

CIVIL ENGINEERING

Graduate studies in civil engineering are offered up to the doctoral level through the Department of Civil, Environmental and Architectural Engineering (<http://www.colorado.edu/ceae/>). Fundamental and applied research areas pursued in the civil engineering program include geotechnical engineering and geomechanics, structural mechanics and engineering, construction management and engineering, environmental and geoenvironmental engineering, hydrology, environmental fluid mechanics, civil engineering systems, and engineering science. Together with relevant advanced coursework, graduates possess high competence and versatility to pursue a wide variety of careers in both engineering and non-engineering fields.

Course code for this program is CVEN.

Research Interests and Facilities

The Department has a variety of computational and experimental research facilities. It has multiple disciplinary computer labs as well as the CEAE Bechtel lab which houses dozens of workstations with a wide range of professional engineering analysis software for teaching and research, and owns time and ready access to the university's supercomputer system. Physical experimental facilities for geotechnical engineering and geomechanics research include 3 geotechnical centrifuges, with one being a world-class 440g-ton centrifuge with a servo-controlled shake table for advanced physical simulations and soil model testing. For soil and rock mechanics research, analytical research can be conducted in the M.Y. Leung Computational Lab for Soils and Structures and its graduate experimental soil mechanics lab which houses multiple triaxial and cubical cells for simulating complicated 3D ascending and cyclic stress paths on geomaterials, consolidation devices with load-, deformation- and seepage-control, and special test cells for unsaturated soil mechanics testing. For structural mechanics and material engineering research, sophisticated testing for static and dynamic response of structures and their components is available by means of multiple high-speed high-force actuators, a large strong floor and a hydraulic shake table. Four uniaxial loading frames and MTS equipment for studies of mechanical and durability properties of structural and construction materials under combined load and environmental conditions are in use. Sophisticated real-time hybrid experimental-computational pseudo-dynamic testing of large-scale structures whose critical part is tested physically as a substructure with its measured response serving as input to a computer model of the rest of the structure which in turn computes the next load increment to be applied experimentally to the former in a coupled manner can also be set up.

The hydraulics and water resources research laboratories include excellent facilities in water quality and water resources management for which an advanced networked workstation environment for developing advanced decision support systems is available. For environmental fluid mechanics research and instruction, a state-of-the-art Ecological Fluid Dynamics Laboratory is available for fluid mechanics and studies of the interaction between biological processes and ecological systems from fluid stirring, mixing, and reactions, and how organisms evolved and adapt to their physical environment. The facility utilizes laser-based instrumentation for quantifying turbulence and transport of contaminants, microorganisms and odors. For environmental engineering research, the Sustainable Energy and Environmental Laboratories (SEEL) houses a variety of experimental facilities including multiple liquid chromatography mass spectrometers and an automated solid

phase extraction system. They offer unique opportunities for studies of environmental microbiology, environmental chemistry, water quality, air quality, molecular biology, toxicology and field ecology with modern PCs in all laboratories for instrument control and data acquisition. For building energy and systems research and studies, the Illumination Laboratory is a special facility for testing and evaluating architectural lighting systems as well as daylighting and lighting control design. Its Larson Building Systems Laboratory (<https://www.colorado.edu/ceae/larsonlab/>) is a unique facility in the HVAC industry for both education and research purposes and is designed for dynamic testing of complete and full-scale commercial HVAC and building systems. The facility consists of a full-size commercial HVAC system, four representative commercial building zones, a system for producing repeatable and controllable loads on the HVAC system, and sophisticated data acquisition and control systems. The graduate program in construction engineering and management is well equipped in terms of computer hardware and software, and can arrange access to other unique lab facilities in the department.

To provide further synergy in research, the department operates several centers:

- The Center for Infrastructure, Energy and Space Testing (<https://www.colorado.edu/geotech-centrifuge/>) supports research and instructions in structural and geotechnical testing, characterization of the fundamental mechanical, structural, hydraulic, and thermal properties of materials relevant to the performance of infrastructural systems.
- The Design of Risk-reducing, Innovative-implementable Small-system Knowledge (DeRISK) Center aims to identify, develop, demonstrate and facilitate widespread acceptance and applicability of novel and innovative technologies and approaches to measure or treat groups of microbiological or chemical contaminants, or their precursors, apply novel new information technology systems and improve the sustainability of small drinking water systems.
- The Center for Environmental Mass Spectrometry (CEMS) is a laboratory that focuses on the detection of pharmaceuticals, hormones and other organic contaminants in water and evaluating the effectiveness of methods for removing these compounds.
- The Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) is an interdisciplinary center of excellence that focuses on applying advanced computing techniques to provide decision makers with decision support systems (DSSs) to help them more effectively manage water and environmental systems.
- The Mortenson Center in Global Engineering focuses on promoting integrated and participatory solutions to humanitarian development by educating globally responsible engineering students and professionals to address pressing problems faced by developing communities worldwide, with the goal of transforming the understanding, application and evaluation of engineering globally.

Current research includes such topics as water and wastewater treatment, surface and subsurface contaminant transport, environmental processes, fluid mechanics, decision support systems, hydraulic research, land treatment, rapid infiltration and activated sludge processes. Cost prediction in construction projects, construction management, worker safety, energy conservation in buildings, solar applications and lighting systems are included. Active research is ongoing in advanced constitutive soil modeling and experimental characterization for geotechnical engineering, computational geomechanics, soil dynamics, seismic wave propagation and geophysics, geotechnical earthquake engineering, wave-based sounding, centrifugal

modeling, geosynthetics and glaciology. Research in structures includes stability, damage and fracture, material microstructures, durability, temperature effects, finite element modeling, reinforced concrete, earthquake responses, reinforced masonry structures, prestressed concrete and dynamic control. In water resources and fluid mechanics, work is continuing in stochastic hydrology and hydroclimatology, physics of scalar transport, mixing and reactions and hydrodynamics of ecological flows. Research in engineering science includes theoretical, mathematical and computational mechanics with applications to solid and fluid dynamics, blast and shock loading, mathematical physics, heat transfer, earth science, and multi-scale multiphase material modeling. Making use of model-based analysis, experimental and past performance data of built and human environment, the civil systems program focuses on providing training of a systems approach for life-cycle design decisions, management and monitoring of civil infrastructure systems, accounting for engineering, social science, economics and public policies in design holistically.

Master's Degrees

- Civil Engineering - Master of Science (MS) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/civil-engineering/civil-engineering-master-science-ms/>)
- Civil Engineering - Professional Master of Science (MSCVE) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/civil-engineering/civil-engineering-professional-master-science-mscve/>)

Doctoral Degree

- Civil Engineering - Doctor of Philosophy (PhD) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/civil-engineering/civil-engineering-doctor-philosophy-phd/>)

Certificates

- Architectural Lighting - Graduate Certificate (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/engineering-applied-science/architectural-lighting-graduate-certificate/>)
- Global Engineering - Graduate Certificate (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/civil-engineering/global-engineering-graduate-certificate/>)
- Water Engineering and Management - Graduate Certificate (<https://catalog.colorado.edu/graduate/colleges-schools/interdisciplinary-programs/water-engineering-management-graduate-certificate/>)

Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Amadei, Bernard (https://experts.colorado.edu/display/fisid_105978/)
Distinguished Professor; PhD, University of California, Berkeley

Amy, Gary L.
Professor Emeritus

Arehart, Joseph Hoberg (https://experts.colorado.edu/display/fisid_164349/)
Instructor; BS, University of Colorado Boulder

Ayer, Steven
Faculty Director, Associate Professor; PhD, Pennsylvania State University

Baker, Kyri A. (https://experts.colorado.edu/display/fisid_159754/)
Assistant Professor, Faculty Director; PhD, Carnegie Mellon University

Balaji, Rajagopalan (https://experts.colorado.edu/display/fisid_118480/)
Professor, Associate Chair; PhD, Utah State University

Behzadan, Amir
Professor; PhD, University of Michigan Ann Arbor

Bhaskar, Aditi
Associate Professor; Ph.D, University of Maryland, Baltimore County

Bielefeldt, Angela R. (https://experts.colorado.edu/display/fisid_110322/)
Professor; PhD, University of Washington; P.E.

Bolhari, Azadeh (https://experts.colorado.edu/display/fisid_167399/)
Associate Teaching Professor; PhD, Colorado State University

Brandemuehl, Michael J. (https://experts.colorado.edu/display/fisid_102573/)
Professor Emeritus; PhD, University of Wisconsin-Madison

Celoza, Amelia (https://experts.colorado.edu/display/fisid_172038/)
Assistant Professor; Ph.D., University of Texas at Austin

Cook, Sherri M. (https://experts.colorado.edu/display/fisid_154773/)
Assistant Professor; PhD, University of Michigan Ann Arbor

Corotis, Ross B. (https://experts.colorado.edu/display/fisid_100942/)
Professor Emeritus; PhD, Massachusetts Institute of Technology

Crimaldi, John P. (https://experts.colorado.edu/display/fisid_115733/)
Professor, Associate Chair; PhD, Stanford University

Dashti, Shideh (https://experts.colorado.edu/display/fisid_148493/)
Associate Professor, Faculty Director; PhD, University of California, Berkeley

DiLaura, David L.
Professor Emeritus

Dow, John O.
Associate Professor Emeritus

Frangopol, Dan M.
Professor Emeritus

Gooseff, Michael N. (https://experts.colorado.edu/display/fisid_155922/)
Professor; PhD, University of Colorado Boulder

Gupta, Vijay
Professor Emeritus

Halek, Milan F.
Senior Instructor Emeritus

Hallowell, Matthew Ryan (https://experts.colorado.edu/display/fisid_146163/)
Professor; PhD, Oregon State University

Hearn, George (https://experts.colorado.edu/display/fisid_101059/)
Associate Professor; PhD, Columbia University

Henze, Gregor P. (https://experts.colorado.edu/display/fisid_146496/)
Professor; PhD, University of Colorado Boulder

Hernandez, Mark T. (https://experts.colorado.edu/display/fisid_107635/)
Professor, Lecturer; PhD, University of California, Berkeley

Hubler, Mija H. (https://experts.colorado.edu/display/fisid_155134/)
Assistant Professor, Faculty Director; PhD, Northwestern University

Javernick-Will, Amy N. (https://experts.colorado.edu/display/fisid_146430/)
Associate Professor, Associate Professor, Associate Faculty Director;
PhD, Stanford University

Kasprzyk, Joseph R. (https://experts.colorado.edu/display/fisid_151506/)
Associate Professor, Associate Chair; PhD, Pennsylvania State University

Klees, Rita C. (https://experts.colorado.edu/display/fisid_145391/)
Associate Faculty Director, Scholar in Residence; PhD, University of Colorado

Ko, Hon-Yim
Professor Emeritus

Korak, Julie A. (https://experts.colorado.edu/display/fisid_155070/)
Assistant Professor; PhD, University of Colorado Boulder

Krarti, Moncef (https://experts.colorado.edu/display/fisid_104154/)
Professor; PhD, University of Colorado Boulder

Kuchenrither, Richard D.
Scholar in Residence, Lecturer; PhD, University of Colorado Boulder

Liel, Abbie B. (https://experts.colorado.edu/display/fisid_146431/)
Professor, Faculty Director, Associate Chair; PhD, Stanford University

Linden, Karl G. (https://experts.colorado.edu/display/fisid_143747/)
Professor, Chair; PhD, University of California, Davis

Livneh, Ben (https://experts.colorado.edu/display/fisid_151999/)
Assistant Professor; PhD, University of Washington

Madabhushi, Srikanth (https://experts.colorado.edu/individual/fisid_165826/)
Assistant Professor; PhD, University of Cambridge (England)

Mansfeldt, Cresten (https://experts.colorado.edu/display/fisid_165411/)
Assistant Professor; PhD, Cornell University

Masters, Sheldon (https://experts.colorado.edu/display/fisid_168570/)
Assistant Professor; PhD, Virginia Polytechnic Institute and State University

McKnight, Diane M. (https://experts.colorado.edu/display/fisid_110517/)
Professor; PhD, Massachusetts Institute of Technology

Molenaar, Keith Robert (https://experts.colorado.edu/display/fisid_102373/)
Professor, Dean; PhD, University of Colorado Boulder

Morris, Matthew R. (https://experts.colorado.edu/display/fisid_150037/)
Senior Instructor; MS, University of Colorado Boulder

Neupauer, Roseanna M. (https://experts.colorado.edu/display/fisid_134747/)
Professor, Associate Chair; PhD, New Mexico Institute of Mining and Technology

Pak, Ronald Y.S. (https://experts.colorado.edu/display/fisid_105977/)
Professor; PhD, California Institute of Technology

Pfeffer, Tad (https://experts.colorado.edu/display/fisid_100207/)
Professor, Lecturer; PhD, University of Washington

Pourahmadian, Fatemeh (https://experts.colorado.edu/display/fisid_158562/)
Assistant Professor; PhD, University of Minnesota

Regueiro, Richard A. (https://experts.colorado.edu/display/fisid_134705/)
Professor, Associate Chair; PhD, Stanford University

Rosario-Ortiz, Fernando L. (https://experts.colorado.edu/display/fisid_146165/)
Director, Professor; DEnv, University of California, Los Angeles

Ryan, Joseph N. (https://experts.colorado.edu/display/fisid_101037/)
Professor; PhD, Massachusetts Institute of Technology

Salvinelli, Carlo (https://experts.colorado.edu/display/fisid_159846/)
Instructor; PhD, Missouri University of Science and Technology

Saouma, Victor E. (https://experts.colorado.edu/display/fisid_100429/)
Professor; PhD, Cornell University

Scheib, Jennifer G. (https://experts.colorado.edu/display/fisid_159887/)
Instructor; MS, University of Colorado Boulder

Senseney, Christopher (https://experts.colorado.edu/individual/fisid_166693/)
Associate Teaching Professor; PhD, Colorado School of Mines

Sholtes, Joel Stephen (https://experts.colorado.edu/display/fisid_164757/)
Instructor; PhD, Colorado State University

Sholtes, Kari A. (https://experts.colorado.edu/display/fisid_164995/)
Instructor; MS, University of North Carolina Chapel Hill

Silverstein, JoAnn (https://experts.colorado.edu/display/fisid_101482/)
Professor Emeritus; PhD, University of California, Davis

Song, Jeong-Hoon (https://experts.colorado.edu/display/fisid_154468/)
Assistant Professor; PhD, Northwestern University

Srubar, Wil V. III (https://experts.colorado.edu/display/fisid_153058/)
Associate Professor, Associate Chair; PhD, Stanford University

Straub, Anthony (https://experts.colorado.edu/display/fisid_165027/)
Assistant Professor; PhD, Yale University

Strzepek, Kenneth M.
Professor Emeritus

Sture, Stein
Professor Emeritus

Summers, Scott R. (https://experts.colorado.edu/display/fisid_113151/)
Professor Emeritus; PhD, Stanford University

Thomas, Evan (https://experts.colorado.edu/display/fisid_163895/)
Professor, Assistant Professor; PhD, University of Colorado Boulder

Torres-Machi, Cristina (https://experts.colorado.edu/display/fisid_159884/)
Assistant Professor; PhD, Universitat Politècnica de Valencia, Spain

Vásconez, Sandra L. (https://experts.colorado.edu/display/fisid_144198/)
Senior Instructor; MA, University of Denver

William, Kaspar J.
Professor Emeritus

Xi, Yunping (https://experts.colorado.edu/display/fisid_110518/)
Professor; PhD, Northwestern University

Zagona, Edith A. (https://experts.colorado.edu/display/fisid_106395/)
Research Professor; PhD, University of Colorado Boulder

Zhai, John Z. (https://experts.colorado.edu/display/fisid_130604/)
Professor; PhD, Massachusetts Institute of Technology

Zhang, Yida (https://experts.colorado.edu/display/fisid_158222/)
Assistant Professor; PhD, Northwestern University

Courses

CVEN 5006 (3) Construction Engineering and Management Fundamentals

Provides an overview of the construction industry to establish a foundation for subsequent graduate courses in construction engineering and management. Students will be exposed to projects of varying funding sources, contracts, scope and complexity. Project phases will be established including planning, funding, design, construction, turnover, operation and maintenance. The course will focus on fundamental construction cost estimating, scheduling, delivery systems, contractual relationships, key contract clauses, risk allocation, building materials/ systems and project controls. Previously offered as a special topics course.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Grading Basis: Letter Grade

CVEN 5111 (3) Structural Dynamics

Focuses on the response of single- and multi-degree of freedom structures subjected to harmonic, impulsive and arbitrary loads (including earthquake base excitation). Sources and modeling of damping will be discussed. Analytical and numerical solutions will be considered for both linear and nonlinear structural systems. Elastic and inelastic response spectra will be discussed.

Requisites: Restricted to College of Engineering (ENGR) graduate students or seniors or students with concurrent degree sub plans C-AREN, C-CVEN, C-MCEN or C-ASEN.

Additional Information: Departmental Category: Mechanics

CVEN 5131 (3) Continuum Mechanics and Elasticity

Provides foundation for advanced study of structural, mechanical and geo-material behavior and continuum theories in mechanics. Topics: Cartesian tensors, formulation of continuum mechanics for small and large deformation, constitutive laws for elastic solids, energy principles, methods of potentials, formulations and solutions of 2D and 3D elastostatic and elastodynamic problems, analytical and numerical formulations.

Requisites: Restricted to College of Engineering (ENGR) graduate students or seniors or students with concurrent degree sub plans C-AREN, C-CVEN, C-MCEN or C-ASEN.

Recommended: Prerequisite CVEN 3161.

Additional Information: Departmental Category: Mechanics

CVEN 5147 (3) Civil Engineering Systems

Theory and application of the principles of engineering economics and classical and metaheuristic optimization techniques for evaluating problems in civil and environmental engineering.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4147

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Miscellaneous

CVEN 5151 (3) Wave Methods for Design and Characterization of Advanced Materials

Covers key theoretical concepts and applications of wave propagation with the focus on ultrasonic scattering. The course material includes: (i) dispersion analysis for design and characterization of materials with random and periodic microstructure, and (ii) advanced elastodynamic formulations rooted in 2D and 3D boundary integral equations for the purpose of inverse scattering and imaging. The course is intended to be self-contained, research-oriented and accessible for multidisciplinary audience.

CVEN 5157 (3) A Systems Approach to Global Engineering

Introduces engineering students to the global context in which engineers are asked to operate in the 21st century using system dynamics tools and other decision-making tools (network analysis, agent based modeling, etc.) necessary to analyze the uncertainty and complexity inherent in global projects.

Equivalent - Duplicate Degree Credit Not Granted: EDEN 4147, CVEN 4157 and EDEN 5147

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

CVEN 5161 (3) Advanced Mechanics of Materials I

Covers advanced topics in the mechanics of solids. Some topics such as asymmetric bending of beams, torsion of non-circular cross-sections, are extensions of topics seen in CVEN 3161. Others like 3-D stress and strain analysis, failure theories and stability of columns and frames are new. Includes selected laboratory experiments.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4161

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Mechanics

CVEN 5206 (3) Design Development

Provides an overview of the development process and proforma, investigates the interrelationship between design decisions and building costs, and evaluates the impact of each major building system on the development budget and schedule. Provides a simulated development experience where students respond to a Request for Proposal, including proformas, design, estimates and outline specifications. Department consent required. Taught intermittently.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Construction

CVEN 5226 (3) Construction Safety

Comprehensively studies construction safety in the construction industry. Focuses on advanced safety management issues such as accident causation theory, economic modeling, safety risk quantification and analysis, design for safety, predictive analytics and learning. Skills developed in this course will prepare graduate students to be effective quality and safety managers or researchers.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Construction

CVEN 5246 (3) Legal Aspects of Construction

Applies law in engineering practice; contracts, construction contract documents, construction specification writing, agency, partnership, and property; types of construction contracts; and legal responsibilities and ethical requirements of the professional engineer. Taught intermittently.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: graduate standing or department consent required.

Additional Information: Departmental Category: Construction

CVEN 5276 (3) Engineering Risk and Decision Analysis

Acquaints students with the fundamental principles and techniques of risk and decision analysis. Oriented toward project-level decisions in which risk or uncertainty plays a central role. Introduces students to Monte Carlo analyses, and various types of multicriteria decision analyses. Culminates in a larger term project.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 3227 and graduate standing or instructor consent required.

Additional Information: Departmental Category: Construction

CVEN 5286 (3) Design Construction Operations

Considers effective/efficient design of construction operations. Front end planning; construction labor relations; productivity management. Emphasizes construction productivity improvement by group field studies and discrete event simulation modeling. How overtime, changes, weather, and staffing levels influence productivity. Industrial engineering techniques are applied to the construction environment to improve the use of equipment, human, and material resources.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: graduate standing or department consent required.

Additional Information: Departmental Category: Construction

CVEN 5313 (3) Environmental Fluid Mechanics

Analysis of viscous incompressible flows, with first-principle solutions for environmental fluid flows in oceans, rivers, lakes and the atmosphere. Topics include the Navier-Stokes equations, kinematics, vorticity dynamics, geophysical fluid dynamics, and density stratification.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: Prerequisites APPM 2350 and APPM 2360 and CVEN 3313.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5323 (3) Applied Stream Ecology

Emphasizes the integration of hydrologic, chemical, and biological processes in controlling river, stream, and reservoir ecosystems at several spatial scales. Students apply ecosystem concepts to current environmental and water quality problems and learn field methods in field trips and a team project.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5333 (3) Physical Hydrology

Introduces hydrology as a quantitative science describing the occurrence, distribution and movement of water at and near the surface of the earth. Develops a quantitative understanding of atmospheric water, infiltration, evapotranspiration and surface runoff. Studies global climatology and large scale climate drivers of regional hydrology at interannual time scales. Solves engineering problems related to water resources.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: Prerequisite CVEN 4333.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5343 (3) Transport and Dispersion in Surface Water

Studies transport and dispersion of introduced contaminants in turbulent surface water flows. Emphasizes developing a physical understanding of fluid processes responsible for turbulent dispersion. Includes analytical development, numerical modeling, and experimental approaches to the problem.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5346 (3) Managing Construction and Engineering Projects and Organizations

Explores organizational and managerial issues and concerns facing executives in engineering and construction organizations. Through readings, case studies, simulation exercises, and projects, students are introduced to and apply concepts of strategy, core competencies, vision, innovation, team dynamics, interpersonal influence, organizational design issues, and global projects to engineering and construction organizations.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Construction

CVEN 5353 (3) Groundwater Hydrology

Studies the occurrence, movement, extraction for use, and quantity and quality aspects of groundwater. Introduces and uses basic concepts to solve engineering and geohydrologic problems.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: Prerequisites CVEN 3313 or AREN 2120 or CHEN 3200 or GEEN 3853 or MCEN 3021 and APPM 2360.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5363 (3) Modeling of Hydrologic Systems

Introduces students to modeling techniques. Focus areas include physical hydrology and hydrometeorology; measurement and inference; climate change impacts; role of scale in hydrology; uncertainty analysis; and a case study project. Projects will examine hydrologic impacts of various drivers such as climate warming or land cover change, utilizing an assessment of historic conditions to better understand and model future disturbance scenarios.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5373 (3) Water Law, Policy, and Institutions

Discusses contemporary issues in water management based on legal doctrine. Identifies legal issues in water resources problems and discusses in close relationship with technical, economic, and political considerations.

Requisites: Restricted to students with 87-180 credits (Seniors), graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5383 (3) Applied Groundwater Modeling

Studies analytical and numerical methods for solving problems of groundwater flow and chemical transport. Emphasizes fundamental modeling techniques and the relationship between the physical system and the model results. Applies models and modeling techniques to solve problems in ground water hydrology using contemporary software. Includes computer laboratory sessions.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4383

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisites APPM 2360 and CVEN 4353 or CVEN 5353.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5393 (3) Water Resources System and Management

Introduces water resources planning and management as an integrated systems problem that satisfies multiple competing objectives under constraints and uncertainty. Includes problem formulation and solution using decision support systems, optimization with and without uncertainty, stochastic simulation, and multiobjective optimization. Introduces water resources economics and planning under uncertainties such as climate change and increasing urbanization.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5404 (3) Water Chemistry

Introduces chemical fundamentals governing the chemistry of natural and treated waters. Topics include thermodynamics and kinetics of acid and base reactions, carbonate chemistry, air-water exchange, precipitation, dissolution, complexation, oxidation-reduction, and sorption.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5414 (3) Water Chemistry Laboratory

Uses experimental and analytical laboratory techniques to develop a better understanding of the concepts of aquatic chemistry and to investigate water chemistry in treated and natural water systems. Techniques include titration, spectrophotometry, gas chromatography, other advanced instrumentation, sampling, portable analyses, and basic statistics and experimental design. Course focuses on water chemistry of Boulder Creek and other local waters.

Requisites: Requires prerequisite course of CVEN 5404 or GEOL 5280 (minimum grade C-). Requires corequisite course of CVEN 5424.

Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5423 (3) Water Resources Engineering Design

Studies principles and techniques of water resources engineering design. Introduces environmental modeling under uncertainty, stormwater design, precipitation estimation and flow routing. Surveys hydropower, reservoir management and water resources economics.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4323

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5424 (3) Environmental Organic Chemistry

Examines the fundamental physical and chemical processes that impact the fate and transport of organic contaminants in natural and engineered systems. Emphasizes both equilibrium and kinetic aspects, including solubility, vapor pressure, air-water exchange, sorption, abiotic redox reactions, and photodegradation.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5434 (3) Environmental Engineering Design

Team-based design of facilities or processes for water or wastewater or solid waste treatment or remediation under multiple real-world constraints. Department consent required.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisite CVEN 5524 or CVEN 5534 or CVEN 5474.

Additional Information: Departmental Category: Environmental

CVEN 5444 (3) Municipal Des Proj

Additional Information: Departmental Category: Environmental

CVEN 5446 (3) Infrastructure Asset Management

Introduces a framework that combines engineering principles with economic theory to facilitate a more organized and logical approach to decision-making in the management of infrastructure. Topics covered include asset valuation, modeling infrastructure deterioration, life-cycle cost analysis, and optimization. Although the concepts introduced in this course are applicable to different infrastructure systems, especial emphasis will be given to transportation projects.

Requisites: Restricted to graduate students only.

Grading Basis: Letter Grade

CVEN 5454 (3) Statistical Methods for Natural and Engineered Systems

Applies traditional and modern probability and statistical methods to environmental, hydrological, climatological and engineering data analysis. Topics include: basic probability, data visualization, fitting univariate and multivariate distributions, Monte Carlo simulations, extreme value distributions, confidence intervals and hypothesis testing, nonparametric density estimators, linear regression, and Bayesian analysis. The data analysis tool, R, is used throughout the course.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Environmental

CVEN 5464 (3) Environmental Engineering Processes

Develops and utilizes analytic solutions for environmental process models that can be used in a) reactor design for processes used in the treatment of water, wastewater and hazardous waste and b) process analysis of natural systems, such as streams and groundwater flow. Models facilitate the tracking of contaminants in engineered and natural systems.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4464 and EVEN 4464

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5474 (3) Hazardous and Industrial Waste Management

Evaluates processes used for treatment of wastes requiring special handling and disposal: toxic organic chemicals, heavy metals, acidic, caustic and radioactive waste material. Discusses techniques for destruction, immobilization and resource recovery and assessment of environmental impact of treatment process end products.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4474

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5484 (3) Applied Microbiology and Toxicology

Surveys microbiology topics germane to modern civil and environmental engineering. Provides fundamentals needed to understand microbial processes and ecology in engineered and natural systems and reviews applications emphasizing the interface between molecular biology and classical civil engineering.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4484 and EVEN 4484

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5494 (3) Surface Water Quality Modeling

Examines the relationships among air, water, and land pollution, water quality, and beneficial uses. Using models, develops the ability to quantify and predict the impacts of pollutants in the aquatic environment, and to develop approaches to minimize unfavorable water quality conditions. Department consent required.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5511 (3) Introduction to Finite Element Analysis

Covers systematic formulation of finite element approximation and isoparametric interpolation (weighted residual and energy methods, triangular and quadrilateral elements). Includes computation applications to the solution of one- and two-dimensional stress-deformation problems and steady and transient heat conduction.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4511

Requisites: Restricted to College of Engineering (ENGR) graduate students or seniors or students with concurrent degree sub plans C-AREN, C-CVEN, C-MCEN or C-ASEN.

Additional Information: Departmental Category: Mechanics

CVEN 5514 (3) Bioremediation

Advanced study on biological processes used to treat toxic organic and inorganic compounds contained in contaminated water, air, and soil; design and evaluation of in situ toxic compound biotransformation; fundamentals of phytoremediation; critical reviews of current literature on bioremediation.

Equivalent - Duplicate Degree Credit Not Granted: EVEN 5514

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 4484 or CVEN 5424 or CVEN 5484.

Additional Information: Departmental Category: Environmental

CVEN 5524 (3) Drinking Water Treatment

Provides advanced study on theory-of-treatment processes, including design and operation of municipal water supplies.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisite CVEN 4464 or CVEN 5464 or graduate standing or instructor consent required.

Additional Information: Departmental Category: Environmental

CVEN 5525 (3) Computational Structural Analysis 1

Covers the principles and formulations of the direct stiffness method and its transition to the finite element method with the computational modelling and analysis of framed structures in 2D plane and 3D space. The dynamic analysis and the introduction to the nonlinear structural problems are provided. Familiarity with the modern computing and programming environments is increased to address the needs in the structural engineering and mechanics area. Computer programming is applied to the solution of problems in structural analysis.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4525

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Grading Basis: Letter Grade

Additional Information: Departmental Category: Structures

CVEN 5534 (3) Wastewater Treatment

Covers the processes used to treat municipal wastewater, focusing on biological processes. Includes: design of aerobic, anoxic, anaerobic and suspended growth technologies to remove and transform pollutants; design and assessment of treatment approaches that recover energy, nutrients and water from wastewater; application of fundamental concepts of aquatic chemistry, environmental microbiology and computational models.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisites CVEN 5404 and CVEN 5484 and CVEN 5464.

Additional Information: Departmental Category: Environmental

CVEN 5537 (3) Numerical Methods in Civil Engineering

Introduces the use of numerical methods in the solution of civil engineering problems, emphasizing obtaining solutions with high-speed electronic computers. Applies methods to all types of civil engineering problems.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4537

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Miscellaneous

CVEN 5544 (3) Solid Waste Management and Resource Recovery

Covers the scope of the nonhazardous solid waste problem and regulations that drive its management; discussions of nonengineering factors that impact waste management and recycling; design of incinerators, composting facilities, and landfills used to treat and dispose of solid waste.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisite CVEN 3414.

Additional Information: Departmental Category: Environmental

CVEN 5554 (3) Fundamentals of Air Quality Management

Introduces engineering methods for the study of air quality. Topics include: indoor air quality, greenhouse gases, dispersion modeling, source apportionment modeling, chemistry of combustion, pollution sources and controls, human exposure to air pollutants. A focus on Engineering for Developing Communities runs throughout. Required for CVEN environmental engineering graduate students.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4554

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5564 (3) Water Profession: Communication and Utility Finance

Develops and improves the skills and tools needed for graduate students and young professionals. Focusing on highly effective leaders; leadership with impact; effective communication tools; and communicating with teams, city councils, governing boards, and the public.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Grading Basis: Letter Grade

Additional Information: Departmental Category: Environmental

CVEN 5565 (3) Life-Cycle Engineering of Civil Infrastructure Systems

Philosophical and analytical issues for lifetime design and operation of civil systems. Optimization tradeoffs of construction, management, and sustainability. Utility of operation and service, including present-value economic analysis. Decision-making alternatives of safety and performance, including hazards consideration. Undergraduates may enroll with the permission of the instructor.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 3227 or equivalent.

Additional Information: Departmental Category: Structures

CVEN 5574 (3) Water Utility Management: Current Issues and Future Challenges

Develops the skills and tools for graduate students and young professionals to work in the water profession. Focuses on management, leadership, communication and utility financial in the new water profession era. Undergraduate seniors may contact instructor for permission to enroll.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5575 (3) Advanced Topics in Steel Design

Covers steel structure design and analysis. Includes plate girders, moment connections for beams, design of multistory frames, and other topics determined by class interest. Undergraduate may enroll with permission of the instructor.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 4545.

Additional Information: Departmental Category: Structures

CVEN 5584 (3) Water Profession: Leadership and Management

Develops the skills and tools for graduate students and young professionals to work in the water profession. Focuses on financing water services, capital planning, rates, management planning, staffing and organization and critical thinking. Undergraduates may request instructor permission to enroll.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Environmental

CVEN 5585 (3) Advanced Topics in Reinforced Concrete Design

Covers design and analysis topics for prestressed concrete and/or reinforced concrete structures. Includes review of the current ACI design code, slabs, prestressed concrete, seismic design, folded plates and shells, finite element analysis, and other topics determined by class interest. Undergraduates may enroll with the permission of the instructor.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 4555.

Additional Information: Departmental Category: Structures

CVEN 5594 (3) Water Reuse and Reclamation

Explores development of a safe, reliable and acceptable program for reusing impaired waters. As fresh water becomes scarcer around the world, communities are looking for security through development of new water resources. Reuse of impaired water is one solution to the growing water crisis. Focus is on advanced treatment technologies with emphasis on public perception, economics and regulations.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4594

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Recommended: Prerequisites CVEN 3141 and CVEN 3424.

Additional Information: Departmental Category: Environmental

CVEN 5604 (3) UV Disinfection and Advanced Oxidation

Provides a fundamental basis for design of UV processes in water and wastewater treatment. Includes principles of photochemistry and photobiology. Applications to disinfection of water and degradation of chemical compounds in the environment. Design of UV disinfection systems and reactors and advanced oxidation processes. Environmental UV-based decay of pollutants.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisites CVEN 3414 and CVEN 3424.

Additional Information: Departmental Category: Environmental

CVEN 5614 (3) Bioenergy & Bioresource Recovery

Introduces fundamental theories and applied technologies used in production and conversion of renewable biomass including waste materials into bioenergy and other value-added products. Conducts quantitative evaluations on conversion processes such as renewable biogas production, electricity generation, liquid fuels, metal and nutrients recovery and organic chemical production.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 4484.

Grading Basis: Letter Grade

Additional Information: Departmental Category: Environmental

CVEN 5628 (3) Seepage and Slopes

Covers fundamental principles of seepage in soils under both saturated and unsaturated conditions and limit equilibrium solution to slope stability problems. The seepage effects on slope stability are analyzed in detail and both conventional slope stability method and the finite element technique are applied to solving the engineering problems.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisites CVEN 3708 and CVEN 3718.

Additional Information: Departmental Category: Geotechnical

CVEN 5678 (3) Soil Improvement and Reinforcement

Provides students with principles and working knowledge of design and construction procedures in soil stabilization, retaining structures, geosynthetics, and soil reinforcement.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 3718.

Additional Information: Departmental Category: Geotechnical

CVEN 5688 (3) Environmental Geotechnics

Provides an understanding of the use of geotechnical concepts in the analysis and design of environmental systems. Focus is placed on the evaluation of waste containment facilities. Including relevant saturated, unsaturated, and multiphase flow mechanisms in cover and liner systems. Includes stability analyses for landfills and geosynthetic interface shear strength. Covers relevant aspects of mining geotechnics and remediation technologies of contaminated sites.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5708 (3) Soil Mechanics

Offers an advanced course in soil mechanics. Coverage includes basic principles of continuum mechanics; elasticity, viscoelasticity, and plasticity theories applied to soils; effective stress principle; consolidation; shear strength; critical state concepts; and constitutive, numerical, and centrifuge modeling.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Geotechnical

CVEN 5718 (3) Mechanics and Dynamics of Glaciers

Develops a quantitative physical basis for understanding the functions of snow, ice and glaciers in the environment, with emphasis on developing an understanding of continuum mechanics and thermodynamics and their application to Earth systems.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4718

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5728 (3) Foundation Engineering

Focuses on geotechnical design of shallow and deep foundations, including spread footings, mats, driven piles and drilled piers. Coverage includes bearing capacity, settlement, group effects and lateral load capacity of the various foundation types. Additional topics include subsurface exploration, construction of deep foundations and analysis of pile behavior using wave equation and dynamic monitoring methods.

Equivalent - Duplicate Degree Credit Not Granted: CVEN 4728

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5738 (3) Applied Geotechnical Analysis

Studies applications of limiting equilibrium and limit plasticity analysis methods to stability problems in geotechnical engineering, such as slopes, lateral earth pressures on retaining structures, and bearing capacities of foundations. Also includes elastic and consolidation analysis of deformations in soil structures.

Requisites: Requires a prerequisite course of CVEN 5708 (minimum grade C-). Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5748 (3) Design of Earth Structures

Covers theory, design, and construction of earth embankments and waste facilities, including isolation systems. Uses published data, field exploration, and laboratory tests on soils and rock in investigating foundations and construction materials. Involves principles of compaction and settlement, permeability analysis, landslide recognition and control, use of composite clay, and liner systems.

Requisites: Requires a prerequisite course of CVEN 5708 (minimum grade C-). Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5758 (3) Flow Processes in Soils

Examines fundamental principles of flow through porous media and related engineering problems. Topics include the saturated seepage theory and flow nets; the unsaturated flow theory; suction-saturation and saturation-hydraulic conductivity relationships; nonlinear finite strain consolidation and desiccation theory; laboratory and field testing methods for determining material characteristics; and numerical models for flow-related engineering problems.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisite CVEN 3718.

Additional Information: Departmental Category: Geotechnical

CVEN 5768 (3) Introduction to Rock Mechanics

Nature of rocks and rock masses; engineering properties rock and rock mass; rock mass classifications; planes of weakness; application of rock mechanics to design of rock slopes, underground excavations, and foundations.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisites CVEN 3708 and CVEN 3718.

Additional Information: Departmental Category: Geotechnical

CVEN 5788 (3) Computational Modeling in Geotechnical Engineering

Introduces computational modeling for geotechnical engineering applications such as the Discrete Element Method (DEM) for granular materials, nonlinear Finite Element Analysis (FEA) of seepage, coupled soil elastoplastic consolidation, elastoplasticity models for soil and rock, and advanced computational methods for failure in soil and rock. Uses DEM, FEA, and other software programs for analysis. Recommended Prereq: CVEN 5708

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5798 (3) Dynamics of Soils and Structures

Covers fundamental characterization of soils, foundations and structures under general dynamic and earthquake loads. Principles of vibrations and wave propagation for 1D, 2D, 3D. In-situ and laboratory determination of dynamic soil properties; methods for site response analysis, foundation vibrations, dynamic soil-structure interaction and liquefaction problems.

Requisites: Restricted to College of Engineering (ENGR) graduate students or seniors or students with concurrent degree sub plans C-AREN, C-CVEN, C-MCEN or C-ASEN.

Recommended: Prerequisite CVEN 3708.

Additional Information: Departmental Category: Geotechnical

CVEN 5818 (3) Geotechnical Earthquake Engineering

Familiarizes students with the fundamentals of engineering seismology, soil and structural dynamics, and the modern practice of geotechnical earthquake engineering. Focuses on describing earthquake hazards and methods for seismic analysis and design.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: Prerequisite CVEN 5798.

Additional Information: Departmental Category: Geotechnical

CVEN 5822 (3) Geographical Information Systems for Civil and Environmental Systems

Theory and use of geographical information systems in civil engineering, environmental studies, natural resources and other related disciplines.

Topics include spatial data models, data capture, global positioning system, database linkage, use in design, analysis and implementation. Laboratory work includes applications of Arc-View and Arc-GIS software.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Surveying and Transportation

CVEN 5830 (1-3) Special Topics for Seniors/Grads

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Building Systems

CVEN 5831 (3) Special Topics

Supervised study of special topics of interest to students under instructor guidance. Department consent required.

Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Mechanics

CVEN 5833 (1-3) Special Topics

Supervised study of special topics of interest to students under instructor guidance.

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 5834 (1-3) Special Topics

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, C-EVENCVEN or C-EVEN) only.

Additional Information: Departmental Category: Environmental

CVEN 5835 (1-3) Special Topics for Seniors/Grads

Supervised study of special topics of interest to students under instructor guidance.

Repeatable: Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Structures

CVEN 5836 (1-3) Special Topics for Seniors/Grads

Supervised study of special topics of interest to students under instructor guidance. Department consent required.

Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Additional Information: Departmental Category: Construction

CVEN 5837 (1-3) Special Topics for Seniors/Grads

Supervised study of special topics of interest to students under instructor guidance.

Repeatable: Repeatable for up to 12.00 total credit hours. Allows multiple enrollment in term.

Additional Information: Departmental Category: Miscellaneous

CVEN 5838 (1-3) Special Topics

Repeatable: Repeatable for up to 12.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Geotechnical

CVEN 5849 (1-6) Independent Study

Available only through approval of graduate advisor. Subject arranged to fit needs of student.

Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Special Topics

CVEN 5899 (1) Graduate Engineering Internship Experience

An academically supervised graduate-level engineering experience that is integral to the students' graduate research and study by connecting classroom instructions to professional practice. Requires a pre-approved written plan of the proposed graduate-level work experience and a signed cooperative agreement or offer letter from employer. The 1-unit course will count toward the graduate student's degree together with the required minimum of 30 credit hours of regular core and elective courses in the student's major.

Repeatable: Repeatable for up to 3.00 total credit hours.

Requisites: Restricted to graduate students only.

CVEN 5919 (3) Global Development for Engineers

Focuses on the fundamental tools necessary to address sustainable community development projects in low-income communities (LICs). Topics include: human development, sustainable development, and presentation of an integrative and participatory framework for development projects in LICs. The framework consists of a combination of development and engineering project management tools. Framework is illustrated through case studies and student-driven team projects.

Requisites: Restricted to students with sub-plan of Engineering Developing Communities (EDC) or certificate (ENDC-CERG) only.

Additional Information: Departmental Category: Special Topics

CVEN 5929 (3) Sustainable Community Development 2

Covers the principles, practices and strategies of appropriate technology as part of an integrated and systems approach to community-based development. Course content areas include technical issues in development, environmental health and communicable disease, appropriate and sustainable technologies with hands-on workshops, and global cooperation in development.

Requisites: Requires prerequisite course of CVEN 5919 (minimum grade C-). Restricted to students with Engineering Developing Communities (EDC) sub-plan or EDC certificate (ENDC-CERG).

Additional Information: Departmental Category: Special Topics

CVEN 5939 (3) Global Development Practicum

Provides a supervised in-field practicum experience in which the student applies theories and concepts learned in CVEN 5919.

Requisites: Requires prerequisite course CVEN 5919 (minimum grade C-). Restricted to students with sub-plan of Global Engineering/Engineering Developing Communities (EDC) or certificate (ENDC-CERG) only.

Additional Information: Departmental Category: Miscellaneous

CVEN 5969 (1-3) Water, Sanitation, and Hygiene

Studies the fundamentals behind effective hygiene and remediation processes and engineering solutions developed/designed for specific international problems. Approaches to hygiene, clean water and sanitation in lesser industrialized countries often demand alternative solutions to those developed for industrialized societies. Explores issues and solutions developed to tackle these problems.

Repeatable: Repeatable for up to 3.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students or students accepted in the AREN, CVEN or EVEN Bachelor Accelerated Masters (BAM) programs.

Recommended: Prerequisites CVEN 3424 and CVEN 3414.

Additional Information: Departmental Category: Environmental

CVEN 6161 (3) Advanced Mechanics of Materials 2

Fundamentals of continuum mechanics, finite deformations, Lagrangian finite strains, Cauchy and Piola Kirchoff stress tensors, plasticity and thermo-elasticity, elements of damage mechanics, elements of fracture mechanics, rheological and viscoelastic theories, and modern experimental techniques.

Recommended: Prerequisite CVEN 5161.

Additional Information: Departmental Category: Mechanics

CVEN 6333 (3) Introduction to Multi-Scale Variability and Scaling in Hydrology

Provides a foundational physical understanding of channel networks, runoff, precipitation, and evapotranspiration at multiple spatial scales of drainage basins using modern analytical concepts for understanding non-linear phenomena, e.g., fractals, multifractals, statistical scaling, criticality, and renormalization.

Requisites: Requires a prerequisite course of CVEN 5333 (minimum grade C-).

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6383 (3) Flow and Transport through Porous Media

Studies basic physics of flow and transport of water, air, and other fluid mixtures through a porous medium. Course topics are relevant to applications in contaminant hydrology, contaminant transport in aquifers, hazardous waste management, geohydrology, soil physics, and geoenvironmental engineering.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6393 (1) Hydrologic Sciences and Water Resources Engineering Seminar

Provides a broad introduction to a variety of research topics from hydrologic sciences and water resources engineering. Offered as a one-hour weekly seminar by the departmental water faculty, graduate students, and external speakers.

Requisites: Restricted to graduate student Civil (CVEN) Engineering students only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6414 (3) Aquatic Surfaces and Particles

Examines the role of surfaces and particles in the fate and transport of contaminants in the aquatic environment. Emphasizes modeling of absorption, dissolution, precipitation, surface-catalyzed reactions, and coagulation and filtration kinetics.

Requisites: Requires prerequisite course of CVEN 5404 or GEOL 5280 (minimum grade C-).

Additional Information: Departmental Category: Environmental

CVEN 6511 (3) Nonlinear Finite Element Analysis of Solids and Porous Media

Covers constitutive modeling, multiphase mechanics, and finite element implementation of constitutive models and coupled solid-fluid mechanical governing equations for inelastic porous media at small strain. Considers transient and steady state conditions. Analyzes structural, geotechnical, geological, mechanical, biomechanical, and other related modern engineering problems. Uses general purpose finite element software program for implementation and analysis.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Mechanics

CVEN 6525 (3) Nonlinear Analysis of Framed Structures

Explores theoretical underpinnings of nonlinear static and dynamic analysis of framed structures, along with exposure to the corresponding programming techniques in Matlab. Topics covered are: flexibility and fiber based beam-column element formulation; structural, section and fiber plasticity; geometric and material nonlinearities; nonlinear pushover and transient analysis of framed structures.

Requisites: Restricted to graduate students only.

Additional Information: Departmental Category: Structures

CVEN 6595 (3) Earthquake Engineering

Analyzes and designs structures for earthquake load covering: properties of earthquake ground motions, ground motion prediction equations, seismic hazard analysis, response spectra, response of linear and nonlinear structures, construction of design spectra, seismic design methods, and building code requirements.

Requisites: Requires prerequisite course of CVEN 5111 (minimum grade of C-). Restricted to graduate students only.

Additional Information: Departmental Category: Structures

CVEN 6830 (3) Special Topics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Building Systems

CVEN 6831 (3) Special Topics

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students only.

Additional Information: Departmental Category: Mechanics

CVEN 6833 (1-3) Special Topics

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Requisites: Restricted to graduate students only.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6834 (1-3) Special Topics

Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

Additional Information: Departmental Category: Environmental

CVEN 6835 (3) Special Topics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Structures

CVEN 6836 (3) Special Topics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Construction

CVEN 6837 (3) Sp Tpcs Comp Graphics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Miscellaneous

CVEN 6838 (3) Special Topics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Geotechnical

CVEN 6839 (1-3) Special Topics

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Special Topics

CVEN 6943 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6944 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Environmental

CVEN 6945 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Structures

CVEN 6946 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Construction

CVEN 6947 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Miscellaneous

CVEN 6948 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Geotechnical

CVEN 6949 (1) Master's Candidate for Degree

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

Additional Information: Departmental Category: Special Topics

CVEN 6951 (1-4) Master's Thesis

Additional Information: Departmental Category: Mechanics

CVEN 6952 (1-4) Master's Thesis

Additional Information: Departmental Category: Surveying and Transportation

CVEN 6953 (1-6) Master's Thesis

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6954 (1-6) Master's Thesis

Additional Information: Departmental Category: Environmental

CVEN 6955 (1-6) Master's Thesis

Additional Information: Departmental Category: Structures

CVEN 6956 (1-6) Master's Thesis

Additional Information: Departmental Category: Construction

CVEN 6957 (1-4) Master's Thesis

Additional Information: Departmental Category: Miscellaneous

CVEN 6958 (1-6) Master's Thesis

Additional Information: Departmental Category: Geotechnical

CVEN 6959 (1-4) Master's Thesis

Additional Information: Departmental Category: Special Topics

CVEN 6961 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Mechanics

CVEN 6962 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Surveying and Transportation

CVEN 6963 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 6964 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Environmental

CVEN 6965 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Structures

CVEN 6966 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Construction

CVEN 6967 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Miscellaneous

CVEN 6968 (1-3) Master's Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Geotechnical

CVEN 6969 (1-3) Masters Report

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Special Topics

CVEN 7111 (3) Advanced Structural Dynamics

Includes general vibrations of civil engineering structures and their response to various types of time-dependent loads.

Requisites: Requires prerequisite course of CVEN 5111 (minimum grade C-).

Additional Information: Departmental Category: Mechanics

CVEN 7141 (3) Plates and Shells

Teaches mathematical theories of plate and shell structures and their applications. Involves numerical finite element solutions of plates and shells of various shapes under static and dynamic loadings.

Requisites: Requires prerequisite courses of CVEN 5131 or CVEN 5161 (minimum grade C-).

Additional Information: Departmental Category: Mechanics

CVEN 7161 (3) Fracture Mechanics

Includes three parts: 1) fundamentals through rigorous mathematical formulations of linear/nonlinear elastic fracture mechanics, 2) materials' theoretical strength, including metals, granular materials, polymers and steel, 3) numerical (finite element) methods in fracture mechanics. Heavy emphasis on project and independent work.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Additional Information: Departmental Category: Mechanics

CVEN 7511 (3) Computational Finite Inelasticity and Multiphase Mechanics

Covers kinematics, thermodynamics, coupled balance equations and constitutive models, numerical time integration, and finite element implementation of finite strain inelasticity and multiphase mechanics. Kinematics of multiplicative decomposition, and finite strain mixture theory. Linearization for global nonlinear Newton-Raphson and solution algorithm of nonlinear constitutive models and coupled balance equations.

Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.

Recommended: Prerequisites CVEN 5131 and CVEN 5511 and CVEN 6511.

Additional Information: Departmental Category: Mechanics

CVEN 7718 (3) Engineering Properties of Soils

Emphasizes engineering aspects of soil mechanics. Implications of soil strength, volume change, consolidation behavior in engineering problems such as slope stability, deformation of retaining walls, surface subsidence due to tunneling. Time effects in soil/long-term bearing capacity of piles. Laboratory determination of constitutive parameters of soils. Field tests/their correlations with soil properties. Case studies using finite element software.

Requisites: Requires prerequisite course of CVEN 5708 (minimum grade of C-).

Additional Information: Departmental Category: Geotechnical

CVEN 7788 (3) Soil Behavior

Topics include soil mineralogy, formation of soils through sedimentary processes and weathering, determination of soil composition, soil water, colloidal phenomena in soils, fabric property relationships, analysis of mechanical behavior including compressibility, strength and deformation, and conduction phenomena in terms of physicochemical principles. Involves applications for stabilization and improvement of soils, and disposal of waste materials.

Recommended: Prerequisite CVEN 3718.

Additional Information: Departmental Category: Geotechnical

CVEN 7831 (1-3) Sp Tpc-Constitutive Mech

Repeatable: Repeatable for up to 10.00 total credit hours. Allows multiple enrollment in term.

Additional Information: Departmental Category: Mechanics

CVEN 7838 (3) Special Topics

Additional Information: Departmental Category: Geotechnical

CVEN 7849 (1-3) Independent Study

Repeatable: Repeatable for up to 6.00 total credit hours.

Additional Information: Departmental Category: Special Topics

CVEN 8991 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Mechanics

CVEN 8992 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Surveying and Transportation

CVEN 8993 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Fluid Mechanics and Water Resources

CVEN 8994 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Environmental

CVEN 8995 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Structures

CVEN 8996 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Construction

CVEN 8997 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Miscellaneous

CVEN 8998 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Geotechnical

CVEN 8999 (1-10) Doctoral Dissertation

Additional Information: Departmental Category: Special Topics