CIVIL AND ENVIRONMENTAL ENGINEERING

Mission Statement

The mission of the Department of Civil and Environmental Engineering is to provide an academic environment where professional education can be pursued, scholarly research in science and technology can be conducted, and the interest of the public can be served through the advancement of knowledge.

In pursuit of this mission, the administration, faculty, and staff join to provide a broad-based, rigorous professional education in civil engineering at the undergraduate level; a graduate education at the master's level in major areas of civil engineering; and doctoral programs in selective areas of excellence within civil engineering.

Educational Objectives of the Bachelor of Science Program

The civil engineering undergraduate program of study prepares its graduates with the following capabilities necessary to attain career and professional accomplishments:

- Technical knowledge: students are able to use their technical knowledge and expertise in mathematics, science, and engineering to identify, formulate, and solve problems involving design, experimentation, and analysis of a wide variety of civil engineering applications;
- Team skills: students develop leadership skills, demonstrate proficiency in all forms of communication, and perform well in a multidisciplinary team environment;
- Continuous education: students recognize the need for continuing their education through graduate studies, continuous education opportunities, and/or self-education;
- Professionalism: students are prepared to exercise the highest standards of personal and professional integrity, demonstrate an understanding of the ethical and professional issues related to the procurement of work, and provide coordination between the design and construction aspects of the civil engineering profession.

These objectives are accomplished through a rigorous curriculum that emphasizes fundamentals in basic sciences, mathematics, humanities, and engineering in five major areas of civil engineering: environmental engineering, geotechnical engineering, structural engineering, water resources engineering, and transportation engineering. The curriculum enables students to use modern engineering tools to work individually and in teams. The curriculum contains a well-structured set of courses that enable students to develop the required analytical, experimental, and design skills.

Educational Outcomes of the Bachelor of Science Program

The civil engineering undergraduate program of study prepares its graduates to have the following capabilities for career and professional advancement:

- Apply knowledge of mathematics, science, and engineering; design and conduct experiments; and analyze and interpret data;
- Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, health and safety, manufacturability, and sustainability constraints;
- Identify, formulate, and solve engineering problems;
- Use the techniques, skills, and modern engineering tools necessary for engineering practice;
- Function on multidisciplinary teams; and
- Communicate effectively.

Students are provided with the broad education necessary to understand the impact of engineering solutions in a global economic, environmental, and social context; a knowledge of contemporary issues; an understanding of professional and ethical responsibility; and a recognition of the need for and ability to engage in lifelong learning.

The civil engineering undergraduate program curriculum includes coverage of proficiency in mathematics through differential equations, probability and statistics, calculus-based physics, and general chemistry; proficiency in a minimum of four recognized major civil engineering areas; the ability to conduct laboratory experiments and to critically analyze and interpret data in more than one of the recognized major civil engineering areas; the ability to perform civil engineering design by means of design experiences integrated throughout the professional component of the curriculum; and an understanding of professional practice issues such as procurement of work, bidding versus quality-based selection processes, how the design professionals and the construction professions interact to construct a project, the importance of professional licensure and continuing education, and/or other professional practice issues.

UNDERGRADUATE

Bachelor's programs

- Bachelor of Science with a major in civil engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/bs-civil-engineering/)
- Bachelor of Science with a major in civil engineering, environmental engineering option (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/bs-civil-engineering/environmental/)

Combined programs

- Dual Bachelor of Science with a major in civil engineering and Master of Science in the field of environmental engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/combined-bs-ms-environmental-engineering/)
- Dual Bachelor of Science with a major in civil engineering and Master of Science in the field of structural engineering (https://bulletin.gwu.edu/engineering-applied-science/

civil-environmental-engineering/combined-bs-ms-structural-engineering/)

- Dual Bachelor of Science with a major in civil engineering and Master of Science in the field of transportation engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/combined-bs-ms-transportation-engineering/)

GRADUATE

Master's program

- Master of Engineering in the field of construction engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/construction-engineering-meng/)
- Master of Science in the field of civil and environmental engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/ms/)

Doctoral program

- Doctor of Philosophy in the field of civil and environmental engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/phd/)

CERTIFICATES

Graduate certificate programs

- Environmental engineering
- Geoenvironmental engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/geoenvironmental-engineering/)
- Smart cities and transportation (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/smart-cities-transportation/)
- Structural engineering (https://bulletin.gwu.edu/engineering-applied-science/civil-environmental-engineering/structural-engineering/)

FACULTY

Faculty

Professors: S.S. Badie, M.T. Manzari (*Chair*), R. Riffat, K. Roddis, P.F. Silva, T. Li

Associate Professors: L. Farhadi, S.H. Hamdar, D. Shuai

Assistant Professors: X. Liu, Z. Xu

Research Professor: K.H. Digges

Professorial Lecturers: M.O. Critchfield, K. Garrahan, K. Ghavami, F. Sadek, C. Tin

COURSES

Explanation of Course Numbers

- Courses in the 1000s are primarily introductory undergraduate courses
- Those in the 2000s to 4000s are upper-level undergraduate courses that also may be taken for graduate credit with permission and additional work assigned
- Those in the 6000s and 8000s are for master's, doctoral, and professional-level students
- The 6000s are open to advanced undergraduate students with approval of the instructor and the dean or advising office

CE 1010. Introduction to Civil and Environmental Engineering. 1 Credit.
An introduction to the profession of civil and environmental engineering. Field visits and laboratory exercises complement classroom instruction. (Fall)

CE 1020. Introduction to a Sustainable World. 1 Credit.
The science underlying the basic processes that gave rise to the world we live in and that maintain its viability for human life. Ecosystem-functioning environmental issues, such as greenhouse gas emission and ozone, with current efforts to resolve them. Technological innovations in the context of sustainability.

CE 1098. Variable Topics. 1-36 Credits.

CE 1099. Variable Topics. 1 Credit.

CE 2210. Engineering Computations. 3 Credits.
Numerical methods for engineering applications. Methods for solving systems of linear equations, root finding, curve fitting, and data approximation. Numerical differentiation and integration and numerical solution of differential equations. Computer applications. Prerequisites: APSC 2113 and CSCI 1121. (Spring)

CE 2220. Introduction to the Mechanics of Solids. 3 Credits.
Stress and strain, axial load problems, torsion, shear force and bending moment, pure bending of beams, shearing stresses in beams, compound stresses, analysis of plane stress and plane strain, combined stresses, deflection of beams, statically indeterminate problems, columns, energy methods. Prerequisites: APSC 2057 and APSC 2113. (Fall and spring, Every year)

CE 2510. Environmental Sustainability. 3 Credits.
An introduction to environmental sustainability with focus on the nexus of water, energy, and climate; energy demands of water systems, water footprints of energy generation, and how the two valuable resources are limiting each other; technologies and research frontiers toward a sustainable water and energy supply.

CE 2710. Introduction to Transportation Engineering. 3 Credits.
Transportation system components; roadway traffic capacity and network performance measures; signalized and un-signalized intersections; monitoring techniques, instruments and data processing. Sustainability issues and environmental impact of transportation systems with focus on urban design, planning and regulation. Prerequisite: MATH 2233. (Spring, Every year)

CE 3110W. Civil Engineering Materials. 2 Credits.
Mechanical properties and behavior of civil engineering materials such as metals, concrete, and fiber-reinforced polymer composites. Properties range from plastic deformations of metallic materials to crushing of confined and unconfined concrete. Basis of the strength of materials. Concepts of creep, fatigue, fracture, and crack propagation. Includes a significant engagement in writing as a form of critical inquiry and scholarly expression to satisfy the WID requirement. Prerequisites: CE 2220 and CHEM 1111. (Fall, Every year)

CE 3111W. Civil Engineering Materials Lab. 1 Credit.
Measurement of stress–strain characteristics and study of failure modes in ductile steel, brittle concrete, and anisotropic composite materials. Experiments include data collection, data analysis, and interpretation and presentation of results regarding tension, compression, bending, impact, and shear properties. Includes a significant engagement in writing as a form of critical inquiry and scholarly expression to satisfy the WID requirement. CE 3110W may be taken as a corequisite. Prerequisites: CE 3110W. (Fall)

CE 3230. Structural Theory I. 3 Credits.
Theory of statically determinate structures; stability and determinacy; influence lines and moving loads. Analysis of beams, frames, trusses, and arches. Calculation of deflections. Prerequisites: CE 2210 and CE 2220. (Fall, Every year)

CE 3240. Structural Theory II. 3 Credits.
Theory of statically indeterminate structures using matrix methods and classical approaches such as moment distribution and slope-deflection; influence lines; energy methods. Prerequisite: CE 3230. (Spring, Every year)

CE 3250. Structural Analysis. 3 Credits.
Stability and determinacy; equilibrium and compatibility; virtual work, flexibility method, stiffness method, computer implementation, and influence lines. Prerequisites: CE 2210 and CE 2220. (Fall, Every year)

CE 3310. Reinforced Concrete Structures. 3 Credits.
Properties of concrete and reinforcement; design of flexural reinforcement, shear reinforcement; development of reinforcement; design of columns, floor slabs; ethics and professionalism in design. A design project, including the use of computer software and a detailed report, is required. CE 3240 may be taken as a corequisite. Prerequisite: CE 3240. (Fall and spring, Every year)

CE 3311. Reinforced Concrete Design Project. 1 Credit.
Reinforced concrete structures design, framing system, preliminary/final design, load estimate, one-way slabs, beams, axially loaded columns and isolated foundation, reinforcement details, CAD drawings, and final report. Restricted to undergraduate students in civil and environmental engineering. Prerequisites: CE 3230. Corequisites: CE 3310. (Spring, Every year)

CE 3520. Environmental Engineering Design: Drinking Water Treatment. 3 Credits.
Water quality and characteristics. Basic water chemistry and kinetics. Principles and design of drinking water treatment processes. Use of engineering economic analysis for process selection. Use of design software for drinking water process design. Prerequisites: CHEM 1111 and MAE 3126. Credit cannot be earned for this course and CE 6502. (Spring, Every year)

CE 3521. Environmental Engineering Laboratory. 1 Credit.
Laboratory experiments for physical and chemical analyses of water and wastewater. Measurement of turbidity, alkalinity, dissolved oxygen, BOD, COD, suspended solids, and optimum coagulant dose using jar tests. Corequisite: CE 3520.

CE 3604. Physical Hydrology. 3 Credits.
Hydrologic cycle, atmosphere, radiation, precipitation, evaporation, transpiration, infiltration, groundwater flow and stream flow. watershed and drainage basins, hydrograph analysis and stream-flow routing. Flood frequency statistics and analysis. Prerequisites: APSC 3115. Corequisites: MAE 3126. (Fall, Every year)

CE 3610. Hydraulics of Open Channel Flow. 3 Credits.
Energy and momentum principles. Types and regimes of flow. Hydraulic jump; flow over steps and contracted areas, single and composite water profiles. Flow in non-prismatic channels and channel design. Prerequisites: MAE 3126. (Spring, Every year)

CE 3611. Hydraulics Laboratory. 1 Credit.
Laboratory experiments and demonstrations of hydraulics in pipe and open-channel flow. Topics include center of pressure, floating bodies, Bernoulli's theorem, discharge coefficients, velocity profile, and head losses. Prerequisite or corequisite: CE 3610.

CE 3720. Highway Engineering and Design. 3 Credits.
Road vehicle performance. Principles of highway design: horizontal and vertical alignments, roadside design; drainage and drainage structures, earthwork, intersections, interchanges, parking facilities; basic traffic models; highway materials. Application of safety standards. APSC 3115 and CE 2220 may be taken as a corequisite. Prerequisites: APSC 3115, CE 2220 and MATH 2233. (Fall and spring, Every year)

CE 4320. Metal Structures. 3 Credits.
Principles of the design of metal structures, structural elements, connections, specific problems of analysis including the use of computer software, methods of construction, professionalism in design. Prerequisite: CE 3240.

CE 4330W. Contracts and Specifications. 3 Credits.
Law of contracts, construction contracts, specifications, bidding, insurance and bonds, professional liability, arbitration of disputes, litigation. Includes a significant engagement in writing as a form of critical inquiry and scholarly expression to satisfy the WID requirement. Restricted to juniors and seniors. (Spring, Every year)

CE 4341. Senior Design Project I. 1 Credit.
First in a two-course sequence for the senior design project in civil and environmental engineering. Outcomes include team formation, project selection, task formulation and assignments, preliminary design validation and/or prototyping. Restricted to students in the civil engineering program with senior standing. (Fall, Every year)

CE 4342. Senior Design Project II. 3 Credits.
Second in a two-course sequence for the senior design project in civil and environmental engineering. Application of civil and environmental engineering concepts in the design of a project that integrates the concepts and technical knowledge learned in two or more of the following disciplines: engineering mechanics, materials, environmental engineering, geotechnical engineering, structural engineering, transportation engineering, and water resources engineering. Restricted to students in the civil engineering program with senior standing. Prerequisite: CE 4341. Recommended background: Knowledge of structural analysis of indeterminate structures, reinforced concrete and structural steel design, and soil mechanics. (Spring, Every year)

CE 4410. Introduction to Geotechnical Engineering. 3 Credits.
Soils and rock formation, soil composition, permeability, seepage and flow netanalysis, stresses in soil medium, consolidation and settlement, shear strength of soil, analysis of lateral earth pressures, soil compaction. Prerequisites: CE 2220, CHEM 1111 and MAE 3126. (Fall, Every year)

CE 4411. Geotechnical Engineering Laboratory. 1 Credit.
Laboratory experiments to evaluate liquid and plastic limits, grain-size distribution, shear strength, compressibility, permeability, and moisture–density relationship of soils. CE 4410 may be taken as a corequisite. Prerequisite: CE 4410. (Fall and spring, Every year)

CE 4450. Introduction to Geo-environmental Engineering. 3 Credits.
Characterization of soils and wastes, engineering properties of soils and geo-synthetics, fundamental concepts of fate and transport of contaminants, common practice in design and construction of waste containment systems, current methods for remediation of contaminated groundwater and soils. Prerequisites: CE 3520 and CE 4410. (Spring, Every year)

CE 4530. Wastewater Treatment Design and Reuse. 3 Credits.
Introduction to wastewater treatment systems including clarification, suspended and attached growth processes. Use of dissolved oxygen models. Design of anaerobic digestion systems for energy generation, biosolids production and reuse. Prerequisites: CE 3520. Credit cannot be earned for this course and CE 6504. (Fall, Every year)

CE 4721. Traffic Engineering and Highway Safety. 3 Credits.
Roadway traffic capacity and network performance measures; steady and unsteady traffic flow phenomena; traffic control signalization theory and implementation; monitoring techniques, instruments, and data processing. Traffic related design concepts. (Fall) Credit cannot be earned for this course and CE 6721.

CE 4810. Research. 1-8 Credits.
Applied research and experimentation projects, as arranged. Prerequisite: junior or senior status. (Fall and spring, Every year)

CE 4820. Special Topics. 1-6 Credits.
Topic announced in the Schedule of Classes. May be repeated for credit provided the topic differs.

CE 5099. Variable Topics. 1-99 Credits.

CE 6101. Numerical Methods in Engineering. 3 Credits.
Eigenvalue problems. Numerical solution of systems of equations and ordinary differential equations. Solution techniques for elliptic, parabolic, and hyperbolic partial differential equations. Numerical methods for solving finite element equations. Introduction to solution of fluid-flow problems. Prerequisite: CE 2210.

CE 6102. Application of Probability Methods in Civil Engineering. 3 Credits.
Uncertainty in real-world information; basic probability concepts and models; random variables; useful probability distributions, statistical estimation of distribution parameters from observed data; empirical determination of distribution models; testing hypothesis; regression and correlation analyses; decision theory. Prerequisite: APSC 3115.

CE 6110. Contracts and Specifications In Construction Engineering. 3 Credits.
Overview of contracts, specifications, and the legal environment for engineers; construction contracts, specifications, bidding, contract administration, bonds and securities, dispute resolution. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6111. Project Management For Construction. 3 Credits.
Principles of project management in construction industry. Elements of project management such as structural organization, planning, scheduling, communications, bidding, change orders, contractual relationship, and labor relations and related activities in construction. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6112. Construction Project Acquisition. 3 Credits.
construction management activities, financial activities, and cost estimating software and techniques. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall, Every year)

CE 6113. Construction Contracts, Insurance, and Bonds. 3 Credits.
Common laws used in construction such as contract, tort and statutory/regulatory laws. Elements of project dispute avoidance, subcontracts, project delivery, and insurance and performance and payment bonds. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6114. Construction Methods, Materials, Equipment, and Systems. 3 Credits.
Principles of construction methods, machinery and equipment selection, and production estimation. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6115. Project Planning and Scheduling. 3 Credits.
Fundamentals of project planning and scheduling, scoping estimation risk analysis with a focus on the tools and techniques available to a project planner for mitigation of project risks. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6116. Green Building Design and Construction. 3 Credits.
Sustainability issues and green building design and delivery with a focus on development of commercial and institutional high performance green buildings; LEED ratings and accreditation. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6117. Construction Finance and Engineering Economics. 3 Credits.
Fundamentals of financing construction projects. Commonly used business models, life cycle cost analysis, and software tools for construction project cost control. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6118. Advanced Construction and Computer-Aided Design. 3 Credits.
Integration of construction techniques and computer-aided design; building information modeling and other technologies in various phases of construction management. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall, Every year)

CE 6119. Construction Safety And Quality Control. 3 Credits.
Principles and importance of construction quality assurance and contractor quality control. Quality control methods to assess design activities in design-build contracts. Overview of hazardous situations that may arise in the construction jobsite and methods for mitigation these dangerous situations. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6121. Construction Project Control. 3 Credits.
Basic principles of scope, cost, schedule, risk, and quality management; the organization of construction firms at the general corporate level and the project level, flow of information between parties in the project, scheduling software. Restricted to graduate students or with approval of the department. Recommended background: bachelor's degree in engineering, sciences, and related fields. (Fall and spring, Every year)

CE 6201. Advanced Strength of Materials. 3 Credits.
Deflection of beams using singular functions, unsymmetrical bending of beams, beams on elastic foundation. Beam-column problems, shear center for thin-walled beam cross sections, curved beams. Applications of energy methods, torsion, basic equations for theory of elasticity, thin- and thick-walled cylinders, stress concentration, and failure criteria. Prerequisites: CE 2220 and CE 3240. (Spring, Every year)

CE 6202. Methods of Structural Analysis. 3 Credits.
Theory and applications of modern methods of structural analysis, direct stiffness approach, energy and variational methods, elastoplastic analysis of frames, P-delta effects, application of commonly available structural analysis software. Prerequisites: CE 2220 and CE 3240. (Fall, Every year)

CE 6203. Reliability Analysis of Engineering Structures. 3 Credits.
Probability theory, theory of structural reliability, probabilistic analysis of strength and loads, risk and reliability function, empirical distribution, probability plot. The design service life, method of perturbation, Monte Carlo simulation. Fatigue and fracture, proof testing, inspection and repair–replacement maintenance. Prerequisite: APSC 3115.

CE 6204. Analysis of Plates and Shells. 3 Credits.
Bending and stretching of thin elastic plates under loading with various boundary conditions, continuous plates and plates on elastic foundations, theory of folded-plate structures. Theory of curved surfaces; general linear bending theory and its simplification to membrane theory; bending stresses in shells of revolution, shallow-shell theory. Prerequisites: CE 2220 and CE 3240. (Spring, Odd years)

CE 6205. Theory of Structural Stability. 3 Credits.
General criteria for stability, buckling of elastic and inelastic columns and frames, torsional and lateral buckling, variational methods. Buckling of plates and shells under static loads, stability of stiffened structures, effect of imperfections and boundary conditions. Prerequisites: CE 2220 and CE 3240. (Fall, Every year)

CE 6206. Continuum Mechanics. 3 Credits.
Introduction to the mechanics of continuous media. Tensor calculus; kinematics; stress and stress rate, conservation of mass, conservation of linear and angular momentum, energy balance, second law of thermodynamics; constitutive theory; linear and nonlinear elasticity, newtonian fluids, micropolar elasticity. Prerequisites: CE 2220. (Fall, spring, and summer, Even years)

CE 6207. Theory of Elasticity I. 3 Credits.
Introduction to Cartesian tensors; deformation, stress, constitutive relations for linear elasticity; formulation of boundary value problems, variational principles, torsion and bending of prismatial rods, plane problems. Prerequisites: CE 2220. (Same as MAE 6207) (Spring)

CE 6208. Plasticity. 3 Credits.
Introduction to the continuum theory of plastic deformation. Physical basis of rate-independent plasticity. Concepts of yield, strain hardening and softening, reverse yield, and cyclic plasticity. Constitutive equations describing plastic deformation. Prerequisite: CE 6201 or CE 6206.

CE 6209. Mechanics of Composite Materials. 3 Credits.
Stress–strain relationship for orthotropic materials, invariant properties of an orthotropic lamina, biaxial strength theory for an orthotropic lamina. Mechanics of materials approach to stiffness, elasticity approach to stiffness. Classical lamination theory, strength of laminates. Statistical theory of fatigue damage. Prerequisite: CE 3240. (Spring, Even years)

CE 6210. Introduction to Finite Element Analysis. 3 Credits.
Calculus of variations. Variational formulation of the finite element method. Weighted residual techniques. Computer implementation of the finite element method. Application to problems in heat transfer, stress analysis, fluid flow, and structural analysis. Prerequisites: Proficiency in one computer language; and CE 2220 and CE 3240. (Fall, Every year)

CE 6301. Design of Reinforced Concrete Structures. 3 Credits.
Structural behavior of reinforced concrete structures, ultimate strength and deformation characteristics; design of structural components including beams, columns, floor slabs, deep beams, corbels, and composite slab/beam systems. Prerequisite: CE 3310.

CE 6302. Prestressed Concrete Structures. 3 Credits.
Structural behavior and failure modes of prestressed concrete structures; design in prestressed concrete, including long-span structures, bridges, and precast systems. Prerequisite: CE 3310.

CE 6310. Advanced Reinforced Concrete Structures. 3 Credits.
Conception, analysis, and design of low-rise and high-rise buildings by ultimate-strength methods, precast systems, progressive collapse, earthquake considerations, domes, folded plates, shell-type structures, and special topics. Prerequisite: CE 6301.

CE 6311. Bridge Design. 3 Credits.
Application of basic design procedures for reinforced and prestressed concrete bridges, according to AASHTO bridge specifications. Various types of concrete bridges, design superstructure bridge elements (deck slab, girders, bearing pads), and development of superstructure/substructure details. Prerequisite: CE 6302.

CE 6320. Design of Metal Structures. 3 Credits.
Structural behavior of metal structures and composite girders. Conception, analysis, and design of low-rise and high-rise buildings by elastic and inelastic methods. Earthquake considerations and special topics. Prerequisite: CE 4320.

CE 6321. Advanced Metal Structures. 3 Credits.
Conception and design of advanced structural components and systems, hysteretic behavior, plastic design principles, box-type girders, cable systems, and unique structural systems. Prerequisite: CE 6320. (As arranged)

CE 6340. Structural Dynamics. 3 Credits.
Vibration of continuous systems: membranes, beam plates, and shells; approximate methods of vibration analysis; methods of integral transform; analysis of nonlinear systems; wave propagation. Prerequisites: APSC 2058 and CE 3240. (Fall, Odd years)

CE 6341. Random Vibration of Structures. 3 Credits.
Introduction to random processes, responses of linear structures to stationary and nonstationary random inputs. Structural responses to earthquakes, waves, boundary-layer turbulences, wind loads, etc. Failure analysis of structures under random loads. Prerequisites: APSC 3115 and CE 6340. (Spring, Even years)

CE 6342. Structural Design to Resist Natural Hazards. 3 Credits.
Prediction of forces due to earthquakes and strong winds; generalized codes; pseudostatic methods for preliminary design; codes based on spectra, energy absorption and ductility; influence of foundations; ground failures; static and aeroelastic effects of strong winds. Design project. Prerequisites: CE 3240 and CE 4340; and CE 6340 or CE 6701. (Spring, Every year)

CE 6350. Introduction to Biomechanics. 3 Credits.
Fundamentals of continuum mechanics as they apply to biological materials: concepts of stress, strain, and equilibrium; elastic and viscoelastic properties of solids; physiological fluid mechanics and bioheat and mass transfer. Fundamentals of solid mechanics of soft tissues and bone structures. Development of computer models and applications. Prerequisite: CE 2220. (Fall, Every year)

CE 6401. Fundamentals of Soil Behavior. 3 Credits.
Soil mineralogy, clay–water–electrolyte systems, soil composition, fabric, structure, volume change behavior, permeability, coupled phenomena, in-situ evaluation of soil behavior. Prerequisite: CE 4410. (Fall, Even years)

CE 6402. Theoretical Geomechanics. 3 Credits.
Porous media, stress–strain behavior of soil skeleton, elastic and elastoplastic models for soil behavior, critical state concept, cam clay, strength of soils, stress–dilatancy, stress paths. (Fall, Odd years)

CE 6403. Foundation Engineering. 3 Credits.
Principles of soil mechanics applied to the analysis and design of mat foundations, pile foundations, retaining structures including sheeting and bracing systems, and waterfront structures. Foundations on difficult soils and reinforced earth structures. Prerequisite: CE 4410. (Spring, Every year)

CE 6404. Geotechnical Earthquake Engineering. 3 Credits.
Ground motion, wave propagation, foundation isolation, site response analysis, seismic stability of retaining structures, soil structure interaction. Prerequisite: graduate standing.

CE 6405. Rock Engineering. 3 Credits.
Classification and properties of rock; nature of rock masses and rock discontinuities; field exploration; methods of excavation; design and applications to foundation slopes, tunnels, and chambers in rock. Prerequisite: CE 4410.

CE 6501. Aquatic Chemistry. 3 Credits.
Principles of thermodynamics and kinetics, acid-base chemistry, titration and buffer, alkalinity, carbonate systems, coordination chemistry, precipitation and dissolution, and redox chemistry. Use of software to solve chemical equilibrium problems. Prerequisites: CHEM 1111. (Fall, Every year)

CE 6502. Environmental Engineering Design: Drinking Water Treatment. 3 Credits.
Water quality and characteristics. Basic water chemistry and kinetics. Principles and design of drinking water treatment processes. Use of engineering economic analysis for process selection. Use of design software for drinking water process design. Credit cannot be earned for this course and CE 3520. (Spring, Every year)

CE 6503. Principles of Environmental Engineering. 3 Credits.
Chemical equilibrium and reaction kinetics, phase change and partitioning, acid-base and redox reactions, chemical transport, and reactors. Reactor design of ozone contactor, air stripping tower, activated carbon adsorption, and membrane filtration. Prerequisites: CE 3520. (Fall, Every year)

CE 6504. Wastewater Treatment Design and Reuse. 3 Credits.
Introduction to wastewater treatment systems including clarification, suspended and attached growth processes. Use of dissolved oxygen models. Design of anaerobic digestion systems for energy generation, biosolids production and reuse. Prerequisites: CE 3520. Credit cannot be earned for this course and CE 4530. (Fall, Every year)

CE 6505. Environmental Impact Assessment. 3 Credits.
Public policy and legislation on environmental quality. Methods for assessing impacts of engineering projects. Technology for assessing impacts on air, water, and land environments, applied to transportation facilities, water and wastewater facilities, industrial and community development. Prerequisites: CE 3520. (Fall)

CE 6506. Microbiology for Environmental Engineers. 3 Credits.
Principles of microbiology and their applications to biological processes in the natural environment and engineered systems. Engineering applications, principles of biochemistry and microbiology of drinking water quality, waste and wastewater treatment, and bioremediation. Prerequisite: CE 3520. (Spring, Even years)

CE 6507. Advanced Technologies in Environmental Engineering. 3 Credits.
Theory and application of water reuse. Wastewater as a source, membrane processes, disinfection, chemical oxidation, sorption, ion exchange, nanotechnology, sustainability, case study of water reuse systems. Prerequisites: CE 3520 and CE 4530. (Spring, Every year)

CE 6508. Industrial Waste Treatment. 3 Credits.
Review of various types of industries and waste generation. Principles of waste minimization, utilization, and treatment. Pertinent environmental laws and regulations. Resource recovery from industrial wastes. (Fall, Every year)

CE 6509. Introduction to Hazardous Wastes. 3 Credits.
Regulations, including RCRA and Superfund; transport and fate of hazardous substances; elements of environmental toxicology, risk assessment, and hazard ranking; monitoring, data collection, and evaluation; waste minimization. Prerequisite: CE 3520. (Spring, Every year)

CE 6601. Hydraulics of Open Channel Flow. 3 Credits.
Energy and momentum principles. Types and regimes of flow. Hydraulic jump; flow over steps and contracted areas, single and composite water profiles. Flow in non-prismatic channels and channel design. Prerequisites: MAE 3126 or equivalent. (Spring, Every year)

CE 6602. Hydraulic Engineering. 3 Credits.
Hydraulic design of conveyance, regulating, and measurement structures. Design for spillways, energy dissipators, inlet and outlet works related to dams. Forces on hydraulic structure and stability analysis. Hydraulic turbines and pumps. Design considerations for flow through pipes. Transients and cavitation. Prerequisite: CE 3610.

CE 6603. Design of Dams. 3 Credits.
Project planning and investigations. Types of dams; design of earth–rock fill dams; stability analysis, foundation treatment, wind–wave protection. Construction methods for dams. Reservoir sedimentation. Safety inspection of dams. Prerequisite: CE 3610.

CE 6604. Physical Hydrology. 3 Credits.
Hydrologic cycle, atmosphere, radiation, precipitation, evaporation, transpiration, infiltration, groundwater flow and stream flow. Watershed and drainage basins, hydrograph analysis and stream-flow routing. Flood frequency statistics and analysis. Prerequisites: APSC 3115 or equivalent. Corequisites: MAE 3126 or equivalent.

CE 6605. Ground Water and Seepage. 3 Credits.
Permeability theory of groundwater flow, flow nets, analogs, computer solutions; applications to engineering problems such as excavation dewatering, flow through dams, stabilization of earth slopes. Prerequisites: CE 4410. (Spring)

CE 6606. Mechanics of Water Waves. 3 Credits.
Irrotational theory for deep- and shallow-water waves, reflexion, refraction, diffraction, attenuation. Water waves of finite amplitude: shallow-water theory, tides, bores, long-waves theory, conoidal and solitary waves. Wave generation by wind. Wave breaking and reflexion. Prerequisites: APSC 6213 and permission of the instructor. (Fall and spring, Every year)

CE 6607. Water Resources Planning and Control. 3 Credits.
The parameters of water resources planning and control, economics of water resources and related natural resources, economics of water-quality control, physical parameters of water resource development, water resources law. Prerequisite: CE 4410. (Fall and spring, Every year)

CE 6608. Hydraulic Modeling. 3 Credits.
Dimensional analysis and similitude. Types of models—physical, mathematical. Distortions in physical models. Erodible bed models. Prerequisite: CE 3610.

CE 6609. Numerical Methods in Environmental and Water Resources. 3 Credits.
Use of microcomputers in water resources. Elements of finite difference schemes, basic operations, convergence, stability, and consistency. Nonuniform flow and error analysis; unsteady laminar flow; diffusion problems; unsteady flow in open channels; water hammer, seepage flow, and diffusion–dispersion problems. Prerequisites: CE 2210 and MAE 3126. (Spring, Every year)

CE 6610. Pollution Transport Systems. 3 Credits.
Distribution of pollutants in natural waters and atmosphere, diffusive and advective transport, mathematics for stream pollutant deoxygenation rates, groundwater pollution transport, sediment transport, thermal transport, numerical simulation of pollutant transports in streams and estuaries. Prerequisites: CE 3610 and MAE 2131. (Fall and spring, Every year)

CE 6611. Advanced Hydrology. 3 Credits.
Fundamentals of mass and energy transfer at the land surface, hydrological scaling and spatial heterogeneity, soil moisture, soil temperature, canopy processes and resistance, soil vegetation atmosphere transfer schemes. Prerequisites: CE 3604 or CE 6604 or equivalent. (Spring, Even years)

CE 6701. Analytical Mechanics. 3 Credits.
Fundamental principles, particle and rigid-body dynamics, generalized coordinates, variational principles and Lagrange's equations, nonholonomic systems, Hamilton's equations, theory of small oscillations. Prerequisites: APSC 2058 and APSC 2113. (Fall, Every year)

CE 6702. Vehicle Dynamics. 3 Credits.
Engineering principles and analytical methods explaining the performance of an automotive vehicle. Basic mechanics governing vehicle dynamic performance in longitudinal, ride, and handling modes. Engineering analysis techniques applied to basic systems and subsystems to derive the governing equations. CE 6701 may be taken as a corequisite. Prerequisite: CE 6701. (Spring, Even years)

CE 6705. Nonlinear Finite Element Modeling and Simulation. 3 Credits.
Rigid and flexible body methods for modeling crashes. Application of dynamic nonlinear finite element methods with contact algorithms for modeling crash phenomena. Modeling and simulation of vehicles, airbags, safety restraining systems, and highway barriers. (Spring)

CE 6706. Pavement and Runway Design. 3 Credits.
Pavement types, wheel-load characteristics; stresses in pavements and subgrades; empirical methods of design of flexible and rigid highway and airfield pavements; general principles of runway design. (Spring, Odd years)

CE 6707. Systems Dynamics Modeling and Control. 3 Credits.
Introduction of concepts in control theory and applications to solve problems in civil and transportation engineering dealing with single-input/single-output and multi-input/multi-output systems. Review of classical control theory in the frequency and time domain, state–space analysis, system optimization, and non-linear control. (Fall)

CE 6711. Civil Infrastructure Optimization. 3 Credits.
Optimization methods to analyze, design, and manage civil infrastructures. Linear programming, nonlinear programming, integer programming, and algebraic modeling languages for describing and solving optimization models. Restricted to seniors and graduate students with departmental approval. Prerequisites: CE 2710. (Fall, Odd years)

CE 6712. Data Science and Artificial Intelligence in Civil and Environmental Engineering. 3 Credits.
Data visualization, exploration, cleaning. Geospatial analytics. Training and testing with AI method. Predictive analysis, cross validation. Decision trees, ensemble model, hyper-parameter tuning, time series Restricted to seniors and graduate students with the approval of the department. Prerequisites: APSC 3115, CSCI 1121, CE 2210, CE 2710, CE 3230, CE 3110W, and CE 3520. (Spring, Every year)

CE 6721. Traffic Engineering and Highway Safety. 3 Credits.
Roadway traffic capacity and network performance measures; steady and unsteady traffic flow phenomena; traffic control signalization theory and implementation; monitoring techniques, instruments, and data processing. Traffic related design concepts. (Fall)

CE 6722. Intelligent Transportation Systems. 3 Credits.
Commands, controls, and communications in modern multimodal transportation; infrastructure/highway and vehicle automation, advanced traffic management, vehicle control and safety systems; information, data, and sensory requirements; practical applications and projects. Prerequisites: CE 2710 or CE 3720. Recommended background: Basic knowledge of transportation engineering. (Spring, Every year)

CE 6723. Fundamentals of Highway Safety. 3 Credits.
Highway safety measures, highway crash characteristics and crash data, quantitative highways safety evaluation, standards, processes and methods for safety evaluation and assessment, economic analysis of projects considering safety. Restricted to seniors and graduate students with departmental approval. Prerequisites: CE 2710. (Fall, Every year)

CE 6730. Sustainable Urban Planning. 3 Credits.
Human and physical processes shaping urban ecologies and environments; human-environment interactions in the context of an urban region; urban land use, transport, and planning. Departmental approval is required prior to enrollment. Prerequisites: CE 2710.

CE 6731. Economics of Transportation Systems. 3 Credits.
Paradigms of transportation systems. Consumer theory, demand and cost functions. Market equilibrium, equilibrium of transportation systems, basics of optimization. Network equilibrium, system optimum, and marginal pricing. Restricted to seniors and graduate students with the approval of the department. Prerequisites: CE 2710. (As arranged and spring, Odd years)

CE 6732. Automation and Sensing in Civil and Environmental Engineering. 3 Credits.
Connected and autonomous vehicles. Policy and economic concerns. Driving perception, planning, and prediction needs. Design components. Vehicle dynamics. Longitudinal and lateral control. Communication protocols. Collaborative paradigms. Restricted to seniors and graduate students wit the approval of the department. Prerequisites: APSC 3115, CE 2710, and CSCI 1121, or equivalent courses. (Spring, Even years)

CE 6733. Human Factors in Civil and Environmental Engineering. 3 Credits.
Collecting human subject data; internal review board processes, interview and experimental design, behavioral measurements in simulator environments, statistical analysis and inferences, augmented and virtual reality integration. Restricted to seniors and graduate students with departmental approval. Prerequisites: CE 2710 or equivalent. (Fall, Even years)

CE 6800. Special Topics. 1-6 Credits.
Topic to be announced in the Schedule of Classes.

CE 6801. Civil and Environmental Engineering Graduate Internship. 1 Credit.
May be repeated once for credit. Additional prerequisites may be required for a specific internship as determined by the research supervisor. Restricted to graduate students in the civil and environmental engineering program. Prerequisites: Required courses in the area of focus and permission of the department. (Fall and spring, Every year)

CE 6808. Research. 1-12 Credits.
Basic research projects, as arranged. May be repeated for credit.

CE 6998. Thesis Research. 3 Credits.

CE 6999. Thesis Research. 3 Credits.

CE 8320. Theory of Elasticity II. 3 Credits.
Application of integral transform and analytic function theory to solution of plane problems; elastic wave propagation. Three-dimensional elasto-statics. Prerequisites: APSC 6211 and CE 6207. (Spring, Every year)

CE 8321. Nonlinear Mechanics of Continua. 3 Credits.
Polar decomposition, invariance, isotropy, representation theorems for invariants and isotropic tensor functions. Deformation, kinematics, stress, balance principles. Principles for constitutive relations. Applications to nonlinear elasticity and non-Newtonian fluids. Prerequisite: CE 6206.

CE 8330. Advanced Finite Element Analysis. 3 Credits.
Review of variational formulation of the finite element method. Formulation of various continuum and structural elements. Application to static and dynamic problems in elasticity, plasticity, large deflection, and instability in plates and shells. Recent developments in finite element methods. Prerequisites: CE 6206 and 6210; or MAE 6210 and MAE 6286. (Same as MAE 6288) (Fall and spring, Every year)

CE 8350. Sedimentation Engineering. 3 Credits.
Problems of erosion and sedimentation. Properties of sediment. Initiation of motion. Suspension of sediment and sediment discharge theories. Sedimentation measurements. Economic and legal aspects. Prerequisites: CE 6601 or permission of the department. (Fall and spring, Every year)

CE 8351. Mechanics of Alluvial Channels. 3 Credits.
Physical processes in drainage basins and channels. Channel forms and bed forms. Hydraulics and sediment transport in alluvial channels. Design of stable channels. Qualitative and quantitative response of rivers. Channel stabilization, navigation channels. Case studies including environmental impacts. Prerequisites: CE 6601 or permission of the department. (Fall and spring, Every year)

CE 8352. Advanced Hydraulics. 3 Credits.
Theory of unsteady flow. Diffusion and dispersion through pipes and open channels. Numerical solutions using finite element and finite difference methods. Prerequisites: CE 6601 or permission of the department. (Fall and spring, Every year)

CE 8370. Intelligent Systems Theory and Applications. 3 Credits.
Overview of artificial intelligence, neural networks, genetic algorithms, fuzzy systems, and hybrid intelligent systems and their integration with other information processing methods. Intelligent systems applications; examples are drawn from ITS and traffic engineering, vehicle safety, remote sensing, and structural design optimization. Prerequisite: CE 6707.

CE 8380. Advanced Biomechanics. 3 Credits.
Historical overview of biomechanics and biomaterials. Fundamental concepts in mechanics as applied to the treatment of biological systems. Approaches to the mechanical analysis of the human structure under physiological and non-physiological loading conditions. Constitutive laws for biological materials. Finite element applications. Prerequisite: CE 6206. (Fall and spring, Every year)

CE 8998. Advanced Reading and Research. 1-12 Credits.
Doctoral candidates preparing for qualifying examination. (Fall and spring, Every year)

CE 8999. Dissertation Research. 1-12 Credits.
Doctoral candidate research. Restricted to doctoral candidates. (Fall and spring, Every year)