Courses →	CE1M1	CB1E2	MA121	MA210	BFI102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202		
Total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Table 6.27: Project Management topics by course from 3rd to 5th Semester

	Sixth Sem		Seventh Sem									.
Knowledge Units of Project Management **Courses →**	MA212	ID203	CE2C1	CE2C2	CE2C6	CE2C8	CE2G1	CE2H1	CE2S1	CE2S2	CE2S3	Total
Total	0	0	0	0	0	0	0	0	0	0	0	

Table 6.28: Project Management topics by course from 6th to 7th Semester

	Eighth Sem										.
Knowledge Units of Project Management **Courses →**	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BMI201	Total
Total	0	0	0	0	0	0	0	0	0	0	

Table 6.29: Project Management topics by course 8th Semester

Ninth Sem.	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201	Total
Knowledge Units of Project Management Courses →																6
DL/Kickoff and Closure Activities (1 hour Core-Tier1, 1 hour Core-Tier2)			6													12
PL/Scope and Requirements Planning (1 hour Core-Tier1, 1 hour Core-Tier2)										12						2
PL/Schedule Planning (1 hour Core-Tier1, 1 hour Core-Tier2)										2						1
PL/Cost and Budget Planning (1 hour Core-Tier1, 1 hour Core-Tier2)										1						6
MS/Key Performance Indicators (1 hour Core-Tier1, 1 hour Core-Tier2)			6													6
MS/Dashboards and Information Radiators (1 hour Core-Tier1, 1 hour Core-Tier2)	6															6
Total	6	0	12	0	0	0	0	0	0	15	0	0	0	0	0	

Table 6.30: Project Management topics by course 9th Semester

Tenth Sem.	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14	Total
Knowledge Units of Project Management Courses →																16
PL/Planning Principles (1 hour Core-Tier1, 1 hour Core-Tier2)														16		16
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	

Table 6.31: Project Management topics by course 10th Semester

6.4 Expected outcomes distributed by course

The following tables provide an overview of the outcomes expected to be achieved in each course of the present curriculum. The complete list of expected outcomes can be found in Section: 1.5.1.

		First Sem									Second Sem						
	Skill/Course	MA100	MA111	BCH101	BME101	BRC101	BIC101	BEC101	CE1G1	CS100	AI161	CB1E1	MA112	BFI101	ID101	BEF201
ABET-1)	Identify, formulate, and solve complex engineering problems.	1	1	1			1	2	2	1	1	2	1	1		
ABET-2)	Apply engineering design to produce solutions that meet specific needs.							2				2				1
ABET-3)	Communicate effectively with diverse audiences.				1	1									1	
ABET-4)	Recognize ethical responsibilities and make informed judgments.									1	1					2
ABET-5)	Function effectively in teams and exercise leadership.														1	
ABET-6)	Develop experiments, analyze data, and draw conclusions.				1				2							
ABET-7)	Acquire and apply new knowledge using learning strategies.				1		1			1						

Table 6.32: Outcomes by course 1st to 2nd Semester

		Third Sem						Fourth Sem							Fifth Sem	
	Skill/Course	CE1M1	CB1E2	MA121	MA210	BFI102	ID102	CE1M2	CE2M1	CE3M1	MA202	MA211	STA251	ID201	CE2M2	ID202
ABET-1)	Identify, formulate, and solve complex engineering problems.	2	2	1	1	2		2	2	2	2	1	1		2	
ABET-2)	Apply engineering design to produce solutions that meet specific needs.		2							2	2					
ABET-3)	Communicate effectively with diverse audiences.						1							1		1
ABET-4)	Recognize ethical responsibilities and make informed judgments.															
ABET-5)	Function effectively in teams and exercise leadership.						1							1		1
ABET-6)	Develop experiments, analyze data, and draw conclusions.	2						2	2	2	2				2	
ABET-7)	Acquire and apply new knowledge using learning strategies.															

Table 6.33: Outcomes by course 3rd to 5th Semester

		Sixth Sem		Seventh Sem								
	Skill/Course	MA212	ID203	CE2C1	CE2C2	CE2C6	CE2C8	CE2G1	CE2H1	CE2S1	CE2S2	CE2S3
ABET-1)	Identify, formulate, and solve complex engineering problems.	1		2	2	2	2	2	2	2	2	2
ABET-2)	Apply engineering design to produce solutions that meet specific needs.			2	2	2	2		2	2	2	2
ABET-3)	Communicate effectively with diverse audiences.		1									
ABET-4)	Recognize ethical responsibilities and make informed judgments.											
ABET-5)	Function effectively in teams and exercise leadership.		1									
ABET-6)	Develop experiments, analyze data, and draw conclusions.			2	2		2	2	2			
ABET-7)	Acquire and apply new knowledge using learning strategies.											

Table 6.34: Outcomes by course 6th to 7th Semester

		Eighth Sem									
	Skill/Course	CE2C3	CE2C5	CE2C7	CE2G2	CE3C2	CE3H1	CE3S1	CE3S5	CE3S9	BMI201
ABET-1)	Identify, formulate, and solve complex engineering problems.	2		2	2	2	2	2	2	2	
ABET-2)	Apply engineering design to produce solutions that meet specific needs.	2	2	2	2	2	2	2	2	2	
ABET-3)	Communicate effectively with diverse audiences.										
ABET-4)	Recognize ethical responsibilities and make informed judgments.										
ABET-5)	Function effectively in teams and exercise leadership.		2								
ABET-6)	Develop experiments, analyze data, and draw conclusions.	2		2			2	2			1
ABET-7)	Acquire and apply new knowledge using learning strategies.										

Table 6.35: Outcomes by course 8th Semester

		Ninth Sem													
	Skill/Course	CE3C15	CE3C5	CE3C9	CE3G3	CE3G4	CE3G5	CE3G6	CE3H2	CE3H3	CE3H4	CE3S11	CE3S4	CE3S8	CE402	BLW201
ABET-1)	Identify, formulate, and solve complex engineering problems.	2		2	2	2	2	2	2	2	2	2	2	2	3	
ABET-2)	Apply engineering design to produce solutions that meet specific needs.	2		2	2	2	2	2		2	2	2	2	2	3	1
ABET-3)	Communicate effectively with diverse audiences.														3	
ABET-4)	Recognize ethical responsibilities and make informed judgments.														3	1
ABET-5)	Function effectively in teams and exercise leadership.														3	
ABET-6)	Develop experiments, analyze data, and draw conclusions.	2	2	2	2	2	2	2	2	2	2	2		2		
ABET-7)	Acquire and apply new knowledge using learning strategies.															

Table 6.36: Outcomes by course 9th Semester

Tenth Sem

Skill/Course	CE3C11	CE3G1	CE3G2	CE3G7	CE3H5	CE3H6	CE3H7	CE3S10	CE3S12	CE3S2	CE3S6	CE3S7	CE403	CE3C13	CE3C14
ABET-1) Identify, formulate, and solve complex engineering problems.		2	2	2	2	2	2	2		2	2	2	3	2	2
ABET-2) Apply engineering design to produce solutions that meet specific needs.	2	2	2	2	2	2	2	2		2	2	2	3	2	
ABET-3) Communicate effectively with diverse audiences.									2				3		
ABET-4) Recognize ethical responsibilities and make informed judgments.									2				3		
ABET-5) Function effectively in teams and exercise leadership.													3		
ABET-6) Develop experiments, analyze data, and draw conclusions.		2	2	2					2			2			
ABET-7) Acquire and apply new knowledge using learning strategies.															

Table 6.37: Outcomes by course 10th Semester

6.5 Courses by Outcome

6.5.1 Outcome: ABET-1) Identify, formulate, and solve complex engineering problems.

- MA100 Basic Mathematics (1st Sem-Pg. 245)
- MA111 Calculus I (1st Sem-Pg. 249)
- BCH101 Chemistry I (1st Sem-Pg. 251)
- BIC101 Introduction to Programming (1st Sem-Pg. 262)
- BEC101 General Economics (1st Sem-Pg. 266)
- CE1G1 General Geology (2nd Sem-Pg. 270)
- CS100 Introduction to Computer Science (2nd Sem-Pg. 274)
- AI161 Applied AI (2nd Sem-Pg. 284)
- CB1E1 Technical Drawing & CAD (2nd Sem-Pg. 288)
- MA112 Calculus II (2nd Sem-Pg. 291)
- BFI101 General Physics (2nd Sem-Pg. 295)
- CE1M1 Statics (3rd Sem-Pg. 306)
- CB1E2 Engineering Drawing II (3rd Sem-Pg. 309)
- MA121 Linear Algebra I (3rd Sem-Pg. 312)
- MA210 Calculus III (3rd Sem-Pg. 314)
- BFI102 Physics II (3rd Sem-Pg. 317)
- CE1M2 Dynamics (4th Sem-Pg. 326)
- CE2M1 Mechanics of Materials I (4th Sem-Pg. 329)
- CE3M1 Concrete Technology (4th Sem-Pg. 332)
- MA202 Numerical Methods (4th Sem-Pg. 335)
- MA211 Calculus IV (4th Sem-Pg. 340)
- STA251 Statistics and Probability (4th Sem-Pg. 343)
- CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)
- MA212 Ordinary Differential Equations (6th Sem-Pg. 359)
- CE2C1 Materials Technology (7th Sem-Pg. 366)
- CE2C2 Construction Technology I (7th Sem-Pg. 371)
- CE2C6 Territorial Planning (7th Sem-Pg. 374)
- CE2C8 Business Management in Construction I (7th Sem-Pg. 377)
- CE2G1 Soil Mechanics I (7th Sem-Pg. 381)
- CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)
- CE2S1 Structural Analysis I (7th Sem-Pg. 391)
- CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)
- CE2S3 Steel Design (7th Sem-Pg. 397)
- CE2C3 Concrete Technology I (8th Sem-Pg. 400)
- CE2C7 Business Organization and Management (8th Sem-Pg. 408)
- CE2G2 Soil Mechanics II (8th Sem-Pg. 413)
- CE3C2 Construction Technology II (8th Sem-Pg. 417)
- CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)
- CE3S1 Structural Analysis II (8th Sem-Pg. 425)
- CE3S5 Bridges and Structures (8th Sem-Pg. 429)
- CE3S9 Prestressed Concrete (8th Sem-Pg. 432)
- CE3C15 Professional Competencies Workshop (9th Sem-Pg. 438)
- CE3C9 Integrated Construction Management (9th Sem-Pg. 448)
- CE3G3 Applied Geology (9th Sem-Pg. 453)
- CE3G4 Soil Mechanics Applied to Transportation Roads (9th Sem-Pg. 458)

- CE3G5 Finite Elements Applied to Geotechnical Engineering (9th Sem-Pg. 461)
- CE3G6 Earth Dams (9th Sem-Pg. 464)
- CE3H2 General Hydrology (9th Sem-Pg. 469)
- CE3H3 Water Supply and Sewerage (9th Sem-Pg. 471)
- CE3H4 Water Resources (9th Sem-Pg. 481)
- CE3S11 Professional Competency Workshop - Structures (9th Sem-Pg. 487)
- CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)
- CE3S8 Architecture and Structural Models (9th Sem-Pg. 497)
- CE402 Capstone project I (9th Sem-Pg. 504)
- CE3G1 Soil Dynamics (10th Sem-Pg. 515)
- CE3G2 Soil Mechanics Applied to Foundations (10th Sem-Pg. 518)
- CE3G7 Professional Competencies Workshop - Geotechnical (10th Sem-Pg. 523)
- CE3H5 Introduction to Fluvial Hydraulics (10th Sem-Pg. 529)
- CE3H6 Irrigation Engineering (10th Sem-Pg. 533)
- CE3H7 Hydraulic and Hydrology Engineering Workshop (10th Sem-Pg. 537)
- CE3S10 Seismic Design of Civil Engineering Works (10th Sem-Pg. 540)
- CE3S2 Reinforced Concrete Design II (10th Sem-Pg. 549)
- CE3S6 Masonry, Adobe, and Timber (10th Sem-Pg. 554)
- CE3S7 Structural Rehabilitation and Retrofitting (10th Sem-Pg. 557)
- CE403 Capstone project II (10th Sem-Pg. 561)
- CE3C13 Project Planning and Control (10th Sem-Pg. 563)
- CE3C14 Sustainable and Resilient Infrastructure (10th Sem-Pg. 566)

6.5.2 Outcome: ABET-2) Apply engineering design to produce solutions that meet specific needs.

- BEC101 General Economics (1st Sem-Pg. 266)
- CB1E1 Technical Drawing & CAD (2nd Sem-Pg. 288)
- BEF201 Ethics and Political Philosophy (2nd Sem-Pg. 303)
- CB1E2 Engineering Drawing II (3rd Sem-Pg. 309)
- CE3M1 Concrete Technology (4th Sem-Pg. 332)
- MA202 Numerical Methods (4th Sem-Pg. 335)
- CE2C1 Materials Technology (7th Sem-Pg. 366)
- CE2C2 Construction Technology I (7th Sem-Pg. 371)
- CE2C6 Territorial Planning (7th Sem-Pg. 374)
- CE2C8 Business Management in Construction I (7th Sem-Pg. 377)
- CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)
- CE2S1 Structural Analysis I (7th Sem-Pg. 391)
- CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)
- CE2S3 Steel Design (7th Sem-Pg. 397)
- CE2C3 Concrete Technology I (8th Sem-Pg. 400)
- CE2C5 Construction Project Management (8th Sem-Pg. 405)
- CE2C7 Business Organization and Management (8th Sem-Pg. 408)
- CE2G2 Soil Mechanics II (8th Sem-Pg. 413)
- CE3C2 Construction Technology II (8th Sem-Pg. 417)
- CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)
- CE3S1 Structural Analysis II (8th Sem-Pg. 425)
- CE3S5 Bridges and Structures (8th Sem-Pg. 429)
- CE3S9 Prestressed Concrete (8th Sem-Pg. 432)

- CE3C15 Professional Competencies Workshop (9th Sem-Pg. 438)
- CE3C9 Integrated Construction Management (9th Sem-Pg. 448)
- CE3G3 Applied Geology (9th Sem-Pg. 453)
- CE3G4 Soil Mechanics Applied to Transportation Roads (9th Sem-Pg. 458)
- CE3G5 Finite Elements Applied to Geotechnical Engineering (9th Sem-Pg. 461)
- CE3G6 Earth Dams (9th Sem-Pg. 464)
- CE3H3 Water Supply and Sewerage (9th Sem-Pg. 471)
- CE3H4 Water Resources (9th Sem-Pg. 481)
- CE3S11 Professional Competency Workshop - Structures (9th Sem-Pg. 487)
- CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)
- CE3S8 Architecture and Structural Models (9th Sem-Pg. 497)
- CE402 Capstone project I (9th Sem-Pg. 504)
- BLW201 Law and Legislation (9th Sem-Pg. 506)
- CE3C11 Sanitary and Electrical Installations (10th Sem-Pg. 512)
- CE3G1 Soil Dynamics (10th Sem-Pg. 515)
- CE3G2 Soil Mechanics Applied to Foundations (10th Sem-Pg. 518)
- CE3G7 Professional Competencies Workshop - Geotechnical (10th Sem-Pg. 523)
- CE3H5 Introduction to Fluvial Hydraulics (10th Sem-Pg. 529)
- CE3H6 Irrigation Engineering (10th Sem-Pg. 533)
- CE3H7 Hydraulic and Hydrology Engineering Workshop (10th Sem-Pg. 537)
- CE3S10 Seismic Design of Civil Engineering Works (10th Sem-Pg. 540)
- CE3S2 Reinforced Concrete Design II (10th Sem-Pg. 549)
- CE3S6 Masonry, Adobe, and Timber (10th Sem-Pg. 554)
- CE3S7 Structural Rehabilitation and Retrofitting (10th Sem-Pg. 557)
- CE403 Capstone project II (10th Sem-Pg. 561)
- CE3C13 Project Planning and Control (10th Sem-Pg. 563)

6.5.3 Outcome: ABET-3) Communicate effectively with diverse audiences.

- BME101 Learning Methodology Workshop (1st Sem-Pg. 255)
- BRC101 Writing and Communication (1st Sem-Pg. 260)
- ID101 Technical and professional English I (2nd Sem-Pg. 300)
- ID102 Technical and professional English II (3rd Sem-Pg. 322)
- ID201 Technical and professional English III (4th Sem-Pg. 348)
- ID202 Technical and professional English IV (5th Sem-Pg. 355)
- ID203 Technical and professional English V (6th Sem-Pg. 362)
- CE402 Capstone project I (9th Sem-Pg. 504)
- CE3S12 Research Workshop (10th Sem-Pg. 544)
- CE403 Capstone project II (10th Sem-Pg. 561)

6.5.4 Outcome: ABET-4) Recognize ethical responsibilities and make informed judgments.

- CS100 Introduction to Computer Science (2nd Sem-Pg. 274)
- AI161 Applied AI (2nd Sem-Pg. 284)
- BEF201 Ethics and Political Philosophy (2nd Sem-Pg. 303)
- CE402 Capstone project I (9th Sem-Pg. 504)
- BLW201 Law and Legislation (9th Sem-Pg. 506)
- CE3S12 Research Workshop (10th Sem-Pg. 544)
- CE403 Capstone project II (10th Sem-Pg. 561)

6.5.5 Outcome: ABET-5) Function effectively in teams and exercise leadership.

- ID101 Technical and professional English I (2nd Sem-Pg. 300)
- ID102 Technical and professional English II (3rd Sem-Pg. 322)
- ID201 Technical and professional English III (4th Sem-Pg. 348)
- ID202 Technical and professional English IV (5th Sem-Pg. 355)
- ID203 Technical and professional English V (6th Sem-Pg. 362)
- CE2C5 Construction Project Management (8th Sem-Pg. 405)
- CE402 Capstone project I (9th Sem-Pg. 504)
- CE403 Capstone project II (10th Sem-Pg. 561)

6.5.6 Outcome: ABET-6) Develop experiments, analyze data, and draw conclusions.

- BME101 Learning Methodology Workshop (1st Sem-Pg. 255)
- CE1G1 General Geology (2nd Sem-Pg. 270)
- CE1M1 Statics (3rd Sem-Pg. 306)
- CE1M2 Dynamics (4th Sem-Pg. 326)
- CE2M1 Mechanics of Materials I (4th Sem-Pg. 329)
- CE3M1 Concrete Technology (4th Sem-Pg. 332)
- MA202 Numerical Methods (4th Sem-Pg. 335)
- CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)
- CE2C1 Materials Technology (7th Sem-Pg. 366)
- CE2C2 Construction Technology I (7th Sem-Pg. 371)
- CE2C8 Business Management in Construction I (7th Sem-Pg. 377)
- CE2G1 Soil Mechanics I (7th Sem-Pg. 381)
- CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)
- CE2C3 Concrete Technology I (8th Sem-Pg. 400)
- CE2C7 Business Organization and Management (8th Sem-Pg. 408)
- CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)
- CE3S1 Structural Analysis II (8th Sem-Pg. 425)
- BMI201 Methodology of Engineering Research (8th Sem-Pg. 435)
- CE3C15 Professional Competencies Workshop (9th Sem-Pg. 438)
- CE3C5 Costs and Budgeting (9th Sem-Pg. 445)
- CE3C9 Integrated Construction Management (9th Sem-Pg. 448)
- CE3G3 Applied Geology (9th Sem-Pg. 453)
- CE3G4 Soil Mechanics Applied to Transportation Roads (9th Sem-Pg. 458)
- CE3G5 Finite Elements Applied to Geotechnical Engineering (9th Sem-Pg. 461)
- CE3G6 Earth Dams (9th Sem-Pg. 464)
- CE3H2 General Hydrology (9th Sem-Pg. 469)
- CE3H3 Water Supply and Sewerage (9th Sem-Pg. 471)
- CE3H4 Water Resources (9th Sem-Pg. 481)
- CE3S11 Professional Competency Workshop - Structures (9th Sem-Pg. 487)
- CE3S8 Architecture and Structural Models (9th Sem-Pg. 497)
- CE3G1 Soil Dynamics (10th Sem-Pg. 515)
- CE3G2 Soil Mechanics Applied to Foundations (10th Sem-Pg. 518)
- CE3G7 Professional Competencies Workshop - Geotechnical (10th Sem-Pg. 523)
- CE3S12 Research Workshop (10th Sem-Pg. 544)
- CE3S7 Structural Rehabilitation and Retrofitting (10th Sem-Pg. 557)

6.5.7 Outcome: ABET-7) Acquire and apply new knowledge using learning strategies.

- BME101 Learning Methodology Workshop (1st Sem-Pg. 255)
- BIC101 Introduction to Programming (1st Sem-Pg. 262)
- CS100 Introduction to Computer Science (2nd Sem-Pg. 274)

6.6 Course distribution in the Career

This proposal can be analyzed by the number of credits dedicated to each area, by course levels (Introductory, Intermediate, Advanced, and Projects).

	General Estudies	Specific	Specialization	
1st Sem	24	3		27
2nd Sem	23	4		27
3rd Sem	20		4	24
4th Sem	13		13	26
5th Sem	2		4	6
6th Sem	2	6		8
7th Sem		37		37
8th Sem		32	4	36
9th Sem		49	4	53
10th Sem		44	4	48
Total	84	175	33	56
	150%	312.5%	58.9%	

Table 6.38: Distribution of credits by area by semester

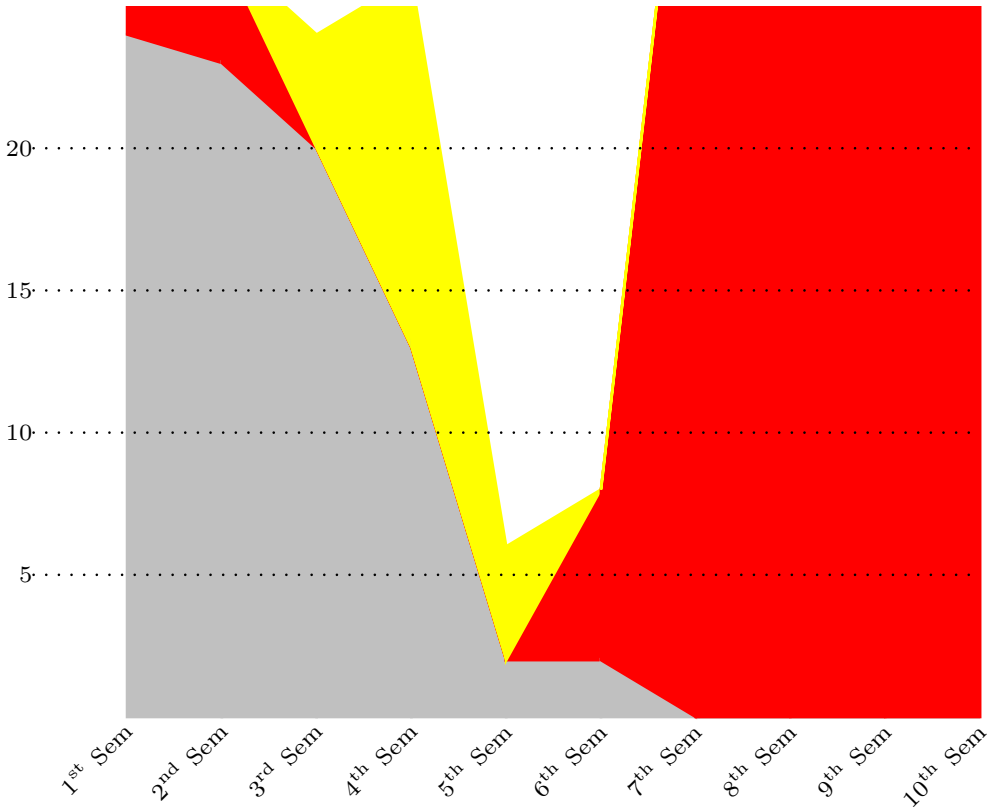

Figure 6.2: Credits by area by semester

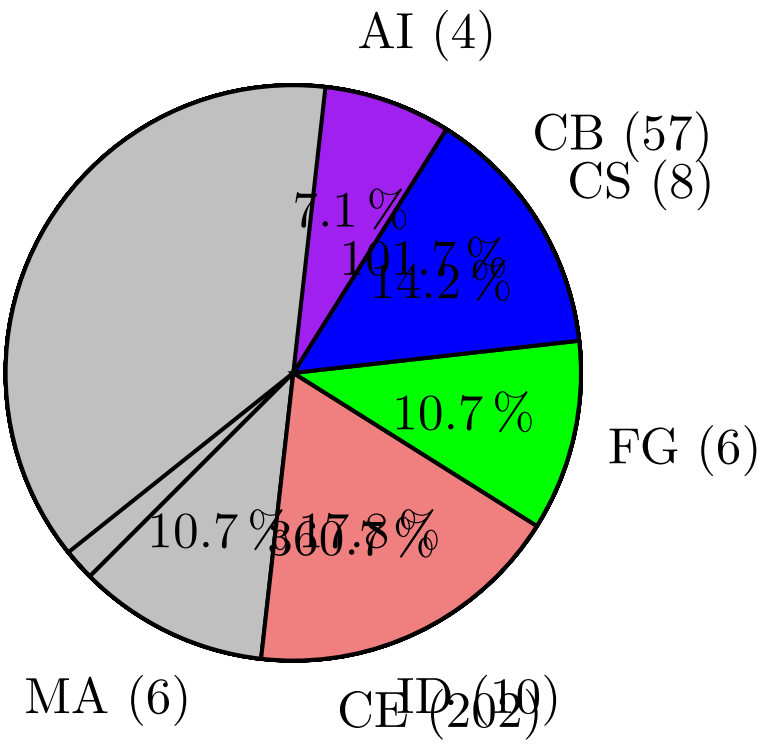

Figure 6.3: Distribution of courses by area considering credits.

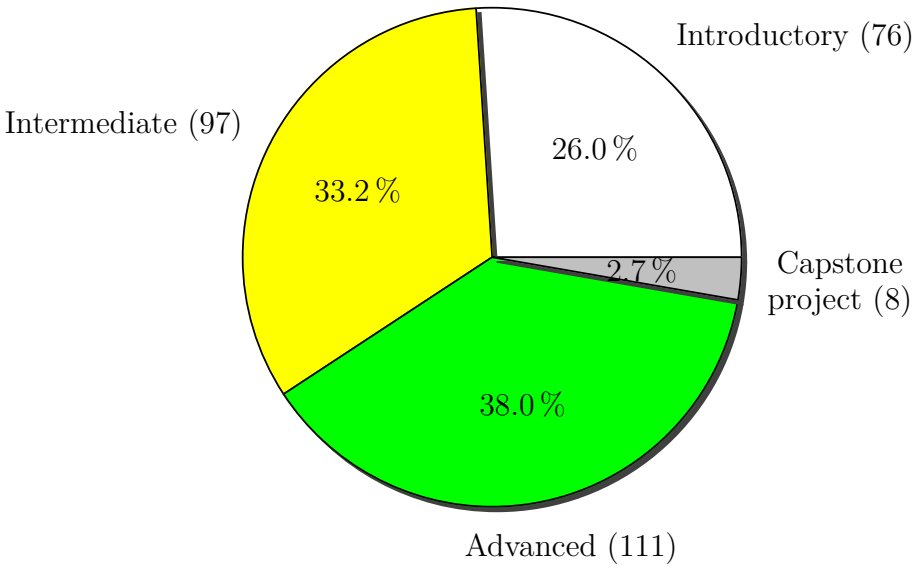

Figure 6.4: Distribution of credits by course levels.

6.7 Departments

6.7.1 Basic Sciences

The list of courses for this department is:

- BIC101 Introduction to Programming (1st Sem)
- BME101 Learning Methodology Workshop (1st Sem)
- BRC101 Writing and Communication (1st Sem)
- AI161 Applied AI (2nd Sem)
- BEF201 Ethics and Political Philosophy (2nd Sem)
- CS100 Introduction to Computer Science (2nd Sem)
- ID101 Technical and professional English I (2nd Sem)
- CB1E2 Engineering Drawing II (3rd Sem)
- ID102 Technical and professional English II (3rd Sem)
- ID201 Technical and professional English III (4th Sem)
- MA202 Numerical Methods (4th Sem)
- STA251 Statistics and Probability (4th Sem)
- ID202 Technical and professional English IV (5th Sem)
- ID203 Technical and professional English V (6th Sem)

6.7.2 Construction

The list of courses for this department is:

- BEC101 General Economics (1st Sem)
- CE3M1 Concrete Technology (4th Sem)
- CE2C1 Materials Technology (7th Sem)
- CE2C2 Construction Technology I (7th Sem)
- CE2C6 Territorial Planning (7th Sem)
- CE2C8 Business Management in Construction I (7th Sem)
- CE2C3 Concrete Technology I (8th Sem)
- CE2C5 Construction Project Management (8th Sem)
- CE2C7 Business Organization and Management (8th Sem)

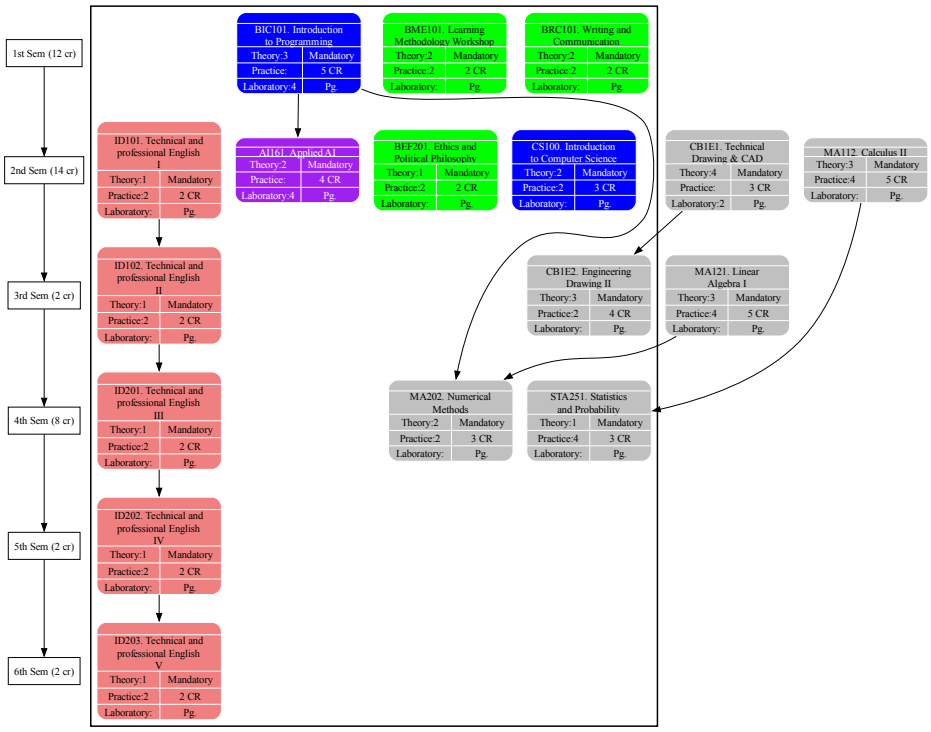

Figure 6.5: Basic Sciences

- CE3C2 Construction Technology II (8th Sem)
- CE3C15 Professional Competencies Workshop (9th Sem)
- CE3C5 Costs and Budgeting (9th Sem)
- CE3C9 Integrated Construction Management (9th Sem)
- CE3C11 Sanitary and Electrical Installations (10th Sem)
- CE3C13 Project Planning and Control (10th Sem)
- CE3C14 Sustainable and Resilient Infrastructure (10th Sem)

6.7.3 Structures

The list of courses for this department is:

- CE2S1 Structural Analysis I (7th Sem)
- CE2S2 Reinforced Concrete Design I (7th Sem)
- CE2S3 Steel Design (7th Sem)
- CE3S1 Structural Analysis II (8th Sem)
- CE3S5 Bridges and Structures (8th Sem)
- CE3S9 Prestressed Concrete (8th Sem)
- CE3S11 Professional Competency Workshop - Structures (9th Sem)
- CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem)
- CE3S8 Architecture and Structural Models (9th Sem)
- CE3S10 Seismic Design of Civil Engineering Works (10th Sem)
- CE3S12 Research Workshop (10th Sem)
- CE3S2 Reinforced Concrete Design II (10th Sem)
- CE3S6 Masonry, Adobe, and Timber (10th Sem)
- CE3S7 Structural Rehabilitation and Retrofitting (10th Sem)

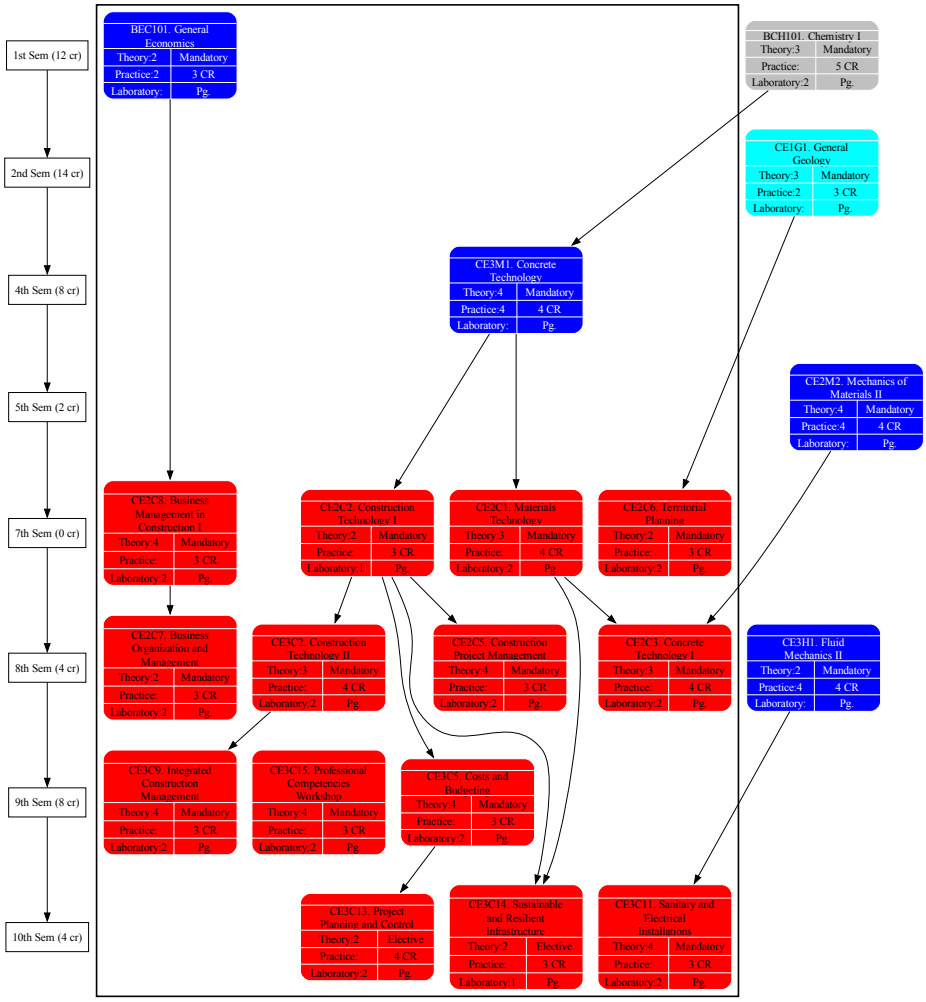

Figure 6.6: Construction

6.7.4 Hydraulics

The list of courses for this department is:

- CE2H1 Fluid Mechanics I (7th Sem)
- CE3H1 Fluid Mechanics II (8th Sem)
- CE3H2 General Hydrology (9th Sem)
- CE3H3 Water Supply and Sewerage (9th Sem)
- CE3H4 Water Resources (9th Sem)
- CE3H5 Introduction to Fluvial Hydraulics (10th Sem)
- CE3H6 Irrigation Engineering (10th Sem)
- CE3H7 Hydraulic and Hydrology Engineering Workshop (10th Sem)

6.7.5 Geotechnical Engineering

The list of courses for this department is:

- CE1G1 General Geology (2nd Sem)
- CE2M1 Mechanics of Materials I (4th Sem)
- CE2M2 Mechanics of Materials II (5th Sem)

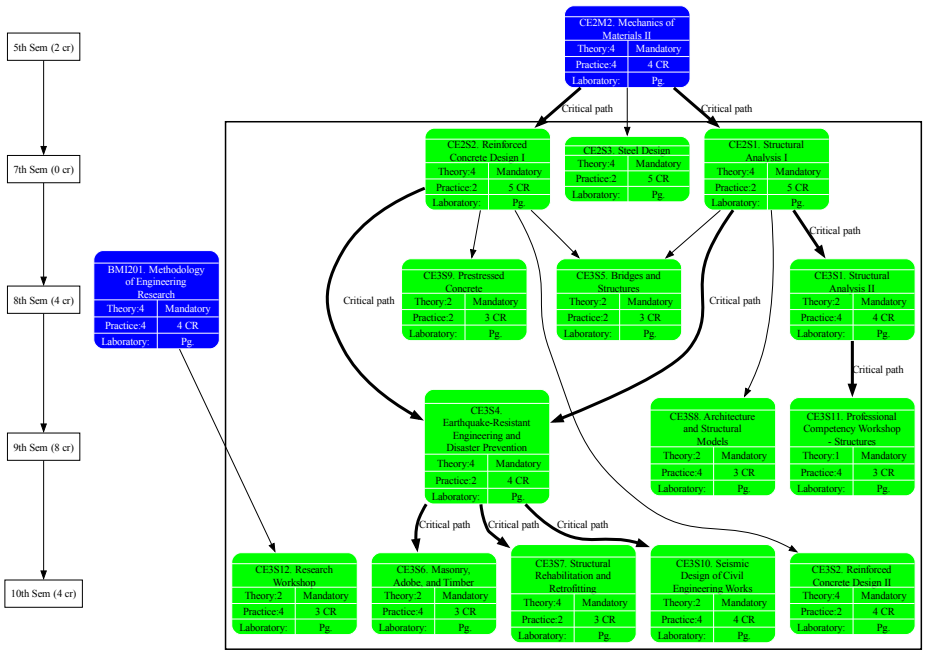

Figure 6.7: Structures

- CE2G1 Soil Mechanics I (7th Sem)
- CE2G2 Soil Mechanics II (8th Sem)
- CE3G3 Applied Geology (9th Sem)
- CE3G4 Soil Mechanics Applied to Transportation Roads (9th Sem)
- CE3G5 Finite Elements Applied to Geotechnical Engineering (9th Sem)
- CE3G6 Earth Dams (9th Sem)
- CE3G1 Soil Dynamics (10th Sem)
- CE3G2 Soil Mechanics Applied to Foundations (10th Sem)
- CE3G7 Professional Competencies Workshop - Geotechnical (10th Sem)

6.7.6 Basic Sciences

The list of courses for this department is:

- BCH101 Chemistry I (1st Sem)
- MA100 Basic Mathematics (1st Sem)
- MA111 Calculus I (1st Sem)
- BFI101 General Physics (2nd Sem)
- CB1E1 Technical Drawing & CAD (2nd Sem)
- MA112 Calculus II (2nd Sem)
- BFI102 Physics II (3rd Sem)
- CE1M1 Statics (3rd Sem)
- MA121 Linear Algebra I (3rd Sem)
- MA210 Calculus III (3rd Sem)
- CE1M2 Dynamics (4th Sem)
- MA211 Calculus IV (4th Sem)
- MA212 Ordinary Differential Equations (6th Sem)

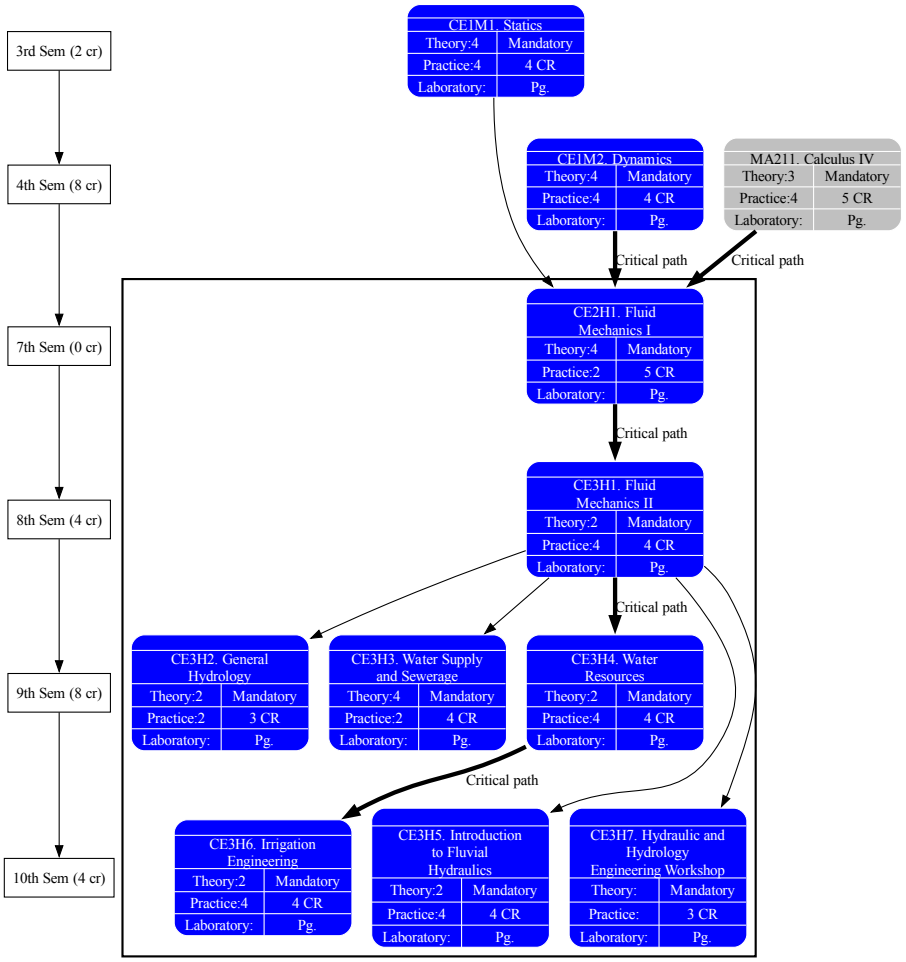

Figure 6.8: Hydraulics

6.8 Compatibility of the Career with International Standards

In this section, we present the distribution of courses by concentration areas in contrast to the international proposals of *Computing Curricula* from IEEE-CS/ACM.

It is necessary to note that in some cases, courses may appear in more than one axis as they have content from more than one area. For example, the operating systems course contains application units that can be classified in Information Technology but at the same time, it contains fundamentals of how an Operating System is structured, which belongs to the Computer Science axis. In these cases, the credits have been divided between the corresponding axes.

1. Civil Engineering (355.00 Créditos)
   - BEC101 General Economics (1st Sem-Pg. 266)
   - CE2C1 Materials Technology (7th Sem-Pg. 366)
   - CE2C2 Construction Technology I (7th Sem-Pg. 371)
   - CE2C6 Territorial Planning (7th Sem-Pg. 374)
   - CE2C8 Business Management in Construction I (7th Sem-Pg. 377)
   - CE2G1 Soil Mechanics I (7th Sem-Pg. 381)
   - CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)
   - CE2S1 Structural Analysis I (7th Sem-Pg. 391)

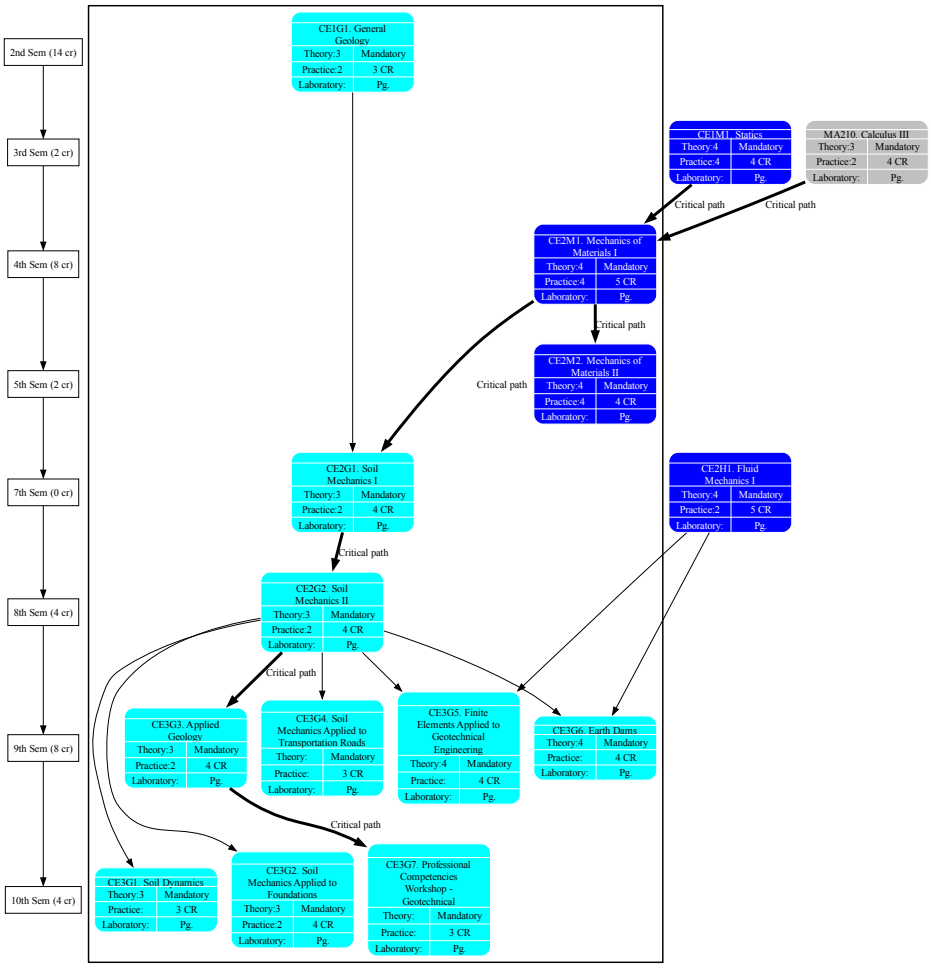

Figure 6.9: Geotechnical Engineering

- CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)
- CE2S3 Steel Design (7th Sem-Pg. 397)
- CE2C3 Concrete Technology I (8th Sem-Pg. 400)
- CE2C5 Construction Project Management (8th Sem-Pg. 405)
- CE2C7 Business Organization and Management (8th Sem-Pg. 408)
- CE2G2 Soil Mechanics II (8th Sem-Pg. 413)
- CE3C2 Construction Technology II (8th Sem-Pg. 417)
- CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)
- CE3S1 Structural Analysis II (8th Sem-Pg. 425)
- CE3S5 Bridges and Structures (8th Sem-Pg. 429)
- CE3S9 Prestressed Concrete (8th Sem-Pg. 432)
- BMI201 Methodology of Engineering Research (8th Sem-Pg. 435)
- CE3C15 Professional Competencies Workshop (9th Sem-Pg. 438)
- CE3C5 Costs and Budgeting (9th Sem-Pg. 445)
- CE3C9 Integrated Construction Management (9th Sem-Pg. 448)
- CE3G3 Applied Geology (9th Sem-Pg. 453)
- CE3G4 Soil Mechanics Applied to Transportation Roads (9th Sem-Pg. 458)
- CE3G5 Finite Elements Applied to Geotechnical Engineering (9th Sem-Pg. 461)

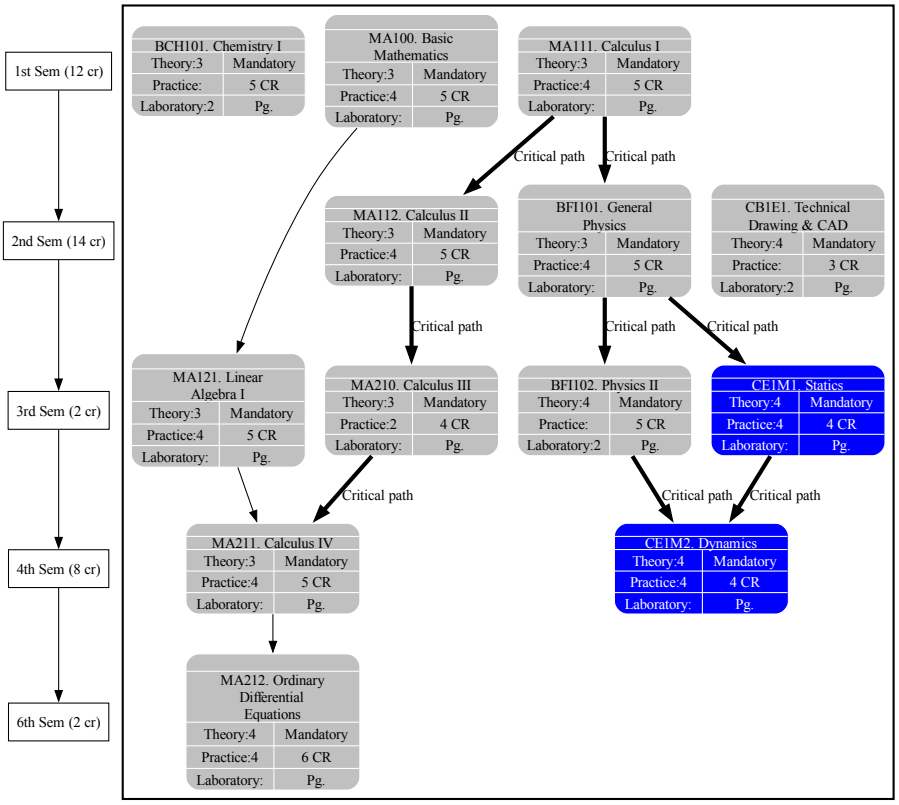

Figure 6.10: Basic Sciences

- CE3G6 Earth Dams (9th Sem-Pg. 464)
- CE3H2 General Hydrology (9th Sem-Pg. 469)
- CE3H3 Water Supply and Sewerage (9th Sem-Pg. 471)
- CE3H4 Water Resources (9th Sem-Pg. 481)
- CE3S11 Professional Competency Workshop - Structures (9th Sem-Pg. 487)
- CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)
- CE3S8 Architecture and Structural Models (9th Sem-Pg. 497)
- CE402 Capstone project I (9th Sem-Pg. 504)
- BLW201 Law and Legislation (9th Sem-Pg. 506)
- CE3C11 Sanitary and Electrical Installations (10th Sem-Pg. 512)
- CE3G1 Soil Dynamics (10th Sem-Pg. 515)
- CE3G2 Soil Mechanics Applied to Foundations (10th Sem-Pg. 518)
- CE3G7 Professional Competencies Workshop - Geotechnical (10th Sem-Pg. 523)
- CE3H5 Introduction to Fluvial Hydraulics (10th Sem-Pg. 529)
- CE3H6 Irrigation Engineering (10th Sem-Pg. 533)
- CE3H7 Hydraulic and Hydrology Engineering Workshop (10th Sem-Pg. 537)
- CE3S10 Seismic Design of Civil Engineering Works (10th Sem-Pg. 540)
- CE3S12 Research Workshop (10th Sem-Pg. 544)
- CE3S2 Reinforced Concrete Design II (10th Sem-Pg. 549)
- CE3S6 Masonry, Adobe, and Timber (10th Sem-Pg. 554)
- CE3S7 Structural Rehabilitation and Retrofitting (10th Sem-Pg. 557)

- CE403 Capstone project II (10th Sem-Pg. 561)
- CE3C13 Project Planning and Control (10th Sem-Pg. 563)
- CE3C14 Sustainable and Resilient Infrastructure (10th Sem-Pg. 566)

2. Geotechnical
   - Ninguno
3. Structures
   - Ninguno
4. Hydraulic
   - Ninguno
5. Transportation
   - Ninguno
6. Construction
   - Ninguno
7. Computer Science (24.00 Créditos)
   - BIC101 Introduction to Programming (1st Sem-Pg. 262)
   - CS100 Introduction to Computer Science (2nd Sem-Pg. 274)
   - AI161 Applied AI (2nd Sem-Pg. 284)
8. Basic Sciences (174.00 Créditos)
   - MA100 Basic Mathematics (1st Sem-Pg. 245)
   - MA111 Calculus I (1st Sem-Pg. 249)
   - BCH101 Chemistry I (1st Sem-Pg. 251)
   - CE1G1 General Geology (2nd Sem-Pg. 270)
   - CB1E1 Technical Drawing & CAD (2nd Sem-Pg. 288)
   - MA112 Calculus II (2nd Sem-Pg. 291)
   - BFI101 General Physics (2nd Sem-Pg. 295)
   - CE1M1 Statics (3rd Sem-Pg. 306)
   - CB1E2 Engineering Drawing II (3rd Sem-Pg. 309)
   - MA121 Linear Algebra I (3rd Sem-Pg. 312)
   - MA210 Calculus III (3rd Sem-Pg. 314)
   - BFI102 Physics II (3rd Sem-Pg. 317)
   - CE1M2 Dynamics (4th Sem-Pg. 326)
   - CE2M1 Mechanics of Materials I (4th Sem-Pg. 329)
   - CE3M1 Concrete Technology (4th Sem-Pg. 332)
   - MA202 Numerical Methods (4th Sem-Pg. 335)
   - MA211 Calculus IV (4th Sem-Pg. 340)
   - STA251 Statistics and Probability (4th Sem-Pg. 343)
   - CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)
   - MA212 Ordinary Differential Equations (6th Sem-Pg. 359)
9. Information Technology
   - Ninguno
10. Business
    - Ninguno
11. General Knowledge (32.00 Créditos)
    - BME101 Learning Methodology Workshop (1st Sem-Pg. 255)
    - BRC101 Writing and Communication (1st Sem-Pg. 260)
    - ID101 Technical and professional English I (2nd Sem-Pg. 300)
    - BEF201 Ethics and Political Philosophy (2nd Sem-Pg. 303)
    - ID102 Technical and professional English II (3rd Sem-Pg. 322)
    - ID201 Technical and professional English III (4th Sem-Pg. 348)
    - ID202 Technical and professional English IV (5th Sem-Pg. 355)
    - ID203 Technical and professional English V (6th Sem-Pg. 362)

Referencias Bibliográficas

Chapter 7

Detailed content by course

First Semester

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

MA100 Basic Mathematics (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**: None

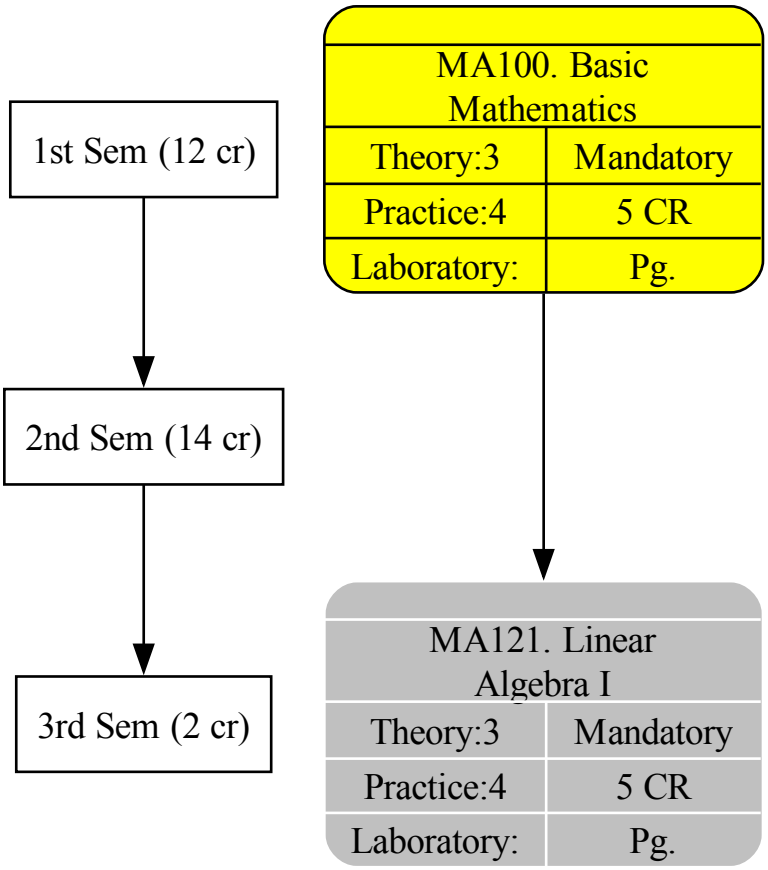

Figure 7.1: Connection Map. MA100 Basic Mathematics

2. Course Rationale

The Basic Mathematics course is mandatory and provides the conceptual tools necessary for logical reasoning and problem solving. The course ranges from propositional logic and set theory to the study of real numbers, complex numbers, polynomials, and matrices. These concepts are fundamental for developing the abstraction and mathematical formalization skills required in the later stages of the Computer Science program.

3. Goals of the Course

- Develop logical reasoning and critical thinking skills through the use of formal languages.
- Understand and apply the properties of number systems (real and complex) in problem solving.
- Manipulate polynomial and matrix structures to solve systems of equations and interpret results.
- Introduce basic concepts of statistics and probability for data analysis.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Logic and Sets, 16 hr(s)

Competences: ABET-1

Topics: **I:** Propositional logic: Connectives, truth tables, and validity. **II:** Logical-mathematical quantifiers. **III:** Set theory: Operations, relations, and functions. **IV:** Families of sets and Cartesian product.

Learning Outcomes **I:** Formalize natural language statements into propositional language [Familiarity]. **II:** Operate with sets using algebraic laws and Venn diagrams [Usage]. **III:** Prove basic properties of sets and logical relations [Assessment].

Bibliography: [Lipschutz, 1991, Rojo, 1995]

5.2 Number Systems, 16 hr(s)

Competences: ABET-1

Topics: **I:** The real number system: Field and order axioms. **II:** Mathematical induction and Newton's binomial theorem. **III:** Complex numbers: Binomial, polar, and exponential forms. **IV:** Roots of complex numbers and De Moivre's theorem.

Learning Outcomes **I:** Identify the algebraic structure of real and complex numbers [Familiarity]. **II:** Apply the principle of mathematical induction in proofs of summations [Usage]. **III:** Solve equations in the complex number field using various representations [Assessment].

Bibliography: [Gentile, 1985, Álvaro Pinzón, 1973]

5.3 Polynomials and Matrices, 16 hr(s)

Competences: ABET-1

Topics: **I:** Polynomials: Division algorithm and roots of polynomials. **II:** Matrices: Types, operations, and determinants. **III:** Inverse matrix and rank of a matrix. **IV:** Systems of linear equations: Gauss-Jordan method.

Learning Outcomes **I:** Recognize the structure of polynomial rings and matrix algebra [Familiarity]. **II:** Use elementary row operations to calculate the inverse of a matrix [Usage]. **III:** Model and solve systems of linear equations applied to contextual problems [Assessment].

Bibliography: [Gentile, 1984, Rojo, 1995]

5.4 Statistics and Probability, 16 hr(s)

Competences: ABET-1

Topics: **I:** Descriptive statistics: Measures of central tendency. **II:** Dispersion measures and graphical representation. **III:** Probability concepts: Sample space and events. **IV:** Conditional probability and independence.

Learning Outcomes **I:** Describe data sets using basic statistical indicators [Familiarity]. **II:** Calculate probabilities of simple and compound events in random experiments [Usage]. **III:** Interpret statistical results for decision making in scientific environments [Assessment].

Bibliography: [Peterson, 2005]

6. Bibliography

[Gentile, 1984] Gentile, E. (1984). *Notas de álgebra*. Editorial Universitaria de Buenos Aires.

[Gentile, 1985] Gentile, E. (1985). *Aritmética Elemental*. Colección de Monografías Científicas Ser.

[Lipschutz, 1991] Lipschutz, S. (1991). *Teoría de conjuntos y temas afines*. McGraw-Hill.

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[Rojo, 1995] Rojo, A. (1995). *Álgebra I*. El Ateneo.

[Álvaro Pinzón, 1973] Álvaro Pinzón (1973). *Conjuntos y estructuras*. Blaisdell Publishing Company.

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

MA111 Calculus I (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**: None

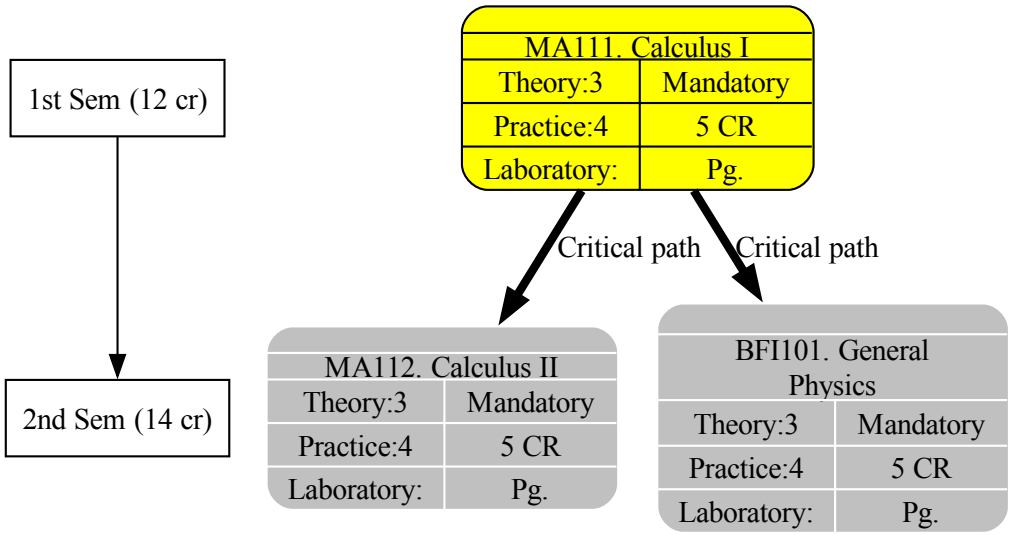

Figure 7.2: Connection Map. MA111 Calculus I

2. Course Rationale

This course introduces the fundamental concepts of differential calculus of single-variable real functions. It provides the mathematical foundations necessary for analyzing change and motion in science and engineering, developing logical reasoning through the study of limits, continuity, and derivatives.

3. Goals of the Course

- Understand the fundamental concepts of limits and continuity.
- Master differentiation techniques for algebraic and transcendental functions.
- Apply derivatives to solve optimization problems and analyze rates of change.
- Develop a rigorous approach to the formal definition of a derivative.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Limits and Continuity, 20 hr(s)

Competences: ABET-1

Topics: **I:** Limits and continuity of single-variable functions

Learning Outcomes **I:** Interpret the concept of limit and continuity of a function and its relevance to modeling the behavior of engineering systems near a point [Familiarity]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

5.2 Differential Calculus, 20 hr(s)

Competences: ABET-1

Topics: **I:** Derivatives and rules of differentiation

Learning Outcomes **I:** Apply differentiation rules to find rates of change and optimize engineering design parameters [Usage] **II:** Formulate and solve optimization problems for engineering systems using differential calculus [Assessment]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

5.3 Integral Calculus, 10 hr(s)

Competences: ABET-1

Topics: **I:** The Fundamental Theorem of Calculus **II:** Integration techniques including substitution and parts **III:** Engineering applications of integration: areas, volumes, centroids, and moments of inertia

Learning Outcomes **I:** State and explain the Fundamental Theorem of Calculus [Familiarity] **II:** Calculate definite integrals arising from engineering problems such as work, fluid pressure, and heat transfer [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

6. Bibliography

[Larson and Edwards, 2018] Larson, R. and Edwards, B. H. (2018). *Cálculo.* Cengage Learning, 10th edition.

[Stewart, 2016] Stewart, J. (2016). *Cálculo de una variable: Trascendentes tempranas.* Cengage Learning, 8th edition.

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Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

BCH101 Chemistry I (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Laboratory**: 2 hours;
- **Prerrequisites**: None

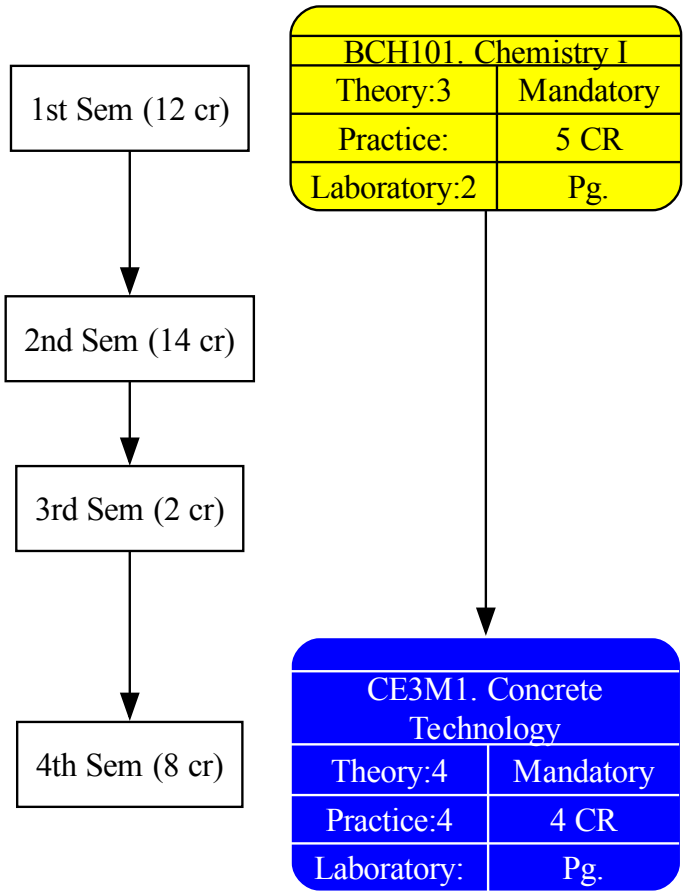

Figure 7.3: Connection Map. BCH101 Chemistry I

2. Course Rationale

Chemistry provides the foundation for understanding the composition, structure, and properties of matter – knowledge required across computing, and engineering programs alike as part of a rigorous grounding in the natural sciences. This course introduces the basic principles of general chemistry and extends them to chemical equilibrium and electrochemistry, together with the applied chemistry of water, polymers, and cement, topics that recur in materials science, environmental analysis, and engineering practice.

3. Goals of the Course

- Understand the structure of matter at the atomic and molecular level.
- Apply the principles of stoichiometry to perform chemical calculations.
- Understand the different types of chemical bonds and their influence on the properties of substances.
- Apply chemical equilibrium, including acid-base and solubility equilibria, to predict the behavior of aqueous systems.
- Apply electrochemical principles to analyze corrosion of metals and reinforced concrete.
- Relate the composition and properties of water, polymers, and cement to their applications in materials science and civil engineering.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Matter and Energy, 8 hr(s)

Competences: ABET-1

Topics: I: Classification of matter: elements, compounds, and mixtures **II:** The scientific method and the international system of units

Learning Outcomes I: Describe the properties of matter and energy and classify a given substance [Familiarity] **II:** Perform unit conversions in engineering chemistry problems [Usage]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.2 Basic Atomic Structure, 10 hr(s)

Competences: ABET-1

Topics: I: Structure of the atom, atomic number, mass number, and isotopes **II:** Quantum model of the atom and electron configuration

Learning Outcomes I: Describe the structure of the atom and its subatomic particles [Familiarity] **II:** Determine the electron configuration of an atom and relate it to its chemical properties [Usage]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.3 Chemical Bonding, 10 hr(s)

Competences: ABET-1

Topics: I: Ionic, covalent, and metallic bonding **II:** Molecular geometry and its relationship to substance properties

Learning Outcomes I: Describe the different types of chemical bonding [Familiarity] **II:** Predict molecular geometry and relate bond type to material properties [Assessment]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.4 Stoichiometry, 10 hr(s)

Competences: ABET-1

Topics: **I:** Molar mass, the mole concept, and balancing chemical equations **II:** Stoichiometric calculations, limiting reagent, and percent yield

Learning Outcomes **I:** Calculate the molar mass of a compound and balance chemical equations [Usage] **II:** Determine the amount of reactants and products in an engineering process using stoichiometric calculations [Assessment]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.5 States of Matter, 10 hr(s)

Competences: ABET-1

Topics: **I:** Properties of gases, liquids, and solids, and phase changes **II:** Ideal gas laws and phase diagrams

Learning Outcomes **I:** Describe the properties of the different states of matter and their phase changes [Familiarity] **II:** Apply ideal gas laws to engineering problems [Usage]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.6 Environmental and Water Chemistry, 4 hr(s)

Competences: ABET-1

Topics: **I:** Water quality parameters (pH, hardness, dissolved oxygen, BOD) for infrastructure design **II:** Fundamentals of water treatment and major air and water pollutants

Learning Outcomes **I:** Interpret water quality parameters for the design of treatment systems [Usage] **II:** Identify pollutants relevant to sanitary and environmental infrastructure projects [Familiarity]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.7 Polymers and Geosynthetics, 4 hr(s)

Competences: ABET-1

Topics: **I:** Classification of polymers: thermoplastics, thermosets, and elastomers **II:** Geosynthetics: geotextiles, geomembranes, and geogrids, and their applications in civil works

Learning Outcomes **I:** Classify a polymer by its structure and thermal behavior [Usage] **II:** Select the appropriate geosynthetic for a given civil engineering application [Usage]

Bibliography: [Chang and Goldsby, 2016, Mamlouk and Zaniewski, 2017]

5.8 Chemical Equilibrium, 4 hr(s)

Competences: ABET-1

Topics: **I:** The equilibrium constant K_c and its relation to stoichiometry **II:** Le Chatelier's principle and its effect on industrial chemical processes

Learning Outcomes **I:** Write the equilibrium constant expression for a reaction of engineering interest [Usage] **II:** Predict the shift of a chemical equilibrium in an engineering process [Assessment]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.9 Ionic Equilibrium and Salt Hydrolysis, 12 hr(s)

Competences: ABET-1

Topics: I: Calculating the pH of strong and weak acids and bases **II:** Salt hydrolysis and its effect on the pH of water and soils

Learning Outcomes I: Calculate the pH of solutions relevant to environmental quality control [Usage] **II:** Predict the effect of salt hydrolysis on the pH of water and soils [Assessment]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.10 Salts, Solubility, and Precipitation Equilibria, 6 hr(s)

Competences: ABET-1

Topics: I: The solubility product K_{sp} and predicting precipitation

Learning Outcomes I: Predict the formation of precipitates or scale in engineering water systems [Usage]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.11 Electrochemistry and Electrolysis, 8 hr(s)

Competences: ABET-1

Topics: I: Redox reactions, galvanic cells, and electrode potentials **II:** Electrochemical corrosion of metals and of reinforcing steel in reinforced concrete, and protection methods

Learning Outcomes I: Calculate the potential of a galvanic cell and predict the spontaneity of a redox reaction [Usage] **II:** Analyze corrosion conditions in engineering structures and propose protection methods [Assessment]

Bibliography: [Brown et al., 2017, Chang and Goldsby, 2016]

5.12 Cement Chemistry, 4 hr(s)

Competences: ABET-1

Topics: I: Chemical composition of Portland cement and its main compounds **II:** Cement hydration reactions and their relation to concrete strength development

Learning Outcomes I: Describe the chemical composition of Portland cement [Familiarity] **II:** Explain the relationship between cement hydration and concrete strength development [Usage]

Bibliography: [Mamlouk and Zaniewski, 2017, Chang and Goldsby, 2016]

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[Brown et al., 2017] Brown, T. L., Jr., H. E. L., Bursten, B. E., Murphy, C. J., and Woodward, P. M. (2017). *Chemistry: The Central Science*. Pearson.

[Chang and Goldsby, 2016] Chang, R. and Goldsby, K. A. (2016). *Chemistry*. McGraw-Hill Education.

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BME101 Learning Methodology Workshop (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

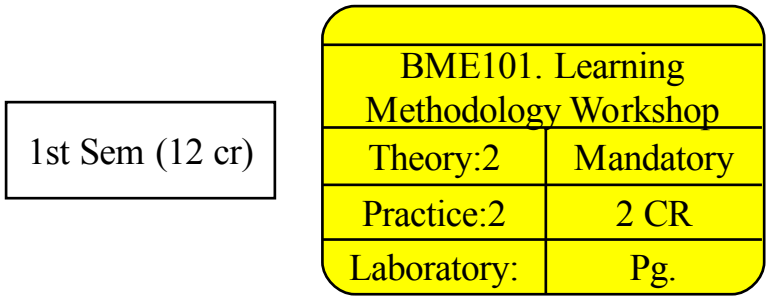

Figure 7.4: Connection Map. BME101 Learning Methodology Workshop

2. Course Rationale

Success in demanding science, engineering, and computing programs depends not only on technical knowledge but also on how effectively students plan their academic and personal life, study, and learn. This workshop equips incoming students in science, engineering, and computing programs with practical learning-methodology tools: life and career planning, evidence-based study techniques, an introduction to how modern AI/ML tools can support their own learning process, the fundamentals of scientific knowledge and applied research, emotional intelligence for personal and interpersonal effectiveness, and the technical communication and teamwork/leadership skills needed to collaborate throughout their studies and professional careers.

3. Goals of the Course

- Design a personal life project, setting academic and career goals aligned with personal values.
- Apply evidence-based study techniques and time-management strategies to improve academic performance.
- Relate machine learning fundamentals to how AI-based tools can support a student's own learning process.
- Communicate technical and academic content effectively to varied audiences.
- Distinguish basic from applied research and apply basic research- methodology and academic-integrity practices.
- Apply emotional-intelligence competencies for self-management and interpersonal effectiveness.
- Apply leadership, teamwork, and stakeholder-management skills in collaborative project settings.

4. General Competences (*Outcomes*)

ABET-7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (Familiarity)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Familiarity)

5. Content

5.1 Life Project, 8 hr(s)

Competences: ABET-7

Topics: **I:** Personal-values clarification as the foundation for life planning. **II:** Short-, medium-, and long-term goal setting using SMART criteria. **III:** From academic path to professional career: mapping academic studies in science, engineering, or computing onto career goals. **IV:** Self-assessment tools: strengths, interests, and personality inventories. **V:** Elaboration of a personal life-project plan with milestones and review points.

Learning Outcomes **I:** Formulate personal values and goals to build a coherent life project [Usage]. **II:** Design short-, medium-, and long-term academic and career goals using structured planning tools [Usage]. **III:** Apply self-assessment techniques to identify personal strengths and areas for improvement [Familiarity].

Bibliography: [Burnett and Evans, 2016]

5.2 Study Techniques and Habits, 12 hr(s)

Competences: ABET-7

Topics: **I:** Active learning techniques: active recall, spaced repetition, and elaborative interrogation. **II:** Note-taking systems: the Cornell method, mapping, and outlining. **III:** Time management and time-blocking; the Pomodoro technique. **IV:** Exam-preparation strategies and self-testing. **V:** Building sustainable study habits and routines.

Learning Outcomes **I:** Apply active-recall and spaced-repetition techniques to improve long-term retention of course material [Usage]. **II:** Use structured note-taking systems (e.g., the Cornell method) to organize academic content [Usage]. **III:** Design a personal time-management plan using time-blocking and the Pomodoro technique [Usage]. **IV:** Apply self-testing and exam-preparation strategies to evaluate personal learning progress [Assessment].

Bibliography: [Dunlosky et al., 2013, Newport, 2007]

5.3 Machine Learning Fundamentals, 4 hr(s)

Competences: ABET-7

Topics: **I:** Definition and examples of a broad variety of machine learning tasks: (a) Supervised learning: i. Classification ii. Regression (b) Reinforcement learning (c) Unsupervised learning: i. Clustering **II:** Fundamental ideas: (a) No free lunch theorem: no one learner can solve all problems; representational design decisions have consequences. (b) Sources of error and undecidability in machine learning **III:** A simple statistical-based supervised learning such as linear regression or decision trees: (a) Focus on how they work without going into mathematical or optimization details; enough to understand and use existing implementations correctly **IV:** The overfitting problem/controlling solution complexity (regularization, pruning - intuition only): (a) The bias (underfitting) - variance (overfitting) tradeoff

Learning Outcomes **I:** Describe the differences among the three main styles of learning (supervised, reinforcement, and unsupervised) and determine which is appropriate to a particular problem domain [Explain] **II:** Differentiate the terms of AI, machine learning, and deep learning [Evaluate] **III:** Frame an application as a classification problem, including the available input features and output to be predicted (e.g., identifying alphabetic characters from pixel grid input) [Apply]

IV: Identify overfitting in the context of a problem and learning curves and describe solutions to overfitting [Evaluate] **V:** Explain how machine learning works as an optimization/search process [Explain]

Bibliography: [Russell and Norvig, 2020]

5.4 Written and Technical Communication, 2 hr(s)

Competences: ABET-3

Topics: I: Audience analysis and adaptation of technical content **II:** Written communication: technical reports, memos, emails, and specifications **III:** Visual communication: graphs, charts, diagrams, and effective slide design

Learning Outcomes I: Write a clear, concise, and well-organized technical report on a laboratory experiment or design project [Usage] **II:** Create effective graphs and diagrams to present engineering data [Assessment]

Bibliography: [Gurak and Lannon, 2013]

5.5 Oral Presentation and Professional Communication, 1 hr(s)

Competences: ABET-3

Topics: I: Oral presentations: structure, delivery techniques, and handling Q&A **II:** Proposal writing: technical approach, management plan, and cost estimating **III:** Executive summaries and communicating with non-technical stakeholders

Learning Outcomes I: Deliver a structured oral presentation on a technical topic using appropriate visual aids [Usage] **II:** Outline the key sections of a competitive engineering proposal [Familiarity] **III:** Develop an executive summary that conveys key project findings to a senior management audience [Usage]

Bibliography: [Gurak and Lannon, 2013]

5.6 Digital and Collaborative Communication, 1 hr(s)

Competences: ABET-3

Topics: I: Collaborative writing and document management in team settings **II:** Digital communication: web content, social media guidelines for engineers **III:** Persuasive communication and negotiation techniques

Learning Outcomes I: Manage a collaborative document (e.g., on Google Docs or SharePoint) for a team project [Assessment] **II:** Explain the professional risks and opportunities associated with engineers using social media [Familiarity] **III:** Employ basic negotiation tactics to resolve a simulated conflict over project scope [Usage]

Bibliography: [Gurak and Lannon, 2013]

5.7 Scientific Knowledge and Applied Research, 16 hr(s)

Competences: ABET-6

Topics: I: Nature and scope of scientific knowledge: definitions and limits. **II:** Basic versus applied research; the role of applied research in engineering, computing, and scientific practice. **III:** Research-methodology basics: problem formulation and literature review. **IV:** Formulating hypotheses and research questions. **V:** Basics of data collection and data analysis for engineering, computing, and scientific research. **VI:** Academic integrity and citation norms: avoiding plagiarism and properly citing sources. **VII:** Introduction to research practice in engineering, computing, and science: reading and using academic papers.

Learning Outcomes I: Distinguish between basic and applied research and identify their role in engineering, computing, and scientific practice [Usage]. **II:** Formulate a research problem and a supporting literature review for a topic in engineering, computing, or science [Usage]. **III:** Formulate testable hypotheses and research questions [Usage]. **IV:** Apply basic data-collection and data-analysis procedures to a simple research exercise [Familiarity]. **V:** Apply academic-integrity principles and standard citation norms when using external sources [Usage].

Bibliography: [Booth et al., 2016, Leedy and Ormrod, 2019]

5.8 Emotional Intelligence, 8 hr(s)

Competences: ABET-3

Topics: I: Goleman's model of emotional intelligence: self-awareness, self-regulation, motivation, empathy, and social skills. **II:** Self-awareness and self-regulation techniques. **III:** Empathy and social-skills development for interpersonal effectiveness. **IV:** Stress-management and resilience-building strategies for academic life.

Learning Outcomes I: Identify the five components of emotional intelligence and relate them to personal behavior [Usage]. **II:** Apply self-regulation and stress-management techniques to cope with academic pressure [Usage]. **III:** Apply empathy and social-skills strategies to improve interpersonal interactions [Familiarity].

Bibliography: [Goleman, 1995]

5.9 Leadership, Team Dynamics, and Stakeholder Management, 4 hr(s)

Competences: ABET-3

Topics: I: Leadership styles, traits, and the difference between leadership and management **II:** Team dynamics: forming, storming, norming, performing stages and roles **III:** Conflict resolution strategies and negotiation **IV:** Stakeholder identification, analysis, and engagement planning **V:** Motivation theories and their application to engineering teams **VI:** Cultural intelligence and leading diverse, global teams **VII:** Change management and leading organizational transformation **VIII:** Emotional intelligence and its role in effective leadership **IX:** Ethical leadership and creating an ethical organizational culture

Learning Outcomes I: Describe different leadership styles and identify situations where each might be effective [Familiarity] **II:** Diagnose the stage of development of a project team and propose appropriate interventions [Assessment] **III:** Resolve a simulated interpersonal conflict within a project team using a structured approach [Usage] **IV:** Develop a stakeholder engagement plan for a project with community opposition [Assessment] **V:** Adapt communication and leadership approach when working with a team from a different cultural background [Assessment] **VI:** Explain the key steps in a change management process for implementing a new technology [Familiarity] **VII:** Evaluate one's own emotional intelligence and identify areas for development [Assessment] **VIII:** Model ethical leadership behavior in a team-based project simulation [Usage]

Bibliography: [Robbins and Coulter, 2017]

6. Bibliography

[Booth et al., 2016] Booth, W. C., Colomb, G. G., Williams, J. M., Bizup, J., and FitzGerald, W. T. (2016). *The Craft of Research*. University of Chicago Press, 4th edition.

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[Robbins and Coulter, 2017] Robbins, S. P. and Coulter, M. (2017). *Management*. Pearson, 14th edition.

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BRC101 Writing and Communication (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

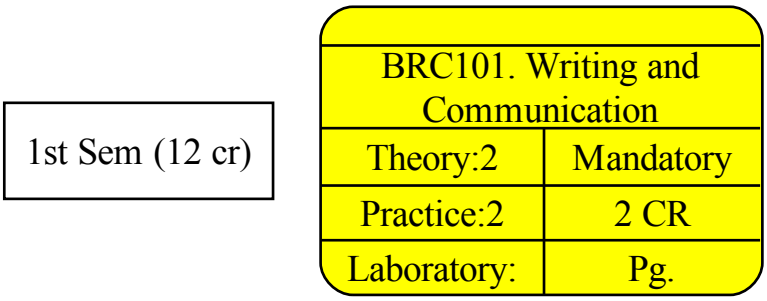

Figure 7.5: Connection Map. BRC101 Writing and Communication

2. Course Rationale

Effective written, oral, and digital communication is a core engineering competency, independent of any particular specialty. This course develops academic and technical writing, oral presentation, and professional digital-communication skills, so that students can produce clear reports and collaborative academic work, apply standard citation norms, and communicate technical content to varied audiences throughout their engineering studies and professional careers.

3. Goals of the Course

- Apply grammar, style, and academic writing conventions to produce clear, well-organized written texts.
- Write academic and group research texts following standard citation norms (APA).
- Deliver structured oral presentations, adapting content to different audiences.
- Communicate professionally through digital channels and with project stakeholders.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

5. Content

5.1 Written and Technical Communication, 19 hr(s)

Competences: ABET-3

Topics: **I:** Audience analysis and adaptation of technical content **II:** Written communication: technical reports, memos, emails, and specifications **III:** Visual communication: graphs, charts, diagrams, and effective slide design

Learning Outcomes I: Write a clear, concise, and well-organized technical report on a laboratory experiment or design project [Usage] **II:** Create effective graphs and diagrams to present engineering data [Assessment]

Bibliography: [Gurak and Lannon, 2013, American Psychological Association, 2020]

5.2 Oral Presentation and Professional Communication, 19 hr(s)

Competences: ABET-3

Topics: I: Oral presentations: structure, delivery techniques, and handling Q&A **II:** Proposal writing: technical approach, management plan, and cost estimating **III:** Executive summaries and communicating with non-technical stakeholders

Learning Outcomes I: Deliver a structured oral presentation on a technical topic using appropriate visual aids [Usage] **II:** Outline the key sections of a competitive engineering proposal [Familiarity] **III:** Develop an executive summary that conveys key project findings to a senior management audience [Usage]

Bibliography: [Gurak and Lannon, 2013, American Psychological Association, 2020]

5.3 Digital and Collaborative Communication, 18 hr(s)

Competences: ABET-3

Topics: I: Collaborative writing and document management in team settings **II:** Digital communication: web content, social media guidelines for engineers **III:** Persuasive communication and negotiation techniques

Learning Outcomes I: Manage a collaborative document (e.g., on Google Docs or SharePoint) for a team project [Assessment] **II:** Explain the professional risks and opportunities associated with engineers using social media [Familiarity] **III:** Employ basic negotiation tactics to resolve a simulated conflict over project scope [Usage]

Bibliography: [Gurak and Lannon, 2013, American Psychological Association, 2020]

6. Bibliography

[American Psychological Association, 2020] American Psychological Association (2020). *Publication Manual of the American Psychological Association*. American Psychological Association, 7th edition.

[Gurak and Lannon, 2013] Gurak, L. J. and Lannon, J. M. (2013). *A Concise Guide to Technical Communication*. Pearson, 4th edition.

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BIC101 Introduction to Programming (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Laboratory**: 4 hours;
- **Prerrequisites**: None

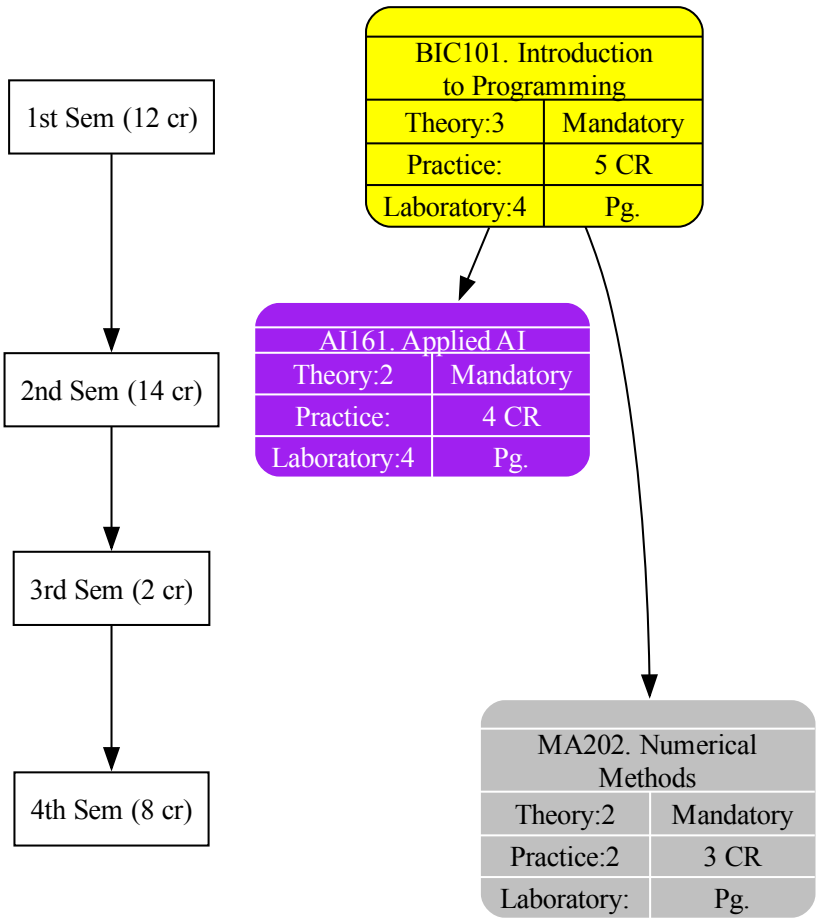

Figure 7.6: Connection Map. BIC101 Introduction to Programming

2. Course Rationale

This is the first course in the sequence of introductory courses to Computer Science. This course introduces participants to the fundamental concepts of programming using Python. Topics include data types, control structures, functions, lists, recursion, and the mechanics of execution, testing, and debugging. Programming is one of the pillars of Computer Science; any professional in the area will need to program to materialize their models and proposals.

3. Goals of the Course

- Introduce the fundamental concepts of programming.

- Develop the ability of abstraction using a programming language.
- Develop problem-solving skills through algorithmic thinking.
- Understand basic data structures and their applications.
- Master the Python programming language for problem solving.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

ABET-7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (Familiarity)

5. Content

5.1 Introduction to Programming and History, 4 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Brief history of computing and programming languages. **II:** Overview of Python programming language. **III:** Programming environments and tools. **IV:** Basic program structure and execution. **V:** Writing, running, and debugging simple programs.

Learning Outcomes **I:** Identify important trends in the history of computing. [Familiarity] **II:** Discuss the historical context of programming language paradigms. [Familiarity] **III:** Compare daily life before and after personal computers and the Internet. [Assessment] **IV:** Write, compile, and run a simple Python program. [Usage]

Bibliography: [Zelle, 2010, Guttag, 2013, Brookshear and Brylow, 2019]

5.2 Type Systems Fundamentals, 6 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** A type as a set of values together with a set of operations: (a) Primitive types (e.g., numbers, Booleans) (b) Compound types built from other types (e.g., records/structs, unions, arrays, lists, functions, references using set operations) **II:** Type safety and errors caused by using values inconsistently given their intended types **III:** Goals and limitations of static and dynamic typing: detecting and eliminating errors as early as possible. **IV:** Primitive data types in Python (int, float, str, bool). **V:** Type conversion and casting.

Learning Outcomes **I:** Describe, for both a primitive and a compound type, the values that have that type [Familiarity] **II:** Describe examples of program errors detected by a type system [Familiarity] **III:** Use types and type-error messages to write and debug programs [Usage] **IV:** Explain Python's dynamic typing system. [Familiarity]

Bibliography: [Zelle, 2010, Guttag, 2013]

5.3 Object-Oriented Programming Fundamentals, 14 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Imperative programming as a subset of object-oriented programming. **II:** Definition of classes: fields, methods, and constructors. **III:** Dynamic vs static properties. **IV:** Variables, expressions, and assignments. **V:** Input and output operations. **VI:** Conditional statements (if, elif, else). **VII:** Iteration structures (for loops, while loops). **VIII:** Nested loops and loop control statements. **IX:** Exception handling basics.

Learning Outcomes **I:** Compose a class through design, implementation, and testing to meet behavioral requirements [Usage] **II:** Predict and validate control flow in a program using dynamic dispatch [Assessment] **III:** Use object-oriented encapsulation mechanisms such as interfaces and private members [Usage] **IV:** Implement programs using conditional and iterative structures. [Usage] **V:** Debug programs with syntax and logical errors. [Usage] **VI:** Design and implement simple algorithms using loops. [Usage]

Bibliography: [Zelle, 2010, Guttag, 2013, Brookshear and Brylow, 2019]

5.4 Functions and Parameter Passing, 10 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Function definition and invocation. **II:** Parameter passing mechanisms (by value, by reference). **III:** Return values and multiple returns. **IV:** Variable scope and lifetime (local, global, nonlocal). **V:** Recursion fundamentals. **VI:** Lambda expressions and higher-order functions. **VII:** Functions as first-class objects. **VIII:** Documentation and testing of functions.

Learning Outcomes **I:** Define and implement functions with proper parameter passing. [Usage] **II:** Explain the difference between pass-by-value and pass-by-reference. [Familiarity] **III:** Implement recursive solutions to simple problems. [Usage] **IV:** Use lambda expressions for functional programming constructs. [Usage] **V:** Design functions with appropriate scope and documentation. [Assessment]

Bibliography: [Zelle, 2010, Guttag, 2013, Hunt and Thomas, 1999]

5.5 Basic Data Structures, 10 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Lists and list operations (indexing, slicing, mutability). **II:** Tuples and immutability. **III:** Dictionaries and key-value mapping. **IV:** Sets and set operations. **V:** Strings as sequences. **VI:** List comprehensions and generator expressions. **VII:** Basic searching and sorting algorithms. **VIII:** Introduction to algorithmic complexity for basic operations.

Learning Outcomes **I:** Implement programs using lists, dictionaries, and sets. [Usage] **II:** Choose appropriate data structures for given problems. [Assessment] **III:** Explain the trade-offs between different data structures. [Familiarity] **IV:** Implement basic search and sort operations on lists. [Usage]

Bibliography: [Zelle, 2010, Guttag, 2013]

5.6 Object-Oriented Programming Fundamentals, 10 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Subclasses, inheritance (including multiple inheritance), and method overriding. **II:** Dynamic dispatch: definition of method-call. **III:** Object-oriented idioms for encapsulation: (a) Privacy, data hiding, and visibility of class members. (b) Interfaces revealing only method signatures. (c) Abstract base classes, traits and mixins. **IV:** Classes and objects in Python. **V:** Attributes and methods. **VI:** Inheritance and polymorphism basics. **VII:** Encapsulation and information hiding.

Learning Outcomes **I:** Build a simple class hierarchy utilizing subclassing that allows code to be reused for distinct subclasses [Usage] **II:** Explain the relationship between object-oriented inheritance (code-sharing and overriding) and subtyping (the idea of a subtype being usable in a context that expects the supertype) [Familiarity] **III:** Compare and contrast the benefits and costs/impact of using inheritance (subclasses) and composition (specifically, how to base composition on higher order functions) [Assessment] **IV:** Design and implement simple classes in Python. [Usage] **V:** Explain the benefits of OOP for code organization. [Familiarity]

Bibliography: [Zelle, 2010, Guttag, 2013]

5.7 Algorithmic Strategies, 6 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Paradigms: (a) Brute-Force (e.g., linear search, selection sort, traveling salesperson, knapsack) (b) Decrease-and-Conquer: i. By a Constant (e.g., insertion sort, topological sort) ii. By a Constant Factor (e.g., binary search) iii. By a Variable Size (e.g., Euclid's) (c) Divide-and-Conquer (e.g., binary search, quicksort, mergesort, Strassen's) (d) Greedy (e.g., Dijkstra's, Kruskal's, Knapsack) (e) Transform-and-Conquer: i. Instance simplification (e.g., find duplicates via list presort) ii. Representation change (e.g., heapsort) iii. Problem reduction (e.g., least-common-multiple, linear programming) iv. Dynamic programming (e.g., Floyd's, Marshall, Bellman-Ford) (f) Space vs time tradeoffs (e.g., hashing) **II:** Iteration vs recursion (e.g., factorial, tree search) **III:** Problem decomposition strategies. **IV:** Algorithm design techniques. **V:** Debugging and testing strategies. **VI:** Tracing program execution.

Learning Outcomes **I:** For each of the paradigms in this unit: (a) Explain its definitional characteristics (b) Explain an example that demonstrates the paradigm including how this example satisfies the paradigm's characteristics. [Familiarity] **II:** Give examples of iterative and recursive algorithms that solve the same problem, explain the benefits and disadvantages of each approach [Usage] **III:** Evaluate whether a greedy approach leads to an optimal solution [Assessment] **IV:** Apply systematic debugging techniques to locate and fix errors. [Usage] **V:** Analyze algorithm complexity for simple problems. [Familiarity]

Bibliography: [Guttag, 2013, Cormen et al., 2009]

5.8 Modern Development Methods and Tool Usage, 4 hr(s)

Competences: ABET-1,ABET-7

Topics: **I:** Using modern programming environments (IDEs, notebooks). **II:** Code search and reuse best practices. **III:** Using standard libraries and APIs. **IV:** Debugging and testing techniques. **V:** Version control basics. **VI:** Code documentation and style guidelines. **VII:** Virtual environments and package management.

Learning Outcomes **I:** Use modern development tools effectively. [Usage] **II:** Apply code reuse principles through libraries and APIs. [Usage] **III:** Debug and test programs systematically. [Usage] **IV:** Follow coding standards and documentation practices. [Familiarity] **V:** Manage Python packages and environments. [Familiarity]

Bibliography: [Zelle, 2010, Hunt and Thomas, 1999]

6. Bibliography

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BEC101 General Economics (Mandatory)

1. General information

- **Semester**: 1st Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

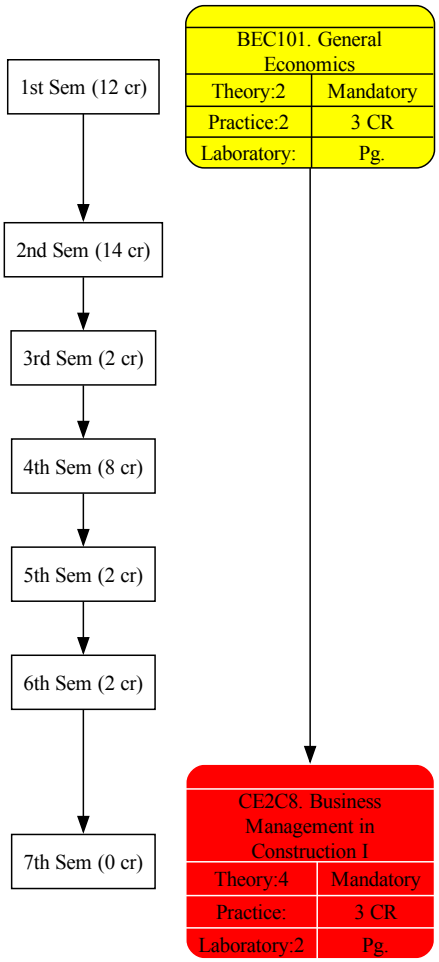

Figure 7.7: Connection Map. BEC101 General Economics

2. Course Rationale

General Economics introduces the fundamentals of economic theory and its historical evolution, market functioning (supply, demand, and elasticity), market structures, production, costs, and firm profits, business economic and financial management, and the basic aspects of macroeconomics, growth, and globalization, as a foundation for the economic decision-making of engineering and computing professionals.

3. Goals of the Course

- Apply the fundamental principles of economic theory to the analysis of engineering decisions.

- Analyze market functioning through supply, demand, and elasticity.
- Analyze the production, costs, and profits of a firm under different market structures.
- Understand the basic aspects of macroeconomics, economic growth, and globalization.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Fundamentals of Economic Theory, 2 hr(s)

Competences: ABET-1

Topics: I: Fundamental concepts of economic theory: scarcity, opportunity cost, and decision-making.

Learning Outcomes I: Explain the fundamental concepts of economic theory [Familiarity].

Bibliography: [Mankiw, 2018]

5.2 Pre-Classical and Classical Economics, 4 hr(s)

Competences: ABET-1

Topics: I: Mercantilist doctrine, Physiocracy, and the Tableau Economique of Quesnay **II:** Adam Smith: invisible hand, division of labor, theory of value, and the critique of mercantilism **III:** David Ricardo: comparative advantage, rent theory, Ricardian equivalence, and the corn laws debate **IV:** Marx's critique of classical economics: surplus value, exploitation, capital accumulation, and crisis theory

Learning Outcomes I: Describe the central contributions of Adam Smith and David Ricardo to classical political economy [Familiarity] **II:** Compare the Ricardian and Smithian theories of value and distribution and trace their influence on later economic schools [Usage] **III:** Evaluate Marx's critique of classical economics and identify which elements retain analytical relevance [Assessment]

Bibliography: [Mankiw, 2018, Samuelson and Nordhaus, 2010]

5.3 Consumer Theory, 10 hr(s)

Competences: ABET-1

Topics: I: Preference axioms (completeness, transitivity, continuity) and utility representation theorems **II:** The utility maximization problem: Marshallian demand functions and Roy's identity **III:** The expenditure minimization problem: Hicksian demand functions and Shephard's lemma **IV:** The Slutsky equation: decomposing price effects into substitution and income effects **V:** Revealed preference theory: WARP, SARP, and empirical content of demand theory

Learning Outcomes I: State the axioms of rational preference and the conditions for utility representation [Familiarity] **II:** Derive Marshallian and Hicksian demand functions from utility and expenditure minimization problems [Usage] **III:** Decompose price effects into substitution and income effects using the Slutsky equation [Assessment]

Bibliography: [Mankiw, 2018]

5.4 Market Structures, 4 hr(s)

Competences: ABET-1

Topics: **I:** Competitive equilibrium: price-taking behavior, short-run and long-run supply, and zero-profit condition **II:** Monopoly pricing: marginal revenue, deadweight loss, price discrimination (first, second, third degree) **III:** Monopolistic competition: product differentiation, markup pricing, and free-entry equilibrium **IV:** Oligopoly models: Cournot, Bertrand, and Stackelberg competition; collusion and the prisoner's dilemma **V:** Advanced pricing: bundling, two-part tariffs, versioning, and peak-load pricing

Learning Outcomes **I:** Compare equilibrium outcomes across market structures in terms of price, output, and efficiency [Familiarity] **II:** Calculate equilibrium price, quantity, and welfare under monopoly and Cournot duopoly [Usage] **III:** Evaluate the welfare effects of market power and the rationale for antitrust policy [Assessment]

Bibliography: [Mankiw, 2018, Samuelson and Nordhaus, 2010]

5.5 Producer Theory, 6 hr(s)

Competences: ABET-1

Topics: **I:** Production functions, isoquants, marginal products, and returns to scale **II:** Cost minimization: conditional factor demands, cost functions, and Shephard's lemma **III:** Profit maximization: output supply and factor demand under competitive and monopolistic conditions **IV:** Short-run vs. long-run costs, economies of scale and scope, and multi-product firms

Learning Outcomes **I:** Describe production technology using production functions, isoquants, and returns to scale [Familiarity] **II:** Derive cost functions and supply schedules from profit-maximizing behavior [Usage] **III:** Analyze how input price changes affect output supply and factor demands using duality [Assessment]

Bibliography: [Mankiw, 2018]

5.6 Financial Markets and Institutions, 10 hr(s)

Competences: ABET-2

Topics: **I:** Market microstructure: bid-ask spread, order flow, liquidity, and price discovery **II:** Financial intermediation: banks as liquidity transformers, maturity mismatch, and bank runs (Diamond-Dybvig) **III:** Systemic risk, financial contagion, macroprudential policy, and the 2008 financial crisis **IV:** Financial regulation: capital requirements, deposit insurance, lender of last resort, and Dodd-Frank

Learning Outcomes **I:** Describe the role of financial intermediaries in the economy and the sources of systemic risk [Familiarity] **II:** Analyze the sources of systemic risk in a financial system and identify channels of contagion using network and balance-sheet linkages [Usage] **III:** Evaluate the design and trade-offs of macroprudential regulation in preventing financial crises [Assessment]

Bibliography: [Blank and Tarquin, 2017, Samuelson and Nordhaus, 2010]

5.7 National Income Accounting, 6 hr(s)

Competences: ABET-1

Topics: **I:** GDP definition and measurement: expenditure, income, and production approaches; nominal vs. real GDP **II:** National income identities: $Y = C + I + G + NX$; saving-investment relationship and current account **III:** Price indices: GDP deflator, CPI, PPI; measurement of inflation and real variables **IV:** Balance of payments accounts: current account, capital account, and financial account

Learning Outcomes I: Define GDP and explain the three approaches to its measurement [Familiarity] **II:** Calculate real GDP growth, the GDP deflator, and the saving-investment balance from national accounts data [Usage] **III:** Interpret discrepancies between national accounting approaches and identify measurement limitations [Assessment]

Bibliography: [Samuelson and Nordhaus, 2010]

5.8 Economic Growth Theory, 6 hr(s)

Competences: ABET-1

Topics: I: Solow-Swan growth model: capital accumulation, steady-state, convergence, and the golden rule **II:** Exogenous technological progress, total factor productivity, and the Solow residual **III:** Endogenous growth models: AK model, R&D-based models (Romer, Aghion-Howitt), and knowledge spillovers **IV:** Cross-country growth regressions, conditional convergence, and the role of institutions and human capital **V:** Institutional determinants of growth: property rights, rule of law, and political economy

Learning Outcomes I: Describe the Solow model and its predictions about capital accumulation and steady-state income [Familiarity] **II:** Analyze the impact of saving rates and technological progress on long-run growth using the Solow model [Usage] **III:** Compare exogenous and endogenous growth theories and their implications for policy [Assessment]

Bibliography: [Samuelson and Nordhaus, 2010]

6. Bibliography

[Blank and Tarquin, 2017] Blank, L. and Tarquin, A. (2017). *Engineering Economy*. McGraw-Hill, 8th edition.

[Mankiw, 2018] Mankiw, N. G. (2018). *Principles of Economics*. Cengage Learning, 8th edition.

[Samuelson and Nordhaus, 2010] Samuelson, P. A. and Nordhaus, W. D. (2010). *Economics*. McGraw-Hill, 19th edition.

Second Semester

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

CE1G1 General Geology (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

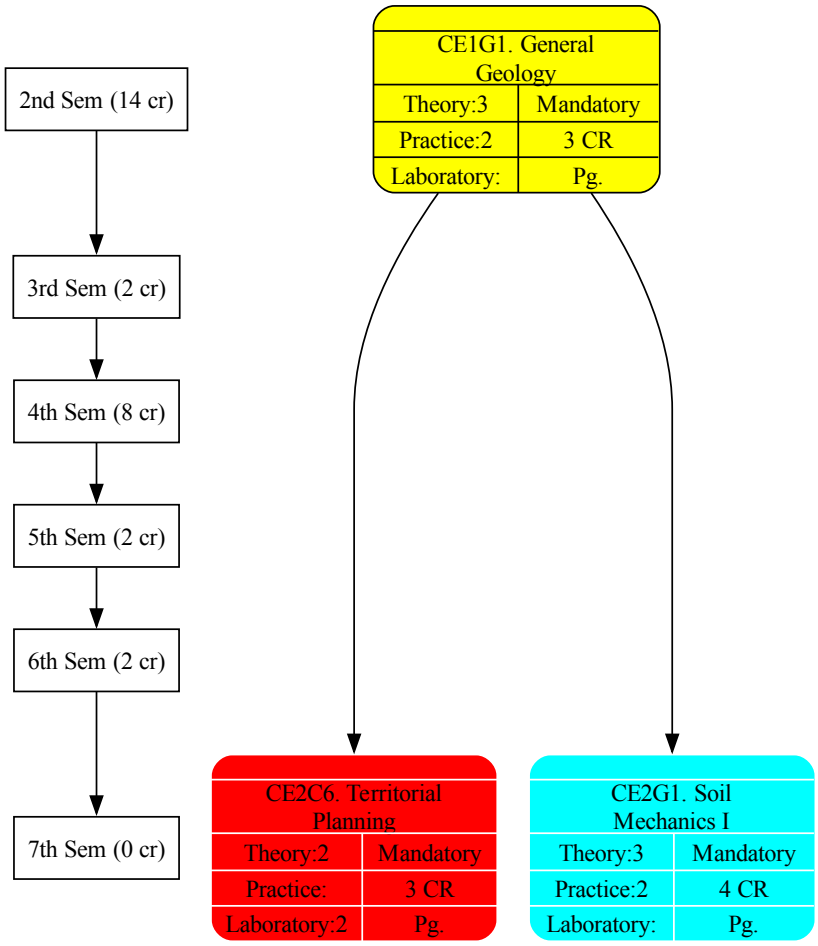

Figure 7.8: Connection Map. CE1G1 General Geology

2. Course Rationale

The General Geology course provides the future civil engineer with the descriptive and analytical foundations of Earth Sciences: the minerals and rocks that constitute geological materials, the structures that record the deformation of the Earth's crust, surface weathering and erosion processes, geological time and the reading of geological maps, and an introduction to applied geology for site characterization. This knowledge constitutes the indispensable conceptual foundation upon which subsequent courses in Soil Mechanics and Geotechnical Engineering are built.

3. Goals of the Course

- Identify the most common minerals and rocks and relate their properties to their expected engineering behavior.
- Recognize and interpret geological structures — folds, faults, and joints — and their influence on the stability of rock masses.
- Understand the processes of weathering, erosion, and landform development relevant to site condition assessment.
- Read and interpret geological maps, stratigraphic columns, and cross-sections.
- Apply the fundamentals of general geology to the preliminary reconnaissance and descriptive characterization of civil engineering sites.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Mineralogy, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Crystal structure and habit of minerals **II:** Main groups of rock-forming minerals: silicates, carbonates, oxides, and sulfates **III:** Mohs hardness scale and scratch tests **IV:** Cleavage, fracture, and other diagnostic physical properties **V:** Luster, color, and streak as identification criteria **VI:** Basic chemical composition and reaction with dilute hydrochloric acid

Learning Outcomes **I:** Identify the most common rock-forming minerals using physical properties [Familiarity] **II:** Apply the Mohs scale to determine the relative hardness of mineral samples [Usage] **III:** Distinguish similar minerals through cleavage, fracture, and luster [Assessment] **IV:** Relate the mineral composition of a rock to its expected engineering behavior [Familiarity] **V:** Perform simple field tests (scratch, acid, luster) for mineral identification [Usage]

Bibliography: [Tarbuck et al., 2014]

5.2 Petrology and the Rock Cycle, 6 hr(s)

Competences: ABET-1

Topics: **I:** Classification of intrusive and extrusive igneous rocks by texture and composition **II:** Sedimentary rock formation processes: erosion, transport, deposition, and lithification **III:** Classification of clastic, chemical, and biochemical sedimentary rocks **IV:** Metamorphic processes: contact and regional metamorphism **V:** Classification of foliated and non-foliated metamorphic rocks **VI:** The rock cycle and transformations between lithologic types **VII:** Relevant engineering properties of rocks: strength, durability, and alterability

Learning Outcomes **I:** Classify hand samples of igneous rocks according to their texture and mineral composition [Assessment] **II:** Explain the formation processes of sedimentary rocks and their engineering significance [Familiarity] **III:** Recognize foliated and non-foliated metamorphic textures in hand samples [Usage] **IV:** Trace the pathways of the rock cycle among the three lithologic groups [Familiarity] **V:** Qualitatively evaluate the suitability of a rock type for use as a construction or foundation material [Assessment]

Bibliography: [Tarbuck et al., 2014, Marshak, 2015]

5.3 Structural Geology, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Stress and strain concepts in rocks **II:** Fold types: anticlines, synclines, and their geometric elements **III:** Fault types: normal, reverse, and strike-slip **IV:** Joint sets and their influence on rock mass strength **V:** Measurement and interpretation of strike and dip **VI:** Unconformities and their significance in geologic history **VII:** Influence of geologic structures on slope and excavation stability

Learning Outcomes **I:** Differentiate folds, faults, and joints based on their geometric features [Familiarity] **II:** Measure the strike and dip of geologic planes using a geologic (Brunton-type) compass [Usage] **III:** Interpret the orientation of structural discontinuities relative to an excavation or slope [Assessment] **IV:** Assess the influence of joint sets on the stability of a rock mass [Assessment] **V:** Recognize unconformities and relate them to regional geologic history [Familiarity]

Bibliography: [Billings, 1972]

5.4 Geomorphology, Weathering, and Erosion Processes, 4 hr(s)

Competences: ABET-1

Topics: **I:** Physical weathering: thermal fragmentation, frost wedging, and unloading **II:** Chemical weathering: hydrolysis, oxidation, and dissolution **III:** Biological weathering and bioerosion **IV:** Residual soil formation from in-situ weathering **V:** Main landforms: valleys, terraces, alluvial fans, and debris cones **VI:** Water and wind erosion processes and mass wasting processes

Learning Outcomes **I:** Distinguish physical, chemical, and biological weathering types present at an outcrop [Familiarity] **II:** Relate the degree of weathering of a rock to the expected quality of a rock mass [Usage] **III:** Identify landforms and their geomorphological origin [Familiarity] **IV:** Evaluate the susceptibility of a slope to erosion and mass wasting processes [Assessment] **V:** Apply weathering grade classification criteria to estimate the durability of rock materials in slopes [Usage]

Bibliography: [Tarbuck et al., 2014]

5.5 Geologic Time, Stratigraphy, and Geologic Mapping, 6 hr(s)

Competences: ABET-6

Topics: **I:** The geologic time scale and the magnitude of deep time **II:** Principles of relative dating: superposition, original horizontality, and cross-cutting relationships **III:** Construction and interpretation of stratigraphic columns **IV:** Symbology and conventions of geologic maps **V:** Construction of geologic cross-sections from maps **VI:** Stratigraphic discontinuities and their expression on geologic maps **VII:** Basic field geologic mapping techniques

Learning Outcomes **I:** Explain the principles of relative dating to establish stratigraphic sequences [Familiarity] **II:** Read and interpret standard geologic maps, including their symbology and legend [Usage] **III:** Construct a geologic cross-section from a geologic map and strike/dip data [Assessment] **IV:** Correlate stratigraphic units between columns from different localities [Assessment] **V:** Apply basic field geologic mapping techniques for a simple survey [Usage]

Bibliography: [Compton, 1985]

5.6 Basic Surface and Groundwater Hydrology of Geologic Materials, 4 hr(s)

Competences: ABET-1

Topics: **I:** Porosity and permeability of soils and rocks **II:** Water table concept and the unsaturated zone **III:** Basic concepts of aquifer, aquitard, and aquiclude **IV:** Springs, seeps, and their relationship to the geologic context **V:** Surface drainage patterns and their relationship to lithology and structure **VI:** Water-rock interaction and its influence on weathering

Learning Outcomes **I:** Differentiate the concepts of porosity and permeability for different geologic materials [Familiarity] **II:** Describe the position of the water table and its seasonal variation at a given site [Familiarity] **III:** Relate the occurrence of springs and seeps to the local geologic and hydrogeologic context [Usage] **IV:** Identify surface drainage patterns characteristic of different geologic conditions [Assessment] **V:** Explain conceptually the water-rock interaction and its role in chemical weathering [Familiarity]

Bibliography: [Tarbuck et al., 2014]

5.7 Applied Geology, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Preliminary geologic site reconnaissance **II:** Qualitative description of rock masses: degree of fracturing and weathering **III:** Types of geologic hazards: landslides, rockfalls, seismic and volcanic activity **IV:** Use of aerial photographs and remote sensing imagery in geologic reconnaissance **V:** Basic elements of a preliminary geologic site report **VI:** Use of field tools: geologic compass, GPS, hand lens, and rock hammer **VII:** Influence of geologic conditions on infrastructure site selection

Learning Outcomes **I:** Conduct a preliminary geologic reconnaissance of a site of interest for civil engineering [Usage] **II:** Qualitatively describe the degree of fracturing and weathering of a rock mass [Assessment] **III:** Recognize the main types of geologic hazards that can affect an infrastructure project [Familiarity] **IV:** Use basic field tools to gather geologic information [Usage] **V:** Prepare a preliminary geologic site report with basic recommendations for further studies [Assessment]

Bibliography: [de Vallejo et al., 2002]

6. Bibliography

[Billings, 1972] Billings, M. P. (1972). *Structural Geology*. Prentice-Hall, 3rd edition.

[Compton, 1985] Compton, R. R. (1985). *Geology in the Field*. Wiley, 1st edition.

[de Vallejo et al., 2002] de Vallejo, L. I. G., Ferrer, M., Ortuño, L., and Oteo, C. (2002). *Ingeniería Geológica*. Pearson Educación, 1st edition.

[Marshak, 2015] Marshak, S. (2015). *Earth: Portrait of a Planet*. W. W. Norton & Company, 5th edition.

[Tarbuck et al., 2014] Tarbuck, E. J., Lutgens, F. K., and Tasa, D. (2014). *Earth: An Introduction to Physical Geology*. Pearson, 11th edition.

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

CS100 Introduction to Computer Science (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

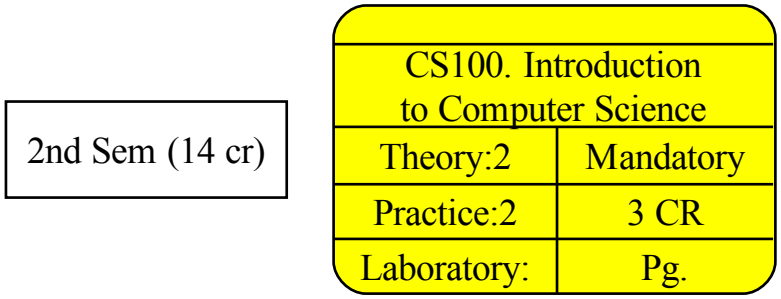

Figure 7.9: Connection Map. CS100 Introduction to Computer Science

2. Course Rationale

This course serves as the foundation for understanding the fundamental concepts of computational thinking applicable across various professions.

The course provides, starting from ground zero, a panoramic view of: introductory computational thinking, data storage, computer architecture, operating systems, networks and the Internet, algorithms, sorting methods, software engineering, databases, data structures, software engineering, computer graphics, artificial intelligence among others.

Designed as an introductory course to Computer Science, the concepts are presented in a playful manner and using an Active Learning methodology. Throughout the course, active audience participation is encouraged, akin to a theatrical performance.

The related knowledge areas covered are directly aligned with the Computing Curricula ACM/IEEE-CS.

The course **does not require** any prior knowledge in computer handling topics and can be taken by student from any field.

3. Goals of the Course

- Introduce the fundamental concepts of Computational Thinking and Computer Science to students from any professional background.
- Develop their ability to abstract.
- Understand how Computational Thinking is applied in each of their professions.
- Apply advanced concepts in a simplified manner in any career.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Familiarity)

ABET-7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (Familiarity)

5. Content

5.1 Computational Thinking (Part I), 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Explanation of the evaluation system. **II:** General course instructions. **III:** Definition of Computing. **IV:** Computing as a Human-Computer binomial. **V:** Distortions in the definition of computing. **VI:** Computing as the automation of abstraction.

VII: Computing and Engineering: similarities and differences. **VIII:** Algorithmic problem-solving. **IX:** Dynamics: Understanding the execution of an algorithm at human speed.

Learning Outcomes **I:** Apply the fundamental concepts of computing in real-life situations. [Usage] **II:** Identify distortions of Computing in real-life situations. [Usage]

III: Clearly identify at least 3 contexts of using the word"Engineer" in English. [Assessment] **IV:** Identify the limitations of humans in solving computational problems. [Usage]

Bibliography: [Brookshear and Brylow, 2019]

5.2 Computational Thinking. Part II, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Decomposition (Breaking a problem in smaller pieces) **II:** Abstraction (Focus on important things) **III:** Pattern recongnition (Identify similar sequences based on previous problems) **IV:** Designing algorithms

Learning Outcomes **I:** Apply Computational Thinking to real-world problems. [Usage]

Bibliography: [Brookshear and Brylow, 2019]

5.3 General concepts, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Binary vs. decimal numbering. **II:** Character representation: the ASCII table. **III:** Binary search. **IV:** Computational complexity of an algorithm.

Learning Outcomes **I:** Apply various numbering systems to real-world problems. [Usage] **II:** Understand the internal representation of characters in the ASCII and UTF-8 tables. [Familiarity] **III:** Apply Divide and Conquer algorithmic strategy. [Usage] **IV:** Determine basic analysis of algorithmic complexity. [Usage]

Bibliography: [Brookshear and Brylow, 2019]

5.4 Machine-Level Data Representation, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Overview and history of computer architecture **II:** Bits, bytes, and words **III:** Unsigned, signed and two's complement representations **IV:** Numeric data representation and number bases: (a) Fixed-point (b) Floating-point **V:** Representation of non-numeric data **VI:** Representation of records, arrays and UTF data types

Learning Outcomes **I:** Discuss why everything in computers are data, including instructions [Debate] **II:** Explain how fixed-length number representations can affect accuracy and precision [Explain] **III:** Describe how negative integers are stored in sign-magnitude and two's-complement representations [Describe] **IV:** Discuss how different formats can represent numerical data [Debate] **V:** Explain the bit-level representation of non-numeric data, such as characters, strings, records, and arrays [Explain] **VI:** Translate numerical data from one format to another [Translate] **VII:** Describe how a single adder (without overflow detection) can handle both signed (two's complement) and unsigned (binary) input without "knowing" which format a given input is using [Describe]

Bibliography: [Brookshear and Brylow, 2019]

5.5 Program Abstraction and Representation, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Programs that take (other) programs as input such as interpreters, compilers, type-checkers, documentation generators **II:** Components of a language: (a) Definitions of alphabets, delimiters, sentences, syntax, and semantics (b) Syntax vs semantics **III:** Program as a set of non-ambiguous meaningful sentences **IV:** Basic programming abstractions: constants, variables, declarations (including nested declarations), command, expression, assignment, selection, definite and indefinite iteration, iterators, function, procedure, modules, exception handling **V:** Types of variables: static, local, nonlocal, global; need and issues with nonlocal and global variables. **VI:** Scope rules: static vs dynamic; visibility of variables; side-effects. **VII:** Environment vs store and their properties **VIII:** Data and control abstraction **IX:** Mechanisms for information exchange between program units such as procedures, functions, and modules: nonlocal variables, global variables, parameter-passing, import-export between modules **X:** Low level instruction representation such as virtual machine instructions, assembly language, and binary representation

Learning Outcomes **I:** Illustrate the scope of variables and visibility using simple programs [Apply] **II:** Illustrate different types of parameter-passing using simple pseudo programming language [Apply] **III:** Explain side-effect using global and nonlocal variables and how to fix such programs [Explain] **IV:** Explain how programs that process other programs treat the other programs as their input data [Explain] **V:** Describe a grammar and an abstract syntax tree for a small language [Describe]

Bibliography: [Brookshear and Brylow, 2019]

5.6 Cryptography Fundamentals, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Basic concepts on Cryptography **II:** Public-keys, Private-keys

Learning Outcomes **I:** Explain the role of cryptography in supporting security and privacy [Explain] **II:** Discuss the risks of inventing one's own cryptographic methods [Debate] **III:** Discuss the importance of prime numbers in cryptography and explain their use in cryptographic algorithms [Debate] **IV:** Implement and cryptanalyze classical ciphers [Implement]

Bibliography: [Brookshear and Brylow, 2019]

5.7 Memory Management, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Review of physical memory, address translation and memory management hardware See also: Memory Hierarchy, Discrete Mathematics **II:** Impact of memory hierarchy including cache concept, cache lookup, and per-CPU caching on operating system mechanisms and policy

See also: Memory Hierarchy, Latency, Cache and Memory Hierarchy, Virtualization and Isolation **III:** Logical and physical addressing, address space virtualization. See also: Memory Hierarchy, Discrete Mathematics **IV:** Concepts of paging, page replacement, thrashing and allocation of pages and frames **V:** Allocation/deallocation/storage techniques (algorithms and data structure) performance and flexibility (a) Arenas, slab allocators, free lists, size classes, heterogeneously sized pages (huge pages) **VI:** Memory caching and cache coherence and the effect of flushing the cache to avoid speculative execution vulnerabilities. See also: Functional Organization, Memory Hierarchy, Latency, Cache and Memory Hierarchy, Virtualization and Isolation **VII:** Virtual memory: leveraging virtual memory hardware for OS services and efficiency

Learning Outcomes **I:** Explain memory hierarchy and cost-performance tradeoffs [Explain] **II:** Summarize the principles of virtual memory as applied to caching and paging [Summarize] **III:** Evaluate the tradeoffs in terms of memory size (main memory, cache memory, auxiliary memory) and processor speed [Evaluate] **IV:** Describe the reason for and use of cache memory (performance and proximity, how caches complicate isolation and virtual machine abstraction) [Describe]

Bibliography: [Brookshear and Brylow, 2019]

5.8 Role and Purpose of Operating Systems, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Operating systems mediate between general purpose hardware and application-specific software. **II:** Universal operating system functions (e.g., process, user and device interfaces, persistence of data) **III:** Influences of security, networking, multimedia, parallel and distributed computing

Learning Outcomes **I:** Understand the objectives and functions of modern operating systems [Explain] **II:** Evaluate the design issues in different usage scenarios (e.g., real time OS, mobile, server) [Evaluate] **III:** Understand how evolution and stability are desirable and mutually antagonistic in operating systems function [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.9 Principles of Operating System, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Operating system software design and approaches (e.g., monolithic, layered, modular, microkernel, unikernel) **II:** Abstractions, processes, and resources **III:** The evolution of the link between hardware architecture and the operating system functions **IV:** Leveraging interrupts from hardware level: service routines and implementations. See also: Assembly Level Machine Organization (a) Timer interrupts for implementing time slices (b) I/O interrupts for putting blocking threads to sleep without polling

Learning Outcomes **I:** Understand how the application of software design approaches to operating systems design/implementation (e.g., layered, modular, etc.) affects the robustness and maintainability of an operating system [Explain] **II:** Categorize system calls by purpose [Categorize] **III:** Apply OS techniques for isolation, protection, and throughput across OS functions (e.g., starvation similarities in process scheduling, disk request scheduling, semaphores, etc.) and beyond [Apply]

Bibliography: [Brookshear and Brylow, 2019]

5.10 Fundamentals of Networks and Communications, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Importance of networking in contemporary computing, and associated challenges. See also: Digital Equity and Accessibility, Social Impact and AI, Civil Liberties and Expression, Data, Surveillance and Privacy Technology, Privacy Philosophical Foundations and Legislation **II:** Organization of the internet (e.g., users, Internet Service Providers, autonomous systems, content providers, content delivery networks) **III:** Layers and their roles (application, transport, network, datalink, and physical) **IV:** Network elements (e.g., routers, switches, hubs, access points, and hosts) **V:** Basic queueing concepts (e.g., relationship with latency, congestion, service levels, etc.)

Learning Outcomes **I:** Articulate the organization of the internet [Articulate] **II:** List and define the appropriate network terminology [List] **III:** Describe the layered structure of a typical networked architecture [Describe]

Bibliography: [Brookshear and Brylow, 2019]

5.11 Networked Applications, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Naming and address schemes (e.g., DNS, and Uniform Resource Identifiers) **II:** Distributed application paradigms (e.g., client/server, peer-to-peer, cloud, edge, and fog). See also: Communication, Coordination **III:** Diversity of networked application demands (e.g., latency, bandwidth, and loss tolerance). See also: Communication, Sustainable Design and Pervasive Computing, Environmental Footprint of Computing Systems, Systemic Effects and Social Context, Digital Equity and Accessibility, Social Impact and AI **IV:** Coverage of application-layer protocols (e.g., HTTP) **V:** Interactions with TCP, UDP, and Socket APIs. See also: Programs: Distribution, Programs: Execution Properties, GPU Programming, Programs: Implementation Mappings, Programs: Declarative Parallelism, Programs: Starting Activities

Learning Outcomes **I:** Define the principles of naming, addressing, resource location [Define] **II:** Analyze the needs of specific networked application demands [Analyze]

Bibliography: [Brookshear and Brylow, 2019]

5.12 Complexity Analysis Framework, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Complexity Analysis Framework: (a) Best, average, and worst-case performance of an algorithm (b) Empirical and relative (Order of Growth) measurements (c) Input size and primitive operations (d) Time and space efficiency **II:** Empirical measurements of performance **III:** Time and space tradeoffs in algorithms

Learning Outcomes **I:** Prepare a presentation that explains to first year students the basic concepts of algorithmic complexity including best, average, and worst-case algorithm behavior, Big-O, Omega, and Theta notations, complexity classes, time and space tradeoffs, empirical measurement, and impact on practical problems [Explain] **II:** For each algorithm in the Foundational Data Structures, Foundational Algorithms, Advanced Algorithms unit, explain its runtime complexity class and why it belongs to this class [Explain] **III:** Informally evaluate the foundational complexity class of simple algorithms [Evaluate] **IV:** Develop empirical studies to determine and validate hypotheses about the runtime complexity of various algorithms by running algorithms on input of various sizes and comparing actual performance to the theoretical analysis [Create] **V:** Explain examples that illustrate time-space tradeoffs of algorithms [Explain] **VI:** Explain how tree balance affects the efficiency of binary search tree operations [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.13 Asymptotic Notation and Complexity Classes, 1 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Asymptotic complexity analysis (average and worst-case bounds): (a) Big-O, Big-Omega, and Big-Theta formal notations (b) Foundational Complexity Classes and Representative Examples/Problems: i. $O(1)$ Constant (e.g., array access) ii. $O(\log_2 n)$ Logarithmic (e.g., binary search) iii. $O(n)$ Linear (e.g., linear search) iv. $O(n \log_2 n)$ Log Linear (e.g., mergesort) v. $O(n^2)$ Quadratic (e.g., selection sort) vi. $O(n^c)$ Polynomial (e.g., $O(n^3)$ Gaussian elimination) vii. $O(2^n)$ Exponential (e.g., Knapsack, Satisfiability (SAT), Traveling Sales-Person (TSP), all subsets) viii. $O(n!)$ Factorial (e.g., Hamiltonian circuit, all permutations)

Learning Outcomes I: Using examples, explain each of the foundational complexity classes in this unit [Explain] **II:** For each foundational complexity class in this unit, explain an algorithm that demonstrates the associated runtime complexity [Explain] **III:** Explain to a non-technical audience the significance of tractable versus intractable algorithms using an intuitive explanation of Big-O complexity [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.14 Complexity Analysis: Recursion, Amortization, and Tight Bounds, 1 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Little-o, Little-Omega, and Little Theta notations

Learning Outcomes I: Given a problem to program for which there may be several algorithmic approaches, evaluate them and determine which are feasible, and select one that is optimal in implementation and run-time behavior [Evaluate]

Bibliography: [Brookshear and Brylow, 2019]

5.15 Foundational Data Structures, 3 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Abstract Data Type (ADT) and operations on an ADT: (a) Dictionary operations (insert, delete, find) **II:** Arrays: (a) Numeric vs non-numeric, character strings (b) Single (vector) vs multidimensional (matrix) **III:** Records/Structs/Tuples and Objects **IV:** Linked lists (for historical reasons): (a) Single vs Double and Linear vs Circular **V:** Stacks **VI:** Queues and deques: (a) Heap-based priority queue **VII:** Hash tables/maps: (a) Collision resolution and complexity (e.g., probing, chaining, rehash) **VIII:** Trees: (a) Binary, n-ary, and search trees (b) Balanced (e.g., AVL, Red-Black, Heap)

Learning Outcomes I: For each ADT/Data-Structure in this unit: (a) Explain its definition, properties, representation(s), and associated ADT operations. (b) Explain step-by-step how the ADT operations associated with the data structure transform it. [Explain] **II:** Explain how collision avoidance and collision resolution is handled in hash tables [Explain] **III:** Explain the heap property and the use of heaps as an implementation of a priority queue [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.16 Foundational Algorithms, 3 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Graphs (e.g., [un]directed, [a]cyclic, [un]connected, and [un]weighted): (a) Graph representation: adjacency list vs matrix **II:** Search algorithms: (a) $O(n)$ complexity (e.g., linear/sequential array/list search) (b) $O(\log_2 n)$ complexity (e.g., binary search) (c) $O(\log_b n)$ complexity (e.g., uninformed depth/breadth-first tree search) **III:** Sorting algorithms (e.g., stable, unstable): (a) $O(n^2)$ complexity (e.g., insertion, selection) (b) $O(n \log n)$ complexity (e.g.,

quicksort, merge, timsort) **IV:** Graph algorithms: (a) Shortest path (e.g., Dijkstra's, Floyd's) (b) Minimal spanning tree (e.g., Prim's, Kruskal's) **V:** Sorting algorithms: (a) $O(n \log n)$ complexity heapsort (b) Pseudo $O(n)$ complexity (e.g., bucket, counting, radix) **VI:** Graph algorithms: (a) Transitive closure (e.g., Warshall's) (b) Topological sort

Learning Outcomes I: For each algorithm in this unit explain step-by-step how the algorithm operates [Explain] **II:** For each algorithmic approach (e.g., sorting) in this unit apply a prototypical example of the approach (e.g., merge sort) [Apply] **III:** Given requirements for a problem, develop multiple solutions using various data structures and algorithms. Subsequently, evaluate the suitability, strengths, and weaknesses selecting an approach that best satisfies the requirements [Create] **IV:** Explain factors beyond computational efficiency that influence the choice of algorithms, such as programming time, maintainability, and the use of application-specific patterns in the input data [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.17 Advanced Algorithms, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Cryptography algorithms (e.g., SHA-256) **II:** Parallel algorithms

Learning Outcomes I: An appreciation of quantum computation and its application to certain problems [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.18 Core Database System Concepts, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Purpose and advantages of database systems **II:** Components of database systems **III:** Design of core DBMS functions (e.g., query mechanisms, transaction management, buffer management, access methods) **IV:** Transaction management **V:** Normalization **VI:** Approaches for managing large volumes of data (e.g., NoSQL database systems, use of MapReduce) **VII:** Distributed databases/cloud-based systems **VIII:** Use of a declarative query language

Learning Outcomes I: Identify at least four advantages that using a database system provides [Analyze] **II:** Enumerate the components of a (relational) database system [Enumerate] **III:** Defend the value of data independence [Defend] **IV:** Compose a simple select-project-join query in SQL [Compose] **V:** Describe the advantages for eliminating duplicate repeated data [Describe] **VI:** Outline how MapReduce uses parallelism to process data efficiently [Outline]

Bibliography: [Brookshear and Brylow, 2019]

5.19 Object-Oriented Programming Fundamentals, 4 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: I: Imperative programming as a subset of object-oriented programming. **II:** Object-oriented design: (a) Decomposition into objects carrying state and having behavior. (b) Class-hierarchy design for modeling. **III:** Definition of classes: fields, methods, and constructors. **IV:** Subclasses, inheritance (including multiple inheritance), and method overriding. **V:** Dynamic dispatch: definition of method-call. **VI:** Object-oriented idioms for encapsulation: (a) Privacy, data hiding, and visibility of class members. (b) Interfaces revealing only method signatures. (c) Abstract base classes, traits and mixins.

Learning Outcomes I: Enumerate the differences between imperative and object-oriented programming paradigms [Enumerate] **II:** Compose a class through design, implementation, and testing to meet behavioral requirements [Compose] **III:** Use object-oriented encapsulation mechanisms such as interfaces and private members [Use]

Bibliography: [Brookshear and Brylow, 2019]

5.20 Version Control and CI/CD, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Software configuration management and version control: Software Development Practices (a) Configuration in version control, reproducible builds/configuration. (b) Version control branching strategies. Development branches vs release branches. Trunk-based development. (c) Merging/rebasing strategies, when relevant. **II:** Release management. **III:** Software process automation: (a) Build systems - the value of fast, hermetic, reproducible builds, compare/contrast approaches to building a project. (b) Continuous Integration (CI) - the use of automation and automated tests to do preliminary validation that the current head/trunk revision builds and passes (basic) tests. (c) Continuous Deployment (CD) - the use of automation to automatically release every change that passes the automated tests to the production environment, ensuring frequent and reliable deliveries. (d) Dependency management - updating external/upstream dependencies, package management, SemVer. **IV:** Tool integration concepts and mechanisms. Software Development Practices **V:** Use of modern IDE facilities - debugging, refactoring, searching/indexing, ML-powered code assistants, etc. Software Development Practices

Learning Outcomes **I:** Describe the difference between centralized and distributed software configuration management [Describe] **II:** Describe how version control can be used to help manage software release management [Describe] **III:** Identify configuration items and use a source code control tool in a small team-based project [Analyze] **IV:** Understand the use of CI/CD systems as a ground-truth for the state of the team's shared code (build and test success) [Explain] **V:** Demonstrate the capability to use software tools in support of the development of a software product of medium size [Demonstrate]

Bibliography: [Brookshear and Brylow, 2019]

5.21 Requirements Engineering, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Describe functional requirements using, for example, use cases or user stories. (a) Using at least one method of documenting and structuring functional requirements. (b) Understanding how the method supports design and implementation. (c) Strengths and weaknesses of using a specific approach. **II:** Requirements elicitation. (a) Sources of requirements, for example, users, administrators, or support personnel. (b) Methods of requirement gathering, for example, surveys, interviews, or behavioral analysis. **III:** Non-functional requirements, for example, security, usability, or performance, also called as Quality Attributes. Sustainable Design and Pervasive Computing, Environmental Footprint of Computing Systems, Systemic Effects and Social Context **IV:** Risk identification and management, including ethical considerations surrounding the proposed product. Ethics Codes and Legal Accountability, Professional Responsibility and Public Policy, Professional Values, Nature and Continuing Development, Ethical Dissent and Cultural Context, Workplace Ethics **V:** Communicating and/or formalizing requirement specifications. **VI:** Prototyping a tool for both eliciting and validating/confirming requirements. **VII:** Product evolution: when requirements change, how to understand what effect that has and what changes need to be made. **VIII:** Effort estimation: (a) Learning techniques for better estimating the effort required to complete a task; (b) Practicing estimation and comparing it to how long tasks take; (c) Effort estimation is quite difficult, so students are likely to be way off in many cases, but seeing the process play out with their own work is valuable.

Learning Outcomes **I:** Compare different methods of eliciting requirements along multiple axes [Compare] **II:** Identify differences between two methods of describing functional requirements (e.g., customer interviews, user studies) and the situations where each would be preferred [Analyze] **III:** Identify which behaviors are required, allowed, or barred from a given set of requirements

and a list of candidate behaviors [Analyze] **IV:** Collect a set of requirements for a simple software system [Analyze] **V:** Identify areas of a software system that need to be changed, given a description of the system and a set of new requirements to be implemented [Analyze] **VI:** Identify the functional and non-functional requirements in a set of requirements [Analyze] **VII:** Estimate the time to complete a set of tasks, then compare estimates to the actual time taken [Estimate] **VIII:** Determine an implementation sequence for a set of tasks, adhering to dependencies between them, with a goal to retire risk as early as possible [Determine] **IX:** Write a requirement specification for a simple software system [Write]

Bibliography: [Brookshear and Brylow, 2019]

5.22 Machine Learning Fundamentals, 1 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Definition and examples of a broad variety of machine learning tasks: (a) Supervised learning: i. Classification ii. Regression (b) Reinforcement learning (c) Unsupervised learning: i. Clustering **II:** Fundamental ideas: (a) No free lunch theorem: no one learner can solve all problems; representational design decisions have consequences. (b) Sources of error and undecidability in machine learning **III:** A simple statistical-based supervised learning such as linear regression or decision trees: (a) Focus on how they work without going into mathematical or optimization details; enough to understand and use existing implementations correctly

Learning Outcomes **I:** Describe the differences among the three main styles of learning (supervised, reinforcement, and unsupervised) and determine which is appropriate to a particular problem domain [Explain] **II:** Differentiate the terms of AI, machine learning, and deep learning [Evaluate] **III:** Explain how machine learning works as an optimization/search process [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.23 Neural Networks and Ethics, 1 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Basic neural networks: (a) Fundamentals of understanding how neural networks work and their training process, without details of the calculations (b) Basic introduction to generative neural networks (e.g., large language models) **II:** Ethics for Machine Learning: (a) Focus on real data, real scenarios, and case studies (b) Dataset/algorithmic/evaluation bias and unintended consequences **III:** Deep learning: (a) Deep feed-forward networks (intuition only, no mathematics) (b) Convolutional neural networks (intuition only, no mathematics) (c) Visualization of learned feature representations from deep nets (d) Other architectures (generative NN, recurrent NN, transformers, etc.) **IV:** Ethics for Machine Learning: (a) Continued focus on real data, real scenarios, and case studies (b) Privacy (c) Fairness (d) Intellectual property (e) Explainability

Learning Outcomes **I:** Describe the neural network training process and resulting learned representations [Explain] **II:** Visualize the training progress of a neural network through learning curves in a well-established toolkit (e.g., TensorBoard) and visualize the learned features of the network [Apply] **III:** Given a real-world application of machine learning, describe ethical issues regarding the choices of data, preprocessing steps, algorithm selection, and visualization/presentation of results [Apply]

Bibliography: [Brookshear and Brylow, 2019]

5.24 Fundamental Concepts of Graphics and Interactive Techniques, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Overview of computer graphics pipeline and interactive systems **II:** Basic rendering concepts: rasterization, ray tracing, shading models **III:** Color theory and color spaces **IV:** Coordinate systems and transformations **V:** Basic interaction techniques: input devices, event handling **VI:** Advanced rendering concepts: global illumination, physically based rendering **VII:** Graphics hardware and acceleration techniques **VIII:** Human perception and visual cognition

Learning Outcomes **I:** Explain the basic stages of the computer graphics pipeline [Explain] **II:** Describe basic rendering techniques such as rasterization and ray tracing [Describe] **III:** Apply color theory to design visually effective graphics [Apply] **IV:** Implement coordinate transformations for 2D and 3D graphics [Implement] **V:** Design basic interactive applications using common input devices and event handling [Design] **VI:** Compare advanced rendering techniques such as global illumination and physically based rendering [Compare] **VII:** Analyze the role of graphics hardware in accelerating rendering tasks [Analyze] **VIII:** Explain how human perception influences graphics and interaction design [Explain]

Bibliography: [Brookshear and Brylow, 2019]

5.25 Applied Rendering and Techniques, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Ray tracing: acceleration structures, sampling, shading **II:** Texture mapping and filtering

Learning Outcomes **I:** Implement rasterization algorithms for primitive rendering [Implement] **II:** Implement basic ray tracing with acceleration structures [Implement]

Bibliography: [Brookshear and Brylow, 2019]

5.26 Closure Class: How Does a Search Engine Like Google Work?, 2 hr(s)

Competences: ABET-1,ABET-4,ABET-7

Topics: **I:** Problem analysis **II:** The index does not grow linearly with the size of the indexed information. **III:** Response time does not depend on the size of the "database." **IV:** Response time does not depend on the number of occurrences found. **V:** Combining various data structures to reach a solution. **VI:** Analyzing the scalability of the solution.

Learning Outcomes **I:** Understand the principles under which a search engine is created [Usage] **II:** Correctly apply data structures to solve the problem [Usage] **III:** Apply concepts related to algorithmic complexity in a search engine [Usage].

Bibliography: [Brookshear and Brylow, 2019]

6. Bibliography

[Brookshear and Brylow, 2019] Brookshear, J. G. and Brylow, D. (2019). *Computer Science: An Overview*. Pearson, global edition edition.

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

AI161 Applied AI (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 4 hours;
- **Prerrequisites**:
  - BIC101 Introduction to Programming (1st Sem-Pg. 262)

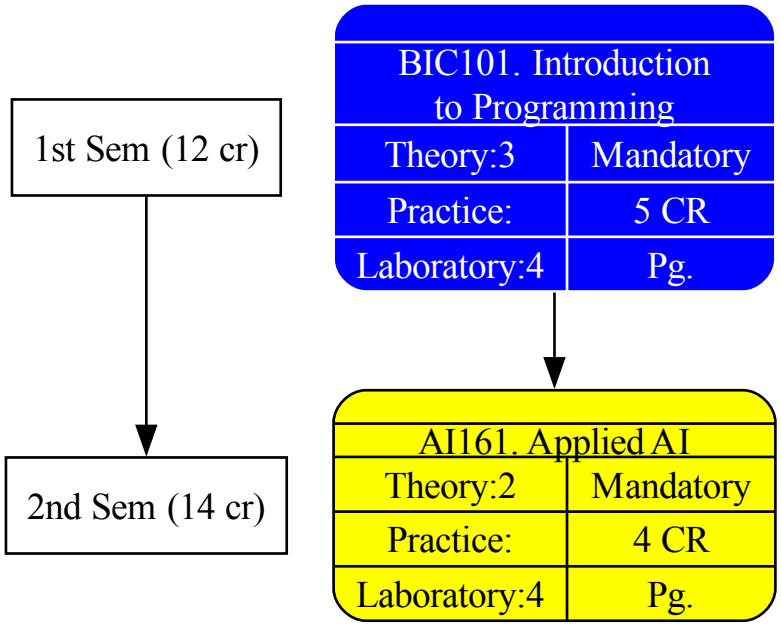

Figure 7.10: Connection Map. AI161 Applied AI

2. Course Rationale

This course provides a practical introduction to Artificial Intelligence (AI) for students from all scientific and engineering disciplines. Focused on developing AI literacy and practical skills, it covers fundamental concepts, modern AI tools (including Western and Chinese platforms), and responsible usage. Students will learn to effectively interact with diverse AI systems, write quality prompts, and apply AI solutions to problems across various domains while understanding ethical implications and cultural contexts of AI deployment.

3. Goals of the Course

- Develop comprehensive AI literacy by understanding fundamental concepts, capabilities, and limitations of modern AI systems across different platforms and cultures.
- Master effective prompt engineering techniques and interaction patterns with various AI tools (Western: ChatGPT, Claude, Gemini; Chinese: DeepSeek, Kimi, ERNIE).
- Apply diverse AI tools to solve practical problems in scientific, engineering, and academic contexts while maintaining critical evaluation of outputs across platforms.

- Understand ethical considerations, biases, cultural contexts, and responsible usage of AI technologies in global professional and academic settings.
- Develop workflows that integrate multiple AI tools to enhance productivity and problem-solving capabilities while understanding regional strengths and specializations.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Familiarity)

5. Content

5.1 AI Fundamentals and Global Landscape, 16 hr(s)

Competences: ABET-1,ABET-4

Topics: **I:** What is AI? Definitions, history, and current global landscape. **II:** Types of AI systems: chatbots, image generators, research assistants across regions. **III:** Western AI ecosystems: OpenAI, Anthropic, Google, Microsoft. **IV:** Chinese AI ecosystems: DeepSeek, Kimi, ERNIE, Zhipu AI, Baidu. **V:** AI capabilities and limitations: comparative analysis across platforms. **VI:** Digital literacy in the AI era: critical thinking about diverse AI outputs.

Learning Outcomes **I:** Apply fundamental AI knowledge to identify system types and their capabilities [Usage]. **II:** Analyze global intelligent systems and their distinctive characteristics [Assessment]. **III:** Critically evaluate AI outputs across different cultural contexts [Assessment].

Bibliography: [Ng, 2019, Mollick and Mollick, 2024, UNESCO, 2023, Institute, 2024]

5.2 Effective AI Interaction and Cross-Platform Prompt Engineering, 20 hr(s)

Competences: ABET-1,ABET-4

Topics: **I:** Principles of effective prompt writing: clarity, context, constraints across platforms. **II:** Prompt patterns: persona, template, chain-of-thought, few-shot for different AI systems. **III:** Western tools: specific techniques for ChatGPT, Claude, Gemini, Copilot. **IV:** Chinese tools: specific features and best practices for DeepSeek, Kimi, ERNIE. **V:** Cross-platform strategies: leveraging different AI strengths for complex tasks. **VI:** Iterative refinement: how to improve prompts based on outputs from diverse systems. **VII:** Practical sessions: comparative prompt writing workshops across platforms.

Learning Outcomes **I:** Design effective prompt solutions for diverse AI systems [Assessment]. **II:** Develop cross-platform workflows that integrate different AI tools [Usage]. **III:** Implement iterative refinement strategies to optimize AI outputs [Usage].

Bibliography: [White et al., 2023, Prompt Engineering Institute, 2024, Microsoft, 2024, DeepSeek, 2024]

5.3 AI Applications Across Disciplines and Platforms, 16 hr(s)

Competences: ABET-1,ABET-4

Topics: **I:** AI for research: literature review, data analysis using multiple AI assistants. **II:** AI for writing: academic papers, reports with cross-platform verification. **III:** AI for problem-solving: scientific calculations, engineering design with specialized tools. **IV:** AI for creativity: brainstorming, concept development across cultural contexts. **V:** Platform-specific strengths: when to use Western vs. Chinese AI tools. **VI:** Discipline-specific workshops: tailored applications

using diverse AI ecosystems. **VII:** Case studies: real-world applications in scientific research across regions.

Learning Outcomes **I:** Apply AI fundamentals to solve discipline-specific problems [Usage]. **II:** Design solutions that integrate multiple intelligent systems for complex tasks [Assessment]. **III:** Develop practical applications using Western and Chinese AI tools [Usage]. **IV:** Implement workflows that leverage specific strengths of each platform [Assessment].

Bibliography: [Mollick, 2023, Google, 2024, Cloud, 2024, OpenAI, 2024]

5.4 Global AI Ethics and Responsible Usage, 12 hr(s)

Competences: ABET-1,ABET-4

Topics: **I:** Understanding AI biases: Western and Eastern cultural perspectives. **II:** Ethical frameworks: comparing EU AI Act, Chinese regulations, and global standards. **III:** Academic integrity: proper citation and AI usage in coursework across platforms. **IV:** Privacy and data security: regional differences in AI data handling. **V:** Cultural sensitivity: navigating AI outputs in global contexts. **VI:** Environmental impact: sustainability considerations of different AI systems. **VII:** Developing personal guidelines for ethical AI usage in international settings. **VIII:** Case studies: ethical dilemmas in AI deployment across regions.

Learning Outcomes **I:** Demonstrate professional responsibility in using AI technologies [Assessment]. **II:** Apply professional ethical principles in global AI contexts [Usage]. **III:** Develop ethical guidelines to mitigate biases in AI systems [Assessment]. **IV:** Evaluate ethical implications of AI deployment across different cultures [Usage].

Bibliography: [UNESCO, 2023, Union, 2024, Bender et al., 2021, of Cyberspace Studies, 2024, Tencent AI Lab, 2023]

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[Bender et al., 2021] Bender, E. M., Gebru, T., et al. (2021). On the dangers of stochastic parrots: Can language models be too big? *FAccT '21: Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency*. Foundational paper on AI ethics with ongoing relevance.

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Universidad Nacional de Ingeniería (UNI)
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CB1E1 Technical Drawing & CAD (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**: None

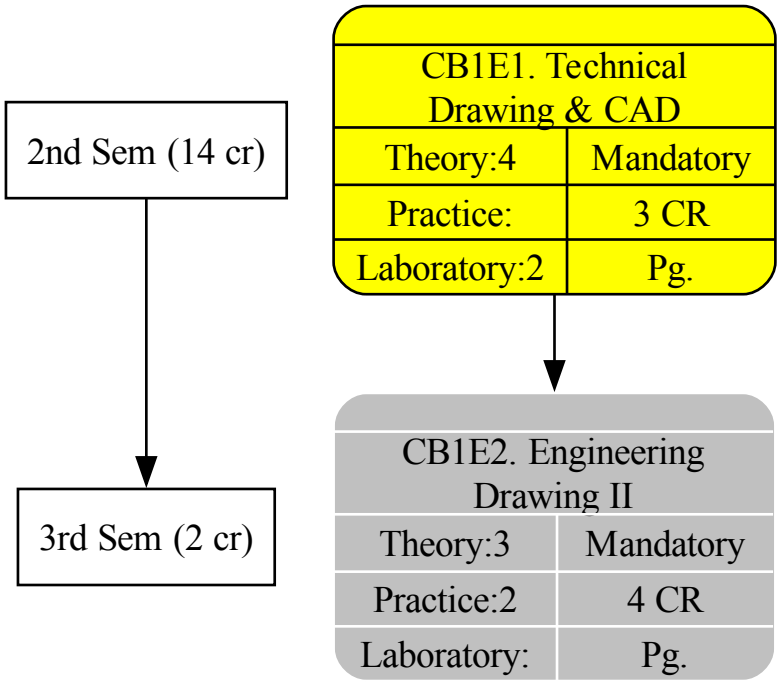

Figure 7.11: Connection Map. CB1E1 Technical Drawing & CAD

2. Course Rationale

Technical Drawing and CAD is a foundational course for engineering students, as it provides the graphical language needed to communicate technical projects. Mastery of descriptive geometry, drafting standards, and Computer-Aided Design (CAD) tools allows students to represent three-dimensional objects with technical precision on a two-dimensional plane, an essential skill for the design, execution, and supervision of engineering projects. The course closes with an application to civil engineering drawings, covering the symbols and conventions used in foundation and basic structural plans.

3. Goals of the Course

- Apply national and international technical drawing standards to produce engineering drawings.
- Develop spatial visualization skills through the study of projections and descriptive geometry.
- Use modern CAD software tools to create geometric models and technical project documentation.
- Apply engineering drawing conventions to civil engineering plans, including foundations and basic structures.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Fundamentals of Technical Drawing and Instrumentation, 8 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** History and importance of technical drawing in engineering **II:** Drawing instruments and graphical scales **III:** Paper formats, title blocks, and line types per technical standards **IV:** Basic geometric constructions

Learning Outcomes **I:** Correctly use technical drawing instruments in accordance with drafting standards [Familiarity] **II:** Apply appropriate scales to represent physical elements in drawings [Usage]

Bibliography: [Luzadder and Duff, 1993, Jensen et al., 2007]

5.2 Descriptive Geometry and Projections, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Orthographic projection system: first-angle and third-angle projection **II:** Projection of points, lines, and planes **III:** Principal views and auxiliary views **IV:** Isometric and oblique (cavalier) perspectives

Learning Outcomes **I:** Develop the ability to represent 3D objects in 2D orthographic projections [Usage] **II:** Interpret auxiliary views to determine true lengths and slopes [Assessment]

Bibliography: [Luzadder and Duff, 1993]

5.3 Computer-Aided Design (CAD) 2D, 16 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** User interface and drawing environment configuration **II:** Commands for creating and editing geometric entities **III:** Layer, block, and attribute management **IV:** Technical dimensioning and generation of print files (layouts)

Learning Outcomes **I:** Fluently handle CAD software commands to create complex geometry [Usage] **II:** Organize graphical information through efficient use of layers and external references [Usage]

Bibliography: [Omura and Benton, 2021]

5.4 Introduction to 3D Modeling and Engineering Drawings, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Basic solid and surface modeling **II:** Automatic generation of views and sections from 3D models **III:** Technical symbols and drawings applied to civil engineering: foundations and basic structures

Learning Outcomes **I:** Create basic three-dimensional models using solid modeling tools [Familiarity]
II: Produce engineering drawings that meet professional presentation standards [Assessment]
III: Apply technical symbols and produce foundation and basic structural drawings for civil engineering [Usage]

Bibliography: [Omura and Benton, 2021, Jensen et al., 2007]

6. Bibliography

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MA112 Calculus II (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA111 Calculus I (1st Sem-Pg. 249)

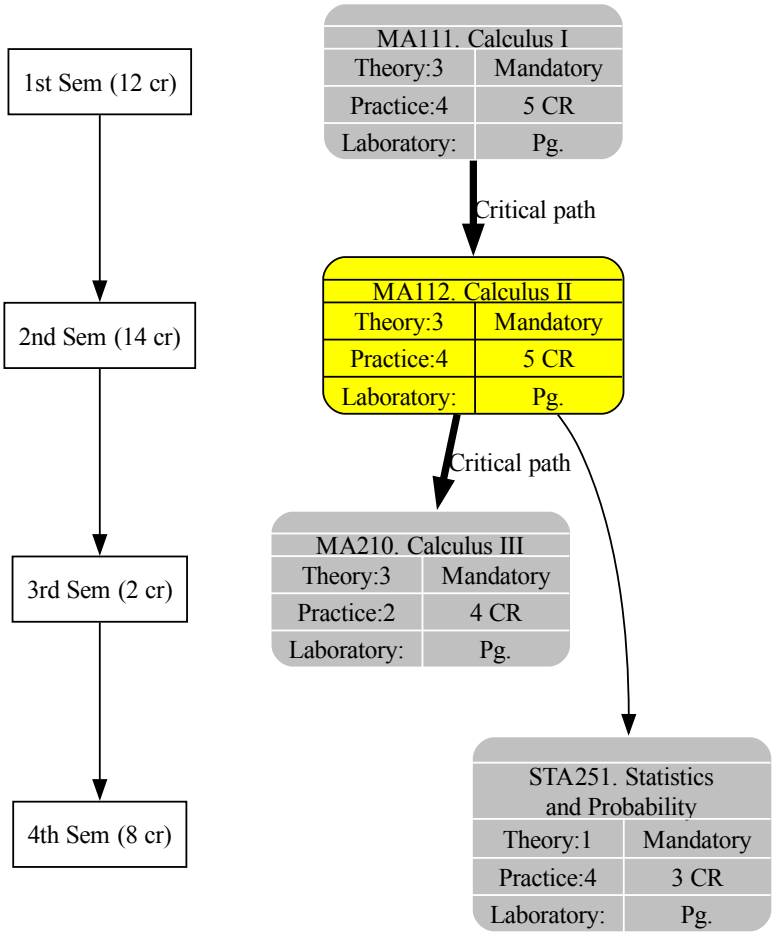

Figure 7.12: Connection Map. MA112 Calculus II

2. Course Rationale

This course covers integral calculus for functions of a single variable and the geometric foundations needed for multivariable calculus. It emphasizes the accumulation of quantities and the inverse relationship between differentiation and integration, provides tools for calculating areas, volumes, arc length, and work, and introduces vectors and the geometry of three-dimensional space, quadric surfaces, parametric equations, polar coordinates, and vector-valued functions of a real variable.

3. Goals of the Course

- Understand the definite integral as a limit of Riemann sums and master techniques of integration, improper integrals, and infinite series.
- Apply the definite integral to calculate areas, volumes of revolution, arc length, surface area, work, and centroids.
- Operate with vectors in three-dimensional space and use them to determine lines and planes.
- Classify quadric surfaces from their general equation.
- Analyze curves described parametrically and in polar coordinates, including their calculus and area.
- Describe space curves as vector-valued functions and compute their arc length, curvature, and torsion.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Integral Calculus, 14 hr(s)

Competences: ABET-1

Topics: **I:** The Fundamental Theorem of Calculus **II:** Integration techniques including substitution and parts **III:** Engineering applications of integration: areas, volumes, centroids, and moments of inertia

Learning Outcomes **I:** State and explain the Fundamental Theorem of Calculus [Familiarity] **II:** Calculate definite integrals arising from engineering problems such as work, fluid pressure, and heat transfer [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

5.2 Improper Integrals, 6 hr(s)

Competences: ABET-1

Topics: **I:** Improper integrals over unbounded intervals **II:** Improper integrals of unbounded (discontinuous) integrands **III:** Convergence criteria and comparison tests for improper integrals

Learning Outcomes **I:** Determine whether an improper integral arising from an engineering model converges, using comparison and other convergence tests [Assessment] **II:** Evaluate an improper integral by taking the appropriate limit, when it converges [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

5.3 Sequences, Series, and Power Series, 14 hr(s)

Competences: ABET-1

Topics: **I:** Sequences and series: convergence tests (ratio, root, comparison, integral) **II:** Power series, radius of convergence, and Taylor/Maclaurin series **III:** Engineering use of Taylor polynomials for linearization and numerical approximation

Learning Outcomes **I:** Determine convergence of a power series and construct a Taylor series for a standard engineering function [Assessment] **II:** Apply a Taylor polynomial to approximate or linearize an engineering function [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018, Thomas et al., 2014]

5.4 Applications of the Definite Integral, 16 hr(s)

Competences: ABET-1

Topics: **I:** Area between curves by integrating with respect to x or y **II:** Volume of solids of revolution by the disk and washer method **III:** Volume of solids of revolution by the cylindrical shell method **IV:** Work via integration (springs, pumping fluids, cables) **V:** Moments and centroid of a plane region or solid

Learning Outcomes **I:** Calculate the volume of a solid of revolution using the disk, washer, or cylindrical shell method [Usage] **II:** Calculate the work done by a variable force using integration [Usage]

Bibliography: [Stewart, 2016, Thomas et al., 2014]

5.5 Vectors and the Geometry of Space, 6 hr(s)

Competences: ABET-1

Topics: **I:** Dot and cross products: definition, properties, and geometric interpretation **II:** Equations of lines and planes in space

Learning Outcomes **I:** Compute the dot and cross products of vectors to solve engineering force and moment problems [Usage] **II:** Determine equations of lines and planes in space from the geometric data of an engineering problem [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018]

5.6 Quadric Surfaces, 6 hr(s)

Competences: ABET-1

Topics: **I:** Classification of quadrics (ellipsoids, paraboloids, hyperboloids) from their general equation

Learning Outcomes **I:** Classify a quadric surface and identify its geometry for engineering component modeling [Usage]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018]

5.7 Parametric Equations and Polar Coordinates, 12 hr(s)

Competences: ABET-1

Topics: **I:** Parametric curves and their calculus, applied to trajectories in kinematics **II:** Polar coordinates and their conversion to Cartesian coordinates

Learning Outcomes **I:** Calculate the velocity and acceleration of a trajectory described parametrically [Usage] **II:** Convert between polar and Cartesian coordinates when modeling engineering geometries [Usage]

Bibliography: [Stewart, 2016, Thomas et al., 2014]

5.8 Vector Functions of a Real Variable, 10 hr(s)

Competences: ABET-1

Topics: **I:** Definition, domain, and range of vector functions of a real variable **II:** Limits, continuity, and derivatives of vector functions **III:** Arc length and natural parametrization of a curve **IV:** Tangent, normal, and binormal vectors; moving Frenet frame **V:** Curvature, torsion, and Frenet-Serret formulas

Learning Outcomes **I:** Identify limits, continuity, and derivatives of vector functions of a real variable [Familiarity] **II:** Compute tangent, normal, and binormal vectors and reparametrize a curve by arc length [Usage] **III:** Calculate curvature and torsion using the Frenet-Serret formulas [Assessment]

Bibliography: [Stewart, 2016, Thomas et al., 2014]

6. Bibliography

[Larson and Edwards, 2018] Larson, R. and Edwards, B. H. (2018). *Cálculo*. Cengage Learning, 10th edition.

[Stewart, 2016] Stewart, J. (2016). *Cálculo de una variable: Trascendentes tempranas*. Cengage Learning, 8th edition.

[Thomas et al., 2014] Thomas, G. B., Weir, M. D., and Hass, J. (2014). *Cálculo de una variable*. Pearson, 13th edition.

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BFI101 General Physics (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA111 Calculus I (1st Sem-Pg. 249)

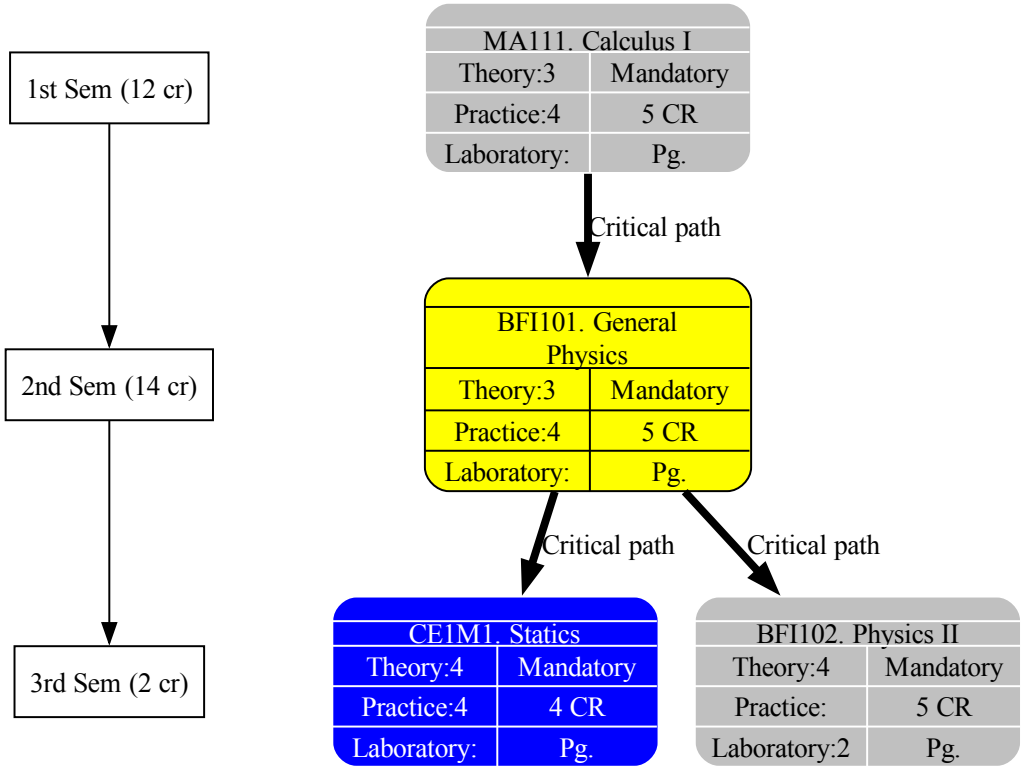

Figure 7.13: Connection Map. BFI101 General Physics

2. Course Rationale

Physics I introduces the foundations of classical mechanics as a mathematical and experimental discipline. Through the study of kinematics, Newtonian dynamics, conservation principles, rotational motion, elasticity, fluid mechanics, vibrations and waves, and an introduction to transport phenomena, students acquire the analytical tools needed to model and solve problems of the physical world. This course provides the indispensable foundation for the study of oscillatory, wave, and electromagnetic phenomena addressed in subsequent courses.

3. Goals of the Course

- Describe the motion of particles in different coordinate systems and formulate the equations of motion from Newton's laws.

- Apply the principles of work, potential energy, and conservation of mechanical energy to systems with conservative and non-conservative forces.
- Solve particle-system dynamics problems using conservation of linear momentum and collision analysis.
- Analyze rotational motion and angular momentum dynamics in systems of particles and extended bodies.
- Apply elastic moduli and Hooke's law to relate stress and strain in solids.
- Apply the principles of hydrostatics and hydrodynamics, including the continuity and Bernoulli equations, to fluid flow problems.
- Analyze simple harmonic motion and mechanical wave propagation, including superposition and resonance phenomena.
- Apply Fourier's and Fick's laws to describe basic heat conduction and mass diffusion processes.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Kinematics and Dynamics of Particles, 22 hr(s)

Competences: ABET-1

Topics: **I:** Vector description of position, velocity, and acceleration in Cartesian, polar, and spherical coordinates **II:** Newton's three laws of motion and inertial reference frames **III:** Formulation and solution of equations of motion for constant and variable forces **IV:** Static and kinetic friction forces, including angle of repose **V:** Numerical integration of equations of motion for engineering dynamics problems

Learning Outcomes **I:** Formulate the equations of motion for a particle in one, two, and three dimensions given a force law [Usage] **II:** Identify all forces acting on a particle and draw a correct free-body diagram [Familiarity] **III:** Calculate the terminal velocity of an object falling through a fluid with drag resistance [Assessment] **IV:** Implement a numerical algorithm to simulate the dynamics of an engineering mechanical system [Usage] **V:** Construct and interpret phase space diagrams for simple engineering oscillatory systems [Assessment]

Bibliography: [Serway and Jewett, 2018, Young and Freedman, 2015]

5.2 Work, Energy, and Conservative Forces, 12 hr(s)

Competences: ABET-1

Topics: **I:** Definition of work as a line integral $W = \int \vec{F} \cdot d\vec{r}$ **II:** Work-energy theorem: $W_{total} = \Delta K$ **III:** Potential energy function and the force relation $\vec{F} = -\nabla U$ **IV:** Conservation of total mechanical energy $E = K + U$ **V:** Energy diagrams, turning points, and equilibrium stability **VI:** Work done by non-conservative forces and energy dissipation in engineering systems

Learning Outcomes **I:** Calculate the work done by a force along a specified engineering path [Usage] **II:** Apply conservation of mechanical energy to solve for speeds and positions in engineering dynamics [Usage] **III:** Analyze an energy diagram to identify equilibrium positions and stability [Assessment] **IV:** Estimate energy dissipated by friction and damping forces in mechanical engineering systems [Assessment]

Bibliography: [Serway and Jewett, 2018, Tipler and Mosca, 2007]

5.3 Systems of Particles and Linear Momentum, 8 hr(s)

Competences: ABET-1

Topics: **I:** Definition and computation of center of mass for particle systems and distributed bodies **II:** Linear momentum of a particle and system: $\vec{P} = M\vec{V}_{CM}$ **III:** Conservation of linear momentum for isolated engineering systems **IV:** Two-body collisions: elastic, inelastic, and the coefficient of restitution **V:** Variable mass systems such as rockets and conveyor belts

Learning Outcomes **I:** Locate the center of mass for discrete particle systems and distributed engineering objects [Usage] **II:** Apply conservation of linear momentum to analyze impact and collision problems [Usage] **III:** Classify collisions as elastic or inelastic and determine energy loss [Familiarity] **IV:** Solve variable-mass system equations to determine velocity gain in propulsion problems [Usage]

Bibliography: [Young and Freedman, 2015, Tipler and Mosca, 2007]

5.4 Rotational Motion and Angular Momentum, 12 hr(s)

Competences: ABET-1

Topics: **I:** Rotational kinematics: angular displacement, velocity, and acceleration **II:** Torque: $\vec{\tau} = \vec{r} \times \vec{F}$ and its computation **III:** Moment of inertia $I = \sum m_i r_i^2$ and the parallel axis theorem **IV:** Rotational kinetic energy: $K_{rot} = \frac{1}{2} I\omega^2$ **V:** Conservation of angular momentum in engineering machines and rotating structures **VI:** Rolling without slipping dynamics and applications to wheels and shafts

Learning Outcomes **I:** Calculate torque about a given axis for an engineering power transmission system [Usage] **II:** Determine the moment of inertia for machine components such as rods, disks, and shafts [Usage] **III:** Apply conservation of angular momentum to analyze speed changes in rotating engineering systems [Assessment] **IV:** Analyze combined translational and rotational motion in wheeled engineering systems [Assessment]

Bibliography: [Serway and Jewett, 2018, Kleppner and Kolenkow, 2013]

5.5 Elasticity, 2 hr(s)

Competences: ABET-1

Topics: **I:** Definition of stress (force/area) and strain ($\Delta L/L$) **II:** Young's modulus and Hooke's law for longitudinal strain: $\sigma = E\epsilon$ **III:** Shear modulus (rigidity) and shear strain **IV:** Bulk modulus (compressibility) and volumetric strain **V:** Elastic limit, plastic region, and fracture point on the stress-strain diagram **VI:** Elastic energy stored in a deformed material

Learning Outcomes **I:** Apply the scalar Hooke's law to calculate the deformation of a rod under axial load [Usage] **II:** Calculate Young's, shear, or bulk modulus from experimental stress-strain data [Usage] **III:** Identify the elastic region, elastic limit, and fracture point on a stress-strain curve [Familiarity] **IV:** Calculate the elastic potential energy stored in a deformed spring or rod [Usage]

Bibliography: [Serway and Jewett, 2018, Young and Freedman, 2015]

5.6 Fluids: Hydrostatics, Hydrodynamics, and Viscosity, 10 hr(s)

Competences: ABET-1

Topics: **I:** Density, pressure, and its variation with depth in a fluid at rest: $p = p_0 + \rho gh$ **II:** Pascal's principle and its applications (hydraulic press) **III:** Archimedes' principle, buoyant force, and flotation **IV:** Pressure measurement with manometers and barometers **V:** Continuity equation for incompressible flow: $A_1 v_1 = A_2 v_2$ **VI:** Bernoulli's equation and energy conservation in ideal

flow **VII:** Applications: Venturi tube, Torricelli's theorem, Pitot tube **VIII:** Viscosity and Poiseuille's law for laminar flow in pipes **IX:** Reynolds number and the transition to turbulent flow **X:** Stokes' law for the drag force on a sphere in a viscous fluid

Learning Outcomes I: Calculate the pressure at a point in a fluid at rest given depth and density [Usage] **II:** Apply Archimedes' principle to determine whether an object floats, sinks, or remains in equilibrium [Usage] **III:** Apply the continuity and Bernoulli equations to solve flow problems in pipes of varying cross-section [Usage] **IV:** Interpret manometer and barometer readings to determine absolute and gauge pressures [Assessment] **V:** Apply Poiseuille's law to calculate the flow rate of a viscous fluid in a cylindrical tube [Usage] **VI:** Estimate the Reynolds number of a flow and predict whether it is laminar or turbulent [Assessment]

Bibliography: [Serway and Jewett, 2018, Young and Freedman, 2015]

5.7 Vibrations and Waves, 14 hr(s)

Competences: ABET-1

Topics: I: Simple harmonic motion (SHM): equation of motion, position, velocity, and acceleration **II:** Oscillating systems: spring-mass and simple/physical pendulum **III:** Energy in simple harmonic motion **IV:** Damped and forced oscillations; introduction to resonance **V:** Transverse and longitudinal waves; propagation speed **VI:** Wave equation and speed of a wave on a taut string: $v = \sqrt{T/\mu}$ **VII:** Superposition principle and standing waves **VIII:** Sound waves, intensity, and sound intensity level (decibels) **IX:** Doppler effect for sound waves **X:** Beats and interference of waves of nearby frequencies

Learning Outcomes I: Derive the equation of motion and the period of a spring-mass system and a simple pendulum [Usage] **II:** Calculate the kinetic, potential, and total energy of a simple harmonic oscillator at any instant [Usage] **III:** Analyze the amplitude response of a forced oscillator near the resonance frequency [Assessment] **IV:** Calculate the propagation speed of a wave on a string from the tension and linear density [Usage] **V:** Determine the frequencies and wavelengths of the normal modes of a standing wave on a fixed string [Usage] **VI:** Calculate the sound intensity level in decibels from the intensity of a sound wave [Usage] **VII:** Apply the Doppler effect formula for a moving source and/or observer [Usage]

Bibliography: [Serway and Jewett, 2018, Young and Freedman, 2015]

5.8 Transport Phenomena, 4 hr(s)

Competences: ABET-1

Topics: I: Heat conduction and Fourier's law: $\vec{q} = -k\nabla T$ **II:** Thermal conductivity of materials and thermal resistance in composite walls **III:** Molecular diffusion and Fick's first law: $\vec{J} = -D\nabla C$ **IV:** Analogy between heat, mass, and momentum transport (Prandtl and Schmidt numbers)

Learning Outcomes I: Apply Fourier's law to calculate the heat flux through a plane or composite wall [Usage] **II:** Apply Fick's first law to calculate the diffusive flux of a species in a concentration gradient [Usage] **III:** Identify mathematical analogies between heat, mass, and momentum transport processes [Familiarity]

Bibliography: [Serway and Jewett, 2018, Tipler and Mosca, 2007]

6. Bibliography

[Kleppner and Kolenkow, 2013] Kleppner, D. and Kolenkow, R. J. (2013). *An Introduction to Mechanics*. Cambridge University Press, 2nd edition.

[Serway and Jewett, 2018] Serway, R. A. and Jewett, J. W. (2018). *Physics for Scientists and Engineers with Modern Physics*. Cengage Learning, 10th edition.

[Tipler and Mosca, 2007] Tipler, P. A. and Mosca, G. (2007). *Physics for Scientists and Engineers*. W. H. Freeman and Company, 6th edition.

[Young and Freedman, 2015] Young, H. D. and Freedman, R. A. (2015). *Sears and Zemansky's University Physics with Modern Physics*. Pearson Education, 14th edition.

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ID101 Technical and professional English I (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

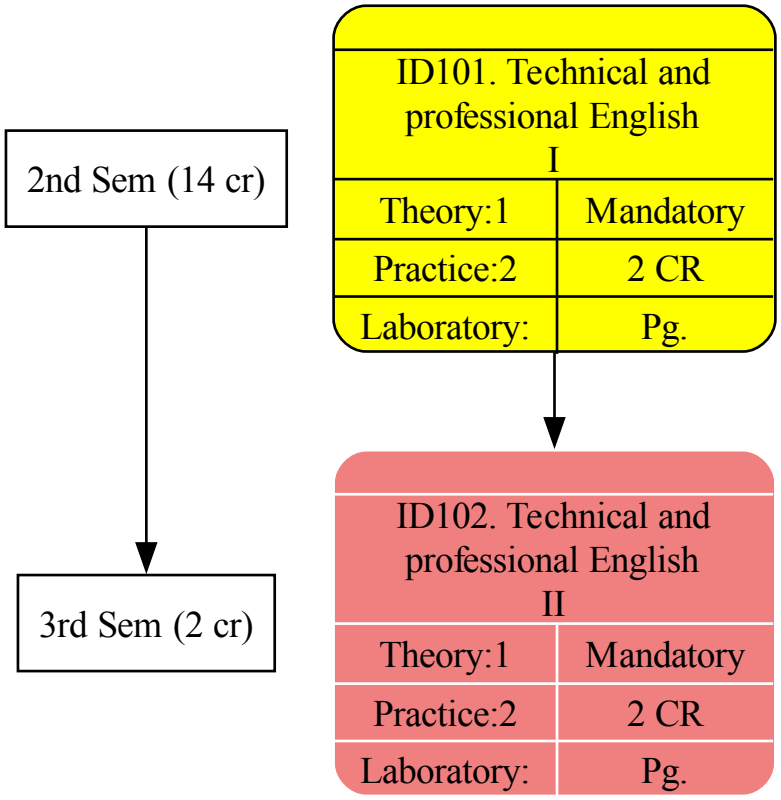

Figure 7.14: Connection Map. ID101 Technical and professional English I

2. Course Rationale

English is the primary language of science, engineering, and technology worldwide. For computing and engineering students, mastering English means gaining direct access to technical documentation, research papers, and professional collaboration without translation barriers. This course builds foundational English skills using contexts drawn from computing systems, hardware, and the everyday work of engineers and scientists.

3. Goals of the Course

- Acquire foundational English grammar structures applied to computing and engineering contexts.
- Identify and use technical vocabulary related to hardware, software, and scientific concepts.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Familiarity)

5. Content

5.1 Welcome to Computing, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Verb To Be: Affirmative, Negative, and Questions. **II:** Personal Pronouns and Possessive Adjectives. **III:** Number Expressions (1-100): Ports, addresses, and binary basics. **IV:** Social Expressions in academic and lab environments.

Learning Outcomes I: By the end of the unit, students use the verb 'to be' to introduce themselves as computing students and describe basic properties of computing systems (e.g., "The processor is fast. It is a 64-bit CPU.").

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.2 Parts and Systems, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Possessive 's and Plural Nouns applied to components (the CPU's speed, the system's memory). **II:** Hardware components and their relationships. **III:** Adjective + Noun structures for technical descriptions. **IV:** Lab interactions: Asking about equipment and tools.

Learning Outcomes I: Students describe computer hardware components and their relationships using possessives and noun phrases (e.g., "the motherboard's slots", "the server's processors").

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.3 How It Works, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Present Simple I (Third person: He/She/It) to describe processes. **II:** Vocabulary: How programs, algorithms, and devices operate. **III:** Telling the time and interpreting system clocks and schedules. **IV:** Verbs of operation: runs, compiles, executes, stores, transmits.

Learning Outcomes I: Students explain how a program or device works using the present simple in the third person (e.g., "The compiler translates source code. It generates an executable file.").

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.4 What Engineers Do, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Present Simple II (I/You/We/They) for describing professional routines. **II:** Questions and negatives with 'Do/Does' in technical contexts. **III:** Engineering roles: developer, analyst, researcher, systems engineer. **IV:** Adverbs of frequency in describing work cycles and testing schedules.

Learning Outcomes I: Students describe the daily tasks and professional roles of computing engineers and scientists using the present simple with accuracy.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.5 Inside a Computer, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Existential: There is / There are applied to architecture descriptions. **II:** Prepositions of place: components on a motherboard, files in a directory. **III:** Vocabulary: memory, storage, buses, slots, ports, layers. **IV:** Describing network topology and physical infrastructure.

Learning Outcomes I: Students describe the spatial organization of hardware components and file systems, enabling them to interpret and produce technical architecture descriptions.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.6 Can Computers Think?, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Modal verb Can/Can't to describe computing capabilities and limitations. **II:** Adverbs of manner applied to system performance. **III:** Past of verb 'To Be' (Was/Were): early computing systems and pioneers. **IV:** Basic expressions for technical support and troubleshooting.

Learning Outcomes I: Students describe what computing systems can and cannot do, and identify basic facts about the early history of computing using simple past structures.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.7 Computing History, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Past Simple: Regular and Irregular verbs to narrate tech history. **II:** Time expressions for the past: invented, developed, published, launched. **III:** Key figures: Turing, Babbage, Lovelace, von Neumann. **IV:** Vocabulary: Generations of computers, milestones, inventions.

Learning Outcomes I: Students narrate key events in the history of computing and science using the simple past correctly, identifying the contributions of foundational figures.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.8 My Professional Goals in Computing, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Introduction to Technical English for Computing and Engineering. **II:** Reading and understanding simple technical specifications. **III:** Working in multicultural engineering teams: communication norms. **IV:** Oral presentation: "My role in the computing field".

Learning Outcomes I: Students present their professional goals in computing using basic technical vocabulary and connect them to the roles and responsibilities of software and hardware engineers.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

6. Bibliography

[Cambridge, 2006] Cambridge (2006). *Diccionario Inglés-Espanol Cambridge*. Editorial Oxford.

[MacGrew, 1999] MacGrew, J. (1999). *Focus on Grammar Basic*. Editorial Oxford.

[Soars and John, 2002d] Soars, L. and John (2002d). *American Headway N 2 Student Book*. Editorial Oxford.

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BEF201 Ethics and Political Philosophy (Mandatory)

1. General information

- **Semester**: 2nd Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**: None

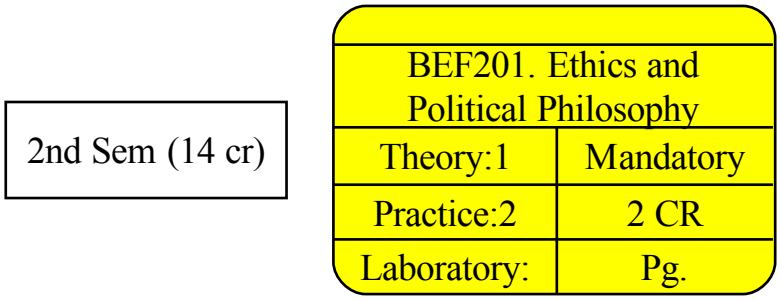

Figure 7.15: Connection Map. BEF201 Ethics and Political Philosophy

2. Course Rationale

This course introduces students to the fundamentals of ethics and political philosophy as a humanistic foundation for professional practice, and extends them to engineering ethics and professional responsibility. Through the study of normative ethical theories, the major traditions of political thought, and contemporary debates in political philosophy, students develop the critical tools to analyze moral and political problems. The course closes with the application of these tools to the ethical dilemmas engineers face in professional practice.

3. Goals of the Course

- Distinguish ethics, morality, and law, and compare the main normative ethical theories.
- Explain the foundations of the social contract tradition and the major modern ethico-political proposals.
- Analyze contemporary political philosophy debates from multiple theoretical perspectives.
- Apply ethical decision-making frameworks and professional codes of conduct to engineering practice.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Familiarity)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Usage)

5. Content

5.1 Basic Notions of Ethics and Political Philosophy, 15 hr(s)

Competences: ABET-2

Topics: **I:** What is ethics? Distinguishing ethics, morality, and law as normative systems **II:** Main normative ethical theories: consequentialism, deontology, and virtue ethics **III:** What is political philosophy? Fundamental questions about power, legitimacy, and the state **IV:** The social contract tradition: Hobbes, Locke, and Rousseau **V:** Conceptions of justice: distributive, procedural, and retributive

Learning Outcomes **I:** Distinguish ethics, morality, and law as normative systems [Familiarity] **II:** Compare the main normative ethical theories and their criteria for moral evaluation [Usage] **III:** Explain the foundations of the social contract tradition and its main proponents [Familiarity] **IV:** Identify different conceptions of justice and apply them to concrete cases [Assessment]

Bibliography: [Rachels and Rachels, 2015, Kymlicka, 2002]

5.2 Major Ethico-Political Proposals, 6 hr(s)

Competences: ABET-2

Topics: **I:** Political and economic liberalism: individual liberty and the limits of the state **II:** Socialism and Marxist thought: the critique of private property and exploitation **III:** Civic republicanism and liberty understood as non-domination **IV:** Communitarianism and its critique of liberal individualism

Learning Outcomes **I:** Compare liberal, socialist, republican, and communitarian proposals in response to a concrete social problem [Usage] **II:** Identify the philosophical foundations of a given ethico-political position [Assessment]

Bibliography: [Kymlicka, 2002]

5.3 Engineering Ethics and Professional Responsibility, 12 hr(s)

Competences: ABET-4

Topics: **I:** Ethical theories applied to engineering: utilitarianism, deontological ethics, virtue ethics **II:** Professional codes of conduct (e.g. NSPE, IEEE, ASME, and national engineering boards) and their fundamental canons **III:** The engineer's paramount responsibility to public safety, health, and welfare **IV:** Ethical dilemmas in practice: conflicts of interest, whistleblowing, gifts **V:** Ethical decision-making frameworks and case-study analysis **VI:** Global engineering ethics and cross-cultural challenges **VII:** Ethical obligations toward sustainable development and environmental stewardship **VIII:** Ethical implications of emerging technologies (AI, automation, data privacy) **IX:** Ethical conduct in dispute resolution and litigation

Learning Outcomes **I:** Explain the fundamental principles of an engineer's code of ethics [Familiarity] **II:** Apply an ethical decision-making framework to a hypothetical engineering scenario [Assessment] **III:** Identify conflicts of interest and other common ethical pitfalls in project work [Familiarity] **IV:** Analyze a historical engineering failure from an ethical perspective [Assessment] **V:** Evaluate the ethical dimensions of a project with significant social or environmental impacts in a different cultural context [Assessment] **VI:** Articulate the ethical argument for incorporating sustainability into all engineering work [Familiarity] **VII:** Discuss the ethical responsibilities related to the collection and use of data in smart infrastructure projects [Assessment] **VIII:** Describe the role of ethics in alternative dispute resolution processes [Familiarity]

Bibliography: [Harris et al., 2013, Fleddermann, 2020]

5.4 Currents in Contemporary Political Philosophy, 9 hr(s)

Competences: ABET-2

Topics: **I:** Rawls's theory of justice: the original position and the veil of ignorance **II:** Contemporary libertarianism: Nozick and property rights **III:** Feminist political philosophy and theories of care **IV:** Multiculturalism, recognition, and identity politics **V:** Deliberative democracy and the public sphere

Learning Outcomes **I:** Explain the concepts of the original position and the veil of ignorance in Rawls's theory [Usage] **II:** Contrast libertarian and Rawlsian proposals on distributive justice [Assessment] **III:** Analyze a contemporary political debate from at least two of the political philosophy currents studied [Assessment] **IV:** Describe the foundations of deliberative democracy and its role in the public sphere [Familiarity]

Bibliography: [Rawls, 1999, Kymlicka, 2002]

6. Bibliography

[Fleddermann, 2020] Fleddermann, C. B. (2020). *Engineering Ethics*. Pearson, 5th edition.

[Harris et al., 2013] Harris, C. E., Pritchard, M. S., and Rabins, M. J. (2013). *Engineering Ethics: Concepts and Cases*. Cengage Learning, 5th edition.

[Kymlicka, 2002] Kymlicka, W. (2002). *Contemporary Political Philosophy: An Introduction*. Oxford University Press, 2nd edition.

[Rachels and Rachels, 2015] Rachels, J. and Rachels, S. (2015). *The Elements of Moral Philosophy*. McGraw-Hill Education, 8th edition.

[Rawls, 1999] Rawls, J. (1999). *A Theory of Justice*. Belknap Press, revised edition.

Third Semester

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CE1M1 Statics (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - BFI101 General Physics (2nd Sem-Pg. 295)

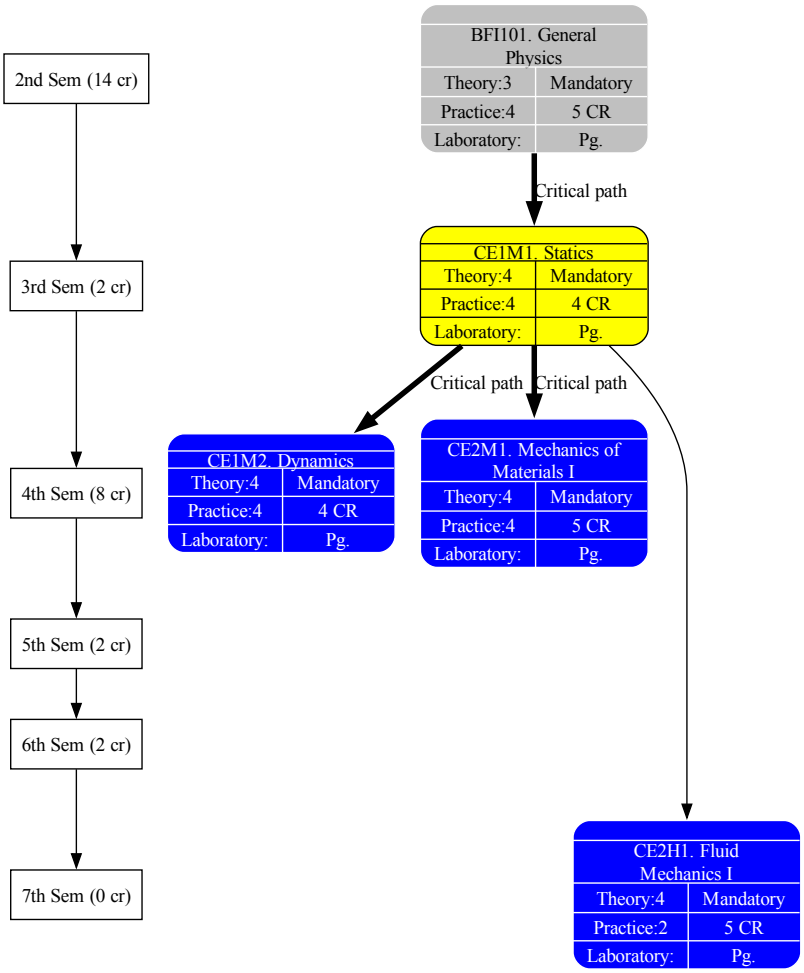

Figure 7.16: Connection Map. CE1M1 Statics

2. Course Rationale

Statics is the first pillar of applied mechanics in Civil Engineering. It provides the tools needed to analyze the equilibrium of particles and rigid bodies subjected to force systems. Understanding the concepts of force, moment, and equilibrium is essential for the analysis and design of structures, enabling the determination of support reactions and internal forces in structural members.

3. Goals of the Course

- Understand and apply Newton's laws and vector algebra to solve equilibrium problems in two and three dimensions.
- Determine internal forces in trusses, frames, and machines accurately.
- Analyze the effect of friction and determine centers of gravity and moments of inertia of complex shapes.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Equilibrium of Particles and Rigid Bodies, 8 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Equilibrium equations and free-body diagrams for particles and rigid bodies in two and three dimensions **II:** Flexible cables under concentrated and distributed loads

Learning Outcomes **I:** Apply equilibrium equations to determine support reactions in two- and three-dimensional rigid-body systems [Usage] **II:** Determine cable tension and shape under concentrated and distributed loads [Usage]

Bibliography: [Hibbeler, 2016, Meriam and Kraige, 2014]

5.2 Internal Forces in Trusses and Frames, 12 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Truss analysis using the method of joints and the method of sections **II:** Free-body diagrams and internal-force analysis of multi-member frames and machines **III:** Internal forces in beams: shear-force and bending-moment diagrams

Learning Outcomes **I:** Analyze planar trusses using both the method of joints and the method of sections [Assessment] **II:** Draw free-body diagrams for multi-member frames and machines and determine internal member forces [Usage] **III:** Construct shear-force and bending-moment diagrams for beams under concentrated and distributed loads [Assessment]

Bibliography: [Hibbeler, 2016, Meriam and Kraige, 2014]

5.3 Geometric Properties of Areas and Friction, 12 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Centroids and centers of gravity of composite areas and lines **II:** Moments of inertia of areas and the parallel-axis theorem **III:** Dry friction: laws of friction, wedges, and screws **IV:** Virtual work and stability of equilibrium

Learning Outcomes **I:** Determine the geometric properties of complex cross-sections used in structural shapes [Usage] **II:** Analyze equilibrium problems involving static friction forces [Assessment] **III:** Apply friction principles to the analysis of wedges and screw mechanisms [Usage] **IV:** Evaluate the stability of equilibrium using virtual work principles [Familiarity]

Bibliography: [Meriam and Kraige, 2014]

6. Bibliography

[Hibbeler, 2016] Hibbeler, R. (2016). *Engineering Mechanics: Statics*. Pearson, 14th edition.

[Meriam and Kraige, 2014] Meriam, J. and Kraige, L. (2014). *Engineering Mechanics: Statics*. Wiley, 8th edition.

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CB1E2 Engineering Drawing II (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CB1E1 Technical Drawing & CAD (2nd Sem-Pg. 288)

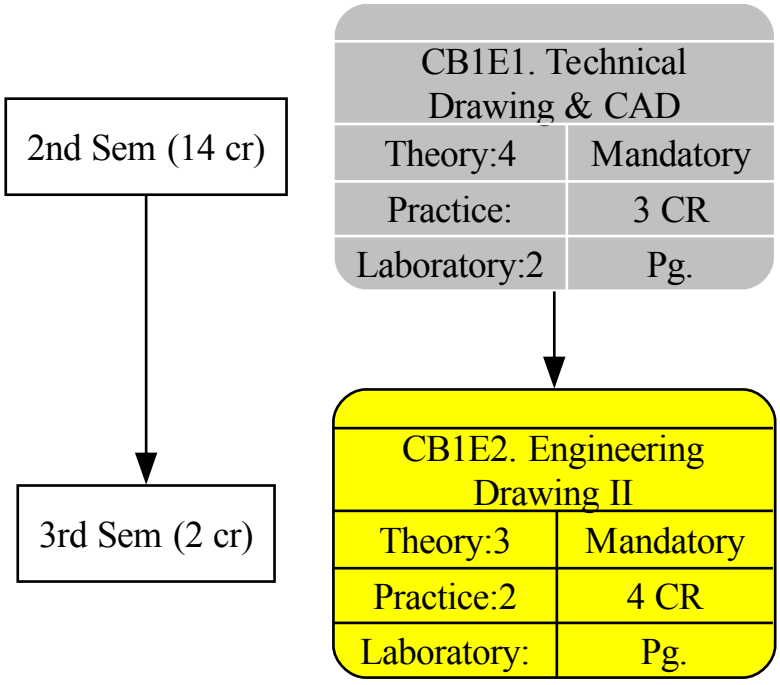

Figure 7.17: Connection Map. CB1E2 Engineering Drawing II

2. Course Rationale

Engineering Drawing II is the direct continuation of Technical Drawing and CAD, deepening students' command of descriptive geometry to solve advanced positional and metric problems involving lines, planes, polyhedra, and surfaces of revolution. The course closes with an introduction to Building Information Modeling (BIM), the digital methodology that has become standard practice for the delivery and lifecycle management of civil engineering projects, connecting the graphical foundations built in the prerequisite course to modern digital project delivery workflows.

3. Goals of the Course

- Solve positional problems (parallelism, perpendicularity, and intersections) between lines, planes, and polyhedra using descriptive geometry methods.
- Solve metric problems, including the determination of true distances between geometric elements.
- Represent surfaces of revolution and determine tangent planes to curved surfaces.

- Apply Building Information Modeling (BIM) concepts and tools to produce and manage digital representations of civil engineering projects for digital delivery and asset management.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Positional and Metric Problems in Descriptive Geometry, 28 hr(s)

Competences: ABET-1

Topics: **I:** Auxiliary-view and change-of-plane methods for solving positional and metric problems **II:** Parallelism and perpendicularity between lines and planes **III:** Intersections of planes, lines, and polyhedral solids **IV:** Metric problems: true distances between points, lines, and planes

Learning Outcomes **I:** Apply auxiliary-view and change-of-plane methods to solve positional problems in orthographic projection [Usage] **II:** Determine parallelism and perpendicularity relationships between lines and planes, and represent intersections of polyhedral solids [Usage] **III:** Calculate true distances between geometric elements using descriptive geometry methods [Assessment]

Bibliography: [Luzadder and Duff, 1993, Pare et al., 1997]

5.2 Surfaces of Revolution and Tangent Planes, 26 hr(s)

Competences: ABET-1

Topics: **I:** Generation and orthographic representation of surfaces of revolution: cylinders, cones, spheres, and tori **II:** Angle problems between lines, planes, and surfaces **III:** The rotation (change of projection) method as an auxiliary technique **IV:** Construction of tangent planes to surfaces of revolution at a point or through an external line

Learning Outcomes **I:** Represent surfaces of revolution and their principal orthographic views [Usage] **II:** Apply the rotation method to determine true angles between lines, planes, and surfaces [Usage] **III:** Determine tangent planes to a surface of revolution at a given point or through an external line [Assessment]

Bibliography: [Pare et al., 1997]

5.3 Building Information Modeling (BIM) for Digital Delivery and Asset Management, 16 hr(s)

Competences: ABET-2

Topics: **I:** BIM concepts: dimensions (3D, 4D, 5D, 6D, 7D), LOD, and LOIN **II:** BIM authoring tools and parametric modeling techniques **III:** Model coordination, clash detection, and interference checking **IV:** Collaboration platforms, Common Data Environments (CDE), and BIM execution plans **V:** BIM-based analysis: quantity takeoff, energy simulation, and structural analysis **VI:** Digital twins and the connection between BIM and operational data **VII:** Interoperability standards: IFC, COBie, and openBIM **VIII:** Asset information models (AIM) and BIM for facilities management (FM) **IX:** Regulatory submission and automated code compliance checking

Learning Outcomes I: Define the different dimensions of BIM (3D-7D) and their associated information [Familiarity] **II:** Create a basic 3D parametric model of a structural framing system using BIM software [Usage] **III:** Perform a clash detection analysis between architectural and structural models [Assessment] **IV:** Outline the key components of a BIM Execution Plan (BEP) [Familiarity] **V:** Extract a material quantity takeoff schedule from a BIM model [Usage] **VI:** Explain the relationship between a BIM model and a digital twin for an asset [Familiarity] **VII:** Export a BIM model using the IFC format to ensure interoperability [Usage] **VIII:** Develop an Asset Information Model (AIM) deliverable for handover to a facility manager [Assessment] **IX:** Evaluate the potential of automated rule-checking for building code compliance [Assessment]

Bibliography: [Eastman et al., 2018]

6. Bibliography

[Eastman et al., 2018] Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*. Wiley, 3rd edition.

[Luzadder and Duff, 1993] Luzadder, W. and Duff, J. (1993). *Fundamentals of Engineering Drawing*. Prentice Hall, 11th edition.

[Pare et al., 1997] Pare, E. G., Loving, R. O., Hill, I. L., and Pare, R. C. (1997). *Descriptive Geometry*. Prentice Hall, 9th edition.

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MA121 Linear Algebra I (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA100 Basic Mathematics (1st Sem-Pg. 245)

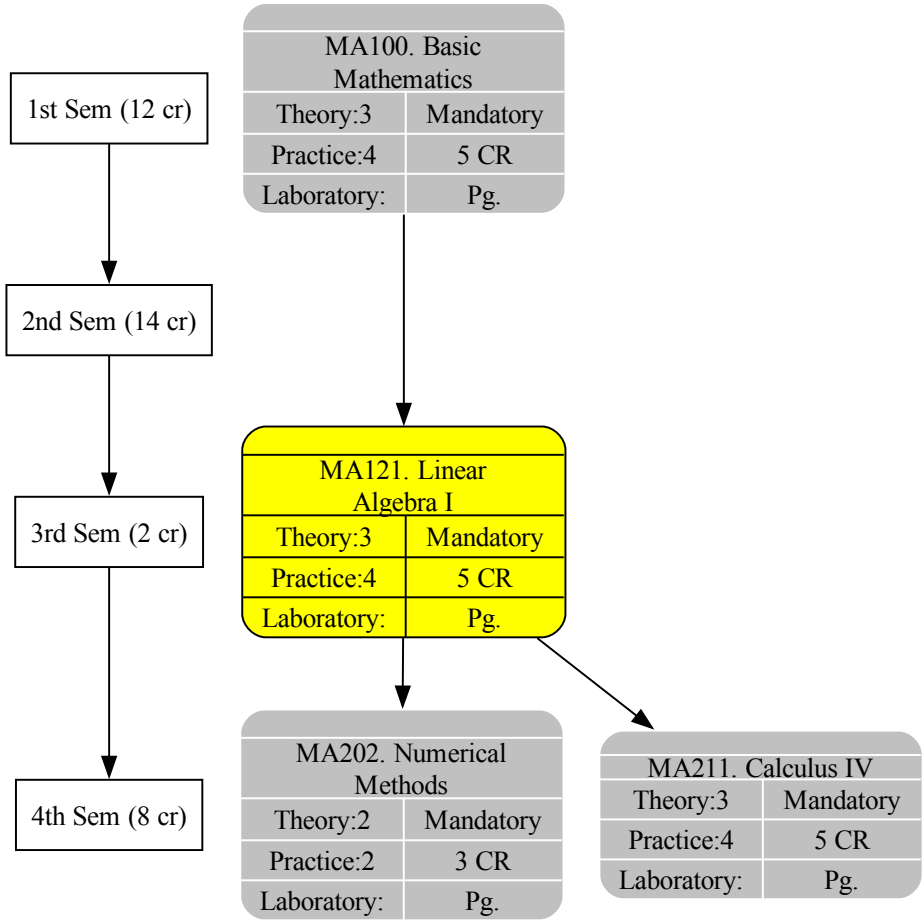

Figure 7.18: Connection Map. MA121 Linear Algebra I

2. Course Rationale

This course introduces the fundamental concepts of linear algebra, providing the mathematical foundations for the study of vector spaces, linear transformations, and systems of linear equations. It develops abstract thinking and problem-solving skills through matrices, determinants, and vectors. The course is fundamental for applications in science, engineering, and computing.

3. Goals of the Course

- Understand the concepts of vector spaces and subspaces.

- Master matrix operations and determinants.
- Solve systems of linear equations using different methods.
- Apply linear transformations and compute eigenvalues and eigenvectors.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Matrices and Systems of Linear Equations, 28 hr(s)

Competences: ABET-1

Topics: I: LU, QR, and Cholesky factorizations for solving engineering linear systems **II:** Singular Value Decomposition (SVD) and least squares solutions

Learning Outcomes I: Solve systems of linear equations arising in structural, circuit, and fluid engineering problems [Usage] **II:** Apply the SVD to solve over-determined systems in data fitting and signal processing [Usage]

Bibliography: [Lay et al., 2016, Strang, 2016, Anton and Rorres, 2014]

5.2 Vector Spaces and Linear Transformations, 22 hr(s)

Competences: ABET-1

Topics: I: Vector spaces, subspaces, bases, and dimension **II:** Linear transformations and their matrix representations in coordinate changes

Learning Outcomes I: Formulate and interpret coordinate system transformations for engineering geometry problems [Assessment]

Bibliography: [Lay et al., 2016, Strang, 2016, Anton and Rorres, 2014]

5.3 Eigenvalues and Inner Product Spaces, 20 hr(s)

Competences: ABET-1

Topics: I: Eigenvalues, eigenvectors, and diagonalization with applications to vibration and stability **II:** Inner product spaces, orthogonality, and the Gram-Schmidt process

Learning Outcomes I: Perform eigenvalue decomposition on symmetric matrices for modal analysis of mechanical structures [Assessment]

Bibliography: [Lay et al., 2016, Strang, 2016, Anton and Rorres, 2014]

6. Bibliography

[Anton and Rorres, 2014] Anton, H. and Rorres, C. (2014). *Álgebra Lineal con Aplicaciones*. Limusa Wiley, 11th edition.

[Lay et al., 2016] Lay, D. C., Lay, S. R., and McDonald, J. J. (2016). *Álgebra Lineal y sus Aplicaciones*. Pearson, 5th edition.

[Strang, 2016] Strang, G. (2016). *Introduction to Linear Algebra*. Wellesley-Cambridge Press, 5th edition.

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MA210 Calculus III (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - MA112 Calculus II (2nd Sem-Pg. 291)

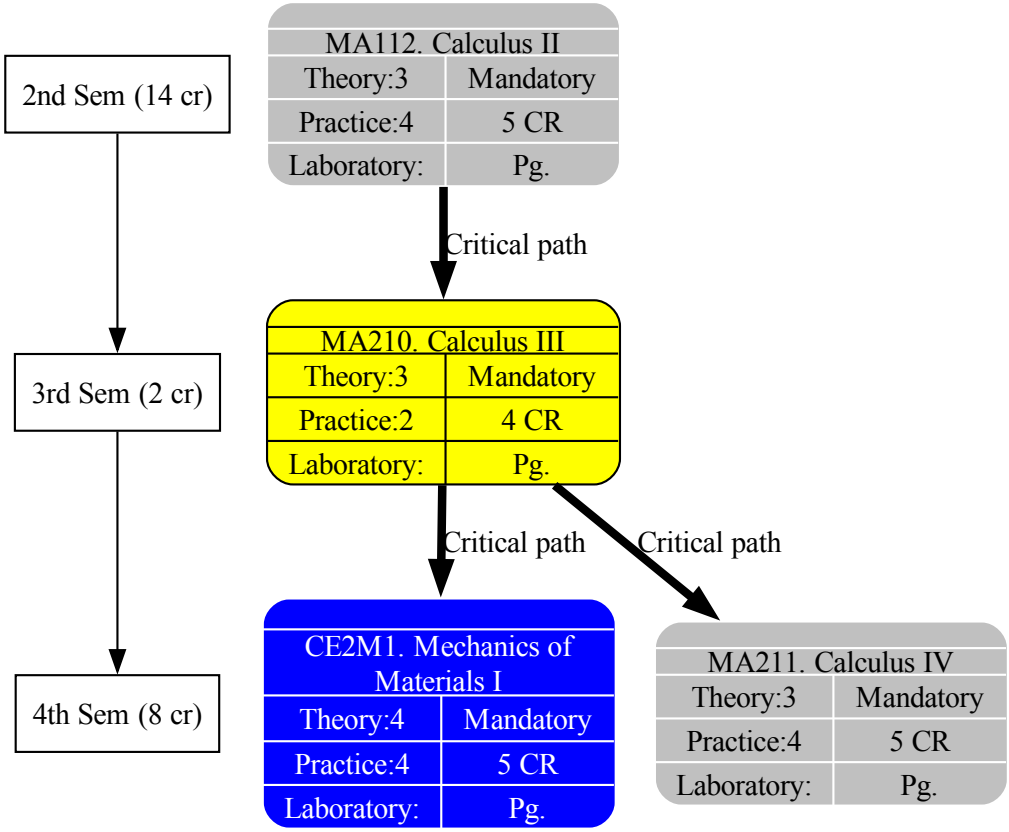

Figure 7.19: Connection Map. MA210 Calculus III

2. Course Rationale

This course continues the study of calculus with functions of several variables, integrating concepts of vector calculus, partial derivatives, multiple integrals, and geometric and physical applications, including line and surface integrals. It develops skills for modeling and solving problems in three dimensions and introduces first-order ordinary differential equations, providing the foundations for advanced areas such as mathematical analysis, physics, and engineering.

3. Goals of the Course

- Understand functions of several variables and their partial derivatives.

- Apply differential and integral calculus in three dimensions.
- Solve optimization problems with multiple variables.
- Master multiple, line, and surface integrals and their applications.
- Solve first-order ordinary differential equations and model simple physical systems with them.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Multivariable and Vector Calculus, 22 hr(s)

Competences: ABET-1

Topics: **I:** Partial derivatives and the gradient vector **II:** Multiple integrals in Cartesian, cylindrical, and spherical coordinate systems **III:** Vector fields and line and surface integrals **IV:** Integral theorems: Green, Stokes, and the Divergence Theorem **V:** Applications to flux, circulation, and conservative fields in engineering contexts

Learning Outcomes **I:** Compute gradients and directional derivatives for scalar fields describing physical quantities [Usage] **II:** Evaluate double and triple integrals for volumes, masses, and centroids of engineering objects [Usage] **III:** Apply Stokes' and Gauss's Divergence Theorems to relate field integrals in electromagnetism and fluid mechanics [Assessment] **IV:** Determine whether a vector force field is conservative and compute the potential function [Assessment]

Bibliography: [Stewart, 2016, Thomas et al., 2014]

5.2 Multiple Integrals, 12 hr(s)

Competences: ABET-1

Topics: **I:** Double integrals over rectangles and general regions; iterated integrals (Fubini's theorem) **II:** Double integrals in polar coordinates and change-of-variables formula **III:** Triple integrals in Cartesian coordinates and applications to volume and mass **IV:** Triple integrals in cylindrical and spherical coordinates **V:** Applications: area, volume, centers of mass, and moments of inertia

Learning Outcomes **I:** Evaluate double and triple integrals over general regions using iterated integrals [Usage] **II:** Apply coordinate changes in polar, cylindrical, and spherical systems to simplify multiple integrals [Usage] **III:** Compute areas, volumes, and centers of mass using multiple integrals [Assessment]

Bibliography: [Stewart, 2016, Larson and Edwards, 2018]

5.3 Line Integrals and Vector Fields, 18 hr(s)

Competences: ABET-1

Topics: **I:** Vector fields: definition, visualization, divergence, and curl **II:** Line integrals of scalar functions: arc length and mass **III:** Line integrals of vector fields: work and circulation **IV:** Conservative fields, potential functions, and path independence **V:** Green's Theorem and its applications in the plane

Learning Outcomes **I:** Compute scalar and vector line integrals over oriented curves [Usage] **II:** Determine whether a vector field is conservative and construct its potential function [Usage] **III:** Apply Green's Theorem to evaluate line integrals via double integrals [Assessment]

Bibliography: [Marsden and Tromba, 2003, Stewart, 2016]

5.4 Surface Integrals and Fundamental Theorems, 16 hr(s)

Competences: ABET-1

Topics: **I:** Parametric surfaces, tangent plane, and surface area **II:** Surface integrals of scalar functions **III:** Flux integrals: surface integrals of vector fields **IV:** Stokes' Theorem: relation between line integrals and surface integrals **V:** Divergence Theorem (Gauss): relation between flux and volume integral

Learning Outcomes **I:** Parametrize surfaces and evaluate scalar and flux surface integrals [Usage] **II:** Apply Stokes' and Divergence Theorems to reduce complex integrals [Assessment] **III:** Relate local differential properties (curl, divergence) to global behavior via integral theorems [Assessment]

Bibliography: [Marsden and Tromba, 2003, Apostol, 1969]

5.5 First-Order Ordinary Differential Equations (ODEs), 16 hr(s)

Competences: ABET-1

Topics: **I:** First-order equations: separable, linear, and exact forms

Learning Outcomes **I:** Solve linear first-order ODEs using integrating factors [Usage]

Bibliography: [Boyce et al., 2017, Stewart, 2016]

6. Bibliography

[Apostol, 1969] Apostol, T. M. (1969). *Calculus, Volume II: Multi-Variable Calculus and Linear Algebra*. Wiley, 2nd edition.

[Boyce et al., 2017] Boyce, W. E., DiPrima, R. C., and Meade, D. B. (2017). *Ecuaciones Diferenciales y Problemas con Valores en la Frontera*. Limusa Wiley, 11th edition.

[Larson and Edwards, 2018] Larson, R. and Edwards, B. H. (2018). *Cálculo Volumen 2*. Cengage Learning, 10th edition.

[Marsden and Tromba, 2003] Marsden, J. E. and Tromba, A. J. (2003). *Cálculo Vectorial*. Pearson, 5th edition.

[Stewart, 2016] Stewart, J. (2016). *Cálculo de varias variables: Trascendentes tempranas*. Cengage Learning, 8th edition.

[Thomas et al., 2014] Thomas, G. B., Weir, M. D., and Hass, J. (2014). *Cálculo de varias variables*. Pearson, 13th edition.

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BFI102 Physics II (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - BFI101 General Physics (2nd Sem-Pg. 295)

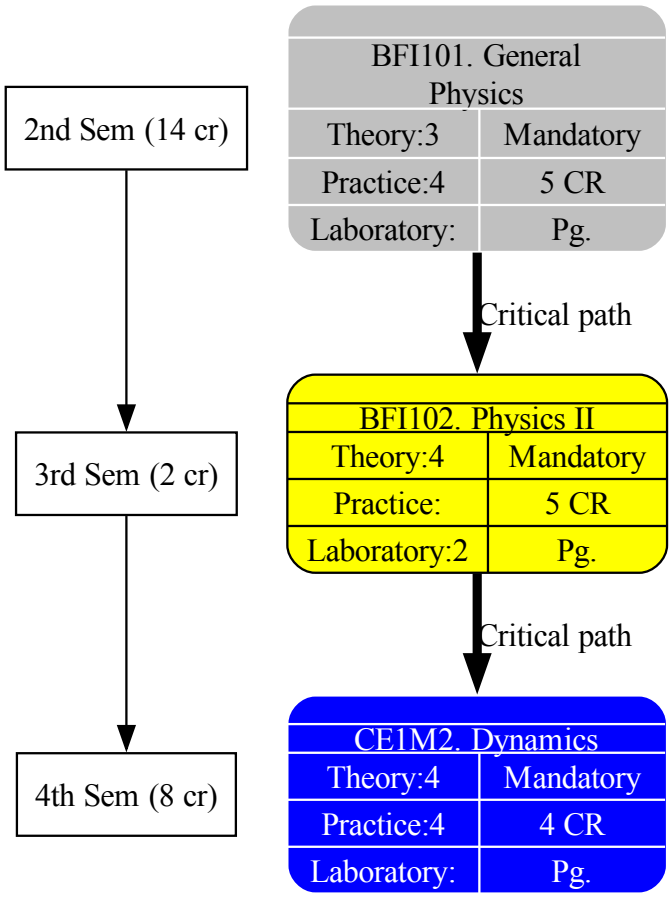

Figure 7.20: Connection Map. BFI102 Physics II

2. Course Rationale

Physics II consolidates the foundations of advanced classical mechanics and electromagnetism. The theory of small oscillations and coupled oscillators provides the analytical framework for the study of vibrational systems in engineering and the sciences. Continuum mechanics supplies the essential tools for the analysis of elastic solids and fluids. The study of electromagnetism, from electrostatics to electromagnetic induction, is fundamental in technology, scientific instrumentation, and geophysical exploration.

3. Goals of the Course

- Apply the theory of small oscillations to the analysis of systems with multiple degrees of freedom to determine their normal modes of vibration.
- Understand the foundations of continuum mechanics for the analysis of elastic solids and fluids in engineering and scientific applications.
- Solve problems in electrostatics, dielectrics, and direct-current circuits using the fundamental laws of the electromagnetic field.
- Analyze magnetostatics and electromagnetic induction in the study of devices and electromagnetically based systems.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Theory of Small Oscillations and Coupled Oscillators, 24 hr(s)

Competences: ABET-1

Topics: **I:** Small oscillation approximation via Taylor expansion about a stable equilibrium **II:** Coupled oscillators and the formulation of equations of motion in matrix form **III:** Normal modes and eigenfrequencies derived from the eigenvalue problem **IV:** Damped oscillators: underdamped, critically damped, and overdamped regimes

Learning Outcomes **I:** Linearize equations of motion about a stable equilibrium point [Usage] **II:** Find normal mode frequencies and eigenvectors for systems of Two coupled oscillators [Usage]

Bibliography: [Marion and Thornton, 2003, French, 1971]

5.2 Continuum Mechanics Foundations, 18 hr(s)

Competences: ABET-1

Topics: **I:** Continuum hypothesis and the definition of density fields **II:** Stress tensor σ_{ij} and the concept of force per unit area **III:** Strain tensor ϵ_{ij} as a measure of local deformation **IV:** Hooke's law for isotropic materials: $\sigma_{ij} = \lambda\epsilon_{kk}\delta_{ij} + 2\mu\epsilon_{ij}$ **V:** Navier-Stokes equation for viscous fluids: $\rho\left(\frac{\partial\vec{v}}{\partial t} + \vec{v}\cdot\nabla\vec{v}\right) = -\nabla p + \mu\nabla^2\vec{v} + \vec{f}$ **VI:** Bernoulli's principle for inviscid and incompressible fluid flow **VII:** Conservation of mass and the continuity equation: $\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0$ **VIII:** Conservation of momentum expressed in continuum mechanics form **IX:** Wave propagation in elastic media including P-waves and S-waves **X:** Viscosity and the rheology of non-Newtonian fluids

Learning Outcomes **I:** Interpret the physical meaning of the components of the stress tensor [Familiarity] **II:** Calculate strain tensor components for simple deformations [Usage] **III:** Apply Hooke's law to relate stress and strain for isotropic elastic materials [Usage] **IV:** Simplify the Navier-Stokes equation for special cases such as steady or inviscid flow [Usage] **V:** Apply Bernoulli's principle to calculate pressure variations in fluid flow [Usage] **VI:** Derive the continuity equation from the principle of mass conservation [Usage] **VII:** Analyze different wave propagation modes in elastic solids [Assessment]

Bibliography: [Marion and Thornton, 2003, Serway and Jewett, 2018]

5.3 Electrostatics: Electric Field and Gauss's Law, 6 hr(s)

Competences: ABET-1

Topics: **I:** Coulomb's law for point charges and the principle of linear superposition **II:** The electric field vector $\vec{E}$ for discrete and continuous charge distributions **III:** Gauss's Law in integral form and its relation to enclosed charge **IV:** Differential form of Gauss's Law: $\nabla \cdot \vec{E} = \rho/\epsilon_0$ **V:** Applications of Gauss's Law to spherical and cylindrical symmetry **VI:** The Divergence Theorem applied to electrostatic fields

Learning Outcomes **I:** Calculate the electrostatic force on a charge distribution using superposition [Usage] **II:** Apply Gauss's Law to find the electric field for systems with high symmetry [Usage] **III:** Evaluate the electric flux through surfaces of engineering interest [Assessment] **IV:** Determine volume charge density from a given expression of the electric field [Usage]

Bibliography: [Griffiths, 2017, Young and Freedman, 2015]

5.4 Electric Potential and Poisson/Laplace Equations, 6 hr(s)

Competences: ABET-1

Topics: **I:** Definition of the scalar potential V and $\vec{E} = -\nabla V$ **II:** Calculating potential for continuous charge distributions **III:** Poisson's equation $\nabla^2 V = -\rho/\epsilon_0$ and Laplace's equation **IV:** Solution of Laplace's equation via separation of variables for engineering geometries **V:** The method of images for computing fields near conducting boundaries

Learning Outcomes **I:** Compute the electrostatic potential energy of a charge configuration [Usage] **II:** Derive the electric field vector from a given scalar potential [Usage] **III:** Solve Laplace's equation for a practical engineering geometry with specified boundary conditions [Assessment] **IV:** Apply the method of images to engineering problems involving grounded conductors [Usage]

Bibliography: [Griffiths, 2017]

5.5 Electrostatic Energy and Dielectrics, 6 hr(s)

Competences: ABET-1

Topics: **I:** Energy density in the electric field: $u = \frac{1}{2}\epsilon_0 E^2$ **II:** Capacitance $C = Q/V$ for standard engineering geometries **III:** The displacement vector $\vec{D}$ and Gauss's Law in dielectric materials **IV:** Linear dielectrics, susceptibility, and relative permittivity ϵ_r **V:** Boundary conditions for $\vec{E}$ and $\vec{D}$ at material interfaces

Learning Outcomes **I:** Calculate the capacitance of parallel-plate and coaxial capacitors filled with dielectrics [Usage] **II:** Evaluate bound charge distributions in polarized dielectric materials [Assessment] **III:** Solve for electric fields on both sides of a dielectric interface using boundary conditions [Usage] **IV:** Analyze the force on a dielectric slab in a partially inserted capacitor [Assessment]

Bibliography: [Griffiths, 2017, Serway and Jewett, 2018]

5.6 Electric Current, Circuits, and Kirchhoff's Laws, 4 hr(s)

Competences: ABET-1

Topics: **I:** Definition of current, current density, and the continuity equation **II:** Ohm's law, resistivity, and temperature dependence of resistance **III:** Kirchhoff's Current Law (KCL) for circuit node analysis **IV:** Kirchhoff's Voltage Law (KVL) for circuit loop analysis **V:** Series and parallel circuit simplification and equivalent resistance **VI:** RC and RL circuit transients and engineering time constants

Learning Outcomes I: Apply KCL and KVL to solve multi-loop DC engineering circuits [Usage] **II:** Calculate power dissipated in resistive circuit elements [Assessment] **III:** Analyze the transient response of RC and RL circuits and determine the time constant [Usage] **IV:** Design a resistor network to meet specified voltage division or current distribution requirements [Assessment]

Bibliography: [Serway and Jewett, 2018, Young and Freedman, 2015]

5.7 Magnetostatics: Biot-Savart and Ampere's Laws, 7 hr(s)

Competences: ABET-1

Topics: I: Lorentz force law: $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ **II:** Magnetic force on current-carrying wires and loops **III:** Biot-Savart Law for the magnetic field of a current element **IV:** Ampere's Law in integral form for high-symmetry engineering configurations **V:** The magnetic vector potential $\vec{A}$ and $\vec{B} = \nabla \times \vec{A}$

Learning Outcomes I: Calculate the magnetic field of solenoids and toroids using Ampere's Law [Usage] **II:** Compute the magnetic field on the axis of a current loop using the Biot-Savart Law [Usage] **III:** Verify that a given magnetic field satisfies $\nabla \cdot \vec{B} = 0$ [Assessment] **IV:** Analyze the torque on a current loop in a non-uniform magnetic field [Assessment]

Bibliography: [Griffiths, 2017, Young and Freedman, 2015]

5.8 Magnetic Properties of Matter, 7 hr(s)

Competences: ABET-1

Topics: I: The magnetization vector $\vec{M}$ as magnetic dipole moment per unit volume **II:** The magnetic field intensity $\vec{H}$ and Ampere's Law in matter **III:** Physical principles of diamagnetism, paramagnetism, and ferromagnetism **IV:** Ferromagnetic domains and the hysteresis loop for engineering material selection **V:** Linear magnetic media and magnetic permeability μ

Learning Outcomes I: Find bound current distributions for magnetized engineering materials [Usage] **II:** Classify materials as diamagnetic, paramagnetic, or ferromagnetic for engineering application suitability [Assessment] **III:** Analyze energy loss per cycle from a ferromagnetic hysteresis loop for transformer core selection [Assessment]

Bibliography: [Griffiths, 2017]

5.9 Electrodynamics: Faraday's Law and Induction, 6 hr(s)

Competences: ABET-1

Topics: I: Faraday's Law of induction and Lenz's Law **II:** Self-inductance L and the back-EMF in engineering inductors **III:** Mutual inductance M and transformer principles **IV:** Energy stored in the magnetic field of inductors **V:** Eddy currents, magnetic braking, and core loss in electrical machines

Learning Outcomes I: Calculate the induced EMF in a rotating coil and relate it to generator operation [Usage] **II:** Apply Lenz's Law to determine the direction of induced currents in engineering scenarios [Assessment] **III:** Compute the magnetic energy stored in a solenoid or toroidal inductor [Usage] **IV:** Evaluate mutual inductance between coupled coils for transformer design [Assessment]

Bibliography: [Griffiths, 2017, Serway and Jewett, 2018]

6. Bibliography

[French, 1971] French, A. P. (1971). *Vibrations and Waves*. W. W. Norton & Company.

[Griffiths, 2017] Griffiths, D. J. (2017). *Introduction to Electrodynamics*. Cambridge University Press, 4th edition.

[Marion and Thornton, 2003] Marion, J. B. and Thornton, S. T. (2003). *Classical Dynamics of Particles and Systems*. Thomson Brooks/Cole, 5th edition.

[Serway and Jewett, 2018] Serway, R. A. and Jewett, J. W. (2018). *Physics for Scientists and Engineers with Modern Physics*. Cengage Learning, 10th edition.

[Young and Freedman, 2015] Young, H. D. and Freedman, R. A. (2015). *Sears and Zemansky's University Physics with Modern Physics*. Pearson Education, 14th edition.

Universidad Nacional de Ingeniería (UNI)
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ID102 Technical and professional English II (Mandatory)

1. General information

- **Semester**: 3rd Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - ID101 Technical and professional English I (2nd Sem-Pg. 300)

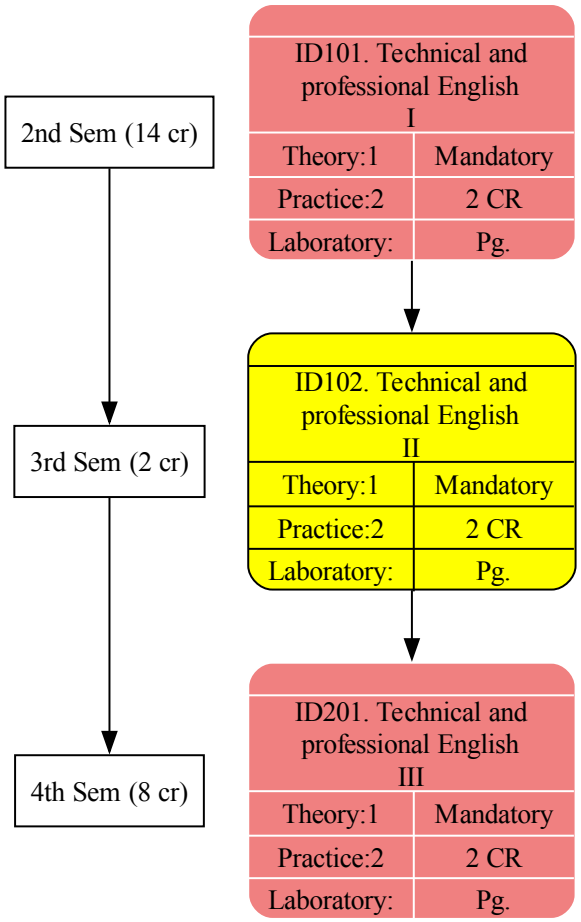

Figure 7.21: Connection Map. ID102 Technical and professional English II

2. Course Rationale

Building on foundational English skills, this course develops the student's ability to communicate in technical and scientific contexts with greater fluency. Grammar structures are practiced through reading and producing descriptions of technological systems, scientific phenomena, and engineering processes. Students gain vocabulary relevant to computing, data, and the physical sciences.

3. Goals of the Course

- Develop fluency in English applied to technical and scientific communication.

- Expand vocabulary in computing, data, and engineering domains.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Familiarity)

5. Content

5.1 Breakthroughs and Discoveries, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Simple Past Review: Affirmative and Negative in scientific contexts. **II:** Time expressions with 'ago': When technologies were invented or released. **III:** Conjunctions: and, so, but, because — structuring technical explanations. **IV:** Vocabulary: Scientific milestones, inventions, and discoveries.

Learning Outcomes I: By the end of the unit, students narrate past technological breakthroughs and connect cause-and-effect relationships using simple past and conjunctions (e.g., "Scientists discovered X, so engineers developed Y").

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.2 Data and Variables, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Countable and Uncountable nouns in computing: files, data, code, memory. **II:** Use of some, any, a lot of in quantifying technical resources. **III:** Expressions of quantity: a little memory, a few errors, too many processes. **IV:** Vocabulary: Data types, variables, constants, and storage units.

Learning Outcomes I: Students correctly use countable and uncountable noun structures to describe data, resources, and system states in technical contexts.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.3 Future of Technology, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Future plans: Verb + to + infinitive in project planning. **II:** Use of 'Will' vs 'Going to' for predictions and scheduled releases. **III:** Auxiliary verbs in forecasting: AI trends, cloud computing, quantum computing. **IV:** Vocabulary: Emerging technologies and career pathways in computing.

Learning Outcomes I: Students express technological intentions and project plans, as well as make evidence-based predictions about computing and engineering trends.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.4 Comparing Technologies, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Comparative and superlative adjectives applied to hardware and software. **II:** Comparing programming languages, operating systems, and algorithms. **III:** Synonyms and antonyms in technical vocabulary. **IV:** Reading: Short technology comparison articles and benchmark reports.

Learning Outcomes **I:** Students make detailed technical comparisons between systems, languages, and tools, using comparative and superlative structures accurately.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.5 Running Processes, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Present Continuous to describe active and ongoing technical processes. **II:** Current use: "The server is processing requests." **III:** Future use with Present Continuous: scheduled deployments and experiments. **IV:** Writing: Status updates and progress reports in technical projects.

Learning Outcomes **I:** Students describe active computing processes, ongoing experiments, and scheduled technical activities using the present continuous form.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.6 Software Milestones, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Introduction to Present Perfect to describe achievements with current relevance. **II:** Keywords: ever, never, yet, just — applied to software releases and research. **III:** Vocabulary: Version history, patches, upgrades, published papers. **IV:** Reading: Technology news and software changelogs.

Learning Outcomes **I:** Students communicate technical achievements and software milestones with present relevance, without specifying an exact time, using the present perfect.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.7 Technical Challenges, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Adjectives ending in -ed and -ing to describe technical experiences and processes. **II:** Modal verbs of obligation: must, have to — applied to engineering requirements. **III:** Vocabulary: Engineering challenges, constraints, trade-offs, and standards. **IV:** Writing: Short technical problem statements.

Learning Outcomes **I:** Students describe the emotional and technical aspects of engineering challenges and express obligations and constraints using specialized vocabulary.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

5.8 English for Technology II, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Technical terminology: Input/output devices, storage, and peripherals. **II:** Reading and following software installation and configuration instructions. **III:** Communication in technical support: Describing symptoms and solutions. **IV:** Presentation: Describing a computing system to a non-specialist audience.

Learning Outcomes I: By the end of the course, students interpret technical instructions, describe hardware components, and communicate basic computing concepts to diverse audiences in English.

Bibliography: [Soars and John, 2002a, Cambridge, 2006, MacGrew, 1999]

6. Bibliography

[Cambridge, 2006] Cambridge (2006). *Diccionario Inglés-Espanol Cambridge*. Editorial Oxford.

[MacGrew, 1999] MacGrew, J. (1999). *Focus on Grammar Basic*. Editorial Oxford.

[Soars and John, 2002a] Soars, L. and John (2002a). *American Headway N 1 Student Book*. Editorial Oxford.

Fourth Semester

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CE1M2 Dynamics (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE1M1 Statics (3rd Sem-Pg. 306)
  - BFI102 Physics II (3rd Sem-Pg. 317)

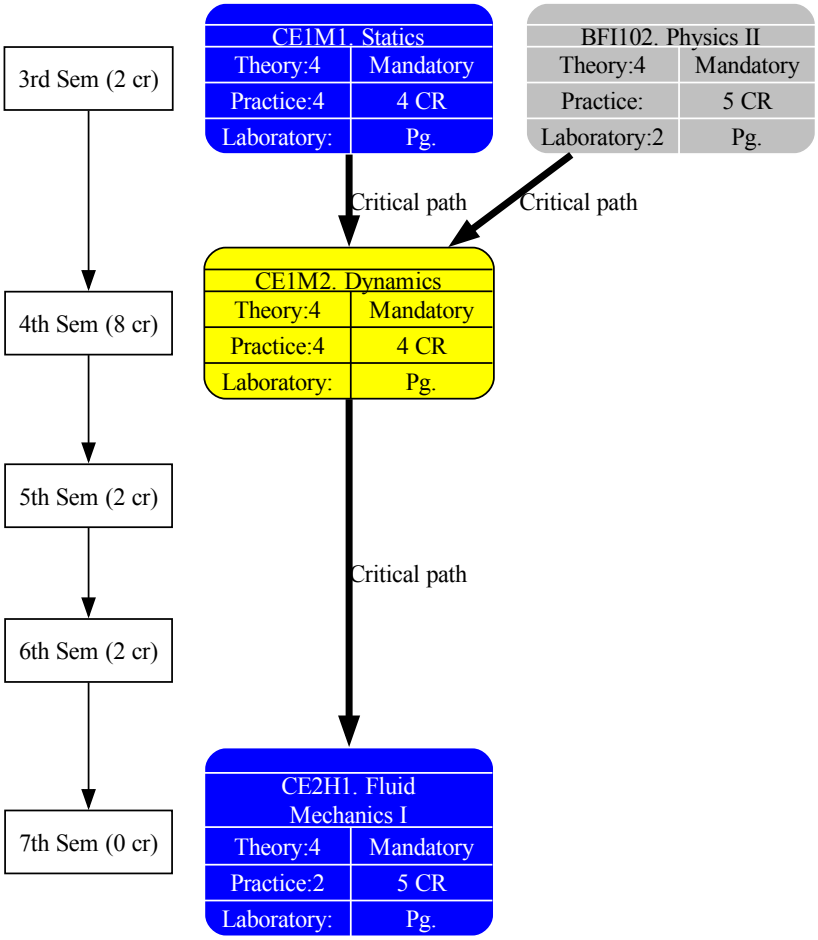

Figure 7.22: Connection Map. CE1M2 Dynamics

2. Course Rationale

Dynamics studies the accelerated motion of particles and rigid bodies under the action of forces. In Civil Engineering, this knowledge is essential for the analysis of structures subjected to time-varying

loads, such as earthquakes, wind, vehicular traffic, and heavy machinery. It provides the foundation for advanced courses such as Earthquake Engineering and Structural Dynamic Analysis.

3. Goals of the Course

- Analyze the kinematics of particles and rigid bodies in various coordinate systems.
- Apply Newton's laws, the principles of work and energy, and impulse and momentum to solve kinetics problems.
- Model and solve single-degree-of-freedom mechanical vibration problems to evaluate structural response.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Kinematics of Rigid Bodies in Plane Motion, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: I: Translation and rotation about a fixed axis **II:** General plane motion: relative velocity and acceleration, and the instantaneous center of rotation

Learning Outcomes I: Determine the velocity and acceleration of any point in a planar mechanism using the instantaneous center of rotation [Usage] **II:** Explain the distinction between translation, fixed-axis rotation, and general plane motion [Familiarity]

Bibliography: [Hibbeler, 2016]

5.2 Kinetics of Rigid Bodies in Plane Motion, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: I: Equations of motion for a rigid body in plane motion **II:** Kinetic energy of a rigid body and the principle of work and energy

Learning Outcomes I: Apply the equations of motion to relate external forces to the angular acceleration of rigid bodies [Assessment] **II:** Analyze rigid-body motion problems using the principle of work and energy [Usage]

Bibliography: [Hibbeler, 2016]

5.3 Introduction to Structural Vibrations, 12 hr(s)

Competences: ABET-1,ABET-6

Topics: I: Undamped free vibration of a single-degree-of-freedom system **II:** Simple pendulum and mass-spring models **III:** Natural frequency, period, and amplitude concepts **IV:** Introduction to damped free vibration

Learning Outcomes I: Model simple structural systems as single-degree-of-freedom systems [Usage] **II:** Calculate the natural frequency of a structure to avoid basic resonance phenomena [Assessment] **III:** Describe the effect of damping on the free-vibration response of a structural system [Familiarity] **IV:** Interpret period and amplitude parameters from a structure's free-vibration response [Usage]

Bibliography: [Bedford and Fowler, 2008]

6. Bibliography

[Bedford and Fowler, 2008] Bedford, A. and Fowler, W. (2008). *Engineering Mechanics: Dynamics*. Prentice Hall, 5th edition.

[Hibbeler, 2016] Hibbeler, R. (2016). *Engineering Mechanics: Dynamics*. Pearson, 14th edition.

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CE2M1 Mechanics of Materials I (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE1M1 Statics (3rd Sem-Pg. 306)
  - MA210 Calculus III (3rd Sem-Pg. 314)

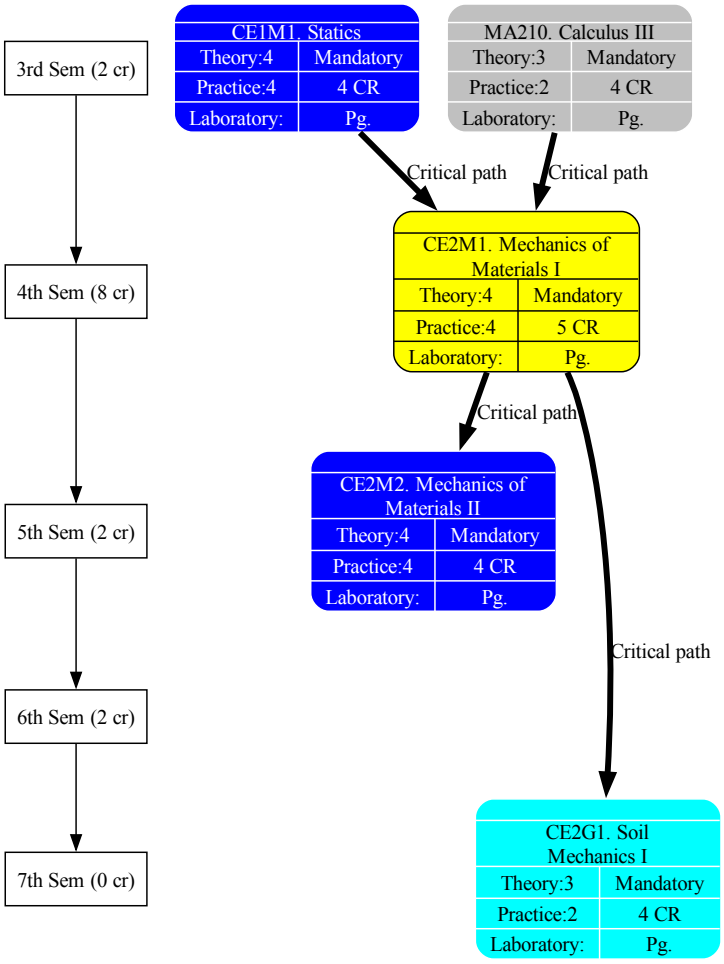

Figure 7.23: Connection Map. CE2M1 Mechanics of Materials I

2. Course Rationale

Mechanics of Materials I studies the behavior of deformable solid bodies subjected to different types of loading. For the civil engineer, understanding concepts such as stress, strain, and elasticity is fundamental, since these allow the strength and stiffness of structural elements to be predicted. This knowledge is the basis for the safe design of beams, columns, and shafts, ensuring that materials operate within their allowable limits.

3. Goals of the Course

- Understand the concepts of stress and strain under axial, torsional, and bending loads.
- Analyze the mechanical properties of materials from tension and compression tests.
- Determine internal stresses and deformations in statically determinate structural elements.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Mechanics of Materials and Structural Behavior, 24 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Stress and strain concepts including normal, shear, and principal stresses **II:** Axial loading and deformation of members **III:** Torsion of circular and non-circular sections **IV:** Bending stress and deflection in beams **V:** Shear stress distribution in beams **VI:** Combined loading and stress transformation **VII:** Buckling of columns and stability analysis **VIII:** Fatigue and fracture mechanics **IX:** Elastic and plastic behavior of materials **X:** Energy methods for structural analysis

Learning Outcomes **I:** Define stress, strain, and their relationships through constitutive laws [Familiarity] **II:** Calculate stresses and deformations in members under axial loading [Usage] **III:** Determine torsional stresses and angles of twist in shafts [Usage] **IV:** Analyze bending stress distribution and deflection in beams [Assessment] **V:** Compute shear stress distribution in beam cross-sections [Usage] **VI:** Apply stress transformation equations for combined loading conditions [Assessment] **VII:** Evaluate column stability and calculate critical buckling loads [Assessment] **VIII:** Explain fatigue failure mechanisms and predict fatigue life [Familiarity] **IX:** Distinguish between elastic and plastic material behavior under loading [Usage] **X:** Use energy methods to solve deflection and indeterminate structural problems [Usage]

Bibliography: [Gere and Goodno, 2017, Hibbeler, 2017]

5.2 Axial Stress and Strain, 16 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Average normal and shear stress. **II:** Normal and shear strain. **III:** Hooke's law and the modulus of elasticity. **IV:** Axially loaded members: changes in length and statically indeterminate systems.

Learning Outcomes **I:** Calculate stresses and deformations in bars subjected to axial load considering cross-sectional variations [Assessment]. **II:** Solve simple statically indeterminate structure problems using the deformation method [Usage].

Bibliography: [Hibbeler, 2017]

5.3 Torsion and Pure Bending, 20 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Torsion in circular shafts: the torsion formula and angle of twist. **II:** Pure bending: bending deformation and the elastic flexure formula. **III:** Shear stresses in beams: the shear flow formula. **IV:** Design of prismatic beams for strength.

Learning Outcomes I: Determine the distribution of shear stresses in circular sections subjected to torque [Usage]. **II:** Calculate the maximum tensile and compressive stresses in beams under various bending moments [Assessment].

Bibliography: [Gere and Goodno, 2017]

5.4 Stress Transformation and Combined Loading, 20 hr(s)

Competences: ABET-1,ABET-6

Topics: I: Plane stress transformation: general equations. **II:** Mohr's circle for plane stress and strain. **III:** Principal stresses and maximum shear stress. **IV:** Stress analysis under combined loading (axial, bending, and torsion).

Learning Outcomes I: Use Mohr's circle to identify the planes where maximum stresses occur [Assessment]. **II:** Analyze the state of stress at a critical point of an element subjected to multiple types of loading [Assessment].

Bibliography: [Hibbeler, 2017, Gere and Goodno, 2017]

6. Bibliography

[Gere and Goodno, 2017] Gere, J. and Goodno, B. (2017). *Mechanics of Materials*. Cengage Learning, 9th edition.

[Hibbeler, 2017] Hibbeler, R. (2017). *Mechanics of Materials*. Pearson, 10th edition.

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CE3M1 Concrete Technology (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - BCH101 Chemistry I (1st Sem-Pg. 251)

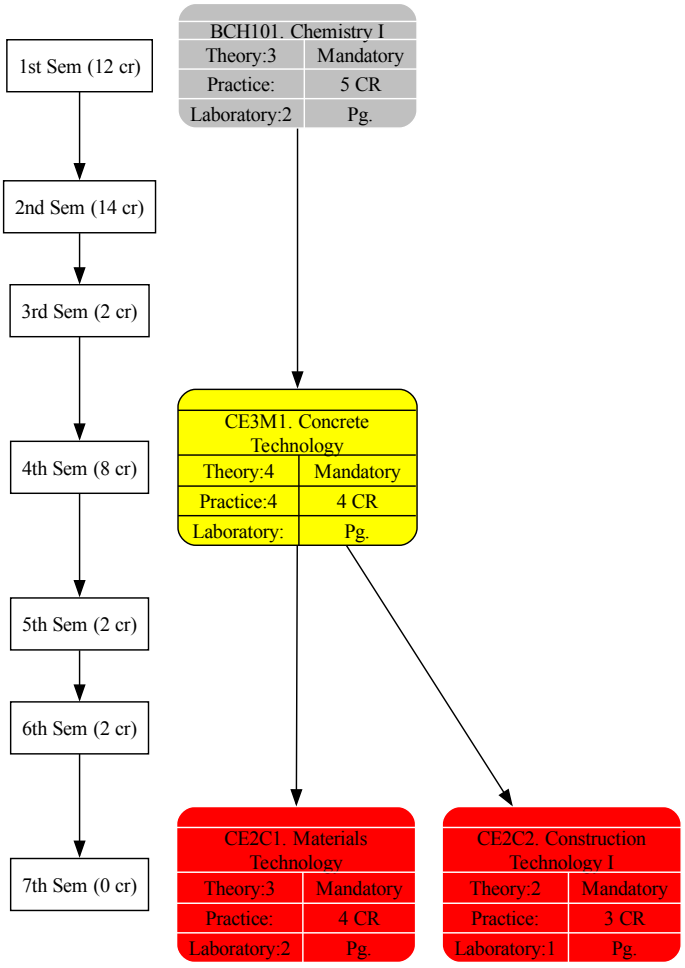

Figure 7.24: Connection Map. CE3M1 Concrete Technology

2. Course Rationale

Concrete is the most widely used construction material in civil engineering worldwide. This course provides students with the knowledge required to understand the nature of its components (cement, aggregates, water, and admixtures), the design of mixtures using various methods, and the techniques of placement, consolidation, and curing. Understanding concrete technology is vital to ensure the durability, strength, and safety of infrastructure structures throughout their service life.

3. Goals of the Course

- Understand the physical and chemical properties of concrete's components and their influence on mixture behavior.
- Design concrete mixtures using standardized methods to achieve specified strength and workability levels.
- Evaluate and control the quality of concrete in its fresh and hardened states through standardized tests.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Concrete Technology and Advanced Cementitious Materials, 24 hr(s)

Competences: ABET-1,ABET-2,ABET-6

Topics: **I:** Portland cement chemistry and hydration process **II:** Aggregates properties and grading requirements **III:** Mix design methodology for normal strength concrete **IV:** Fresh concrete properties including workability, slump, and setting time **V:** Hardened concrete properties including strength, modulus, and shrinkage **VI:** Chemical and mineral admixtures for concrete **VII:** High-performance and high-strength concrete design **VIII:** Self-consolidating concrete and fiber-reinforced concrete **IX:** Durability aspects including alkali-silica reaction, sulfate attack, and freeze-thaw **X:** Sustainable and low-carbon concrete technologies including supplementary cementitious materials such as fly ash, slag, and silica fume

Learning Outcomes **I:** Describe the chemistry of portland cement and the hydration process [Familiarity] **II:** Evaluate aggregate quality and suitability for concrete production [Assessment] **III:** Design concrete mixes for specified strength and workability requirements [Usage] **IV:** Test and interpret fresh concrete properties using standard procedures [Assessment] **V:** Predict hardened concrete properties based on mix proportions and curing conditions [Usage] **VI:** Explain the function and effects of various concrete admixtures [Familiarity] **VII:** Formulate high-performance concrete mixes for demanding applications [Usage] **VIII:** Select appropriate special concretes for specific construction scenarios [Assessment] **IX:** Incorporate supplementary cementitious materials to optimize concrete performance [Usage] **X:** Analyze durability risks and specify protective measures for concrete structures [Assessment] **XI:** Compare environmental impacts and carbon footprints of different concrete formulations [Familiarity]

Bibliography: [Kosmatka and Wilson, 2016, Neville, 2011]

5.2 Concrete Transport and Placement, 20 hr(s)

Competences: ABET-1,ABET-2,ABET-6

Topics: **I:** Transit mixer transport: maximum delivery time, slump verification, and admissible conditions **II:** Concrete pumping: pumpable mix design, operating pressure, reach, and blockage prevention **III:** Placement methods: direct discharge, chutes, buckets, and crane placement **IV:** Concrete consolidation: internal and external vibration, frequency, amplitude, and insertion depth **V:** Underwater concrete placement by tremie method and in restricted-access conditions

VI: Belt conveyor and pneumatic transport systems for large-volume concrete **VII:** Concrete surface finishing: leveling, troweling, texturing, and immediate curing

Learning Outcomes I: Plan concrete transport considering delivery distance, setting time, and environmental conditions [Usage] **II:** Execute standardized concrete placement procedures for different types of structural elements [Usage] **III:** Apply correct vibration techniques to achieve uniform concrete consolidation [Usage] **IV:** Evaluate concrete placement quality and identify deficiencies such as segregation, honeycombs, and cold joints [Assessment] **V:** Design pumpable concrete mixes for specific pumping height and distance conditions [Usage] **VI:** Specify placement methods for restricted-access structures or underwater placement conditions [Assessment] **VII:** Develop placement plans minimizing cold joints and ensuring concrete continuity in large structural elements [Usage]

Bibliography: [Neville, 2011]

5.3 Statistical Quality Control of Concrete, 20 hr(s)

Competences: ABET-1,ABET-2,ABET-6

Topics: I: Sampling procedures and fresh concrete specimen preparation according to ASTM standards **II:** Compressive strength testing: procedure, minimum frequency, and testing conditions **III:** Basic statistics applied to concrete: mean, standard deviation, and coefficient of variation **IV:** Concrete acceptance criteria according to ACI 318 and equivalent standards **V:** Statistical control charts ($\bar{X}$, R) for continuous monitoring of concrete production **VI:** Non-conforming results analysis: investigation procedures, additional tests, and structural decisions **VII:** Process capability indices (C_p, C_{pk}) and target mean strength adjustment

Learning Outcomes I: Apply standardized sampling and specimen fabrication procedures for concrete on site [Usage] **II:** Interpret compressive strength test results and determine their validity [Assessment] **III:** Calculate basic statistical parameters from series of concrete strength test results [Usage] **IV:** Evaluate concrete acceptance or rejection applying ACI 318 normative criteria [Assessment] **V:** Construct statistical control charts for continuous monitoring of concrete production [Usage] **VI:** Diagnose causes of excessive variability and propose corrective actions in concrete production [Assessment] **VII:** Determine the target mean strength (f'_{cr}) considering the statistical variability of the production process [Usage]

Bibliography: [Neville, 2011, López, 2000]

6. Bibliography

[Kosmatka and Wilson, 2016] Kosmatka, S. and Wilson, M. (2016). *Design and Control of Concrete Mixtures*. Portland Cement Association (PCA), 16th edition.

[López, 2000] López, E. R. (2000). *Naturaleza y Materiales del Concreto*. Capítulo Peruano del American Concrete Institute, 1st edition.

[Neville, 2011] Neville, A. (2011). *Properties of Concrete*. Pearson Education, 5th edition.

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MA202 Numerical Methods (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - MA121 Linear Algebra I (3rd Sem-Pg. 312)
  - BIC101 Introduction to Programming (1st Sem-Pg. 262)

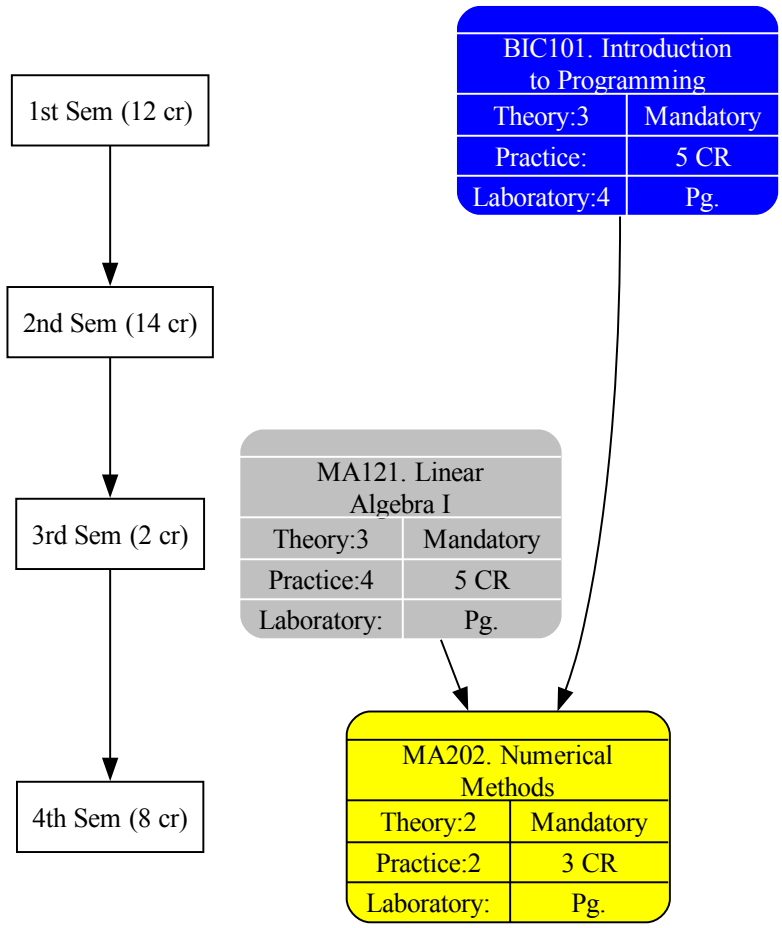

Figure 7.25: Connection Map. MA202 Numerical Methods

2. Course Rationale

Numerical methods are a fundamental tool shared by computer science and engineering disciplines for approximating solutions to mathematical problems that cannot be solved analytically. This course provides an introduction to the most common numerical methods, including error analysis, solution of nonlinear equations, interpolation, numerical integration, and solution of differential equations, in scientific and engineering contexts.

3. Goals of the Course

- Understand the importance of numerical methods in solving scientific and engineering problems.
- Apply different numerical methods to approximate solutions to mathematical problems.
- Analyze the accuracy and efficiency of the numerical methods used.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Error Analysis and Floating Point Arithmetic, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Floating point representation and round-off errors in engineering software **II:** Conditioning of engineering problems and stability of numerical algorithms **III:** Truncation error in series approximations and finite difference stencils **IV:** Error propagation through chains of computations in engineering simulations

Learning Outcomes **I:** Explain the sources and consequences of round-off and truncation errors in engineering computations [Familiarity] **II:** Calculate the condition number of a linear system and interpret its effect on solution accuracy [Assessment] **III:** Estimate the propagation of measurement uncertainties through an engineering calculation chain [Usage] **IV:** Select numerical methods with appropriate stability properties for engineering simulation requirements [Assessment]

Bibliography: [Chapra and Canale, 2015, Burden and Faires, 2010]

5.2 Numerical Solution of Nonlinear Equations, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Bracketing methods: bisection and false position **II:** Newton-Raphson method and the secant method **III:** Order of convergence and stopping criteria in iterative methods

Learning Outcomes **I:** Explain the basis and convergence guarantees of the bisection and false position methods [Familiarity] **II:** Apply the Newton-Raphson and secant methods to approximate roots of engineering equations [Usage] **III:** Compare the convergence order of different iterative methods and select the most appropriate one for a given problem [Assessment]

Bibliography: [Chapra and Canale, 2015, Burden and Faires, 2010]

5.3 Approximation Theory and Interpolation, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Polynomial interpolation: Lagrange, Newton divided differences, and Runge's phenomenon **II:** Spline interpolation: cubic splines, B-splines, and piecewise polynomial methods **III:** Best approximation in normed spaces: Chebyshev (minimax) and least squares **IV:** Chebyshev polynomials: properties, orthogonality, and spectral convergence **V:** Trigonometric approximation and the fast Fourier transform (FFT)

Learning Outcomes **I:** Explain Runge's phenomenon and justify the choice of Chebyshev nodes to mitigate it [Familiarity] **II:** Construct cubic spline and Chebyshev interpolants for given data and estimate the interpolation error [Usage] **III:** Apply the FFT to efficiently compute trigonometric approximations of a sampled function [Assessment]

Bibliography: [Chapra and Canale, 2015, Burden and Faires, 2010]

5.4 Numerical Integration and Quadrature, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Newton-Cotes rules: trapezoidal, Simpson's, and composite rules; error analysis **II:** Adaptive quadrature and automatic error control **III:** Gaussian quadrature: optimal nodes and weights, orthogonal polynomial connection **IV:** Numerical treatment of improper and singular integrals **V:** Monte Carlo integration and quasi-Monte Carlo methods for high-dimensional integrals

Learning Outcomes **I:** Derive the error formula for composite Simpson's rule and identify its order of accuracy [Familiarity] **II:** Select and apply an appropriate quadrature rule (Gaussian, adaptive) based on integrand regularity [Usage] **III:** Apply Monte Carlo integration to estimate high-dimensional integrals and quantify the statistical error [Assessment]

Bibliography: [Chapra and Canale, 2015, Burden and Faires, 2010]

5.5 Numerical Methods for ODEs and PDEs, 12 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Runge-Kutta methods and adaptive time-stepping for engineering ODE problems **II:** Stability analysis and stiffness in engineering ODE integrators **III:** Finite difference discretization of engineering PDEs (heat equation, Laplace equation) **IV:** Finite element and shooting methods for engineering boundary value problems

Learning Outcomes **I:** Implement a fourth-order Runge-Kutta integrator for a mechanical vibration problem [Usage] **II:** Determine the region of absolute stability for an explicit time-stepping scheme [Assessment] **III:** Discretize the 2D heat equation using finite differences and set up the resulting linear system [Usage] **IV:** Compare finite difference and finite element approaches for solving an engineering PDE [Assessment]

Bibliography: [Chapra and Canale, 2015, Burden and Faires, 2010]

5.6 Numerical Linear Algebra, 12 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** LU and QR decompositions for solving engineering linear systems **II:** Iterative solvers: Jacobi, Gauss-Seidel, and Conjugate Gradient for large sparse systems **III:** Singular Value Decomposition (SVD) for data fitting and model reduction **IV:** Sparse matrix storage formats and efficient solvers for large engineering FEM/FVM systems

Learning Outcomes **I:** Solve engineering linear systems using LU decomposition with partial pivoting [Usage] **II:** Analyze the convergence rate of iterative solvers applied to engineering stiffness matrices [Assessment] **III:** Implement a Conjugate Gradient solver for a large symmetric positive-definite engineering system [Usage] **IV:** Apply SVD to compress a structural mode shape dataset and assess the approximation quality [Assessment]

Bibliography: [Burden and Faires, 2010, Trefethen and III, 1997]

5.7 Finite Element Method, 8 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Weak (variational) formulation of boundary value problems and Sobolev spaces **II:** Galerkin method: finite-dimensional approximation spaces and the stiffness matrix **III:** Triangular and quadrilateral finite element spaces: Lagrange elements and conformity **IV:** A priori error estimates: Céa's lemma and interpolation error bounds **V:** A posteriori error estimates and adaptive mesh refinement

Learning Outcomes **I:** Derive the weak formulation of an elliptic BVP and show its equivalence to the strong form [Familiarity] **II:** Assemble the global stiffness matrix and load vector for a linear finite element discretization [Usage] **III:** Estimate the H^1 error of a finite element solution using Céa's lemma and interpolation theory [Assessment]

Bibliography: [Reddy, 2019, Burden and Faires, 2010]

5.8 Optimization Algorithms, 4 hr(s)

Competences: ABET-2,ABET-6

Topics: **I:** Gradient descent and line search methods: Armijo-Wolfe conditions and convergence rates **II:** Newton's method and quasi-Newton methods (BFGS, L-BFGS) **III:** Constrained optimization: KKT conditions, penalty methods, and sequential quadratic programming **IV:** Convex optimization algorithms: interior-point methods and the alternating direction method of multipliers (ADMM) **V:** Stochastic gradient descent (SGD), variance reduction, and Adam optimizer

Learning Outcomes **I:** Explain the convergence guarantees of gradient descent for smooth convex functions [Familiarity] **II:** Apply Newton and quasi-Newton methods to unconstrained optimization problems [Usage] **III:** Formulate a constrained optimization problem as a KKT system and apply an interior-point method [Assessment]

Bibliography: [Nocedal and Wright, 2006]

5.9 Parallel and High-Performance Computing, 4 hr(s)

Competences: ABET-6

Topics: **I:** Parallel architectures: shared memory (OpenMP), distributed memory (MPI), and GPU (CUDA) **II:** Performance models: Amdahl's law, roofline model, and communication complexity **III:** Parallel algorithms for dense and sparse linear algebra (ScaLAPACK, PETSc) **IV:** Domain decomposition and parallel PDE solvers **V:** Automatic differentiation (forward and reverse mode) and its role in scientific ML

Learning Outcomes **I:** Explain Amdahl's law and identify the bottlenecks limiting parallel speedup in a given algorithm [Familiarity] **II:** Implement a parallel linear algebra routine using MPI or OpenMP and measure parallel efficiency [Usage] **III:** Apply automatic differentiation to compute gradients of complex scientific functions for optimization [Assessment]

Bibliography: [Pacheco and Malensek, 2022]

5.10 Graph Theory, 4 hr(s)

Competences: ABET-1

Topics: **I:** Graphs: definitions, isomorphism, degree sequences, trees, and spanning trees **II:** Connectivity, Menger's theorem, and network flows (max-flow min-cut) **III:** Matchings (Hall's theorem), graph colorings, and the chromatic polynomial **IV:** Planar graphs, Euler's formula, Kuratowski's theorem, and the four-color theorem **V:** Adjacency and Laplacian matrices, eigenvalues, and expander graphs

Learning Outcomes **I:** Identify structural properties of graphs (connectivity, planarity, bipartiteness) and apply Euler's formula [Familiarity] **II:** Apply Hall's marriage theorem and network flow algorithms to matching and routing problems [Usage] **III:** Analyze a graph's spectrum to bound its chromatic number and connectivity properties [Assessment]

Bibliography: [West, 2001]

5.11 Time Series Analysis, 2 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Stationarity, autocovariance function, and the autocorrelation function (ACF) **II:** ARMA models: identification, estimation (Yule-Walker, MLE), and diagnostics **III:** Spectral density, the periodogram, and Wiener-Khinchin theorem **IV:** State-space models and the Kalman filter **V:** ARIMA models, seasonal adjustment, and multi-step forecasting

Learning Outcomes **I:** Identify stationarity and determine the order of an ARMA model from ACF and PACF plots [Familiarity] **II:** Fit ARIMA models to time series data, validate residuals, and produce forecasts [Usage] **III:** Apply the Kalman filter to estimate hidden states in a linear Gaussian state-space model [Assessment]

Bibliography: [Shumway and Stoffer, 2017]

6. Bibliography

[Burden and Faires, 2010] Burden, R. L. and Faires, J. D. (2010). *Numerical Analysis*. Cengage Learning.

[Chapra and Canale, 2015] Chapra, S. C. and Canale, R. P. (2015). *Numerical Methods for Engineers*. McGraw-Hill Education.

[Nocedal and Wright, 2006] Nocedal, J. and Wright, S. J. (2006). *Numerical Optimization*. Springer, 2nd edition.

[Pacheco and Malensek, 2022] Pacheco, P. S. and Malensek, M. (2022). *An Introduction to Parallel Programming*. Morgan Kaufmann, 2nd edition.

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[Trefethen and III, 1997] Trefethen, L. N. and III, D. B. (1997). *Numerical Linear Algebra*. SIAM.

[West, 2001] West, D. B. (2001). *Introduction to Graph Theory*. Prentice Hall, 2nd edition.

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MA211 Calculus IV (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA210 Calculus III (3rd Sem-Pg. 314)
  - MA121 Linear Algebra I (3rd Sem-Pg. 312)

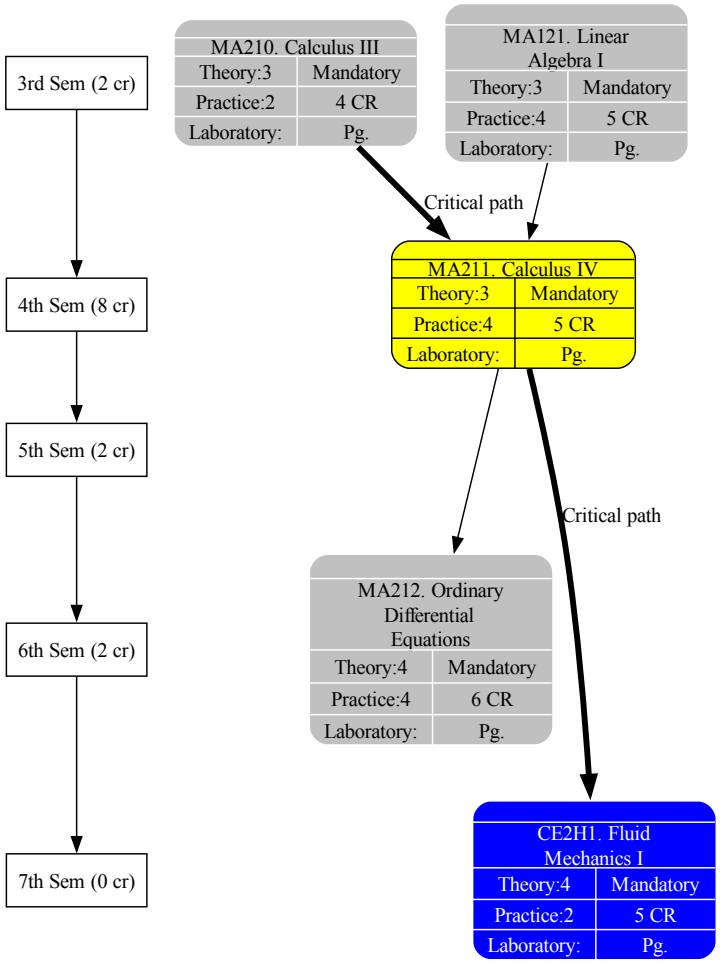

Figure 7.26: Connection Map. MA211 Calculus IV

2. Course Rationale

This course covers ordinary differential equations, an introduction to partial differential equations, and asymptotic and perturbation methods, extending the multivariable calculus foundations built in previous courses. It develops the analytical tools needed to model and solve differential equations arising in physics and engineering, and to approximate the solutions of problems that cannot be solved in closed form.

3. Goals of the Course

- Solve first-order ordinary differential equations and model physical systems with them.
- Solve higher-order linear ordinary differential equations and systems of ODEs.
- Classify and solve elementary partial differential equations using separation of variables and Fourier methods.
- Construct asymptotic expansions and apply regular and singular perturbation methods to approximate solutions.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 First-Order Ordinary Differential Equations (ODEs), 30 hr(s)

Competences: ABET-1

Topics: I: First-order equations: separable, linear, and exact forms

Learning Outcomes I: Solve linear first-order ODEs using integrating factors [Usage]

Bibliography: [Boyce et al., 2017, Stewart, 2016]

5.2 Higher-Order Differential Equations and Systems (ODEs), 20 hr(s)

Competences: ABET-1

Topics: I: Linear higher-order equations with constant coefficients **II:** Systems of first-order linear ODEs and state-space formulation **III:** Laplace transform method for solving engineering ODEs with initial conditions **IV:** Modeling of mass-spring-damper, RLC circuits, and heat conduction with ODEs

Learning Outcomes I: Apply the Laplace transform method to solve linear engineering ODEs with initial conditions [Usage] **II:** Model a damped mechanical oscillator or RLC circuit as a second-order linear ODE [Usage] **III:** Analyze the stability and transient response of engineering systems described by systems of ODEs [Assessment] **IV:** Formulate state-space representations for multi-variable engineering dynamic systems [Usage]

Bibliography: [Boyce et al., 2017]

5.3 Partial Differential Equations (PDEs), 16 hr(s)

Competences: ABET-1

Topics: I: Separation of variables for heat and wave equations in engineering geometries **II:** Laplace transform methods applied to initial-boundary value problems **III:** Classification of PDEs: elliptic, parabolic, and hyperbolic types and their physical significance **IV:** Formulation and physical interpretation of boundary conditions in engineering problems **V:** Green's functions and boundary value problems for advanced engineering analysis

Learning Outcomes I: Apply separation of variables to solve the 1D heat conduction and wave equations [Usage] **II:** Classify a given PDE and select the appropriate analytical or numerical solution approach [Assessment] **III:** Formulate boundary conditions for a heat transfer or stress analysis problem [Assessment] **IV:** Derive the governing PDE for steady-state heat conduction using Fourier's law [Usage]

Bibliography: [Strauss, 2008, Stewart, 2016]

5.4 Asymptotic Analysis and Perturbation Methods, 4 hr(s)

Competences: ABET-1

Topics: **I:** Asymptotic expansions and the Landau order symbols (O, o, $\sim$) **II:** Regular perturbation theory for algebraic equations and ODEs **III:** Singular perturbation theory and matched asymptotic expansions (boundary layers) **IV:** Method of multiple scales and the WKB approximation

Learning Outcomes **I:** Construct a regular perturbation expansion for an ODE with a small parameter [Familiarity] **II:** Apply matched asymptotic expansions to solve singular perturbation problems with boundary layers [Usage]

Bibliography: [Bender and Orszag, 1999]

6. Bibliography

[Bender and Orszag, 1999] Bender, C. M. and Orszag, S. A. (1999). *Advanced Mathematical Methods for Scientists and Engineers I: Asymptotic Methods and Perturbation Theory*. Springer.

[Boyce et al., 2017] Boyce, W. E., DiPrima, R. C., and Meade, D. B. (2017). *Ecuaciones Diferenciales y Problemas con Valores en la Frontera*. Limusa Wiley, 11th edition.

[Stewart, 2016] Stewart, J. (2016). *Multivariable Calculus: Early Transcendentals*. Cengage Learning, 8th edition.

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STA251 Statistics and Probability (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA112 Calculus II (2nd Sem-Pg. 291)

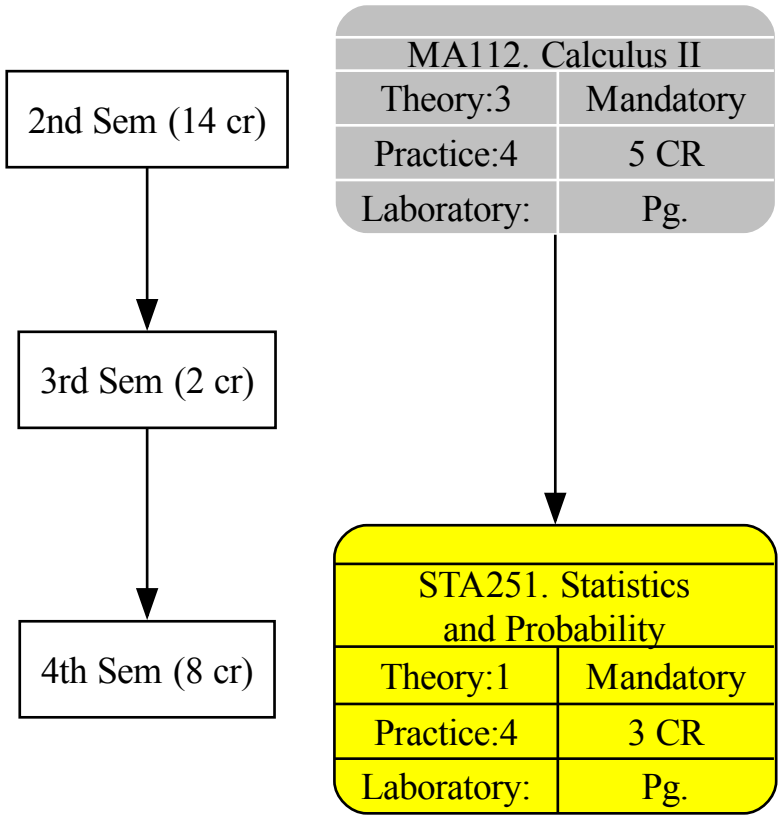

Figure 7.27: Connection Map. STA251 Statistics and Probability

2. Course Rationale

Probability and statistics provide the mathematical foundation for reasoning under uncertainty, analyzing data, and building predictive models – skills that are essential across computing, artificial intelligence, computational mathematics, and engineering alike. This course develops a rigorous understanding of probability theory and its use in describing random phenomena, together with the fundamentals of descriptive statistics, statistical inference (estimation, hypothesis testing, and Bayesian reasoning), and regression modeling, so that students can summarize and analyze data, quantify uncertainty, and draw sound quantitative conclusions in their own field of application.

3. Goals of the Course

- Understand the fundamentals of probability theory and descriptive statistics.
- Apply probability distributions and statistical inference methods to analyze data and quantify uncertainty.
- Develop skills to model random phenomena and build predictive statistical models such as linear regression.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 Numerical Summaries: Location, Spread, and Shape, 4 hr(s)

Competences: ABET-1

Topics: **I:** Measures of location: mean, median, mode, trimmed mean, and weighted mean **II:** Measures of spread: variance, standard deviation, IQR, MAD, and range **III:** Measures of shape: skewness and kurtosis; quantiles and percentiles **IV:** Robust summary statistics: resistance to outliers and heavy-tailed distributions

Learning Outcomes **I:** Calculate and interpret measures of location, spread, and shape for a univariate dataset [Usage] **II:** Select appropriate summary statistics based on the distributional properties of the data [Usage] **III:** Compare classical and robust summary statistics and justify the choice for a given dataset [Assessment]

Bibliography: [Devore, 2016]

5.2 Sample Spaces and Events, 4 hr(s)

Competences: ABET-1

Topics: **I:** Random experiments, outcomes, and sample spaces: finite, countable, and uncountable **II:** Set-theoretic operations on events: union, intersection, complement, and De Morgan's laws **III:** Sigma-algebras and measurable spaces as the foundation for rigorous probability **IV:** Borel sets and the Borel sigma-algebra on the real line

Learning Outcomes **I:** Define sample spaces, events, and sigma-algebras for a given random experiment [Familiarity] **II:** Apply set-theoretic operations to compute probabilities of compound events [Usage] **III:** Construct appropriate sigma-algebras for measurable spaces arising in statistical problems [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.3 Probability Axioms and Properties, 4 hr(s)

Competences: ABET-1

Topics: **I:** Kolmogorov's three axioms of probability and their consequences **II:** Derived properties: complement rule, addition rule, monotonicity, and continuity of probability **III:** Classical, frequentist, and subjective (Bayesian) interpretations of probability **IV:** Counting methods: permutations, combinations, and the multiplication principle

Learning Outcomes **I:** State Kolmogorov's axioms and derive fundamental probability properties [Familiarity] **II:** Calculate probabilities of events using the addition rule and complement rule [Usage] **III:** Apply counting methods to compute probabilities in finite sample spaces [Usage]

Bibliography: [Ross, 2014, Devore, 2016]

5.4 Conditional Probability and Independence, 4 hr(s)

Competences: ABET-1

Topics: **I:** Definition and interpretation of conditional probability P(A|B) and its properties **II:** Bayes' theorem and the law of total probability: derivation and applications **III:** Independence of events: pairwise and mutual independence **IV:** Conditional independence and its role in probabilistic graphical models

Learning Outcomes **I:** Explain conditional probability and independence and their relationship [Familiarity] **II:** Apply Bayes' theorem and the law of total probability to solve probability problems [Usage] **III:** Analyze whether events are independent or conditionally independent in a given probability model [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.5 Discrete Random Variables and Distributions, 4 hr(s)

Competences: ABET-1

Topics: **I:** Probability mass functions (PMF) and cumulative distribution functions (CDF) for discrete random variables **II:** Key discrete distributions: Bernoulli, Binomial, Geometric, Negative Binomial, Poisson, Hypergeometric **III:** Properties of discrete distributions: mean, variance, skewness, and kurtosis **IV:** Poisson approximation to the Binomial and limiting distribution arguments

Learning Outcomes **I:** Identify and describe the key discrete probability distributions and their parameters [Familiarity] **II:** Calculate probabilities, means, and variances using PMFs of standard discrete distributions [Usage] **III:** Select an appropriate discrete distribution to model a given random phenomenon and justify the choice [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.6 Continuous Random Variables and Distributions, 4 hr(s)

Competences: ABET-1

Topics: **I:** Probability density functions (PDF) and CDFs for continuous random variables **II:** Key continuous distributions: Uniform, Normal, Exponential, Gamma, Beta, Chi-squared, t, F **III:** The Normal distribution: properties, standard normal, and its central role in statistical inference **IV:** The exponential family of distributions: canonical form and sufficient statistics

Learning Outcomes **I:** Describe the properties and parameters of key continuous probability distributions [Familiarity] **II:** Calculate probabilities and quantiles for standard continuous distributions [Usage] **III:** Identify distributions belonging to the exponential family and derive their sufficient statistics [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.7 Joint, Marginal, and Conditional Distributions, 4 hr(s)

Competences: ABET-1

Topics: **I:** Joint PMFs and PDFs for two or more random variables **II:** Marginal and conditional distributions derived from joint distributions **III:** Covariance, correlation, and their properties; independence implies zero covariance (converse not always true) **IV:** The bivariate normal distribution and its conditional distributions

Learning Outcomes **I:** Derive marginal and conditional distributions from a given joint distribution [Usage] **II:** Calculate covariance and correlation between two random variables [Usage] **III:** Analyze the conditional structure of the bivariate normal distribution [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.8 Limit Theorems: LLN and CLT, 4 hr(s)

Competences: ABET-1

Topics: **I:** Weak law of large numbers: convergence in probability and its implications for estimation **II:** Central limit theorem: statement, conditions, and role in justifying normal approximations **III:** Applications of the CLT: normal approximation to the binomial and sampling distributions **IV:** Strong law of large numbers: almost sure convergence **V:** The delta method: asymptotic distribution of smooth functions of estimators

Learning Outcomes **I:** State the LLN and CLT and explain the conditions under which they hold [Familiarity] **II:** Apply the CLT to derive normal approximations and sampling distributions [Usage] **III:** Apply the delta method to derive asymptotic distributions of nonlinear estimators [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.9 Point Estimation, 4 hr(s)

Competences: ABET-1

Topics: **I:** Desirable properties: unbiasedness, consistency, efficiency, and sufficiency **II:** Method of moments estimation: derivation and asymptotic properties **III:** Maximum likelihood estimation: derivation, properties, and invariance principle **IV:** Cramer-Rao lower bound and the concept of Fisher information

Learning Outcomes **I:** Describe the key properties of estimators and explain the trade-offs between them [Familiarity] **II:** Derive method of moments and MLE estimators for standard distributions [Usage] **III:** Evaluate the efficiency of an estimator using the Cramer-Rao lower bound [Assessment]

Bibliography: [Devore, 2016]

5.10 Interval Estimation and Confidence Intervals, 4 hr(s)

Competences: ABET-1

Topics: **I:** Constructing confidence intervals using pivotal quantities and exact distributions **II:** Correct interpretation of confidence intervals: coverage probability and common misconceptions **III:** Large-sample confidence intervals based on asymptotic normality **IV:** Duality between confidence intervals and hypothesis tests

Learning Outcomes **I:** Construct confidence intervals for means, proportions, and variances using exact and large-sample methods [Usage] **II:** Interpret confidence intervals correctly and identify common misinterpretations [Usage] **III:** Explain the duality between confidence intervals and hypothesis tests and use it to draw inferences [Assessment]

Bibliography: [Devore, 2016]

5.11 Hypothesis Testing Foundations, 4 hr(s)

Competences: ABET-1

Topics: **I:** Neyman-Pearson framework: null/alternative hypotheses, rejection regions, Type I and II errors **II:** p-values: definition, correct interpretation, and common misuse; power and sample size **III:** Common parametric tests: z-test, t-test, F-test, chi-squared test **IV:** Neyman-Pearson lemma and uniformly most powerful tests

Learning Outcomes **I:** Explain the logic of hypothesis testing, Type I and II errors, and the meaning of a p-value [Familiarity] **II:** Apply standard parametric tests and interpret the results in context [Usage] **III:** Derive the most powerful test for a simple hypothesis using the Neyman-Pearson lemma [Assessment]

Bibliography: [Devore, 2016]

5.12 Bayesian Inference, 4 hr(s)

Competences: ABET-1

Topics: **I:** Bayesian framework: prior, likelihood, posterior, and the role of Bayes' theorem **II:** Prior distributions: informative, non-informative, and conjugate priors **III:** Posterior inference: point estimates, credible intervals, and posterior predictive distributions **IV:** Bayesian model comparison: Bayes factors and posterior model probabilities

Learning Outcomes **I:** Explain the Bayesian approach to inference and contrast it with the frequentist approach [Familiarity] **II:** Derive the posterior distribution for standard conjugate models [Usage] **III:** Apply Bayes factors to compare statistical models and interpret the evidence [Assessment]

Bibliography: [Ross, 2014, Devore, 2016]

5.13 Simple Linear Regression, 4 hr(s)

Competences: ABET-1

Topics: **I:** Ordinary least squares estimation: derivation of coefficients and their properties **II:** Inference for regression coefficients: t-tests, confidence intervals, and p-values **III:** Coefficient of determination R-squared and analysis of variance decomposition **IV:** Gauss-Markov theorem: BLUE property of OLS under classical assumptions

Learning Outcomes **I:** Fit a simple linear regression model and interpret the estimated coefficients [Usage] **II:** Conduct hypothesis tests and construct confidence intervals for regression parameters [Usage] **III:** Verify the Gauss-Markov assumptions and assess their consequences when violated [Assessment]

Bibliography: [Devore, 2016]

6. Bibliography

[Devore, 2016] Devore, J. L. (2016). *Probability and Statistics for Engineering and the Sciences.* Cengage Learning.

[Ross, 2014] Ross, S. M. (2014). *A First Course in Probability.* Pearson.

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ID201 Technical and professional English III (Mandatory)

1. General information

- **Semester**: 4th Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - ID102 Technical and professional English II (3rd Sem-Pg. 322)

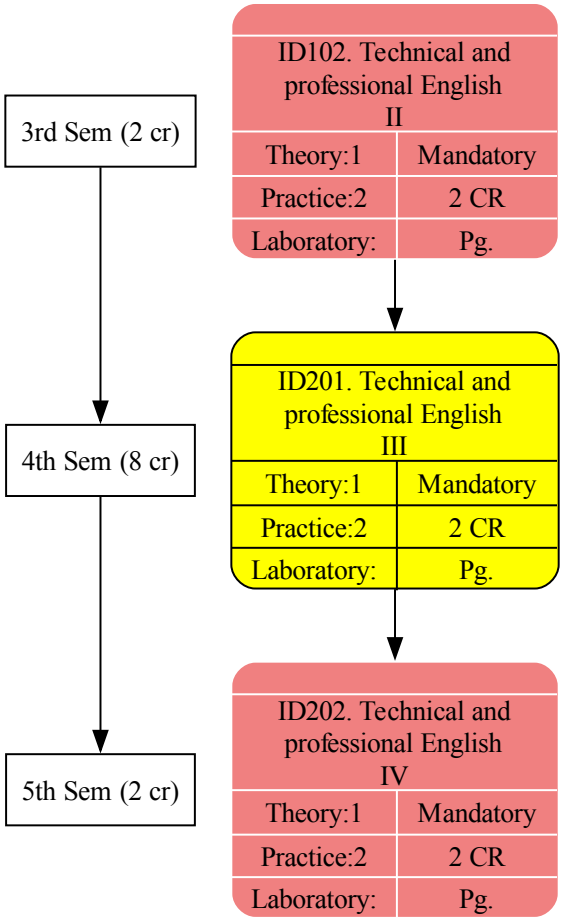

Figure 7.28: Connection Map. ID201 Technical and professional English III

2. Course Rationale

At this level, students engage with English as the primary medium for accessing and producing technical content in computing, engineering, and the sciences. Grammar structures are applied to reading scientific articles, writing technical reports, describing engineering processes, and participating in professional discussions. The course bridges everyday English fluency with the demands of technical communication.

3. Goals of the Course

- Train students to read, understand, and produce technical communication in English.
- Provide linguistic tools for connecting ideas in descriptive and analytical writing about computing and engineering.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Familiarity)

5. Content

5.1 Technical Communication, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Review of Tenses: Present, Past, and Future in technical documentation. **II:** Interrogative sentences with complex Wh- questions for system analysis. **III:** Words with more than one meaning in technical contexts (Polysemy). **IV:** Expressions for describing professional activities and research interests.

Learning Outcomes I: By the end of the unit, students use various tenses to exchange detailed technical information and formulate precise questions about computing systems and engineering processes.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.2 Comparing Architectures, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Use of "What's it like?": Describing system characteristics and interfaces. **II:** Advanced comparative and superlative adjectives in benchmark analysis. **III:** Collocations in computing: high-performance, low-level, fault-tolerant. **IV:** Reading: Architecture comparison reports (RISC vs. CISC, SQL vs. NoSQL).

Learning Outcomes I: Students analyze and describe differences between computing architectures, frameworks, and systems using varied comparative structures with technical precision.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.3 Then and Now in Computing, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Present Perfect vs. Simple Past: Contrasting historic events with current state. **II:** Time expressions: for, since, ever, never applied to technology evolution. **III:** Adverbs of time and manner in scientific narrative. **IV:** Vocabulary: Generations of technology, legacy systems, current platforms.

Learning Outcomes I: Students differentiate and correctly apply the present perfect and the simple past to narrate the evolution of computing technologies and contrast historical achievements with the current state of the field.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.4 Engineering Standards and Protocols, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Modals of obligation and permission: Have to, Must, Can in professional norms. **II:** Giving technical recommendations: Should, Ought to — code reviews and design. **III:** Vocabulary: IEEE/ACM standards, coding conventions, security policies. **IV:** Formal writing: Technical memos and engineering recommendations.

Learning Outcomes I: Students express engineering rules, standards, and professional recommendations using appropriate modal verbs in formal technical writing and peer discussion.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.5 How Systems Are Built, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Passive Voice: Present and Simple Past to describe engineering processes. **II:** Vocabulary: Manufacturing, deployment, integration, and testing. **III:** Expressions for giving technical opinions and discussing design trade-offs. **IV:** Writing: Process description for a software or hardware system.

Learning Outcomes I: Students use the passive voice to describe how systems are designed, built, tested, and deployed, participating in technical discussions about engineering processes.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.6 Debugging and Analysis, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Past Continuous vs. Simple Past in incident and failure reports. **II:** Narrative and sequence connectors: while, when, suddenly, as a result. **III:** Vocabulary: Bugs, exceptions, crashes, logs, root cause analysis. **IV:** Writing: Incident report for a software or network failure.

Learning Outcomes I: Students narrate debugging sessions, system failures, and experimental incidents using narrative tenses and technical sequencing connectors fluently.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.7 Research and Innovation, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Future Forms: Will, Going to, Present Continuous for research projection. **II:** Expressions of probability and certainty in scientific contexts. **III:** Vocabulary: Innovation cycles, research proposals, technology forecasting. **IV:** Oral presentations: "The future of computing in my field".

Learning Outcomes I: Students project research goals and discuss future directions in computing and engineering using various future structures with appropriate degrees of certainty.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.8 Technical English III, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Programming and Web Development terminology: functions, APIs, frameworks. **II:** User Interface (UI/UX) descriptions and usability concepts. **III:** Basic project management vocabulary: sprints, milestones, deliverables. **IV:** Writing: Simple technical specification or README document.

Learning Outcomes I: By the end of the course, students use specialized software development vocabulary to describe logical and functional components and produce basic technical documentation in English.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

6. Bibliography

[Cambridge, 2006] Cambridge (2006). *Diccionario Inglés-Espanol Cambridge*. Editorial Oxford.

[MacGrew, 1999] MacGrew, J. (1999). *Focus on Grammar Basic*. Editorial Oxford.

[Soars and John, 2002d] Soars, L. and John (2002d). *American Headway N 2 Student Book*. Editorial Oxford.

Fifth Semester

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CE2M2 Mechanics of Materials II (Mandatory)

1. General information

- **Semester**: 5th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE2M1 Mechanics of Materials I (4th Sem-Pg. 329)

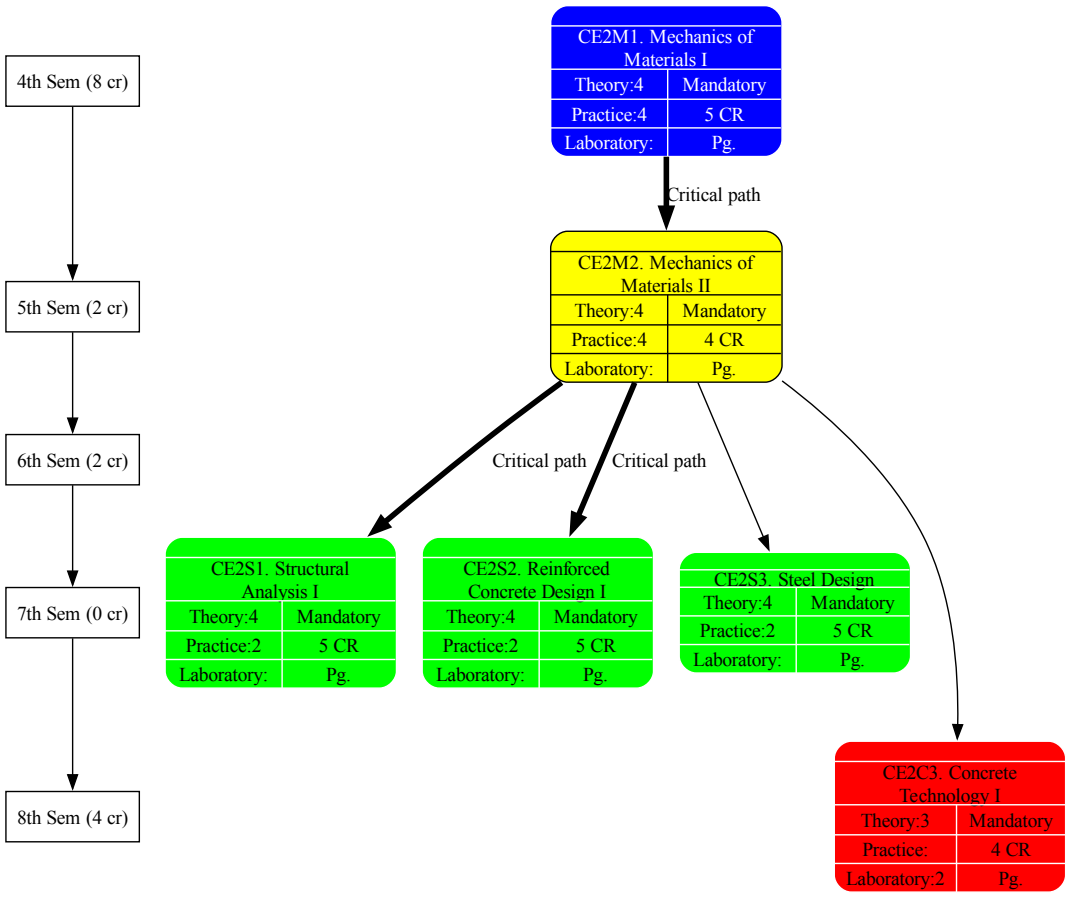

Figure 7.29: Connection Map. CE2M2 Mechanics of Materials II

2. Course Rationale

Mechanics of Materials II is the advanced continuation of the study of deformable solids. This course addresses problems of greater technical complexity, such as beam deflection using various methods, the elastic stability of columns, and combined-stress failure analysis. These concepts enable students to carry out more refined structural designs and understand the limits of failure by instability, ensuring the integrity of buildings and civil engineering structures.

3. Goals of the Course

- Determine deflections and slopes in beams using integration, area-moment, and energy methods.
- Analyze and design columns subjected to axial load considering elastic and inelastic buckling.
- Apply failure theories for ductile and brittle materials in the design of elements under complex stress states.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Beam Deflections, 24 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** The equation of the elastic curve. **II:** Double integration method and discontinuity functions. **III:** Moment-area method and the conjugate-beam method. **IV:** Analysis of statically indeterminate beams by superposition.

Learning Outcomes **I:** Calculate displacements and rotations in beams under various loading and support conditions [Assessment]. **II:** Solve statically indeterminate structures through compatibility-of-deformation analysis [Usage].

Bibliography: [Hibbeler, 2017, Gere and Goodno, 2017]

5.2 Column Stability, 16 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Concept of stability and Euler's critical load. **II:** Columns with different support conditions: effective length. **III:** Inelastic buckling and the secant formula. **IV:** Design of columns under concentric and eccentric loading.

Learning Outcomes **I:** Determine the maximum load a slender column can support before failing by instability [Assessment]. **II:** Design column cross-sections that comply with structural safety codes [Usage].

Bibliography: [Hibbeler, 2017]

5.3 Energy Methods and Failure Theories, 24 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Strain energy due to axial load, bending, and torsion. **II:** Castigliano's theorem and its application to deflections. **III:** Failure theories for ductile materials: Tresca and von Mises. **IV:** Failure theories for brittle materials: Mohr-Coulomb.

Learning Outcomes **I:** Apply energy principles to solve displacement problems in structures of complex geometry [Usage]. **II:** Predict the onset of yielding or fracture of a material under combined stress states [Assessment].

Bibliography: [Gere and Goodno, 2017]

6. Bibliography

[Gere and Goodno, 2017] Gere, J. and Goodno, B. (2017). *Mechanics of Materials*. Cengage Learning, 9th edition.

[Hibbeler, 2017] Hibbeler, R. (2017). *Mechanics of Materials*. Pearson, 10th edition.

Universidad Nacional de Ingeniería (UNI)
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ID202 Technical and professional English IV (Mandatory)

1. General information

- **Semester**: 5th Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - ID201 Technical and professional English III (4th Sem-Pg. 348)

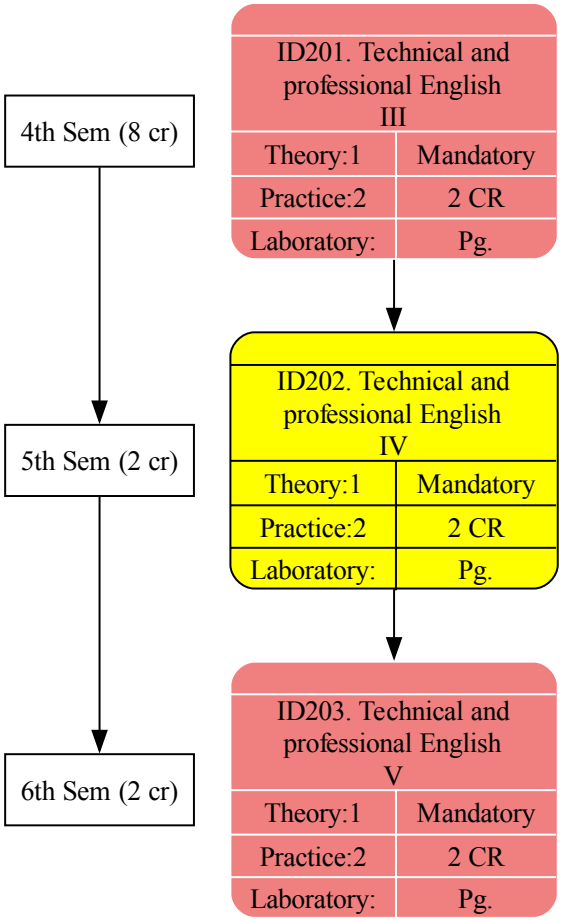

Figure 7.30: Connection Map. ID202 Technical and professional English IV

2. Course Rationale

At the intermediate level, students apply English to the full range of technical communication required in computing and engineering practice: reading research papers, writing structured technical documents, analyzing case studies, and engaging in professional dialogue. Grammar structures are taught through authentic computing and engineering contexts, reinforcing both linguistic competence and disciplinary knowledge.

3. Goals of the Course

- Develop the ability to write and read structured technical documents in English.
- Bring the student to a more fluent and natural expression in technical and scientific English.
- Master vocabulary for computing, systems engineering, and applied sciences.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Familiarity)

5. Content

5.1 Best Practices and Ethics, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Modals of obligation and advice: Should, Must, Have to in engineering codes. **II:** Prohibition and absence of obligation in software licensing and data privacy. **III:** Vocabulary: Professional ethics, intellectual property, responsible AI. **IV:** Writing: Formal technical recommendation and policy documents.

Learning Outcomes I: By the end of the unit, students correctly use modal auxiliaries to express engineering standards, ethical obligations, and professional recommendations in formal technical environments.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.2 Failures and Root Causes, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Past Perfect: Structure and use in root cause analysis and post-mortems. **II:** Contrast between Simple Past, Continuous, and Perfect in failure timelines. **III:** Vocabulary: System outages, security breaches, cascading failures. **IV:** Expressions for reporting information: reported speech in incident briefings.

Learning Outcomes I: Students reconstruct complex failure timelines and root cause analyses by establishing clear chronological sequences through the use of past tense contrasts.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.3 If-Then Logic, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Conditionals Type 0, 1, and 2 applied to computing logic and engineering decisions. **II:** Sentences with "If" and "Unless" for system constraints and requirements. **III:** Vocabulary: Hypothetical scenarios, risk analysis, and optimization trade-offs. **IV:** Expressions of what-if design thinking: "If we used X, the system would..."

Learning Outcomes I: Students pose real and hypothetical technical scenarios and their consequences, using conditional structures to reason about design choices and engineering decisions.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.4 Ongoing Research, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Present Perfect Continuous for describing research in progress. **II:** Contrast between Simple and Continuous Present Perfect in scientific writing. **III:** Vocabulary: Continuous integration, agile development, iterative research. **IV:** Word formation: Prefixes and suffixes in scientific and technical terminology.

Learning Outcomes **I:** Students describe research activities and development processes that began in the past and continue into the present, emphasizing duration and iterative progress.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.5 Manufacturing and Deployment, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Passive Voice in all basic tenses for technical process descriptions. **II:** Verbs with two objects in passive: data is sent to the server by the client. **III:** Vocabulary: Hardware manufacturing, cloud deployment, CI/CD pipelines. **IV:** Writing: Technical description of a deployment or production process.

Learning Outcomes **I:** Students use the passive voice across multiple tenses to describe technical processes where the action, system, or result is the focus rather than the agent.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.6 Tech Roadmaps, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Future Continuous and Future Perfect for project timelines and milestones. **II:** Adverbs of probability: perhaps, probably, definitely — in tech forecasting. **III:** Vocabulary: Product roadmaps, release planning, emerging research areas. **IV:** Oral presentations: "The state of AI / quantum computing in 5 years".

Learning Outcomes **I:** Students project technical states, completed future milestones, and research outcomes, discussing computing and engineering roadmaps with advanced vocabulary.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.7 Technical Teams, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: **I:** Indirect questions and Tag questions in technical interviews and peer reviews. **II:** Common Phrasal Verbs in engineering and research environments. **III:** Vocabulary: Collaboration tools, code review practices, team roles. **IV:** Writing: Short technical blog posts and engineering team updates.

Learning Outcomes **I:** Students use polite inquiry forms and confirmation strategies in technical interviews and team discussions, improving their fluency and naturalness in professional engineering contexts.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

5.8 Technical English IV: Networks and Security, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Networking terminology: protocols, topologies, OSI model, routing. **II:** Cybersecurity vocabulary: vulnerabilities, threats, encryption, authentication. **III:** Reading and writing network incident and security audit reports. **IV:** Project: Security assessment plan for a computing infrastructure.

Learning Outcomes I: By the end of the course, students command networking and cybersecurity technical terminology to read specialized documentation and communicate effectively with IT and security professionals in English.

Bibliography: [Soars and John, 2002d, Cambridge, 2006, MacGrew, 1999]

6. Bibliography

[Cambridge, 2006] Cambridge (2006). *Diccionario Inglés-Espanol Cambridge*. Editorial Oxford.

[MacGrew, 1999] MacGrew, J. (1999). *Focus on Grammar Basic*. Editorial Oxford.

[Soars and John, 2002d] Soars, L. and John (2002d). *American Headway N 2 Student Book*. Editorial Oxford.

Sixth Semester

Universidad Nacional de Ingeniería (UNI)
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MA212 Ordinary Differential Equations (Mandatory)

1. General information

- **Semester**: 6th Sem. **Credits**: 6
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - MA211 Calculus IV (4th Sem-Pg. 340)

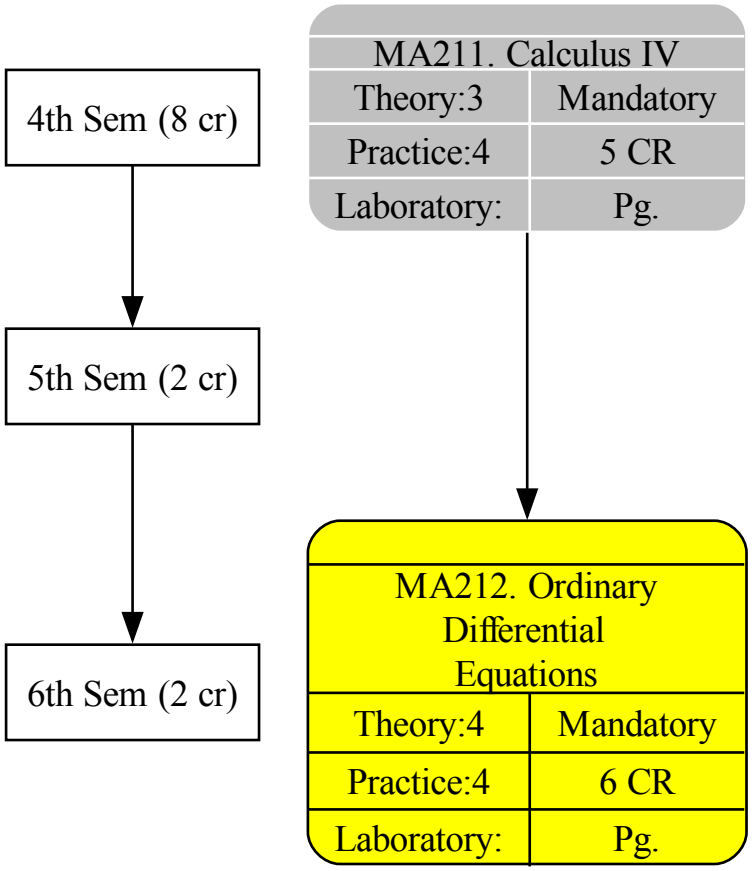

Figure 7.31: Connection Map. MA212 Ordinary Differential Equations

2. Course Rationale

The Ordinary Differential Equations course provides the mathematical tools to analyze systems that evolve with respect to a single independent variable. It focuses on the modeling of dynamic systems through first-order equations, higher-order equations, and systems of equations, using both

analytical and numerical methods. It is fundamental for the understanding of mechanics, electrical circuits, and population models.

3. Goals of the Course

- Solve first-order and higher-order ordinary differential equations using analytical methods.
- Apply the Laplace transform to solve initial value problems involving discontinuous functions.
- Analyze the stability of linear and nonlinear systems of differential equations.
- Implement numerical methods for approximating solutions in complex models.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Familiarity)

5. Content

5.1 First-Order Ordinary Differential Equations (ODEs), 20 hr(s)

Competences: ABET-1

Topics: I: Modeling with first-order equations: growth, mixtures, and cooling

Learning Outcomes I: Solve linear first-order ODEs using integrating factors [Usage]

Bibliography: [Boyce et al., 2017, Zill, 2018]

5.2 Higher-Order Differential Equations and Systems (ODEs), 40 hr(s)

Competences: ABET-1

Topics: I: Definition and properties of the Laplace Transform; inverse transforms and translation theorems **II:** Derivatives of a transform and convolution integrals

Learning Outcomes I: Apply the Laplace transform method to solve linear engineering ODEs with initial conditions [Usage] **II:** Model a damped mechanical oscillator or RLC circuit as a second-order linear ODE [Usage] **III:** Analyze the stability and transient response of engineering systems described by systems of ODEs [Assessment] **IV:** Formulate state-space representations for multi-variable engineering dynamic systems [Usage]

Bibliography: [Boyce et al., 2017, Zill, 2018]

5.3 Numerical Methods for ODEs and PDEs, 36 hr(s)

Competences: ABET-1

Topics: I: Phase portraits and linearization of nonlinear engineering systems **II:** Stability of critical points and nonlinear systems

Learning Outcomes I: Implement a fourth-order Runge-Kutta integrator for a mechanical vibration problem [Usage] **II:** Determine the region of absolute stability for an explicit time-stepping scheme [Assessment] **III:** Discretize the 2D heat equation using finite differences and set up the resulting linear system [Usage] **IV:** Compare finite difference and finite element approaches for solving an engineering PDE [Assessment]

Bibliography: [Boyce et al., 2017, Zill, 2018]

6. Bibliography

[Boyce et al., 2017] Boyce, W. E., DiPrima, R. C., and Meade, D. B. (2017). *Ecuaciones Diferenciales y Problemas con Valores en la Frontera*. Limusa Wiley, 11th edition.

[Zill, 2018] Zill, D. G. (2018). *Ecuaciones Diferenciales con Aplicaciones de Modelado*. Cengage Learning, 11th edition.

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ID203 Technical and professional English V (Mandatory)

1. General information

- **Semester**: 6th Sem. **Credits**: 2
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - ID202 Technical and professional English IV (5th Sem-Pg. 355)

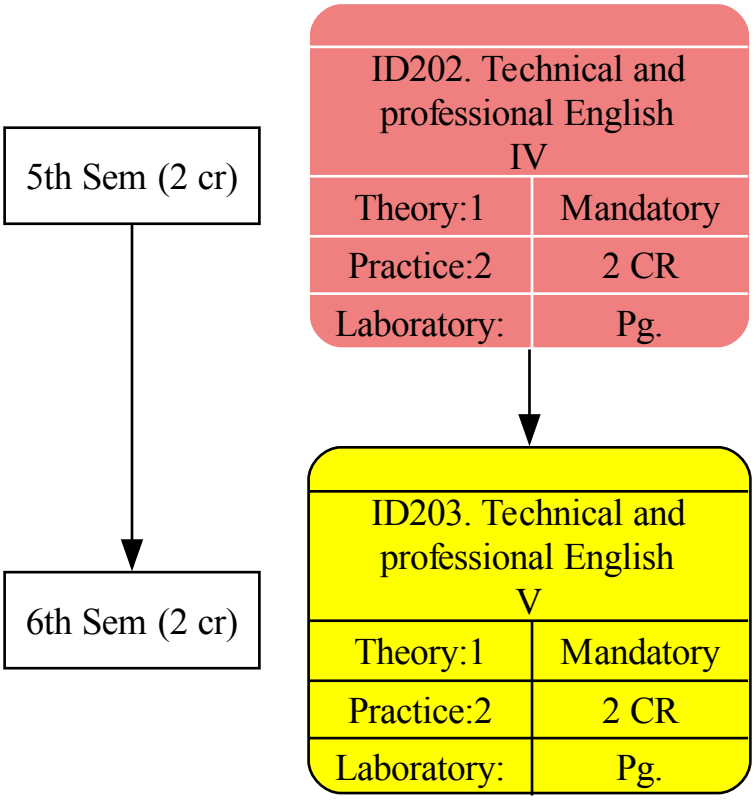

Figure 7.32: Connection Map. ID203 Technical and professional English V

2. Course Rationale

A fundamental part of the integral formation of a professional is the ability to communicate in a foreign language in addition to the native language itself. In the engineering and computing career, technical English is the most critical tool for accessing the forefront of knowledge and research, writing scientific papers, participating in international conferences, and collaborating in global teams. This course brings students to the level of autonomous technical communicators capable of producing and critically evaluating academic and professional content.

3. Goals of the Course

- Increase the ability and fluency to communicate complex technical ideas in English.

- Ensure that students interact with emphasis on scientific argumentation and advanced technical writing.
- Master vocabulary for software engineering, data science, and systems research.

4. General Competences (*Outcomes*)

ABET-3) An ability to communicate effectively with a range of audiences. (Familiarity)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Familiarity)

5. Content

5.1 Scientific Argumentation, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Advanced review of auxiliary verbs and verb tenses in academic writing. **II:** Negative questions and emphatic answers in scientific debate. **III:** Word formation: Prefixes and suffixes common in computing and science. **IV:** Correcting misconceptions: Refuting claims in technical discussions.

Learning Outcomes I: By the end of the unit, students use auxiliaries and tenses precisely to construct scientific arguments, challenge erroneous technical claims, and engage in structured academic debate.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.2 Research Methodology, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Present Simple vs. Present Continuous: Distinguishing general facts from ongoing experiments. **II:** State verbs and action verbs in experimental descriptions. **III:** Vocabulary: Research design, experimental variables, data collection methods. **IV:** Writing: Description of a research method or experimental procedure.

Learning Outcomes I: Students differentiate between stative and progressive uses to accurately describe scientific laws, ongoing experiments, and research methodologies in computing and engineering.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.3 Case Studies, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Narrative tenses: Simple Past, Past Continuous, and Past Perfect in case study analysis. **II:** Structure of "Used to" and "Would" for describing legacy systems and past practices. **III:** Vocabulary: Historical computing cases, paradigm shifts, engineering lessons learned. **IV:** Writing: Structured case study report on a computing incident or innovation.

Learning Outcomes I: Students analyze and narrate sequences of technical events and historical computing cases fluently, applying narrative tenses correctly in professional case study reports.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.4 Research Proposals, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Predictions and plans: Future tense review for academic proposal writing. **II:** Future Continuous and Future Perfect in project scope and outcomes. **III:** Vocabulary: Research objectives, expected contributions, scope and limitations. **IV:** Writing: Short research proposal or technical project abstract.

Learning Outcomes I: Students project research goals and anticipated outcomes, and make evidence-based predictions about the evolution of technology using appropriate future forms in formal academic writing.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.5 Technical Documentation, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Verb patterns (Verbs followed by -ing or infinitive) in instructional writing. **II:** Expressions with "Like" for analogies and technical comparisons. **III:** Vocabulary: API documentation, user manuals, technical specifications. **IV:** Debates: Standards for open-source documentation and reproducibility.

Learning Outcomes I: Students use complex verb patterns to write clear, precise technical documentation and use analogical reasoning to explain technical concepts to diverse audiences.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.6 Long-term Projects, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Present Perfect Continuous vs. Simple Present Perfect in research progress reports. **II:** Modal verbs of deduction (Present and Past) for interpreting experimental results. **III:** Vocabulary: Long-running systems, sustained research programs, startup development. **IV:** Oral presentations: "Progress report on a computing research project".

Learning Outcomes I: Students discuss long-term research and development activities, make deductions about technical outcomes, and present progress reports on computing projects with appropriate academic register.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.7 Advanced Technical Writing, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Relative clauses (Defining vs. Non-defining) in technical paper writing. **II:** Advanced passive voice in formal scientific and engineering prose. **III:** Vocabulary: Peer review, impact factors, citation practices, open access. **IV:** Writing: Abstract and introduction section of a computing research paper.

Learning Outcomes I: Students write precise, well-structured technical and scientific texts using relative clauses and advanced passive constructions to add depth and clarity to research writing.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

5.8 English for Software Engineering, 12 hr(s)

Competences: ABET-3,ABET-5

Topics: I: Agile Methodologies: Scrum, Kanban, and XP terminology in English. **II:** QA (Quality Assurance) and Testing: Test plans, bug reports, acceptance criteria. **III:** Software requirements documentation: user stories, use cases, specifications. **IV:** Simulation: Technical team meeting (Sprint planning and retrospective).

Learning Outcomes I: By the end of the course, students command software engineering and project management terminology, can produce professional technical documents, and actively participate in international technical meetings and reviews in English.

Bibliography: [Soars and John, 2002g, Soars and John, 2002i, Soars and John, 2002h, Cambridge, 2006, MacGrew, 1999]

6. Bibliography

[Cambridge, 2006] Cambridge (2006). *Diccionario Inglés-Espanol Cambridge*. Editorial Oxford.

[MacGrew, 1999] MacGrew, J. (1999). *Focus on Grammar Basic*. Editorial Oxford.

[Soars and John, 2002g] Soars, L. and John (2002g). *American Headway N 3 Student Book*. Editorial Oxford.

[Soars and John, 2002h] Soars, L. and John (2002h). *American Headway N 3 Teachers Book*. Editorial Oxford.

[Soars and John, 2002i] Soars, L. and John (2002i). *American Headway N 3 Work Book*. Editorial Oxford.

Seventh Semester

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

CE2C1 Materials Technology (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE3M1 Concrete Technology (4th Sem-Pg. 332)

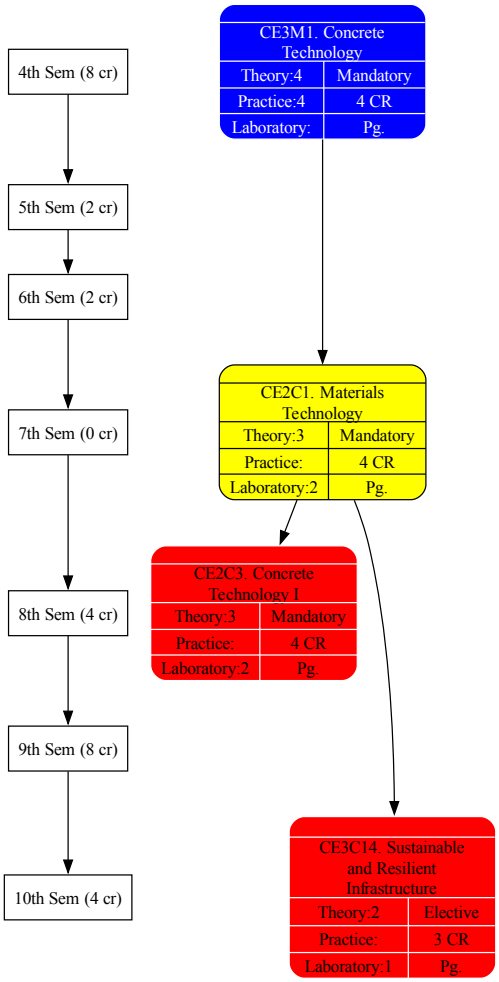

Figure 7.33: Connection Map. CE2C1 Materials Technology

2. Course Rationale

Materials Technology covers the science and technology of the main materials used in construction: traditional and vernacular materials (rocks, adobe, quincha, rammed earth, bamboo), concrete and advanced cementitious materials, structural metals, polymeric and sustainable composite materials,

and standardized quality control and failure analysis testing. The course concludes with design in masonry, timber, and light-gauge steel.

3. Goals of the Course

- Characterize the physical and mechanical properties of traditional and modern construction materials.
- Apply concrete and structural metals technology to the design and quality control of construction elements.
- Perform standardized quality control tests and interpret failure analysis results.
- Design elements in masonry, timber, and light-gauge steel.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Construction Materials Science, 10 hr(s)

Competences: ABET-1

Topics: **I:** Physical and mechanical properties of construction materials including density, porosity, strength, and elasticity **II:** Microstructure and phase composition of construction materials **III:** Durability mechanisms including weathering, chemical attack, and environmental degradation **IV:** Thermal and moisture properties of construction materials **V:** Crystalline and amorphous structures in construction materials **VI:** Material selection criteria based on performance requirements **VII:** Degradation mechanisms and service life prediction

Learning Outcomes **I:** Describe the fundamental physical and mechanical properties of major construction materials [Familiarity] **II:** Analyze the relationship between microstructure and macroscopic properties of materials [Assessment] **III:** Evaluate the durability performance of materials under specific environmental conditions [Usage] **IV:** Explain the effects of thermal and moisture variations on material behavior [Familiarity] **V:** Select appropriate construction materials based on design specifications and performance criteria [Assessment] **VI:** Predict service life and degradation patterns of materials in various environments [Usage]

Bibliography: [Neville, 2011]

5.2 Traditional and Vernacular Construction Materials, 18 hr(s)

Competences: ABET-1

Topics: **I:** Construction stone: classification and properties **II:** Adobe as a construction material: fabrication and properties **III:** Quincha as a construction system: materials and technique **IV:** Tapial (rammed earth) as a construction material: fabrication and properties **V:** Bamboo as a construction material: properties and structural applications **VI:** Quality control testing for vernacular construction materials

Learning Outcomes **I:** Classify construction stone by its properties and applications [Familiarity] **II:** Characterize the physical and mechanical properties of adobe, quincha, and tapial [Usage] **III:** Evaluate the suitability of bamboo as a structural material in construction [Assessment]

IV: Perform quality control tests on vernacular construction materials [Usage] **V:** Recommend the use of an appropriate vernacular material based on a project's conditions [Assessment]

Bibliography: [Blondet et al., 2003]

5.3 Concrete Technology and Advanced Cementitious Materials, 14 hr(s)

Competences: ABET-1

Topics: **I:** Portland cement chemistry and hydration process **II:** Aggregates properties and grading requirements **III:** Mix design methodology for normal strength concrete **IV:** Fresh concrete properties including workability, slump, and setting time **V:** Hardened concrete properties including strength, modulus, and shrinkage **VI:** Chemical and mineral admixtures for concrete **VII:** High-performance and high-strength concrete design **VIII:** Self-consolidating concrete and fiber-reinforced concrete **IX:** Durability aspects including alkali-silica reaction, sulfate attack, and freeze-thaw **X:** Sustainable and low-carbon concrete technologies including supplementary cementitious materials such as fly ash, slag, and silica fume

Learning Outcomes **I:** Describe the chemistry of portland cement and the hydration process [Familiarity] **II:** Evaluate aggregate quality and suitability for concrete production [Assessment] **III:** Design concrete mixes for specified strength and workability requirements [Usage] **IV:** Test and interpret fresh concrete properties using standard procedures [Assessment] **V:** Predict hardened concrete properties based on mix proportions and curing conditions [Usage] **VI:** Explain the function and effects of various concrete admixtures [Familiarity] **VII:** Formulate high-performance concrete mixes for demanding applications [Usage] **VIII:** Select appropriate special concretes for specific construction scenarios [Assessment] **IX:** Incorporate supplementary cementitious materials to optimize concrete performance [Usage] **X:** Analyze durability risks and specify protective measures for concrete structures [Assessment] **XI:** Compare environmental impacts and carbon footprints of different concrete formulations [Familiarity]

Bibliography: [Neville, 2011]

5.4 Structural Metals, Alloys, and Corrosion Engineering, 5 hr(s)

Competences: ABET-1

Topics: **I:** Steel composition, classification, and grade designations **II:** Mechanical properties of structural steel including yield strength and ductility **III:** Heat treatment processes and their effects on steel properties **IV:** Weldability and connection behavior of structural metals **V:** Corrosion mechanisms in metallic structures **VI:** High-strength and weathering steel applications **VII:** Aluminum alloys and their structural applications **VIII:** Fatigue behavior and fracture toughness of metals **IX:** Corrosion protection methods including coatings and cathodic protection **X:** Material selection for corrosive and high-temperature environments

Learning Outcomes **I:** Identify different steel grades and their appropriate structural applications [Familiarity] **II:** Interpret stress-strain curves and determine mechanical properties of metals [Assessment] **III:** Explain how heat treatment affects the microstructure and properties of steel [Familiarity] **IV:** Evaluate weldability of metals and specify appropriate welding procedures [Usage] **V:** Describe the electrochemical basis of metallic corrosion [Familiarity] **VI:** Select high-strength or weathering steel for specific structural requirements [Usage] **VII:** Compare aluminum alloys with steel for lightweight structural applications [Assessment] **VIII:** Analyze fatigue loading scenarios and predict service life of metal components [Assessment] **IX:** Design corrosion protection systems for metallic structures in aggressive environments [Usage] **X:** Specify appropriate materials for structures exposed to extreme conditions [Assessment]

Bibliography: [Callister and Rethwisch, 2020]

5.5 Polymeric, Composite, and Sustainable Construction Materials, 4 hr(s)

Competences: ABET-1

Topics: **I:** Polymer chemistry and classification of construction polymers **II:** Mechanical and thermal behavior of polymeric materials **III:** Fiber-reinforced polymer composites and their structural applications **IV:** Adhesives, sealants, and waterproofing materials **V:** Composite material mechanics and laminate theory **VI:** FRP strengthening and rehabilitation of concrete and masonry structures **VII:** Bio-based and recycled materials for sustainable construction **VIII:** Geopolymers and alternative binder systems **IX:** Environmental degradation and long-term performance of polymers and composites

Learning Outcomes **I:** Classify polymers used in construction and describe their basic properties [Familiarity] **II:** Characterize the mechanical and thermal behavior of polymeric materials [Assessment] **III:** Apply fiber-reinforced polymers in structural design and retrofitting applications [Usage] **IV:** Select appropriate adhesives and sealants for specific construction applications [Familiarity] **V:** Analyze composite laminates using classical lamination theory [Usage] **VI:** Design FRP strengthening systems for existing concrete or masonry structures [Assessment] **VII:** Evaluate the sustainability and life-cycle performance of bio-based construction materials [Assessment] **VIII:** Compare geopolymer binders with traditional portland cement systems [Familiarity] **IX:** Predict long-term degradation of polymers and composites under environmental exposure [Usage]

Bibliography: [Callister and Rethwisch, 2020]

5.6 Standardized Testing, Quality Control, and Failure Analysis, 5 hr(s)

Competences: ABET-6

Topics: **I:** Standard test methods for material characterization and acceptance testing **II:** Sampling procedures and representative sample selection **III:** Quality control and quality assurance protocols in construction **IV:** Statistical analysis of test data and acceptance criteria **V:** Nondestructive testing methods for materials and structures **VI:** Advanced material characterization techniques including microscopy and spectroscopy **VII:** Failure analysis methodology and root cause investigation **VIII:** Forensic engineering and distress evaluation **IX:** Performance-based testing and specification approaches **X:** Certification, compliance, and third-party testing requirements

Learning Outcomes **I:** Perform standard material tests according to ASTM or equivalent specifications [Usage] **II:** Develop appropriate sampling plans for construction material acceptance [Assessment] **III:** Implement quality control procedures for construction materials and processes [Usage] **IV:** Analyze test data using statistical methods and establish acceptance criteria [Assessment] **V:** Apply non-destructive testing techniques for in-situ material evaluation [Familiarity] **VI:** Utilize advanced characterization techniques to investigate material microstructure [Usage] **VII:** Conduct systematic failure analysis to determine root causes of material distress [Assessment] **VIII:** Investigate structural failures using forensic engineering methodologies [Assessment] **IX:** Design performance-based test protocols for innovative materials [Usage] **X:** Interpret certification requirements and coordinate third-party testing programs [Familiarity]

Bibliography: [Neville, 2011]

5.7 Masonry Structural Design, 4 hr(s)

Competences: ABET-2

Topics: **I:** Masonry materials, units, and mortar properties **II:** Unreinforced masonry wall design for compression and flexure **III:** Reinforced masonry design and detailing **IV:** Seismic design of masonry and timber structures

Learning Outcomes I: Identify masonry unit types and specify appropriate mortar for applications [Familiarity] **II:** Design unreinforced masonry walls for gravity and lateral loads [Assessment] **III:** Proportion reinforced masonry elements and specify reinforcement details [Usage] **IV:** Implement seismic design provisions for masonry and timber buildings [Usage]

Bibliography: [Drysdale and Hamid, 2008]

5.8 Timber and Light-Gauge Steel Framing Design, 6 hr(s)

Competences: ABET-2

Topics: I: Timber properties, grading, and design values **II:** Sawn lumber and glued-laminated timber design **III:** Timber connections including nails, bolts, and metal connectors **IV:** Cold-formed steel members and sectional properties **V:** Light-gauge steel framing systems and design **VI:** Engineered wood products including I-joists and structural composite lumber

Learning Outcomes I: Select timber species and grades based on structural requirements [Familiarity] **II:** Design timber beams, columns, and combined loading members [Assessment] **III:** Specify timber connections and calculate their capacity [Usage] **IV:** Calculate effective section properties for cold-formed steel members [Assessment] **V:** Design light-gauge steel wall studs and floor joists [Usage] **VI:** Apply engineered wood products in floor and roof systems [Assessment]

Bibliography: [Drysdale and Hamid, 2008]

6. Bibliography

[Blondet et al., 2003] Blondet, M., Garcia, G. V., and Brzev, S. (2003). Earthquake-resistant construction of adobe buildings: A tutorial. Technical report, EERI/IAEE World Housing Encyclopedia.

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[Drysdale and Hamid, 2008] Drysdale, R. G. and Hamid, A. A. (2008). *Masonry Structures: Behavior and Design*. Masonry Society, 3rd edition.

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CE2C2 Construction Technology I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 1 hours;
- **Prerrequisites**:
  - CE3M1 Concrete Technology (4th Sem-Pg. 332)

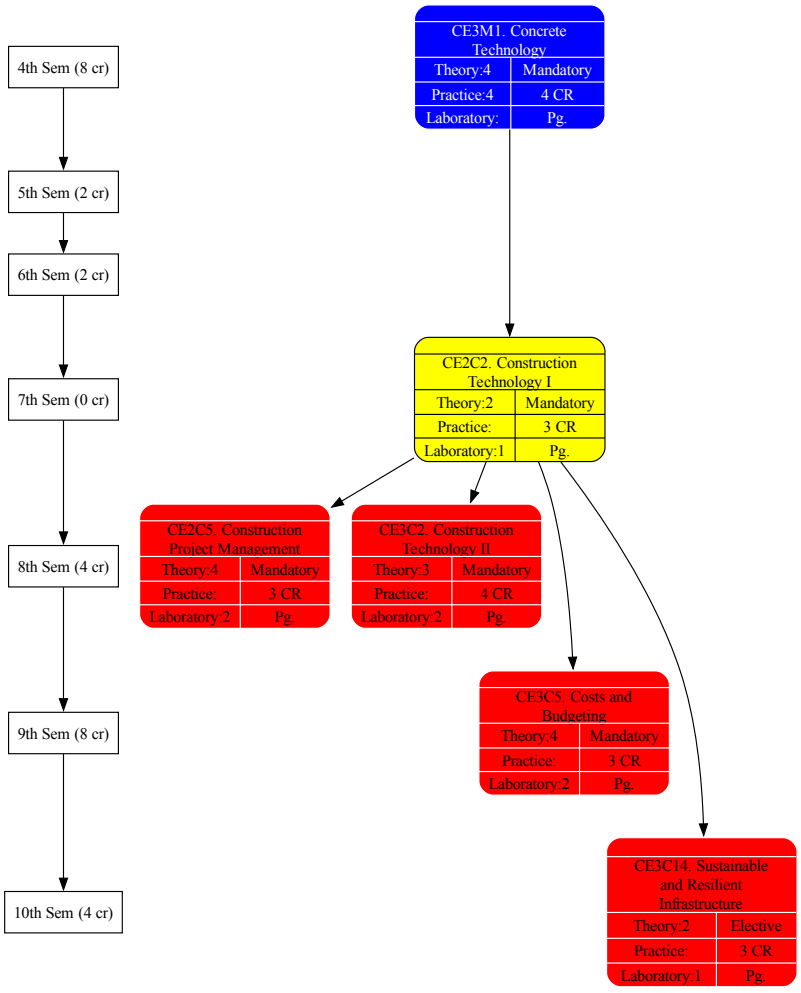

Figure 7.34: Connection Map. CE2C2 Construction Technology I

2. Course Rationale

Construction Technology I covers construction methods, equipment, and productivity, including earthmoving and construction processes for concrete and steel structures. The course also includes safety and risk management on construction sites, and an introduction to digital construction technologies (BIM) for project management.

3. Goals of the Course

- Select appropriate methods, equipment, and construction processes for earthmoving operations and structural construction.
- Measure and analyze the productivity of construction operations.
- Apply safety and risk management principles on construction sites.
- Use BIM tools for digital management of construction projects.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Construction Methods, Equipment, and Productivity, 38 hr(s)

Competences: ABET-2

Topics: **I:** Earthwork operations: excavation, hauling, compaction, and mass diagrams **II:** Concrete construction: formwork, placing, finishing, and curing **III:** Steel erection, connection, and safety procedures **IV:** Construction equipment types, capabilities, and selection criteria **V:** Productivity measurement, cycle time analysis, and crew balancing **VI:** Heavy civil construction methods for tunnels, dams, and bridges **VII:** Equipment economics: ownership vs. rental, depreciation, and operating cost **VIII:** Trenchless technologies and deep excavation support systems **IX:** Automation and robotics in construction operations

Learning Outcomes **I:** Select appropriate construction equipment for common earthwork and material handling tasks [Usage] **II:** Design basic formwork and shoring for a concrete slab or wall [Assessment] **III:** Explain the sequence and safety considerations for steel erection [Familiarity] **IV:** Calculate productivity rates and cycle times for equipment operations [Usage] **V:** Balance a construction crew to optimize productivity for a given task [Assessment] **VI:** Compare construction methods for a heavy civil project like a cut-and-cover tunnel [Assessment] **VII:** Analyze the economic life and hourly cost of a piece of construction equipment [Usage] **VIII:** Describe the applications and limitations of trenchless construction technologies [Familiarity] **IX:** Evaluate the potential for automation to improve safety and productivity on a construction site [Assessment]

Bibliography: [Peurifoy et al., 2018]

5.2 Construction Safety, Health, and Risk Management, 4 hr(s)

Competences: ABET-1

Topics: **I:** Safety management systems and the role of safety culture **II:** Common construction hazards: falls, struck-by, electrocution, caught-in/between **III:** Occupational Safety and Health Administration (OSHA) regulations and compliance **IV:** Risk identification and assessment techniques (e.g., JSA, checklists) **V:** Hierarchy of controls: elimination, substitution, engineering, administrative, PPE **VI:** Occupational health: silica, noise, ergonomics, and industrial hygiene **VII:** Emergency response planning and incident investigation **VIII:** Insurance and bonding principles for construction risk transfer **IX:** Proactive safety leading indicators and predictive analytics

Learning Outcomes **I:** Identify the "Fatal Four" construction hazards and basic OSHA requirements for each [Familiarity] **II:** Conduct a Job Safety Analysis (JSA) for a common construction task [Assessment] **III:** Develop a site-specific safety plan for a given project scenario [Usage] **IV:** Apply the hierarchy of controls to mitigate an identified safety risk [Familiarity] **V:** Evaluate occupational health exposures (e.g., noise, dust) and recommend monitoring strategies [Assessment] **VI:** Create an emergency response plan for a construction site [Usage] **VII:** Explain the purpose and types of insurance (e.g., CGL, workers' comp) in construction risk management [Familiarity] **VIII:** Propose leading safety indicators to track and predict site safety performance [Assessment]

Bibliography: [Hinze, 2005]

5.3 Building Information Modeling (BIM) for Digital Delivery and Asset Management, 2 hr(s)

Competences: ABET-6

Topics: **I:** BIM concepts: dimensions (3D, 4D, 5D, 6D, 7D), LOD, and LOIN **II:** BIM authoring tools and parametric modeling techniques **III:** Model coordination, clash detection, and interference checking **IV:** Collaboration platforms, Common Data Environments (CDE), and BIM execution plans **V:** BIM-based analysis: quantity takeoff, energy simulation, and structural analysis **VI:** Digital twins and the connection between BIM and operational data **VII:** Interoperability standards: IFC, COBie, and openBIM **VIII:** Asset information models (AIM) and BIM for facilities management (FM) **IX:** Regulatory submission and automated code compliance checking

Learning Outcomes **I:** Define the different dimensions of BIM (3D-7D) and their associated information [Familiarity] **II:** Create a basic 3D parametric model of a structural framing system using BIM software [Usage] **III:** Perform a clash detection analysis between architectural and structural models [Assessment] **IV:** Outline the key components of a BIM Execution Plan (BEP) [Familiarity] **V:** Extract a material quantity takeoff schedule from a BIM model [Usage] **VI:** Explain the relationship between a BIM model and a digital twin for an asset [Familiarity] **VII:** Export a BIM model using the IFC format to ensure interoperability [Usage] **VIII:** Develop an Asset Information Model (AIM) deliverable for handover to a facility manager [Assessment] **IX:** Evaluate the potential of automated rule-checking for building code compliance [Assessment]

Bibliography: [Eastman et al., 2018]

6. Bibliography

[Eastman et al., 2018] Eastman, C., Teicholz, P., Sacks, R., and Lee, G. (2018). *BIM Handbook: A Guide to Building Information Modeling.* Wiley, 3rd edition.

[Hinze, 2005] Hinze, J. W. (2005). *Construction Safety.* Prentice Hall, 2nd edition.

[Peurifoy et al., 2018] Peurifoy, R. L., Schexnayder, C. J., Shapira, A., and Jha, K. N. (2018). *Construction Planning, Equipment, and Methods.* McGraw-Hill, 9th edition.

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CE2C6 Territorial Planning (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE1G1 General Geology (2nd Sem-Pg. 270)

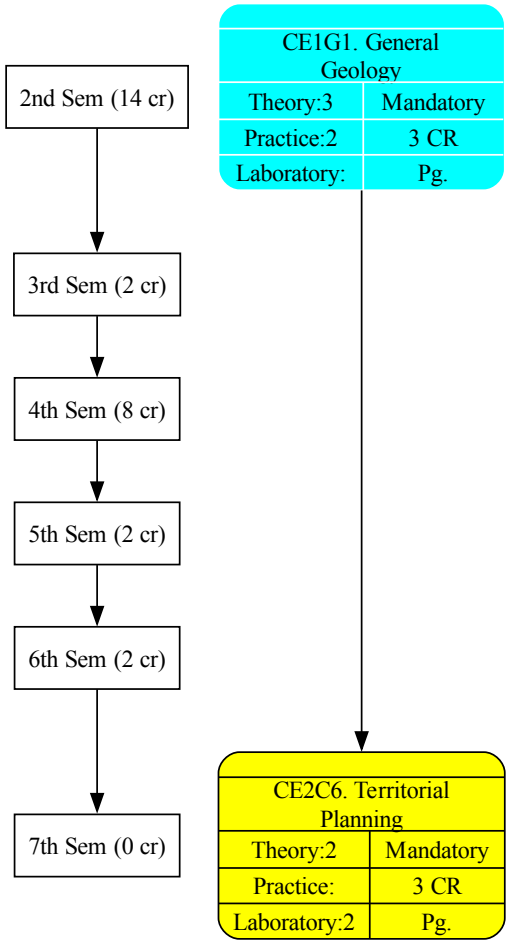

Figure 7.35: Connection Map. CE2C6 Territorial Planning

2. Course Rationale

Territorial Planning I introduces the historical process of human settlement and territorial planning, planning theories and methodologies, and the different types and modalities of urban and territorial planning through case studies.

3. Goals of the Course

- Describe the historical process of human settlement and its relationship with territorial planning.

- Apply planning theories and methodologies to the analysis of a territory.
- Distinguish the types and modalities of urban and territorial planning based on case studies.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Historical Urban Planning Theories, 15 hr(s)

Competences: ABET-1

Topics: I: Classic urban theories: Howard's Garden City, Le Corbusier's Radiant City (Towers in the Park), Wright's Broadacre City, and their influence on 20th-century planning and zoning **II:** Post-WWII planning: the rise of the master plan, Team 10 critique of CIAM, Jane Jacobs' advocacy for mixed-use and short blocks,

Learning Outcomes I: Describe the key historical urban planning theories and their influence on 20th-century city form, and explain the shift from master planning to strategic [Familiarity]

Bibliography: [Hall and Tewdwr-Jones, 2014]

5.2 Contemporary Planning Methods and Theory, 29 hr(s)

Competences: ABET-1

Topics: I: Planning methods: zoning (Euclidean, form-based, performance-based), master planning vs. strategic planning, public participation (charrettes, community workshops **II:** Smart growth and new urbanism: principles (transit-oriented development, walkability, mixed-income housing, urban growth boundaries), Andrés Duany's transect, **III:** Contemporary urban theory: Lefebvre's production of space, Harvey's right to the city, Sennett's open city, and the role of informality, participation, **IV:** Integration of civil engineering technical constraints (structural, geotechnical, utility infrastructure, and transportation) into urban planning and architectural design frameworks; the collaborative role of civil engineers in multidisciplinary building and urban project teams

Learning Outcomes I: Apply a planning method - such as form-based coding or scenario planning - to a specific urban site, producing land use or built form regulations that align with stated policy [Usage] **II:** Evaluate a current urban plan or zoning code against contemporary planning principles (walkability, mixed-use, transit orientation, social equity), identifying strengths [Assessment]

Bibliography: [Hall and Tewdwr-Jones, 2014]

5.3 Urban Design at Multiple Scales, 12 hr(s)

Competences: ABET-2

Topics: I: Regional and city scale: transit corridors, green belts, growth boundaries, satellite towns, and the relationship between density **II:** Neighborhood scale: walkability (5-10 minute walking radius), mixed-use zoning, social infrastructure (schools, clinics, community centers), and the 20-minute neighborhood concept **III:** Block and street scale: block length for pedestrian permeability (80-120 m max), street section design (lane widths, sidewalks, bike lanes, street trees, furniture zone), **IV:** Public space design: squares, plazas, parks, pocket parks, and streets

as public space; William Whyte's elements of successful public space (sittable space, sun, food **V:** Urban design guidelines: building setbacks, height limits, architectural character, facade articulation, signage, lighting,

Learning Outcomes **I:** Describe the key design considerations at each urban scale - regional, neighborhood, block, street, and public space - [Familiarity] **II:** Develop a set of urban design guidelines for a specific neighborhood or street typology, integrating density, building height, block length, street section, [Usage] **III:** Evaluate an urban design project for its multi-scale coherence, assessing how well it integrates regional transit, neighborhood walkability, block permeability, street safety, [Assessment]

Bibliography: [Hall and Tewdwr-Jones, 2014]

6. Bibliography

[Hall and Tewdwr-Jones, 2014] Hall, P. and Tewdwr-Jones, M. (2014). *Urban and Regional Planning*. Routledge, 6th edition.

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CE2C8 Business Management in Construction I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - BEC101 General Economics (1st Sem-Pg. 266)

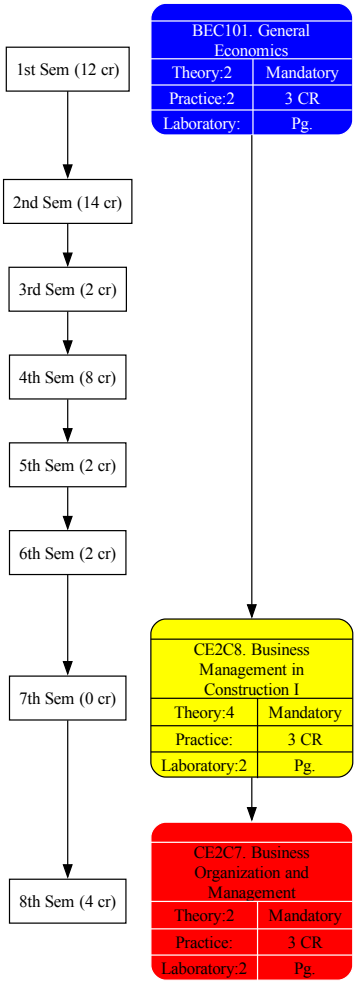

Figure 7.36: Connection Map. CE2C8 Business Management in Construction I

2. Course Rationale

Business Management in Construction I applies the fundamentals of business administration – contract law, project finance, cost accounting, entrepreneurship, marketing, labor regulation, and managerial decision-making – to the specific problem of running a construction company. Building on the introductory organizational and operational concepts covered in Organization and Business Management, this course equips the future civil engineer to negotiate and manage construction contracts,

evaluate the financial viability of projects and control their costs, structure and market a construction business, comply with labor regulation, and make sound managerial decisions under the risk and uncertainty typical of the construction sector.

3. Goals of the Course

- Analyze the formation, terms, breach, and remedies of construction contracts.
- Apply capital budgeting techniques to evaluate the financial viability of construction investment projects.
- Apply cost-volume-profit analysis, budgeting, and variance analysis to control the costs of a construction company.
- Design and validate the business model of a construction company using the Business Model Canvas and customer discovery techniques.
- Design a digital marketing strategy for construction services.
- Explain the employment-law and regulatory-compliance obligations of a construction employer.
- Apply managerial decision-making models under risk and uncertainty to construction management problems.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Contract Law and Business Transactions, 14 hr(s)

Competences: ABET-1

Topics: **I:** Elements of a valid contract: offer, acceptance, consideration, capacity, and legality **II:** Express and implied terms, exclusion clauses, misrepresentation, and frustration of contracts **III:** Breach of contract: types, consequences, and remedies (damages, specific performance, rescission) **IV:** E-contracts and digital signatures: legal validity, electronic signature laws (eIDAS, ESIGN), and click-wrap and browse-wrap agreements

Learning Outcomes **I:** Identify the essential elements of a legally binding contract and the circumstances that render contracts void or voidable [Familiarity] **II:** Apply contract law principles to analyze the legal enforceability of a business agreement [Usage] **III:** Evaluate contractual remedies available in a given breach scenario and recommend appropriate legal action [Assessment]

Bibliography: [Clarkson et al., 2021]

5.2 Capital Budgeting and Investment Decisions, 12 hr(s)

Competences: ABET-2

Topics: **I:** Net present value (NPV), internal rate of return (IRR), modified IRR, and their decision rules **II:** Payback period, discounted payback, and profitability index as capital budgeting criteria **III:** Sensitivity analysis, scenario analysis, Monte Carlo simulation, and break-even analysis in capital projects **IV:** Real options in capital investment: option to expand, abandon, or defer; recognizing strategic flexibility in project valuation

Learning Outcomes I: Explain the NPV rule and its superiority over alternative capital budgeting criteria [Familiarity] **II:** Calculate NPV and IRR for a capital project and apply decision rules [Usage] **III:** Evaluate a capital investment proposal under uncertainty using sensitivity and scenario analysis [Assessment]

Bibliography: [Brealey et al., 2020]

5.3 Managerial Accounting and Cost Analysis, 12 hr(s)

Competences: ABET-6

Topics: I: Cost classification: fixed vs. variable, direct vs. indirect, product vs. period, and relevant costs for decisions **II:** CVP analysis: break-even point, contribution margin, margin of safety, and operating leverage **III:** Master budgets, flexible budgets, standard costing, and variance analysis (price and efficiency variances) **IV:** Activity-based costing (ABC): cost drivers, activity pools, overhead allocation accuracy, and ABC versus traditional costing

Learning Outcomes I: Identify different types of costs and explain their relevance for managerial decision-making [Familiarity] **II:** Calculate break-even point, contribution margin, and budget variances for a business unit [Usage] **III:** Evaluate a business unit's performance using variance analysis and flexible budgets [Assessment]

Bibliography: [Garrison et al., 2021]

5.4 Business Model Design and Validation, 12 hr(s)

Competences: ABET-2

Topics: I: Business Model Canvas: nine building blocks (customer segments, value propositions, channels, revenue streams, key resources, key activities, key partnerships, cost structure) **II:** Customer discovery and validation: problem interviews, solution interviews, and pivot vs. persevere decisions **III:** Minimum viable product (MVP): design principles, lean experimentation, and build-measure-learn feedback loop **IV:** Platform business models and network effects: multi-sided platforms, winner-take-all dynamics, and monetization strategies for digital platforms

Learning Outcomes I: Describe the components of the Business Model Canvas and explain how they interact to create and deliver value [Familiarity] **II:** Design a business model canvas for a new venture idea and identify key assumptions to test [Usage] **III:** Evaluate a startup's business model for internal consistency and market viability [Assessment]

Bibliography: [Osterwalder and Pigneur, 2010]

5.5 Digital Marketing, 10 hr(s)

Competences: ABET-1

Topics: I: SEO, SEM, and social media marketing: platforms, algorithms, organic vs. paid reach, and community management **II:** Content marketing strategy: content types, editorial calendars, storytelling, and inbound marketing **III:** Digital analytics: web metrics, conversion funnels, A/B testing, and data-driven campaign optimization **IV:** Email marketing and marketing automation: segmentation, drip campaigns, lead nurturing, CRM integration, and deliverability metrics

Learning Outcomes I: Describe the key digital marketing channels and the metrics used to measure their effectiveness [Familiarity] **II:** Develop a digital marketing plan including channel selection, content strategy, and KPI definition [Usage] **III:** Evaluate the ROI of a digital marketing campaign using analytics data [Assessment]

Bibliography: [Chaffey and Ellis-Chadwick, 2019]

5.6 Regulatory Compliance and Employment Law, 12 hr(s)

Competences: ABET-1

Topics: **I:** Antitrust and competition law: prohibited agreements, abuse of dominance, merger control, and enforcement **II:** Data protection regulation: GDPR principles, data subject rights, controller/processor responsibilities, and breach notification **III:** Employment law: contract of employment, wrongful dismissal, discrimination, health and safety, and collective bargaining **IV:** Consumer protection law: unfair commercial practices, product liability, warranty obligations, and redress mechanisms for consumers

Learning Outcomes **I:** Identify the major regulatory frameworks affecting business operations in key domains (competition, data, employment) [Familiarity] **II:** Apply data privacy and employment law principles to analyze a business compliance scenario [Usage] **III:** Design a compliance management framework for a specific regulatory area faced by a business [Assessment]

Bibliography: [Clarkson et al., 2021]

5.7 Managerial Decision-Making, 12 hr(s)

Competences: ABET-2

Topics: **I:** Rational decision-making model vs. bounded rationality; satisficing and heuristics in managerial decisions **II:** Decision-making under risk and uncertainty: expected value, decision trees, and sensitivity analysis **III:** Common cognitive biases (anchoring, overconfidence, availability heuristic) and debiasing strategies **IV:** Group decision-making techniques: Delphi method, nominal group technique, brainstorming, and consensus building processes

Learning Outcomes **I:** Describe the rational model of decision-making and its limitations under bounded rationality [Familiarity] **II:** Construct a decision tree and calculate expected values to support a managerial decision under risk [Usage] **III:** Evaluate how cognitive biases distort managerial decisions and recommend debiasing interventions [Assessment]

Bibliography: [Robbins and Coulter, 2017]

6. Bibliography

[Brealey et al., 2020] Brealey, R. A., Myers, S. C., and Allen, F. (2020). *Principles of Corporate Finance*. McGraw-Hill, 13th edition.

[Chaffey and Ellis-Chadwick, 2019] Chaffey, D. and Ellis-Chadwick, F. (2019). *Digital Marketing*. Pearson, 7th edition.

[Clarkson et al., 2021] Clarkson, K. W., Miller, R. L., and Cross, F. B. (2021). *Business Law: Text and Cases*. Cengage Learning, 15th edition.

[Garrison et al., 2021] Garrison, R. H., Noreen, E. W., and Brewer, P. C. (2021). *Managerial Accounting*. McGraw-Hill, 17th edition.

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[Robbins and Coulter, 2017] Robbins, S. P. and Coulter, M. (2017). *Management*. Pearson, 14th edition.

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CE2G1 Soil Mechanics I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE1G1 General Geology (2nd Sem-Pg. 270)
  - CE2M1 Mechanics of Materials I (4th Sem-Pg. 329)

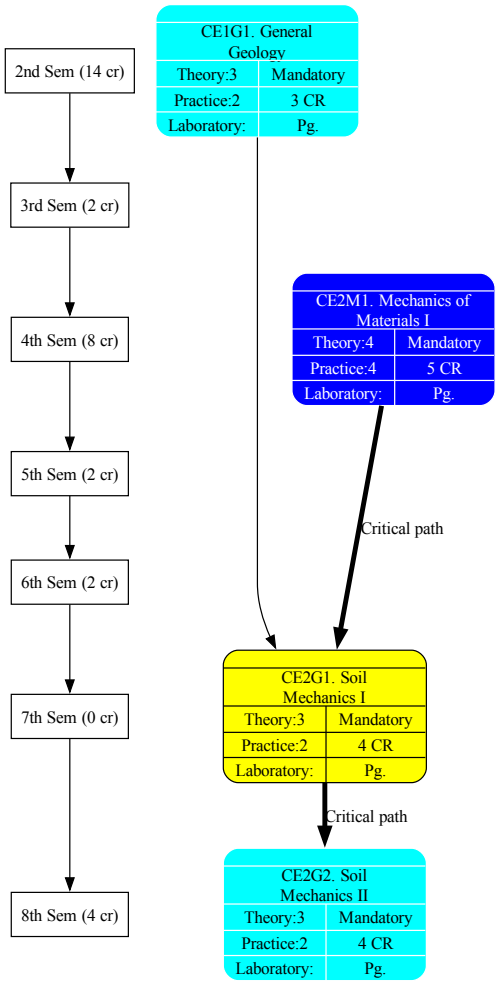

Figure 7.37: Connection Map. CE2G1 Soil Mechanics I

2. Course Rationale

Soil Mechanics I introduces the future civil engineer to soil as an engineering material, building on the descriptive foundations established in General Geology. The course develops the phase-relationship framework used to describe the state of a soil, the classification systems (USCS and AASHTO) used to communicate its expected engineering behavior, the theory and field control of compaction as the primary tool for improving earthwork properties, and the hydraulic behavior of soils — permeability,

seepage, capillarity, and effective stress — that governs the interaction between water and the soil skeleton in geotechnical design. The course closes with an introduction to subsurface exploration and sampling methods, providing the field basis on which the laboratory characterization covered earlier in the course, and the subsequent Geotechnical Engineering sequence (Soil Mechanics II, Foundations, Earth Retaining Structures), are built.

3. Goals of the Course

- Calculate phase relationships and index properties of soils from laboratory data, and relate the origin and formation of soil deposits to their expected engineering behavior.
- Classify soils according to the USCS and AASHTO systems from particle size distribution and Atterberg limit test results.
- Apply compaction theory to specify and control earthwork compaction in the laboratory and in the field.
- Determine soil permeability, construct flow nets, and calculate seepage quantities using Darcy's law.
- Explain the effective stress principle and analyze capillarity and frost action in partially saturated soils.
- Select appropriate subsurface exploration, boring, and sampling methods for a geotechnical investigation program.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Phase Relationships and Seepage, 66 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Phase relationships and index properties of soils **II:** Soil classification systems including USCS and AASHTO **III:** Particle size distribution and Atterberg limits **IV:** Compaction theory and field control methods **V:** Permeability and Darcy's law **VI:** Seepage analysis and flow nets **VII:** Effective stress principle and pore water pressure **VIII:** Capillarity and soil suction **IX:** Frost action and thermal properties of soils

Learning Outcomes **I:** Calculate phase relationships and derive index properties from laboratory data [Usage] **II:** Classify soils according to USCS and AASHTO classification systems [Assessment] **III:** Interpret particle size distribution curves and plasticity charts [Assessment] **IV:** Apply compaction theory to field construction control [Usage] **V:** Determine soil permeability using laboratory and field methods [Assessment] **VI:** Construct flow nets and calculate seepage quantities [Usage] **VII:** Explain the effective stress principle and its engineering significance [Familiarity] **VIII:** Analyze capillary rise and soil suction effects in partially saturated soils [Assessment] **IX:** Evaluate frost susceptibility and design frost protection measures [Familiarity]

Bibliography: [Das, 2019]

5.2 Site Investigation and In-Situ Testing, 4 hr(s)

Competences: ABET-6

Topics: **I:** Investigation planning and scope determination **II:** Boring methods and subsurface exploration techniques **III:** Sampling methods for disturbed and undisturbed samples **IV:** Standard Penetration Test and correlations **V:** Laboratory testing program and test selection **VI:** Cone

Penetration Test and piezocone testing **VII:** Vane shear test and pressuremeter testing **VIII:** Geophysical methods including seismic and resistivity surveys **IX:** Groundwater monitoring and piezometer installation **X:** Report preparation and geotechnical data presentation **XI:** In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment **XII:** Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes **I:** Develop appropriate site investigation programs based on project requirements [Assessment] **II:** Select appropriate boring and exploration methods for different soil conditions [Familiarity] **III:** Specify sampling techniques to obtain quality samples for testing [Usage] **IV:** Interpret SPT data and apply empirical correlations for design parameters [Assessment] **V:** Design laboratory testing programs for geotechnical projects [Usage] **VI:** Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment] **VII:** Apply vane shear and pressuremeter tests for soft clay characterization [Usage] **VIII:** Utilize geophysical methods to complement traditional investigation techniques [Assessment] **IX:** Monitor groundwater conditions and interpret piezometric data [Usage] **X:** Prepare comprehensive geotechnical investigation reports [Assessment] **XI:** Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage] **XII:** Characterize borrow areas for embankment fill material quantity and quality [Assessment]

Bibliography: [Das, 2019]

6. Bibliography

[Das, 2019] Das, B. M. (2019). *Principles of Geotechnical Engineering*. Cengage Learning, 9th edition.

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CE2H1 Fluid Mechanics I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE1M1 Statics (3rd Sem-Pg. 306)
  - CE1M2 Dynamics (4th Sem-Pg. 326)
  - MA211 Calculus IV (4th Sem-Pg. 340)

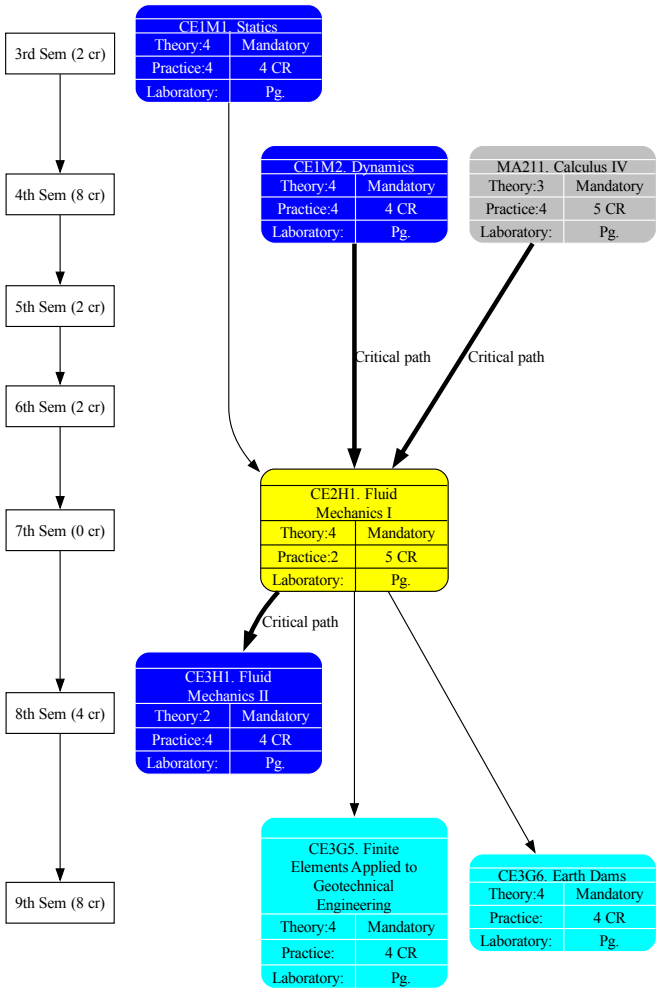

Figure 7.38: Connection Map. CE2H1 Fluid Mechanics I

2. Course Rationale

Fluid Mechanics I is the introductory course in the Hydraulics area that lays the physical and mathematical foundations — mechanics of materials, analytical mechanics, and thermodynamics — necessary to analyze the behavior of fluids at rest and in motion. The course culminates with the formulation of the continuity and Navier-Stokes equations, the resolution of pressurized pipe flow,

and the preliminary design of hydraulic structures, preparing students for subsequent courses in the Hydraulics line.

3. Goals of the Course

- Apply the principles of mechanics of materials and analytical mechanics to the behavior of engineering hydraulic systems.
- Formulate and simplify the continuity and Navier-Stokes equations for civil engineering flow problems.
- Design and verify pressurized pipe flow systems and basic hydraulic structures.
- Recognize the role of numerical methods (finite elements) and thermodynamic tools in modern hydraulic analysis.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Mechanics of Materials and Structural Behavior, 13 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Stress and strain concepts including normal, shear, and principal stresses **II:** Axial loading and deformation of members **III:** Torsion of circular and non-circular sections **IV:** Bending stress and deflection in beams **V:** Shear stress distribution in beams **VI:** Combined loading and stress transformation **VII:** Buckling of columns and stability analysis **VIII:** Fatigue and fracture mechanics **IX:** Elastic and plastic behavior of materials **X:** Energy methods for structural analysis

Learning Outcomes **I:** Define stress, strain, and their relationships through constitutive laws [Familiarity] **II:** Calculate stresses and deformations in members under axial loading [Usage] **III:** Determine torsional stresses and angles of twist in shafts [Usage] **IV:** Analyze bending stress distribution and deflection in beams [Assessment] **V:** Compute shear stress distribution in beam cross-sections [Usage] **VI:** Apply stress transformation equations for combined loading conditions [Assessment] **VII:** Evaluate column stability and calculate critical buckling loads [Assessment] **VIII:** Explain fatigue failure mechanisms and predict fatigue life [Familiarity] **IX:** Distinguish between elastic and plastic material behavior under loading [Usage] **X:** Use energy methods to solve deflection and indeterminate structural problems [Usage]

Bibliography: [Hibbeler, 2017]

5.2 Kinematics and Dynamics of Particles, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Vector description of position, velocity, and acceleration in Cartesian, polar, and spherical coordinates **II:** Newton's three laws of motion and inertial reference frames **III:** Formulation and solution of equations of motion for constant and variable forces **IV:** Static and kinetic friction forces, including angle of repose **V:** Numerical integration of equations of motion for engineering dynamics problems

Learning Outcomes **I:** Formulate the equations of motion for a particle in one, two, and three dimensions given a force law [Usage] **II:** Identify all forces acting on a particle and draw a correct free-body diagram [Familiarity] **III:** Calculate the terminal velocity of an object falling through a fluid with drag resistance [Assessment] **IV:** Implement a numerical algorithm to simulate the dynamics of an engineering mechanical system [Usage] **V:** Construct and interpret phase space diagrams for simple engineering oscillatory systems [Assessment]

Bibliography: [Goldstein et al., 2002]

5.3 Non-Inertial Reference Frames and Fictitious Forces, 21 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Transformations between inertial and accelerating reference frames **II:** Centrifugal force defined as $F_{cent} = -m\vec{\omega} \times (\vec{\omega} \times \vec{r}')$ **III:** Coriolis force defined as $F_{Cor} = -2m\vec{\omega} \times \vec{v}'$ **IV:** Euler force for non-constant rotation: $F_{Euler} = -m\frac{d\vec{\omega}}{dt} \times \vec{r}'$ **V:** Effective gravity on the rotating Earth: $g_{eff} = g - \vec{\omega} \times (\vec{\omega} \times \vec{R})$ **VI:** Foucault pendulum as a demonstration of the Earth's rotation **VII:** Coriolis effect on global weather patterns and ocean currents **VIII:** Larmor precession in magnetic fields viewed as a rotating frame effect **IX:** Tidal forces as differential gravitational effects in co-rotating frames **X:** Connection to General Relativity's equivalence principle

Learning Outcomes **I:** Transform Newton's second law to a uniformly rotating reference frame [Usage] **II:** Calculate centrifugal and Coriolis forces for given positions and velocities in a rotating frame [Usage] **III:** Predict the deflection direction of projectiles due to the Earth's rotation through the Coriolis effect [Assessment] **IV:** Explain the precession of a Foucault pendulum in terms of the Earth's rotation [Familiarity] **V:** Compute effective gravitational acceleration at different latitudes on Earth [Usage] **VI:** Analyze Larmor precession using the concept of rotating reference frames [Assessment] **VII:** Compare tidal forces to centrifugal forces in co-rotating systems [Assessment]

Bibliography: [Goldstein et al., 2002]

5.4 Lagrangian and Hamiltonian Mechanics, 21 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Principle of least action and Hamilton's principle of stationary action **II:** Lagrangian definition: $L = T - V$ for conservative systems **III:** Euler-Lagrange equations of motion: $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) = \frac{\partial L}{\partial q_i}$ **IV:** Generalized coordinates and the treatment of holonomic constraints **V:** Cyclic coordinates and the associated conservation laws **VI:** Legendre transform from the Lagrangian to the Hamiltonian: $H = \sum p_i \dot{q}_i - L$ **VII:** Hamilton's equations: $\dot{q}_i = \frac{\partial H}{\partial p_i}$ and $\dot{p}_i = -\frac{\partial H}{\partial q_i}$ **VIII:** Poisson brackets: $\{f, g\} = \sum\left(\frac{\partial f}{\partial q_i}\frac{\partial g}{\partial p_i} - \frac{\partial f}{\partial p_i}\frac{\partial g}{\partial q_i}\right)$ **IX:** Canonical transformations and their generating functions **X:** Action-angle variables for periodic Hamiltonian systems

Learning Outcomes **I:** Construct the Lagrangian for simple mechanical systems in appropriate generalized coordinates [Usage] **II:** Derive equations of motion from the Euler-Lagrange equations [Usage] **III:** Identify cyclic coordinates and their associated conserved quantities in a given Lagrangian [Assessment] **IV:** Formulate the Hamiltonian from a given Lagrangian system [Usage] **V:** Solve Hamilton's equations for simple systems such as the harmonic oscillator [Usage] **VI:** Compute Poisson brackets for pairs of dynamical variables [Usage] **VII:** Apply canonical transformations to simplify the description of Hamiltonian systems [Usage]

Bibliography: [Goldstein et al., 2002]

5.5 Continuum Mechanics Foundations, 8 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Continuum hypothesis and the definition of density fields **II:** Stress tensor σ_{ij} and the concept of force per unit area **III:** Strain tensor ϵ_{ij} as a measure of local deformation **IV:** Hooke's law for isotropic materials: $\sigma_{ij} = \lambda\epsilon_{kk}\delta_{ij} + 2\mu\epsilon_{ij}$ **V:** Navier-Stokes equation for viscous fluids: $\rho\left(\frac{\partial\vec{v}}{\partial t} + \vec{v}\cdot\nabla\vec{v}\right) = -\nabla p + \mu\nabla^2\vec{v} + \vec{f}$ **VI:** Bernoulli's principle for inviscid and incompressible fluid flow **VII:** Conservation of mass and the continuity equation: $\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0$ **VIII:** Conservation of momentum expressed in continuum mechanics form **IX:** Wave propagation in elastic media including P-waves and S-waves **X:** Viscosity and the rheology of non-Newtonian fluids

Learning Outcomes **I:** Interpret the physical meaning of the components of the stress tensor [Familiarity] **II:** Calculate strain tensor components for simple deformations [Usage] **III:** Apply Hooke's law to relate stress and strain for isotropic elastic materials [Usage] **IV:** Simplify the Navier-Stokes equation for special cases such as steady or inviscid flow [Usage] **V:** Apply Bernoulli's principle to calculate pressure variations in fluid flow [Usage] **VI:** Derive the continuity equation from the principle of mass conservation [Usage] **VII:** Analyze different wave propagation modes in elastic solids [Assessment]

Bibliography: [Mase et al., 2010]

5.6 Laws of Thermodynamics and State Functions, 4 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Zeroth Law of Thermodynamics and temperature equilibrium **II:** First Law of Thermodynamics: $dU = dQ - dW$ for engineering systems **III:** Enthalpy $H = U + PV$ and its role in flow processes and chemical reactions **IV:** Heat capacities C_V and C_P and their engineering measurement and application **V:** Adiabatic processes and isentropic flow conditions in turbomachinery

Learning Outcomes **I:** Calculate work done by a gas during isothermal and adiabatic expansions in engineering cycles [Usage] **II:** Evaluate internal energy changes and apply the First Law to engineering thermodynamic processes [Assessment] **III:** Apply Mayer's relation to determine heat capacity ratios for engineering working fluids [Usage] **IV:** Analyze isentropic flow conditions in engineering nozzles and turbines [Assessment]

Bibliography: [Cengel and Boles, 2019]

5.7 Kinetic Theory of Gases, 4 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Derivation of macroscopic pressure from molecular momentum transfer **II:** Maxwell-Boltzmann speed distribution and its engineering implications **III:** Equipartition theorem and degrees of freedom for monatomic and polyatomic gases **IV:** Mean free path and its relevance to gas flow and vacuum engineering **V:** Transport phenomena: viscosity, thermal conductivity, and diffusion in engineering gases

Learning Outcomes **I:** Compute the rms and average molecular velocities for engineering working gases [Usage] **II:** Interpret the Maxwell-Boltzmann distribution and its temperature dependence for engineering applications [Assessment] **III:** Calculate mean free path and relate it to viscosity in gas-dynamics engineering problems [Usage] **IV:** Estimate thermal conductivity and viscosity of a gas from kinetic theory for engineering design [Assessment]

Bibliography: [Cengel and Boles, 2019]

5.8 First-Order Ordinary Differential Equations (ODEs), 4 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** First-order equations: separable, linear, and exact forms

Learning Outcomes **I:** Solve linear first-order ODEs using integrating factors [Usage]

Bibliography: [Boyce and DiPrima, 2017]

5.9 Mathematical Fluid Dynamics, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Continuum hypothesis, material derivative, and the Reynolds transport theorem **II:** Euler equations for inviscid flow: conservation form, vorticity, and potential flow **III:** Navier-Stokes equations: derivation, exact solutions, and dimensional analysis **IV:** Boundary layer theory: Prandtl equations and the Blasius solution **V:** Turbulence: Reynolds averaging, the k-ε model, and direct numerical simulation

Learning Outcomes **I:** Derive the Navier-Stokes equations from conservation principles and identify each term's physical meaning [Familiarity] **II:** Analyze inviscid flows using the Euler equations and apply Bernoulli's principle [Usage] **III:** Apply boundary layer theory to estimate drag on a flat plate and compare with the Blasius solution [Assessment]

Bibliography: [Chorin and Marsden, 1993]

5.10 Pressurized Pipe Flow and Pump Systems, 8 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Pipe flow fundamentals and Darcy-Weisbach equation **II:** Minor losses and pipe system analysis **III:** Pipe network analysis methods **IV:** Pump characteristics and system curves **V:** Pump selection and installation requirements **VI:** Water hammer and surge analysis **VII:** Pipeline design and material selection **VIII:** Variable speed pumps and energy efficiency **IX:** Network modeling and optimization **X:** Valve selection and hydraulic control systems

Learning Outcomes **I:** Calculate head losses in pipe systems using friction equations [Assessment] **II:** Determine total head loss including minor losses in complex piping [Usage] **III:** Analyze pipe networks using Hardy Cross or equivalent methods [Assessment] **IV:** Construct pump characteristic curves and system head curves [Usage] **V:** Select appropriate pumps based on operating point and efficiency [Assessment] **VI:** Evaluate water hammer effects and design surge protection [Usage] **VII:** Design pipelines considering hydraulic, structural, and economic factors [Assessment] **VIII:** Apply variable speed drives for pump system optimization [Usage] **IX:** Optimize water distribution networks using modeling software [Assessment] **X:** Specify valves and control systems for pipeline operations [Usage]

Bibliography: [White, 2016]

5.11 Design of Hydraulic Structures, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes **I:** Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control [Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [White, 2016]

5.12 Numerical Methods for ODEs and PDEs, 8 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Runge-Kutta methods and adaptive time-stepping for engineering ODE problems **II:** Stability analysis and stiffness in engineering ODE integrators **III:** Finite difference discretization of engineering PDEs (heat equation, Laplace equation) **IV:** Finite element and shooting methods for engineering boundary value problems

Learning Outcomes **I:** Implement a fourth-order Runge-Kutta integrator for a mechanical vibration problem [Usage] **II:** Determine the region of absolute stability for an explicit time-stepping scheme [Assessment] **III:** Discretize the 2D heat equation using finite differences and set up the resulting linear system [Usage] **IV:** Compare finite difference and finite element approaches for solving an engineering PDE [Assessment]

Bibliography: [Chapra and Canale, 2015]

5.13 Finite Element Method, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Weak (variational) formulation of boundary value problems and Sobolev spaces **II:** Galerkin method: finite-dimensional approximation spaces and the stiffness matrix **III:** Triangular and quadrilateral finite element spaces: Lagrange elements and conformity **IV:** A priori error estimates: Céa's lemma and interpolation error bounds **V:** A posteriori error estimates and adaptive mesh refinement

Learning Outcomes **I:** Derive the weak formulation of an elliptic BVP and show its equivalence to the strong form [Familiarity] **II:** Assemble the global stiffness matrix and load vector for a linear finite element discretization [Usage] **III:** Estimate the H^1 error of a finite element solution using Céa's lemma and interpolation theory [Assessment]

Bibliography: [Reddy, 2019]

6. Bibliography

[Boyce and DiPrima, 2017] Boyce, W. E. and DiPrima, R. C. (2017). *Elementary Differential Equations and Boundary Value Problems*. Wiley, 11th edition.

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[Reddy, 2019] Reddy, J. N. (2019). *An Introduction to the Finite Element Method*. McGraw-Hill, 4th edition.

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CE2S1 Structural Analysis I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)

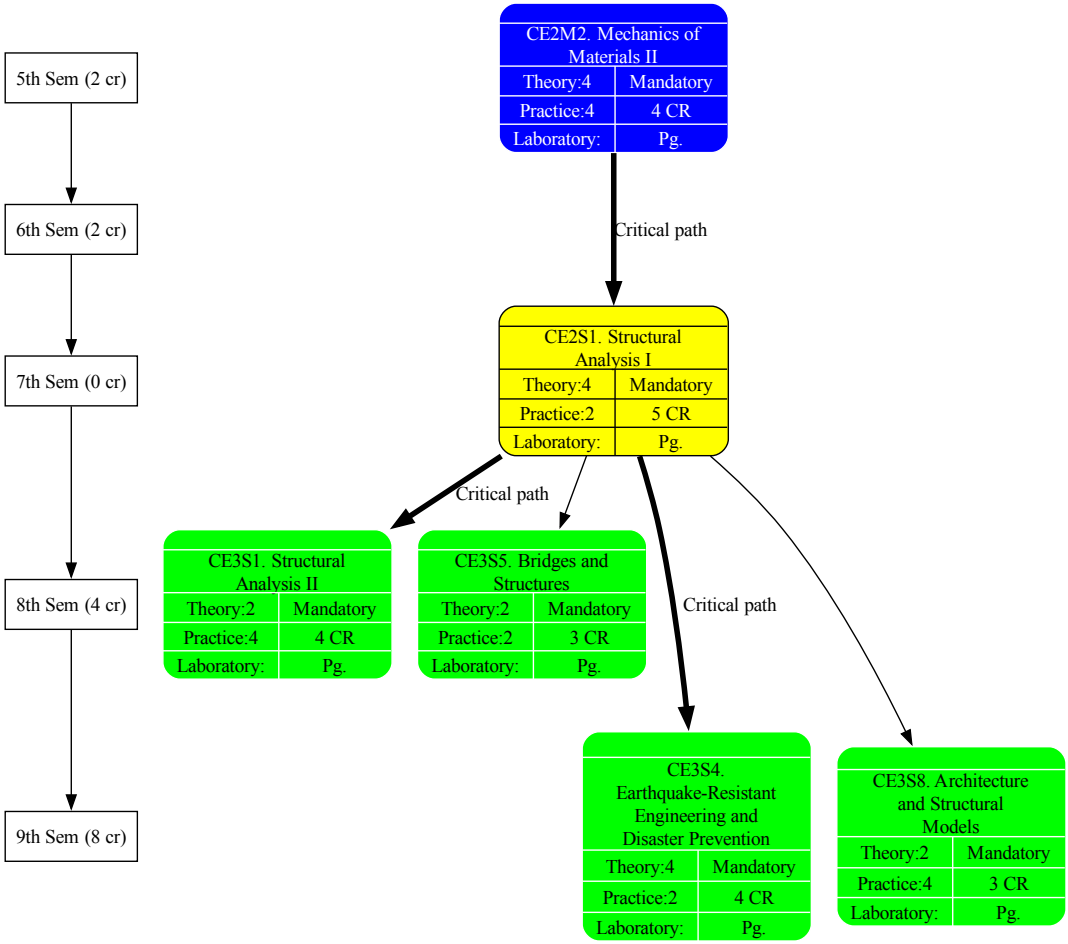

Figure 7.39: Connection Map. CE2S1 Structural Analysis I

2. Course Rationale

Structural Analysis I addresses the behavior of statically indeterminate structural systems, building on the mechanics-of-materials foundation of determinate analysis. Students learn the classical energy principles (virtual work, Castigliano's theorems, and the Betti-Maxwell reciprocal theorems) that underlie the force method, apply the force method itself to beams, frames, and arches, and are introduced to displacement-based matrix formulations (slope-deflection, moment distribution, and the direct stiffness method) that make computer-based structural analysis possible. This course provides

the analytical foundation required for the subsequent design of reinforced concrete, steel, and masonry structural elements.

3. Goals of the Course

- Identify the degree of static indeterminacy of structural systems and formulate their governing compatibility conditions.
- Apply energy methods (virtual work, Castigliano's first theorem, and the Betti-Maxwell reciprocal theorems) to compute displacements in structures.
- Apply the force method and the principle of minimum work to analyze statically indeterminate beams, frames, and arches.
- Formulate the analysis of indeterminate structures using displacement-based matrix methods, including the direct stiffness method.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Energy Methods for Structural Analysis, 36 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Indeterminacy and degree of freedom concepts **II:** Internal work of deformation and the principle of virtual work **III:** Castigliano's first theorem for the calculation of displacements **IV:** Betti's and Maxwell's reciprocal theorems

Learning Outcomes **I:** Identify the degree of indeterminacy for structural systems [Assessment] **II:** Apply the principle of virtual work to calculate internal deformation energy in structural systems [Usage] **III:** Apply Castigliano's first theorem to determine displacements in indeterminate structures [Usage] **IV:** Verify the reciprocity of displacements and forces using Betti's and Maxwell's theorems [Assessment]

Bibliography: [Hibbeler, 2018, Kassimali, 2020, McCormac and Nelson, 2013]

5.2 Force Method for Indeterminate Structures, 36 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Force method and flexibility approach for indeterminate structures **II:** Principle of minimum work (Castigliano's second theorem) for the calculation of redundants **III:** Analysis of statically indeterminate arches **IV:** Influence lines for indeterminate structures using Mueller-Breslau principle

Learning Outcomes **I:** Apply the force method to analyze indeterminate beams and frames [Usage] **II:** Apply the principle of minimum work to calculate redundant forces in the force method [Usage] **III:** Analyze statically indeterminate arches under combined loading [Assessment] **IV:** Construct influence lines for indeterminate structures qualitatively [Usage]

Bibliography: [Hibbeler, 2018, Kassimali, 2020, McCormac and Nelson, 2013]

5.3 Classical Displacement Methods, 18 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Slope-deflection method for continuous beams and frames **II:** Moment distribution method

Learning Outcomes **I:** Use slope-deflection equations to solve continuous beam and frame problems [Assessment] **II:** Perform moment distribution analysis for indeterminate structures [Usage]

Bibliography: [Hibbeler, 2018, Kassimali, 2020, McCormac and Nelson, 2013]

6. Bibliography

[Hibbeler, 2018] Hibbeler, R. C. (2018). *Structural Analysis*. Pearson, 10th edition.

[Kassimali, 2020] Kassimali, A. (2020). *Structural Analysis*. Cengage Learning, 6th edition.

[McCormac and Nelson, 2013] McCormac, J. C. and Nelson, J. K. (2013). *Structural Analysis: Using Classical and Matrix Methods*. Wiley, 5th edition.

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CE2S2 Reinforced Concrete Design I (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)

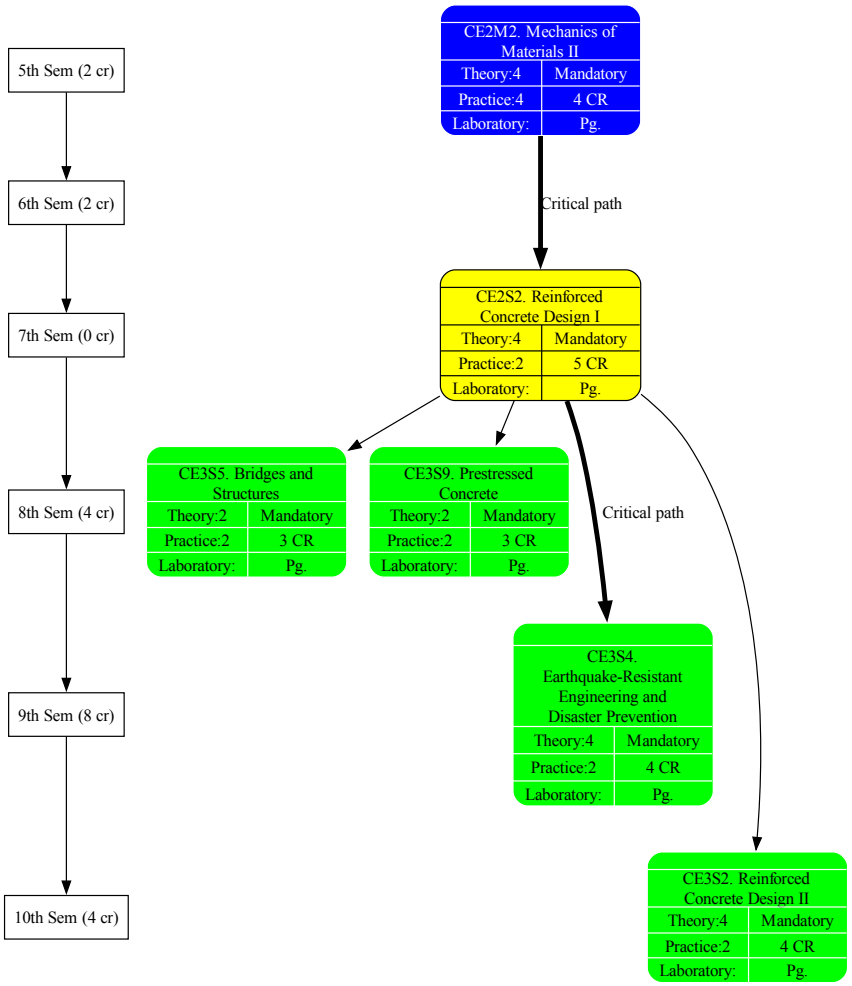

Figure 7.40: Connection Map. CE2S2 Reinforced Concrete Design I

2. Course Rationale

Reinforced Concrete Design I introduces the principles and methodology for the design of reinforced concrete members following limit state design philosophy and the ACI 318 building code. Building on the mechanics of materials, students learn to design beams for flexure and shear, columns for combined axial load and biaxial bending, one-way slabs, and to verify deflection and serviceability requirements. The course also covers the design of supported and cantilevered concrete staircases and an introduction to shallow foundation design, providing the structural design foundation required for subsequent reinforced concrete and earthquake-resistant design courses.

3. Goals of the Course

- Apply limit state design philosophy and load factor combinations to reinforced concrete design.
- Design reinforced concrete beams for flexure and shear.
- Design reinforced concrete columns for axial load and biaxial bending.
- Design one-way reinforced concrete slabs and verify deflection and serviceability requirements.
- Design supported and cantilevered concrete staircases.
- Design isolated spread footings for shallow foundations.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Reinforced Concrete Design, 68 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Design philosophy and limit state methodology for concrete structures **II:** Flexural design of rectangular and T-beams **III:** Shear and torsion design of concrete members **IV:** Compression members and column design **V:** Slab design including one-way and two-way systems **VI:** Development length and splicing of reinforcement **VII:** Deflection control and serviceability requirements for concrete beams and slabs

Learning Outcomes **I:** Explain limit state design philosophy and load factor combinations [Familiarity] **II:** Design reinforced concrete beams for flexure and check serviceability [Assessment] **III:** Calculate shear and torsional reinforcement requirements [Usage] **IV:** Proportion columns for axial load and biaxial bending [Assessment] **V:** Design one-way and two-way slab systems with appropriate reinforcement [Usage] **VI:** Determine development lengths and design lap splices for reinforcing bars [Assessment] **VII:** Control deflections and verify serviceability requirements through adequate member sizing and reinforcement [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, McCormac and Brown, 2021]

5.2 Design of Reinforced Concrete Stairs, 6 hr(s)

Competences: ABET-2

Topics: **I:** Geometry of stair flights, landings, and waist slabs **II:** Load distribution and effective span for simply supported staircases **III:** Load distribution and effective span for cantilevered staircases **IV:** Reinforcement detailing for stair flights, landings, and supports

Learning Outcomes **I:** Design a supported reinforced concrete staircase for gravity loads [Assessment] **II:** Design a cantilevered reinforced concrete staircase for gravity loads [Assessment] **III:** Detail reinforcement for stair flights, landings, and supports [Usage]

Bibliography: [McCormac and Brown, 2021]

5.3 Bearing Capacity and Design, 10 hr(s)

Competences: ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment] **III:** Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Coduto, 2001]

6. Bibliography

[ACI Committee 318, 2019] ACI Committee 318 (2019). Building code requirements for structural concrete (aci 318-19) and commentary. Technical report, American Concrete Institute.

[Coduto, 2001] Coduto, D. P. (2001). *Foundation Design: Principles and Practices*. Prentice Hall, 2nd edition.

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CE2S3 Steel Design (Mandatory)

1. General information

- **Semester**: 7th Sem. **Credits**: 5
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)

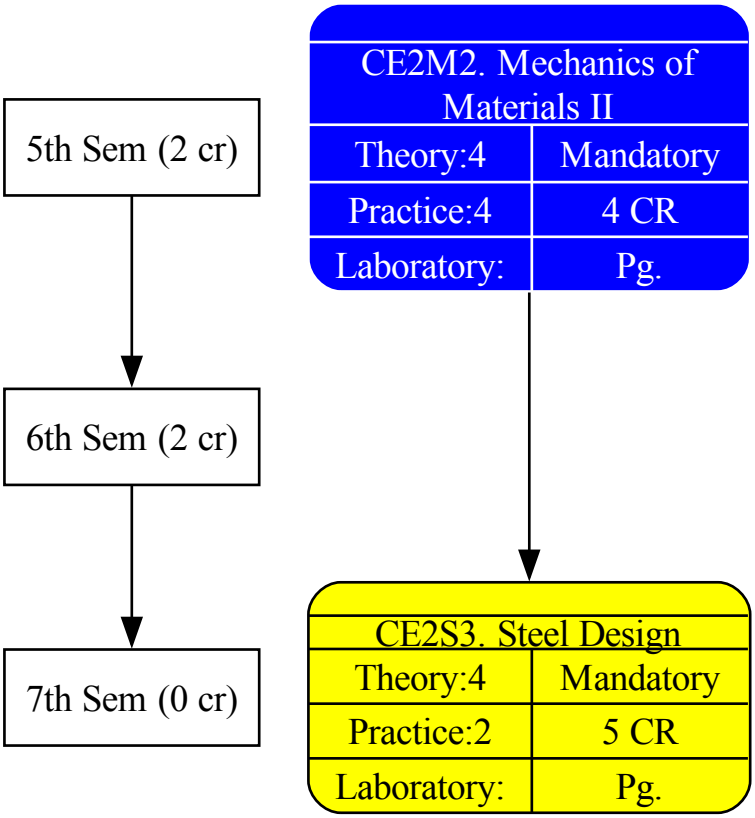

Figure 7.41: Connection Map. CE2S3 Steel Design

2. Course Rationale

Steel Design covers the fundamentals and application of the limit states design method (LRFD/ASD) to structural steel members and connections. The course addresses structural steel grades, design criteria and load combinations, the design of tension and compression members, compact and non-compact beams and plate girders, beam-columns under combined flexure-compression/tension, bolted and welded connections, and composite members in compression and in flexure. It provides the design competencies required for steel-framed buildings and industrial structures.

3. Goals of the Course

- Apply LRFD/ASD design criteria and load combinations to structural steel members.

- Design tension members, compression members, beams, and plate girders using the limit states method.
- Design beam-columns under combined axial force and bending, and their bolted and welded connections.
- Design composite members in compression (encased and concrete-filled columns) and in flexure (composite beams).

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Design of Steel Members in Tension and Compression, 19 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Tension member design and effective area considerations **II:** Compression member design and column buckling

Learning Outcomes **I:** Design tension members considering net area and block shear [Assessment] **II:** Select appropriate column sections and check buckling capacity [Usage]

Bibliography: [McCormac and Csernak, 2019, of Steel Construction, 2017]

5.2 Design of Steel Members in Flexure, 29 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Flexural design of beams and lateral-torsional buckling **II:** Combined axial force and bending interaction **III:** Plate girders and web design

Learning Outcomes **I:** Proportion steel beams considering both local and lateral-torsional buckling [Assessment] **II:** Evaluate beam-columns using interaction equations [Usage] **III:** Design plate girders with consideration of web buckling and stiffeners [Assessment]

Bibliography: [McCormac and Csernak, 2019, of Steel Construction, 2017]

5.3 Steel Connections and Composite Systems, 36 hr(s)

Competences: ABET-2

Topics: **I:** Bolted connections design and failure modes **II:** Welded connections and design considerations **III:** Composite beams and shear connectors **IV:** Moment-resisting frames and seismic provisions for steel structures **V:** Braced frames and concentrically braced frame design **VI:** Connection design for special moment frames and prequalified connections

Learning Outcomes **I:** Design bolted connections for shear, tension, and combined loading [Assessment] **II:** Specify welded connections and determine weld sizes [Usage] **III:** Analyze composite beams and design shear stud connectors [Usage] **IV:** Design moment-resisting frames for seismic and wind loads [Assessment] **V:** Proportion bracing members and connections in braced frame systems [Usage] **VI:** Detail prequalified moment connections according to seismic provisions [Assessment]

Bibliography: [Segui, 2018, of Steel Construction, 2017]

6. Bibliography

[McCormac and Csernak, 2019] McCormac, J. C. and Csernak, S. F. (2019). *Structural Steel Design*. Pearson, 6th edition.

[of Steel Construction, 2017] of Steel Construction, A. I. (2017). Steel construction manual. Technical report, American Institute of Steel Construction.

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Eighth Semester

Universidad Nacional de Ingeniería (UNI)
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CE2C3 Concrete Technology I (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE2C1 Materials Technology (7th Sem-Pg. 366)
  - CE2M2 Mechanics of Materials II (5th Sem-Pg. 352)

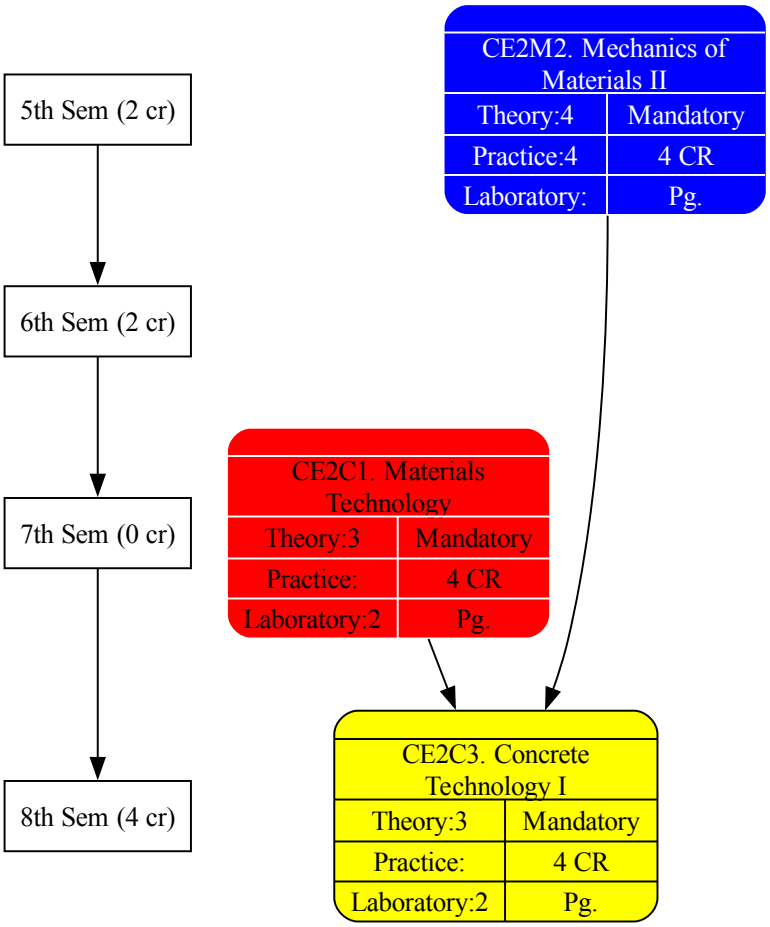

Figure 7.42: Connection Map. CE2C3 Concrete Technology I

2. Course Rationale

Concrete Technology I deepens the science of construction materials and concrete technology: advanced cementitious materials, special concretes and concrete in extreme climates, transportation

and placement, and statistical quality control. The course also includes polymeric and sustainable composite materials, and concludes with rehabilitation, strengthening, and structural retrofitting.

3. Goals of the Course

- Apply materials science to the selection of construction materials and advanced cementitious materials.
- Design and control the quality of special concretes and concretes in extreme climates, including their transportation and placement.
- Apply statistical quality control to concrete production.
- Evaluate and design rehabilitation, strengthening, and structural retrofitting interventions.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Construction Materials Science, 12 hr(s)

Competences: ABET-1

Topics: **I:** Physical and mechanical properties of construction materials including density, porosity, strength, and elasticity **II:** Microstructure and phase composition of construction materials **III:** Durability mechanisms including weathering, chemical attack, and environmental degradation **IV:** Thermal and moisture properties of construction materials **V:** Crystalline and amorphous structures in construction materials **VI:** Material selection criteria based on performance requirements **VII:** Degradation mechanisms and service life prediction

Learning Outcomes **I:** Describe the fundamental physical and mechanical properties of major construction materials [Familiarity] **II:** Analyze the relationship between microstructure and macroscopic properties of materials [Assessment] **III:** Evaluate the durability performance of materials under specific environmental conditions [Usage] **IV:** Explain the effects of thermal and moisture variations on material behavior [Familiarity] **V:** Select appropriate construction materials based on design specifications and performance criteria [Assessment] **VI:** Predict service life and degradation patterns of materials in various environments [Usage]

Bibliography: [Neville, 2011]

5.2 Concrete Technology and Advanced Cementitious Materials, 25 hr(s)

Competences: ABET-1

Topics: **I:** Portland cement chemistry and hydration process **II:** Aggregates properties and grading requirements **III:** Mix design methodology for normal strength concrete **IV:** Fresh concrete properties including workability, slump, and setting time **V:** Hardened concrete properties including strength, modulus, and shrinkage **VI:** Chemical and mineral admixtures for concrete **VII:** High-performance and high-strength concrete design **VIII:** Self-consolidating concrete and fiber-reinforced concrete **IX:** Durability aspects including alkali-silica reaction, sulfate attack, and freeze-thaw **X:** Sustainable and low-carbon concrete technologies including supplementary cementitious materials such as fly ash, slag, and silica fume

Learning Outcomes **I:** Describe the chemistry of portland cement and the hydration process [Familiarity] **II:** Evaluate aggregate quality and suitability for concrete production [Assessment] **III:** Design concrete mixes for specified strength and workability requirements [Usage] **IV:** Test and interpret fresh concrete properties using standard procedures [Assessment] **V:** Predict hardened concrete properties based on mix proportions and curing conditions [Usage] **VI:** Explain the function and effects of various concrete admixtures [Familiarity] **VII:** Formulate high-performance concrete mixes for demanding applications [Usage] **VIII:** Select appropriate special concretes for specific construction scenarios [Assessment] **IX:** Incorporate supplementary cementitious materials to optimize concrete performance [Usage] **X:** Analyze durability risks and specify protective measures for concrete structures [Assessment] **XI:** Compare environmental impacts and carbon footprints of different concrete formulations [Familiarity]

Bibliography: [Neville, 2011]

5.3 Polymeric, Composite, and Sustainable Construction Materials, 4 hr(s)

Competences: ABET-1

Topics: **I:** Polymer chemistry and classification of construction polymers **II:** Mechanical and thermal behavior of polymeric materials **III:** Fiber-reinforced polymer composites and their structural applications **IV:** Adhesives, sealants, and waterproofing materials **V:** Composite material mechanics and laminate theory **VI:** FRP strengthening and rehabilitation of concrete and masonry structures **VII:** Bio-based and recycled materials for sustainable construction **VIII:** Geopolymers and alternative binder systems **IX:** Environmental degradation and long-term performance of polymers and composites

Learning Outcomes **I:** Classify polymers used in construction and describe their basic properties [Familiarity] **II:** Characterize the mechanical and thermal behavior of polymeric materials [Assessment] **III:** Apply fiber-reinforced polymers in structural design and retrofitting applications [Usage] **IV:** Select appropriate adhesives and sealants for specific construction applications [Familiarity] **V:** Analyze composite laminates using classical lamination theory [Usage] **VI:** Design FRP strengthening systems for existing concrete or masonry structures [Assessment] **VII:** Evaluate the sustainability and life-cycle performance of bio-based construction materials [Assessment] **VIII:** Compare geopolymer binders with traditional portland cement systems [Familiarity] **IX:** Predict long-term degradation of polymers and composites under environmental exposure [Usage]

Bibliography: [Callister and Rethwisch, 2020]

5.4 Special Concretes and Concrete in Extreme Climates, 6 hr(s)

Competences: ABET-1

Topics: **I:** Hot-weather concrete: heat effects on hydration, retarding admixtures, and curing methods **II:** Cold-weather concrete: freeze protection, accelerating admixtures, and enclosure protection methods **III:** Structural lightweight concrete: materials, properties, and mix design **IV:** Mass and heavyweight concrete: heat of hydration control and applications **V:** Shotcrete: mix design, application process, and quality control **VI:** Concrete for underwater structures: antiwashout mixes and placement methods **VII:** Pervious and architectural concrete: properties and applications

Learning Outcomes **I:** Identify the effects of hot and cold weather on fresh and hardened concrete properties [Familiarity] **II:** Apply preventive and corrective measures for concrete production and placement in adverse weather conditions [Usage] **III:** Select the appropriate special concrete type according to project functional and environmental requirements [Assessment] **IV:** Design lightweight concrete mixes meeting specified strength and density requirements [Usage] **V:** Specify shotcrete mixing, transport, and placement procedures for tunnel and slope

applications [Usage] **VI:** Evaluate the suitability of special concretes for extreme exposure conditions [Assessment] **VII:** Develop specifications for concrete in extreme temperature conditions following ACI 305 and ACI 306 standards [Usage]

Bibliography: [Neville, 2011]

5.5 Concrete Transport and Placement, 4 hr(s)

Competences: ABET-2

Topics: **I:** Transit mixer transport: maximum delivery time, slump verification, and admissible conditions **II:** Concrete pumping: pumpable mix design, operating pressure, reach, and blockage prevention **III:** Placement methods: direct discharge, chutes, buckets, and crane placement **IV:** Concrete consolidation: internal and external vibration, frequency, amplitude, and insertion depth **V:** Underwater concrete placement by tremie method and in restricted-access conditions **VI:** Belt conveyor and pneumatic transport systems for large-volume concrete **VII:** Concrete surface finishing: leveling, troweling, texturing, and immediate curing

Learning Outcomes **I:** Plan concrete transport considering delivery distance, setting time, and environmental conditions [Usage] **II:** Execute standardized concrete placement procedures for different types of structural elements [Usage] **III:** Apply correct vibration techniques to achieve uniform concrete consolidation [Usage] **IV:** Evaluate concrete placement quality and identify deficiencies such as segregation, honeycombs, and cold joints [Assessment] **V:** Design pumpable concrete mixes for specific pumping height and distance conditions [Usage] **VI:** Specify placement methods for restricted-access structures or underwater placement conditions [Assessment] **VII:** Develop placement plans minimizing cold joints and ensuring concrete continuity in large structural elements [Usage]

Bibliography: [Neville, 2011]

5.6 Statistical Quality Control of Concrete, 3 hr(s)

Competences: ABET-6

Topics: **I:** Sampling procedures and fresh concrete specimen preparation according to ASTM standards **II:** Compressive strength testing: procedure, minimum frequency, and testing conditions **III:** Basic statistics applied to concrete: mean, standard deviation, and coefficient of variation **IV:** Concrete acceptance criteria according to ACI 318 and equivalent standards **V:** Statistical control charts ($\bar{X}$, R) for continuous monitoring of concrete production **VI:** Non-conforming results analysis: investigation procedures, additional tests, and structural decisions **VII:** Process capability indices (C_p, C_{pk}) and target mean strength adjustment

Learning Outcomes **I:** Apply standardized sampling and specimen fabrication procedures for concrete on site [Usage] **II:** Interpret compressive strength test results and determine their validity [Assessment] **III:** Calculate basic statistical parameters from series of concrete strength test results [Usage] **IV:** Evaluate concrete acceptance or rejection applying ACI 318 normative criteria [Assessment] **V:** Construct statistical control charts for continuous monitoring of concrete production [Usage] **VI:** Diagnose causes of excessive variability and propose corrective actions in concrete production [Assessment] **VII:** Determine the target mean strength (f'_{cr}) considering the statistical variability of the production process [Usage]

Bibliography: [Neville, 2011]

5.7 Structural Rehabilitation, Strengthening, and Retrofit, 3 hr(s)

Competences: ABET-2

Topics: **I:** Condition assessment and structural evaluation procedures **II:** Load rating and capacity evaluation of existing structures **III:** Concrete repair materials and techniques **IV:** Strengthening techniques using external reinforcement **V:** FRP strengthening systems for flexure and shear **VI:** Seismic retrofit strategies for buildings and bridges **VII:** Steel jacketing and external post-tensioning **VIII:** Masonry rehabilitation and historic structure preservation **IX:** Performance-based assessment and retrofit design **X:** Nondestructive evaluation and structural health monitoring

Learning Outcomes **I:** Conduct comprehensive condition assessments of existing structures [Assessment] **II:** Evaluate load-carrying capacity of existing structural members [Usage] **III:** Select appropriate concrete repair materials and application methods [Familiarity] **IV:** Design strengthening interventions using conventional techniques [Assessment] **V:** Apply FRP systems for flexural and shear strengthening of concrete members [Usage] **VI:** Develop seismic retrofit strategies for deficient structures [Assessment] **VII:** Implement steel jacketing and external post-tensioning systems [Usage] **VIII:** Rehabilitate masonry structures while preserving historic character [Assessment] **IX:** Perform performance-based assessment and design retrofit interventions [Usage] **X:** Utilize nondestructive testing and monitoring technologies for damage assessment [Familiarity]

Bibliography: [Institute, 2021]

6. Bibliography

[Callister and Rethwisch, 2020] Callister, W. D. and Rethwisch, D. G. (2020). *Materials Science and Engineering: An Introduction*. Wiley, 10th edition.

[Institute, 2021] Institute, A. C. (2021). Aci 562: Code requirements for assessment, repair, and rehabilitation of existing concrete structures. Technical report, American Concrete Institute.

[Neville, 2011] Neville, A. M. (2011). *Properties of Concrete*. Pearson, 5th edition.

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CE2C5 Construction Project Management (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE2C2 Construction Technology I (7th Sem-Pg. 371)

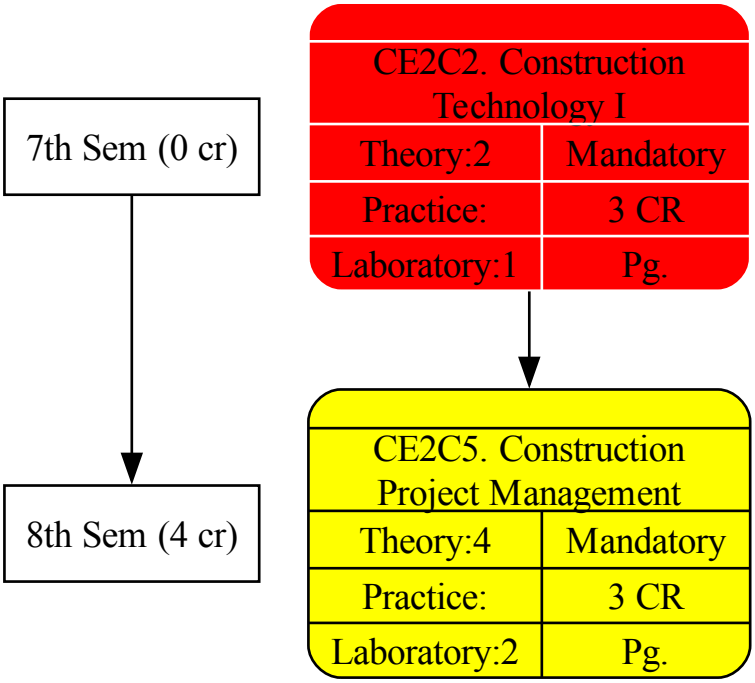

Figure 7.43: Connection Map. CE2C5 Construction Project Management

2. Course Rationale

Construction Project Management I covers the planning, scheduling, and management of construction works, including the use of Critical Path Method (CPM) and 4D/5D modeling tools for project control, construction cost estimating and financial management, and the day-to-day management of construction site execution.

3. Goals of the Course

- Plan a construction project by defining its scope and work breakdown structure.
- Schedule a construction project using the Critical Path Method (CPM) and 4D/5D modeling tools.
- Estimate construction costs and manage the financial control of a construction project.
- Manage and control the execution of a construction project at the site level.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Usage)

5. Content

5.1 Project Planning, Scheduling, and Control (CPM, 4D/5D), 42 hr(s)

Competences: ABET-2

Topics: **I:** Work breakdown structure (WBS) development and activity definition **II:** Network diagramming: activity-on-node (AON) and precedence diagramming method (PDM) **III:** Critical Path Method (CPM) for schedule calculation: forward/backward pass, floats **IV:** Resource allocation, loading, and leveling techniques **V:** Schedule updating, monitoring, and control using earned value management (EVM) **VI:** Program Evaluation and Review Technique (PERT) for schedule risk analysis **VII:** Line of balance (LOB) scheduling for repetitive projects **VIII:** 4D scheduling (time + 3D model) for visualization and clash detection **IX:** 5D scheduling (time + cost + 3D model) for integrated cost control

Learning Outcomes **I:** Develop a Work Breakdown Structure (WBS) for a medium-scale construction project [Usage] **II:** Construct a CPM network diagram and calculate the critical path and activity floats [Assessment] **III:** Perform resource leveling on a simple project schedule to minimize resource fluctuations [Usage] **IV:** Monitor project progress using schedule variance (SV) and cost variance (CV) from earned value data [Assessment] **V:** Apply PERT to estimate project duration probabilities and identify schedule risks [Assessment] **VI:** Create a Line of Balance (LOB) schedule for a repetitive housing project [Usage] **VII:** Generate a 4D simulation to visualize the construction sequence and identify spatial conflicts [Usage] **VIII:** Integrate cost data with a 3D model to perform a 5D analysis for budget tracking [Assessment]

Bibliography: [Callahan et al., 1992, Institute, 2021]

5.2 Construction Cost Estimating and Quantification, 10 hr(s)

Competences: ABET-5

Topics: **I:** Estimating types: conceptual, preliminary, and detailed **II:** Quantity takeoff methods from drawings and digital models **III:** Pricing components: labor, material, equipment, and overhead **IV:** Parametric and probabilistic estimating techniques **V:** Life-cycle cost analysis for building systems

Learning Outcomes **I:** Perform a detailed quantity takeoff for concrete, formwork, and reinforcement from construction drawings [Usage] **II:** Prepare a unit price estimate for a defined work package [Assessment] **III:** Apply parametric models to develop a conceptual cost estimate for a building [Assessment] **IV:** Conduct a life-cycle cost analysis to compare two alternative building envelope systems [Usage]

Bibliography: [RSMeans, 2024, Institute, 2021]

5.3 Construction Budgeting, Bidding, and Financial Control, 8 hr(s)

Competences: ABET-5

Topics: **I:** Bid preparation, submission, and analysis processes **II:** Cash flow forecasting and management for construction projects **III:** Value engineering and constructability analysis **IV:** Financial statements and performance metrics for construction firms

Learning Outcomes **I:** Explain the components and typical markup structure of a competitive bid [Familiarity] **II:** Develop a monthly cash flow forecast for a construction project [Usage] **III:** Perform a value engineering workshop to identify cost-saving alternatives without sacrificing function [Assessment] **IV:** Interpret key financial ratios for assessing a construction company's health [Familiarity]

Bibliography: [RSMeans, 2024, Institute, 2021]

5.4 Construction Site and Field Management, 24 hr(s)

Competences: ABET-5

Topics: **I:** Site mobilization: temporary facilities, access, utilities, and site organization **II:** Field supervision and daily site operations management **III:** Subcontractor and trade coordination and sequencing **IV:** Progress reporting, documentation, and site coordination meetings **V:** Materials management: procurement tracking, delivery, and storage **VI:** Quality control and inspection during construction execution **VII:** Stakeholder communication and conflict resolution on site **VIII:** Project closeout: punch lists, commissioning, and turnover

Learning Outcomes **I:** Develop a site mobilization plan including temporary facilities and access logistics [Usage] **II:** Supervise daily site operations and resolve field-level execution issues [Assessment] **III:** Coordinate subcontractor and trade sequencing to avoid schedule conflicts [Usage] **IV:** Prepare a progress report and lead a site coordination meeting [Usage] **V:** Track material procurement, delivery, and on-site storage for a work package [Assessment] **VI:** Conduct a quality control inspection during a construction execution phase [Assessment] **VII:** Resolve a stakeholder conflict arising during site execution [Familiarity] **VIII:** Manage project closeout activities, including punch lists and turnover [Usage]

Bibliography: [Gould, 2018, Fisk and Reynolds, 2013]

6. Bibliography

[Callahan et al., 1992] Callahan, M. T., Quackenbush, D. G., and Rowings, J. E. (1992). *Construction Project Scheduling*. McGraw-Hill.

[Fisk and Reynolds, 2013] Fisk, E. R. and Reynolds, W. D. (2013). *Construction Project Administration*. Pearson, 10th edition.

[Gould, 2018] Gould, F. E. (2018). *Managing the Construction Process: Estimating, Scheduling, and Project Control*. Pearson, 6th edition.

[Institute, 2021] Institute, P. M. (2021). *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. Project Management Institute, 7th edition.

[RSMeans, 2024] RSMeans (2024). *RSMeans Building Construction Cost Data*. Gordian.

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CE2C7 Business Organization and Management (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE2C8 Business Management in Construction I (7th Sem-Pg. 377)

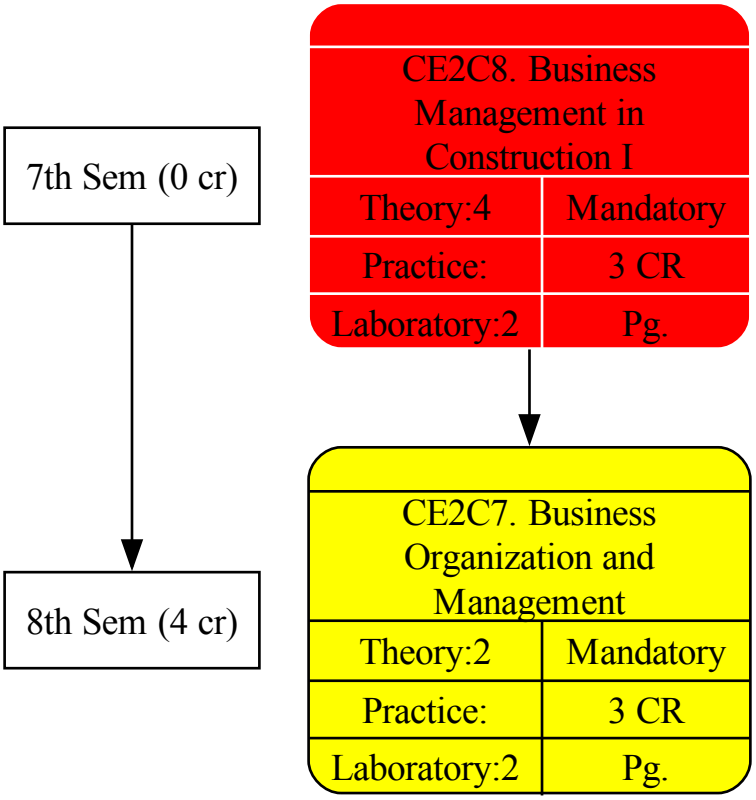

Figure 7.44: Connection Map. CE2C7 Business Organization and Management

2. Course Rationale

Business Organization and Management introduces the fundamentals of business administration: business types and structure, management and leadership, organization and organizational behavior, logistics, accounting, production, and marketing, as a foundation for the management of construction companies.

3. Goals of the Course

- Distinguish the types and structures of companies and their legal implications.
- Apply principles of organization, management, and leadership to a company.
- Understand the processes of logistics, accounting, production, and marketing in a company.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Organizational Behavior, 8 hr(s)

Competences: ABET-1

Topics: **I:** Motivation theories: Maslow's hierarchy, Herzberg's two-factor theory, expectancy theory, and self-determination theory **II:** Team formation, group roles, cohesion, diversity, and performance in organizational settings **III:** Organizational culture: dimensions, formation, cultural change, and its impact on performance **IV:** Sources of organizational conflict, conflict resolution strategies, and negotiation fundamentals

Learning Outcomes **I:** Explain major motivation theories and their implications for managerial practice [Familiarity] **II:** Analyze team dynamics and cultural factors affecting organizational performance [Usage] **III:** Design an intervention to address a specific organizational behavior challenge [Assessment]

Bibliography: [Robbins and Coulter, 2017]

5.2 Business Entity Law, 4 hr(s)

Competences: ABET-1

Topics: **I:** Legal forms: sole proprietorship, general/limited partnership, LLC, and corporation; comparative liability and taxation **II:** Corporate formation, articles of incorporation, shareholder rights, board duties (fiduciary duty of care and loyalty) **III:** Agency relationships in business: actual and apparent authority, principal-agent duties, and vicarious liability **IV:** Mergers, acquisitions, and dissolution: legal process, shareholder approval, due diligence, and winding-up procedures

Learning Outcomes **I:** Compare the liability, tax, and governance characteristics of different business entity forms [Familiarity] **II:** Analyze the legal implications of a business transaction from the perspective of agency law [Usage] **III:** Select the appropriate legal entity form for a new business venture, justifying the choice on legal and strategic grounds [Assessment]

Bibliography: [Robbins and Coulter, 2017]

5.3 Strategic Management, 4 hr(s)

Competences: ABET-2

Topics: **I:** External and internal analysis using PESTEL, Porter's Five Forces, and SWOT frameworks **II:** Generic strategies (cost leadership, differentiation, focus) and their application to competitive positioning **III:** Strategy implementation: organizational alignment, balanced scorecard, and performance management systems **IV:** Corporate-level strategy: diversification, vertical integration, mergers and acquisitions, and portfolio management

Learning Outcomes **I:** Describe the strategic management process and the role of environmental analysis in strategy formulation [Familiarity] **II:** Apply competitive strategy frameworks to analyze the strategic position of a real organization [Usage] **III:** Evaluate the coherence and feasibility of a corporate strategy using analytical frameworks [Assessment]

Bibliography: [Robbins and Coulter, 2017]

5.4 Leadership Theory and Practice, 4 hr(s)

Competences: ABET-2

Topics: **I:** Leadership theories: trait, behavioral (Ohio State, Michigan), situational (Hersey-Blanchard), and contingency (Fiedler) models **II:** Transformational and transactional leadership: vision, inspiration, intellectual stimulation, and individualized consideration **III:** Emotional intelligence dimensions (self-awareness, empathy, social skills) and their relevance to leadership effectiveness **IV:** Ethical and servant leadership: leader as steward, moral courage, values-based decision-making, and community service orientation

Learning Outcomes **I:** Compare major leadership theories and identify the contextual conditions favoring each approach [Familiarity] **II:** Apply situational leadership principles to diagnose leader behavior appropriate for a given team context [Usage] **III:** Evaluate a leader's effectiveness using multiple theoretical lenses including transformational and ethical leadership criteria [Assessment]

Bibliography: [Robbins and Coulter, 2017]

5.5 Inventory Management and Logistics, 4 hr(s)

Competences: ABET-2

Topics: **I:** Economic order quantity (EOQ): derivation, assumptions, extensions, and total inventory cost minimization **II:** Reorder point models, safety stock calculation, and service level determination under demand uncertainty **III:** Logistics management: transportation modes, warehousing, distribution network design, and 3PL providers **IV:** ABC inventory classification: Pareto principle applied to inventory value, cycle counting policy, and selective control strategies

Learning Outcomes **I:** Explain the trade-offs between ordering costs and holding costs in inventory management [Familiarity] **II:** Calculate EOQ, reorder points, and safety stock for a product with specified demand parameters [Usage] **III:** Evaluate the inventory and logistics performance of a supply chain and recommend improvements [Assessment]

Bibliography: [Heizer et al., 2020]

5.6 Financial Accounting and Reporting, 4 hr(s)

Competences: ABET-6

Topics: **I:** Accounting equation (Assets = Liabilities + Equity), double-entry bookkeeping, and the chart of accounts **II:** The accounting cycle: journalizing, posting, trial balance, adjusting entries, closing entries, and financial statement preparation **III:** Income statement, balance sheet, statement of cash flows, and statement of changes in equity: structure and content **IV:** Ratio analysis and financial statement interpretation: liquidity, solvency, profitability, and efficiency ratios for decision-making

Learning Outcomes **I:** Explain the accounting equation and the logic of double-entry bookkeeping [Familiarity] **II:** Prepare journal entries and basic financial statements for a simple business entity [Usage] **III:** Analyze the financial position and performance of a firm using its financial statements [Assessment]

Bibliography: [Weygandt et al., 2018]

5.7 Operations Strategy and Process Design, 4 hr(s)

Competences: ABET-2

Topics: **I:** Competitive priorities in operations: cost, quality, speed, flexibility, and dependability **II:** Process types: job shop, batch, assembly line, and continuous flow; process selection and product-process matrix **III:** Capacity measurement, capacity planning strategies (lead, lag, match), and bottleneck analysis **IV:** Facility layout types (product, process, fixed-position, cellular) and layout efficiency measures

Learning Outcomes **I:** Describe the main competitive priorities in operations and explain how process type selection reflects strategic objectives [Familiarity] **II:** Apply capacity planning methods and bottleneck analysis to improve throughput in a production system [Usage] **III:** Design a facility layout for a specified production environment and evaluate its efficiency [Assessment]

Bibliography: [Heizer et al., 2020]

5.8 Marketing Mix Strategy, 4 hr(s)

Competences: ABET-1

Topics: **I:** Product decisions: product mix, product life cycle, new product development, and packaging **II:** Pricing methods: cost-based, competition-based, value-based, and dynamic pricing; price elasticity **III:** Distribution channel design: direct and indirect channels, channel conflict, logistics, and omnichannel retailing **IV:** Integrated marketing communications: advertising, sales promotion, public relations, personal selling, and direct marketing

Learning Outcomes **I:** Identify the components of the marketing mix and explain how they are integrated to create customer value [Familiarity] **II:** Apply pricing and channel strategies to a specific product/market combination [Usage] **III:** Design an integrated marketing communication plan aligned with a given marketing strategy [Assessment]

Bibliography: [Kotler and Armstrong, 2016]

5.9 Human Resource Management, 6 hr(s)

Competences: ABET-1

Topics: **I:** Workforce planning, job analysis, recruitment channels, and selection methods (interviews, testing, assessment centers) **II:** Compensation structures (base pay, incentives, benefits) and performance appraisal methods **III:** Training needs assessment, onboarding, career development, and succession planning **IV:** Document control and records management: filing systems, correspondence control, document version/traceability, and retention policies supporting HR and administrative functions

Learning Outcomes **I:** Describe the core HR functions of recruitment, compensation, and training within an organization [Familiarity] **II:** Design a recruitment and selection process for a specified position and organizational context [Usage] **III:** Evaluate an organization's document control and records management practices against administrative best practices [Assessment]

Bibliography: [DeCenzo et al., 2019]

5.10 Corporate Governance, 4 hr(s)

Competences: ABET-2

Topics: **I:** Agency theory: principal-agent problem, information asymmetry, moral hazard, and alignment mechanisms **II:** Board of directors: composition, independence, committees, fiduciary duties, and board effectiveness **III:** Corporate governance codes and regulation: Sarbanes-Oxley, OECD Principles, and ESG reporting requirements **IV:** ESG and stakeholder governance models: environmental, social, and governance criteria, materiality assessment, and multi-stakeholder accountability

Learning Outcomes **I:** Explain the agency problem and the governance mechanisms designed to align managerial and shareholder interests [Familiarity] **II:** Analyze the governance structure of a corporation and identify potential weaknesses [Usage] **III:** Evaluate the effectiveness of corporate governance practices against best-practice standards [Assessment]

Bibliography: [Robbins and Coulter, 2017]

6. Bibliography

[DeCenzo et al., 2019] DeCenzo, D. A., Robbins, S. P., and Verhulst, S. L. (2019). *Fundamentals of Human Resource Management*. Wiley, 13th edition.

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[Kotler and Armstrong, 2016] Kotler, P. and Armstrong, G. (2016). *Principles of Marketing*. Pearson, 16th edition.

[Robbins and Coulter, 2017] Robbins, S. P. and Coulter, M. (2017). *Management*. Pearson, 14th edition.

[Weygandt et al., 2018] Weygandt, J. J., Kimmel, P. D., and Kieso, D. E. (2018). *Financial Accounting*. Wiley, 10th edition.

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CE2G2 Soil Mechanics II (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2G1 Soil Mechanics I (7th Sem-Pg. 381)

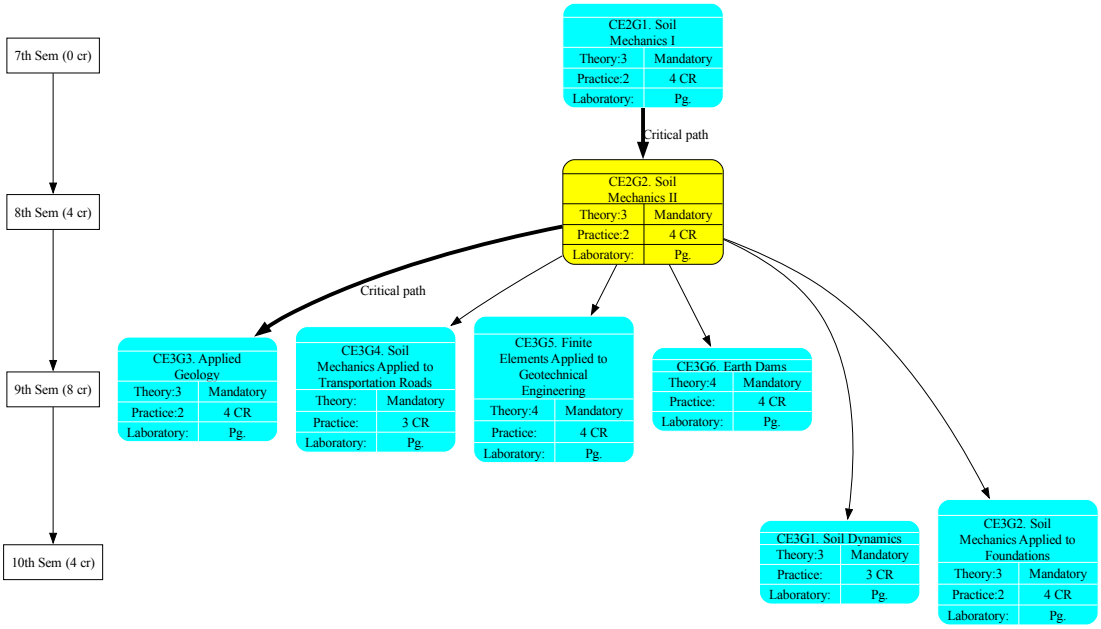

Figure 7.45: Connection Map. CE2G2 Soil Mechanics II

2. Course Rationale

Soil Mechanics II builds directly on Soil Mechanics I, extending the phase-relationship and hydraulic-behavior framework already developed there into the stress-deformation and strength behavior that governs how soils respond to load. The course first develops shear strength theory and laboratory test interpretation, one-dimensional consolidation and settlement prediction, and stress distribution beneath loaded areas, and then applies this behavioral framework to four major geotechnical design problems: lateral earth pressure and earth-retaining structures, slope stability and landslide mitigation, shallow foundation design, and deep foundation design (piles and drilled shafts). As the second, broad-survey course of the Geotechnical Engineering track, each design topic is introduced at a level appropriate for a first exposure; students who continue into the track's specialization electives will revisit these same topics at a substantially deeper level.

3. Goals of the Course

- Determine shear strength parameters of soils from direct shear and triaxial test data, and distinguish drained from undrained behavior.
- Predict consolidation settlement and its time-rate for saturated clays, and compute stress distribution beneath loaded areas.
- Apply lateral earth pressure theory to design retaining walls, anchored walls, and mechanically stabilized earth systems.

- Analyze the stability of natural and engineered slopes and design stabilization measures for identified failure modes.
- Design shallow foundations (isolated, combined, mat) based on bearing capacity and settlement criteria.
- Design deep foundations (piles and drilled shafts) considering axial capacity, lateral capacity, and group effects.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Shear Strength and Consolidation, 30 hr(s)

Competences: ABET-1

Topics: **I:** Shear strength of soils and Mohr-Coulomb failure criterion **II:** Direct shear and triaxial testing methods **III:** Drained and undrained shear strength behavior **IV:** Consolidation theory and settlement analysis **V:** Time-rate of consolidation and degree of consolidation **VI:** Stress distribution in soil masses using elastic theory **VII:** Critical state soil mechanics concepts **VIII:** Residual shear strength and sensitivity of clays **IX:** Secondary compression and creep behavior **X:** Anisotropy and stress path effects on soil behavior

Learning Outcomes **I:** Apply Mohr-Coulomb criterion to determine shear strength parameters [Familiarity] **II:** Interpret direct shear and triaxial test results [Assessment] **III:** Distinguish between drained and undrained loading conditions [Usage] **IV:** Calculate consolidation settlement using one-dimensional theory [Assessment] **V:** Predict time-rate of settlement for consolidating soils [Usage] **VI:** Compute stress distribution beneath loaded areas using Boussinesq theory [Assessment] **VII:** Explain critical state concepts and their application to soil behavior [Familiarity] **VIII:** Evaluate residual strength and sensitivity for slope stability problems [Assessment] **IX:** Estimate secondary compression for highly plastic soils [Usage] **X:** Analyze the effects of stress paths and anisotropy on soil response [Familiarity]

Bibliography: [Das, 2019]

5.2 Earth Retaining Systems, 10 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Earth pressure theory including active and passive pressures **II:** Retaining wall types and selection criteria **III:** Load testing methods including static and dynamic tests **IV:** Anchored walls and tied-back systems **V:** Mechanically stabilized earth walls and reinforced soil systems **VI:** Basement and foundation wall design considering top-of-wall restraint conditions **VII:** Counterfort and buttressed retaining wall design

Learning Outcomes **I:** Apply lateral earth pressure theories for retaining wall design [Assessment] **II:** Design gravity and cantilever retaining walls [Usage] **III:** Design anchored wall systems including ground anchor capacity [Assessment] **IV:** Proportion mechanically stabilized earth walls and select reinforcement [Usage] **V:** Design basement and foundation walls considering top restraint, surcharge, and hydrostatic loads [Assessment] **VI:** Design counterfort retaining walls including stem, heel, toe, and counterfort elements [Usage]

Bibliography: [Das, 2019, Coduto, 2001]

5.3 Slope Stability Analysis and Stabilization, 10 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Infinite slope analysis for simple geometries **II:** Method of slices and limit equilibrium analysis **III:** Circular and non-circular failure surfaces **IV:** Factor of safety determination and acceptance criteria **V:** Stability charts and simplified methods **VI:** Landslide types and failure mechanisms **VII:** Seismic slope stability and pseudo-static analysis **VIII:** Stabilization methods including drainage and reinforcement **IX:** Monitoring systems and early warning for unstable slopes **X:** Probabilistic slope stability analysis

Learning Outcomes **I:** Perform infinite slope stability analysis for uniform slopes [Assessment] **II:** Apply method of slices to analyze slope stability [Usage] **III:** Analyze slopes with circular and non-circular failure surfaces [Assessment] **IV:** Calculate factors of safety and interpret results [Usage] **V:** Use stability charts for rapid slope evaluation [Assessment] **VI:** Identify landslide types and their characteristic features [Familiarity] **VII:** Evaluate seismic stability using pseudo-static methods [Usage] **VIII:** Design slope stabilization measures for specific failure modes [Assessment] **IX:** Implement monitoring systems for potentially unstable slopes [Usage] **X:** Conduct probabilistic stability analysis considering parameter uncertainty [Assessment]

Bibliography: [Duncan et al., 2014]

5.4 Bearing Capacity and Design, 10 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment] **III:** Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Coduto, 2001, Das, 2019]

5.5 Deep Foundations, 10 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Pile types and installation methods **II:** Axial capacity of single piles in cohesive and cohesionless soils **III:** Lateral load capacity and p-y method **IV:** Pile group behavior and group efficiency **V:** Drilled shaft design and construction considerations **VI:** Negative skin friction and downdrag forces

Learning Outcomes **I:** Select appropriate pile types based on soil conditions and loading [Familiarity] **II:** Calculate axial capacity of piles using static methods [Assessment] **III:** Analyze laterally loaded piles using p-y curves [Usage] **IV:** Evaluate pile group capacity and settlement [Assessment] **V:** Design drilled shaft foundations including shaft diameter and reinforcement [Usage] **VI:** Interpret pile load test results and verify design assumptions [Assessment]

Bibliography: [Coduto, 2001, Das, 2019]

6. Bibliography

[Coduto, 2001] Coduto, D. P. (2001). *Foundation Design: Principles and Practices*. Prentice Hall, 2nd edition.

[Das, 2019] Das, B. M. (2019). *Principles of Geotechnical Engineering*. Cengage Learning, 9th edition.

[Duncan et al., 2014] Duncan, J. M., Wright, S. G., and Brandon, T. L. (2014). *Soil Strength and Slope Stability*. John Wiley & Sons, 2nd edition.

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CE3C2 Construction Technology II (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE2C2 Construction Technology I (7th Sem-Pg. 371)

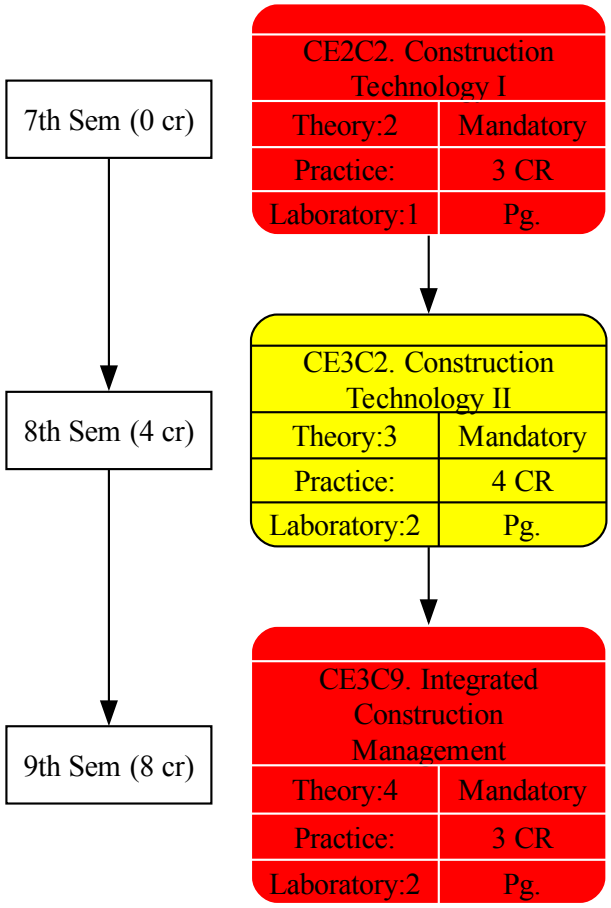

Figure 7.46: Connection Map. CE3C2 Construction Technology II

2. Course Rationale

Construction Technology II deepens the construction processes of structural elements: layout and staking of works, formwork and shoring systems, soil mechanics applied to foundations, shallow and deep foundations, structural and non-structural masonry, and rebar detailing and placement of reinforcing steel.

3. Goals of the Course

- Perform the layout and staking of a construction project and design the necessary formwork and shoring systems.
- Apply soil mechanics to the design of shallow and deep foundations.
- Execute and supervise construction processes for structural and non-structural masonry.
- Design and detail the reinforcing steel placement for reinforced concrete elements.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Construction Methods, Equipment, and Productivity, 20 hr(s)

Competences: ABET-2

Topics: **I:** Earthwork operations: excavation, hauling, compaction, and mass diagrams **II:** Concrete construction: formwork, placing, finishing, and curing **III:** Steel erection, connection, and safety procedures **IV:** Construction equipment types, capabilities, and selection criteria **V:** Productivity measurement, cycle time analysis, and crew balancing **VI:** Heavy civil construction methods for tunnels, dams, and bridges **VII:** Equipment economics: ownership vs. rental, depreciation, and operating cost **VIII:** Trenchless technologies and deep excavation support systems **IX:** Automation and robotics in construction operations

Learning Outcomes **I:** Select appropriate construction equipment for common earthwork and material handling tasks [Usage] **II:** Design basic formwork and shoring for a concrete slab or wall [Assessment] **III:** Explain the sequence and safety considerations for steel erection [Familiarity] **IV:** Calculate productivity rates and cycle times for equipment operations [Usage] **V:** Balance a construction crew to optimize productivity for a given task [Assessment] **VI:** Compare construction methods for a heavy civil project like a cut-and-cover tunnel [Assessment] **VII:** Analyze the economic life and hourly cost of a piece of construction equipment [Usage] **VIII:** Describe the applications and limitations of trenchless construction technologies [Familiarity] **IX:** Evaluate the potential for automation to improve safety and productivity on a construction site [Assessment]

Bibliography: [Peurifoy et al., 2018]

5.2 Shear Strength and Consolidation, 6 hr(s)

Competences: ABET-1

Topics: **I:** Shear strength of soils and Mohr-Coulomb failure criterion **II:** Direct shear and triaxial testing methods **III:** Drained and undrained shear strength behavior **IV:** Consolidation theory and settlement analysis **V:** Time-rate of consolidation and degree of consolidation **VI:** Stress distribution in soil masses using elastic theory **VII:** Critical state soil mechanics concepts **VIII:** Residual shear strength and sensitivity of clays **IX:** Secondary compression and creep behavior **X:** Anisotropy and stress path effects on soil behavior

Learning Outcomes **I:** Apply Mohr-Coulomb criterion to determine shear strength parameters [Familiarity] **II:** Interpret direct shear and triaxial test results [Assessment] **III:** Distinguish between drained and undrained loading conditions [Usage] **IV:** Calculate consolidation settlement using one-dimensional theory [Assessment] **V:** Predict time-rate of settlement for consolidating

soils [Usage] **VI:** Compute stress distribution beneath loaded areas using Boussinesq theory [Assessment] **VII:** Explain critical state concepts and their application to soil behavior [Familiarity] **VIII:** Evaluate residual strength and sensitivity for slope stability problems [Assessment] **IX:** Estimate secondary compression for highly plastic soils [Usage] **X:** Analyze the effects of stress paths and anisotropy on soil response [Familiarity]

Bibliography: [Das, 2019]

5.3 Bearing Capacity and Design, 3 hr(s)

Competences: ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment] **III:** Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Das, 2019]

5.4 Deep Foundations, 3 hr(s)

Competences: ABET-2

Topics: **I:** Pile types and installation methods **II:** Axial capacity of single piles in cohesive and cohesionless soils **III:** Lateral load capacity and p-y method **IV:** Pile group behavior and group efficiency **V:** Drilled shaft design and construction considerations **VI:** Negative skin friction and downdrag forces

Learning Outcomes **I:** Select appropriate pile types based on soil conditions and loading [Familiarity] **II:** Calculate axial capacity of piles using static methods [Assessment] **III:** Analyze laterally loaded piles using p-y curves [Usage] **IV:** Evaluate pile group capacity and settlement [Assessment] **V:** Design drilled shaft foundations including shaft diameter and reinforcement [Usage] **VI:** Interpret pile load test results and verify design assumptions [Assessment]

Bibliography: [Das, 2019]

5.5 Masonry Structural Design, 6 hr(s)

Competences: ABET-2

Topics: **I:** Masonry materials, units, and mortar properties **II:** Unreinforced masonry wall design for compression and flexure **III:** Reinforced masonry design and detailing **IV:** Seismic design of masonry and timber structures

Learning Outcomes **I:** Identify masonry unit types and specify appropriate mortar for applications [Familiarity] **II:** Design unreinforced masonry walls for gravity and lateral loads [Assessment] **III:** Proportion reinforced masonry elements and specify reinforcement details [Usage] **IV:** Implement seismic design provisions for masonry and timber buildings [Usage]

Bibliography: [Drysdale and Hamid, 2008]

5.6 Reinforced Concrete Design, 6 hr(s)

Competences: ABET-2

Topics: **I:** Design philosophy and limit state methodology for concrete structures **II:** Flexural design of rectangular and T-beams **III:** Shear and torsion design of concrete members **IV:** Compression members and column design **V:** Slab design including one-way and two-way systems **VI:** Development length and splicing of reinforcement **VII:** Deflection control and serviceability requirements for concrete beams and slabs

Learning Outcomes **I:** Explain limit state design philosophy and load factor combinations [Familiarity] **II:** Design reinforced concrete beams for flexure and check serviceability [Assessment] **III:** Calculate shear and torsional reinforcement requirements [Usage] **IV:** Proportion columns for axial load and biaxial bending [Assessment] **V:** Design one-way and two-way slab systems with appropriate reinforcement [Usage] **VI:** Determine development lengths and design lap splices for reinforcing bars [Assessment] **VII:** Control deflections and verify serviceability requirements through adequate member sizing and reinforcement [Usage]

Bibliography: [Institute, 2019]

5.7 Construction Layout and Staking of Works, 6 hr(s)

Competences: ABET-2

Topics: **I:** Establishment and preservation of horizontal and vertical control points **II:** Staking of building axes, column lines, and reference offsets **III:** Transfer of design elevations and benchmarks to excavation and formwork **IV:** Layout instruments: total station, automatic/digital level, and GNSS/GPS receivers

Learning Outcomes **I:** Establish horizontal and vertical control points for a building site using a total station [Usage] **II:** Stake out building axes and column locations from a foundation layout plan [Usage] **III:** Explain the appropriate use of GNSS/GPS receivers for construction layout tasks [Familiarity]

Bibliography: [Ghilani and Wolf, 2020]

5.8 Formwork Design and Shoring Systems, 14 hr(s)

Competences: ABET-2

Topics: **I:** Lateral pressure of fresh concrete on formwork and design loads **II:** Formwork systems for walls and columns: panel, ganged, and slip forms **III:** Formwork systems for slabs and beams: conventional, flying, and table forms **IV:** Formwork materials: wood, plywood, engineered forms, and modular metal systems **V:** Shoring and falsework design: post shores, scaffold shoring, and heavy-duty shoring towers **VI:** Reshoring and backshoring procedures for multistory construction **VII:** Formwork removal and stripping time criteria based on concrete strength gain **VIII:** Safety considerations in formwork and shoring erection and dismantling

Learning Outcomes **I:** Calculate the lateral pressure of fresh concrete on wall formwork for a given pour rate [Assessment] **II:** Design wall or column formwork, including sheathing, studs, and ties, for a specified pressure [Assessment] **III:** Select an appropriate slab formwork system for a given floor plan and cycle time [Usage] **IV:** Design a shoring system, including post shore spacing and load path, for an elevated slab [Assessment] **V:** Plan a reshoring sequence for a multistory concrete building [Usage] **VI:** Determine the minimum stripping time for formwork based on concrete strength development [Assessment]

Bibliography: [Hurd, 2005, Peurifoy et al., 2018]

5.9 Rebar Detailing, Fabrication, and Placement, 10 hr(s)

Competences: ABET-2

Topics: **I:** Interpretation of structural drawings and bar bending schedules (BBS) **II:** Bar bending and cutting to standard hooks, bends, and fabrication tolerances **III:** Splicing methods: lap splices, mechanical couplers, and welded splices **IV:** Placement, support (chairs/spacers), and tying of reinforcing bars **V:** Concrete cover and bar spacing tolerances for durability and structural performance **VI:** Site quality control and inspection of reinforcement prior to concrete pour

Learning Outcomes **I:** Interpret a bar bending schedule and structural drawing to fabricate reinforcing bars [Usage] **II:** Select an appropriate splicing method for a given bar size and location [Assessment] **III:** Place and tie reinforcing steel to meet specified cover and spacing tolerances [Usage] **IV:** Inspect a completed reinforcement placement for compliance before authorizing concrete pour [Assessment]

Bibliography: [Institute, 2020, Institute, 2019]

6. Bibliography

[Das, 2019] Das, B. M. (2019). *Principles of Geotechnical Engineering*. Cengage Learning, 9th edition.

[Drysdale and Hamid, 2008] Drysdale, R. G. and Hamid, A. A. (2008). *Masonry Structures: Behavior and Design*. Masonry Society, 3rd edition.

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[Hurd, 2005] Hurd, M. K. (2005). *Formwork for Concrete*. American Concrete Institute, 7th edition. ACI SP-4.

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[Institute, 2020] Institute, C. R. S. (2020). Manual of standard practice. Technical report, Concrete Reinforcing Steel Institute.

[Peurifoy et al., 2018] Peurifoy, R. L., Schexnayder, C. J., Shapira, A., and Jha, K. N. (2018). *Construction Planning, Equipment, and Methods*. McGraw-Hill, 9th edition.

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CE3H1 Fluid Mechanics II (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)

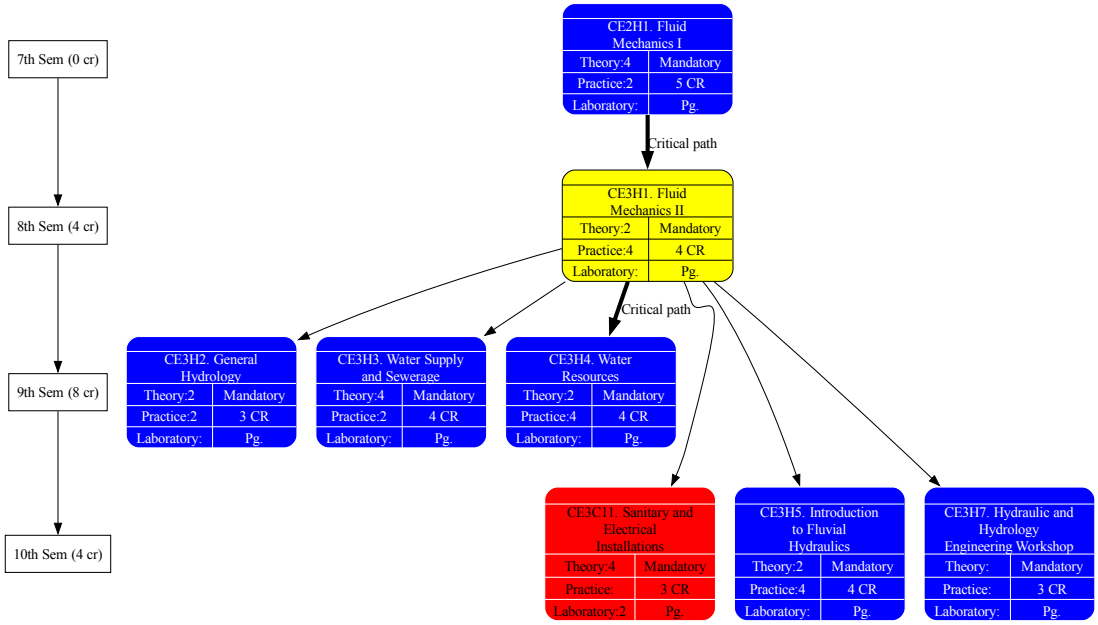

Figure 7.47: Connection Map. CE3H1 Fluid Mechanics II

2. Course Rationale

Fluid Mechanics II deepens the hydraulic analysis and design initiated in Fluid Mechanics I, covering three major blocks: pressurized pipe flow and pumping systems (including networks, transients, and modeling with specialized software), open channel flow (uniform flow, specific energy, rapidly and gradually varied flow, and modeling with HEC-RAS), and the design of hydraulic control structures (weirs, gates, inverted siphons, and culverts). The course combines classical analytical development with the use of hydraulic modeling tools (WaterCAD, HEC-RAS) employed in professional practice.

3. Goals of the Course

- Analyze and design pressurized piping systems, including networks, pumps, and transient phenomena such as water hammer.
- Apply hydraulic modeling tools (WaterCAD, HEC-RAS) for the analysis of pipe networks and open channel flow.
- Analyze uniform and varied flow in open channels and design efficient and stable channel sections.
- Design hydraulic control structures such as weirs, gates, inverted siphons, and culverts.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Pressurized Pipe Flow and Pump Systems, 42 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Pipe flow fundamentals and Darcy-Weisbach equation **II:** Minor losses and pipe system analysis **III:** Pipe network analysis methods **IV:** Pump characteristics and system curves **V:** Pump selection and installation requirements **VI:** Water hammer and surge analysis **VII:** Pipeline design and material selection **VIII:** Variable speed pumps and energy efficiency **IX:** Network modeling and optimization **X:** Valve selection and hydraulic control systems

Learning Outcomes **I:** Calculate head losses in pipe systems using friction equations [Assessment] **II:** Determine total head loss including minor losses in complex piping [Usage] **III:** Analyze pipe networks using Hardy Cross or equivalent methods [Assessment] **IV:** Construct pump characteristic curves and system head curves [Usage] **V:** Select appropriate pumps based on operating point and efficiency [Assessment] **VI:** Evaluate water hammer effects and design surge protection [Usage] **VII:** Design pipelines considering hydraulic, structural, and economic factors [Assessment] **VIII:** Apply variable speed drives for pump system optimization [Usage] **IX:** Optimize water distribution networks using modeling software [Assessment] **X:** Specify valves and control systems for pipeline operations [Usage]

Bibliography: [White, 2016, Ávila, 2002]

5.2 Open Channel Flow and River Mechanics, 30 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Channel flow classification and hydraulic elements **II:** Energy and momentum principles in open channels **III:** Uniform flow and Manning's equation **IV:** Critical flow and specific energy concepts **V:** Gradually varied flow profiles **VI:** Hydraulic jump and rapidly varied flow **VII:** Channel design for stable conveyance **VIII:** Sediment transport in open channels **IX:** River morphology and channel stability **X:** Scour analysis and protection measures

Learning Outcomes **I:** Classify open channel flow regimes and calculate hydraulic elements [Familiarity] **II:** Apply energy and momentum equations to solve channel flow problems [Assessment] **III:** Calculate normal depth and discharge using Manning's equation [Usage] **IV:** Determine critical depth and analyze specific energy relationships [Assessment] **V:** Compute gradually varied flow profiles using standard methods [Usage] **VI:** Analyze hydraulic jumps and calculate energy dissipation [Assessment] **VII:** Design stable channels with appropriate cross-sections and linings [Usage] **VIII:** Estimate sediment transport rates in alluvial channels [Assessment] **IX:** Evaluate river channel stability and bank erosion potential [Familiarity] **X:** Predict scour depths at hydraulic structures and design protection [Assessment]

Bibliography: [Chow, 1959]

5.3 Design of Hydraulic Structures, 12 hr(s)

Competences: ABET-2

Topics: **I:** Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes **I:** Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control [Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [Novak et al., 2007]

6. Bibliography

[Chow, 1959] Chow, V. T. (1959). *Open-Channel Hydraulics*. McGraw-Hill.

[Novak et al., 2007] Novak, P., Moffat, A. I. B., Nalluri, C., and Narayanan, R. (2007). *Hydraulic Structures*. Taylor & Francis, 4th edition.

[White, 2016] White, F. M. (2016). *Fluid Mechanics*. McGraw-Hill, 8th edition.

[Ávila, 2002] Ávila, G. S. (2002). *Hidráulica General, Tomo I: Fundamentos*. Limusa, 2da edition.

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CE3S1 Structural Analysis II (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE2S1 Structural Analysis I (7th Sem-Pg. 391)

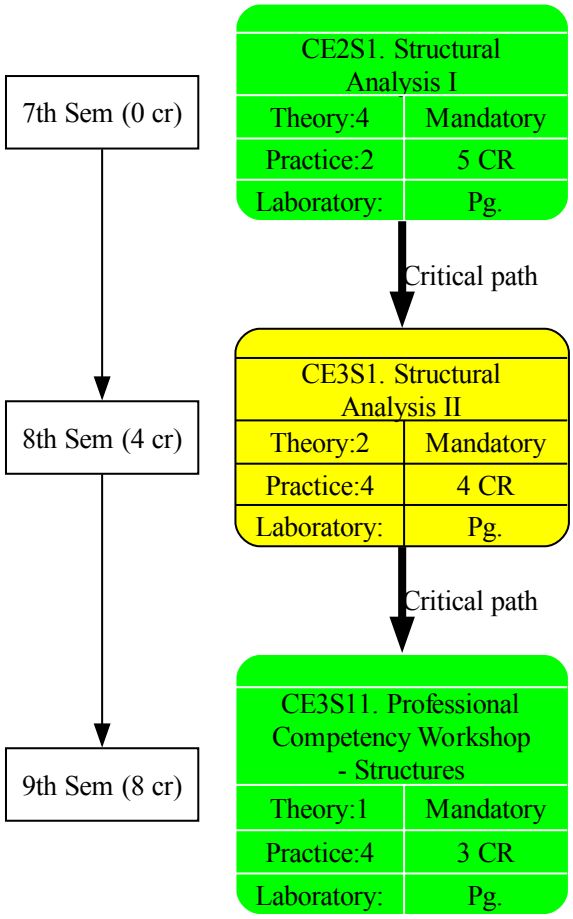

Figure 7.48: Connection Map. CE3S1 Structural Analysis II

2. Course Rationale

Structural Analysis II extends the matrix methods introduced in Structural Analysis I to the practical, computer-based analysis of building structural systems. Students deepen their command of the direct stiffness method through its application to plane trusses and frames, incorporate seismic loading through dynamic and response-spectrum analysis, and apply these tools in team seminars to the analysis of real building case studies. The course concludes with an introduction to the finite element method and to material and geometric nonlinear analysis, providing the computational foundation required for advanced structural design and specialized graduate study.

3. Goals of the Course

- Apply the direct stiffness method to formulate and solve the analysis of plane trusses and frames using matrix-based computer methods.
- Apply dynamic and response-spectrum analysis to determine the seismic response of building structural systems.
- Analyze real building structural systems in team-based seminars, integrating stiffness-method and seismic-analysis techniques into practical models.
- Formulate finite element models of structural systems, including an introduction to material and geometric nonlinear analysis.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Matrix Structural Analysis, 38 hr(s)

Competences: ABET-1

Topics: **I:** Displacement method and stiffness approach **II:** Direct stiffness method and matrix formulation **III:** Coordinate transformations and assembly of global stiffness matrices

Learning Outcomes **I:** Implement the displacement method for structural analysis [Assessment] **II:** Formulate structural problems using the direct stiffness method in matrix form [Usage] **III:** Assemble global stiffness matrices and solve for nodal displacements [Assessment]

Bibliography: [McGuire et al., 2000, Kassimali, 2012]

5.2 Structural Dynamics and Earthquake Engineering, 14 hr(s)

Competences: ABET-2

Topics: **I:** Single-degree-of-freedom systems and free vibration **II:** Forced vibration and harmonic excitation **III:** Damping models and energy dissipation mechanisms **IV:** Response spectrum analysis **V:** Earthquake ground motion characteristics and seismicity **VI:** Multi-degree-of-freedom systems and modal analysis **VII:** Time-history analysis and numerical integration methods **VIII:** Seismic design philosophy and capacity design principles **IX:** Base isolation and energy dissipation devices **X:** Performance-based seismic design methodology

Learning Outcomes **I:** Analyze free vibration of single-degree-of-freedom systems and determine natural frequencies [Assessment] **II:** Calculate structural response to harmonic and periodic loads [Usage] **III:** Explain the role of damping in reducing dynamic response [Familiarity] **IV:** Apply response spectrum method for seismic analysis [Usage] **V:** Interpret earthquake ground motion parameters and seismic hazard maps [Familiarity] **VI:** Perform modal analysis for multi-degree-of-freedom systems [Assessment] **VII:** Conduct time-history analysis using numerical integration techniques [Usage] **VIII:** Design structures following capacity design and ductile detailing principles [Assessment] **IX:** Evaluate the effectiveness of base isolation and damping systems [Familiarity] **X:** Implement performance-based seismic design procedures [Assessment]

Bibliography: [Chopra, 2017]

5.3 Building Structural Analysis and Modeling Practicum, 12 hr(s)

Competences: ABET-2

Topics: **I:** Overview of case-study buildings: geometry, structural systems, and load paths **II:** Development of plane frame and truss models of real buildings using stiffness-method-based structural analysis software **III:** Application of static and seismic response-spectrum analysis to representative building case studies **IV:** Presentation and peer discussion of structural analysis results and their design implications **V:** Definition of geometry, materials, sections, and boundary conditions for a three-dimensional building model in commercial structural analysis software (ETABS, Midas Gen) **VI:** Assignment of gravity, seismic, and wind loads and their combinations to a three-dimensional building model **VII:** Static and dynamic (modal) analysis of building models and interpretation of results, including story drifts, member forces, and vibration periods **VIII:** Verification of software-generated results against simplified hand calculations and code checks

Learning Outcomes **I:** Model real building structural systems for stiffness-method-based static and seismic analysis using structural analysis software [Usage] **II:** Interpret and validate computer-generated analysis results against expected structural behavior [Assessment] **III:** Present and defend structural analysis results and their design implications to peers [Usage] **IV:** Assign gravity, seismic, and wind loads and load combinations to a three-dimensional building model in commercial structural analysis software [Usage] **V:** Interpret dynamic analysis results, including story drifts, member forces, and vibration periods [Assessment] **VI:** Verify software-generated results against simplified hand calculations [Assessment]

Bibliography: [McGuire et al., 2000, Chopra, 2017]

5.4 Finite Element Methods in Structural Engineering, 20 hr(s)

Competences: ABET-6

Topics: **I:** Fundamentals of finite element theory and discretization **II:** Element types including truss, beam, and frame elements **III:** Stiffness matrix formulation and assembly **IV:** Plane stress and plane strain elements **V:** Modeling techniques, boundary conditions, and mesh refinement **VI:** Shell and plate elements **VII:** Solid elements and three-dimensional analysis **VIII:** Nonlinear analysis including material and geometric nonlinearity **IX:** Dynamic analysis using finite element methods **X:** Verification, validation, and error estimation in FEA

Learning Outcomes **I:** Explain the fundamental principles and assumptions of finite element analysis [Familiarity] **II:** Formulate element stiffness matrices for basic element types [Usage] **III:** Assemble global stiffness matrices and apply boundary conditions [Assessment] **IV:** Apply plane stress and plane strain elements to two-dimensional problems [Usage] **V:** Develop appropriate finite element models with proper mesh density [Assessment] **VI:** Utilize shell and plate elements for thin-walled structure analysis [Usage] **VII:** Model complex three-dimensional structures using solid elements [Assessment] **VIII:** Perform nonlinear finite element analysis for material and geometric effects [Usage] **IX:** Conduct dynamic finite element analysis including modal and time-history analysis [Assessment] **X:** Validate finite element results and estimate discretization errors [Assessment]

Bibliography: [Bathe, 2014]

6. Bibliography

[Bathe, 2014] Bathe, K.-J. (2014). *Finite Element Procedures.* K.J. Bathe, 2nd edition.

[Chopra, 2017] Chopra, A. K. (2017). *Dynamics of Structures: Theory and Applications to Earthquake Engineering.* Pearson, 5th edition.

[Kassimali, 2012] Kassimali, A. (2012). *Matrix Analysis of Structures.* Cengage Learning, 2nd edition.

[McGuire et al., 2000] McGuire, W., Gallagher, R. H., and Ziemian, R. D. (2000). *Matrix Structural Analysis*. Wiley, 2nd edition.

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CE3S5 Bridges and Structures (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2S1 Structural Analysis I (7th Sem-Pg. 391)
  - CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)

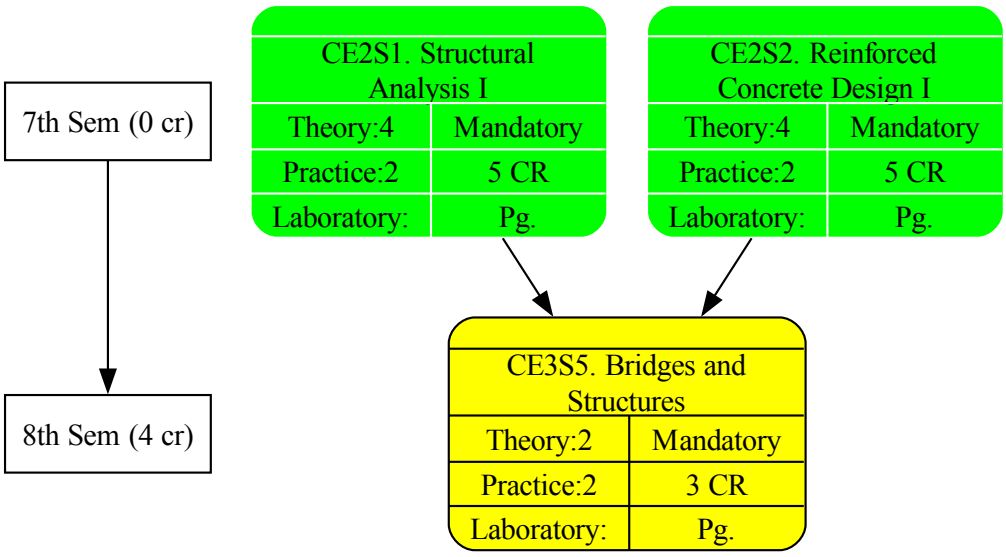

Figure 7.49: Connection Map. CE3S5 Bridges and Structures

2. Course Rationale

Bridges and Structures introduces the fundamentals of bridge engineering, from conceptual planning and typology selection to the structural analysis and design of highway bridge superstructures and substructures according to the AASHTO LRFD Bridge Design Specifications. Building on structural analysis and reinforced concrete design, students learn the basic site and design studies required for a bridge project, the loads and load combinations that govern bridge design, approximate and refined methods for analyzing slab-and-girder superstructures, and the flexural and shear design of reinforced concrete, prestressed concrete, steel composite, and truss superstructure members. The course also covers the design of bridge bearings, abutments, and foundations, and closes with an introduction to road and bridge asset management, providing the design foundation required for professional practice in bridge engineering.

3. Goals of the Course

- Identify the basic studies, design specifications, aesthetic considerations, and typology-selection factors involved in a bridge project.
- Determine the loads, load models, and load combinations that govern the design of highway bridges according to AASHTO LRFD.

- Model and analyze bridge superstructures using refined and approximate methods for slab-and-girder systems.
- Design reinforced concrete, prestressed concrete, and steel composite bridge superstructure members for flexure and shear according to AASHTO LRFD.
- Design truss bridge members subject to combined flexure and axial force, and design bridge bearings, abutments, and foundations.
- Recognize the fundamentals of road and bridge asset management for the operation and preservation of highway infrastructure.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Bridge Superstructure Design, 36 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Bridge types, components, and structural systems **II:** Load models and load combinations for bridge design **III:** Concrete slab bridges and T-beam bridge design **IV:** Steel girder bridges and composite bridge deck design **V:** Prestressed concrete girder bridges **VI:** Box girder and curved bridge analysis **VII:** Truss bridge design considerations for members under combined flexure and axial force

Learning Outcomes **I:** Classify bridge types and select appropriate systems for given site conditions [Familiarity] **II:** Apply AASHTO load models and determine critical load combinations [Usage] **III:** Design reinforced concrete slab bridges and T-beam superstructures [Assessment] **IV:** Proportion steel girders and design composite deck systems [Assessment] **V:** Analyze and design prestressed concrete girder bridges [Assessment] **VI:** Model box girder bridges and analyze curved alignment effects [Usage] **VII:** Design truss bridge members subject to combined flexo-tension and flexo-compression [Usage]

Bibliography: [Barker and Puckett, 2013, AASHTO, 2020, Chen and Duan, 2014]

5.2 Bridge Substructure, Evaluation, and Special Systems, 4 hr(s)

Competences: ABET-2

Topics: **I:** Substructure design including abutments and piers **II:** Cable-stayed and suspension bridge concepts **III:** Bearings, expansion joints, and bridge deck details **IV:** Bridge load rating and evaluation procedures **V:** Seismic design of bridges and isolation systems

Learning Outcomes **I:** Design bridge abutments and piers for vertical and lateral loads [Usage] **II:** Explain the structural behavior of cable-supported bridge systems [Familiarity] **III:** Select and design bridge bearings and expansion joint systems [Assessment] **IV:** Perform load rating analysis for existing bridges [Usage] **V:** Implement seismic design criteria for bridge structures [Assessment]

Bibliography: [Barker and Puckett, 2013, AASHTO, 2020]

5.3 Road and Bridge Asset Management, 2 hr(s)

Competences: ABET-2

Topics: **I:** Inventory, inspection, and condition assessment of roads and bridges **II:** Condition indices, deterioration models, and prioritization criteria for maintenance and rehabilitation programs **III:** Life-cycle cost analysis and budgeting for road and bridge network preservation

Learning Outcomes **I:** Describe the fundamentals of an infrastructure asset management system for roads and bridges [Familiarity] **II:** Apply condition indices and prioritization criteria to plan maintenance and rehabilitation actions for a road or bridge network [Usage] **III:** Analyze life-cycle cost to budget preservation programs for road and bridge infrastructure [Assessment]

Bibliography: [Hudson et al., 1997]

6. Bibliography

[AASHTO, 2020] AASHTO (2020). Aashto lrfd bridge design specifications. Technical report, American Association of State Highway and Transportation Officials.

[Barker and Puckett, 2013] Barker, R. M. and Puckett, J. A. (2013). *Design of Highway Bridges: An LRFD Approach*. Wiley, 3rd edition.

[Chen and Duan, 2014] Chen, W.-F. and Duan, L., editors (2014). *Bridge Engineering Handbook*. CRC Press, 2nd edition.

[Hudson et al., 1997] Hudson, W. R., Haas, R., and Uddin, W. (1997). *Infrastructure Management: Integrating Design, Construction, Maintenance, Rehabilitation, and Renovation*. McGraw-Hill.

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CE3S9 Prestressed Concrete (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)

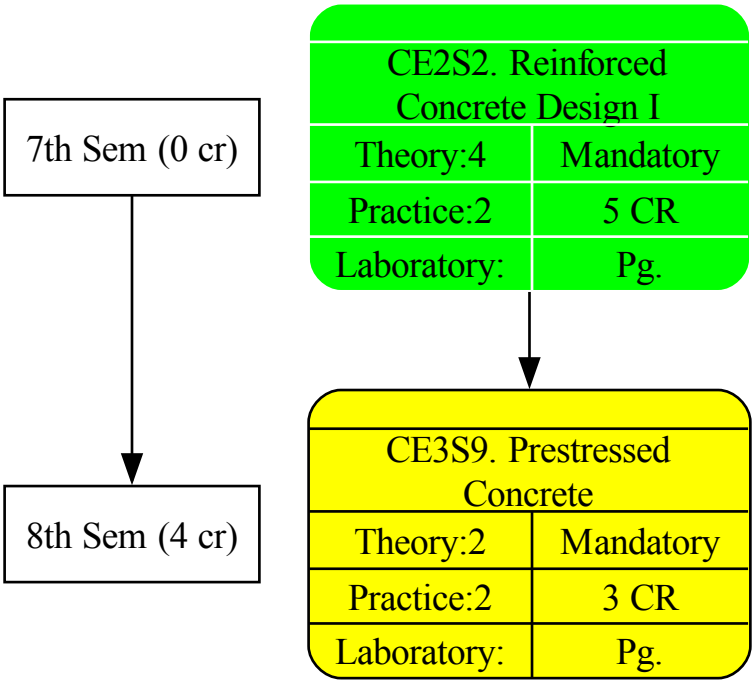

Figure 7.50: Connection Map. CE3S9 Prestressed Concrete

2. Course Rationale

Prestressed Concrete introduces the fundamental principles, elastic analysis, and design methodology for prestressed and post-tensioned concrete members following the ACI 318 building code, building directly on the limit state design foundation established in Reinforced Concrete Design I. Students learn to analyze elastic stresses in prestressed concrete sections under service loads, evaluate composite construction combining precast members and cast-in-place concrete, and calculate immediate and time-dependent losses of prestress. The course develops the design of pretensioned and post-tensioned members for flexural, shear, and torsional strength at the ultimate limit state, the design of post-tensioned slabs including tendon layout, the analysis of statically indeterminate prestressed concrete structures, and the verification of deflection and serviceability requirements, preparing students for advanced structural design practice involving prestressed concrete elements.

3. Goals of the Course

- Apply elastic theory to analyze stresses in prestressed concrete sections under service loads.

- Design composite prestressed concrete sections combining precast members and cast-in-place concrete.
- Calculate immediate and time-dependent losses of prestress.
- Design prestressed concrete members for flexural strength at the ultimate limit state.
- Design prestressed concrete members for shear and torsion strength.
- Design post-tensioned slabs and beams, including tendon layout.
- Analyze statically indeterminate prestressed concrete structures, including secondary moments, and control deflections.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Seismic Detailing of Reinforced Concrete, 16 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Beam-column joints and moment-resisting frame connections **II:** Seismic detailing and ductile design of concrete structures **III:** Design of special reinforced concrete structural walls (shear walls) for seismic lateral force resistance **IV:** Special seismic detailing provisions for reinforced concrete moment-resisting frames

Learning Outcomes **I:** Detail beam-column joints for moment transfer and shear resistance [Assessment] **II:** Implement seismic detailing requirements for ductile concrete frames [Assessment] **III:** Design special reinforced concrete structural walls for combined axial, flexural, and shear demands under seismic loading [Assessment] **IV:** Apply special seismic detailing provisions to reinforced concrete moment frame members and beam-column joints [Usage]

Bibliography: [Nawy, 2010, Nilson, 1987, ACI Committee 318, 2019, Lin and Burns, 1981]

5.2 Prestressed Concrete Analysis, 16 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Prestressed concrete principles and pre-tensioning methods **II:** Elastic analysis of stresses in prestressed concrete sections under service loads **III:** Composite prestressed concrete sections: precast members with cast-in-place topping **IV:** Immediate and time-dependent losses of prestress

Learning Outcomes **I:** Apply prestressing principles to design pre-tensioned members [Usage] **II:** Analyze stresses in prestressed concrete sections under service loads using elastic theory [Usage] **III:** Design composite prestressed concrete sections combining precast members and cast-in-place concrete [Assessment] **IV:** Calculate immediate and time-dependent losses of prestress [Usage]

Bibliography: [Nawy, 2010, Nilson, 1987, ACI Committee 318, 2019, Lin and Burns, 1981]

5.3 Prestressed Concrete Design, 20 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Post-tensioned concrete systems and tendon design **II:** Deflection control and serviceability requirements **III:** Flexural strength of prestressed concrete members at ultimate limit state **IV:** Shear and torsion design of prestressed concrete members **V:** Statically indeterminate prestressed concrete structures, including secondary moments

Learning Outcomes **I:** Design post-tensioned slabs and beams including tendon layout [Assessment] **II:** Control deflections through appropriate member sizing and reinforcement [Usage] **III:** Design prestressed concrete members for flexural strength at the ultimate limit state [Assessment] **IV:** Design prestressed concrete members for shear and torsion strength [Assessment] **V:** Analyze statically indeterminate prestressed concrete structures, including secondary moments [Assessment]

Bibliography: [Nawy, 2010, Nilson, 1987, ACI Committee 318, 2019, Lin and Burns, 1981]

6. Bibliography

[ACI Committee 318, 2019] ACI Committee 318 (2019). Building code requirements for structural concrete (aci 318-19) and commentary. Technical report, American Concrete Institute.

[Lin and Burns, 1981] Lin, T. Y. and Burns, N. H. (1981). *Design of Prestressed Concrete Structures*. John Wiley & Sons, 3rd edition.

[Nawy, 2010] Nawy, E. G. (2010). *Prestressed Concrete: A Fundamental Approach*. Pearson, 5th edition.

[Nilson, 1987] Nilson, A. H. (1987). *Design of Prestressed Concrete*. John Wiley & Sons, 2nd edition.

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BMI201 Methodology of Engineering Research (Mandatory)

1. General information

- **Semester**: 8th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - 150Cr

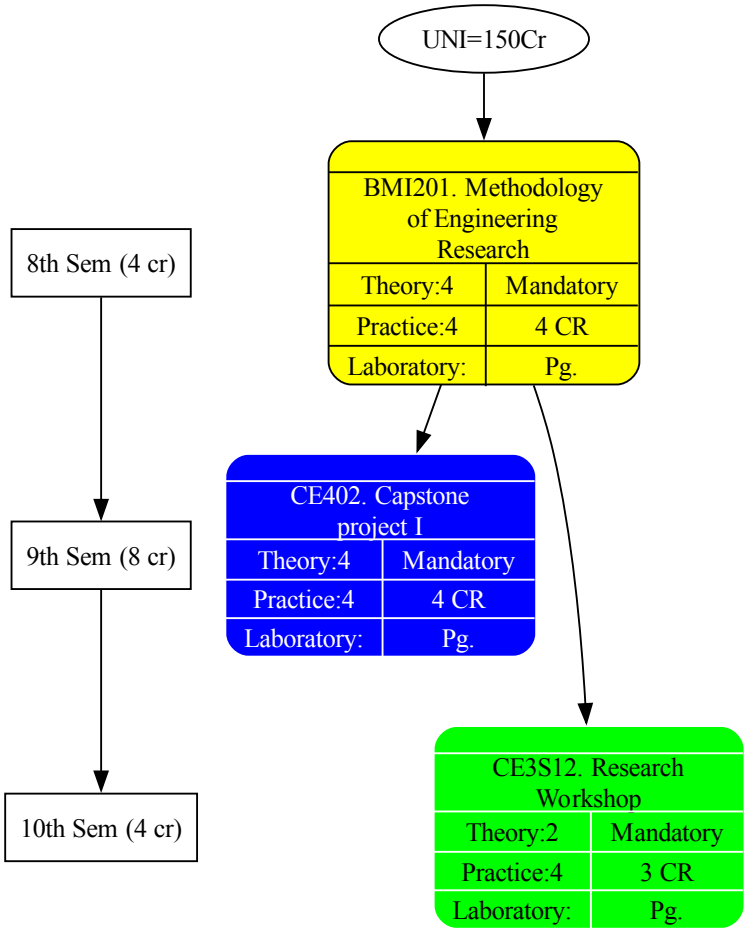

Figure 7.51: Connection Map. BMI201 Methodology of Engineering Research

2. Course Rationale

Research Methodology in Engineering introduces students to the systematic process of formulating, conducting, and communicating engineering research. The course covers the foundations of the scientific and engineering research process – problem formulation, literature review, research design, data collection and analysis, and academic writing and citation norms – and then applies them directly: each student develops an original research or applied-engineering proposal under individualized faculty advising, presenting and defending it through continuous and final evaluation.

3. Goals of the Course

- Formulate a well-defined engineering research problem and conduct a supporting literature review.
- Design a research approach appropriate to an engineering problem, selecting suitable data-collection and data-analysis methods.
- Apply academic-integrity principles and standard citation norms when producing engineering research writing.
- Develop, under individualized advising, an original research or applied-engineering proposal from problem formulation through preliminary results.
- Present and defend engineering research work, responding to continuous and final evaluation.

4. General Competences (*Outcomes*)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Familiarity)

5. Content

5.1 Problem Formulation and Literature Review, 10 hr(s)

Competences: ABET-6

Topics: **I:** The engineering research process: from problem identification to dissemination of results **II:** Formulating a research problem and specific, investigable research questions for engineering practice **III:** Literature review methodology: search strategies, source evaluation, and synthesis

Learning Outcomes **I:** Formulate a specific, investigable engineering research problem [Usage] **II:** Conduct a supporting literature review, evaluating and synthesizing sources [Usage]

Bibliography: [Booth et al., 2016, Leedy and Ormrod, 2019, of Civil Engineers (ASCE), 2019]

5.2 Research Design and Data Methods, 10 hr(s)

Competences: ABET-6

Topics: **I:** Research design: quantitative, qualitative, and mixed-methods approaches applied to engineering problems **II:** Data collection instruments and methods for engineering research (surveys, experiments, field measurements, simulation) **III:** Data analysis methods and interpretation of engineering research results

Learning Outcomes **I:** Design a research approach, appropriate for an engineering research question, including data collection and analysis methods [Usage] **II:** Select data collection instruments and analysis methods appropriate to a given engineering research question [Usage]

Bibliography: [Booth et al., 2016, Leedy and Ormrod, 2019, of Civil Engineers (ASCE), 2019]

5.3 Research Communication and Academic Integrity, 10 hr(s)

Competences: ABET-6

Topics: **I:** Academic integrity, plagiarism, and citation standards (reference norms) in engineering writing **II:** Structure of a research proposal, thesis, and technical paper **III:** Oral presentation and defense of engineering research work

Learning Outcomes **I:** Apply academic integrity principles and standard citation norms in an engineering research write-up [Usage] **II:** Structure a research proposal or technical paper following standard engineering academic conventions [Assessment] **III:** Present and defend engineering research work in response to an evaluation committee's questions [Assessment]

Bibliography: [Booth et al., 2016, Leedy and Ormrod, 2019, of Civil Engineers (ASCE), 2019]

6. Bibliography

[Booth et al., 2016] Booth, W. C., Colomb, G. G., Williams, J. M., Bizup, J., and FitzGerald, W. T. (2016). *The Craft of Research*. University of Chicago Press, 4th edition.

[Leedy and Ormrod, 2019] Leedy, P. D. and Ormrod, J. E. (2019). *Practical Research: Planning and Design*. Pearson, 12th edition.

[of Civil Engineers (ASCE), 2019] of Civil Engineers (ASCE), A. S. (2019). Guide to preparing engineering research reports and theses. Technical report, ASCE.

Ninth Semester

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CE3C15 Professional Competencies Workshop (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE3C9 Integrated Construction Management (9th Sem-Pg. 448)

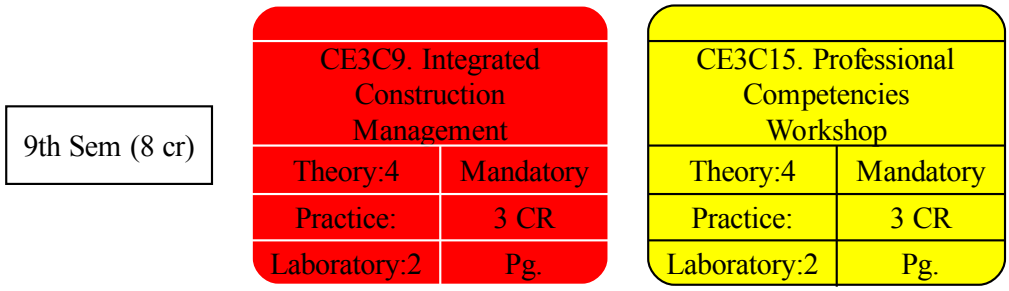

Figure 7.52: Connection Map. CE3C15 Professional Competencies Workshop

2. Course Rationale

Professional Skills Workshop is an integrative course that applies, to a real construction project, feasibility, environmental, and social studies, material selection, procurement and contract management, process standardization and quality management, safety and environmental management, planning, simulation of construction processes with BIM tools, and cost, risk, and opportunity control through an integrated management dashboard.

3. Goals of the Course

- Develop feasibility, environmental, and social studies for a construction project.
- Apply procurement, contract, quality, safety, and environmental management to a construction project.
- Plan and simulate construction processes of a project using BIM tools.
- Control costs, risks, and opportunities of a project through an integrated management dashboard.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Project Context, 6 hr(s)

Competences: ABET-1

Topics: I: Context and scope of the construction project to be developed in the workshop.

Learning Outcomes I: Describe the context and scope of a real construction project [Familiarity].

Bibliography: [Institute, 2021]

5.2 Engineering Economics and Project Financing (PPPs), 6 hr(s)

Competences: ABET-1

Topics: I: Time value of money: present worth, future worth, annual worth calculations **II:** Comparison of project alternatives: present worth, rate of return, benefit-cost analysis **III:** Depreciation methods and tax considerations in engineering economics **IV:** Project feasibility studies and break-even analysis **V:** Risk and uncertainty in economic analysis: sensitivity and scenario analysis **VI:** Life-cycle costing for infrastructure assets **VII:** Project financing models: debt, equity, and public-private partnerships (PPPs) **VIII:** Valuation of intangible benefits and costs in public projects **IX:** Real options analysis for flexible project planning

Learning Outcomes I: Calculate present worth, future worth, and annual worth for a series of cash flows [Usage] **II:** Compare two mutually exclusive project alternatives using present worth analysis [Assessment] **III:** Apply straight-line and MACRS depreciation methods to a capital asset [Usage] **IV:** Conduct a basic sensitivity analysis on the key variables of a project's economic model [Assessment] **V:** Perform a life-cycle cost analysis for a bridge, considering initial construction, maintenance, and end-of-life costs [Usage] **VI:** Compare the risk allocation in a Design-Bid-Build project versus a Public-Private Partnership (PPP) [Familiarity] **VII:** Monetize the societal benefits (e.g., reduced travel time) of a transportation project for a benefit-cost analysis [Assessment] **VIII:** Explain how real options analysis can add value to the planning of a multi-phase infrastructure project [Familiarity]

Bibliography: [Blank and Tarquin, 2017]

5.3 Environmental Impact Assessment and Sustainability Metrics, 6 hr(s)

Competences: ABET-2

Topics: I: EIA process: screening, scoping, impact analysis, mitigation, and public participation **II:** Impact prediction methods for air, water, soil, noise, and ecological systems **III:** Mitigation hierarchy and design of environmental management plans **IV:** Legal and institutional frameworks for EIA **V:** Sustainability concepts and the triple bottom line (environment, economy, society) **VI:** Cumulative impact assessment and strategic environmental assessment (SEA) **VII:** Social impact assessment and stakeholder engagement methods **VIII:** Sustainability metrics and indicator frameworks (e.g., SDGs, Envision) **IX:** Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes I: Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity] **II:** Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage] **III:** Develop mitigation measures for identified significant environmental impacts [Assessment] **IV:** Explain the legal requirements and purpose of EIA in the project approval process [Familiarity] **V:** Apply the triple bottom line framework to evaluate a simple engineering project [Assessment] **VI:** Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment] **VII:** Design a stakeholder engagement plan for a controversial development project [Usage] **VIII:** Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment] **IX:** Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

Bibliography: [Glasson and Therivel, 2019]

5.4 Standardized Testing, Quality Control, and Failure Analysis, 6 hr(s)

Competences: ABET-6

Topics: **I:** Standard test methods for material characterization and acceptance testing **II:** Sampling procedures and representative sample selection **III:** Quality control and quality assurance protocols in construction **IV:** Statistical analysis of test data and acceptance criteria **V:** Non-destructive testing methods for materials and structures **VI:** Advanced material characterization techniques including microscopy and spectroscopy **VII:** Failure analysis methodology and root cause investigation **VIII:** Forensic engineering and distress evaluation **IX:** Performance-based testing and specification approaches **X:** Certification, compliance, and third-party testing requirements

Learning Outcomes **I:** Perform standard material tests according to ASTM or equivalent specifications [Usage] **II:** Develop appropriate sampling plans for construction material acceptance [Assessment] **III:** Implement quality control procedures for construction materials and processes [Usage] **IV:** Analyze test data using statistical methods and establish acceptance criteria [Assessment] **V:** Apply non-destructive testing techniques for in-situ material evaluation [Familiarity] **VI:** Utilize advanced characterization techniques to investigate material microstructure [Usage] **VII:** Conduct systematic failure analysis to determine root causes of material distress [Assessment] **VIII:** Investigate structural failures using forensic engineering methodologies [Assessment] **IX:** Design performance-based test protocols for innovative materials [Usage] **X:** Interpret certification requirements and coordinate third-party testing programs [Familiarity]

Bibliography: [Neville, 2011]

5.5 Contracts, Specifications, and Construction Law, 6 hr(s)

Competences: ABET-2

Topics: **I:** Contract types: lump sum, unit price, cost-plus, and design-build **II:** Procurement methods and bidding strategies **III:** Project specifications: MasterFormat, performance vs. prescriptive **IV:** General conditions of contract and key clauses (e.g., AIA, FIDIC) **V:** Change orders, extra work, and variation procedures **VI:** Claims management: delay, disruption, and acceleration **VII:** Dispute resolution: negotiation, mediation, arbitration, litigation **VIII:** Professional liability, negligence, and standard of care **IX:** Ethical dilemmas and professional conduct in construction

Learning Outcomes **I:** Compare the risk allocation between owner and contractor in different contract types [Familiarity] **II:** Select an appropriate procurement method for a given project delivery model [Assessment] **III:** Write a clear, unambiguous technical specification for a construction material [Usage] **IV:** Explain the purpose of key clauses in standard general conditions of contract [Familiarity] **V:** Process a hypothetical change order, documenting cost and time impacts [Usage] **VI:** Analyze a simple delay claim and determine entitlement and damages [Assessment] **VII:** Recommend an appropriate dispute resolution method for a given conflict scenario [Assessment] **VIII:** Define the engineer's standard of care and potential liabilities for design errors [Familiarity] **IX:** Resolve an ethical dilemma related to bidding practices or site safety reporting [Assessment]

Bibliography: [de las Contrataciones del Estado (OSCE), 2019]

5.6 Quality Management, 6 hr(s)

Competences: ABET-6

Topics: **I:** Total Quality Management: Deming's 14 points, continuous improvement (kaizen), and quality culture **II:** Six Sigma methodology (DMAIC): process capability, control charts, and defects per million opportunities **III:** Quality standards and certification: ISO 9001 framework, quality cost categories (prevention, appraisal, failure) **IV:** Quality function deployment (QFD) and voice of the customer: House of Quality matrix, customer requirement translation, and design prioritization

Learning Outcomes **I:** Explain the TQM philosophy and the key tools used in the DMAIC improvement cycle [Familiarity] **II:** Apply basic statistical process control methods to monitor process quality [Usage] **III:** Evaluate the quality performance of a process and recommend improvement priorities using cost-of-quality analysis [Assessment]

Bibliography: [for Standardization, 2015]

5.7 Staged Deliverable I, 6 hr(s)

Competences: ABET-6

Topics: **I:** Preparation and submission of the workshop's first staged deliverable report, consolidating the project context, feasibility, environmental and social studies, material selection, procurement and contract management, and quality management work completed so far. **II:** Oral defense of the staged deliverable before a review panel.

Learning Outcomes **I:** Prepare a staged project report consolidating the findings of the workshop's initial phases [Usage]. **II:** Defend the staged deliverable orally before a review panel, responding to technical questions [Assessment].

Bibliography: [Institute, 2021]

5.8 Construction Safety, Health, and Risk Management, 6 hr(s)

Competences: ABET-1

Topics: **I:** Safety management systems and the role of safety culture **II:** Common construction hazards: falls, struck-by, electrocution, caught-in/between **III:** Occupational Safety and Health Administration (OSHA) regulations and compliance **IV:** Risk identification and assessment techniques (e.g., JSA, checklists) **V:** Hierarchy of controls: elimination, substitution, engineering, administrative, PPE **VI:** Occupational health: silica, noise, ergonomics, and industrial hygiene **VII:** Emergency response planning and incident investigation **VIII:** Insurance and bonding principles for construction risk transfer **IX:** Proactive safety leading indicators and predictive analytics

Learning Outcomes **I:** Identify the "Fatal Four" construction hazards and basic OSHA requirements for each [Familiarity] **II:** Conduct a Job Safety Analysis (JSA) for a common construction task [Assessment] **III:** Develop a site-specific safety plan for a given project scenario [Usage] **IV:** Apply the hierarchy of controls to mitigate an identified safety risk [Familiarity] **V:** Evaluate occupational health exposures (e.g., noise, dust) and recommend monitoring strategies [Assessment] **VI:** Create an emergency response plan for a construction site [Usage] **VII:** Explain the purpose and types of insurance (e.g., CGL, workers' comp) in construction risk management [Familiarity] **VIII:** Propose leading safety indicators to track and predict site safety performance [Assessment]

Bibliography: [Hinze, 2005, de Trabajo y Promoción del Empleo del Perú, 2010]

5.9 Project Planning, Scheduling, and Control (CPM, 4D/5D), 6 hr(s)

Competences: ABET-2

Topics: **I:** Work breakdown structure (WBS) development and activity definition **II:** Network diagramming: activity-on-node (AON) and precedence diagramming method (PDM) **III:** Critical Path Method (CPM) for schedule calculation: forward/backward pass, floats **IV:** Resource allocation, loading, and leveling techniques **V:** Schedule updating, monitoring, and control using earned value management (EVM) **VI:** Program Evaluation and Review Technique (PERT) for schedule risk analysis **VII:** Line of balance (LOB) scheduling for repetitive projects **VIII:** 4D scheduling (time + 3D model) for visualization and clash detection **IX:** 5D scheduling (time + cost + 3D model) for integrated cost control

Learning Outcomes **I:** Develop a Work Breakdown Structure (WBS) for a medium-scale construction project [Usage] **II:** Construct a CPM network diagram and calculate the critical path and activity floats [Assessment] **III:** Perform resource leveling on a simple project schedule to minimize resource fluctuations [Usage] **IV:** Monitor project progress using schedule variance (SV) and cost variance (CV) from earned value data [Assessment] **V:** Apply PERT to estimate project duration probabilities and identify schedule risks [Assessment] **VI:** Create a Line of Balance (LOB) schedule for a repetitive housing project [Usage] **VII:** Generate a 4D simulation to visualize the construction sequence and identify spatial conflicts [Usage] **VIII:** Integrate cost data with a 3D model to perform a 5D analysis for budget tracking [Assessment]

Bibliography: [Callahan et al., 1992]

5.10 Building Information Modeling (BIM) for Digital Delivery and Asset Management, 6 hr(s)

Competences: ABET-6

Topics: **I:** BIM concepts: dimensions (3D, 4D, 5D, 6D, 7D), LOD, and LOIN **II:** BIM authoring tools and parametric modeling techniques **III:** Model coordination, clash detection, and interference checking **IV:** Collaboration platforms, Common Data Environments (CDE), and BIM execution plans **V:** BIM-based analysis: quantity takeoff, energy simulation, and structural analysis **VI:** Digital twins and the connection between BIM and operational data **VII:** Interoperability standards: IFC, COBie, and openBIM **VIII:** Asset information models (AIM) and BIM for facilities management (FM) **IX:** Regulatory submission and automated code compliance checking

Learning Outcomes **I:** Define the different dimensions of BIM (3D-7D) and their associated information [Familiarity] **II:** Create a basic 3D parametric model of a structural framing system using BIM software [Usage] **III:** Perform a clash detection analysis between architectural and structural models [Assessment] **IV:** Outline the key components of a BIM Execution Plan (BEP) [Familiarity] **V:** Extract a material quantity takeoff schedule from a BIM model [Usage] **VI:** Explain the relationship between a BIM model and a digital twin for an asset [Familiarity] **VII:** Export a BIM model using the IFC format to ensure interoperability [Usage] **VIII:** Develop an Asset Information Model (AIM) deliverable for handover to a facility manager [Assessment] **IX:** Evaluate the potential of automated rule-checking for building code compliance [Assessment]

Bibliography: [Eastman et al., 2018]

5.11 Construction Methods, Equipment, and Productivity, 6 hr(s)

Competences: ABET-2

Topics: **I:** Earthwork operations: excavation, hauling, compaction, and mass diagrams **II:** Concrete construction: formwork, placing, finishing, and curing **III:** Steel erection, connection, and safety procedures **IV:** Construction equipment types, capabilities, and selection criteria **V:** Productivity measurement, cycle time analysis, and crew balancing **VI:** Heavy civil construction methods for tunnels, dams, and bridges **VII:** Equipment economics: ownership vs. rental, depreciation, and operating cost **VIII:** Trenchless technologies and deep excavation support systems **IX:** Automation and robotics in construction operations

Learning Outcomes **I:** Select appropriate construction equipment for common earthwork and material handling tasks [Usage] **II:** Design basic formwork and shoring for a concrete slab or wall [Assessment] **III:** Explain the sequence and safety considerations for steel erection [Familiarity] **IV:** Calculate productivity rates and cycle times for equipment operations [Usage] **V:** Balance a construction crew to optimize productivity for a given task [Assessment] **VI:** Compare construction methods for a heavy civil project like a cut-and-cover tunnel [Assessment] **VII:** Analyze the economic life and hourly cost of a piece of construction equipment [Usage] **VIII:** Describe the applications and limitations of trenchless construction technologies [Familiarity] **IX:** Evaluate the potential for automation to improve safety and productivity on a construction site [Assessment]

Bibliography: [Peurifoy et al., 2018]

5.12 Construction Budgeting, Bidding, and Financial Control, 6 hr(s)

Competences: ABET-6

Topics: **I:** Bid preparation, submission, and analysis processes **II:** Cash flow forecasting and management for construction projects **III:** Value engineering and constructability analysis **IV:** Financial statements and performance metrics for construction firms

Learning Outcomes **I:** Explain the components and typical markup structure of a competitive bid [Familiarity] **II:** Develop a monthly cash flow forecast for a construction project [Usage] **III:** Perform a value engineering workshop to identify cost-saving alternatives without sacrificing function [Assessment] **IV:** Interpret key financial ratios for assessing a construction company's health [Familiarity]

Bibliography: [de la Construcción (CAPECO), 2020]

5.13 Dashboards and Information Radiators, 6 hr(s)

Competences: ABET-6

Topics: **I:** Designing effective project dashboards: key metrics, visual clarity, and stakeholder relevance **II:** Information radiators: physical and digital tools for continuous team transparency **III:** Real-time dashboards: automated data feeds and live project status visualization **IV:** Maintaining and evolving dashboards as the project progresses and information needs change

Learning Outcomes **I:** Design a project performance dashboard with relevant KPIs for team and stakeholder use [Usage] **II:** Implement information radiators that provide real-time project transparency to the team [Assessment] **III:** Evaluate the effectiveness of a dashboard in communicating project health and recommend improvements [Assessment]

Bibliography: [Institute, 2021]

5.14 Staged Deliverable II, 6 hr(s)

Competences: ABET-6

Topics: **I:** Preparation and submission of the workshop's final staged deliverable report, consolidating the safety and environmental management, planning, BIM modeling, construction process simulation, and cost/risk/opportunity control work completed in the second half of the workshop. **II:** Oral defense of the final deliverable before a review panel.

Learning Outcomes **I:** Prepare a final staged project report consolidating the findings of the workshop's later phases [Usage]. **II:** Defend the final deliverable orally before a review panel, responding to technical questions [Assessment].

Bibliography: [Institute, 2021]

6. Bibliography

[Blank and Tarquin, 2017] Blank, L. and Tarquin, A. (2017). *Engineering Economy*. McGraw-Hill, 8th edition.

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[Peurifoy et al., 2018] Peurifoy, R. L., Schexnayder, C. J., Shapira, A., and Jha, K. N. (2018). *Construction Planning, Equipment, and Methods*. McGraw-Hill, 9th edition.

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CE3C5 Costs and Budgeting (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE2C2 Construction Technology I (7th Sem-Pg. 371)

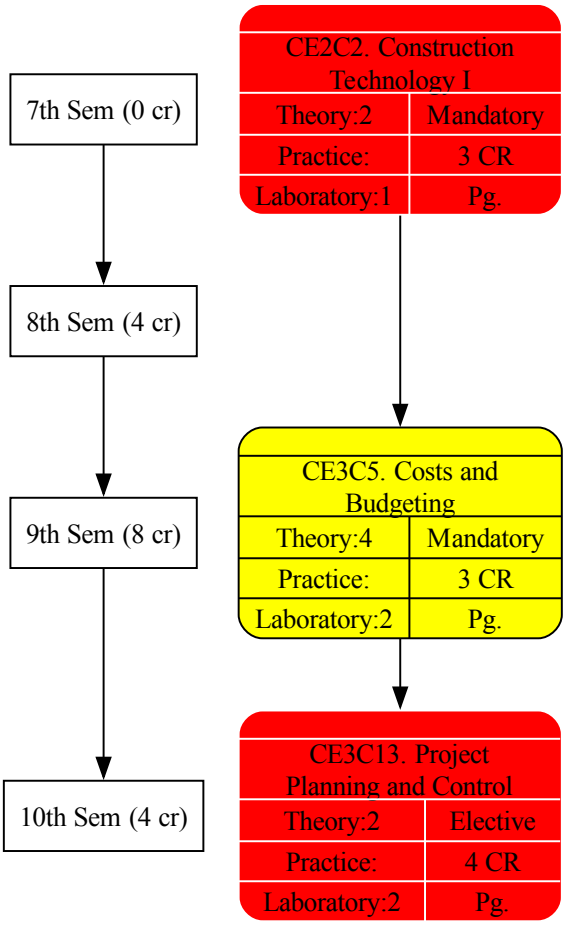

Figure 7.53: Connection Map. CE3C5 Costs and Budgeting

2. Course Rationale

Costs and Budgeting deepens the economic management and control of construction works: analysis of bid documents, quantity takeoffs by specialty, unit cost analysis, direct and indirect costs, budgeting, bidding, and cost control, together with the mechanisms used to adjust contract prices for cost escalation and to certify and pay work actually performed: polynomial price-adjustment formulas and monthly progress valuations.

3. Goals of the Course

- Analyze bid documents and prepare quantity takeoffs by specialty.
- Prepare project budgets distinguishing direct and indirect costs, and analyze a competitive bid.
- Exercise economic control of a construction project through cost tracking and cash-flow management.
- Apply the polynomial price-adjustment formula and prepare monthly progress valuations for a construction contract.

4. General Competences (*Outcomes*)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Construction Cost Estimating and Quantification, 54 hr(s)

Competences: ABET-6

Topics: **I:** Estimating types: conceptual, preliminary, and detailed **II:** Quantity takeoff methods from drawings and digital models **III:** Pricing components: labor, material, equipment, and overhead **IV:** Parametric and probabilistic estimating techniques **V:** Life-cycle cost analysis for building systems

Learning Outcomes **I:** Perform a detailed quantity takeoff for concrete, formwork, and reinforcement from construction drawings [Usage] **II:** Prepare a unit price estimate for a defined work package [Assessment] **III:** Apply parametric models to develop a conceptual cost estimate for a building [Assessment] **IV:** Conduct a life-cycle cost analysis to compare two alternative building envelope systems [Usage]

Bibliography: [Peurifoy et al., 2018, de la Construcción (CAPECO), 2020]

5.2 Construction Budgeting, Bidding, and Financial Control, 44 hr(s)

Competences: ABET-6

Topics: **I:** Bid preparation, submission, and analysis processes **II:** Cash flow forecasting and management for construction projects **III:** Value engineering and constructability analysis **IV:** Financial statements and performance metrics for construction firms

Learning Outcomes **I:** Explain the components and typical markup structure of a competitive bid [Familiarity] **II:** Develop a monthly cash flow forecast for a construction project [Usage] **III:** Perform a value engineering workshop to identify cost-saving alternatives without sacrificing function [Assessment] **IV:** Interpret key financial ratios for assessing a construction company's health [Familiarity]

Bibliography: [Peurifoy et al., 2018, de la Construcción (CAPECO), 2020]

5.3 Price Adjustment and Progress Valuations, 32 hr(s)

Competences: ABET-6

Topics: **I:** Polynomial price-adjustment formula: structure, incidence coefficients (coeficientes de incidencia), and representative unit-cost components **II:** Official unified construction cost indices: publication cycle, sourcing, and application to the adjustment formula **III:** Monthly progress valuations: measurement of completed quantities and certification for payment **IV:** Advance payments and retentions: calculation and amortization schedule within progress valuations **V:** Disputed price-adjustment and valuation calculations: common sources of disagreement and resolution mechanisms

Learning Outcomes **I:** Calculate the adjusted contract price for a work item using a polynomial price-adjustment formula and official cost indices [Usage] **II:** Prepare a monthly progress valuation certifying completed quantities for payment [Usage] **III:** Explain the role of advance payments and retentions in a progress-payment schedule [Familiarity] **IV:** Resolve a disputed price-adjustment calculation by correctly applying index-based escalation rules [Assessment]

Bibliography: [de la Construcción (CAPECO), 2020]

6. Bibliography

[de la Construcción (CAPECO), 2020] de la Construcción (CAPECO), C. P. (2020). Costos y presupuestos en edificación. Technical report, CAPECO.

[Peurifoy et al., 2018] Peurifoy, R. L., Schexnayder, C. J., Shapira, A., and Jha, K. N. (2018). *Construction Planning, Equipment, and Methods*. McGraw-Hill, 9th edition.

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CE3C9 Integrated Construction Management (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE3C2 Construction Technology II (8th Sem-Pg. 417)

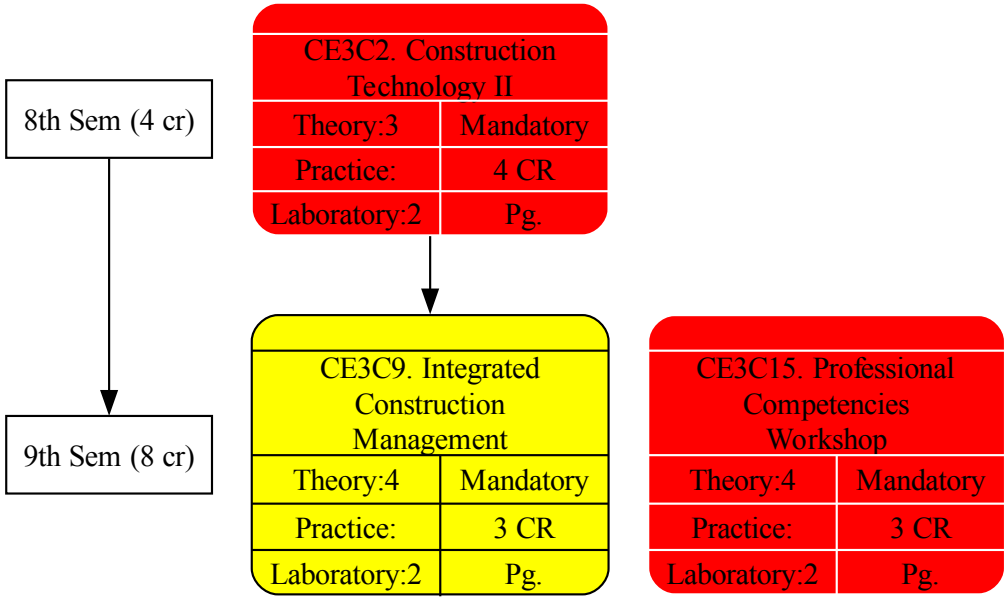

Figure 7.54: Connection Map. CE3C9 Integrated Construction Management

2. Course Rationale

Integrated Construction Management covers quality management systems (ISO 9001), environmental management (ISO 14001), and occupational health and safety (ISO 45001) on construction sites, as well as their integration and joint auditing. The course includes on-site environmental management, sustainability and impact mitigation, occupational health and safety according to Peruvian regulations, and concludes with project optimization and project closure.

3. Goals of the Course

- Apply the fundamentals of quality management (ISO 9001) to the control of processes and materials on site.
- Manage the environmental impacts of a construction project and apply sustainability and mitigation measures.
- Apply Peruvian occupational health and safety regulations (G.050) and emergency prevention and response protocols.
- Integrate quality, environmental, and occupational health and safety management systems, and optimize project closure.

4. General Competences (*Outcomes*)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Quality Management, 28 hr(s)

Competences: ABET-6

Topics: **I:** Total Quality Management: Deming's 14 points, continuous improvement (kaizen), and quality culture **II:** Six Sigma methodology (DMAIC): process capability, control charts, and defects per million opportunities **III:** Quality standards and certification: ISO 9001 framework, quality cost categories (prevention, appraisal, failure) **IV:** Quality function deployment (QFD) and voice of the customer: House of Quality matrix, customer requirement translation, and design prioritization

Learning Outcomes **I:** Explain the TQM philosophy and the key tools used in the DMAIC improvement cycle [Familiarity] **II:** Apply basic statistical process control methods to monitor process quality [Usage] **III:** Evaluate the quality performance of a process and recommend improvement priorities using cost-of-quality analysis [Assessment]

Bibliography: [for Standardization, 2015b, Institute, 2021]

5.2 Integrated Quality, Environmental, and Safety Management Systems, 12 hr(s)

Competences: ABET-6

Topics: **I:** Common high-level structure (Annex SL) shared by ISO 9001, 14001, and 45001: aligned clauses for context, leadership, planning, support, operation, performance evaluation, and improvement **II:** Integrated management policy and objectives spanning quality, environmental, and OH&S goals; a single integrated management manual and shared documented information **III:** Integrated internal and external audit programs covering multiple standards in a single audit cycle: combined checklists, joint findings, and non-conformance tracking **IV:** Synergies between the three systems (shared risk-based thinking, PDCA cycle, documented information) versus potential conflicts (competing priorities, resource allocation), and approaches to resolve them

Learning Outcomes **I:** Explain the common high-level structure shared by ISO 9001, 14001, and 45001 and how it enables management system integration [Familiarity] **II:** Design an integrated audit checklist covering quality, environmental, and occupational health and safety requirements for a construction site [Usage] **III:** Evaluate the effectiveness of an integrated management system on a construction project, identifying synergies and unresolved conflicts between its component systems [Assessment]

Bibliography: [for Standardization, 2015b, for Standardization, 2015a, for Standardization, 2018]

5.3 Environmental Impact Assessment and Sustainability Metrics, 12 hr(s)

Competences: ABET-2

Topics: **I:** EIA process: screening, scoping, impact analysis, mitigation, and public participation **II:** Impact prediction methods for air, water, soil, noise, and ecological systems **III:** Mitigation hierarchy and design of environmental management plans **IV:** Legal and institutional frameworks for EIA **V:** Sustainability concepts and the triple bottom line (environment, economy, society) **VI:** Cumulative impact assessment and strategic environmental assessment (SEA) **VII:** Social impact assessment and stakeholder engagement methods **VIII:** Sustainability metrics and indicator frameworks (e.g., SDGs, Envision) **IX:** Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes **I:** Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity] **II:** Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage] **III:** Develop mitigation measures for identified significant environmental impacts [Assessment] **IV:** Explain the legal requirements and purpose of EIA in the project approval process [Familiarity] **V:** Apply the triple bottom line framework to evaluate a simple engineering project [Assessment] **VI:** Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment] **VII:** Design a stakeholder engagement plan for a controversial development project [Usage] **VIII:** Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment] **IX:** Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

Bibliography: [Glasson and Therivel, 2019]

5.4 Air Quality and Pollution Control Engineering, 12 hr(s)

Competences: ABET-2

Topics: **I:** Atmospheric structure, composition, and basic meteorology **II:** Pollutant types, sources, and health/environmental effects **III:** Monitoring techniques and ambient air quality standards **IV:** Dispersion modeling fundamentals and Gaussian plume model **V:** Control technologies for particulate matter: cyclones, baghouses, and ESPs **VI:** Gaseous pollutant control: absorption, adsorption, and catalytic systems **VII:** Mobile source emissions and control strategies **VIII:** Indoor air quality and ventilation **IX:** Climate change and greenhouse gas mitigation engineering

Learning Outcomes **I:** Describe the major classes of air pollutants, their sources, and impacts [Familiarity] **II:** Apply the Gaussian plume model to estimate ground-level concentrations from a point source [Usage] **III:** Select appropriate particulate control devices based on particle size distribution and efficiency requirements [Assessment] **IV:** Interpret ambient air quality monitoring data relative to regulatory standards [Familiarity] **V:** Design a basic absorption tower for removing a gaseous pollutant from a flue gas stream [Assessment] **VI:** Explain the engineering approaches for controlling emissions from mobile sources [Familiarity] **VII:** Evaluate indoor air quality parameters and propose mitigation measures for a building [Assessment] **VIII:** Propose engineering strategies for reducing greenhouse gas emissions from an industrial facility [Usage]

Bibliography: [Davis and Cornwell, 2010]

5.5 Construction Safety, Health, and Risk Management, 24 hr(s)

Competences: ABET-1

Topics: **I:** Safety management systems and the role of safety culture **II:** Common construction hazards: falls, struck-by, electrocution, caught-in/between **III:** Occupational Safety and Health Administration (OSHA) regulations and compliance **IV:** Risk identification and assessment techniques (e.g., JSA, checklists) **V:** Hierarchy of controls: elimination, substitution, engineering, administrative, PPE **VI:** Occupational health: silica, noise, ergonomics, and industrial hygiene **VII:** Emergency response planning and incident investigation **VIII:** Insurance and bonding principles for construction risk transfer **IX:** Proactive safety leading indicators and predictive analytics

Learning Outcomes **I:** Identify the "Fatal Four" construction hazards and basic OSHA requirements for each [Familiarity] **II:** Conduct a Job Safety Analysis (JSA) for a common construction task [Assessment] **III:** Develop a site-specific safety plan for a given project scenario [Usage] **IV:** Apply the hierarchy of controls to mitigate an identified safety risk [Familiarity] **V:** Evaluate occupational health exposures (e.g., noise, dust) and recommend monitoring strategies [Assessment] **VI:** Create an emergency response plan for a construction site [Usage] **VII:** Explain the purpose and types of insurance (e.g., CGL, workers' comp) in construction risk management [Familiarity] **VIII:** Propose leading safety indicators to track and predict site safety performance [Assessment]

Bibliography: [Hinze, 2005, de Trabajo y Promoción del Empleo del Perú, 2010]

5.6 Lean Construction and Integrated Project Delivery (IPD), 4 hr(s)

Competences: ABET-1

Topics: **I:** Lean thinking principles: value, value stream, flow, pull, perfection **II:** Identification and elimination of the eight wastes in construction **III:** Last Planner System (LPS) for production planning and control **IV:** Visual management tools: 5S, Kanban, and Andon **V:** Integrated Project Delivery (IPD) principles and multi-party agreements **VI:** Target Value Delivery (TVD) and Set-Based Design **VII:** Collaboration technologies and Big Room co-location **VIII:** Performance measurement: Percent Plan Complete (PPC), Takt time **IX:** Culture change and implementation strategies for lean transformation

Learning Outcomes **I:** Define the seven (or eight) types of waste (Muda) in a construction context [Familiarity] **II:** Apply the Last Planner System to develop a reliable weekly work plan [Usage] **III:** Identify opportunities to apply visual management (5S) on a construction site [Assessment] **IV:** Explain how Integrated Project Delivery (IPD) aligns goals and shares risk among project stakeholders [Familiarity] **V:** Use Target Value Delivery principles to guide design decisions within a cost target [Assessment] **VI:** Facilitate a collaborative pull planning session with multiple trades [Usage] **VII:** Calculate and interpret Percent Plan Complete (PPC) as a lean performance metric [Assessment] **VIII:** Develop a basic implementation plan for introducing lean practices to a project team [Assessment]

Bibliography: [Ballard, 2000]

5.7 Key Performance Indicators, 6 hr(s)

Competences: ABET-6

Topics: **I:** Selecting KPIs: relevance to project objectives, measurability, and actionability **II:** Balanced metric sets: leading and lagging indicators, outcome and output metrics **III:** Setting KPI thresholds and alert levels for triggering corrective action **IV:** Reviewing and adapting the KPI set as the project evolves and stakeholder priorities shift

Learning Outcomes **I:** Define a balanced KPI set for monitoring a project across multiple performance dimensions [Usage] **II:** Evaluate a given set of KPIs for balance, relevance, and potential for metric dysfunction [Assessment] **III:** Design a KPI review cycle that keeps performance metrics aligned with evolving project objectives [Assessment]

Bibliography: [Institute, 2021]

5.8 Kickoff and Closure Activities, 6 hr(s)

Competences: ABET-6

Topics: **I:** Project kickoff: aligning team and stakeholders on objectives, approach, and working agreements **II:** Phase transition activities: reviews, approvals, and handoffs between phases **III:** Project closure: final deliverable acceptance, lessons learned, and team release **IV:** Integrating lessons learned from closure into organizational knowledge assets

Learning Outcomes **I:** Conduct an effective project kickoff that aligns team and stakeholders on goals and approach [Usage] **II:** Execute project closure activities including final acceptance and lessons learned archiving [Usage] **III:** Design a comprehensive project closure checklist ensuring all administrative, contractual, and knowledge capture obligations are met [Assessment]

Bibliography: [Institute, 2021]

6. Bibliography

[Ballard, 2000] Ballard, G. (2000). The last planner system of production control. *PhD Thesis, University of Birmingham*.

[Davis and Cornwell, 2010] Davis, M. L. and Cornwell, D. A. (2010). *Introduction to Environmental Engineering*. McGraw-Hill, 5th edition.

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CE3G3 Applied Geology (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)

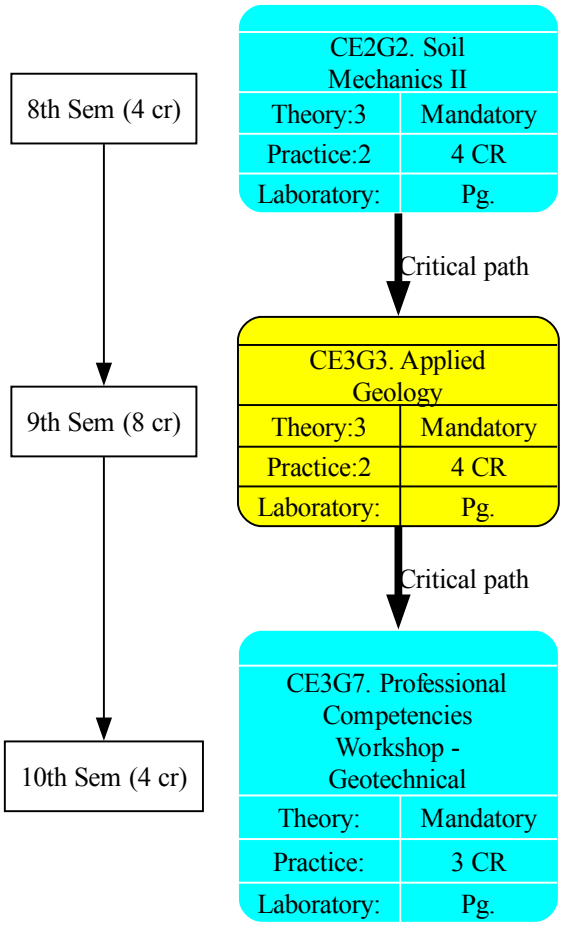

Figure 7.55: Connection Map. CE3G3 Applied Geology

2. Course Rationale

Applied Geology extends the descriptive foundations of General Geology, and draws on the field investigation skills introduced in the Geotechnical Engineering sequence, into the practicing engineering geologist's toolkit for civil infrastructure. The course develops rock mass characterization and standard classification systems, engineering geological and geotechnical mapping, and the geological evaluation of soils and rocks as natural resources for construction materials, then applies this framework to the siting and design of two major groups of infrastructure works — roads and canals, and

bridges, tunnels, and dams — and closes with the classification, field recognition, and hazard mapping of mass movements and other geological hazards relevant to civil works. As part of the Geotechnical specialization track, it complements the design-oriented Soil Mechanics sequence (Soil Mechanics I-II) with the geological judgment required to characterize sites, select construction materials, choose infrastructure alignments, and anticipate geological hazards.

3. Goals of the Course

- Plan and interpret geotechnical field investigations to characterize subsurface conditions for engineering projects.
- Characterize rock masses in the field and estimate their strength and deformability using standard classification systems (RMR, Q, GSI, and the Hoek-Brown criterion).
- Prepare and interpret engineering geological and geotechnical maps for infrastructure planning and hazard zonation.
- Evaluate soils and rocks as natural resources for construction materials.
- Apply engineering geological criteria to the siting and design of roads and canals.
- Apply engineering geological criteria to the siting and design of bridges, tunnels, and dams.
- Classify, recognize in the field, and map geological hazards and mass movements, and propose appropriate mitigation measures.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Site Investigation and In-Situ Testing, 5 hr(s)

Competences: ABET-6

Topics: **I:** Investigation planning and scope determination **II:** Boring methods and subsurface exploration techniques **III:** Sampling methods for disturbed and undisturbed samples **IV:** Standard Penetration Test and correlations **V:** Laboratory testing program and test selection **VI:** Cone Penetration Test and piezocone testing **VII:** Vane shear test and pressuremeter testing **VIII:** Geophysical methods including seismic and resistivity surveys **IX:** Groundwater monitoring and piezometer installation **X:** Report preparation and geotechnical data presentation **XI:** In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment **XII:** Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes **I:** Develop appropriate site investigation programs based on project requirements [Assessment] **II:** Select appropriate boring and exploration methods for different soil conditions [Familiarity] **III:** Specify sampling techniques to obtain quality samples for testing [Usage] **IV:** Interpret SPT data and apply empirical correlations for design parameters [Assessment] **V:** Design laboratory testing programs for geotechnical projects [Usage] **VI:** Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment] **VII:** Apply vane shear and pressuremeter tests for soft clay characterization [Usage] **VIII:** Utilize geophysical methods to complement traditional investigation techniques [Assessment] **IX:** Monitor groundwater conditions and interpret piezometric data [Usage] **X:** Prepare comprehensive geotechnical investigation reports [Assessment] **XI:** Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage] **XII:** Characterize borrow areas for embankment fill material quantity and quality [Assessment]

Bibliography: [Das, 2019]

5.2 Engineering Geological and Geotechnical Mapping, 5 hr(s)

Competences: ABET-6

Topics: **I:** Types and purposes of engineering geological and geotechnical maps **II:** Geotechnical zonation and microzonation mapping for urban and infrastructure planning **III:** Specialized symbology and legends for engineering geological maps **IV:** Use of GIS and remote sensing tools in geotechnical mapping

Learning Outcomes **I:** Distinguish the types and purposes of engineering geological and geotechnical maps [Familiarity] **II:** Prepare a basic geotechnical zonation map for a project area [Usage] **III:** Apply GIS tools to compile and present geotechnical mapping information [Usage]

Bibliography: [de Vallejo et al., 2002]

5.3 Rock Mass Characterization and Applied Rock and Soil Mechanics, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Characterization of rock mass discontinuities: orientation, spacing, persistence, roughness, aperture, and infill **II:** Rock Quality Designation (RQD) and geotechnical core logging **III:** Rock mass classification systems: RMR, Q-system, and GSI **IV:** Estimation of rock mass strength and deformability using the Hoek-Brown criterion **V:** Influence of weathering grade on rock mass mechanical behavior **VI:** Influence of geological origin -residual versus transported- on soil engineering properties

Learning Outcomes **I:** Characterize rock mass discontinuities from field or core data [Usage] **II:** Determine RQD and classify rock mass quality using RMR, Q, and GSI systems [Assessment] **III:** Estimate rock mass strength and deformability parameters using the Hoek-Brown criterion [Assessment] **IV:** Relate weathering grade to expected rock mass mechanical behavior [Familiarity] **V:** Relate the geological origin of a soil to its expected engineering properties [Usage]

Bibliography: [Bieniawski, 1989, Hoek and Bray, 1981, de Vallejo et al., 2002]

5.4 Soils and Rocks as Natural Resources for Construction Materials, 5 hr(s)

Competences: ABET-1

Topics: **I:** Geological sources and quality evaluation of aggregates for concrete and construction **II:** Site selection and geological evaluation of quarries and borrow pits **III:** Dimension stone and other rock and soil resources used in construction **IV:** Basic quality control criteria and tests for construction material sources

Learning Outcomes **I:** Evaluate geological sources of aggregates and construction materials for quality and suitability [Usage] **II:** Select and assess quarry and borrow-pit sites based on geological criteria [Assessment] **III:** Apply basic quality control criteria to construction material sources [Familiarity]

Bibliography: [Smith and Collis, 2001, de Vallejo et al., 2002]

5.5 Engineering Geology Applied to Roads and Canals, 15 hr(s)

Competences: ABET-2

Topics: **I:** Geological considerations for highway and road alignment selection **II:** Geological and hydrogeological conditions for canal siting and seepage control **III:** Structural geological controls on cut-slope stability along transportation corridors **IV:** Geological and geotechnical conditions for road and canal embankment foundations **V:** Engineering geological mapping and hazard identification along linear infrastructure corridors

Learning Outcomes **I:** Evaluate geological conditions to support road and canal alignment selection [Assessment] **II:** Assess seepage and foundation conditions for canal design based on geological survey [Usage] **III:** Analyze structural geological controls on cut-slope stability along a transportation corridor [Assessment] **IV:** Prepare an engineering geological map identifying hazards along a linear infrastructure corridor [Usage]

Bibliography: [Federal Highway Administration, 2001, de Vallejo et al., 2002]

5.6 Engineering Geology Applied to Bridges, Tunnels, and Dams, 20 hr(s)

Competences: ABET-2

Topics: **I:** Engineering geological studies required at each phase of an infrastructure project: reconnaissance, feasibility, design, and construction **II:** Geological and rock mass considerations for tunnel alignment, excavation method, and support selection **III:** Geological siting and foundation and abutment characterization for dams **IV:** Reservoir geology: seepage, landslide-induced impoundment hazards, and sedimentation sources **V:** Geological considerations for bridge site selection and pier and abutment foundation conditions **VI:** Comparative geological criteria for selecting sites and alignments among infrastructure alternatives

Learning Outcomes **I:** Identify the engineering geological studies required at each phase of an infrastructure project [Familiarity] **II:** Evaluate rock mass conditions relevant to tunnel excavation method and support selection [Assessment] **III:** Characterize the geological suitability of a site for dam foundations and abutments [Assessment] **IV:** Assess reservoir-related geological hazards including landslide-induced impoundment risk [Usage] **V:** Evaluate geological conditions relevant to bridge foundation siting [Usage]

Bibliography: [Federal Highway Administration, 2001, Hoek et al., 1995, de Vallejo et al., 2002]

5.7 Geological Hazards and Mass Movements, 10 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Classification of mass movements: falls, topples, slides, flows, and lateral spreads **II:** Triggering and controlling factors of mass movements: geological, hydrological, and seismic **III:** Field recognition of landslide morphology and indicators of active or past instability **IV:** Geological hazards from seismic and volcanic activity relevant to civil infrastructure **V:** Geological hazard susceptibility mapping and risk zonation **VI:** Overview of structural and non-structural mitigation measures for geological hazards

Learning Outcomes **I:** Classify mass movements according to their mechanism and material type [Assessment] **II:** Identify triggering and controlling factors of mass movements at a given site [Familiarity] **III:** Recognize field indicators of landslide morphology and slope instability [Usage] **IV:** Prepare a geological hazard susceptibility map for a project area [Assessment] **V:** Propose mitigation measures appropriate to a specific type of geological hazard [Usage]

Bibliography: [Cruden and Varnes, 1996, Hoek and Bray, 1981, de Vallejo et al., 2002]

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CE3G4 Soil Mechanics Applied to Transportation Roads (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**:
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)

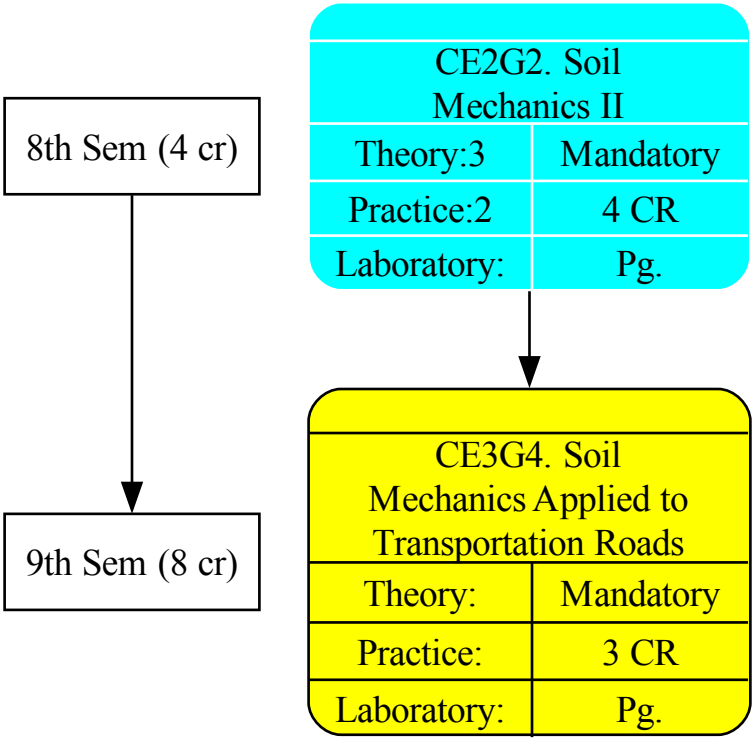

Figure 7.56: Connection Map. CE3G4 Soil Mechanics Applied to Transportation Roads

2. Course Rationale

Soil Mechanics Applied to Transportation Roads is the pavement-engineering course of the Geotechnical Engineering track, building on the subgrade behavior established in Soil Mechanics II to address the design, evaluation, and management of the pavement structure itself. The course first develops the design philosophy of pavements and the mechanisms by which flexible and rigid pavements fail, then covers the traffic, subgrade, and material parameters that govern pavement design, the structural design of flexible and rigid pavements using empirical and mechanistic-empirical methods, and the criteria used to decide when and how to rehabilitate an existing pavement. The course closes with the surface and structural evaluation techniques (distress surveys, roughness, and deflection testing) used to diagnose the condition of an in-service pavement, and the maintenance and rehabilitation planning that follows from that diagnosis.

3. Goals of the Course

- Characterize subgrade, aggregate, and asphalt materials, and recognize pavement types and failure mechanisms relevant to pavement design.
- Determine the traffic, reliability, serviceability, and environmental parameters required as inputs for pavement structural design.
- Design flexible and rigid pavement structures using empirical and mechanistic-empirical methods, and select rehabilitation strategies based on established criteria.
- Conduct surface distress and roughness evaluations of in-service pavements, including pavement condition index (PCI) computation.
- Perform structural evaluation of pavements using deflection testing, and backcalculate layer moduli to assess structural capacity.
- Estimate the remaining service life of a pavement and develop maintenance and rehabilitation program plans.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Pavement Materials and Characterization, 6 hr(s)

Competences: ABET-1

Topics: **I:** Pavement types and structural components **II:** Asphalt binder and mixture properties **III:** Aggregate properties and gradation requirements **IV:** Subgrade characterization and stabilization **V:** Sustainable pavement technologies and recycling

Learning Outcomes **I:** Identify pavement types and describe their structural functions [Familiarity] **II:** Characterize asphalt binders and design asphalt mixtures [Assessment] **III:** Evaluate aggregate quality for pavement applications [Usage] **IV:** Assess subgrade strength and specify stabilization treatments [Assessment] **V:** Incorporate sustainable practices and recycled materials in pavement design [Familiarity]

Bibliography: [Huang, 2004]

5.2 Pavement Design and Management, 14 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Traffic load characterization and equivalent single axle load (ESAL) computation **II:** Design reliability, serviceability, and drainage/environmental factors in pavement design **III:** Flexible pavement design using empirical methods **IV:** Rigid pavement design and joint systems **V:** Mechanistic-empirical pavement design methods **VI:** Pavement performance prediction and distress mechanisms **VII:** Rehabilitation strategies and overlay design **VIII:** Pavement management systems and life-cycle cost analysis

Learning Outcomes **I:** Compute the design equivalent single axle load (ESAL) from traffic composition and growth projections [Usage] **II:** Determine design reliability, serviceability, and drainage/environmental parameters for flexible and rigid pavement design [Assessment] **III:** Design flexible pavements using AASHTO or equivalent methods [Assessment] **IV:** Proportion

rigid pavement thickness and design joint spacing [Usage] **V:** Apply mechanistic-empirical methods for pavement design [Usage] **VI:** Predict pavement performance and identify distress mechanisms [Assessment] **VII:** Select appropriate rehabilitation strategies and design overlays [Usage] **VIII:** Implement pavement management systems and perform life-cycle analysis [Assessment]

Bibliography: [Huang, 2004, AASHTO, 1993]

5.3 Pavement Condition Evaluation and Maintenance Planning, 10 hr(s)

Competences: ABET-6

Topics: I: Visual distress surveys and pavement condition index (PCI) computation **II:** Pavement roughness measurement and the international roughness index (IRI) **III:** Structural evaluation using deflection testing (falling weight deflectometer, Benkelman beam) **IV:** Backcalculation of pavement layer moduli and structural capacity assessment **V:** Remaining service life estimation and rehabilitation treatment selection **VI:** Maintenance and rehabilitation program planning and scheduling

Learning Outcomes I: Conduct visual distress surveys and compute the pavement condition index (PCI) [Usage] **II:** Explain pavement roughness measurement methods and interpret the international roughness index [Familiarity] **III:** Perform structural evaluation of in-service pavements using deflection testing methods [Usage] **IV:** Backcalculate pavement layer moduli from deflection basin data [Assessment] **V:** Estimate the remaining service life of a pavement and select an appropriate treatment [Assessment] **VI:** Develop maintenance and rehabilitation program plans and schedules [Usage]

Bibliography: [Huang, 2004, Hudson et al., 1997]

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CE3G5 Finite Elements Applied to Geotechnical Engineering (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours;
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)
  - CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)

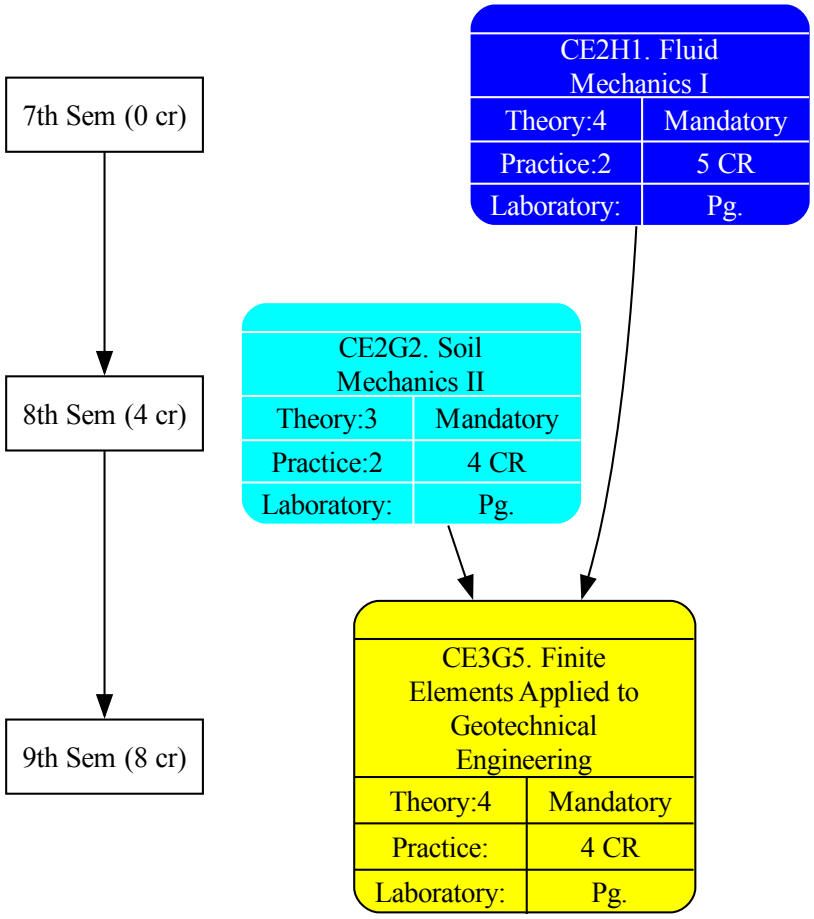

Figure 7.57: Connection Map. CE3G5 Finite Elements Applied to Geotechnical Engineering

2. Course Rationale

Finite Elements Applied to Geotechnical Engineering introduces the finite element method as a numerical tool for the analysis and design of geotechnical structures and problems that cannot be solved reliably with classical closed-form methods. Building on the shear-strength, consolidation, and

design framework developed in Soil Mechanics II and the numerical modeling background introduced in Fluid Mechanics II, the course first develops the mathematical foundations of the finite element method (variational formulation, Galerkin approximation, finite element spaces, and error estimation) and then applies them to geotechnical-specific problems: boundary conditions, initial stress states, and staged-construction modeling; one-dimensional analysis of consolidation and pile-soil interaction; two-dimensional plane-strain analysis of excavations, embankments, and retaining structures; an introduction to dynamic numerical analysis of seismic geotechnical problems; and the constitutive soil models (Mohr-Coulomb, Cam-Clay, and Hardening Soil Model) that make nonlinear soil behavior tractable in finite element software. As part of the Geotechnical Engineering specialization track, the course prepares students to use modern numerical modeling tools in professional geotechnical design practice.

3. Goals of the Course

- Derive and formulate the finite element method (weak formulation, Galerkin approximation, and error estimation) for boundary value problems.
- Establish appropriate boundary conditions, initial stress states, and staged-construction sequencing for geotechnical finite element models.
- Formulate one-dimensional finite element models for consolidation and pile-soil interaction problems.
- Develop two-dimensional plane-strain finite element models for excavation, embankment, and retaining-structure design problems.
- Analyze the dynamic response of geotechnical systems using numerical dynamic analysis.
- Select and apply constitutive soil models (Mohr-Coulomb, Cam-Clay, Hardening Soil Model) appropriate to nonlinear geotechnical finite element analysis.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Finite Element Method, 6 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Weak (variational) formulation of boundary value problems and Sobolev spaces **II:** Galerkin method: finite-dimensional approximation spaces and the stiffness matrix **III:** Triangular and quadrilateral finite element spaces: Lagrange elements and conformity **IV:** A priori error estimates: Céa's lemma and interpolation error bounds **V:** A posteriori error estimates and adaptive mesh refinement

Learning Outcomes **I:** Derive the weak formulation of an elliptic BVP and show its equivalence to the strong form [Familiarity] **II:** Assemble the global stiffness matrix and load vector for a linear finite element discretization [Usage] **III:** Estimate the H^1 error of a finite element solution using Céa's lemma and interpolation theory [Assessment]

Bibliography: [Reddy, 2019]

5.2 Geotechnical Numerical Modeling and Applications, 50 hr(s)

Competences: ABET-1,ABET-2,ABET-6

Topics: **I:** Boundary conditions, initial stress state, and staged construction (excavation and fill sequencing) in geotechnical finite element models **II:** Soil-structure interaction modeling: interface elements and contact behavior between soil and structural elements **III:** One-dimensional numerical models for consolidation and axially loaded pile-soil interaction **IV:** Two-dimensional plane-strain numerical models for excavations, embankments, and retaining structures **V:** Dynamic numerical analysis of seismic site response and soil-structure dynamic interaction **VI:** Constitutive soil models: Mohr-Coulomb, Cam-Clay, and Hardening Soil Model for nonlinear geotechnical analysis

Learning Outcomes **I:** Explain the boundary conditions, initial stress state, and staged construction sequencing required for geotechnical finite element models [Familiarity] **II:** Model soil-structure interaction using interface elements in a finite element mesh [Usage] **III:** Formulate one-dimensional finite element models for consolidation and pile-soil interaction problems [Usage] **IV:** Develop two-dimensional plane-strain finite element models for excavation, embankment, and retaining-structure problems [Usage] **V:** Analyze the dynamic response of geotechnical systems using numerical dynamic analysis [Assessment] **VI:** Select and apply appropriate constitutive soil models (Mohr-Coulomb, Cam-Clay, Hardening Soil Model) in nonlinear finite element analysis [Usage]

Bibliography: [Potts and Zdravković, 2001, Zienkiewicz et al., 2013, Kramer, 1996]

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CE3G6 Earth Dams (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours;
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)
  - CE2H1 Fluid Mechanics I (7th Sem-Pg. 384)

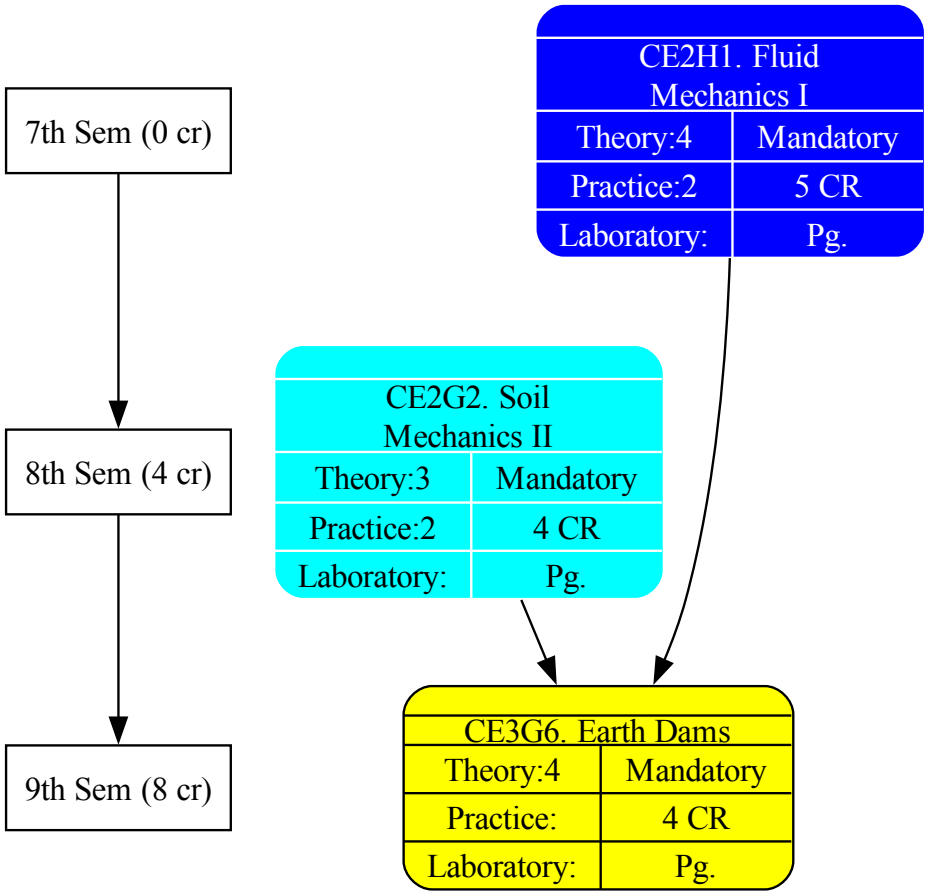

Figure 7.58: Connection Map. CE3G6 Earth Dams

2. Course Rationale

Earth Dams is a Geotechnical Engineering track specialization elective that applies the shear strength, seepage, and slope stability framework developed in Soil Mechanics II, together with the open-channel and hydraulic-structures framework developed in Fluid Mechanics II, to the analysis, design, construction, and operational safety of embankment (earth and rockfill) dams. The course

begins with the definition and typology of earth dams and the geotechnical characterization of foundation and borrow materials specific to dam projects, then develops the dam-specific investigation program – building on the general subsurface investigation techniques introduced in Soil Mechanics I – that supports embankment design. It then addresses the geotechnical design of the embankment itself: seepage control through cores, cutoffs, and grout curtains; slope stability of the dam faces under steady-state, rapid-drawdown, and seismic conditions; and filter/drain design against internal erosion. The course closes with the instrumentation and monitoring systems used to verify embankment performance, the constructive aspects of foundation treatment and fill placement, and the operational management and safety practices – surveillance, risk assessment, and emergency action planning – required over a dam's service life.

3. Goals of the Course

- Classify earth and rockfill dam typologies and describe the zoning of an embankment dam.
- Characterize foundation and borrow materials for embankment dam design.
- Plan and interpret geotechnical investigation programs specific to dam projects, including foundation permeability testing and borrow area evaluation.
- Design seepage control measures and filter/drain systems, and evaluate the slope stability of embankment dam faces.
- Design an instrumentation and monitoring program to track dam performance throughout construction and operation.
- Apply construction quality-control practices for foundation treatment and fill placement in embankment dams.
- Evaluate dam safety management practices, including risk assessment and emergency action planning, for dam operation.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Earth Dams, 4 hr(s)

Competences: ABET-1

Topics: **I:** Definition, function, and role of earth dams within water resources infrastructure **II:** Typology of embankment dams: homogeneous and zoned earthfill/rockfill dams, and selection criteria **III:** Dam zoning: core, shell, filters, drains, and transition zones **IV:** Site selection factors and reservoir/dam-site feasibility considerations

Learning Outcomes **I:** Explain the function of earth dams and their role within water resources infrastructure [Familiarity] **II:** Classify embankment dams by type and select an appropriate typology for given site and material conditions [Assessment] **III:** Describe the zoning of an earth dam and the function of each zone (core, shell, filters, drains) [Familiarity] **IV:** Evaluate site selection factors governing dam type and location choice [Usage]

Bibliography: [Fell et al., 2015, U.S. Bureau of Reclamation, 1987]

5.2 Geotechnical Characterization for Earth Dams, 6 hr(s)

Competences: ABET-1

Topics: **I:** Foundation geotechnical characterization: rock and soil foundation conditions for embankment dams **II:** Characterization of borrow materials for core, shell, and filter zones **III:** Compaction and shear strength properties of compacted fill materials **IV:** Permeability characterization of foundation and embankment materials **V:** Dispersive soil identification and erodibility assessment for core materials

Learning Outcomes **I:** Characterize foundation soil and rock conditions relevant to embankment dam design [Assessment] **II:** Evaluate borrow material sources for suitability as core, shell, or filter material [Usage] **III:** Determine compaction and shear strength properties of compacted embankment materials [Assessment] **IV:** Assess dispersive soil potential and erodibility of candidate core materials [Usage]

Bibliography: [Fell et al., 2015, U.S. Bureau of Reclamation, 1987]

5.3 Site Investigation and In-Situ Testing, 6 hr(s)

Competences: ABET-6

Topics: **I:** Investigation planning and scope determination **II:** Boring methods and subsurface exploration techniques **III:** Sampling methods for disturbed and undisturbed samples **IV:** Standard Penetration Test and correlations **V:** Laboratory testing program and test selection **VI:** Cone Penetration Test and piezocone testing **VII:** Vane shear test and pressuremeter testing **VIII:** Geophysical methods including seismic and resistivity surveys **IX:** Groundwater monitoring and piezometer installation **X:** Report preparation and geotechnical data presentation **XI:** In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment **XII:** Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes **I:** Develop appropriate site investigation programs based on project requirements [Assessment] **II:** Select appropriate boring and exploration methods for different soil conditions [Familiarity] **III:** Specify sampling techniques to obtain quality samples for testing [Usage] **IV:** Interpret SPT data and apply empirical correlations for design parameters [Assessment] **V:** Design laboratory testing programs for geotechnical projects [Usage] **VI:** Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment] **VII:** Apply vane shear and pressuremeter tests for soft clay characterization [Usage] **VIII:** Utilize geophysical methods to complement traditional investigation techniques [Assessment] **IX:** Monitor groundwater conditions and interpret piezometric data [Usage] **X:** Prepare comprehensive geotechnical investigation reports [Assessment] **XI:** Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage] **XII:** Characterize borrow areas for embankment fill material quantity and quality [Assessment]

Bibliography: [Das, 2019, Fell et al., 2015]

5.4 Geotechnical Design of Embankment Dams, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Seepage analysis through the embankment and foundation using flow nets and numerical methods **II:** Seepage control measures: core design, cutoff walls, and grout curtains **III:** Filter and drain design criteria to prevent internal erosion and piping **IV:** Slope stability analysis of upstream and downstream dam faces under static and rapid drawdown conditions **V:** Seismic design considerations and deformation analysis for embankment dams **VI:** Freeboard determination and settlement/camber allowance in embankment design

Learning Outcomes **I:** Analyze seepage through the embankment and foundation using flow nets or numerical seepage models [Assessment] **II:** Design seepage control measures including impervious cores, cutoff walls, and grout curtains [Usage] **III:** Design filter and drain zones according

to piping and internal erosion criteria [Assessment] **IV:** Evaluate slope stability of dam faces under steady-state seepage, rapid drawdown, and end-of-construction conditions [Usage] **V:** Incorporate seismic loading and deformation analysis into embankment dam design [Assessment] **VI:** Determine freeboard and settlement allowances for embankment design [Usage]

Bibliography: [Fell et al., 2015, Sherard et al., 1963, U.S. Army Corps of Engineers, 2003]

5.5 Dam Instrumentation and Monitoring, 12 hr(s)

Competences: ABET-6

Topics: **I:** Instrumentation planning: objectives, parameters to monitor, and instrument selection **II:** Piezometers and pore pressure measurement systems **III:** Settlement and deformation monitoring: surface markers, inclinometers, and extensometers **IV:** Seepage flow monitoring using weirs and flow measurement devices **V:** Data acquisition, automation, and interpretation of monitoring records **VI:** Threshold (alert/alarm) values and performance evaluation criteria

Learning Outcomes **I:** Plan an instrumentation program defining monitoring objectives and parameters [Usage] **II:** Select and locate piezometers to monitor pore pressure within the embankment and foundation [Assessment] **III:** Specify deformation monitoring instruments (markers, inclinometers, extensometers) for an embankment dam [Usage] **IV:** Monitor seepage flow and interpret trends against baseline conditions [Assessment] **V:** Interpret monitoring data and establish threshold values for dam safety alerts [Usage]

Bibliography: [Dunnicliff, 1993, Fell et al., 2015]

5.6 Construction of Earth Dams, 8 hr(s)

Competences: ABET-2

Topics: **I:** Foundation preparation and treatment: stripping, grouting, and cutoff trench excavation **II:** Placement and compaction of core, filter, and shell fill materials **III:** Field compaction quality control and acceptance testing **IV:** Construction sequencing, staged construction, and river diversion during construction **V:** Construction-phase monitoring and as-built verification

Learning Outcomes **I:** Specify foundation treatment methods including cutoff trench excavation and grouting [Usage] **II:** Control fill placement and compaction to meet design specifications [Assessment] **III:** Verify compaction quality through field acceptance testing [Usage] **IV:** Sequence embankment construction considering staged construction and river diversion [Assessment]

Bibliography: [U.S. Bureau of Reclamation, 1987, Fell et al., 2015]

5.7 Operation and Safety Management of Dams, 8 hr(s)

Competences: ABET-2

Topics: **I:** Dam surveillance programs: visual inspection and periodic evaluation procedures **II:** Risk assessment and hazard classification of dams **III:** Emergency action plans and downstream hazard/inundation mapping **IV:** Regulatory framework and dam safety programs (e.g., Peru's ANA dam safety regulations) **V:** Dam rehabilitation, decommissioning, and aging infrastructure management

Learning Outcomes **I:** Conduct dam surveillance inspections and evaluate performance indicators [Usage] **II:** Classify dam hazard potential and assess associated risks [Assessment] **III:** Develop an emergency action plan including downstream inundation mapping [Usage] **IV:** Apply regulatory dam safety requirements to an operating dam [Assessment] **V:** Propose rehabilitation measures for aging or deficient dam infrastructure [Usage]

Bibliography: [Federal Emergency Management Agency, 2004, Fell et al., 2015]

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Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil
CE3H2 General Hydrology (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

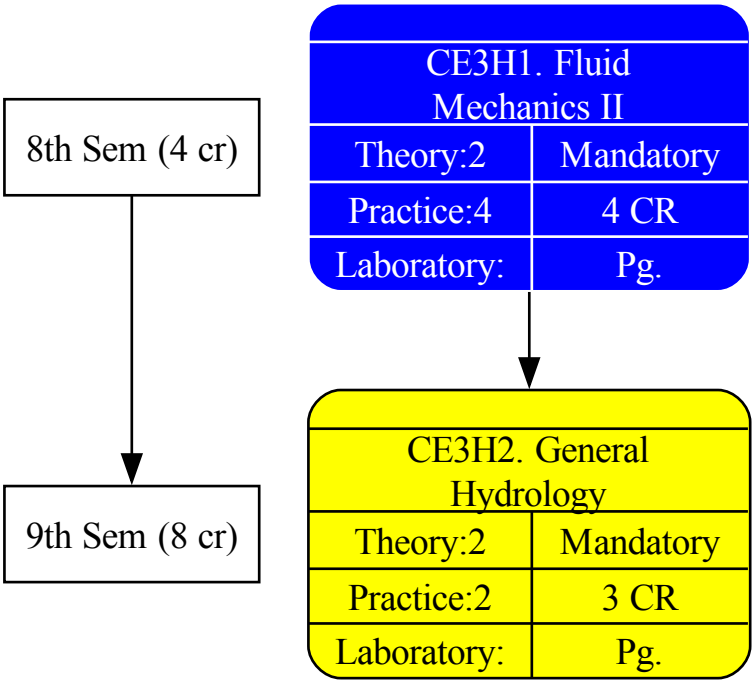

Figure 7.59: Connection Map. CE3H2 General Hydrology

2. Course Rationale

General Hydrology covers the hydrologic cycle processes relevant to water resources engineering: climatology and basic meteorology, measurement and analysis of basin-scale precipitation, hydrometric station networks, and statistical analysis of extreme hydrological events (maximum floods) using probability distributions. The course provides the hydrological analysis tools that support the design of hydraulic and water resources structures in subsequent courses of the Hydraulics line.

3. Goals of the Course

- Understand the processes of the hydrologic cycle and estimate its components (precipitation, evaporation, runoff) at the basin scale.
- Analyze precipitation records using areal estimation methods (arithmetic, Thiessen, isohyetal, hypsometric).
- Perform frequency analysis of maximum floods applying goodness-of-fit tests and probability distributions (Normal, Log Normal, Pearson III, Log Pearson III, Gumbel).

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Hydrologic Cycle and Water Balance, 22 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Hydrologic cycle and water balance concepts **II:** Precipitation measurement and analysis **III:** Evaporation and evapotranspiration estimation **IV:** Infiltration theory and rainfall-runoff processes

Learning Outcomes **I:** Explain the hydrologic cycle and quantify water balance components [Familiarity] **II:** Analyze precipitation data and develop depth-area-duration relationships [Assessment] **III:** Estimate evaporation and evapotranspiration using empirical methods [Usage] **IV:** Apply infiltration models to estimate runoff from rainfall events [Assessment]

Bibliography: [Chow et al., 1988]

5.2 Surface Hydrology and Watershed Modeling, 17 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Hydrograph analysis and unit hydrograph method **II:** Watershed modeling and hydrologic simulation **III:** Streamflow measurement and gauging techniques

Learning Outcomes **I:** Derive unit hydrographs and synthesize runoff hydrographs [Usage] **II:** Develop watershed models using software tools for hydrologic simulation [Usage] **III:** Conduct streamflow measurements and interpret flow duration curves [Assessment]

Bibliography: [Chow et al., 1988]

5.3 Flood Frequency Analysis and Climate Change, 17 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Flood frequency analysis and design storms **II:** Hydrologic routing methods for channels and reservoirs **III:** Climate change impacts on hydrologic systems

Learning Outcomes **I:** Perform flood frequency analysis using statistical methods [Assessment] **II:** Route flood hydrographs through channels and reservoirs [Usage] **III:** Evaluate climate change impacts on watershed hydrology and design implications [Assessment]

Bibliography: [Chow et al., 1988]

6. Bibliography

[Chow et al., 1988] Chow, V. T., Maidment, D. R., and Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

CE3H3 Water Supply and Sewerage (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

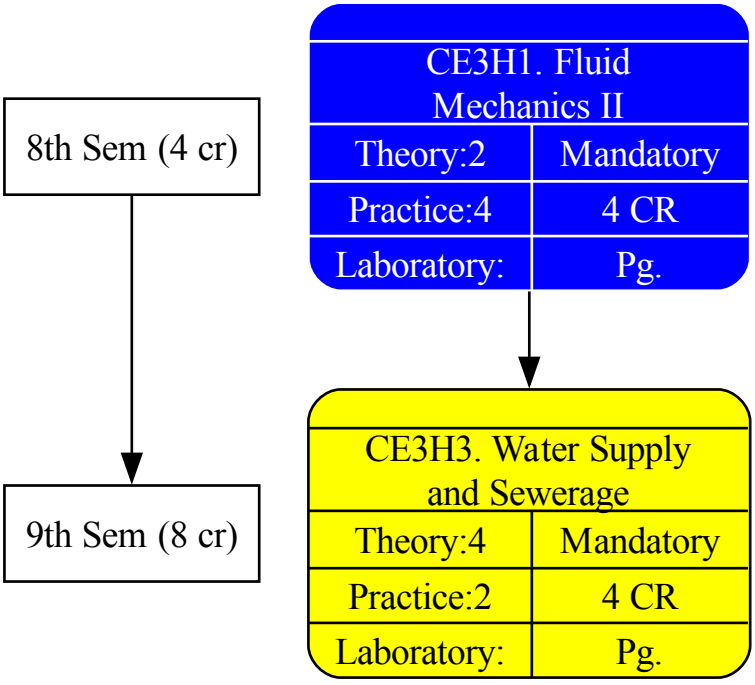

Figure 7.60: Connection Map. CE3H3 Water Supply and Sewerage

2. Course Rationale

Water Supply and Sewerage is an integrative course that brings together knowledge from hydrology, hydraulics, geotechnics, materials science, environmental chemistry, statistics, optimization, and project management for the design of urban water supply and sanitation systems. The student applies this multidisciplinary foundation to demand projection, the design of distribution and sewer networks, water and wastewater treatment, and the evaluation of sustainability and environmental impact of these systems.

3. Goals of the Course

- Apply principles of hydrology, fluid mechanics, and geotechnics to the design of water supply and sewerage systems.
- Design potable water distribution networks and sewerage systems, including the selection of materials and associated hydraulic structures.

- Apply statistical, optimization, and graph theory tools to network sizing and layout.
- Evaluate the sustainability, environmental impact, and economic feasibility of water and sanitation projects.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Hydrologic Cycle and Water Balance, 2 hr(s)

Competences: ABET-1

Topics: **I:** Hydrologic cycle and water balance concepts **II:** Precipitation measurement and analysis **III:** Evaporation and evapotranspiration estimation **IV:** Infiltration theory and rainfall-runoff processes

Learning Outcomes **I:** Explain the hydrologic cycle and quantify water balance components [Familiarity] **II:** Analyze precipitation data and develop depth-area-duration relationships [Assessment] **III:** Estimate evaporation and evapotranspiration using empirical methods [Usage] **IV:** Apply infiltration models to estimate runoff from rainfall events [Assessment]

Bibliography: [Chow et al., 1988]

5.2 Surface Hydrology and Watershed Modeling, 2 hr(s)

Competences: ABET-1

Topics: **I:** Hydrograph analysis and unit hydrograph method **II:** Watershed modeling and hydrologic simulation **III:** Streamflow measurement and gauging techniques

Learning Outcomes **I:** Derive unit hydrographs and synthesize runoff hydrographs [Usage] **II:** Develop watershed models using software tools for hydrologic simulation [Usage] **III:** Conduct streamflow measurements and interpret flow duration curves [Assessment]

Bibliography: [Chow et al., 1988]

5.3 Flood Frequency Analysis and Climate Change, 2 hr(s)

Competences: ABET-1

Topics: **I:** Flood frequency analysis and design storms **II:** Hydrologic routing methods for channels and reservoirs **III:** Climate change impacts on hydrologic systems

Learning Outcomes **I:** Perform flood frequency analysis using statistical methods [Assessment] **II:** Route flood hydrographs through channels and reservoirs [Usage] **III:** Evaluate climate change impacts on watershed hydrology and design implications [Assessment]

Bibliography: [Chow et al., 1988]

5.4 Environmental Chemistry and Microbiology for Engineers, 4 hr(s)

Competences: ABET-1

Topics: **I:** Aquatic chemistry principles: acidity, alkalinity, hardness, and buffer capacity **II:** Chemical equilibria and kinetics relevant to environmental processes **III:** Microbial metabolism, growth, and classification in environmental contexts **IV:** Biogeochemical cycles of carbon, nitrogen, phosphorus, and sulfur **V:** Water quality indicators and standard analytical methods **VI:** Colloid and surface chemistry for contaminant fate and transport **VII:** Toxicology and risk assessment of environmental contaminants **VIII:** Molecular biology tools for environmental engineering applications **IX:** Fate and transport modeling of pollutants in engineered and natural systems

Learning Outcomes **I:** Calculate pH, buffer intensity, and chemical speciation in aquatic systems [Usage] **II:** Explain the role of key microbial groups in wastewater treatment and biogeochemical cycling [Familiarity] **III:** Apply mass balance and reaction kinetics to environmental systems [Assessment] **IV:** Describe the major steps and environmental significance of the nitrogen and phosphorus cycles [Familiarity] **V:** Interpret water quality data from standard analytical reports [Usage] **VI:** Analyze the role of colloidal and interfacial processes in contaminant removal [Assessment] **VII:** Define key toxicological parameters and concepts used in environmental risk assessment [Familiarity] **VIII:** Evaluate the application of molecular techniques for monitoring engineered biological systems [Assessment] **IX:** Model the fate and transport of a conservative pollutant in a simple environmental compartment [Usage]

Bibliography: [Davis and Cornwell, 2010]

5.5 Population Dynamics, 4 hr(s)

Competences: ABET-1

Topics: **I:** Exponential and logistic growth models; carrying capacity and the Allee effect **II:** Lotka-Volterra predator-prey and competition models; equilibria and stability analysis **III:** Age-structured models: Leslie matrices and the Euler-Lotka equation **IV:** Reaction-diffusion models and traveling waves in spatial ecology (Fisher-KPP equation) **V:** Evolutionary dynamics: replicator equations, game theory, and the Price equation

Learning Outcomes **I:** Analyze the stability of equilibria in Lotka-Volterra systems using linearization and phase portraits [Familiarity] **II:** Construct age-structured population models using Leslie matrices and compute long-term growth rates [Usage] **III:** Apply reaction-diffusion theory to model the spatial spread of an invasive species using the Fisher-KPP equation [Assessment]

Bibliography: [Eddy et al., 2013]

5.6 Mathematical Statistics and Estimation Theory, 4 hr(s)

Competences: ABET-6

Topics: **I:** Point estimation: Method of Moments and Maximum Likelihood Estimation **II:** Construction and interpretation of confidence intervals in engineering tests **III:** Hypothesis testing for engineering quality control and process validation **IV:** Linear and nonlinear regression for engineering data fitting **V:** Introduction to Design of Experiments (DoE) for engineering optimization

Learning Outcomes **I:** Derive Maximum Likelihood Estimators for parameters of engineering failure models [Usage] **II:** Verify the statistical significance of engineering test results using hypothesis testing [Assessment] **III:** Construct confidence intervals for key process parameters from experimental data [Usage] **IV:** Apply linear regression to model and predict engineering performance from measured data [Assessment]

Bibliography: [Ang and Tang, 2007]

5.7 Interest Theory and Time Value of Money, 4 hr(s)

Competences: ABET-1

Topics: **I:** Compound interest: accumulation functions, effective and nominal rates, and force of interest **II:** Annuities-immediate and annuities-due: present and accumulated values, perpetuities **III:** Bond pricing: price-yield relationship, duration, convexity, and amortization schedules **IV:** Yield curves: spot rates, forward rates, and bootstrap methods for term structure **V:** Portfolio immunization: Redington's conditions and cash-flow matching

Learning Outcomes **I:** Compute the present value and accumulated value of annuities under various interest rate assumptions [Familiarity] **II:** Price bonds using the price-yield relationship and calculate duration and convexity for interest rate sensitivity [Usage] **III:** Construct a portfolio satisfying Redington's immunization conditions against parallel yield curve shifts [Assessment]

Bibliography: [Blank and Tarquin, 2017]

5.8 Urban Water Systems, 8 hr(s)

Competences: ABET-2

Topics: **I:** Water demand estimation and distribution system design **II:** Distribution network analysis and modeling **III:** Water quality considerations in distribution systems **IV:** Stormwater runoff estimation using rational method **V:** Storm sewer design and hydraulic analysis **VI:** Urban drainage best management practices **VII:** Advanced water distribution system modeling **VIII:** Detention and retention facility design **IX:** Green infrastructure and low impact development **X:** Combined sewer systems and overflow control

Learning Outcomes **I:** Estimate water demands and design distribution system capacity [Assessment] **II:** Analyze distribution networks for pressure and flow adequacy [Usage] **III:** Address water quality issues including disinfection and corrosion [Familiarity] **IV:** Calculate stormwater runoff using the rational method [Assessment] **V:** Design storm sewer systems following hydraulic grade line principles [Usage] **VI:** Implement stormwater best management practices for runoff control [Assessment] **VII:** Develop advanced water distribution models for system optimization [Usage] **VIII:** Proportion detention and retention basins for peak flow reduction [Assessment] **IX:** Apply green infrastructure techniques for sustainable stormwater management [Usage] **X:** Evaluate combined sewer overflow issues and design control measures [Assessment]

Bibliography: [Eddy et al., 2013, White, 2016]

5.9 Design of Hydraulic Structures, 4 hr(s)

Competences: ABET-2

Topics: **I:** Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes **I:** Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control [Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [Novak et al., 2007]

5.10 Site Investigation and In-Situ Testing, 4 hr(s)

Competences: ABET-1

Topics: **I:** Investigation planning and scope determination **II:** Boring methods and subsurface exploration techniques **III:** Sampling methods for disturbed and undisturbed samples **IV:** Standard Penetration Test and correlations **V:** Laboratory testing program and test selection **VI:** Cone Penetration Test and piezocone testing **VII:** Vane shear test and pressuremeter testing **VIII:** Geophysical methods including seismic and resistivity surveys **IX:** Groundwater monitoring and piezometer installation **X:** Report preparation and geotechnical data presentation **XI:** In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment **XII:** Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes **I:** Develop appropriate site investigation programs based on project requirements [Assessment] **II:** Select appropriate boring and exploration methods for different soil conditions [Familiarity] **III:** Specify sampling techniques to obtain quality samples for testing [Usage] **IV:** Interpret SPT data and apply empirical correlations for design parameters [Assessment] **V:** Design laboratory testing programs for geotechnical projects [Usage] **VI:** Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment] **VII:** Apply vane shear and pressuremeter tests for soft clay characterization [Usage] **VIII:** Utilize geophysical methods to complement traditional investigation techniques [Assessment] **IX:** Monitor groundwater conditions and interpret piezometric data [Usage] **X:** Prepare comprehensive geotechnical investigation reports [Assessment] **XI:** Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage] **XII:** Characterize borrow areas for embankment fill material quantity and quality [Assessment]

Bibliography: [Das, 2019]

5.11 Pressurized Pipe Flow and Pump Systems, 6 hr(s)

Competences: ABET-2

Topics: **I:** Pipe flow fundamentals and Darcy-Weisbach equation **II:** Minor losses and pipe system analysis **III:** Pipe network analysis methods **IV:** Pump characteristics and system curves **V:** Pump selection and installation requirements **VI:** Water hammer and surge analysis **VII:** Pipeline design and material selection **VIII:** Variable speed pumps and energy efficiency **IX:** Network modeling and optimization **X:** Valve selection and hydraulic control systems

Learning Outcomes **I:** Calculate head losses in pipe systems using friction equations [Assessment] **II:** Determine total head loss including minor losses in complex piping [Usage] **III:** Analyze pipe networks using Hardy Cross or equivalent methods [Assessment] **IV:** Construct pump characteristic curves and system head curves [Usage] **V:** Select appropriate pumps based on operating point and efficiency [Assessment] **VI:** Evaluate water hammer effects and design surge protection [Usage] **VII:** Design pipelines considering hydraulic, structural, and economic factors [Assessment] **VIII:** Apply variable speed drives for pump system optimization [Usage] **IX:** Optimize water distribution networks using modeling software [Assessment] **X:** Specify valves and control systems for pipeline operations [Usage]

Bibliography: [White, 2016, Ávila, 2002]

5.12 Mechanics of Materials and Structural Behavior, 6 hr(s)

Competences: ABET-1

Topics: **I:** Stress and strain concepts including normal, shear, and principal stresses **II:** Axial loading and deformation of members **III:** Torsion of circular and non-circular sections **IV:** Bending stress and deflection in beams **V:** Shear stress distribution in beams **VI:** Combined loading and stress transformation **VII:** Buckling of columns and stability analysis **VIII:** Fatigue and fracture mechanics **IX:** Elastic and plastic behavior of materials **X:** Energy methods for structural analysis

Learning Outcomes I: Define stress, strain, and their relationships through constitutive laws [Familiarity] **II:** Calculate stresses and deformations in members under axial loading [Usage] **III:** Determine torsional stresses and angles of twist in shafts [Usage] **IV:** Analyze bending stress distribution and deflection in beams [Assessment] **V:** Compute shear stress distribution in beam cross-sections [Usage] **VI:** Apply stress transformation equations for combined loading conditions [Assessment] **VII:** Evaluate column stability and calculate critical buckling loads [Assessment] **VIII:** Explain fatigue failure mechanisms and predict fatigue life [Familiarity] **IX:** Distinguish between elastic and plastic material behavior under loading [Usage] **X:** Use energy methods to solve deflection and indeterminate structural problems [Usage]

Bibliography: [Hibbeler, 2017]

5.13 Standardized Testing, Quality Control, and Failure Analysis, 4 hr(s)

Competences: ABET-6

Topics: I: Standard test methods for material characterization and acceptance testing **II:** Sampling procedures and representative sample selection **III:** Quality control and quality assurance protocols in construction **IV:** Statistical analysis of test data and acceptance criteria **V:** Non-destructive testing methods for materials and structures **VI:** Advanced material characterization techniques including microscopy and spectroscopy **VII:** Failure analysis methodology and root cause investigation **VIII:** Forensic engineering and distress evaluation **IX:** Performance-based testing and specification approaches **X:** Certification, compliance, and third-party testing requirements

Learning Outcomes I: Perform standard material tests according to ASTM or equivalent specifications [Usage] **II:** Develop appropriate sampling plans for construction material acceptance [Assessment] **III:** Implement quality control procedures for construction materials and processes [Usage] **IV:** Analyze test data using statistical methods and establish acceptance criteria [Assessment] **V:** Apply non-destructive testing techniques for in-situ material evaluation [Familiarity] **VI:** Utilize advanced characterization techniques to investigate material microstructure [Usage] **VII:** Conduct systematic failure analysis to determine root causes of material distress [Assessment] **VIII:** Investigate structural failures using forensic engineering methodologies [Assessment] **IX:** Design performance-based test protocols for innovative materials [Usage] **X:** Interpret certification requirements and coordinate third-party testing programs [Familiarity]

Bibliography: [Neville, 2011]

5.14 Construction Materials Science, 6 hr(s)

Competences: ABET-1

Topics: I: Physical and mechanical properties of construction materials including density, porosity, strength, and elasticity **II:** Microstructure and phase composition of construction materials **III:** Durability mechanisms including weathering, chemical attack, and environmental degradation **IV:** Thermal and moisture properties of construction materials **V:** Crystalline and amorphous structures in construction materials **VI:** Material selection criteria based on performance requirements **VII:** Degradation mechanisms and service life prediction

Learning Outcomes I: Describe the fundamental physical and mechanical properties of major construction materials [Familiarity] **II:** Analyze the relationship between microstructure and macroscopic properties of materials [Assessment] **III:** Evaluate the durability performance of materials under specific environmental conditions [Usage] **IV:** Explain the effects of thermal and moisture variations on material behavior [Familiarity] **V:** Select appropriate construction materials based on design specifications and performance criteria [Assessment] **VI:** Predict service life and degradation patterns of materials in various environments [Usage]

Bibliography: [Neville, 2011]

5.15 Solid State and Material Chemistry, 4 hr(s)

Competences: ABET-1

Topics: **I:** Crystal systems, Bravais lattices, and Miller indices for engineering materials **II:** X-ray diffraction for crystal structure determination and phase identification **III:** Ionic compounds: crystal structures and lattice energies **IV:** Metallic and covalent network solids: bonding and engineering properties **V:** Point defects, vacancies, interstitials, and non-stoichiometry in engineering solids **VI:** Band theory and the electronic properties of engineering conductors, semiconductors, and insulators **VII:** Synthesis methods for engineering inorganic materials: solid-state reactions, sol-gel, and CVD

Learning Outcomes **I:** Identify crystal systems and describe symmetry operations in engineering solid materials [Familiarity] **II:** Interpret X-ray diffraction patterns to identify crystal phases and determine unit cell parameters [Usage] **III:** Calculate lattice energies using Born-Haber cycles for engineering ionic compounds [Usage] **IV:** Explain how point defects control diffusion, conductivity, and corrosion in engineering materials [Assessment] **V:** Apply band theory to predict and engineer the electrical properties of solid materials [Assessment] **VI:** Select synthesis methods appropriate for producing specific engineering inorganic materials [Usage]

Bibliography: [Callister and Rethwisch, 2020]

5.16 Optimization Algorithms, 4 hr(s)

Competences: ABET-6

Topics: **I:** Gradient descent and line search methods: Armijo-Wolfe conditions and convergence rates **II:** Newton's method and quasi-Newton methods (BFGS, L-BFGS) **III:** Constrained optimization: KKT conditions, penalty methods, and sequential quadratic programming **IV:** Convex optimization algorithms: interior-point methods and the alternating direction method of multipliers (ADMM) **V:** Stochastic gradient descent (SGD), variance reduction, and Adam optimizer

Learning Outcomes **I:** Explain the convergence guarantees of gradient descent for smooth convex functions [Familiarity] **II:** Apply Newton and quasi-Newton methods to unconstrained optimization problems [Usage] **III:** Formulate a constrained optimization problem as a KKT system and apply an interior-point method [Assessment]

Bibliography: [Nocedal and Wright, 2006]

5.17 Graph Theory, 4 hr(s)

Competences: ABET-6

Topics: **I:** Graphs: definitions, isomorphism, degree sequences, trees, and spanning trees **II:** Connectivity, Menger's theorem, and network flows (max-flow min-cut) **III:** Matchings (Hall's theorem), graph colorings, and the chromatic polynomial **IV:** Planar graphs, Euler's formula, Kuratowski's theorem, and the four-color theorem **V:** Adjacency and Laplacian matrices, eigenvalues, and expander graphs

Learning Outcomes **I:** Identify structural properties of graphs (connectivity, planarity, bipartiteness) and apply Euler's formula [Familiarity] **II:** Apply Hall's marriage theorem and network flow algorithms to matching and routing problems [Usage] **III:** Analyze a graph's spectrum to bound its chromatic number and connectivity properties [Assessment]

Bibliography: [West, 2001]

5.18 Climate Adaptation Engineering for Water Systems, 4 hr(s)

Competences: ABET-2

Topics: **I:** Climate science fundamentals and downscaling of global climate model projections **II:** Hydrologic impacts of climate change: precipitation intensity, drought, and snowmelt **III:** Vulnerability and risk assessment frameworks for water infrastructure **IV:** Water supply system adaptation: source diversification and demand management **V:** Stormwater system adaptation for increased intensity rainfall **VI:** Coastal adaptation strategies: managed retreat, protective structures, and nature-based solutions **VII:** Decision-making under uncertainty and adaptive management pathways **VIII:** Infrastructure design standards and codes under non-stationary climate conditions **IX:** Economic appraisal of adaptation options and financing mechanisms

Learning Outcomes **I:** Interpret downscaled climate projections for key hydrologic variables [Familiarity] **II:** Assess the vulnerability of a water supply system to projected changes in drought frequency [Assessment] **III:** Redesign a stormwater culvert for increased design rainfall intensity based on climate projections [Usage] **IV:** Describe adaptation strategies for managing urban water demand under water scarcity [Familiarity] **V:** Compare hard and soft (nature-based) engineering options for coastal flood protection [Assessment] **VI:** Develop an adaptive management plan for a reservoir facing uncertain future inflow regimes [Usage] **VII:** Propose revisions to infrastructure design standards to incorporate climate resilience [Assessment] **VIII:** Conduct a cost-benefit analysis for a portfolio of water infrastructure adaptation measures [Usage]

Bibliography: [Davis and Cornwell, 2010]

5.19 Open Channel Flow and River Mechanics, 8 hr(s)

Competences: ABET-1

Topics: **I:** Channel flow classification and hydraulic elements **II:** Energy and momentum principles in open channels **III:** Uniform flow and Manning's equation **IV:** Critical flow and specific energy concepts **V:** Gradually varied flow profiles **VI:** Hydraulic jump and rapidly varied flow **VII:** Channel design for stable conveyance **VIII:** Sediment transport in open channels **IX:** River morphology and channel stability **X:** Scour analysis and protection measures

Learning Outcomes **I:** Classify open channel flow regimes and calculate hydraulic elements [Familiarity] **II:** Apply energy and momentum equations to solve channel flow problems [Assessment] **III:** Calculate normal depth and discharge using Manning's equation [Usage] **IV:** Determine critical depth and analyze specific energy relationships [Assessment] **V:** Compute gradually varied flow profiles using standard methods [Usage] **VI:** Analyze hydraulic jumps and calculate energy dissipation [Assessment] **VII:** Design stable channels with appropriate cross-sections and linings [Usage] **VIII:** Estimate sediment transport rates in alluvial channels [Assessment] **IX:** Evaluate river channel stability and bank erosion potential [Familiarity] **X:** Predict scour depths at hydraulic structures and design protection [Assessment]

Bibliography: [Chow, 1959]

5.20 Environmental Impact Assessment and Sustainability Metrics, 4 hr(s)

Competences: ABET-2

Topics: **I:** EIA process: screening, scoping, impact analysis, mitigation, and public participation **II:** Impact prediction methods for air, water, soil, noise, and ecological systems **III:** Mitigation hierarchy and design of environmental management plans **IV:** Legal and institutional frameworks for EIA **V:** Sustainability concepts and the triple bottom line (environment, economy, society) **VI:** Cumulative impact assessment and strategic environmental assessment (SEA) **VII:** Social impact assessment and stakeholder engagement methods **VIII:** Sustainability metrics and indicator frameworks (e.g., SDGs, Envision) **IX:** Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes **I:** Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity] **II:** Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage] **III:** Develop mitigation measures for identified significant environmental impacts [Assessment] **IV:** Explain the legal requirements and purpose of EIA in the project approval process [Familiarity] **V:** Apply the triple bottom line framework to evaluate a simple engineering project [Assessment] **VI:** Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment] **VII:** Design a stakeholder engagement plan for a controversial development project [Usage] **VIII:** Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment] **IX:** Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

Bibliography: [Glasson and Therivel, 2019]

5.21 Green Building Systems and Sustainable Urban Development, 4 hr(s)

Competences: ABET-2

Topics: **I:** High-performance building envelopes and passive design strategies **II:** Energy modeling, efficient HVAC systems, and on-site renewable generation **III:** Water efficiency: low-flow fixtures, rainwater harvesting, and greywater reuse **IV:** Indoor environmental quality (IEQ): thermal comfort, daylighting, and air quality **V:** Sustainable site design: stormwater management, heat island reduction, habitat preservation **VI:** Net-zero energy and water building design **VII:** Smart building technologies and IoT for operational optimization **VIII:** Urban sustainability: transit-oriented development, density, and mixed-use planning **IX:** Green building certification systems: LEED, BREEAM, Living Building Challenge

Learning Outcomes **I:** Design a building section illustrating key passive heating and cooling strategies [Assessment] **II:** Size a rainwater harvesting system for a given roof area and demand [Usage] **III:** Explain the key parameters affecting indoor air quality and thermal comfort [Familiarity] **IV:** Develop a site plan that minimizes impervious surfaces and incorporates green infrastructure [Usage] **V:** Model a building's energy use to demonstrate a path to net-zero energy [Assessment] **VI:** Describe how a building automation system can optimize energy and water use [Familiarity] **VII:** Plan a transit-oriented development (TOD) node for reduced vehicle dependence [Assessment] **VIII:** Prepare documentation for a project targeting a specific level of LEED certification [Usage]

Bibliography: [Kibert, 2016]

5.22 Water and Wastewater Treatment Process Design, 8 hr(s)

Competences: ABET-2

Topics: **I:** Water quality parameters and regulatory standards for drinking water and wastewater effluent **II:** Physical treatment processes: screening, sedimentation, flotation, and filtration **III:** Chemical treatment processes: coagulation, flocculation, disinfection, and pH adjustment **IV:** Biological treatment principles: suspended growth (activated sludge) and attached growth (trickling filters) systems **V:** Process selection and design criteria based on source water or wastewater characteristics **VI:** Advanced treatment processes: membrane filtration, advanced oxidation, and nutrient removal (N&P) **VII:** Sludge and biosolids handling, treatment, and disposal methods **VIII:** Plant layout, hydraulic profile, and pumping system design **IX:** Industrial wastewater pretreatment and specific contaminant removal strategies **X:** Process control, monitoring, and troubleshooting in treatment plants

Learning Outcomes **I:** Identify key water quality parameters and their significance for human health and the environment [Familiarity] **II:** Select appropriate physical and chemical unit processes for a given water or wastewater treatment objective [Assessment] **III:** Design fundamental components of water treatment plants, such as rapid mix basins, flocculators, and sedimentation

tanks [Usage] **IV:** Explain the biological mechanisms and operational parameters of activated sludge systems [Familiarity] **V:** Size primary and secondary treatment units based on flow rates and pollutant loading [Assessment] **VI:** Design advanced treatment trains for water reuse or stringent nutrient discharge limits [Usage] **VII:** Evaluate sludge management alternatives and select appropriate thickening/dewatering methods [Assessment] **VIII:** Develop hydraulic profiles and pump specifications for treatment plant layouts [Usage] **IX:** Propose pretreatment strategies for specific industrial wastewater streams [Assessment] **X:** Implement basic process control strategies to optimize treatment plant performance [Usage]

Bibliography: [Eddy et al., 2013]

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CE3H4 Water Resources (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

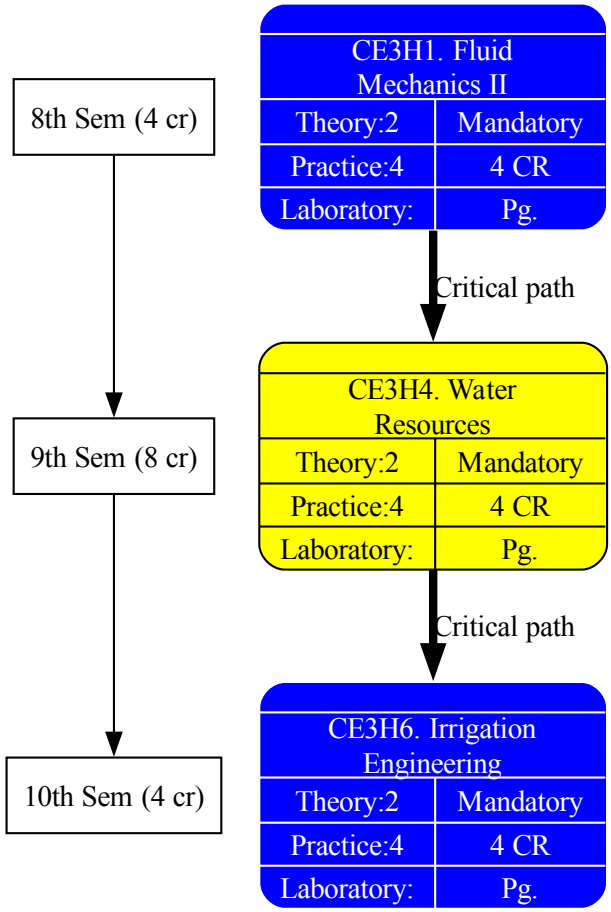

Figure 7.61: Connection Map. CE3H4 Water Resources

2. Course Rationale

Water Resources addresses the comprehensive planning of water utilization projects: from the analysis of availability and demand (irrigation, municipal use, energy, navigation, ecological flow) and groundwater hydrology, to the formulation and evaluation of projects through economic, financial, environmental, social, and multi-criteria criteria. The course concludes with the application of linear programming and system optimization criteria, as well as the operating criteria and the national regulatory framework that govern water resources projects in Peru.

3. Goals of the Course

- Analyze the availability and demand of water resources for different uses, including the groundwater component.
- Formulate water resources projects by defining the problem, alternatives, schedule, and budget.
- Evaluate project alternatives using economic, financial, environmental, social, and multi-criteria criteria.
- Apply linear programming and system optimization criteria to water resources planning.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Introduction and Methodology of Water Resources Analysis, 6 hr(s)

Competences: ABET-1

Topics: **I:** Definitions and methodology for water resources project analysis. History of water resources development. **II:** Current status of water resources in Peru and the National Water Resources Plan. **III:** Management of basic information and water resources simulation tools.

Learning Outcomes **I:** Describe the general methodological framework for the analysis of water resources projects [Familiarity]. **II:** Collect and organize the basic information required for a water resources study [Usage].

Bibliography: [Loucks and van Beek, 2017]

5.2 Hydrologic Cycle and Water Balance, 11 hr(s)

Competences: ABET-1

Topics: **I:** Hydrologic cycle and water balance concepts **II:** Precipitation measurement and analysis **III:** Evaporation and evapotranspiration estimation **IV:** Infiltration theory and rainfall-runoff processes

Learning Outcomes **I:** Explain the hydrologic cycle and quantify water balance components [Familiarity] **II:** Analyze precipitation data and develop depth-area-duration relationships [Assessment] **III:** Estimate evaporation and evapotranspiration using empirical methods [Usage] **IV:** Apply infiltration models to estimate runoff from rainfall events [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.3 Surface Hydrology and Watershed Modeling, 9 hr(s)

Competences: ABET-1

Topics: **I:** Hydrograph analysis and unit hydrograph method **II:** Watershed modeling and hydrologic simulation **III:** Streamflow measurement and gauging techniques

Learning Outcomes **I:** Derive unit hydrographs and synthesize runoff hydrographs [Usage] **II:** Develop watershed models using software tools for hydrologic simulation [Usage] **III:** Conduct streamflow measurements and interpret flow duration curves [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.4 Flood Frequency Analysis and Climate Change, 8 hr(s)

Competences: ABET-1

Topics: **I:** Flood frequency analysis and design storms **II:** Hydrologic routing methods for channels and reservoirs **III:** Climate change impacts on hydrologic systems

Learning Outcomes **I:** Perform flood frequency analysis using statistical methods [Assessment] **II:** Route flood hydrographs through channels and reservoirs [Usage] **III:** Evaluate climate change impacts on watershed hydrology and design implications [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.5 Groundwater Hydrology, 8 hr(s)

Competences: ABET-1

Topics: **I:** Aquifer types: confined, unconfined, and semi-confined **II:** Darcy's law applied to groundwater flow and hydraulic conductivity **III:** Well hydraulics: Theis and Thiem equations for transient and steady-state flow **IV:** Pumping tests and estimation of hydrogeologic parameters (transmissivity, storativity) **V:** Numerical modeling of groundwater flow and aquifer water balance **VI:** Groundwater-surface water interaction and conjunctive use of resources **VII:** Groundwater quality and basic contaminant transport **VIII:** Design and construction of water supply wells **IX:** Sustainable aquifer management and prevention of overexploitation

Learning Outcomes **I:** Classify aquifer types and describe their hydraulic boundary conditions [Familiarity] **II:** Apply Darcy's law to calculate groundwater flow rates and velocities [Usage] **III:** Solve the Theis and Thiem equations to determine drawdown in pumping wells [Assessment] **IV:** Estimate hydrogeologic parameters from pumping test data [Usage] **V:** Model the water balance of an aquifer and evaluate exploitation scenarios [Assessment] **VI:** Design a water supply well accounting for aquifer characteristics [Usage] **VII:** Evaluate the sustainability of aquifer exploitation and propose management measures [Assessment]

Bibliography: [Fetter, 2001]

5.6 Scope and Requirements Planning, 12 hr(s)

Competences: ABET-2

Topics: **I:** Requirements elicitation techniques across predictive and adaptive approaches **II:** Scope definition: project scope statement vs. product backlog depending on approach **III:** Requirements traceability: linking requirements to outcomes across all approaches **IV:** Scope decomposition: WBS for predictive, backlog structuring for adaptive

Learning Outcomes **I:** Define project and product scope using techniques appropriate to the selected development approach [Usage] **II:** Compare scope planning approaches in predictive and adaptive development contexts [Assessment] **III:** Design a requirements traceability approach ensuring all deliverables are linked to stated stakeholder needs [Assessment]

Bibliography: [Institute, 2021]

5.7 Schedule Planning, 2 hr(s)

Competences: ABET-2

Topics: **I:** Activity estimation techniques: analogous, parametric, three-point, and story points **II:** Schedule development: critical path for predictive, sprint and release planning for adaptive **III:** Building schedule flexibility: buffers, contingency, and iteration capacity **IV:** Schedule baseline in predictive vs. release roadmap in adaptive: comparison and use

Learning Outcomes **I:** Develop a project schedule appropriate to the selected development approach [Usage] **II:** Compare scheduling practices in predictive and adaptive project environments [Assessment] **III:** Evaluate a project schedule for realism, buffer adequacy, and alignment with scope and resource constraints [Assessment]

Bibliography: [Institute, 2021]

5.8 Cost and Budget Planning, 1 hr(s)

Competences: ABET-2

Topics: **I:** Cost estimation techniques: analogous, parametric, bottom-up, and three-point **II:** Budget structure: cost baseline, contingency reserves, and management reserves **III:** Cost planning in adaptive environments: fixed-capacity budgeting and cost per iteration **IV:** Establishing and maintaining the cost performance baseline and managing reserve drawdown

Learning Outcomes **I:** Estimate project costs and develop a budget using appropriate techniques [Usage] **II:** Adapt cost planning practices for adaptive and hybrid project environments [Assessment] **III:** Evaluate the adequacy of a project budget including contingency and management reserves [Assessment]

Bibliography: [Institute, 2021, Blank and Tarquin, 2017]

5.9 Economic, Financial and Social Evaluation of Water Resources Projects, 12 hr(s)

Competences: ABET-1

Topics: **I:** Economic evaluation indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost ratio **II:** Selecting among project alternatives by comparing economic indicators **III:** Sensitivity analysis to variations in costs, benefits, and discount rate **IV:** Funding sources and financial structuring of water projects **V:** User payment capacity and tariff schemes **VI:** Cost allocation among beneficiaries in multipurpose projects **VII:** Social evaluation of projects: exchange theory and shadow prices **VIII:** Distributional impacts and equity in project social evaluation

Learning Outcomes **I:** Calculate NPV, IRR, and Benefit-Cost ratio for a water resources project [Usage] **II:** Select among project alternatives based on compared economic indicators [Assessment] **III:** Perform a sensitivity analysis of project profitability to changes in key variables [Usage] **IV:** Evaluate funding sources and tariff schemes based on user payment capacity [Assessment] **V:** Allocate costs among beneficiaries in a multipurpose project [Usage] **VI:** Apply social evaluation principles to estimate a project's net benefit to society [Assessment]

Bibliography: [Blank and Tarquin, 2017]

5.10 Environmental Impact Assessment and Sustainability Metrics, 3 hr(s)

Competences: ABET-2

Topics: **I:** EIA process: screening, scoping, impact analysis, mitigation, and public participation **II:** Impact prediction methods for air, water, soil, noise, and ecological systems **III:** Mitigation hierarchy and design of environmental management plans **IV:** Legal and institutional frameworks for EIA **V:** Sustainability concepts and the triple bottom line (environment, economy,

society) **VI:** Cumulative impact assessment and strategic environmental assessment (SEA) **VII:** Social impact assessment and stakeholder engagement methods **VIII:** Sustainability metrics and indicator frameworks (e.g., SDGs, Envision) **IX:** Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes I: Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity] **II:** Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage] **III:** Develop mitigation measures for identified significant environmental impacts [Assessment] **IV:** Explain the legal requirements and purpose of EIA in the project approval process [Familiarity] **V:** Apply the triple bottom line framework to evaluate a simple engineering project [Assessment] **VI:** Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment] **VII:** Design a stakeholder engagement plan for a controversial development project [Usage] **VIII:** Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment] **IX:** Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

Bibliography: [Glasson and Therivel, 2019]

5.11 Weighted Sum and Scoring Methods, 3 hr(s)

Competences: ABET-6

Topics: I: Weighted sum model (SAW): normalization of criteria, weight assignment, and aggregation **II:** Weight elicitation methods: direct assignment, rank order centroid, and swing weights **III:** Weighted product model and its advantage for ratio-scale criteria **IV:** VIKOR method: compromise ranking based on closeness to the ideal and maximum group utility

Learning Outcomes I: Apply the weighted sum model to rank alternatives and conduct sensitivity analysis on weights [Usage] **II:** Elicit criteria weights using swing weights or rank order centroid and justify the chosen method [Usage] **III:** Compare weighted sum and VIKOR rankings and explain differences due to aggregation approach [Assessment]

Bibliography: [Triantaphyllou, 2000]

5.12 LP Formulation and Modeling, 6 hr(s)

Competences: ABET-6

Topics: I: Decision variables, objective function (minimization and maximization), and constraint types **II:** Standard and canonical forms of an LP: converting inequalities to equalities, non-negativity restrictions **III:** Common LP modeling patterns: resource allocation, blending, production planning, and diet problems **IV:** Modeling with soft constraints: penalty methods and goal relaxation in LP formulations

Learning Outcomes I: Formulate a linear programming model from a verbal problem description, identifying variables, objective, and constraints [Usage] **II:** Convert an LP between its inequality, equality (standard), and canonical forms [Usage] **III:** Evaluate the adequacy of an LP model and identify modeling errors or inappropriate linearization assumptions [Assessment]

Bibliography: [Hillier and Lieberman, 2021]

5.13 Operation Criteria and Regulatory Framework, 3 hr(s)

Competences: ABET-2

Topics: I: Operation criteria for water utilization systems. **II:** National regulatory framework for water resources (Water Resources Law and its regulations).

Learning Outcomes I: Apply operation criteria to a water utilization system [Usage]. **II:** Identify the national regulatory framework applicable to a water resources project [Familiarity].

Bibliography: [del Agua (ANA), 2016]

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CE3S11 Professional Competency Workshop - Structures (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3S1 Structural Analysis II (8th Sem-Pg. 425)

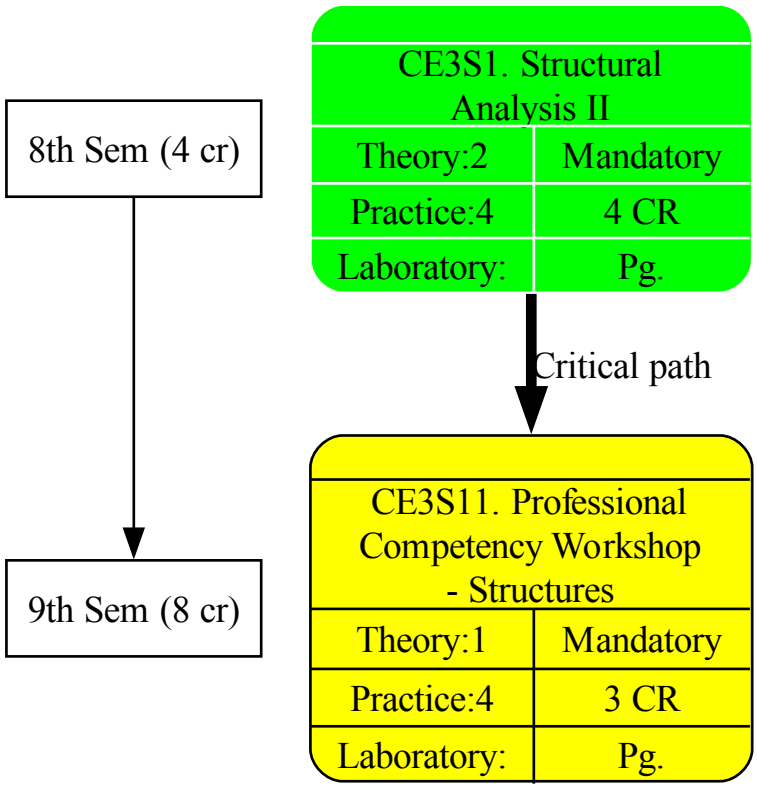

Figure 7.62: Connection Map. CE3S11 Professional Competency Workshop - Structures

2. Course Rationale

Professional Competency Workshop - Structures is an integrative review course that consolidates and applies the structural engineering competencies developed throughout the Structures specialization track. It revisits mechanics of materials and structural behavior, standardized testing and quality control, structural dynamics and seismic-resistant engineering, reinforced concrete and prestressed concrete design, structural health monitoring technologies, resilient design for natural hazards and climate change, and engineering ethics and professional responsibility, preparing students to face the professional practice of structural engineering as a whole.

3. Goals of the Course

- Review and apply mechanics of materials and structural behavior principles to real structural elements.
- Apply standardized testing, quality control, and failure analysis methods to structural materials and systems.
- Analyze the seismic response of structures and apply seismic-resistant design criteria.
- Design reinforced concrete and prestressed concrete structural elements.
- Apply structural health monitoring (SHM) and sensor technologies to assess the condition of civil infrastructure.
- Formulate resilient design solutions for natural hazards and climate change.
- Apply engineering ethics and professional responsibility principles to structural engineering practice.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Mechanics of Materials and Structural Behavior, 10 hr(s)

Competences: ABET-1

Topics: **I:** Stress and strain concepts including normal, shear, and principal stresses **II:** Axial loading and deformation of members **III:** Torsion of circular and non-circular sections **IV:** Bending stress and deflection in beams **V:** Shear stress distribution in beams **VI:** Combined loading and stress transformation **VII:** Buckling of columns and stability analysis **VIII:** Fatigue and fracture mechanics **IX:** Elastic and plastic behavior of materials **X:** Energy methods for structural analysis

Learning Outcomes **I:** Define stress, strain, and their relationships through constitutive laws [Familiarity] **II:** Calculate stresses and deformations in members under axial loading [Usage] **III:** Determine torsional stresses and angles of twist in shafts [Usage] **IV:** Analyze bending stress distribution and deflection in beams [Assessment] **V:** Compute shear stress distribution in beam cross-sections [Usage] **VI:** Apply stress transformation equations for combined loading conditions [Assessment] **VII:** Evaluate column stability and calculate critical buckling loads [Assessment] **VIII:** Explain fatigue failure mechanisms and predict fatigue life [Familiarity] **IX:** Distinguish between elastic and plastic material behavior under loading [Usage] **X:** Use energy methods to solve deflection and indeterminate structural problems [Usage]

Bibliography: [Gere and Goodno, 2017, Hibbeler, 2017]

5.2 Standardized Testing, Quality Control, and Failure Analysis, 6 hr(s)

Competences: ABET-6

Topics: **I:** Standard test methods for material characterization and acceptance testing **II:** Sampling procedures and representative sample selection **III:** Quality control and quality assurance protocols in construction **IV:** Statistical analysis of test data and acceptance criteria **V:** Nondestructive testing methods for materials and structures **VI:** Advanced material characterization

techniques including microscopy and spectroscopy **VII:** Failure analysis methodology and root cause investigation **VIII:** Forensic engineering and distress evaluation **IX:** Performance-based testing and specification approaches **X:** Certification, compliance, and third-party testing requirements

Learning Outcomes **I:** Perform standard material tests according to ASTM or equivalent specifications [Usage] **II:** Develop appropriate sampling plans for construction material acceptance [Assessment] **III:** Implement quality control procedures for construction materials and processes [Usage] **IV:** Analyze test data using statistical methods and establish acceptance criteria [Assessment] **V:** Apply non-destructive testing techniques for in-situ material evaluation [Familiarity] **VI:** Utilize advanced characterization techniques to investigate material microstructure [Usage] **VII:** Conduct systematic failure analysis to determine root causes of material distress [Assessment] **VIII:** Investigate structural failures using forensic engineering methodologies [Assessment] **IX:** Design performance-based test protocols for innovative materials [Usage] **X:** Interpret certification requirements and coordinate third-party testing programs [Familiarity]

Bibliography: [Neville, 2011]

5.3 Structural Dynamics and Earthquake Engineering, 10 hr(s)

Competences: ABET-1

Topics: **I:** Single-degree-of-freedom systems and free vibration **II:** Forced vibration and harmonic excitation **III:** Damping models and energy dissipation mechanisms **IV:** Response spectrum analysis **V:** Earthquake ground motion characteristics and seismicity **VI:** Multi-degree-of-freedom systems and modal analysis **VII:** Time-history analysis and numerical integration methods **VIII:** Seismic design philosophy and capacity design principles **IX:** Base isolation and energy dissipation devices **X:** Performance-based seismic design methodology

Learning Outcomes **I:** Analyze free vibration of single-degree-of-freedom systems and determine natural frequencies [Assessment] **II:** Calculate structural response to harmonic and periodic loads [Usage] **III:** Explain the role of damping in reducing dynamic response [Familiarity] **IV:** Apply response spectrum method for seismic analysis [Usage] **V:** Interpret earthquake ground motion parameters and seismic hazard maps [Familiarity] **VI:** Perform modal analysis for multi-degree-of-freedom systems [Assessment] **VII:** Conduct time-history analysis using numerical integration techniques [Usage] **VIII:** Design structures following capacity design and ductile detailing principles [Assessment] **IX:** Evaluate the effectiveness of base isolation and damping systems [Familiarity] **X:** Implement performance-based seismic design procedures [Assessment]

Bibliography: [Chopra, 2017]

5.4 Seismic Design Code and Structural Configuration Criteria, 10 hr(s)

Competences: ABET-2

Topics: **I:** Scope and structure of the Peruvian seismic design code E.030 **II:** Seismic hazard parameters: seismic zonation (Z), usage factor (U), and soil profile (S) **III:** Structural systems and seismic force reduction coefficient (R) **IV:** Plan structural irregularities: torsional irregularity, re-entrant corners, and diaphragm discontinuity **V:** Vertical structural irregularities: soft story, weak story, and mass irregularity **VI:** Structuring principles: symmetry, redundancy, hyperstaticity, and continuity **VII:** Minimum base shear and inter-story drift limits

Learning Outcomes **I:** Explain the scope and structure of the Peruvian seismic design code E.030 [Familiarity] **II:** Determine the seismic hazard parameters (Z, U, S) applicable to a given site [Usage] **III:** Select the structural system and corresponding reduction coefficient R [Usage] **IV:** Classify the plan and vertical structural irregularities of a building [Assessment] **V:** Apply structuring principles to propose a regular structural configuration [Usage] **VI:** Verify the minimum base shear and inter-story drift limits [Assessment]

Bibliography: [Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de Vivie Bazán and Meli, 2002]

5.5 Reinforced Concrete Design, 10 hr(s)

Competences: ABET-2

Topics: **I:** Design philosophy and limit state methodology for concrete structures **II:** Flexural design of rectangular and T-beams **III:** Shear and torsion design of concrete members **IV:** Compression members and column design **V:** Slab design including one-way and two-way systems **VI:** Development length and splicing of reinforcement **VII:** Deflection control and serviceability requirements for concrete beams and slabs

Learning Outcomes **I:** Explain limit state design philosophy and load factor combinations [Familiarity] **II:** Design reinforced concrete beams for flexure and check serviceability [Assessment] **III:** Calculate shear and torsional reinforcement requirements [Usage] **IV:** Proportion columns for axial load and biaxial bending [Assessment] **V:** Design one-way and two-way slab systems with appropriate reinforcement [Usage] **VI:** Determine development lengths and design lap splices for reinforcing bars [Assessment] **VII:** Control deflections and verify serviceability requirements through adequate member sizing and reinforcement [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, McCormac and Brown, 2021]

5.6 Seismic Detailing of Reinforced Concrete, 3 hr(s)

Competences: ABET-2

Topics: **I:** Beam-column joints and moment-resisting frame connections **II:** Seismic detailing and ductile design of concrete structures **III:** Design of special reinforced concrete structural walls (shear walls) for seismic lateral force resistance **IV:** Special seismic detailing provisions for reinforced concrete moment-resisting frames

Learning Outcomes **I:** Detail beam-column joints for moment transfer and shear resistance [Assessment] **II:** Implement seismic detailing requirements for ductile concrete frames [Assessment] **III:** Design special reinforced concrete structural walls for combined axial, flexural, and shear demands under seismic loading [Assessment] **IV:** Apply special seismic detailing provisions to reinforced concrete moment frame members and beam-column joints [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.7 Prestressed Concrete Analysis, 3 hr(s)

Competences: ABET-2

Topics: **I:** Prestressed concrete principles and pre-tensioning methods **II:** Elastic analysis of stresses in prestressed concrete sections under service loads **III:** Composite prestressed concrete sections: precast members with cast-in-place topping **IV:** Immediate and time-dependent losses of prestress

Learning Outcomes **I:** Apply prestressing principles to design pre-tensioned members [Usage] **II:** Analyze stresses in prestressed concrete sections under service loads using elastic theory [Usage] **III:** Design composite prestressed concrete sections combining precast members and cast-in-place concrete [Assessment] **IV:** Calculate immediate and time-dependent losses of prestress [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.8 Prestressed Concrete Design, 4 hr(s)

Competences: ABET-2

Topics: **I:** Post-tensioned concrete systems and tendon design **II:** Deflection control and serviceability requirements **III:** Flexural strength of prestressed concrete members at ultimate limit state **IV:** Shear and torsion design of prestressed concrete members **V:** Statically indeterminate prestressed concrete structures, including secondary moments

Learning Outcomes **I:** Design post-tensioned slabs and beams including tendon layout [Assessment] **II:** Control deflections through appropriate member sizing and reinforcement [Usage] **III:** Design prestressed concrete members for flexural strength at the ultimate limit state [Assessment] **IV:** Design prestressed concrete members for shear and torsion strength [Assessment] **V:** Analyze statically indeterminate prestressed concrete structures, including secondary moments [Assessment]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.9 Structural Health Monitoring (SHM) and Sensor Technologies, 2 hr(s)

Competences: ABET-6

Topics: **I:** SHM objectives, paradigms, and lifecycle cost-benefit analysis **II:** Sensor types: strain gauges, accelerometers, tiltmeters, fiber optics, piezoelectrics **III:** Data acquisition systems, signal conditioning, and sampling theory **IV:** Wireless sensor networks (WSN) and IoT communication protocols **V:** Vibration-based damage detection and modal analysis **VI:** Advanced sensing: distributed fiber optics, computer vision, and radar interferometry **VII:** Data management, cloud storage, and cybersecurity for SHM systems **VIII:** Statistical pattern recognition and anomaly detection algorithms **IX:** Decision-support systems for maintenance planning based on SHM data

Learning Outcomes **I:** List the primary objectives and potential benefits of a Structural Health Monitoring (SHM) system [Familiarity] **II:** Select appropriate sensor types for monitoring specific structural responses (strain, vibration, deflection) [Assessment] **III:** Design the layout of a basic sensor network for a simply supported beam or a bridge pier [Usage] **IV:** Explain the advantages and challenges of wireless sensor networks over wired systems [Familiarity] **V:** Perform a basic modal analysis on a set of acceleration data to identify natural frequencies [Usage] **VI:** Compare advanced sensing technologies for detecting crack propagation or settlement [Assessment] **VII:** Develop a data management plan for a long-term SHM project, considering cloud storage [Usage] **VIII:** Apply a simple statistical control chart to identify anomalies in time-series sensor data [Assessment] **IX:** Propose a maintenance action based on the output of a SHM-based decision-support system [Usage]

Bibliography: [Farrar and Worden, 2013]

5.10 Resilient Design for Natural Hazards and Climate Change, 8 hr(s)

Competences: ABET-2

Topics: **I:** Resilience concepts: robustness, redundancy, resourcefulness, rapid recovery **II:** Hazard identification and probabilistic risk assessment **III:** Multi-hazard design approaches and trade-offs **IV:** Climate change projections and their translation into design parameters **V:** Structural resilience: performance-based design and damage-control technologies **VI:** System-of-systems resilience for interconnected infrastructure networks **VII:** Adaptive capacity and flexible design for uncertain futures **VIII:** Community resilience and social dimensions of infrastructure recovery **IX:** Financing resilience: benefit-cost analysis and innovative funding mechanisms

Learning Outcomes **I:** Describe the four key properties (4Rs) of a resilient system [Familiarity] **II:** Perform a qualitative risk assessment for a site exposed to multiple natural hazards [Assessment] **III:** Incorporate projected sea-level rise or increased precipitation into the design basis

for a coastal or drainage structure [Usage] **IV:** Explain how base isolation or damping devices enhance structural resilience [Familiarity] **V:** Analyze the cascading failures in interconnected water and power networks after an earthquake [Assessment] **VI:** Design a flexible foundation system that can be adapted for future increased loads [Usage] **VII:** Evaluate the role of social capital and community preparedness in post-disaster recovery [Assessment] **VIII:** Conduct a benefit-cost analysis for a proposed infrastructure resilience upgrade [Usage]

Bibliography: [of Civil Engineers (ASCE), 2018]

5.11 Engineering Ethics and Professional Responsibility, 4 hr(s)

Competences: ABET-2

Topics: **I:** Ethical theories: utilitarianism, duty ethics, virtue ethics **II:** Professional codes of conduct (e.g., ASCE, NSPE) and their fundamental canons **III:** Engineer's paramount responsibility to public safety, health, and welfare **IV:** Ethical dilemmas in practice: conflicts of interest, whistleblowing, gift-giving **V:** Ethical decision-making frameworks and case study analysis **VI:** Global engineering ethics and cross-cultural challenges **VII:** Ethical obligations for sustainable development and environmental stewardship **VIII:** Ethical implications of emerging technologies (AI, automation, data privacy) **IX:** Ethical conduct in dispute resolution and litigation

Learning Outcomes **I:** Explain the primary tenets of the engineer's code of ethics [Familiarity] **II:** Apply an ethical decision-making framework to a hypothetical engineering scenario [Assessment] **III:** Identify conflicts of interest and other common ethical pitfalls in project work [Familiarity] **IV:** Analyze a historical engineering failure case from an ethical perspective [Assessment] **V:** Evaluate the ethical dimensions of a project with significant social or environmental impacts in a different cultural context [Assessment] **VI:** Articulate the ethical argument for incorporating sustainability into all engineering work [Familiarity] **VII:** Discuss the ethical responsibilities related to data collection and use in smart infrastructure projects [Assessment] **VIII:** Describe the role of ethics in alternative dispute resolution processes [Familiarity]

Bibliography: [Harris et al., 2019]

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CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2S1 Structural Analysis I (7th Sem-Pg. 391)
  - CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)

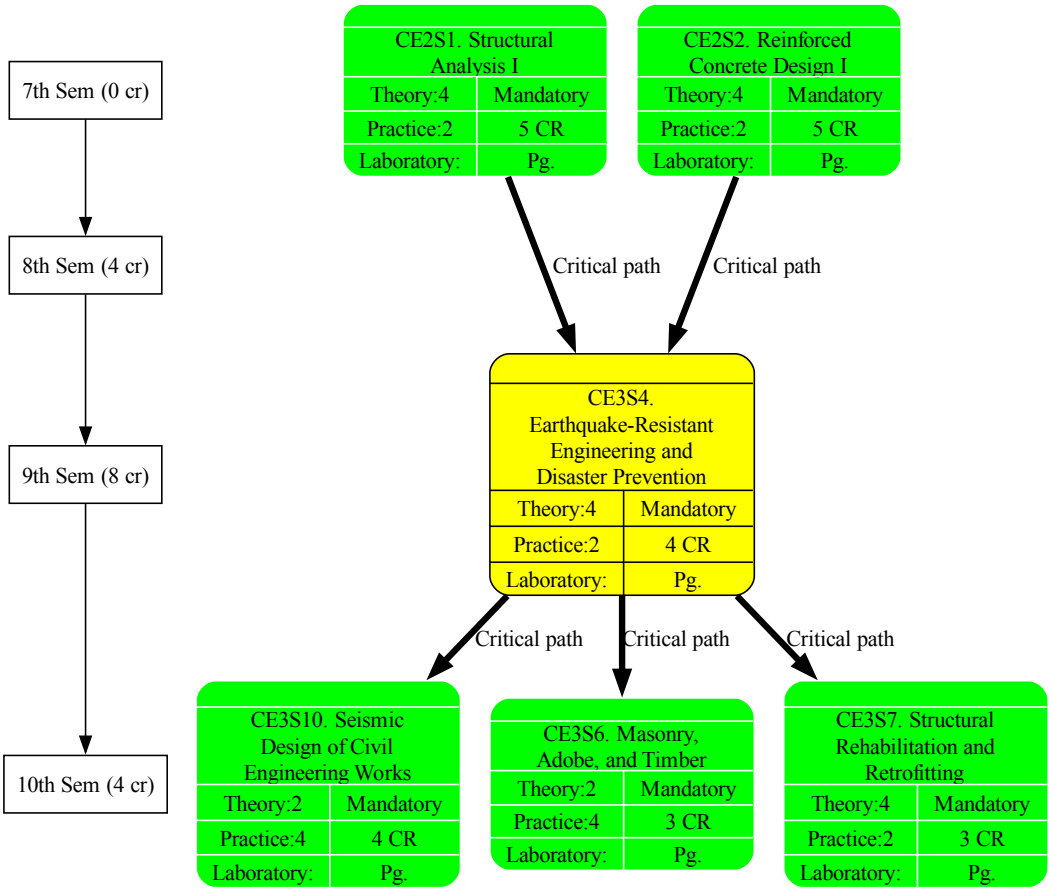

Figure 7.63: Connection Map. CE3S4 Earthquake-Resistant Engineering and Disaster Prevention

2. Course Rationale

Earthquake-Resistant Engineering and Disaster Prevention introduces the seismological and regulatory foundations required to design earthquake- resistant civil structures in Peru's highly seismic environment. Students begin with the fundamentals of seismology and plate tectonics, the typology of natural disasters, and disaster risk management, before studying the Peruvian seismic design code (E.030) and the structural configuration criteria – regularity, redundancy, and torsional control –

that govern the layout of earthquake-resistant buildings. The course closes with structural dynamics: from single- and multi-degree-of-freedom vibration theory to response-spectrum and modal analysis, providing the analytical foundation for the seismic design of building structures.

3. Goals of the Course

- Explain the seismological origin of earthquakes and the typology and management of natural disaster risk relevant to civil engineering practice in Peru.
- Apply the Peruvian seismic design code (E.030) to determine seismic hazard parameters and select an appropriate structural system.
- Apply structural configuration criteria to identify and avoid plan and vertical irregularities in the earthquake-resistant design of a building.
- Analyze the dynamic response of single- and multi-degree-of-freedom structural systems subjected to earthquake ground motion.
- Apply the modal response-spectrum method to determine the seismic design forces and displacements of building structural systems.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Seismology and Natural Hazards, 17 hr(s)

Competences: ABET-1

Topics: **I:** Plate tectonics and earthquake generation mechanisms through fault rupture **II:** Seismic waves: types (P, S, surface) and their propagation **III:** Magnitude (seismic moment) and intensity (Modified Mercalli) scales **IV:** Historical seismicity and subduction tectonic context of Peru **V:** Typology of natural disasters: seismic, volcanic, tsunami, and mass movement **VI:** Disaster risk management: prevention, mitigation, preparedness, and response (SINAGERD framework) **VII:** Seismological instrumentation: seismographs, accelerographs, and national monitoring networks

Learning Outcomes **I:** Explain plate tectonics and earthquake generation mechanisms through fault rupture [Familiarity] **II:** Differentiate types of seismic waves and their effects on buildings [Usage] **III:** Interpret and distinguish between earthquake magnitude and intensity scales [Usage] **IV:** Describe the historical seismicity and subduction context of Peru [Familiarity] **V:** Classify the main types of natural disasters affecting Peruvian territory [Familiarity] **VI:** Analyze the disaster risk management framework for earthquake prevention and response [Assessment]

Bibliography: [Bolt, 2005, Kramer, 1996]

5.2 Seismic Design Code and Structural Configuration Criteria, 11 hr(s)

Competences: ABET-2

Topics: **I:** Scope and structure of the Peruvian seismic design code E.030 **II:** Seismic hazard parameters: seismic zonation (Z), usage factor (U), and soil profile (S) **III:** Structural systems and seismic force reduction coefficient (R) **IV:** Plan structural irregularities: torsional irregularity, re-entrant corners, and diaphragm discontinuity **V:** Vertical structural irregularities: soft story, weak story, and mass irregularity **VI:** Structuring principles: symmetry, redundancy, hyperstaticity, and continuity **VII:** Minimum base shear and inter-story drift limits

Learning Outcomes I: Explain the scope and structure of the Peruvian seismic design code E.030 [Familiarity] **II:** Determine the seismic hazard parameters (Z, U, S) applicable to a given site [Usage] **III:** Select the structural system and corresponding reduction coefficient R [Usage] **IV:** Classify the plan and vertical structural irregularities of a building [Assessment] **V:** Apply structuring principles to propose a regular structural configuration [Usage] **VI:** Verify the minimum base shear and inter-story drift limits [Assessment]

Bibliography: [Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de Vivie Bazán and Meli, 2002]

5.3 Structural Dynamics and Earthquake Engineering, 56 hr(s)

Competences: ABET-1,ABET-2

Topics: I: Single-degree-of-freedom systems and free vibration **II:** Forced vibration and harmonic excitation **III:** Damping models and energy dissipation mechanisms **IV:** Response spectrum analysis **V:** Earthquake ground motion characteristics and seismicity **VI:** Multi-degree-of-freedom systems and modal analysis **VII:** Time-history analysis and numerical integration methods **VIII:** Seismic design philosophy and capacity design principles **IX:** Base isolation and energy dissipation devices **X:** Performance-based seismic design methodology

Learning Outcomes I: Analyze free vibration of single-degree-of-freedom systems and determine natural frequencies [Assessment] **II:** Calculate structural response to harmonic and periodic loads [Usage] **III:** Explain the role of damping in reducing dynamic response [Familiarity] **IV:** Apply response spectrum method for seismic analysis [Usage] **V:** Interpret earthquake ground motion parameters and seismic hazard maps [Familiarity] **VI:** Perform modal analysis for multi-degree-of-freedom systems [Assessment] **VII:** Conduct time-history analysis using numerical integration techniques [Usage] **VIII:** Design structures following capacity design and ductile detailing principles [Assessment] **IX:** Evaluate the effectiveness of base isolation and damping systems [Familiarity] **X:** Implement performance-based seismic design procedures [Assessment]

Bibliography: [Chopra, 2017]

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CE3S8 Architecture and Structural Models (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE2S1 Structural Analysis I (7th Sem-Pg. 391)

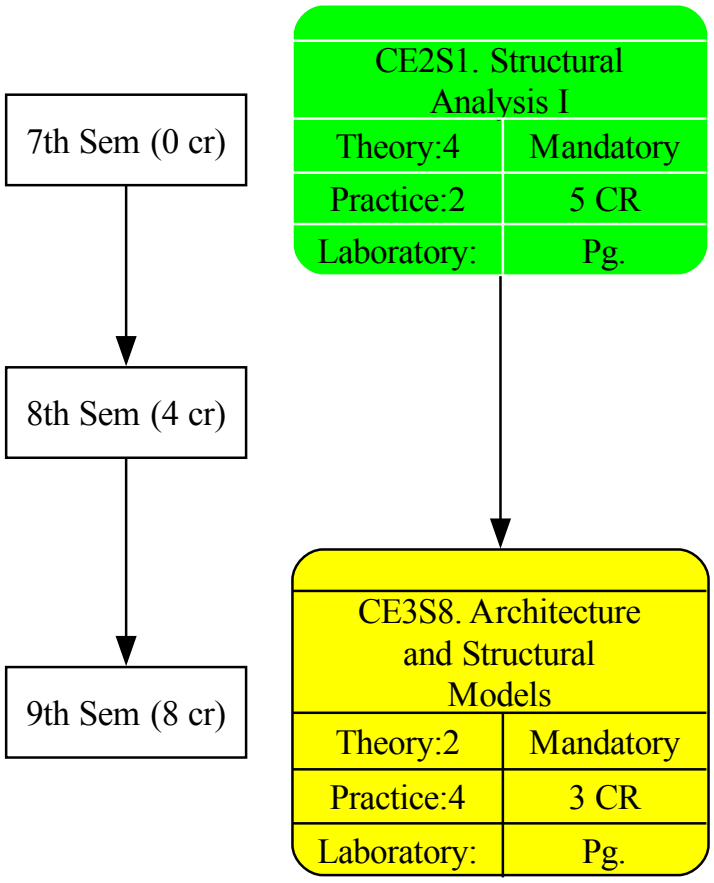

Figure 7.64: Connection Map. CE3S8 Architecture and Structural Models

2. Course Rationale

Architecture and Structural Models bridges the architectural design studio and the structural engineering practice that supports it. The course opens with the methodology of architectural design and urban planning that civil engineers must understand to collaborate effectively with architects on building and urban projects. It then reviews the analysis of statically determinate structural systems and influence lines, the foundation on which structural models for architectural proposals are built. The course places heavy emphasis on Building Information Modeling (BIM) as the digital platform

used to develop, coordinate, and deliver integrated architectural-structural models, and closes with the principles of sustainable and green building systems, and the professional practice skills – technical communication, engineering licensure and legal liability, and global engineering practice – that civil engineers need to operate in multidisciplinary, international project teams.

3. Goals of the Course

- Describe the methodology of architectural design and the principles of urban planning as they relate to civil engineering practice.
- Analyze statically determinate structural systems and construct influence lines for moving loads.
- Develop and coordinate an integrated architectural-structural Building Information Model (BIM) for digital project delivery.
- Apply green building and sustainable urban development principles to a building design proposal.
- Communicate technical and design information effectively, and describe the professional licensure, legal liability, and international practice frameworks relevant to civil engineering.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Foundations of Architectural Design, 6 hr(s)

Competences: ABET-2

Topics: **I:** Space, form, and order: positive and negative space, enclosure, threshold, spatial sequence, hierarchy, scale, and proportion as fundamental architectural design concepts **II:** Architectural elements and their spatial roles: wall, floor, ceiling, and roof as enclosure; column, beam, and slab as structure **III:** Composition and formal operations: symmetry, asymmetry, balance, rhythm, repetition, modulation, contrast, and tension as tools of architectural formal organization **IV:** Light and shadow as design media: natural light quality by orientation and time, shadow and material surface perception, light as spatial modifier - compression, expansion, focus **V:** Program and spatial organization: functional zoning and bubble diagrams, circulation systems (horizontal, vertical, service), spatial hierarchy, and programmatic sequence **VI:** Precedent study methods: formal analysis frameworks for canonical architectural works; reading plans, sections, and photographs as design intelligence

Learning Outcomes **I:** Identify and describe the key spatial, formal, and compositional concepts that constitute the foundations of architectural design [Familiarity] **II:** Apply foundational design principles - space, light, program, and composition - in the development of a spatial architectural proposal [Usage] **III:** Evaluate a design or building project for the quality of its spatial organization, formal coherence, and use of light and program, identifying strengths and areas for improvement [Assessment]

Bibliography: [Ching, 2014]

5.2 Design Process and Creative Methods, 6 hr(s)

Competences: ABET-2

Topics: **I:** Brief analysis and problem framing: decomposing a design brief into spatial, functional, contextual, and performative requirements; identifying constraints and opportunities **II:** Ideation and concept development: sketching, diagramming, and collage as tools to explore spatial ideas; translating abstract concepts into spatial and formal proposals **III:** Physical model-making as a design tool: study models for spatial exploration, massing studies, sectional models, and the role of making in discovering design solutions **IV:** Iterative design and critique: pin-up and desk critique culture, receiving and integrating feedback, revision cycles, and developing design judgment through reflection **V:** Design narrative and argumentation: articulating design intent verbally and graphically, building a coherent design argument, and presenting spatial proposals persuasively **VI:** Collaborative and interdisciplinary design processes: co-design with engineers, landscape architects, and community stakeholders

Learning Outcomes **I:** Describe the stages of an iterative architectural design process from brief analysis through concept development, revision, and final proposal [Familiarity] **II:** Apply systematic ideation and iterative critique methods to develop and refine a spatial architectural proposal in response to a design brief [Usage] **III:** Evaluate the coherence and effectiveness of a design process, including the quality of concept articulation, iteration, and responsiveness to critique [Assessment]

Bibliography: [Ching, 2014]

5.3 Urban Form and Morphology, 6 hr(s)

Competences: ABET-2

Topics: **I:** Kevin Lynch's city image elements: paths, edges, districts, nodes, and landmarks; their role in legibility and wayfinding; application to urban design analysis and intervention **II:** Street, block, and plot systems: typologies (grid, radial, organic, cul-de-sac), block dimensions and permeability, plot subdivision, **III:** Urban building typologies: single-family detached, row house (townhouse), courtyard building, slab, point tower, and linear block **IV:** Morphological analysis methods: Conzenian (burgage cycle, fringe belts), space syntax (integration, connectivity, choice), and figure-ground diagrams for reading urban form **V:** Urban fabric layers: plot subdivision history, street network evolution, land use succession, and the persistence of plot boundaries over centuries as a design constraint

Learning Outcomes **I:** Identify the key morphological elements of a city - streets, blocks, plots, buildings - and describe the relationships among them that define urban character [Familiarity] **II:** Apply morphological analysis tools (figure-ground, space syntax) to an urban sector, identifying its legibility, connectivity, and typological diversity [Usage] **III:** Evaluate the morphological coherence and permeability of a proposed urban design, comparing block sizes, street connectivity, [Assessment]

Bibliography: [Lynch, 1960]

5.4 Historical Urban Planning Theories, 2 hr(s)

Competences: ABET-2

Topics: **I:** Classic urban theories: Howard's Garden City, Le Corbusier's Radiant City (Towers in the Park), Wright's Broadacre City, and their influence on 20th-century planning and zoning **II:** Post-WWII planning: the rise of the master plan, Team 10 critique of CIAM, Jane Jacobs' advocacy for mixed-use and short blocks,

Learning Outcomes **I:** Describe the key historical urban planning theories and their influence on 20th-century city form, and explain the shift from master planning to strategic [Familiarity]

Bibliography: [Lynch, 1960]

5.5 Contemporary Planning Methods and Theory, 4 hr(s)

Competences: ABET-2

Topics: **I:** Planning methods: zoning (Euclidean, form-based, performance-based), master planning vs. strategic planning, public participation (charrettes, community workshops **II:** Smart growth and new urbanism: principles (transit-oriented development, walkability, mixed-income housing, urban growth boundaries), Andrés Duany's transect, **III:** Contemporary urban theory: Lefebvre's production of space, Harvey's right to the city, Sennett's open city, and the role of informality, participation, **IV:** Integration of civil engineering technical constraints (structural, geotechnical, utility infrastructure, and transportation) into urban planning and architectural design frameworks; the collaborative role of civil engineers in multidisciplinary building and urban project teams

Learning Outcomes **I:** Apply a planning method - such as form-based coding or scenario planning - to a specific urban site, producing land use or built form regulations that align with stated policy [Usage] **II:** Evaluate a current urban plan or zoning code against contemporary planning principles (walkability, mixed-use, transit orientation, social equity), identifying strengths [Assessment]

Bibliography: [Lynch, 1960]

5.6 Structural Analysis I, 8 hr(s)

Competences: ABET-1

Topics: **I:** Equilibrium equations and free body diagrams for structural systems **II:** Reactions and internal forces in determinate beams and frames **III:** Truss analysis using method of joints and method of sections **IV:** Shear force and bending moment diagrams **V:** Cables and arches under concentrated and distributed loads **VI:** Influence lines for beams and trusses **VII:** Moving load analysis and envelope diagrams **VIII:** Three-dimensional truss and frame analysis **IX:** Compound structures and classification of structural forms

Learning Outcomes **I:** Apply equilibrium equations to determine support reactions in determinate structures [Usage] **II:** Calculate internal forces and moments at any section of beams and frames [Assessment] **III:** Analyze planar trusses using both method of joints and method of sections [Usage] **IV:** Construct shear force and bending moment diagrams for various loading conditions [Assessment] **V:** Determine internal forces in cables and arches under specified loads [Usage] **VI:** Develop influence lines for reactions and internal forces in determinate structures [Assessment] **VII:** Utilize influence lines to determine maximum effects from moving loads [Usage] **VIII:** Analyze three-dimensional structural systems and determine spatial force components [Assessment] **IX:** Classify structures as determinate or indeterminate and identify stability conditions [Familiarity]

Bibliography: [Hibbeler, 2018, Kassimali, 2020]

5.7 Building Information Modeling (BIM) for Digital Delivery and Asset Management, 36 hr(s)

Competences: ABET-6

Topics: **I:** BIM concepts: dimensions (3D, 4D, 5D, 6D, 7D), LOD, and LOIN **II:** BIM authoring tools and parametric modeling techniques **III:** Model coordination, clash detection, and interference checking **IV:** Collaboration platforms, Common Data Environments (CDE), and BIM execution plans **V:** BIM-based analysis: quantity takeoff, energy simulation, and structural analysis **VI:** Digital twins and the connection between BIM and operational data **VII:** Interoperability standards: IFC, COBie, and openBIM **VIII:** Asset information models (AIM) and BIM for facilities management (FM) **IX:** Regulatory submission and automated code compliance checking

Learning Outcomes **I:** Define the different dimensions of BIM (3D-7D) and their associated information [Familiarity] **II:** Create a basic 3D parametric model of a structural framing system using BIM software [Usage] **III:** Perform a clash detection analysis between architectural and structural models [Assessment] **IV:** Outline the key components of a BIM Execution Plan (BEP) [Familiarity] **V:** Extract a material quantity takeoff schedule from a BIM model [Usage] **VI:** Explain the relationship between a BIM model and a digital twin for an asset [Familiarity] **VII:** Export a BIM model using the IFC format to ensure interoperability [Usage] **VIII:** Develop an Asset Information Model (AIM) deliverable for handover to a facility manager [Assessment] **IX:** Evaluate the potential of automated rule-checking for building code compliance [Assessment]

Bibliography: [Eastman et al., 2018]

5.8 Green Building Systems and Sustainable Urban Development, 4 hr(s)

Competences: ABET-2

Topics: **I:** High-performance building envelopes and passive design strategies **II:** Energy modeling, efficient HVAC systems, and on-site renewable generation **III:** Water efficiency: low-flow fixtures, rainwater harvesting, and greywater reuse **IV:** Indoor environmental quality (IEQ): thermal comfort, daylighting, and air quality **V:** Sustainable site design: stormwater management, heat island reduction, habitat preservation **VI:** Net-zero energy and water building design **VII:** Smart building technologies and IoT for operational optimization **VIII:** Urban sustainability: transit-oriented development, density, and mixed-use planning **IX:** Green building certification systems: LEED, BREEAM, Living Building Challenge

Learning Outcomes **I:** Design a building section illustrating key passive heating and cooling strategies [Assessment] **II:** Size a rainwater harvesting system for a given roof area and demand [Usage] **III:** Explain the key parameters affecting indoor air quality and thermal comfort [Familiarity] **IV:** Develop a site plan that minimizes impervious surfaces and incorporates green infrastructure [Usage] **V:** Model a building's energy use to demonstrate a path to net-zero energy [Assessment] **VI:** Describe how a building automation system can optimize energy and water use [Familiarity] **VII:** Plan a transit-oriented development (TOD) node for reduced vehicle dependence [Assessment] **VIII:** Prepare documentation for a project targeting a specific level of LEED certification [Usage]

Bibliography: [Kibert, 2016]

5.9 Written and Technical Communication, 2 hr(s)

Competences: ABET-2

Topics: **I:** Audience analysis and adaptation of technical content **II:** Written communication: technical reports, memos, emails, and specifications **III:** Visual communication: graphs, charts, diagrams, and effective slide design

Learning Outcomes **I:** Write a clear, concise, and well-organized technical report on a laboratory experiment or design project [Usage] **II:** Create effective graphs and diagrams to present engineering data [Assessment]

Bibliography: [Beer and McMurrey, 2018]

5.10 Oral Presentation and Professional Communication, 1 hr(s)

Competences: ABET-2

Topics: **I:** Oral presentations: structure, delivery techniques, and handling Q&A **II:** Proposal writing: technical approach, management plan, and cost estimating **III:** Executive summaries and communicating with non-technical stakeholders

Learning Outcomes **I:** Deliver a structured oral presentation on a technical topic using appropriate visual aids [Usage] **II:** Outline the key sections of a competitive engineering proposal [Familiarity] **III:** Develop an executive summary that conveys key project findings to a senior management audience [Usage]

Bibliography: [Beer and McMurrey, 2018]

5.11 Digital and Collaborative Communication, 1 hr(s)

Competences: ABET-2

Topics: **I:** Collaborative writing and document management in team settings **II:** Digital communication: web content, social media guidelines for engineers **III:** Persuasive communication and negotiation techniques

Learning Outcomes **I:** Manage a collaborative document (e.g., on Google Docs or SharePoint) for a team project [Assessment] **II:** Explain the professional risks and opportunities associated with engineers using social media [Familiarity] **III:** Employ basic negotiation tactics to resolve a simulated conflict over project scope [Usage]

Bibliography: [Beer and McMurrey, 2018]

5.12 Engineering Licensure, Legal Liability, and Regulatory Frameworks, 4 hr(s)

Competences: ABET-2

Topics: **I:** Professional licensure process: EIT/FE exam, experience requirements, PE exam **II:** Legal fundamentals: torts (negligence), contracts, and intellectual property **III:** Professional liability, errors and omissions, and standard of care **IV:** Regulatory framework for design and construction (building codes, environmental regulations) **V:** Risk management strategies: insurance, indemnification, limitation of liability **VI:** International licensure and mutual recognition agreements **VII:** Forensic engineering and expert witness testimony **VIII:** Government contracting and the Federal Acquisition Regulation (FAR) **IX:** Compliance programs and ethics training for engineering firms

Learning Outcomes **I:** Outline the typical steps and requirements to become a licensed Professional Engineer (PE) [Familiarity] **II:** Define the legal concepts of negligence, standard of care, and breach of contract in an engineering context [Familiarity] **III:** Analyze a case to determine if an engineer's actions met the professional standard of care [Assessment] **IV:** Identify the key regulatory permits required for a typical land development project [Familiarity] **V:** Explain the purpose of professional liability insurance and common policy exclusions [Familiarity] **VI:** Compare the licensure requirements in two different countries [Familiarity] **VII:** Prepare an outline for an expert witness report on a technical failure [Assessment] **VIII:** Describe the unique challenges and rules of government contracting for engineering services [Familiarity] **IX:** Design a simple ethics and compliance training module for an engineering consultancy [Assessment]

Bibliography: [of Examiners for Engineering and (NCEES), 2019, Uff, 2017]

5.13 Global Engineering Practice and International Standards, 4 hr(s)

Competences: ABET-2

Topics: **I:** Globalization of engineering: drivers, opportunities, and challenges **II:** Cultural dimensions and their impact on communication, negotiation, and project management **III:** International standards organizations (ISO) and their role in harmonization **IV:** FIDIC contract conditions and international project delivery **V:** Global challenges: UN Sustainable Development Goals (SDGs) and the engineer's role **VI:** Global supply chain management and logistics for construction **VII:** Expatriate assignments and working in multinational teams **VIII:** Risk management

for international projects: political, currency, force majeure **IX:** Technology transfer and capacity building in developing regions

Learning Outcomes **I:** Describe how cultural differences can affect team dynamics and project outcomes on international projects [Familiarity] **II:** Use a cultural dimensions framework to analyze a cross-cultural misunderstanding in a project case study [Assessment] **III:** Identify key ISO standards relevant to quality management (ISO 9001) and environmental management (ISO 14001) in engineering [Familiarity] **IV:** Explain the structure and key principles of FIDIC Red and Yellow Books [Familiarity] **V:** Map the objectives of a civil engineering project to relevant UN Sustainable Development Goals (SDGs) [Assessment] **VI:** Develop a risk register for an international joint venture project, identifying political and currency risks [Assessment] **VII:** Outline the key considerations for an engineer accepting a long-term assignment in a foreign country [Familiarity] **VIII:** Design a technology transfer plan for implementing a new water treatment process in a developing community [Assessment]

Bibliography: [of Consulting Engineers (FIDIC), 2017, Hofstede et al., 2010]

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CE402 Capstone project I (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - BMI201 Methodology of Engineering Research (8th Sem-Pg. 435)

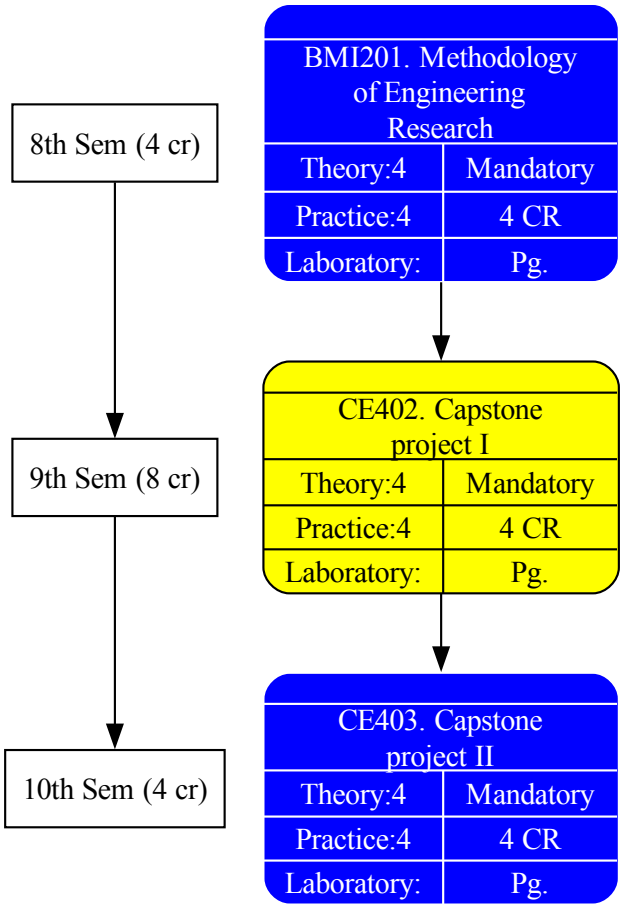

Figure 7.65: Connection Map. CE402 Capstone project I

2. Course Rationale

Este curso tiene por objetivo que el alumno pueda realizar un estudio del estado del arte de un tema escogido para investigar dentro del ámbito de la ingeniería civil. Se busca que el estudiante consolide su base teórica y demuestre capacidad crítica para evaluar soluciones técnicas existentes.

3. Goals of the Course

- Que el alumno realice una investigación inicial en un tema específico realizando el estudio del estado del arte del tema elegido.

- Que el alumno muestre dominio en el tema de la línea de investigación elegida (p.e. comportamiento inelástico de materiales, modelación hidrológica, etc.).
- Que el alumno elija un docente que domine el área de investigación elegida como asesor.
- Los entregables de este curso son:

  Avance parcial: Bibliografía sólida y avance de un Reporte Técnico.

  Final: Reporte Técnico con experimentos o simulaciones preliminares comparativas que demuestren que el alumno ya conoce las técnicas existentes en el área de su proyecto.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Assessment)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Assessment)

ABET-3) An ability to communicate effectively with a range of audiences. (Assessment)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Assessment)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Assessment)

5. Content

5.1 Levantamiento del estado del arte, 60 hr(s)

Competences: ABET-1,ABET-2,ABET-3,ABET-4,ABET-5

Topics: I: Realizar un estudio profundo del estado del arte en un determinado tópico del área de Ingeniería Civil. **II:** Redacción de reportes técnicos y artículos científicos.

Learning Outcomes I: Hacer un levantamiento bibliográfico del estado del arte del tema escogido (capítulos de marco teórico y revisión crítica) [Usage]. **II:** Redactar un documento en LaTeX en formato artículo (*paper*) con alta calidad técnica (tablas, figuras, ecuaciones, citaciones) [Usage]. **III:** Realizar presentaciones de avance utilizando herramientas profesionales como Beamer o similares [Usage]. **IV:** Mostrar resultados de experimentos básicos o simulaciones computacionales preliminares [Usage]. **V:** Elegir un asesor que domine el área de investigación realizada [Usage].

Bibliography: [ASCE, 2022]

6. Bibliography

[ASCE, 2022] ASCE (2022). Guidelines for state-of-the-art reports. *Journal of Structural Engineering.*

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

BLW201 Law and Legislation (Mandatory)

1. General information

- **Semester**: 9th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 1 hours; **Practice**: 1 hours;
- **Prerrequisites**: None

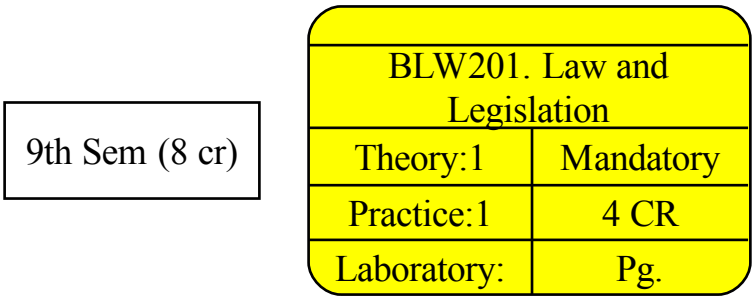

Figure 7.66: Connection Map. BLW201 Law and Legislation

2. Course Rationale

Engineers routinely operate within a dense web of legal obligations: they sign and administer contracts, employ and supervise construction personnel, own or encumber the land and equipment their projects require, pay taxes on their professional and business activity, and compete for and execute public infrastructure works regulated by the state procurement system. This course gives future engineers the legal literacy needed to recognize, anticipate, and responsibly manage these obligations. Starting from the foundations of legal theory and the civil law of persons, the course proceeds through obligations and contracts, property and real securities, labor legislation, tax law, and closes with the rules governing public contracting before Peru's public procurement regulator (OSCE), preparing students to interact competently with legal counsel and public authorities throughout their professional careers.

3. Goals of the Course

- Identify the sources and structure of legal norms and apply them to resolve conflicts between competing rules.
- Explain the legal capacity and attributes of natural and legal persons relevant to professional and business activity.
- Apply the rules governing the formation, validity, and content of contracts and obligations to engineering practice.
- Apply the civil law framework of ownership, possession, and real securities to real estate and infrastructure projects.
- Recognize the employer's labor obligations throughout the life of the employment relationship.
- Determine the tax obligations applicable to an engineering firm or construction project.
- Apply the legal framework governing public contracting and the procedures administered by OSCE to compete for and execute public works.

4. General Competences (*Outcomes*)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Familiarity)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Familiarity)

5. Content

5.1 Sources of Law, 2 hr(s)

Competences: ABET-4

Topics: **I:** Formal sources: constitution, legislation, delegated legislation, international treaties, custom, and general principles of law **II:** Kelsenian hierarchy of norms; constitutional supremacy; conflicts between norms; derogation and abrogation **III:** Role of case law and judicial precedent in civil law systems vs. stare decisis in common law; doctrine as a persuasive source **IV:** Soft law instruments: codes of conduct, guidelines, recommendations, and their legal significance

Learning Outcomes **I:** Identify the formal sources of law applicable in a given legal system and explain their hierarchical relationship [Familiarity] **II:** Apply the hierarchy of norms to resolve conflicts between competing legal rules of different rank [Usage] **III:** Compare the role of judicial decisions as a source of law in civil law and common law systems [Assessment]

Bibliography: [Correa, 2009, Vásquez, 2014]

5.2 Structure and Validity of Legal Norms, 2 hr(s)

Competences: ABET-4

Topics: **I:** Hart's distinction between primary duty-imposing rules and secondary power-conferring rules (recognition, change, adjudication) **II:** Dworkin's rules vs. principles distinction; weight and balance in hard cases; integrity in law **III:** Formal validity (enacted by competent authority), substantive validity (constitutional conformity), and sociological efficacy **IV:** Deontic operators: obligation, permission, prohibition; normative conflicts and their resolution (lex superior, lex posterior, lex specialis)

Learning Outcomes **I:** Describe the structural difference between legal rules and legal principles and explain how each operates in legal reasoning [Familiarity] **II:** Distinguish valid from efficacious norms and apply criteria of formal and substantive validity to a given legal provision [Usage] **III:** Resolve normative conflicts using lex superior, lex posterior, and lex specialis criteria and justify the chosen solution [Assessment]

Bibliography: [Correa, 2009, Vásquez, 2014]

5.3 Natural Persons: Capacity and Civil Status, 2 hr(s)

Competences: ABET-4

Topics: **I:** Beginning of personhood: live birth and the protection of the conceived (nasciturus); end of personhood: death, presumption of death, and declaration of absence **II:** Capacity to enjoy rights (capacidad de goce) vs. capacity to exercise them (capacidad de ejercicio); restrictions affecting minors and judicially interdicted persons; emancipation **III:** Name, domicile, and civil registry (Registro Civil) as attributes of the person; acts subject to mandatory registration (birth, marriage, death) **IV:** Rights of the personality: right to life, physical integrity, honor, image, and privacy; civil remedies for their infringement

Learning Outcomes **I:** Describe the requirements for the beginning and end of legal personhood and distinguish capacity to enjoy rights from capacity to exercise them [Familiarity] **II:** Apply the rules on capacity to determine whether a minor or a judicially interdicted person may validly perform a given legal act [Usage] **III:** Analyze a dispute over a person's civil status or personal rights and assess the civil remedies available [Assessment]

Bibliography: [Sessarego, 2015]

5.4 Legal Persons: Formation, Attributes, and Extinction, 2 hr(s)

Competences: ABET-4

Topics: **I:** Legal person defined and distinguished from natural persons; main types: associations, foundations, committees, and corporations of private and public law **II:** Constitutive act and registration; attributes of the legal person: name, domicile, nationality, and patrimony autonomous from that of its members **III:** Legal representation through organs and representatives; capacity limited by corporate purpose (objeto social); liability of representatives for acts beyond that purpose **IV:** Causes of dissolution, the liquidation process, and extinction of legal personality; protection of creditors during liquidation

Learning Outcomes **I:** Identify the main types of legal persons recognized by civil law and describe the attributes that distinguish them from natural persons [Familiarity] **II:** Apply the rules on legal representation and corporate purpose to determine whether an act performed by a representative binds the legal person [Usage] **III:** Evaluate the dissolution and liquidation process of a legal person and assess the protections available to its creditors [Assessment]

Bibliography: [Sessarego, 2015]

5.5 Fundamentals of Obligations, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Obligation defined: legal bond (vinculum iuris), debtor and creditor, object (conduct or performance), and the patrimonial interest of the creditor **II:** Classification by object (to give, to do, not to do), by plurality (joint, several, solidary), and by condition (pure, conditional, modal, term) **III:** Modes of extinguishment: payment/performance, novation, compensation (set-off), confusion, remission, impossibility, and prescription **IV:** Plurality of parties: joint obligations (mancomunadas) vs. solidary obligations (solidarias); active and passive solidarity

Learning Outcomes **I:** Describe the essential elements of a civil law obligation and classify a given obligation by its object and structure [Familiarity] **II:** Apply the rules on modes of extinguishment to determine whether a specific obligation has been discharged [Usage] **III:** Analyze a complex obligational relationship involving solidarity and indivisibility and determine each party's rights and duties [Assessment]

Bibliography: [Parodi and Freyre, 2008]

5.6 Contract Formation and Validity, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Essential elements: offer and acceptance, free and informed consent, legal capacity of the parties, licit and possible object, and lawful cause **II:** Vices of consent: error (substance and person), fraud (dolo), duress (intimidación), and unconscionable advantage (lesión); effect on contract validity **III:** Absolute nullity (nulidad absoluta): grounds and effects; relative nullity/voidability (anulabilidad): grounds, confirmation, and the action for annulment **IV:** Electronic contracts: formation via digital platforms, click-wrap and browse-wrap agreements, e-signature validity under UNCITRAL Model Law

Learning Outcomes **I:** Explain the essential elements required for a valid contract in civil law and identify the consequences when each element is absent or defective [Familiarity] **II:** Assess whether a contract is void or voidable given a set of facts involving defective consent or lack of capacity [Usage] **III:** Evaluate the policy rationale for distinguishing absolute from relative nullity and analyze its practical consequences for third-party rights [Assessment]

Bibliography: [de la Puente y Lavalle, 2001]

5.7 Concept and Content of Ownership, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Ownership as the fullest real right: ius utendi, fruendi, abutendi; absolute, exclusive, and perpetual character; object of ownership (corporeal and incorporeal things) **II:** Constitutional limits on ownership: social and ecological function; expropriation for public interest (requirements, indemnification, and procedure) **III:** Neighbourhood relations: restrictions on immissions, right of passage, boundaries and encroachments; abuse of right (abuso del derecho) doctrine **IV:** Indigenous communal property and collective territorial rights under ILO Convention 169: inalienability of ancestral lands, prior consultation,

Learning Outcomes **I:** Describe the attributes of ownership in civil law and explain the constitutional and statutory limitations on the exercise of property rights [Familiarity] **II:** Apply the rules on neighbourhood law and abuse of right to resolve a dispute between adjoining landowners [Usage] **III:** Evaluate the tension between the absolute character of ownership and the social function doctrine as expressed in Latin American constitutional law [Assessment]

Bibliography: [Valdez and Arana, 2017]

5.8 Limited Real Rights: Usufruct, Easements, and Securities, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Usufruct: content, duration, obligations of the usufructuary (inventory, bond, conservation), and modes of extinction; use and habitation as lesser personal servitudes **II:** Predial servitudes (servidumbres): positive and negative; apparent and non-apparent; continuous and discontinuous; creation by title, prescription, and destination **III:** Mortgage (hipoteca): accessory character, registration requirement, enforcement by judicial sale; pledge (prenda): possession requirement, non-possessory pledge; antichresis **IV:** Fiduciary transfer (fideicomiso / patrimonio autónomo): structure as a separate estate, uses in project finance and estate planning, obligations of the trustee,

Learning Outcomes **I:** Describe the main categories of limited real rights and explain how each affects the owner's bundle of rights [Familiarity] **II:** Distinguish usufruct from a lease and predial easements from personal servitudes, identifying the legal consequences of each classification [Usage] **III:** Evaluate the adequacy of a mortgage as a security device compared to a pledge in a commercial financing transaction [Assessment]

Bibliography: [Valdez and Arana, 2017]

5.9 The Individual Employment Relationship, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Employment contract defined: subordination (dependencia), personal service, and remuneration; indicators of subordination: schedule, instructions, tools, exclusivity **II:** Types: indefinite, fixed-term, part-time, seasonal, apprenticeship, telework; formal requirements and written contract obligation; probationary period **III:** Sham contracting (desnaturalización): conversion of fixed-term to indefinite; triangular relationships: labor supply (tercerización/outsourcing), employer's joint **IV:** Non-standard forms of employment: part-time, fixed-term, temporary

agency work, and telework/remote work - applicable legal frameworks, rights, and employer obligations

Learning Outcomes **I:** Define the individual employment contract and identify the element of subordination that distinguishes it from an independent contractor relationship [Familiarity] **II:** Identify the indicators of a sham contracting arrangement and determine whether a worker is entitled to the protections of employment law [Usage] **III:** Analyze the legal consequences of triangular labor relationships for the principal employer's liability toward outsourced workers [Assessment]

Bibliography: [Mujica, 2009]

5.10 Termination of Employment, 2 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Just cause for dismissal: types (serious misconduct, poor performance, objective economic causes); procedural requirements: written notice, prior hearing **II:** Unfair (arbitrary) dismissal: reinstatement vs. compensation options; special protection against dismissal: pregnant workers, union representatives, disabled persons **III:** Severance pay (indemnización por años de servicios) and CTS compensation fund (compensación por tiempo de servicios): calculation, payment, and forfeiture conditions **IV:** Individual dismissal: causas justas de despido, procedural requirements (prior written notice and hearing), severance pay calculation,

Learning Outcomes **I:** Explain the grounds for justified dismissal and the procedural steps an employer must follow before terminating an employment contract [Familiarity] **II:** Apply severance pay rules to calculate the total liquidation benefit owed to a worker dismissed without just cause [Usage] **III:** Assess the adequacy of special dismissal protection for vulnerable categories of workers and evaluate its effect on employer flexibility [Assessment]

Bibliography: [Mujica, 2009]

5.11 Fundamentals of Taxation, 4 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Tax obligation (obligación tributaria): taxable event (hecho imponible), taxpayer, tax base, and tax rate; birth, determination, and extinction of the obligation **II:** Classification of taxes: impuestos, tasas, and contribuciones; income tax and value-added tax (IGV/VAT); municipal taxes relevant to construction and real estate (predial, alcabala) **III:** Powers of the tax administration: assessment (fiscalización) and collection; taxpayer obligations: filing, payment, and bookkeeping; withholding obligations applicable to contractors **IV:** Tax infractions and penalties; administrative tax procedure and appeals (reclamación, apelación) before the tax administration and tax courts

Learning Outcomes **I:** Describe the essential elements of the tax obligation and classify the main types of taxes applicable to a professional or business activity [Familiarity] **II:** Apply income, value-added, and municipal tax rules to determine the tax obligations of an engineering firm or construction project [Usage] **III:** Analyze a tax dispute scenario and assess the administrative remedies available against a tax administration's determination [Assessment]

Bibliography: [Cucci, 2015]

5.12 Public Contracting and Concessions, 6 hr(s)

Competences: ABET-2,ABET-4

Topics: **I:** Principles of public procurement: publicity, competition, equal treatment, and transparency; award procedures: open tender, restricted tender, direct contracting **II:** Exorbitant clauses of public contracts: right to modify (ius variandi), right to terminate for public interest, direction and control powers; maintenance of financial equilibrium **III:** Concession contracts:

public service concession, infrastructure concession; public-private partnerships (APP): risk allocation, investment recovery, and regulatory framework **IV:** Claims and disputes in public contracts: contractual claims mechanism, dispute boards, and administrative arbitration as alternative to judicial review of public contract conflicts

Learning Outcomes I: Describe the main public procurement procedures and identify the legal principles that govern the award of public contracts [Familiarity] **II:** Apply the rules on exorbitant clauses to assess the state's right to modify a public contract and the contractor's right to financial rebalancing [Usage] **III:** Compare the legal regime of public contracts with private law contracts, identifying the special rules and exorbitant clauses that characterize the public contract [Assessment]

Bibliography: [Linares, 2019, Ordóñez, 2016]

6. Bibliography

[Correa, 2009] Correa, M. R. (2009). *El Sistema Jurídico: Introducción al Derecho*. Fondo Editorial de la Pontificia Universidad Católica del Perú, 10th edition.

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[Parodi and Freyre, 2008] Parodi, F. O. and Freyre, M. C. (2008). *Compendio de Derecho de las Obligaciones*. Palestra Editores.

[Sessarego, 2015] Sessarego, C. F. (2015). *Derecho de las Personas: Exposición de Motivos y Comentarios al Libro Primero del Código Civil Peruano*. Editorial Motivensa, 11th edition.

[Valdez and Arana, 2017] Valdez, J. A. and Arana, F. A. (2017). *Derechos Reales*. Fondo Editorial de la Pontificia Universidad Católica del Perú.

[Vásquez, 2014] Vásquez, A. T. (2014). *Introducción al Derecho: Teoría General del Derecho*. Instituto Pacífico, 4th edition.

Tenth Semester

Universidad Nacional de Ingeniería (UNI)
Facultad de Ingeniería Civil
Escuela Profesional de Ingeniería Civil

CE3C11 Sanitary and Electrical Installations (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

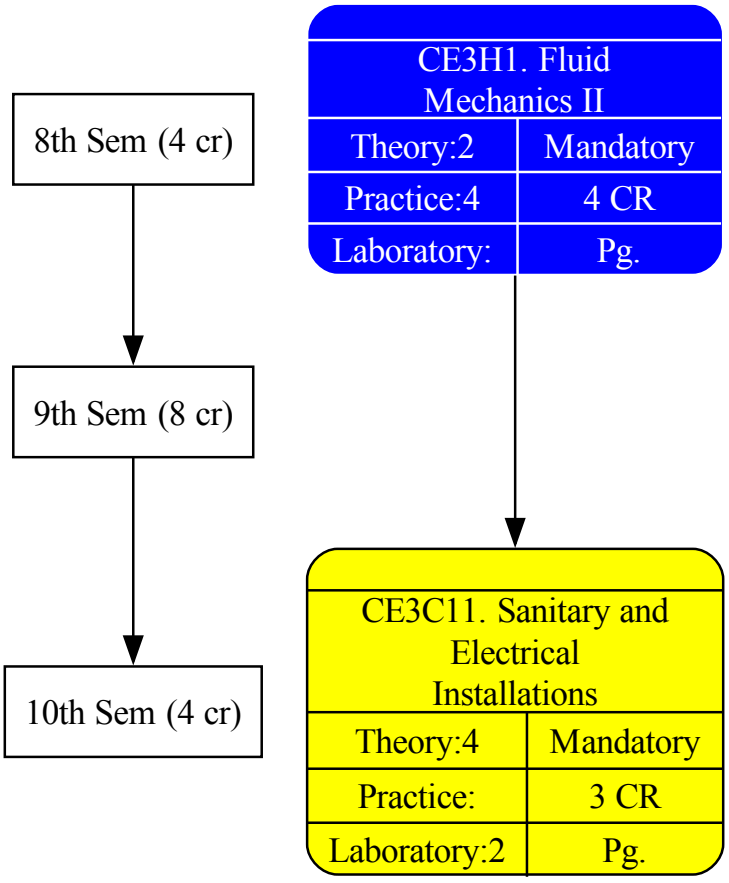

Figure 7.67: Connection Map. CE3C11 Sanitary and Electrical Installations

2. Course Rationale

Sanitary and Electrical Installations covers the design of sanitary installations (water supply and wastewater and stormwater drainage) and electrical installations (installed power, maximum demand, lighting, and grounding) within a building.

3. Goals of the Course

- Design the water supply system and the wastewater and stormwater drainage system of a building.
- Determine the installed power and maximum demand of a residential electrical installation applying current regulations.
- Apply complementary concepts of lighting, grounding, and electricity tariffs to the design of electrical installations.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Water Supply System in Building Sanitary Installations, 17 hr(s)

Competences: ABET-2

Topics: **I:** Importance and scope of sanitary installations in a building **II:** Cold water system design: demand allowance, pressures, and pipe sizing **III:** Hot water system design and other building water uses **IV:** Cisterns, elevated tanks, and water pumping systems

Learning Outcomes **I:** Explain the importance and scope of sanitary installations in a building [Familiarity] **II:** Design a building's cold and hot water system, determining demand allowance, pressures, and pipe sizing [Usage] **III:** Size cisterns, elevated tanks, and water pumping systems for a building [Assessment]

Bibliography: [de Capacitación para la Industria de la Construcción (SENCICO), 2006]

5.2 Drainage System in Building Sanitary Installations, 13 hr(s)

Competences: ABET-2

Topics: **I:** Wastewater drainage system design **II:** Building stormwater drainage system design **III:** Sanitary venting systems and traps for odor control

Learning Outcomes **I:** Design a building's wastewater and stormwater drainage system [Usage] **II:** Apply sanitary venting and odor control criteria to the design of a drainage system [Assessment]

Bibliography: [de Capacitación para la Industria de la Construcción (SENCICO), 2006]

5.3 Building Electrical Installations, 26 hr(s)

Competences: ABET-2

Topics: **I:** Importance and scope of electrical installations in a building **II:** Determination of installed power per applicable standards **III:** Maximum demand calculation and demand factors **IV:** Design of branch circuits and feeders **V:** Basic lighting design concepts for buildings **VI:** Grounding systems **VII:** Electricity tariffs and service billing

Learning Outcomes **I:** Explain the importance of electrical installations in a building [Familiarity] **II:** Determine the installed power of a building per current standards [Usage] **III:** Calculate the maximum demand of a building applying the corresponding demand factors [Assessment] **IV:** Design the branch circuits and feeders of a residential electrical installation [Usage] **V:** Apply lighting and grounding concepts to the design of an electrical installation [Assessment]

Bibliography: [de Energía y Minas del Perú, 2011]

6. Bibliography

[de Capacitación para la Industria de la Construcción (SENCICO), 2006] de Capacitación para la Industria de la Construcción (SENCICO), S. N. (2006). Norma is.010: Instalaciones sanitarias para edificaciones. Technical report, Reglamento Nacional de Edificaciones del Perú.

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Universidad Nacional de Ingeniería (UNI)
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CE3G1 Soil Dynamics (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 3 hours;
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)

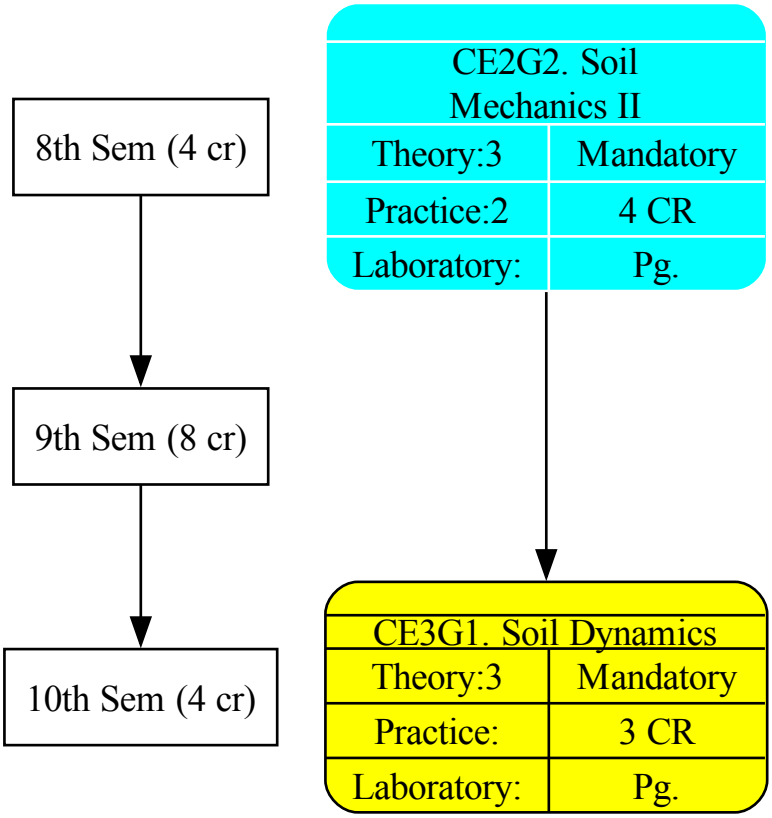

Figure 7.68: Connection Map. CE3G1 Soil Dynamics

2. Course Rationale

Soil Dynamics is an advanced elective of the Geotechnical Engineering track that extends the static shear-strength and deformation framework developed in Soil Mechanics II into the time-varying loading regime relevant to earthquakes and vibrating machinery. The course begins with the theoretical foundations of single-degree-of-freedom dynamic systems and one-dimensional wave propagation through soil deposits, then develops the tools needed to characterize seismicity, process strong-motion signals, and determine the dynamic properties of soils from laboratory and field testing. This foundation supports the analysis of seismic site response and the seismic stability of slopes, retaining structures, and foundations, and is applied to two design problems of markedly different scale: the

design of foundations for vibrating machinery under steady-state dynamic loads, and the assessment, mitigation, and post-earthquake analysis of soil liquefaction, including the residual strength of liquefied soils. As a specialization elective following Soil Mechanics I and II, the course prepares students to perform the seismic geotechnical analyses required in professional practice in a seismically active country.

3. Goals of the Course

- Formulate single-degree-of-freedom dynamic models and one-dimensional wave-propagation equations to characterize how seismic waves travel through soil deposits.
- Characterize regional seismicity, classify earthquakes by their expected consequences, and process strong-motion signals for use in geotechnical seismic analysis.
- Determine the dynamic properties of soils from laboratory and field testing for use in seismic response and liquefaction analyses.
- Perform seismic site response analysis to estimate ground motion amplification and design ground motions.
- Analyze the seismic stability of slopes, retaining structures, and foundations using pseudo-static and performance-based methods.
- Design foundations for vibrating machinery considering dynamic soil-foundation stiffness, resonance avoidance, and permissible vibration amplitudes.
- Evaluate liquefaction susceptibility and triggering, assess its effects on structures and infrastructure, and select mitigation measures including ground improvement.
- Evaluate the residual strength of liquefied soils and perform post-earthquake stability analysis.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Geotechnical Earthquake Engineering, 42 hr(s)

Competences: ABET-1,ABET-2,ABET-6

Topics: **I:** Single-degree-of-freedom dynamic systems and one-dimensional wave propagation through soil deposits **II:** Site response and ground motion amplification **III:** Seismic hazard analysis and design ground motions **IV:** Liquefaction susceptibility and triggering mechanisms **V:** Cyclic stress ratio and liquefaction evaluation procedures **VI:** Effects of liquefaction on structures and infrastructure **VII:** Dynamic soil properties and laboratory testing **VIII:** Design of foundations for vibrating machinery under dynamic loading **IX:** Ground improvement methods for liquefaction mitigation **X:** Lateral spreading and flow failures **XI:** Seismically induced settlement and bearing capacity **XII:** Performance-based design for geotechnical earthquake engineering

Learning Outcomes **I:** Formulate single-degree-of-freedom models and one-dimensional wave-propagation equations to characterize seismic wave transmission through soil deposits [Usage] **II:** Explain site response effects and ground motion characteristics [Familiarity] **III:** Determine design ground motions for geotechnical seismic analysis [Assessment] **IV:** Evaluate liquefaction susceptibility using field investigation data [Usage] **V:** Calculate cyclic stress ratios and assess liquefaction potential [Assessment] **VI:** Assess the consequences of liquefaction on foundations and structures [Familiarity] **VII:** Characterize dynamic soil properties from laboratory and field tests

[Usage] **VIII:** Proportion machine foundations considering dynamic soil-foundation stiffness, resonance avoidance, and permissible vibration amplitudes [Assessment] **IX:** Select and design ground improvement methods to mitigate liquefaction [Assessment] **X:** Predict lateral spreading displacements and flow failure potential [Usage] **XI:** Analyze seismically induced settlement and reduced bearing capacity [Assessment] **XII:** Implement performance-based approaches for seismic geotechnical design [Assessment]

Bibliography: [Kramer, 1996, Das, 1983, Prakash, 1981]

6. Bibliography

[Das, 1983] Das, B. M. (1983). *Fundamentals of Soil Dynamics*. Elsevier.

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[Prakash, 1981] Prakash, S. (1981). *Soil Dynamics*. McGraw-Hill.

Universidad Nacional de Ingeniería (UNI)
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CE3G2 Soil Mechanics Applied to Foundations (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 3 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2G2 Soil Mechanics II (8th Sem-Pg. 413)

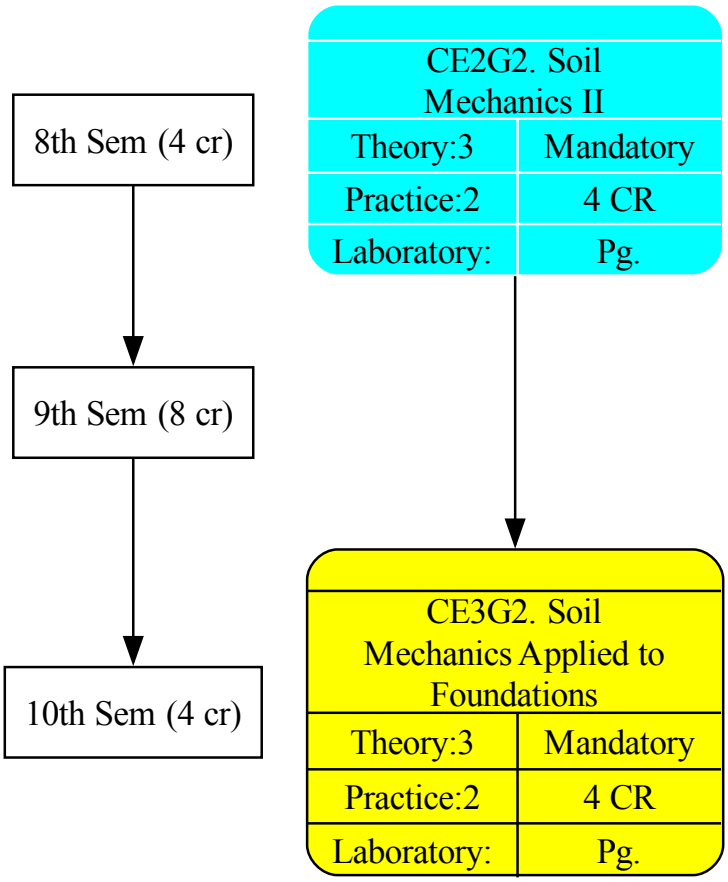

Figure 7.69: Connection Map. CE3G2 Soil Mechanics Applied to Foundations

2. Course Rationale

Soil Mechanics Applied to Foundations is a specialization elective of the Geotechnical Engineering track, taken after Soil Mechanics II, in which the foundation-design and slope-stability topics introduced there at a survey level are revisited in substantially greater depth. The course opens with the identification and classification of foundation soils – including problematic soils such as expansive, collapsible, and dispersive soils, and engineered fills – and the site-investigation criteria required under Peru's RNE Norma E.050. It then develops ground improvement techniques for weak or hazard-prone

soils, extends bearing capacity theory to stratified profiles, sloping ground, and seismic loading, and deepens the design of both shallow and deep foundations, including pile load testing and integrity testing. The course closes with the static and pseudo-static (seismic) stability analysis of slopes. Together, these topics prepare students to characterize difficult foundation conditions and design the full range of foundation solutions encountered in professional geotechnical practice.

3. Goals of the Course

- Classify foundation soils from geologic maps and subsurface data, and identify expansive, collapsible, dispersive, and engineered-fill soils and their implications for foundation design.
- Apply Peru's RNE Norma E.050 criteria to define foundation-soil classification and geotechnical investigation requirements.
- Select and design ground improvement measures for soils with inadequate bearing or settlement characteristics.
- Evaluate liquefaction susceptibility of foundation soils using field investigation data.
- Design shallow foundations considering bearing capacity in stratified soils, sloping ground, and seismic loading conditions.
- Design deep foundations (piles) and interpret static and dynamic load test and integrity test results.
- Analyze the static and pseudo-static (seismic) stability of slopes and design stabilization measures.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Problematic Soils and Foundation-Soil Classification, 17 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Types of foundation soils and site characterization from geologic maps and subsurface data **II:** Foundation-soil classification and investigation requirements under Peru's RNE Norma E.050 **III:** Identification and mineralogy of expansive (swelling) soils **IV:** Swell potential testing and foundation design measures for expansive soils **V:** Identification and behavior of collapsible (metastable) soils **VI:** Identification and treatment of dispersive soils **VII:** Specification and quality control of engineered fill for foundation support

Learning Outcomes **I:** Classify foundation soils using geologic maps and subsurface investigation data [Familiarity] **II:** Apply Peru's RNE Norma E.050 criteria to classify foundation soils and define investigation requirements [Assessment] **III:** Identify expansive soils from mineralogy and index test data [Usage] **IV:** Design foundations for expansive soils based on swell potential test results [Assessment] **V:** Recognize collapsible and dispersive soil behavior from field and laboratory indicators [Familiarity] **VI:** Specify engineered fill requirements for foundation support [Usage]

Bibliography: [Coduto, 2001, Nelson and Miller, 1992, Ministerio de Vivienda, 2018]

5.2 Geotechnical Earthquake Engineering, 3 hr(s)

Competences: ABET-1,ABET-6

Topics: **I:** Single-degree-of-freedom dynamic systems and one-dimensional wave propagation through soil deposits **II:** Site response and ground motion amplification **III:** Seismic hazard analysis and design ground motions **IV:** Liquefaction susceptibility and triggering mechanisms **V:** Cyclic stress ratio and liquefaction evaluation procedures **VI:** Effects of liquefaction on structures and infrastructure **VII:** Dynamic soil properties and laboratory testing **VIII:** Design of foundations for vibrating machinery under dynamic loading **IX:** Ground improvement methods for liquefaction mitigation **X:** Lateral spreading and flow failures **XI:** Seismically induced settlement and bearing capacity **XII:** Performance-based design for geotechnical earthquake engineering

Learning Outcomes **I:** Formulate single-degree-of-freedom models and one-dimensional wave-propagation equations to characterize seismic wave transmission through soil deposits [Usage] **II:** Explain site response effects and ground motion characteristics [Familiarity] **III:** Determine design ground motions for geotechnical seismic analysis [Assessment] **IV:** Evaluate liquefaction susceptibility using field investigation data [Usage] **V:** Calculate cyclic stress ratios and assess liquefaction potential [Assessment] **VI:** Assess the consequences of liquefaction on foundations and structures [Familiarity] **VII:** Characterize dynamic soil properties from laboratory and field tests [Usage] **VIII:** Proportion machine foundations considering dynamic soil-foundation stiffness, resonance avoidance, and permissible vibration amplitudes [Assessment] **IX:** Select and design ground improvement methods to mitigate liquefaction [Assessment] **X:** Predict lateral spreading displacements and flow failure potential [Usage] **XI:** Analyze seismically induced settlement and reduced bearing capacity [Assessment] **XII:** Implement performance-based approaches for seismic geotechnical design [Assessment]

Bibliography: [Kramer, 1996, Das, 2019]

5.3 Ground Improvement Techniques, 10 hr(s)

Competences: ABET-2

Topics: **I:** Compaction methods including dynamic and vibratory techniques **II:** Stone columns and vibro-replacement methods **III:** Preloading and vertical drains for soft ground treatment **IV:** Deep mixing and jet grouting techniques **V:** Chemical stabilization and grouting methods

Learning Outcomes **I:** Select appropriate ground improvement methods for specific soil conditions [Familiarity] **II:** Design stone column systems for settlement reduction [Assessment] **III:** Calculate consolidation time reduction using vertical drains [Usage] **IV:** Identify geosynthetic types and their engineering applications [Familiarity] **V:** Proportion reinforcement for mechanically stabilized earth structures [Assessment]

Bibliography: [Koerner, 2012, Das, 2019]

5.4 Bearing Capacity and Design, 26 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment]

III: Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Coduto, 2001, Das, 2019]

5.5 Deep Foundations, 8 hr(s)

Competences: ABET-2,ABET-6

Topics: **I:** Pile types and installation methods **II:** Axial capacity of single piles in cohesive and cohesionless soils **III:** Lateral load capacity and p-y method **IV:** Pile group behavior and group efficiency **V:** Drilled shaft design and construction considerations **VI:** Negative skin friction and downdrag forces

Learning Outcomes **I:** Select appropriate pile types based on soil conditions and loading [Familiarity] **II:** Calculate axial capacity of piles using static methods [Assessment] **III:** Analyze laterally loaded piles using p-y curves [Usage] **IV:** Evaluate pile group capacity and settlement [Assessment] **V:** Design drilled shaft foundations including shaft diameter and reinforcement [Usage] **VI:** Interpret pile load test results and verify design assumptions [Assessment]

Bibliography: [Coduto, 2001, Das, 2019]

5.6 Slope Stability Analysis and Stabilization, 6 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Infinite slope analysis for simple geometries **II:** Method of slices and limit equilibrium analysis **III:** Circular and non-circular failure surfaces **IV:** Factor of safety determination and acceptance criteria **V:** Stability charts and simplified methods **VI:** Landslide types and failure mechanisms **VII:** Seismic slope stability and pseudo-static analysis **VIII:** Stabilization methods including drainage and reinforcement **IX:** Monitoring systems and early warning for unstable slopes **X:** Probabilistic slope stability analysis

Learning Outcomes **I:** Perform infinite slope stability analysis for uniform slopes [Assessment] **II:** Apply method of slices to analyze slope stability [Usage] **III:** Analyze slopes with circular and non-circular failure surfaces [Assessment] **IV:** Calculate factors of safety and interpret results [Usage] **V:** Use stability charts for rapid slope evaluation [Assessment] **VI:** Identify landslide types and their characteristic features [Familiarity] **VII:** Evaluate seismic stability using pseudo-static methods [Usage] **VIII:** Design slope stabilization measures for specific failure modes [Assessment] **IX:** Implement monitoring systems for potentially unstable slopes [Usage] **X:** Conduct probabilistic stability analysis considering parameter uncertainty [Assessment]

Bibliography: [Duncan et al., 2014]

6. Bibliography

[Coduto, 2001] Coduto, D. P. (2001). *Foundation Design: Principles and Practices.* Prentice Hall, 2nd edition.

[Das, 2019] Das, B. M. (2019). *Principles of Geotechnical Engineering.* Cengage Learning, 9th edition.

[Duncan et al., 2014] Duncan, J. M., Wright, S. G., and Brandon, T. L. (2014). *Soil Strength and Slope Stability.* John Wiley & Sons, 2nd edition.

[Koerner, 2012] Koerner, R. M. (2012). *Designing with Geosynthetics*. Xlibris Corporation, 6th edition.

[Kramer, 1996] Kramer, S. L. (1996). *Geotechnical Earthquake Engineering*. Prentice Hall.

[Ministerio de Vivienda, 2018] Ministerio de Vivienda, C. y. S. d. P. (2018). Norma e.050: Suelos y cimentaciones. Technical report, Reglamento Nacional de Edificaciones del Perú.

[Nelson and Miller, 1992] Nelson, J. D. and Miller, D. J. (1992). *Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*. John Wiley & Sons.

Universidad Nacional de Ingeniería (UNI)
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Escuela Profesional de Ingeniería Civil

CE3G7 Professional Competencies Workshop - Geotechnical (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**:
- **Prerrequisites**:
  - CE3G3 Applied Geology (9th Sem-Pg. 453)

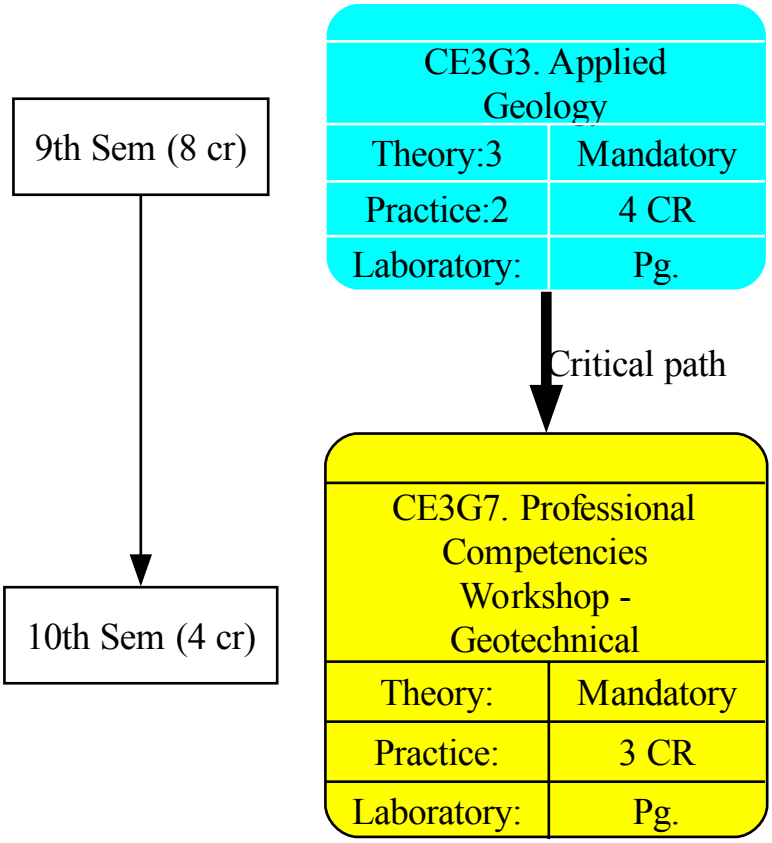

Figure 7.70: Connection Map. CE3G7 Professional Competencies Workshop - Geotechnical

2. Course Rationale

Professional Competencies Workshop is the capstone/synthesis course of the Geotechnical Engineering specialization track. It integrates, around real project scenarios, the shear-strength and stress-distribution framework and the site investigation and in-situ testing techniques developed earlier in the track with the four principal design domains of geotechnical practice: slope stability and landslide mitigation, geotechnical earthquake engineering and liquefaction, shallow and deep foundation design, earth retaining systems, ground improvement and geosynthetics engineering, and the

geotechnical design of earth and rockfill dams – including dam typology selection and the geotechnical characterization of foundation and borrow materials that supports that design. Rather than introducing new content, the workshop revisits and applies, at a professional level of integration, the knowledge units developed throughout the specialization's preceding courses.

3. Goals of the Course

- Plan and interpret geotechnical site investigation programs and apply shear strength and stress distribution principles to characterize project sites.
- Analyze slope stability and design landslide mitigation and stabilization measures.
- Evaluate seismic hazards and liquefaction potential and design mitigation measures for geotechnical earthquake engineering problems.
- Design shallow and deep foundations and earth retaining systems for representative structures.
- Select and design ground improvement and geosynthetic solutions for problematic ground conditions.
- Select an embankment dam typology and apply geotechnical characterization and design methods to size an earth or rockfill dam.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 Site Investigation and In-Situ Testing, 9 hr(s)

Competences: ABET-6

Topics: **I:** Investigation planning and scope determination **II:** Boring methods and subsurface exploration techniques **III:** Sampling methods for disturbed and undisturbed samples **IV:** Standard Penetration Test and correlations **V:** Laboratory testing program and test selection **VI:** Cone Penetration Test and piezocone testing **VII:** Vane shear test and pressuremeter testing **VIII:** Geophysical methods including seismic and resistivity surveys **IX:** Groundwater monitoring and piezometer installation **X:** Report preparation and geotechnical data presentation **XI:** In-situ permeability (Lugeon/packer) testing for foundation grouting and seepage assessment **XII:** Borrow area investigation for embankment fill material quantity and quality

Learning Outcomes **I:** Develop appropriate site investigation programs based on project requirements [Assessment] **II:** Select appropriate boring and exploration methods for different soil conditions [Familiarity] **III:** Specify sampling techniques to obtain quality samples for testing [Usage] **IV:** Interpret SPT data and apply empirical correlations for design parameters [Assessment] **V:** Design laboratory testing programs for geotechnical projects [Usage] **VI:** Analyze CPT and piezocone data for soil profiling and parameter evaluation [Assessment] **VII:** Apply vane shear and pressuremeter tests for soft clay characterization [Usage] **VIII:** Utilize geophysical methods to complement traditional investigation techniques [Assessment] **IX:** Monitor groundwater conditions and interpret piezometric data [Usage] **X:** Prepare comprehensive geotechnical investigation reports [Assessment] **XI:** Perform packer (Lugeon) testing and interpret results for foundation grouting curtain design [Usage] **XII:** Characterize borrow areas for embankment fill material quantity and quality [Assessment]

Bibliography: [Das, 2019]

5.2 Shear Strength and Consolidation, 6 hr(s)

Competences: ABET-1

Topics: **I:** Shear strength of soils and Mohr-Coulomb failure criterion **II:** Direct shear and triaxial testing methods **III:** Drained and undrained shear strength behavior **IV:** Consolidation theory and settlement analysis **V:** Time-rate of consolidation and degree of consolidation **VI:** Stress distribution in soil masses using elastic theory **VII:** Critical state soil mechanics concepts **VIII:** Residual shear strength and sensitivity of clays **IX:** Secondary compression and creep behavior **X:** Anisotropy and stress path effects on soil behavior

Learning Outcomes **I:** Apply Mohr-Coulomb criterion to determine shear strength parameters [Familiarity] **II:** Interpret direct shear and triaxial test results [Assessment] **III:** Distinguish between drained and undrained loading conditions [Usage] **IV:** Calculate consolidation settlement using one-dimensional theory [Assessment] **V:** Predict time-rate of settlement for consolidating soils [Usage] **VI:** Compute stress distribution beneath loaded areas using Boussinesq theory [Assessment] **VII:** Explain critical state concepts and their application to soil behavior [Familiarity] **VIII:** Evaluate residual strength and sensitivity for slope stability problems [Assessment] **IX:** Estimate secondary compression for highly plastic soils [Usage] **X:** Analyze the effects of stress paths and anisotropy on soil response [Familiarity]

Bibliography: [Das, 2019]

5.3 Slope Stability Analysis and Stabilization, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Infinite slope analysis for simple geometries **II:** Method of slices and limit equilibrium analysis **III:** Circular and non-circular failure surfaces **IV:** Factor of safety determination and acceptance criteria **V:** Stability charts and simplified methods **VI:** Landslide types and failure mechanisms **VII:** Seismic slope stability and pseudo-static analysis **VIII:** Stabilization methods including drainage and reinforcement **IX:** Monitoring systems and early warning for unstable slopes **X:** Probabilistic slope stability analysis

Learning Outcomes **I:** Perform infinite slope stability analysis for uniform slopes [Assessment] **II:** Apply method of slices to analyze slope stability [Usage] **III:** Analyze slopes with circular and non-circular failure surfaces [Assessment] **IV:** Calculate factors of safety and interpret results [Usage] **V:** Use stability charts for rapid slope evaluation [Assessment] **VI:** Identify landslide types and their characteristic features [Familiarity] **VII:** Evaluate seismic stability using pseudo-static methods [Usage] **VIII:** Design slope stabilization measures for specific failure modes [Assessment] **IX:** Implement monitoring systems for potentially unstable slopes [Usage] **X:** Conduct probabilistic stability analysis considering parameter uncertainty [Assessment]

Bibliography: [Duncan et al., 2014]

5.4 Geotechnical Earthquake Engineering, 15 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Single-degree-of-freedom dynamic systems and one-dimensional wave propagation through soil deposits **II:** Site response and ground motion amplification **III:** Seismic hazard analysis and design ground motions **IV:** Liquefaction susceptibility and triggering mechanisms **V:** Cyclic stress ratio and liquefaction evaluation procedures **VI:** Effects of liquefaction on structures and infrastructure **VII:** Dynamic soil properties and laboratory testing **VIII:** Design of foundations for vibrating machinery under dynamic loading **IX:** Ground improvement methods for liquefaction mitigation **X:** Lateral spreading and flow failures **XI:** Seismically induced settlement and bearing capacity **XII:** Performance-based design for geotechnical earthquake engineering

Learning Outcomes **I:** Formulate single-degree-of-freedom models and one-dimensional wave-propagation equations to characterize seismic wave transmission through soil deposits [Usage] **II:** Explain site response effects and ground motion characteristics [Familiarity] **III:** Determine design ground motions for geotechnical seismic analysis [Assessment] **IV:** Evaluate liquefaction susceptibility using field investigation data [Usage] **V:** Calculate cyclic stress ratios and assess liquefaction potential [Assessment] **VI:** Assess the consequences of liquefaction on foundations and structures [Familiarity] **VII:** Characterize dynamic soil properties from laboratory and field tests [Usage] **VIII:** Proportion machine foundations considering dynamic soil-foundation stiffness, resonance avoidance, and permissible vibration amplitudes [Assessment] **IX:** Select and design ground improvement methods to mitigate liquefaction [Assessment] **X:** Predict lateral spreading displacements and flow failure potential [Usage] **XI:** Analyze seismically induced settlement and reduced bearing capacity [Assessment] **XII:** Implement performance-based approaches for seismic geotechnical design [Assessment]

Bibliography: [Kramer, 1996, Das, 2019]

5.5 Bearing Capacity and Design, 9 hr(s)

Competences: ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment] **III:** Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Coduto, 2001, Das, 2019]

5.6 Ground Improvement Techniques, 6 hr(s)

Competences: ABET-2

Topics: **I:** Compaction methods including dynamic and vibratory techniques **II:** Stone columns and vibro-replacement methods **III:** Preloading and vertical drains for soft ground treatment **IV:** Deep mixing and jet grouting techniques **V:** Chemical stabilization and grouting methods

Learning Outcomes **I:** Select appropriate ground improvement methods for specific soil conditions [Familiarity] **II:** Design stone column systems for settlement reduction [Assessment] **III:** Calculate consolidation time reduction using vertical drains [Usage] **IV:** Identify geosynthetic types and their engineering applications [Familiarity] **V:** Proportion reinforcement for mechanically stabilized earth structures [Assessment]

Bibliography: [Koerner, 2012, Das, 2019]

5.7 Deep Foundations, 5 hr(s)

Competences: ABET-2

Topics: **I:** Pile types and installation methods **II:** Axial capacity of single piles in cohesive and cohesionless soils **III:** Lateral load capacity and p-y method **IV:** Pile group behavior and group efficiency **V:** Drilled shaft design and construction considerations **VI:** Negative skin friction and downdrag forces

Learning Outcomes **I:** Select appropriate pile types based on soil conditions and loading [Familiarity] **II:** Calculate axial capacity of piles using static methods [Assessment] **III:** Analyze laterally loaded piles using p-y curves [Usage] **IV:** Evaluate pile group capacity and settlement [Assessment] **V:** Design drilled shaft foundations including shaft diameter and reinforcement [Usage] **VI:** Interpret pile load test results and verify design assumptions [Assessment]

Bibliography: [Coduto, 2001, Das, 2019]

5.8 Earth Retaining Systems, 4 hr(s)

Competences: ABET-2

Topics: **I:** Earth pressure theory including active and passive pressures **II:** Retaining wall types and selection criteria **III:** Load testing methods including static and dynamic tests **IV:** Anchored walls and tied-back systems **V:** Mechanically stabilized earth walls and reinforced soil systems **VI:** Basement and foundation wall design considering top-of-wall restraint conditions **VII:** Counterfort and buttressed retaining wall design

Learning Outcomes **I:** Apply lateral earth pressure theories for retaining wall design [Assessment] **II:** Design gravity and cantilever retaining walls [Usage] **III:** Design anchored wall systems including ground anchor capacity [Assessment] **IV:** Proportion mechanically stabilized earth walls and select reinforcement [Usage] **V:** Design basement and foundation walls considering top restraint, surcharge, and hydrostatic loads [Assessment] **VI:** Design counterfort retaining walls including stem, heel, toe, and counterfort elements [Usage]

Bibliography: [Das, 2019, Coduto, 2001]

5.9 Earth Dams, 4 hr(s)

Competences: ABET-1

Topics: **I:** Definition, function, and role of earth dams within water resources infrastructure **II:** Typology of embankment dams: homogeneous and zoned earthfill/rockfill dams, and selection criteria **III:** Dam zoning: core, shell, filters, drains, and transition zones **IV:** Site selection factors and reservoir/dam-site feasibility considerations

Learning Outcomes **I:** Explain the function of earth dams and their role within water resources infrastructure [Familiarity] **II:** Classify embankment dams by type and select an appropriate typology for given site and material conditions [Assessment] **III:** Describe the zoning of an earth dam and the function of each zone (core, shell, filters, drains) [Familiarity] **IV:** Evaluate site selection factors governing dam type and location choice [Usage]

Bibliography: [Fell et al., 2015, U.S. Bureau of Reclamation, 1987]

5.10 Geotechnical Characterization for Earth Dams, 5 hr(s)

Competences: ABET-1

Topics: **I:** Foundation geotechnical characterization: rock and soil foundation conditions for embankment dams **II:** Characterization of borrow materials for core, shell, and filter zones **III:** Compaction and shear strength properties of compacted fill materials **IV:** Permeability characterization of foundation and embankment materials **V:** Dispersive soil identification and erodibility assessment for core materials

Learning Outcomes **I:** Characterize foundation soil and rock conditions relevant to embankment dam design [Assessment] **II:** Evaluate borrow material sources for suitability as core, shell, or filter material [Usage] **III:** Determine compaction and shear strength properties of compacted embankment materials [Assessment] **IV:** Assess dispersive soil potential and erodibility of candidate core materials [Usage]

Bibliography: [Fell et al., 2015, U.S. Bureau of Reclamation, 1987]

5.11 Geotechnical Design of Embankment Dams, 9 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Seepage analysis through the embankment and foundation using flow nets and numerical methods **II:** Seepage control measures: core design, cutoff walls, and grout curtains **III:** Filter and drain design criteria to prevent internal erosion and piping **IV:** Slope stability analysis of upstream and downstream dam faces under static and rapid drawdown conditions **V:** Seismic design considerations and deformation analysis for embankment dams **VI:** Freeboard determination and settlement/camber allowance in embankment design

Learning Outcomes **I:** Analyze seepage through the embankment and foundation using flow nets or numerical seepage models [Assessment] **II:** Design seepage control measures including impervious cores, cutoff walls, and grout curtains [Usage] **III:** Design filter and drain zones according to piping and internal erosion criteria [Assessment] **IV:** Evaluate slope stability of dam faces under steady-state seepage, rapid drawdown, and end-of-construction conditions [Usage] **V:** Incorporate seismic loading and deformation analysis into embankment dam design [Assessment] **VI:** Determine freeboard and settlement allowances for embankment design [Usage]

Bibliography: [Fell et al., 2015, Sherard et al., 1963, U.S. Army Corps of Engineers, 2003]

6. Bibliography

[Coduto, 2001] Coduto, D. P. (2001). *Foundation Design: Principles and Practices*. Prentice Hall, 2nd edition.

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CE3H5 Introduction to Fluvial Hydraulics (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

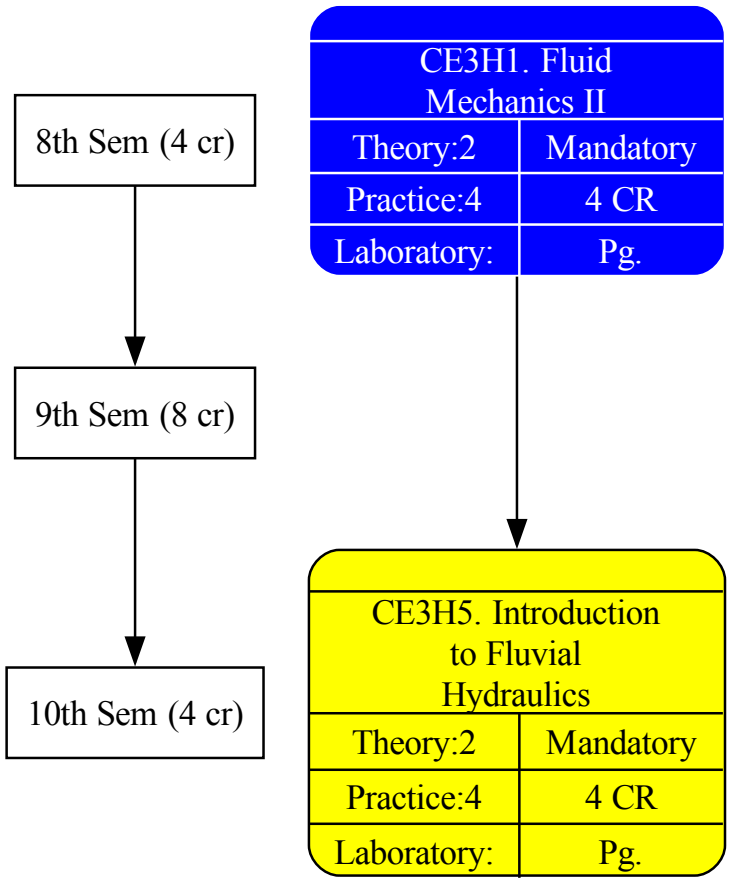

Figure 7.71: Connection Map. CE3H5 Introduction to Fluvial Hydraulics

2. Course Rationale

Introduction to Fluvial Hydraulics covers the behavior of natural channels under the action of flow and sediment transport: from basin erosion and sediment properties, through the calculation of bed load, suspended load, and total load, to the analysis of scour and fluvial morphology using tools such as the Lane balance. The course culminates with the design of channel stabilization and bank protection works, reservoir sedimentation management, and an introduction to river navigation.

3. Goals of the Course

- Analyze bed load, suspended load, and total sediment transport in alluvial channels.
- Calculate general and local scour, and analyze the morphology and stability of river channels.
- Design channel stabilization works and bank protection structures.
- Evaluate reservoir sedimentation and the fundamentals of river navigation.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Introduction to Fluvial Hydraulics, 2 hr(s)

Competences: ABET-1

Topics: I: Scope and objectives of the Fluvial Hydraulics course.

Learning Outcomes I: Describe the scope of river engineering and its role in water resources engineering [Familiarity].

Bibliography: [Julien, 2010]

5.2 Sediment Transport in Alluvial Channels, 22 hr(s)

Competences: ABET-1

Topics: I: Watershed erosion and sediment yield **II:** Physical properties of sediment: size, shape, density, and fall velocity **III:** Flow in sand and gravel channels and associated bedforms **IV:** Flow resistance in alluvial channels **V:** Incipient motion condition and design of erodible channels **VI:** Fundamentals and techniques for measuring sediment transport **VII:** Bed load sediment transport **VIII:** Suspended load sediment transport **IX:** Sediment entry into intakes and diversion structures **X:** Total sediment load transport formulas

Learning Outcomes I: Explain watershed erosion processes and their relation to sediment yield [Familiarity] **II:** Classify sediments by their physical properties and estimate their fall velocity [Usage] **III:** Determine the incipient motion condition for a given alluvial channel [Assessment] **IV:** Calculate flow resistance in an alluvial channel accounting for bedforms [Usage] **V:** Estimate bed load and suspended load transport rates using standard formulas [Assessment] **VI:** Apply total sediment load formulas to an alluvial channel design problem [Usage] **VII:** Evaluate sediment entry into an intake and propose exclusion measures [Assessment]

Bibliography: [Julien, 2010, García, 2008]

5.3 Open Channel Flow and River Mechanics, 8 hr(s)

Competences: ABET-1

Topics: I: Channel flow classification and hydraulic elements **II:** Energy and momentum principles in open channels **III:** Uniform flow and Manning's equation **IV:** Critical flow and specific energy concepts **V:** Gradually varied flow profiles **VI:** Hydraulic jump and rapidly varied flow **VII:** Channel design for stable conveyance **VIII:** Sediment transport in open channels **IX:** River morphology and channel stability **X:** Scour analysis and protection measures

Learning Outcomes **I:** Classify open channel flow regimes and calculate hydraulic elements [Familiarity] **II:** Apply energy and momentum equations to solve channel flow problems [Assessment] **III:** Calculate normal depth and discharge using Manning's equation [Usage] **IV:** Determine critical depth and analyze specific energy relationships [Assessment] **V:** Compute gradually varied flow profiles using standard methods [Usage] **VI:** Analyze hydraulic jumps and calculate energy dissipation [Assessment] **VII:** Design stable channels with appropriate cross-sections and linings [Usage] **VIII:** Estimate sediment transport rates in alluvial channels [Assessment] **IX:** Evaluate river channel stability and bank erosion potential [Familiarity] **X:** Predict scour depths at hydraulic structures and design protection [Assessment]

Bibliography: [Chow, 1959]

5.4 Design of Hydraulic Structures, 2 hr(s)

Competences: ABET-2

Topics: **I:** Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes **I:** Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control [Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [Novak et al., 2007]

5.5 Scour and Fluvial Morphology, 26 hr(s)

Competences: ABET-1

Topics: **I:** Scour fundamentals and long-term bed elevation changes **II:** Computation of general scour **III:** Local scour from contractions, bends, and confluences **IV:** Local scour at bridge piers and abutments **V:** Fluvial morphology cycles and processes **VI:** Shape, geometry, and stability of alluvial channels **VII:** Lane balance: qualitative channel response and modeling **VIII:** Interaction between highway infrastructure and natural streams

Learning Outcomes **I:** Calculate the general scour depth in a channel reach [Assessment] **II:** Determine local scour from contraction and at bridge piers and abutments [Usage] **III:** Analyze long-term bed elevation changes in a fluvial reach [Assessment] **IV:** Describe the cycles and processes governing alluvial channel morphology [Familiarity] **V:** Apply the Lane balance to predict the qualitative response of a channel to changes in its variables [Usage] **VI:** Evaluate interaction problems between highway infrastructure and natural streams [Assessment]

Bibliography: [García, 2008, Julien, 2010]

5.6 River Engineering, 24 hr(s)

Competences: ABET-2

Topics: **I:** Channel stabilization: design criteria and examples **II:** Control structures for riverbank protection **III:** Design of riprap, gabions, and protective filters **IV:** Practical design considerations for river protection works **V:** Reservoir sedimentation and dead storage volume **VI:** Trap efficiency and management of reservoir sedimentation **VII:** Analytical fundamentals of river navigation **VIII:** River navigation paradigms and port conditioning

Learning Outcomes **I:** Design a channel stabilization structure for a given reach [Usage] **II:** Select and size bank protection structures (riprap, gabions, filters) [Assessment] **III:** Apply practical design considerations to a conceptual river protection case [Usage] **IV:** Estimate the dead storage volume and useful life of a reservoir due to sedimentation [Assessment] **V:** Evaluate the sediment trap efficiency of a reservoir and propose management measures [Usage] **VI:** Explain the analytical fundamentals of river navigation and its port conditioning [Familiarity]

Bibliography: [García, 2008]

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[Julien, 2010] Julien, P. Y. (2010). *Erosion and Sedimentation*. Cambridge University Press, 2nd edition.

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CE3H6 Irrigation Engineering (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3H4 Water Resources (9th Sem-Pg. 481)

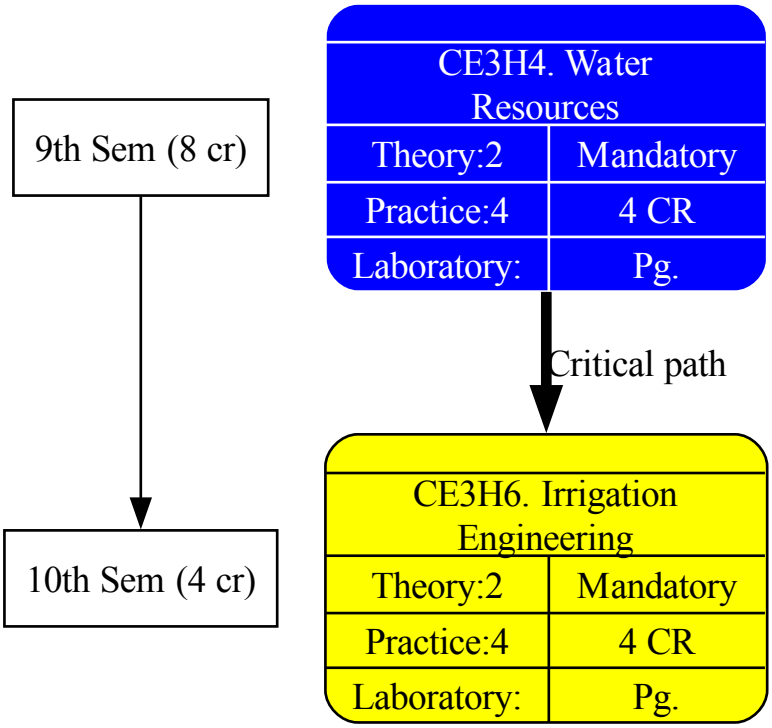

Figure 7.72: Connection Map. CE3H6 Irrigation Engineering

2. Course Rationale

Irrigation addresses the comprehensive design of irrigation projects: from the context of Peruvian agriculture and the soil-water-plant relationship, the estimation of evapotranspiration and agricultural water demand, to the hydraulic sizing of dams and reservoirs, the design of intake structures (diversion weirs, desanders) and conveyance structures (canals), and the agronomic and hydraulic design of gravity and pressurized irrigation systems (including drip irrigation). The course concludes with the evaluation of irrigation projects from environmental, social, and economic perspectives.

3. Goals of the Course

- Estimate agricultural water demand based on the soil-water-plant relationship and crop evapotranspiration.

- Size dams, reservoirs, and intake and conveyance structures for an irrigation project.
- Design gravity and pressurized irrigation systems, including the agronomic and hydraulic design of drip irrigation.
- Evaluate irrigation projects considering environmental, social, and economic criteria.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Agriculture in Peru and Description of an Irrigation Project, 6 hr(s)

Competences: ABET-1

Topics: I: Context and current status of irrigated agriculture in Peru. **II:** Components and general description of an irrigation project.

Learning Outcomes I: Describe the context of irrigated agriculture in Peru and its main challenges [Familiarity]. **II:** Identify the main components of an irrigation project [Familiarity].

Bibliography: [Chambouleyron, 2005]

5.2 Agricultural Water Demand, 12 hr(s)

Competences: ABET-1

Topics: I: Soil-water-plant relationships and soil water availability **II:** Estimation of reference and crop evapotranspiration **III:** Crop water requirement and crop coefficients **IV:** Water supply-and-demand balance for an irrigation project **V:** Irrigation scheduling and cropping calendars **VI:** Irrigation efficiency at the field, conveyance, and system level

Learning Outcomes I: Explain the soil-water-plant relationship and its effect on water availability for crops [Familiarity] **II:** Calculate reference and crop evapotranspiration using standard methods [Usage] **III:** Estimate a crop's water requirement throughout its growth cycle [Assessment] **IV:** Develop the water supply-and-demand balance for an irrigation project [Usage] **V:** Design an irrigation schedule accounting for the cropping calendar [Assessment] **VI:** Evaluate the irrigation efficiency of a system and propose improvements [Usage]

Bibliography: [Allen et al., 1998, Chambouleyron, 2005]

5.3 Design of Hydraulic Structures, 12 hr(s)

Competences: ABET-2

Topics: I: Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes I: Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control

[Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [Novak et al., 2007]

5.4 Open Channel Flow and River Mechanics, 9 hr(s)

Competences: ABET-2

Topics: **I:** Channel flow classification and hydraulic elements **II:** Energy and momentum principles in open channels **III:** Uniform flow and Manning's equation **IV:** Critical flow and specific energy concepts **V:** Gradually varied flow profiles **VI:** Hydraulic jump and rapidly varied flow **VII:** Channel design for stable conveyance **VIII:** Sediment transport in open channels **IX:** River morphology and channel stability **X:** Scour analysis and protection measures

Learning Outcomes **I:** Classify open channel flow regimes and calculate hydraulic elements [Familiarity] **II:** Apply energy and momentum equations to solve channel flow problems [Assessment] **III:** Calculate normal depth and discharge using Manning's equation [Usage] **IV:** Determine critical depth and analyze specific energy relationships [Assessment] **V:** Compute gradually varied flow profiles using standard methods [Usage] **VI:** Analyze hydraulic jumps and calculate energy dissipation [Assessment] **VII:** Design stable channels with appropriate cross-sections and linings [Usage] **VIII:** Estimate sediment transport rates in alluvial channels [Assessment] **IX:** Evaluate river channel stability and bank erosion potential [Familiarity] **X:** Predict scour depths at hydraulic structures and design protection [Assessment]

Bibliography: [Chow, 1959]

5.5 Irrigation Systems Design, 33 hr(s)

Competences: ABET-2

Topics: **I:** Types of irrigation intake works **II:** Headworks design **III:** Desander design **IV:** Other structures of the irrigation conveyance and distribution system **V:** Design of gravity irrigation systems **VI:** Design of pressurized (technified) irrigation systems **VII:** Agronomic design of drip irrigation **VIII:** Hydraulic design of drip irrigation: laterals, distribution lines, and emitters

Learning Outcomes **I:** Select the appropriate intake work type for the conditions of an irrigation project [Usage] **II:** Design a headworks structure and its associated desander [Assessment] **III:** Design a gravity irrigation system for a given field [Usage] **IV:** Compare pressurized irrigation alternatives against gravity irrigation [Assessment] **V:** Perform the agronomic design of a drip irrigation system [Usage] **VI:** Hydraulically design the lateral and distribution lines of a drip irrigation system [Assessment]

Bibliography: [Chambouleyron, 2005, Karmeli and Keller, 1975]

5.6 Economic, Financial and Social Evaluation of Water Resources Projects, 9 hr(s)

Competences: ABET-1

Topics: **I:** Economic evaluation indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost ratio **II:** Selecting among project alternatives by comparing economic indicators **III:** Sensitivity analysis to variations in costs, benefits, and discount rate **IV:** Funding sources and financial structuring of water projects **V:** User payment capacity and tariff schemes **VI:** Cost allocation among beneficiaries in multipurpose projects **VII:** Social evaluation of projects: exchange theory and shadow prices **VIII:** Distributional impacts and equity in project social evaluation

Learning Outcomes **I:** Calculate NPV, IRR, and Benefit-Cost ratio for a water resources project [Usage] **II:** Select among project alternatives based on compared economic indicators [Assessment] **III:** Perform a sensitivity analysis of project profitability to changes in key variables [Usage] **IV:** Evaluate funding sources and tariff schemes based on user payment capacity [Assessment] **V:** Allocate costs among beneficiaries in a multipurpose project [Usage] **VI:** Apply social evaluation principles to estimate a project's net benefit to society [Assessment]

Bibliography: [Blank and Tarquin, 2017]

5.7 Environmental Impact Assessment and Sustainability Metrics, 3 hr(s)

Competences: ABET-2

Topics: **I:** EIA process: screening, scoping, impact analysis, mitigation, and public participation **II:** Impact prediction methods for air, water, soil, noise, and ecological systems **III:** Mitigation hierarchy and design of environmental management plans **IV:** Legal and institutional frameworks for EIA **V:** Sustainability concepts and the triple bottom line (environment, economy, society) **VI:** Cumulative impact assessment and strategic environmental assessment (SEA) **VII:** Social impact assessment and stakeholder engagement methods **VIII:** Sustainability metrics and indicator frameworks (e.g., SDGs, Envision) **IX:** Decision-support tools and multi-criteria analysis for sustainable design

Learning Outcomes **I:** Outline the key stages of a standardized Environmental Impact Assessment (EIA) process [Familiarity] **II:** Predict primary environmental impacts of a proposed infrastructure project on local air and water quality [Usage] **III:** Develop mitigation measures for identified significant environmental impacts [Assessment] **IV:** Explain the legal requirements and purpose of EIA in the project approval process [Familiarity] **V:** Apply the triple bottom line framework to evaluate a simple engineering project [Assessment] **VI:** Conduct a scoping exercise to define the boundaries and key issues for a cumulative impact assessment [Assessment] **VII:** Design a stakeholder engagement plan for a controversial development project [Usage] **VIII:** Select appropriate sustainability metrics to track the performance of a green infrastructure project [Assessment] **IX:** Use a simple multi-criteria decision analysis (MCDA) tool to compare alternative project designs [Usage]

Bibliography: [Glasson and Therivel, 2019]

6. Bibliography

[Allen et al., 1998] Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Technical report, FAO Irrigation and Drainage Paper 56.

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CE3H7 Hydraulic and Hydrology Engineering Workshop (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**:
- **Prerrequisites**:
  - CE3H1 Fluid Mechanics II (8th Sem-Pg. 422)

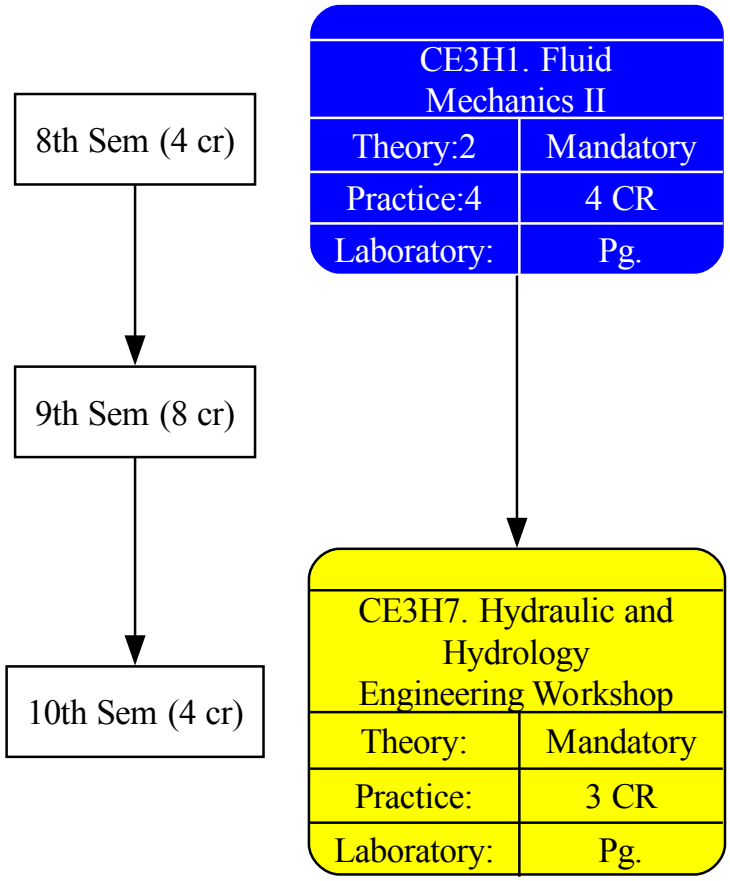

Figure 7.73: Connection Map. CE3H7 Hydraulic and Hydrology Engineering Workshop

2. Course Rationale

Hydraulic and Hydrological Engineering Workshop is an applied course on dam design: it begins with hydraulic planning (water availability and demand, reservoir sizing methods) and then covers the engineering and structural design of gravity concrete dams, hollow gravity dams, earthfill dams, and rockfill dams, including stability and seepage analysis, and the design of associated intake, diversion, and control structures.

3. Goals of the Course

- Estimate water availability and demand for reservoir planning.
- Size reservoir capacity using simulation methods and stochastic analysis (Ripple, range, Markov chains).
- Design concrete dams (gravity and hollow gravity) and earthfill and rockfill dams, including stability and seepage analysis.
- Design the associated intake, diversion, and control structures for a dam project.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Hydrologic Cycle and Water Balance, 5 hr(s)

Competences: ABET-1

Topics: **I:** Hydrologic cycle and water balance concepts **II:** Precipitation measurement and analysis **III:** Evaporation and evapotranspiration estimation **IV:** Infiltration theory and rainfall-runoff processes

Learning Outcomes **I:** Explain the hydrologic cycle and quantify water balance components [Familiarity] **II:** Analyze precipitation data and develop depth-area-duration relationships [Assessment] **III:** Estimate evaporation and evapotranspiration using empirical methods [Usage] **IV:** Apply infiltration models to estimate runoff from rainfall events [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.2 Surface Hydrology and Watershed Modeling, 4 hr(s)

Competences: ABET-1

Topics: **I:** Hydrograph analysis and unit hydrograph method **II:** Watershed modeling and hydrologic simulation **III:** Streamflow measurement and gauging techniques

Learning Outcomes **I:** Derive unit hydrographs and synthesize runoff hydrographs [Usage] **II:** Develop watershed models using software tools for hydrologic simulation [Usage] **III:** Conduct streamflow measurements and interpret flow duration curves [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.3 Flood Frequency Analysis and Climate Change, 3 hr(s)

Competences: ABET-1

Topics: **I:** Flood frequency analysis and design storms **II:** Hydrologic routing methods for channels and reservoirs **III:** Climate change impacts on hydrologic systems

Learning Outcomes **I:** Perform flood frequency analysis using statistical methods [Assessment] **II:** Route flood hydrographs through channels and reservoirs [Usage] **III:** Evaluate climate change impacts on watershed hydrology and design implications [Assessment]

Bibliography: [Chow et al., 1988, Loucks and van Beek, 2017]

5.4 Design of Hydraulic Structures, 66 hr(s)

Competences: ABET-2

Topics: **I:** Dam types and selection criteria **II:** Spillway hydraulics and design **III:** Weir and gate flow equations **IV:** Energy dissipation and stilling basin design **V:** Culvert hydraulics and design **VI:** Dam safety analysis and risk assessment **VII:** Outlet works and control structures **VIII:** Fish passage facilities and environmental hydraulics **IX:** Cavitation analysis and prevention **X:** Physical hydraulic modeling and scale effects

Learning Outcomes **I:** Classify dam types and select appropriate configurations for site conditions [Familiarity] **II:** Design spillways for flood discharge capacity [Assessment] **III:** Calculate discharge over weirs and through gates [Usage] **IV:** Proportion energy dissipation structures and stilling basins [Assessment] **V:** Analyze culvert hydraulics for inlet and outlet control [Usage] **VI:** Perform dam safety evaluations and hazard classification [Assessment] **VII:** Design outlet works including intake structures and conduits [Usage] **VIII:** Incorporate fish passage requirements in hydraulic structure design [Assessment] **IX:** Evaluate cavitation potential and design preventive measures [Usage] **X:** Interpret physical model results and apply scale corrections [Assessment]

Bibliography: [Novak et al., 2007, of Reclamation, 1987]

6. Bibliography

[Chow et al., 1988] Chow, V. T., Maidment, D. R., and Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

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[Novak et al., 2007] Novak, P., Moffat, A. I. B., Nalluri, C., and Narayanan, R. (2007). *Hydraulic Structures*. Taylor & Francis, 4th edition.

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CE3S10 Seismic Design of Civil Engineering Works (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)

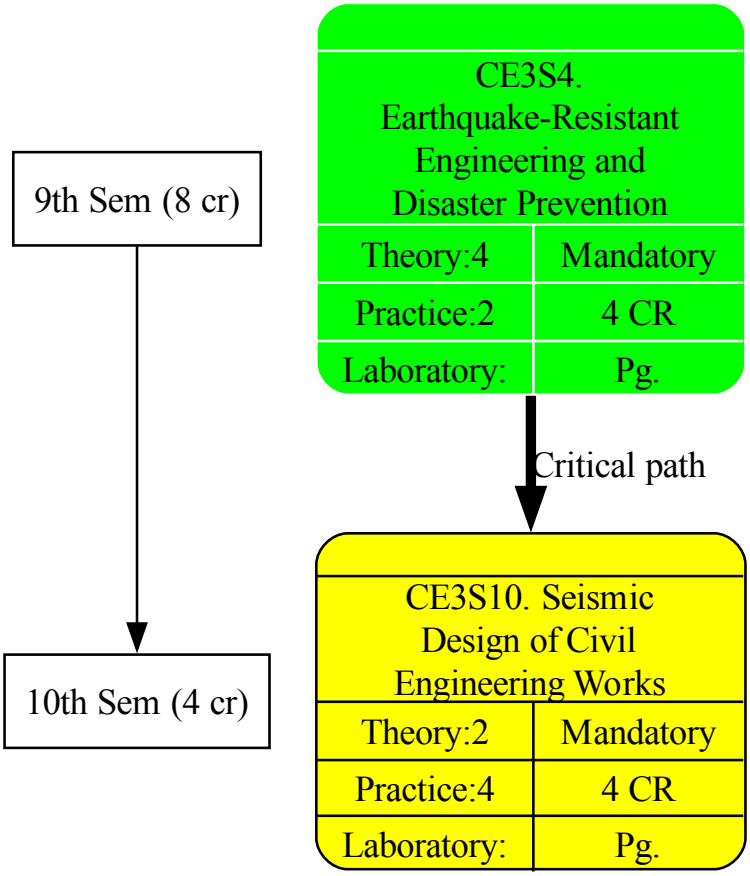

Figure 7.74: Connection Map. CE3S10 Seismic Design of Civil Engineering Works

2. Course Rationale

Seismic Design of Civil Engineering Works introduces the seismic analysis and reinforced concrete design of special/industrial civil engineering structures – free-standing chimneys and liquid-storage tanks – extending the seismological, code, and structural-dynamics fundamentals from Earthquake-Resistant Engineering to structures whose seismic behavior differs fundamentally from that of buildings. The course opens with the professional and regulatory context of civil engineering works, framing

the elevated public-safety risk profile of special/industrial structures, then reviews the seismic phenomenon, the Peruvian seismic design code, and the fundamentals of structural dynamics before applying them to the seismic analysis and reinforced concrete design of chimneys – modeled as equivalent cantilever systems – and liquid-storage tanks, whose seismic response is governed by the hydrodynamic impulsive-convective interaction between the contained liquid and the tank walls, following ACI 307 and ACI 350.3.

3. Goals of the Course

- Explain the professional and regulatory context of civil engineering works, with emphasis on the public-safety risk profile of special/industrial structures.
- Explain the seismic phenomenon and apply the Peruvian seismic design code to determine seismic hazard parameters and structural configuration criteria.
- Analyze the dynamic response of structural systems subjected to earthquake ground motion.
- Analyze the seismic behavior of free-standing chimneys and design their reinforced concrete shell for seismic loading according to ACI 307.
- Analyze the hydrodynamic seismic response of liquid-storage tanks and design their reinforced concrete walls and base for seismic-induced hydrodynamic pressures according to ACI 350.3.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Professional and Regulatory Context, 12 hr(s)

Competences: ABET-2

Topics: **I:** Typology of civil engineering works: buildings, transportation and hydraulic infrastructure, and special/industrial structures (chimneys, tanks, silos) **II:** Peruvian regulatory framework (Reglamento Nacional de Edificaciones) and applicable international standards (ACI, ASCE) for special/industrial structures **III:** Professional responsibility and public-safety risk considerations specific to special/industrial structures under seismic hazard **IV:** Design process and stakeholders involved in a special/industrial structures project: owner, design engineer, and regulatory authority

Learning Outcomes **I:** Classify civil engineering works by typology and identify the regulatory framework applicable to special/industrial structures [Familiarity] **II:** Explain the professional responsibility and public-safety risk considerations specific to the design of special/industrial structures [Familiarity] **III:** Describe the design process and the stakeholders involved in a special/industrial structures project [Usage]

Bibliography: [Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de V

5.2 Seismology and Natural Hazards, 6 hr(s)

Competences: ABET-1

Topics: **I:** Plate tectonics and earthquake generation mechanisms through fault rupture **II:** Seismic waves: types (P, S, surface) and their propagation **III:** Magnitude (seismic moment) and intensity (Modified Mercalli) scales **IV:** Historical seismicity and subduction tectonic context of Peru **V:** Typology of natural disasters: seismic, volcanic, tsunami, and mass movement **VI:** Disaster risk management: prevention, mitigation, preparedness, and response (SINAGERD

framework) **VII:** Seismological instrumentation: seismographs, accelerographs, and national monitoring networks

Learning Outcomes I: Explain plate tectonics and earthquake generation mechanisms through fault rupture [Familiarity] **II:** Differentiate types of seismic waves and their effects on buildings [Usage] **III:** Interpret and distinguish between earthquake magnitude and intensity scales [Usage] **IV:** Describe the historical seismicity and subduction context of Peru [Familiarity] **V:** Classify the main types of natural disasters affecting Peruvian territory [Familiarity] **VI:** Analyze the disaster risk management framework for earthquake prevention and response [Assessment]

Bibliography: [Bolt, 2005, Kramer, 1996]

5.3 Seismic Design Code and Structural Configuration Criteria, 6 hr(s)

Competences: ABET-2

Topics: I: Scope and structure of the Peruvian seismic design code E.030 **II:** Seismic hazard parameters: seismic zonation (Z), usage factor (U), and soil profile (S) **III:** Structural systems and seismic force reduction coefficient (R) **IV:** Plan structural irregularities: torsional irregularity, re-entrant corners, and diaphragm discontinuity **V:** Vertical structural irregularities: soft story, weak story, and mass irregularity **VI:** Structuring principles: symmetry, redundancy, hyperstaticity, and continuity **VII:** Minimum base shear and inter-story drift limits

Learning Outcomes I: Explain the scope and structure of the Peruvian seismic design code E.030 [Familiarity] **II:** Determine the seismic hazard parameters (Z, U, S) applicable to a given site [Usage] **III:** Select the structural system and corresponding reduction coefficient R [Usage] **IV:** Classify the plan and vertical structural irregularities of a building [Assessment] **V:** Apply structuring principles to propose a regular structural configuration [Usage] **VI:** Verify the minimum base shear and inter-story drift limits [Assessment]

Bibliography: [Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de Vivie Bazán and Meli, 2002]

5.4 Structural Dynamics and Earthquake Engineering, 12 hr(s)

Competences: ABET-1

Topics: I: Single-degree-of-freedom systems and free vibration **II:** Forced vibration and harmonic excitation **III:** Damping models and energy dissipation mechanisms **IV:** Response spectrum analysis **V:** Earthquake ground motion characteristics and seismicity **VI:** Multi-degree-of-freedom systems and modal analysis **VII:** Time-history analysis and numerical integration methods **VIII:** Seismic design philosophy and capacity design principles **IX:** Base isolation and energy dissipation devices **X:** Performance-based seismic design methodology

Learning Outcomes I: Analyze free vibration of single-degree-of-freedom systems and determine natural frequencies [Assessment] **II:** Calculate structural response to harmonic and periodic loads [Usage] **III:** Explain the role of damping in reducing dynamic response [Familiarity] **IV:** Apply response spectrum method for seismic analysis [Usage] **V:** Interpret earthquake ground motion parameters and seismic hazard maps [Familiarity] **VI:** Perform modal analysis for multi-degree-of-freedom systems [Assessment] **VII:** Conduct time-history analysis using numerical integration techniques [Usage] **VIII:** Design structures following capacity design and ductile detailing principles [Assessment] **IX:** Evaluate the effectiveness of base isolation and damping systems [Familiarity] **X:** Implement performance-based seismic design procedures [Assessment]

Bibliography: [Chopra, 2017]

5.5 Industrial Structures: Chimneys and Tanks, 48 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Dynamic idealization of a free-standing chimney as an equivalent cantilever stick model **II:** Seismic force and overturning moment distribution along the height of a chimney per ACI 307 **III:** Flexural and shear design of reinforced concrete chimney shell sections under seismic loading **IV:** Seismic reinforcement detailing for chimney shells, openings, and construction joints **V:** Housner's impulsive-convective two-mass model for the hydrodynamic seismic response of liquid-storage tanks **VI:** Impulsive and convective (sloshing) hydrodynamic pressure distribution on tank walls and base per ACI 350.3 **VII:** Design of reinforced concrete tank walls and base slab for seismic-induced hydrodynamic pressures **VIII:** Sloshing wave height, freeboard requirements, and anchorage design for storage tanks

Learning Outcomes **I:** Explain the dynamic idealization of a free-standing chimney as an equivalent cantilever stick model for seismic analysis [Familiarity] **II:** Determine the seismic force and overturning moment distribution along the height of a reinforced concrete chimney [Usage] **III:** Design the reinforced concrete shell section of a chimney for flexure and shear under seismic loading [Assessment] **IV:** Detail seismic reinforcement for chimney shells, openings, and construction joints [Usage] **V:** Explain Housner's impulsive-convective mass model for the hydrodynamic seismic response of liquid-storage tanks [Familiarity] **VI:** Determine impulsive and convective hydrodynamic pressure distributions on tank walls and base [Usage] **VII:** Design reinforced concrete tank walls and base slab for seismic-induced hydrodynamic pressures [Assessment] **VIII:** Calculate sloshing wave height and freeboard requirements, and design anchorage for a storage tank [Usage]

Bibliography: [307, 2022, 350, 2020, Housner, 1963]

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[307, 2022] 307, A. C. (2022). Standard practice for the design and construction of cast-in-place reinforced concrete chimneys (aci 307-22). Technical report, American Concrete Institute.

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CE3S12 Research Workshop (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - BMI201 Methodology of Engineering Research (8th Sem-Pg. 435)

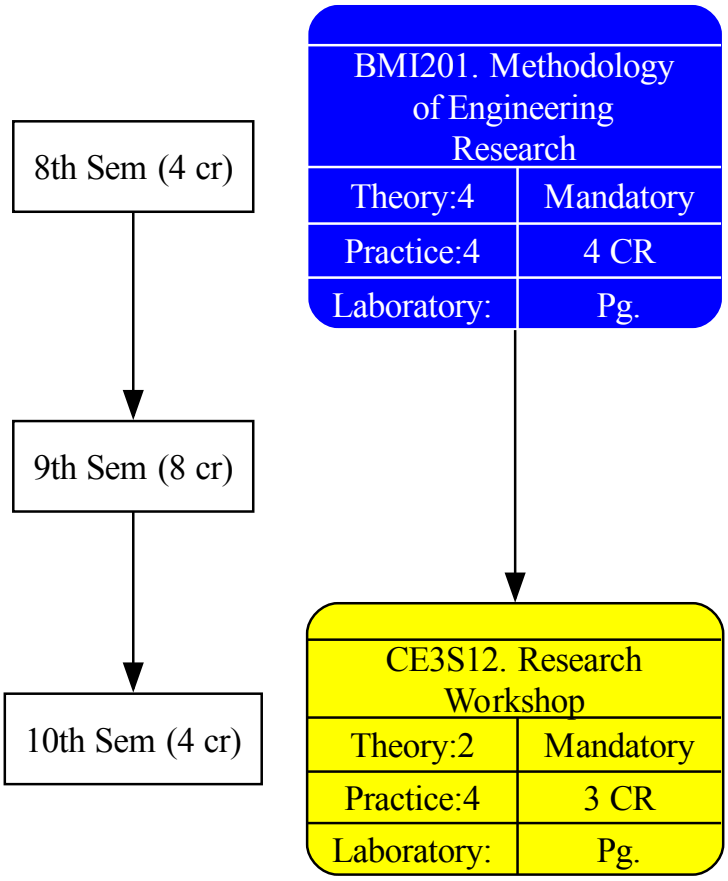

Figure 7.75: Connection Map. CE3S12 Research Workshop

2. Course Rationale

Research Workshop introduces students to the fundamentals of engineering research methodology in preparation for capstone-level research work in Civil Engineering. Students learn to identify a research idea and formulate a research problem, build the theoretical and conceptual framework that supports a study, formulate testable hypotheses and operationalize the variables involved, select and justify an appropriate type and design of research, and collect and analyze data to answer a civil engineering research question. The course also reinforces the professional ethics and technical communication skills required to conduct and disseminate engineering research responsibly.

3. Goals of the Course

- Formulate a well-defined civil engineering research idea and problem statement grounded in a real technical need.
- Build a theoretical framework through systematic literature review and critical synthesis of prior research.
- Formulate testable research hypotheses and operationalize the variables of a civil engineering study.
- Select and justify an appropriate type and design of research (quantitative, qualitative, or mixed methods) for a given research problem.
- Collect and statistically analyze data to answer a civil engineering research question.
- Apply engineering ethics and produce clear technical communication throughout the research process.
- The deliverables for this course are:

  Midterm: Research idea, problem statement, and theoretical framework document.

  Final: Complete research proposal including hypotheses, variables, research type and design, and a preliminary data collection and analysis plan.

4. General Competences (*Outcomes*)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Usage)

ABET-3) An ability to communicate effectively with a range of audiences. (Usage)

5. Content

5.1 Research Design and Methodologies, 28 hr(s)

Competences: ABET-6

Topics: **I:** Formulating research questions in architecture: descriptive, relational, causal; turning design problems into researchable questions **II:** Choosing a research methodology: quantitative (hypothesis testing, statistical), qualitative (interpretive, case study), mixed methods, **III:** Validity and reliability in architectural research: internal validity, external validity (generalizability), construct validity, **IV:** Research ethics in architectural research: informed consent, privacy (anonymization of building users), institutional review board (IRB) protocols, **V:** Mixed methods research: sequential (qualitative then quantitative) and concurrent designs; integrating qualitative findings (user interviews) with quantitative data (occupancy

Learning Outcomes **I:** Describe the main research methodologies in architecture - quantitative, qualitative, mixed methods, practice-based - and explain their appropriate applications [Familiarity] **II:** Develop a research design for an architectural inquiry, including research question, literature review, methodology selection, data collection protocol, and analysis plan [Usage] **III:** Evaluate the research design of a published architectural study for validity, reliability, and ethical soundness, identifying methodological strengths and weaknesses [Assessment]

Bibliography: [Creswell, 2018, Leedy and Ormrod, 2019]

5.2 Theoretical Framework and Literature Review, 16 hr(s)

Competences: ABET-6

Topics: **I:** Systematic search of scientific and technical literature: specialized databases (Scopus, Web of Science, ASCE Library), keywords, and Boolean operators **II:** Critical reading and synthesis of scientific articles, technical standards, and prior research reports **III:** Building the conceptual and theoretical framework: defining key concepts, relationships between variables, and reference theoretical models **IV:** Identifying knowledge gaps (research gap) and justifying the originality of the proposed contribution **V:** Bibliographic reference management and citation styles (APA, IEEE) using tools such as Zotero or Mendeley

Learning Outcomes **I:** Explain the structure and purpose of a theoretical framework within a civil engineering research project [Familiarity] **II:** Conduct a systematic search of scientific and technical literature on a chosen research topic using specialized databases [Usage] **III:** Synthesize the state of the art of a research topic into a coherent theoretical framework that identifies a knowledge gap [Assessment]

Bibliography: [Booth et al., 2016, Creswell, 2018]

5.3 Research Hypotheses and Variables, 16 hr(s)

Competences: ABET-6

Topics: **I:** Types of hypotheses: null, alternative, directional, and non-directional, and their relationship to research questions **II:** Classification of variables: independent, dependent, control, and confounding **III:** Operationalizing variables: defining measurable indicators and measurement scales (nominal, ordinal, interval, ratio) **IV:** Relationship between hypotheses, variables, and statistical significance tests: significance level, Type I and Type II error **V:** Graphical representation of the relationship between variables through conceptual or operational models

Learning Outcomes **I:** Distinguish between null and alternative hypotheses, and between independent, dependent, and control variables, in a civil engineering research problem [Familiarity] **II:** Formulate a testable research hypothesis and operationalize its variables for a specific problem in the chosen specialization area [Usage] **III:** Evaluate the consistency between the theoretical framework, the stated hypothesis, and the proposed data-collection design [Assessment]

Bibliography: [Montgomery and Runger, 2018, Kumar, 2019]

5.4 Quantitative Methods in Architectural Research, 12 hr(s)

Competences: ABET-6

Topics: **I:** Survey design for architectural research: sampling methods (probability, convenience), questionnaire design (Likert scales, semantic differential), response rate optimization, **II:** Experimental designs: true experiments (random assignment, control group), quasi-experiments (non-randomized, pre-post, time series), **III:** Descriptive statistics: measures of central tendency (mean, median, mode), dispersion (standard deviation, range, interquartile range), **IV:** Inferential statistics: hypothesis testing (t-test, ANOVA, chi-square), correlation and regression (linear, multiple), and interpretation of p-values **V:** Instrumentation for quantitative data collection: environmental sensors (temperature, light, CO_2), occupancy counters, objective performance measures (task completion time

Learning Outcomes **I:** Describe the main quantitative methods in architectural research - surveys, experiments, quasi-experiments - [Familiarity] **II:** Design a survey or experiment to test a hypothesis about the effect of a design variable (lighting, color, layout) on user satisfaction, task performance, or behavior [Usage] **III:** Evaluate a quantitative architectural study for sampling validity, statistical analysis appropriateness, and correct interpretation of p-values and effect sizes [Assessment]

Bibliography: [Montgomery and Runger, 2018, Creswell, 2018]

5.5 Engineering Ethics and Professional Responsibility, 4 hr(s)

Competences: ABET-4

Topics: **I:** Ethical theories: utilitarianism, duty ethics, virtue ethics **II:** Professional codes of conduct (e.g., ASCE, NSPE) and their fundamental canons **III:** Engineer's paramount responsibility to public safety, health, and welfare **IV:** Ethical dilemmas in practice: conflicts of interest, whistleblowing, gift-giving **V:** Ethical decision-making frameworks and case study analysis **VI:** Global engineering ethics and cross-cultural challenges **VII:** Ethical obligations for sustainable development and environmental stewardship **VIII:** Ethical implications of emerging technologies (AI, automation, data privacy) **IX:** Ethical conduct in dispute resolution and litigation

Learning Outcomes **I:** Explain the primary tenets of the engineer's code of ethics [Familiarity] **II:** Apply an ethical decision-making framework to a hypothetical engineering scenario [Assessment] **III:** Identify conflicts of interest and other common ethical pitfalls in project work [Familiarity] **IV:** Analyze a historical engineering failure case from an ethical perspective [Assessment] **V:** Evaluate the ethical dimensions of a project with significant social or environmental impacts in a different cultural context [Assessment] **VI:** Articulate the ethical argument for incorporating sustainability into all engineering work [Familiarity] **VII:** Discuss the ethical responsibilities related to data collection and use in smart infrastructure projects [Assessment] **VIII:** Describe the role of ethics in alternative dispute resolution processes [Familiarity]

Bibliography: [Harris et al., 2013, Fleddermann, 2020]

5.6 Written and Technical Communication, 3 hr(s)

Competences: ABET-3

Topics: **I:** Audience analysis and adaptation of technical content **II:** Written communication: technical reports, memos, emails, and specifications **III:** Visual communication: graphs, charts, diagrams, and effective slide design

Learning Outcomes **I:** Write a clear, concise, and well-organized technical report on a laboratory experiment or design project [Usage] **II:** Create effective graphs and diagrams to present engineering data [Assessment]

Bibliography: [Gurak and Lannon, 2013]

5.7 Oral Presentation and Professional Communication, 3 hr(s)

Competences: ABET-3

Topics: **I:** Oral presentations: structure, delivery techniques, and handling Q&A **II:** Proposal writing: technical approach, management plan, and cost estimating **III:** Executive summaries and communicating with non-technical stakeholders

Learning Outcomes **I:** Deliver a structured oral presentation on a technical topic using appropriate visual aids [Usage] **II:** Outline the key sections of a competitive engineering proposal [Familiarity] **III:** Develop an executive summary that conveys key project findings to a senior management audience [Usage]

Bibliography: [Gurak and Lannon, 2013]

5.8 Digital and Collaborative Communication, 2 hr(s)

Competences: ABET-3

Topics: **I:** Collaborative writing and document management in team settings **II:** Digital communication: web content, social media guidelines for engineers **III:** Persuasive communication and negotiation techniques

Learning Outcomes I: Manage a collaborative document (e.g., on Google Docs or SharePoint) for a team project [Assessment] **II:** Explain the professional risks and opportunities associated with engineers using social media [Familiarity] **III:** Employ basic negotiation tactics to resolve a simulated conflict over project scope [Usage]

Bibliography: [Gurak and Lannon, 2013]

6. Bibliography

[Booth et al., 2016] Booth, W. C., Colomb, G. G., and Williams, J. M. (2016). *The Craft of Research*. University of Chicago Press, 4th edition.

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[Fleddermann, 2020] Fleddermann, C. B. (2020). *Engineering Ethics*. Pearson, 5th edition.

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CE3S2 Reinforced Concrete Design II (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE2S2 Reinforced Concrete Design I (7th Sem-Pg. 394)

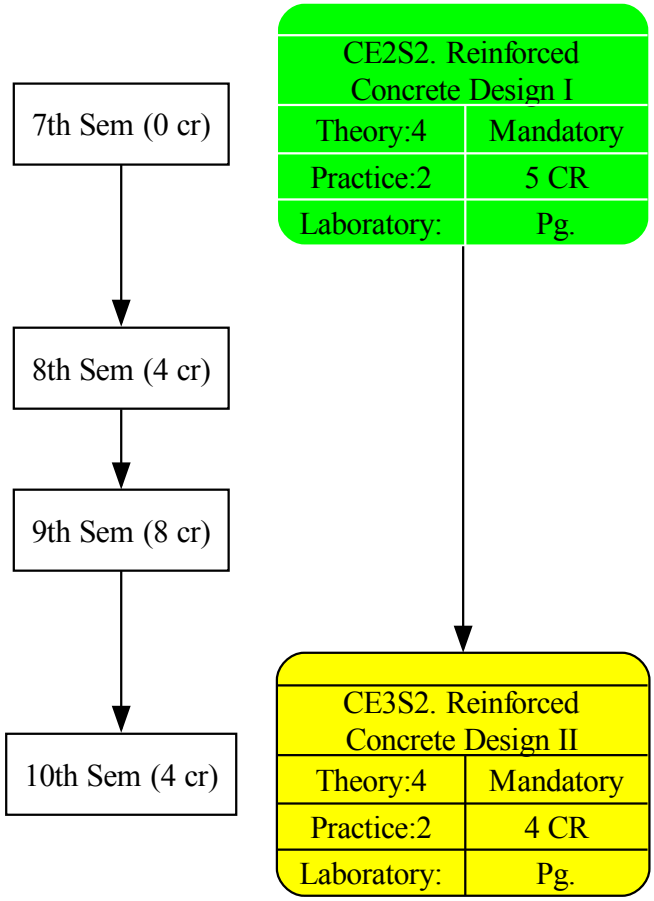

Figure 7.76: Connection Map. CE3S2 Reinforced Concrete Design II

2. Course Rationale

Reinforced Concrete Design II builds directly on Reinforced Concrete Design I, extending limit state design methodology to the structuring and design of building slab systems, seismic-resistant reinforced concrete structural walls (shear walls) and special moment frame provisions, and the use of structural analysis software for three-dimensional building modeling. The course also develops earth-retaining structure design, including basement walls, anchored walls, gravity walls, and cantilever and counterfort retaining walls, together with advanced shallow foundation design covering isolated,

combined, connected, eccentric, and continuous footings. Through progressive, integrated design exercises, students apply current design codes to produce a complete seismic-resistant reinforced concrete building design, preparing them for advanced structural and earthquake-resistant design coursework.

3. Goals of the Course

- Structure reinforced concrete buildings and design one-way (precast) and two-way reinforced concrete slab systems.
- Design special reinforced concrete structural walls (shear walls) for seismic lateral force resistance.
- Apply special seismic detailing provisions to reinforced concrete moment-resisting frames.
- Build and analyze three-dimensional structural models of reinforced concrete buildings using structural analysis software.
- Design earth-retaining structures, including basement walls, anchored walls, gravity walls, and cantilever and counterfort retaining walls.
- Design shallow foundations, including isolated, combined, connected, eccentric, and continuous footings.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Reinforced Concrete Design, 18 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Design philosophy and limit state methodology for concrete structures **II:** Flexural design of rectangular and T-beams **III:** Shear and torsion design of concrete members **IV:** Compression members and column design **V:** Slab design including one-way and two-way systems **VI:** Development length and splicing of reinforcement **VII:** Deflection control and serviceability requirements for concrete beams and slabs

Learning Outcomes **I:** Explain limit state design philosophy and load factor combinations [Familiarity] **II:** Design reinforced concrete beams for flexure and check serviceability [Assessment] **III:** Calculate shear and torsional reinforcement requirements [Usage] **IV:** Proportion columns for axial load and biaxial bending [Assessment] **V:** Design one-way and two-way slab systems with appropriate reinforcement [Usage] **VI:** Determine development lengths and design lap splices for reinforcing bars [Assessment] **VII:** Control deflections and verify serviceability requirements through adequate member sizing and reinforcement [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, McCormac and Brown, 2021]

5.2 Earth Retaining Systems, 26 hr(s)

Competences: ABET-2

Topics: **I:** Earth pressure theory including active and passive pressures **II:** Retaining wall types and selection criteria **III:** Load testing methods including static and dynamic tests **IV:** Anchored walls and tied-back systems **V:** Mechanically stabilized earth walls and reinforced soil systems **VI:** Basement and foundation wall design considering top-of-wall restraint conditions **VII:** Counterfort and buttressed retaining wall design

Learning Outcomes **I:** Apply lateral earth pressure theories for retaining wall design [Assessment] **II:** Design gravity and cantilever retaining walls [Usage] **III:** Design anchored wall systems including ground anchor capacity [Assessment] **IV:** Proportion mechanically stabilized earth walls and select reinforcement [Usage] **V:** Design basement and foundation walls considering top restraint, surcharge, and hydrostatic loads [Assessment] **VI:** Design counterfort retaining walls including stem, heel, toe, and counterfort elements [Usage]

Bibliography: [Das, 2019, ACI Committee 318, 2019]

5.3 Seismic Detailing of Reinforced Concrete, 7 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Beam-column joints and moment-resisting frame connections **II:** Seismic detailing and ductile design of concrete structures **III:** Design of special reinforced concrete structural walls (shear walls) for seismic lateral force resistance **IV:** Special seismic detailing provisions for reinforced concrete moment-resisting frames

Learning Outcomes **I:** Detail beam-column joints for moment transfer and shear resistance [Assessment] **II:** Implement seismic detailing requirements for ductile concrete frames [Assessment] **III:** Design special reinforced concrete structural walls for combined axial, flexural, and shear demands under seismic loading [Assessment] **IV:** Apply special seismic detailing provisions to reinforced concrete moment frame members and beam-column joints [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.4 Prestressed Concrete Analysis, 7 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Prestressed concrete principles and pre-tensioning methods **II:** Elastic analysis of stresses in prestressed concrete sections under service loads **III:** Composite prestressed concrete sections: precast members with cast-in-place topping **IV:** Immediate and time-dependent losses of prestress

Learning Outcomes **I:** Apply prestressing principles to design pre-tensioned members [Usage] **II:** Analyze stresses in prestressed concrete sections under service loads using elastic theory [Usage] **III:** Design composite prestressed concrete sections combining precast members and cast-in-place concrete [Assessment] **IV:** Calculate immediate and time-dependent losses of prestress [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.5 Prestressed Concrete Design, 8 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Post-tensioned concrete systems and tendon design **II:** Deflection control and serviceability requirements **III:** Flexural strength of prestressed concrete members at ultimate limit state **IV:** Shear and torsion design of prestressed concrete members **V:** Statically indeterminate prestressed concrete structures, including secondary moments

Learning Outcomes **I:** Design post-tensioned slabs and beams including tendon layout [Assessment] **II:** Control deflections through appropriate member sizing and reinforcement [Usage] **III:** Design prestressed concrete members for flexural strength at the ultimate limit state [Assessment] **IV:** Design prestressed concrete members for shear and torsion strength [Assessment] **V:** Analyze statically indeterminate prestressed concrete structures, including secondary moments [Assessment]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019, Moehle, 2015]

5.6 Building Structural Analysis and Modeling Practicum, 4 hr(s)

Competences: ABET-2

Topics: **I:** Overview of case-study buildings: geometry, structural systems, and load paths **II:** Development of plane frame and truss models of real buildings using stiffness-method-based structural analysis software **III:** Application of static and seismic response-spectrum analysis to representative building case studies **IV:** Presentation and peer discussion of structural analysis results and their design implications **V:** Definition of geometry, materials, sections, and boundary conditions for a three-dimensional building model in commercial structural analysis software (ETABS, Midas Gen) **VI:** Assignment of gravity, seismic, and wind loads and their combinations to a three-dimensional building model **VII:** Static and dynamic (modal) analysis of building models and interpretation of results, including story drifts, member forces, and vibration periods **VIII:** Verification of software-generated results against simplified hand calculations and code checks

Learning Outcomes **I:** Model real building structural systems for stiffness-method-based static and seismic analysis using structural analysis software [Usage] **II:** Interpret and validate computer-generated analysis results against expected structural behavior [Assessment] **III:** Present and defend structural analysis results and their design implications to peers [Usage] **IV:** Assign gravity, seismic, and wind loads and load combinations to a three-dimensional building model in commercial structural analysis software [Usage] **V:** Interpret dynamic analysis results, including story drifts, member forces, and vibration periods [Assessment] **VI:** Verify software-generated results against simplified hand calculations [Assessment]

Bibliography: [Wight and MacGregor, 2016]

5.7 Bearing Capacity and Design, 26 hr(s)

Competences: ABET-2

Topics: **I:** Bearing capacity theory and failure mechanisms **II:** Ultimate bearing capacity equations for various conditions **III:** Settlement analysis using elastic and consolidation methods **IV:** Isolated spread footing design **V:** Combined footings and strap footings **VI:** Allowable bearing pressure and factor of safety selection **VII:** Mat foundation analysis and design **VIII:** Eccentric and inclined loading effects **IX:** Soil-structure interaction effects **X:** Differential settlement and tolerable limits **XI:** Continuous (strip) footing design for basement and foundation walls

Learning Outcomes **I:** Explain bearing capacity failure mechanisms in shallow foundations [Familiarity] **II:** Calculate ultimate bearing capacity using Terzaghi and Meyerhof equations [Assessment] **III:** Predict total and differential settlements for shallow foundations [Usage] **IV:** Design isolated spread footings for gravity loads [Assessment] **V:** Proportion combined and strap footings for column arrangements [Usage] **VI:** Determine allowable bearing pressures based on strength and settlement criteria [Assessment] **VII:** Analyze mat foundations using conventional and finite element methods [Assessment] **VIII:** Evaluate bearing capacity under eccentric and inclined loading [Usage] **IX:** Consider soil-structure interaction in foundation design [Familiarity] **X:** Assess differential settlement and apply tolerable settlement criteria [Assessment] **XI:** Design continuous strip footings for basement and foundation walls [Usage]

Bibliography: [Coduto, 2001, Das, 2019]

5.8 Integrated Structural Design Project, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Progressive design exercise integrating slab, structural wall, and foundation design for a multi-story reinforced concrete building **II:** Coordination of structural design decisions with the architectural and geotechnical constraints of the project **III:** Structural design documentation, including calculation memoranda and design drawings

Learning Outcomes I: Develop a progressive, integrated structural design for a reinforced concrete building incorporating slabs, structural walls, and foundations [Assessment] **II:** Apply course content cumulatively to solve realistic, open-ended design problems under code and site constraints [Assessment] **III:** Prepare structural calculation documentation communicating design decisions [Usage]

Bibliography: [Wight and MacGregor, 2016, ACI Committee 318, 2019]

6. Bibliography

[ACI Committee 318, 2019] ACI Committee 318 (2019). Building code requirements for structural concrete (aci 318-19) and commentary. Technical report, American Concrete Institute.

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[Wight and MacGregor, 2016] Wight, J. K. and MacGregor, J. G. (2016). *Reinforced Concrete: Mechanics and Design*. Pearson, 7th edition.

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CE3S6 Masonry, Adobe, and Timber (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)

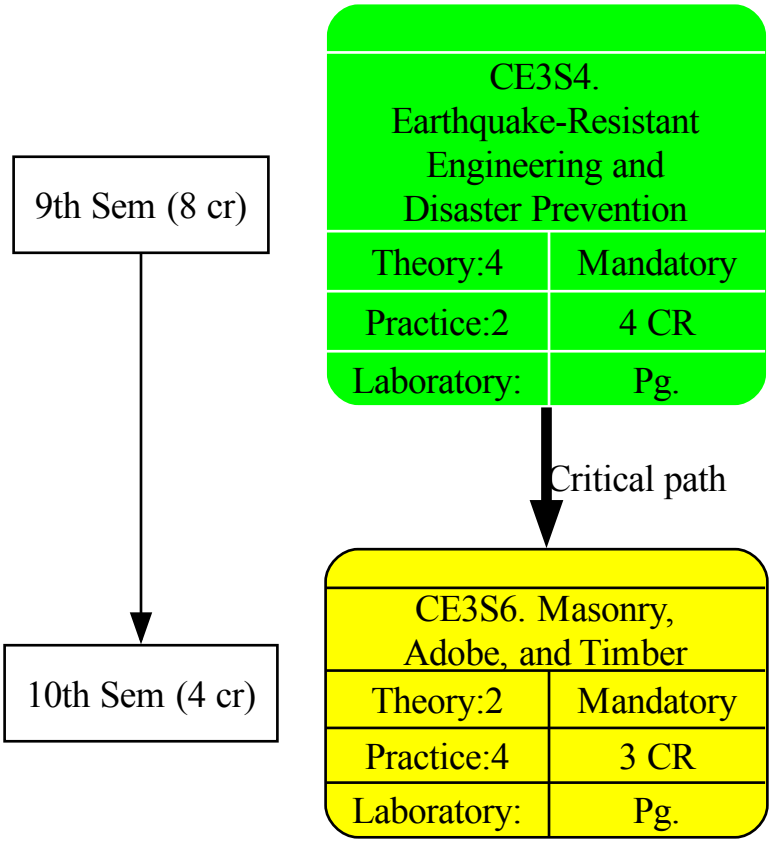

Figure 7.77: Connection Map. CE3S6 Masonry, Adobe, and Timber

2. Course Rationale

Masonry, Adobe, and Timber covers the seismic-resistant design of low-rise buildings using the structural systems most widely used in Peruvian construction: structural masonry, adobe, and timber. Building on the seismic engineering fundamentals from Earthquake-Resistant Engineering, the course develops a design studio that applies material selection criteria, seismic code requirements, and structural detailing to complete building design projects in masonry, adobe, and timber.

3. Goals of the Course

- Formulate the design process for a low-rise building, integrating site conditions, material selection, and applicable Peruvian building codes.
- Design structural and non-structural masonry walls for gravity and seismic loads.
- Design adobe walls and specify seismic reinforcement techniques according to Standard E.080.
- Design timber structural elements and connections for buildings and light structures.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

5. Content

5.1 Design Process for Low-Rise Buildings, 12 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Site and soil recognition, project requirements, and applicable regulatory framework (E.030, E.070, E.080, E.010) **II:** Criteria for selecting a structural system among masonry, adobe, and timber based on site conditions, materials availability, and seismic hazard **III:** Integration of the structural design with the architectural layout of a building project

Learning Outcomes **I:** Describe the design process of a low-rise building, identifying site conditions and the applicable Peruvian regulatory framework [Familiarity] **II:** Select an appropriate structural system for a building project based on site conditions, materials, and seismic hazard [Usage] **III:** Formulate the scope and requirements of a building project that integrates masonry, adobe, or timber systems [Assessment]

Bibliography: [Institute, 2021, Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) /

5.2 Masonry Structural Design, 22 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Masonry materials, units, and mortar properties **II:** Unreinforced masonry wall design for compression and flexure **III:** Reinforced masonry design and detailing **IV:** Seismic design of masonry and timber structures

Learning Outcomes **I:** Identify masonry unit types and specify appropriate mortar for applications [Familiarity] **II:** Design unreinforced masonry walls for gravity and lateral loads [Assessment] **III:** Proportion reinforced masonry elements and specify reinforcement details [Usage] **IV:** Implement seismic design provisions for masonry and timber buildings [Usage]

Bibliography: [Drysdale and Hamid, 2008, de Capacitación para la Industria de la Construcción (SENCICO), 2006b]

5.3 Timber and Light-Gauge Steel Framing Design, 33 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Timber properties, grading, and design values **II:** Sawn lumber and glued-laminated timber design **III:** Timber connections including nails, bolts, and metal connectors **IV:** Cold-formed steel members and sectional properties **V:** Light-gauge steel framing systems and design **VI:** Engineered wood products including I-joists and structural composite lumber

Learning Outcomes **I:** Select timber species and grades based on structural requirements [Familiarity] **II:** Design timber beams, columns, and combined loading members [Assessment] **III:** Specify timber connections and calculate their capacity [Usage] **IV:** Calculate effective section properties for cold-formed steel members [Assessment] **V:** Design light-gauge steel wall studs and floor joists [Usage] **VI:** Apply engineered wood products in floor and roof systems [Assessment]

Bibliography: [Breyer et al., 2015, de Capacitación para la Industria de la Construcción (SENCICO), 2006a]

5.4 Adobe Structural Design, 17 hr(s)

Competences: ABET-1,ABET-2

Topics: **I:** Adobe as a structural material: mechanical properties and seismic behavior **II:** Adobe wall design for gravity loads and verification of thickness and slenderness per Standard E.080 **III:** Seismic reinforcement techniques for adobe construction: meshes, geomeshes, and horizontal and vertical reinforcement

Learning Outcomes **I:** Characterize the mechanical properties of adobe and its seismic behavior [Familiarity] **II:** Design adobe walls according to the thickness, slenderness, and geometric requirements of Standard E.080 [Assessment] **III:** Specify seismic reinforcement techniques for new and existing adobe buildings [Usage]

Bibliography: [Blondet et al., 2003, de Capacitación para la Industria de la Construcción (SENCICO), 2017]

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[Blondet et al., 2003] Blondet, M., Garcia, G. V., and Brzev, S. (2003). Earthquake-resistant construction of adobe buildings: A tutorial. Technical report, EERI/IAEE World Housing Encyclopedia.

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CE3S7 Structural Rehabilitation and Retrofitting (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 2 hours;
- **Prerrequisites**:
  - CE3S4 Earthquake-Resistant Engineering and Disaster Prevention (9th Sem-Pg. 494)

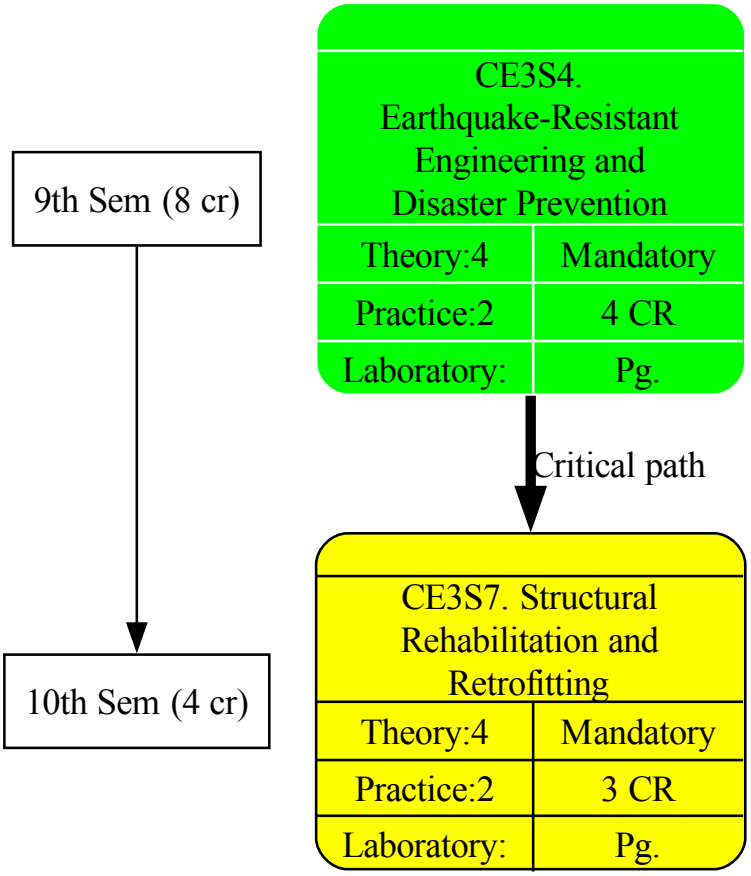

Figure 7.78: Connection Map. CE3S7 Structural Rehabilitation and Retrofitting

2. Course Rationale

Structural Rehabilitation and Retrofitting addresses the assessment, strengthening, and retrofit of Peru's existing civil infrastructure. Building on the seismic engineering fundamentals of Earthquake-Resistant Engineering and Disaster Prevention, the course begins with the national context of Peru's aging and deficient infrastructure and a review of the seismic design code criteria that establish the baseline performance expectations against which existing structures are evaluated. Students then

characterize the permanent, live, environmental, and deterioration-induced loads acting on existing structures, and study the nonlinear behavior of structural components – including hysteretic response, plastic hinge modeling, and pushover analysis – required to evaluate structural performance beyond the elastic range. The course closes with the field evaluation procedures, and the strength, ductility, durability, and serviceability rehabilitation techniques used to retrofit existing structures.

3. Goals of the Course

- Describe the national context and condition of Peru's existing civil infrastructure and the regulatory framework applicable to its assessment and rehabilitation.
- Characterize the permanent, live, environmental, and deterioration-induced loads acting on existing structures.
- Apply nonlinear structural analysis methods, including pushover analysis and displacement-based assessment, to evaluate the performance of existing structures.
- Conduct field evaluation procedures, including nondestructive testing, to assess the condition of existing structures.
- Design strengthening and retrofit interventions to improve the strength, ductility, durability, and serviceability of existing structures.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. (Usage)

5. Content

5.1 National Context of Existing Civil Infrastructure, 2 hr(s)

Competences: ABET-1

Topics: **I:** Overview of Peru's existing civil infrastructure inventory and condition: buildings, bridges, and lifelines **II:** Causes and consequences of infrastructure deficiency: aging, inadequate maintenance, unregulated construction, and seismic vulnerability **III:** Economic, social, and risk-management implications of infrastructure rehabilitation versus replacement **IV:** Institutional and regulatory framework for the rehabilitation of existing structures in Peru

Learning Outcomes **I:** Describe the condition and typology of Peru's existing civil infrastructure [Familiarity] **II:** Explain the causes and consequences of infrastructure deficiency in the Peruvian context [Familiarity] **III:** Discuss the economic and risk-management criteria used to decide between rehabilitation and replacement of existing infrastructure [Usage]

Bibliography: [of Civil Engineers, 2021]

5.2 Seismic Design Code and Structural Configuration Criteria, 4 hr(s)

Competences: ABET-2

Topics: **I:** Scope and structure of the Peruvian seismic design code E.030 **II:** Seismic hazard parameters: seismic zonation (Z), usage factor (U), and soil profile (S) **III:** Structural systems and seismic force reduction coefficient (R) **IV:** Plan structural irregularities: torsional irregularity, re-entrant corners, and diaphragm discontinuity **V:** Vertical structural irregularities: soft story, weak story, and mass irregularity **VI:** Structuring principles: symmetry, redundancy, hyperstaticity, and continuity **VII:** Minimum base shear and inter-story drift limits

Learning Outcomes I: Explain the scope and structure of the Peruvian seismic design code E.030 [Familiarity] **II:** Determine the seismic hazard parameters (Z, U, S) applicable to a given site [Usage] **III:** Select the structural system and corresponding reduction coefficient R [Usage] **IV:** Classify the plan and vertical structural irregularities of a building [Assessment] **V:** Apply structuring principles to propose a regular structural configuration [Usage] **VI:** Verify the minimum base shear and inter-story drift limits [Assessment]

Bibliography: [Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de V

5.3 Nature and Characterization of Loads on Existing Infrastructure, 10 hr(s)

Competences: ABET-1

Topics: I: Permanent (dead) and live load characterization for existing structures **II:** Environmental loads: wind, thermal, and differential settlement effects on infrastructure **III:** Deterioration-induced load effects: corrosion, creep, shrinkage, and fatigue **IV:** Load history reconstruction and service load estimation for existing structures **V:** Overload and abnormal load events: impact, blast, and accidental actions **VI:** Load combinations for structural assessment and rehabilitation design

Learning Outcomes I: Characterize the permanent and live loads applicable to existing civil infrastructure [Familiarity] **II:** Determine environmental load effects, including wind, thermal, and differential settlement, on existing structures [Usage] **III:** Identify deterioration-induced load effects such as corrosion, creep, shrinkage, and fatigue [Assessment] **IV:** Reconstruct the load history and estimate in-service loads for an existing structure [Usage] **V:** Recognize overload and abnormal load events relevant to infrastructure assessment [Familiarity] **VI:** Establish load combinations appropriate for structural assessment and rehabilitation design [Assessment]

Bibliography: [of Civil Engineers, 2022]

5.4 Nonlinear Behavior of Structures, 18 hr(s)

Competences: ABET-1,ABET-2

Topics: I: Material nonlinearity: stress-strain behavior of concrete and reinforcing steel beyond yield **II:** Geometric nonlinearity and P-delta effects in structural response **III:** Hysteretic behavior and energy dissipation of structural components under cyclic loading **IV:** Plastic hinge formation, hinge length, and moment-curvature relationships **V:** Nonlinear static (pushover) analysis and capacity curve development **VI:** Displacement ductility and curvature ductility demand **VII:** Performance levels and acceptance criteria for structural and nonstructural components **VIII:** Displacement-based assessment methods for existing structures

Learning Outcomes I: Explain the material and geometric sources of nonlinear structural behavior [Familiarity] **II:** Determine moment-curvature relationships and plastic hinge properties for structural members [Usage] **III:** Perform nonlinear static (pushover) analysis to develop a structure's capacity curve [Usage] **IV:** Calculate displacement and curvature ductility demands for structural components [Assessment] **V:** Evaluate structural and nonstructural performance levels against acceptance criteria [Assessment] **VI:** Apply displacement-based methods to assess the seismic performance of existing structures [Usage]

Bibliography: [Priestley et al., 2007]

5.5 Structural Rehabilitation, Strengthening, and Retrofit, 50 hr(s)

Competences: ABET-2,ABET-6

Topics: I: Condition assessment and structural evaluation procedures **II:** Load rating and capacity evaluation of existing structures **III:** Concrete repair materials and techniques **IV:** Strengthening techniques using external reinforcement **V:** FRP strengthening systems for flexure and shear

VI: Seismic retrofit strategies for buildings and bridges **VII:** Steel jacketing and external post-tensioning **VIII:** Masonry rehabilitation and historic structure preservation **IX:** Performance-based assessment and retrofit design **X:** Nondestructive evaluation and structural health monitoring

Learning Outcomes I: Conduct comprehensive condition assessments of existing structures [Assessment] **II:** Evaluate load-carrying capacity of existing structural members [Usage] **III:** Select appropriate concrete repair materials and application methods [Familiarity] **IV:** Design strengthening interventions using conventional techniques [Assessment] **V:** Apply FRP systems for flexural and shear strengthening of concrete members [Usage] **VI:** Develop seismic retrofit strategies for deficient structures [Assessment] **VII:** Implement steel jacketing and external post-tensioning systems [Usage] **VIII:** Rehabilitate masonry structures while preserving historic character [Assessment] **IX:** Perform performance-based assessment and design retrofit interventions [Usage] **X:** Utilize nondestructive testing and monitoring technologies for damage assessment [Familiarity]

Bibliography: [Institute, 2021, of Civil Engineers, 2017, Agency, 2000, Institute, 2017]

6. Bibliography

[Agency, 2000] Agency, F. E. M. (2000). Fema 356: Prestandard and commentary for the seismic rehabilitation of buildings. Technical report, Federal Emergency Management Agency.

[Institute, 2017] Institute, A. C. (2017). Aci 440.2r-17: Guide for the design and construction of externally bonded frp systems for strengthening concrete structures. Technical report, American Concrete Institute.

[Institute, 2021] Institute, A. C. (2021). Aci 562: Code requirements for assessment, repair, and rehabilitation of existing concrete structures. Technical report, American Concrete Institute.

[of Civil Engineers, 2017] of Civil Engineers, A. S. (2017). Asce/sei 41-17: Seismic evaluation and retrofit of existing buildings. Technical report, American Society of Civil Engineers.

[of Civil Engineers, 2021] of Civil Engineers, A. S. (2021). 2021 infrastructure report card. Technical report, American Society of Civil Engineers.

[of Civil Engineers, 2022] of Civil Engineers, A. S. (2022). Asce/sei 7-22: Minimum design loads and associated criteria for buildings and other structures. Technical report, American Society of Civil Engineers.

[Priestley et al., 2007] Priestley, M. J. N., Calvi, G. M., and Kowalsky, M. J. (2007). *Displacement-Based Seismic Design of Structures*. IUSS Press.

[Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de Vivienda, 2018] Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) / Ministerio de Vivienda, C. y. S. d. P. (2018). Norma técnica e.030: Diseño sismorresistente. Technical report, Reglamento Nacional de Edificaciones del Perú.

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CE403 Capstone project II (Mandatory)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 4 hours; **Practice**: 4 hours;
- **Prerrequisites**:
  - CE402 Capstone project I (9th Sem-Pg. 504)

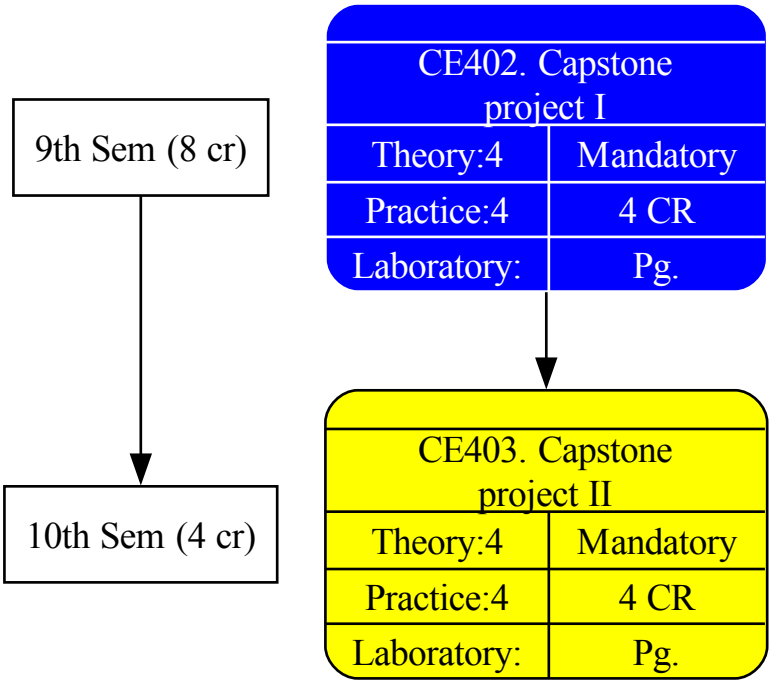

Figure 7.79: Connection Map. CE403 Capstone project II

2. Course Rationale

Este curso tiene por objetivo que el alumno desarrolle su propuesta técnica y sus experimentos en base al estado del arte ya levantado previamente. Es la etapa de consolidación donde se define el aporte original o la aplicación novedosa de la ingeniería civil que dará lugar a su tesis profesional.

3. Goals of the Course

- Que el alumno esté en la capacidad de presentar formalmente su proyecto de tesis con el marco teórico y levantamiento bibliográfico completo.
- Que el alumno desarrolle su propuesta de investigación (metodología, diseño experimental o modelamiento).
- Los entregables de este curso son:

  Avance parcial: Plan de tesis detallado que incluye motivación, definición del problema, objetivos, cronograma y avances de la propuesta técnica (uso/mejora de métodos existentes).

Final: Plan de tesis en etapa avanzada y borrador de tesis incluyendo capítulos de propuesta y resultados experimentales preliminares.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Assessment)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Assessment)

ABET-3) An ability to communicate effectively with a range of audiences. (Assessment)

ABET-4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. (Assessment)

ABET-5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (Assessment)

5. Content

5.1 Proyecto de Tesis, 30 hr(s)

Competences: ABET-1,ABET-2,ABET-3,ABET-4,ABET-5

Topics: I: Estructuración formal del Proyecto de Tesis. **II:** Definición de la metodología de investigación aplicada.

Learning Outcomes I: Aplicar el formato institucional para el plan de tesis [Assessment]. **II:** Concluir el plan del proyecto de tesis con objetivos medibles [Assessment]. **III:** Presentar el estado del arte del tema de tesis al 50% [Assessment].

Bibliography: [Yin, 2018, Meredith, 1993]

5.2 Avance de Tesis, 30 hr(s)

Competences: ABET-1,ABET-2,ABET-3,ABET-4,ABET-5

Topics: I: Desarrollo de la propuesta técnica. **II:** Ejecución de ensayos o simulaciones numéricas.

Learning Outcomes I: Dominar el formato de tesis de la Universidad utilizando LaTeX [Assessment]. **II:** Concluir el capítulo del Marco Teórico y Trabajos Relacionados [Assessment]. **III:** Presentar resultados (formales o estadísticos) de experimentos orientados a su tema de tesis [Assessment].

Bibliography: [ASTM, 2021]

6. Bibliography

[ASTM, 2021] ASTM (2021). *Form and Style for ASTM Standards*. ASTM International.

[Meredith, 1993] Meredith, J. (1993). Theory building through conceptual methods. *International Journal of Operations & Production Management*.

[Yin, 2018] Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods*. SAGE Publications, 6th edition.

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CE3C13 Project Planning and Control (Elective)

1. General information

- **Semester**: 10th Sem. **Credits**: 4
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 2 hours;
- **Prerrequisites**:
  - CE3C5 Costs and Budgeting (9th Sem-Pg. 445)

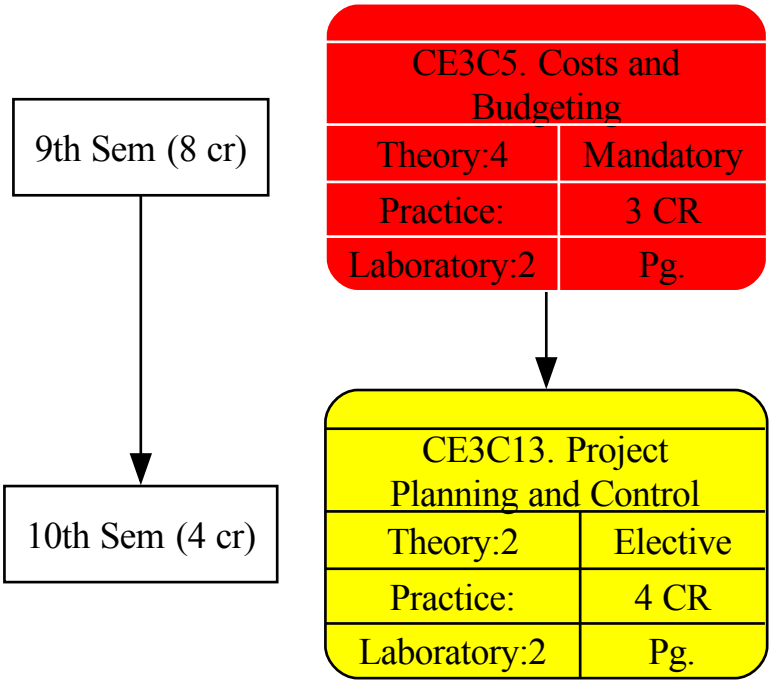

Figure 7.80: Connection Map. CE3C13 Project Planning and Control

2. Course Rationale

Project Planning and Control introduces strategic planning and management plans according to the PMBOK guide, project planning, scheduling, and control using the Critical Path Method (CPM) and 4D/5D modeling, project management and control philosophies, and the soft and managerial skills necessary to lead project teams.

3. Goals of the Course

- Apply strategic planning and management plans according to the PMBOK guide to a construction project.
- Plan, schedule, and control a project using the Critical Path Method (CPM) and 4D/5D modeling tools.
- Apply management philosophies to the control of construction projects.
- Develop soft and managerial skills in communication, leadership, teamwork, and conflict resolution.

4. General Competences (*Outcomes*)

ABET-2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Usage)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Planning Principles, 16 hr(s)

Competences: ABET-2

Topics: **I:** Planning as an ongoing and iterative activity throughout the project life cycle **II:** Just-enough planning: balancing detail with flexibility based on uncertainty **III:** Relationship between planning depth and the selected development approach **IV:** Adaptive planning: rolling wave, progressive elaboration, and iterative refinement

Learning Outcomes **I:** Describe the principles of iterative and just-enough planning in PMBoK 7th edition [Familiarity] **II:** Apply adaptive planning principles to a project with high uncertainty and evolving requirements [Assessment] **III:** Evaluate whether a project's planning approach provides sufficient detail and flexibility for its uncertainty level [Assessment]

Bibliography: [Institute, 2021]

5.2 Project Planning, Scheduling, and Control (CPM, 4D/5D), 16 hr(s)

Competences: ABET-2

Topics: **I:** Work breakdown structure (WBS) development and activity definition **II:** Network diagramming: activity-on-node (AON) and precedence diagramming method (PDM) **III:** Critical Path Method (CPM) for schedule calculation: forward/backward pass, floats **IV:** Resource allocation, loading, and leveling techniques **V:** Schedule updating, monitoring, and control using earned value management (EVM) **VI:** Program Evaluation and Review Technique (PERT) for schedule risk analysis **VII:** Line of balance (LOB) scheduling for repetitive projects **VIII:** 4D scheduling (time + 3D model) for visualization and clash detection **IX:** 5D scheduling (time + cost + 3D model) for integrated cost control

Learning Outcomes **I:** Develop a Work Breakdown Structure (WBS) for a medium-scale construction project [Usage] **II:** Construct a CPM network diagram and calculate the critical path and activity floats [Assessment] **III:** Perform resource leveling on a simple project schedule to minimize resource fluctuations [Usage] **IV:** Monitor project progress using schedule variance (SV) and cost variance (CV) from earned value data [Assessment] **V:** Apply PERT to estimate project duration probabilities and identify schedule risks [Assessment] **VI:** Create a Line of Balance (LOB) schedule for a repetitive housing project [Usage] **VII:** Generate a 4D simulation to visualize the construction sequence and identify spatial conflicts [Usage] **VIII:** Integrate cost data with a 3D model to perform a 5D analysis for budget tracking [Assessment]

Bibliography: [Callahan et al., 1992]

5.3 Lean Construction and Integrated Project Delivery (IPD), 12 hr(s)

Competences: ABET-1

Topics: **I:** Lean thinking principles: value, value stream, flow, pull, perfection **II:** Identification and elimination of the eight wastes in construction **III:** Last Planner System (LPS) for production planning and control **IV:** Visual management tools: 5S, Kanban, and Andon **V:** Integrated Project Delivery (IPD) principles and multi-party agreements **VI:** Target Value Delivery (TVD)

and Set-Based Design **VII:** Collaboration technologies and Big Room co-location **VIII:** Performance measurement: Percent Plan Complete (PPC), Takt time **IX:** Culture change and implementation strategies for lean transformation

Learning Outcomes **I:** Define the seven (or eight) types of waste (Muda) in a construction context [Familiarity] **II:** Apply the Last Planner System to develop a reliable weekly work plan [Usage] **III:** Identify opportunities to apply visual management (5S) on a construction site [Assessment] **IV:** Explain how Integrated Project Delivery (IPD) aligns goals and shares risk among project stakeholders [Familiarity] **V:** Use Target Value Delivery principles to guide design decisions within a cost target [Assessment] **VI:** Facilitate a collaborative pull planning session with multiple trades [Usage] **VII:** Calculate and interpret Percent Plan Complete (PPC) as a lean performance metric [Assessment] **VIII:** Develop a basic implementation plan for introducing lean practices to a project team [Assessment]

Bibliography: [Ballard, 2000]

5.4 Leadership, Team Dynamics, and Stakeholder Management, 12 hr(s)

Competences: ABET-1

Topics: **I:** Leadership styles, traits, and the difference between leadership and management **II:** Team dynamics: forming, storming, norming, performing stages and roles **III:** Conflict resolution strategies and negotiation **IV:** Stakeholder identification, analysis, and engagement planning **V:** Motivation theories and their application to engineering teams **VI:** Cultural intelligence and leading diverse, global teams **VII:** Change management and leading organizational transformation **VIII:** Emotional intelligence and its role in effective leadership **IX:** Ethical leadership and creating an ethical organizational culture

Learning Outcomes **I:** Describe different leadership styles and identify situations where each might be effective [Familiarity] **II:** Diagnose the stage of development of a project team and propose appropriate interventions [Assessment] **III:** Resolve a simulated interpersonal conflict within a project team using a structured approach [Usage] **IV:** Develop a stakeholder engagement plan for a project with community opposition [Assessment] **V:** Adapt communication and leadership approach when working with a team from a different cultural background [Assessment] **VI:** Explain the key steps in a change management process for implementing a new technology [Familiarity] **VII:** Evaluate one's own emotional intelligence and identify areas for development [Assessment] **VIII:** Model ethical leadership behavior in a team-based project simulation [Usage]

Bibliography: [Robbins and Coulter, 2017]

6. Bibliography

[Ballard, 2000] Ballard, G. (2000). The last planner system of production control. *PhD Thesis, University of Birmingham*.

[Callahan et al., 1992] Callahan, M. T., Quackenbush, D. G., and Rowings, J. E. (1992). *Construction Project Scheduling*. McGraw-Hill.

[Institute, 2021] Institute, P. M. (2021). *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. Project Management Institute, 7th edition.

[Robbins and Coulter, 2017] Robbins, S. P. and Coulter, M. (2017). *Management*. Pearson, 14th edition.

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CE3C14 Sustainable and Resilient Infrastructure (Elective)

1. General information

- **Semester**: 10th Sem. **Credits**: 3
- **Hour of this course**: **Theory**: 2 hours; **Laboratory**: 1 hours;
- **Prerrequisites**:
  - CE2C1 Materials Technology (7th Sem-Pg. 366)
  - CE2C2 Construction Technology I (7th Sem-Pg. 371)

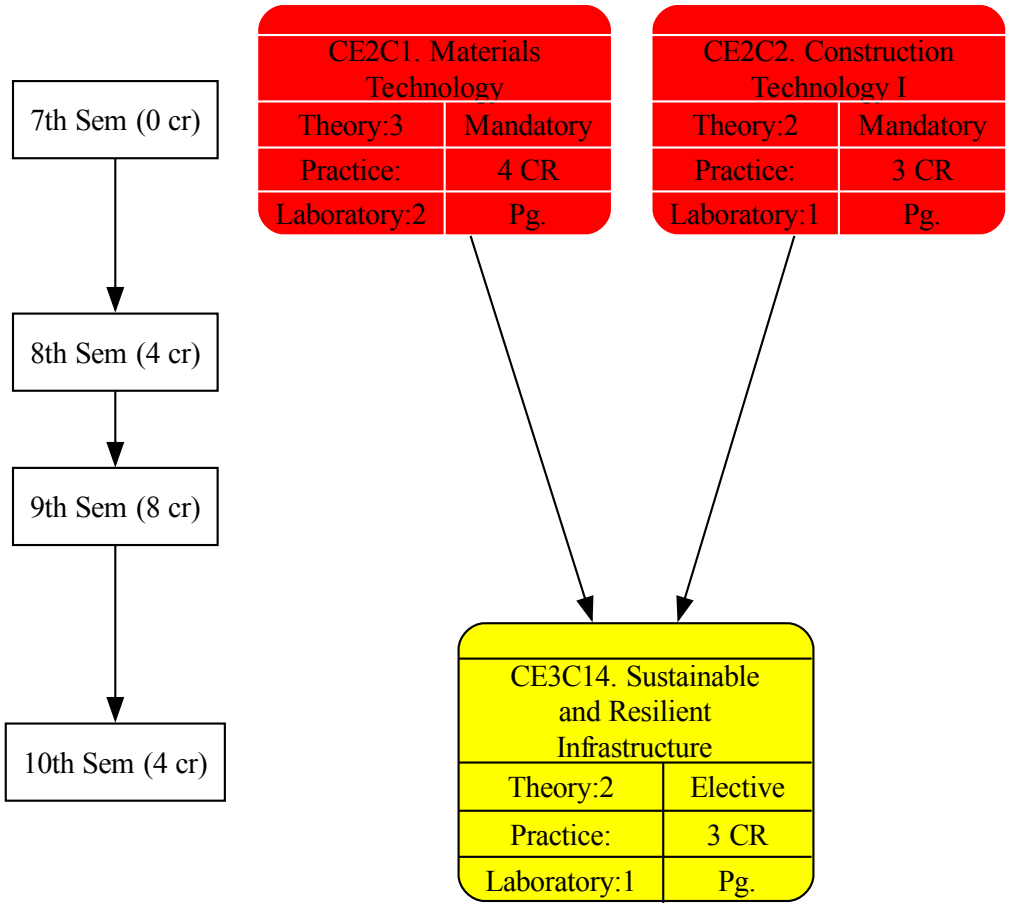

Figure 7.81: Connection Map. CE3C14 Sustainable and Resilient Infrastructure

2. Course Rationale

Sustainable Infrastructure covers the principles, planning, design, materials, and management of sustainable infrastructure: the triple bottom line, life-cycle thinking, resource efficiency, the circular economy, and the social, economic, and governance dimensions of sustainable infrastructure projects.

3. Goals of the Course

- Apply the principles of sustainable infrastructure to the planning, design, materials, and operation of construction projects.
- Evaluate the sustainable performance of an infrastructure project and its governance.

4. General Competences (*Outcomes*)

ABET-1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (Usage)

5. Content

5.1 Foundational Sustainability Principles and Triple Bottom Line, 15 hr(s)

Competences: ABET-1

Topics: **I:** Triple bottom line (TBL) framework and sustainability metrics **II:** Life-cycle thinking and stage-gate analysis for infrastructure projects **III:** Regenerative design and net-positive impact goals

Learning Outcomes **I:** Define the three pillars of the triple bottom line and give an infrastructure-related example for each [Familiarity] **II:** Apply life-cycle thinking to compare the long-term impacts of two alternative paving materials [Assessment] **III:** Develop a project goal for achieving a net-positive environmental impact [Assessment]

Bibliography: [Kibert, 2016]

5.2 Resource Efficiency and Circular Economy, 15 hr(s)

Competences: ABET-1

Topics: **I:** Resource efficiency: energy, water, and material consumption minimization **II:** Circular economy principles: reduce, reuse, recycle, recover (R4) **III:** Sustainable procurement and supply chain management

Learning Outcomes **I:** Calculate the embodied energy or water footprint of a simple structural component [Usage] **II:** Explain how circular economy principles can be applied to construction and demolition waste [Familiarity]

Bibliography: [Kibert, 2016]

5.3 Social, Economic, and Governance Dimensions of Sustainable Infrastructure, 16 hr(s)

Competences: ABET-1

Topics: **I:** Social sustainability: equity, accessibility, and community well-being **II:** Economic sustainability: life-cycle costing and total cost of ownership **III:** Policy frameworks and green rating systems (e.g., Envision, LEED for Infrastructure)

Learning Outcomes **I:** Evaluate the social equity implications of a proposed transportation project [Assessment] **II:** Perform a life-cycle cost analysis to justify a higher initial investment in a durable material [Usage] **III:** Use a green infrastructure rating system checklist to assess a project's sustainability performance [Familiarity]

Bibliography: [Kibert, 2016]

6. Bibliography

[Kibert, 2016] Kibert, C. J. (2016). *Sustainable Construction: Green Building Design and Delivery.* Wiley, 5th edition.

Chapter 8

Professors & Courses

Taught courses by professor

There are no professors assigned in this document.

Professor assigned per course

- First Semester
  - MA100 . Basic Mathematics (Pág 245)
    - There is no professor for this course
  - MA111 . Calculus I (Pág 249)
    - There is no professor for this course
  - BCH101 . Chemistry I (Pág 251)
    - There is no professor for this course
  - BME101 . Learning Methodology Workshop (Pág 255)
    - There is no professor for this course
  - BRC101 . Writing and Communication (Pág 260)
    - There is no professor for this course
  - BIC101 . Introduction to Programming (Pág 262)
    - There is no professor for this course
  - BEC101 . General Economics (Pág 266)
    - There is no professor for this course
- Second Semester
  - CE1G1 . General Geology (Pág 270)
    - There is no professor for this course
  - CS100 . Introduction to Computer Science (Pág 274)
    - There is no professor for this course
  - AI161 . Applied AI (Pág 284)
    - There is no professor for this course
  - CB1E1 . Technical Drawing & CAD (Pág 288)
    - There is no professor for this course
  - MA112 . Calculus II (Pág 291)
    - There is no professor for this course
  - BFI101 . General Physics (Pág 295)
    - There is no professor for this course
  - ID101 . Technical and professional English I (Pág 300)
    - There is no professor for this course
  - BEF201 . Ethics and Political Philosophy (Pág 303)
    - There is no professor for this course
- Third Semester
  - CE1M1 . Statics (Pág 306)

    - ∗ There is no professor for this course
  - CB1E2 . Engineering Drawing II (Pág 309)
    - ∗ There is no professor for this course
  - MA121 . Linear Algebra I (Pág 312)
    - ∗ There is no professor for this course
  - MA210 . Calculus III (Pág 314)
    - ∗ There is no professor for this course
  - BFI102 . Physics II (Pág 317)
    - ∗ There is no professor for this course
  - ID102 . Technical and professional English II (Pág 322)
    - ∗ There is no professor for this course
- Fourth Semester
  - CE1M2 . Dynamics (Pág 326)
    - ∗ There is no professor for this course
  - CE2M1 . Mechanics of Materials I (Pág 329)
    - ∗ There is no professor for this course
  - CE3M1 . Concrete Technology (Pág 332)
    - ∗ There is no professor for this course
  - MA202 . Numerical Methods (Pág 335)
    - ∗ There is no professor for this course
  - MA211 . Calculus IV (Pág 340)
    - ∗ There is no professor for this course
  - STA251 . Statistics and Probability (Pág 343)
    - ∗ There is no professor for this course
  - ID201 . Technical and professional English III (Pág 348)
    - ∗ There is no professor for this course
- Fifth Semester
  - CE2M2 . Mechanics of Materials II (Pág 352)
    - ∗ There is no professor for this course
  - ID202 . Technical and professional English IV (Pág 355)
    - ∗ There is no professor for this course
- Sixth Semester
  - MA212 . Ordinary Differential Equations (Pág 359)
    - ∗ There is no professor for this course
  - ID203 . Technical and professional English V (Pág 362)
    - ∗ There is no professor for this course
- Seventh Semester
  - CE2C1 . Materials Technology (Pág 366)
    - ∗ There is no professor for this course
  - CE2C2 . Construction Technology I (Pág 371)
    - ∗ There is no professor for this course
  - CE2C6 . Territorial Planning (Pág 374)
    - ∗ There is no professor for this course
  - CE2C8 . Business Management in Construction I (Pág 377)
    - ∗ There is no professor for this course
  - CE2G1 . Soil Mechanics I (Pág 381)
    - ∗ There is no professor for this course
  - CE2H1 . Fluid Mechanics I (Pág 384)
    - ∗ There is no professor for this course
  - CE2S1 . Structural Analysis I (Pág 391)
    - ∗ There is no professor for this course
  - CE2S2 . Reinforced Concrete Design I (Pág 394)
    - ∗ There is no professor for this course
  - CE2S3 . Steel Design (Pág 397)
    - ∗ There is no professor for this course
- Eighth Semester

  - CE2C3. Concrete Technology I (Pág 400)
    - There is no professor for this course
  - CE2C5. Construction Project Management (Pág 405)
    - There is no professor for this course
  - CE2C7. Business Organization and Management (Pág 408)
    - There is no professor for this course
  - CE2G2. Soil Mechanics II (Pág 413)
    - There is no professor for this course
  - CE3C2. Construction Technology II (Pág 417)
    - There is no professor for this course
  - CE3H1. Fluid Mechanics II (Pág 422)
    - There is no professor for this course
  - CE3S1. Structural Analysis II (Pág 425)
    - There is no professor for this course
  - CE3S5. Bridges and Structures (Pág 429)
    - There is no professor for this course
  - CE3S9. Prestressed Concrete (Pág 432)
    - There is no professor for this course
  - BMI201. Methodology of Engineering Research (Pág 435)
    - There is no professor for this course
- Ninth Semester
  - CE3C15. Professional Competencies Workshop (Pág 438)
    - There is no professor for this course
  - CE3C5. Costs and Budgeting (Pág 445)
    - There is no professor for this course
  - CE3C9. Integrated Construction Management (Pág 448)
    - There is no professor for this course
  - CE3G3. Applied Geology (Pág 453)
    - There is no professor for this course
  - CE3G4. Soil Mechanics Applied to Transportation Roads (Pág 458)
    - There is no professor for this course
  - CE3G5. Finite Elements Applied to Geotechnical Engineering (Pág 461)
    - There is no professor for this course
  - CE3G6. Earth Dams (Pág 464)
    - There is no professor for this course
  - CE3H2. General Hydrology (Pág 469)
    - There is no professor for this course
  - CE3H3. Water Supply and Sewerage (Pág 471)
    - There is no professor for this course
  - CE3H4. Water Resources (Pág 481)
    - There is no professor for this course
  - CE3S11. Professional Competency Workshop - Structures (Pág 487)
    - There is no professor for this course
  - CE3S4. Earthquake-Resistant Engineering and Disaster Prevention (Pág 494)
    - There is no professor for this course
  - CE3S8. Architecture and Structural Models (Pág 497)
    - There is no professor for this course
  - CE402. Capstone project I (Pág 504)
    - There is no professor for this course
  - BLW201. Law and Legislation (Pág 506)
    - There is no professor for this course
- Tenth Semester
  - CE3C11. Sanitary and Electrical Installations (Pág 512)
    - There is no professor for this course
  - CE3G1. Soil Dynamics (Pág 515)
    - There is no professor for this course

- CE3G2. Soil Mechanics Applied to Foundations (Pág 518)
  - There is no professor for this course
- CE3G7. Professional Competencies Workshop - Geotechnical (Pág 523)
  - There is no professor for this course
- CE3H5. Introduction to Fluvial Hydraulics (Pág 529)
  - There is no professor for this course
- CE3H6. Irrigation Engineering (Pág 533)
  - There is no professor for this course
- CE3H7. Hydraulic and Hydrology Engineering Workshop (Pág 537)
  - There is no professor for this course
- CE3S10. Seismic Design of Civil Engineering Works (Pág 540)
  - There is no professor for this course
- CE3S12. Research Workshop (Pág 544)
  - There is no professor for this course
- CE3S2. Reinforced Concrete Design II (Pág 549)
  - There is no professor for this course
- CE3S6. Masonry, Adobe, and Timber (Pág 554)
  - There is no professor for this course
- CE3S7. Structural Rehabilitation and Retrofitting (Pág 557)
  - There is no professor for this course
- CE403. Capstone project II (Pág 561)
  - There is no professor for this course
- CE3C13. Project Planning and Control (Pág 563)
  - There is no professor for this course
- CE3C14. Sustainable and Resilient Infrastructure (Pág 566)
  - There is no professor for this course

Chapter 9

Equivalences with Other Curriculum Plans

Below are the equivalences of this curriculum with the previous curriculum plan(s). For more details on the proposed curriculum, see section 6.2 (p. 192).

Chapter 10

Laboratories

BCH101. Chemistry I (Mandatory) 1st Sem, Lab: 2 hr(s)

Chemistry Laboratory:

- **Equipment**: Spectrophotometers (Thermo Fisher, Unico), water bath, turbidimeter, and pH meter.
- **Analysis**: Water testing (sulfates, chlorides, pH, organic matter) under NTP and ASTM standards.

BIC101. Introduction to Programming (Mandatory) 1st Sem, Lab: 4 hr(s)

FIC Computer Center:

- **Infrastructure**: 5 computer labs (A, B, C, D, E) equipped with Core i7-13700 processors, 16GB RAM, and SSD/M.2 drives.
- **Software**: AutoCAD 2026, Civil 3D 2026, Revit 2026, Recap, Octave, Dev C++, and PSI.

AI161. Applied AI (Mandatory) 2nd Sem, Lab: 4 hr(s)

FIC Computer Center:

- **Infrastructure**: 5 computer labs (A, B, C, D, E) equipped with Core i7-13700 processors, 16GB RAM, and SSD/M.2 drives.
- **Software**: AutoCAD 2026, Civil 3D 2026, Revit 2026, Recap, Octave, Dev C++, and PSI.

CB1E1. Technical Drawing & CAD (Mandatory) 2nd Sem, Lab: 2 hr(s)

FIC Computer Center:

- **Infrastructure**: 5 computer labs (A, B, C, D, E) equipped with Core i7-13700 processors, 16GB RAM, and SSD/M.2 drives.
- **Software**: AutoCAD 2026, Civil 3D 2026, Revit 2026, Recap, Octave, Dev C++, and PSI.

BFI102. Physics II (Mandatory) 3rd Sem, Lab: 2 hr(s)

Physics Laboratory:

- **Equipment and Tools**: Optical benches, force tables, pendulums, dynamic carts, spectrometers, PASCO sensors, and measurement modules (multimeters, power supplies, calipers).
- **Hardware and Technology**: Academic-use laptops, Arduino sensors, and modules for data acquisition.

- **Software**: Arduino IDE, MATLAB for analysis, Microsoft Office, and specialized experimental data acquisition software.
- **Services and Experiments**: Physics I and II lab sessions (Mechanics, Thermodynamics, Electromagnetism, Waves), instrumentation training, and support for research projects.

CE2C1. Materials Technology (Mandatory) 7th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C2. Construction Technology I (Mandatory) 7th Sem, Lab: 1 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C6. Territorial Planning (Mandatory) 7th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C8. Business Management in Construction I (Mandatory) 7th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C3. Concrete Technology I (Mandatory) 8th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C5. Construction Project Management (Mandatory) 8th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE2C7. Business Organization and Management (Mandatory) 8th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C2. Construction Technology II (Mandatory) 8th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C15. Professional Competencies Workshop (Mandatory) 9th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C5. Costs and Budgeting (Mandatory) 9th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C9. Integrated Construction Management (Mandatory) 9th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C11. Sanitary and Electrical Installations (Mandatory) 10th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C13. Project Planning and Control (Elective) 10th Sem, Lab: 2 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.

CE3C14. Sustainable and Resilient Infrastructure (Elective) 10th Sem, Lab: 1 hr(s)

Materials Testing Laboratory (LEM):

- **Equipment**: 3000kN hydraulic press, digital sclerometer (rebound hammer), rebar detector, corrosion analyzer, and ultrasonic testing equipment.
- **Focus**: Testing of masonry, steel, concrete (diamond core drilling, mix design), and timber.
- **Innovation**: Implementation of Virtual Reality for BIM technologies linked to material testing.