ECI280B: Linear and Nonlinear Dynamic Finite Elements and Modeling and Simulation of Earthquakes, Soils, Structures and their Interaction

Instructor: Boris Jeremić, Jeremic@ucdavis.edu
Class meeting: Spring Quarter, 2019, Time: M,W 12:10pm - 1:50pm, Ghausi 1007
Office hours: Spring Quarter, 2019, Time: M,W 2:00pm - 4:00pm, Ghausi 3147
Course WWW: http://sokocalo.engr.ucdavis.edu/~jeremic/ECI280B/

Course objectives: Students will learn about elastic and inelastic dynamic finite elements and will be able to use state of the art modeling and simulation tools, the Real-ESSI Simulator system, http://real-essi.info, to analyze practical dynamics problems. Special emphasis is on Realistic Modeling and Simulation of Earthquakes, Soils, Structures and their Interaction, aka Real-ESSI.

Part One, Dynamic FEM

Week I
Intro: Course objectives, methodology, computer modeling and simulation. Introduction to the Real-ESSI Simulator system.
Accessing Real-ESSI on AWS
Theory: Deformation, kinematics of moving systems, elasticity, dynamic equilibrium relations, d’Alembert’s principle, forces in dynamic equilibrium, mass, damping, stiffness, external force.
Examples: Model Development, simple models versus sophisticated models, model verification.
Lecture notes reading: Chapters 101, 102, 209, 701.

Week II
Theory: Dynamic finite element method, FEM equations, virtual work method in dynamics, nonlinear dynamic equations of motion, consistent and lumped mass, velocity and displacement proportional damping, Rayleigh and Caughey damping, linear and nonlinear material behavior.
Examples: Structural and solid elements and models, dynamic excitations, resonance, linear and nonlinear material models, viscous damping, consistent and lumped mass matrix.
Lecture notes reading: Chapters 102, 104.

Week III
Theory: Elasto-plasticity, material models for dynamics of soils and structures, material parameter calibration, uncertainty in material parameters, explicit and implicit constitutive integrations, porous solid - pore fluid, saturated system modeling.
Examples: Elastic-plastic solids, beams and shells, energy dissipation, coupled u-p-U modeling,
Lecture notes reading: Chapter 104.

Week IV
Theory: Direct, time marching solution for dynamics of nonlinear, inelastic systems, general Newmark family of methods, stability and accuracy, nonlinear resonance, numerical damping, explicit and implicit algorithms, unconditionally and conditionally stable Newmark and Hilber–Hughes–Taylor α–method.
Examples: Direct time integration, mesh size, time step size, energy dissipation: material/hysteretic, viscous, algorithmic.
Lecture notes reading: Chapter 108.

Part Two, ESSI Application

Week V
Theory: Introduction: Earthquake Soil Structure Interaction, ESSI Background, problem definition, seismic motions, seismic body and surface wave field, seismic energy propagation, free field motions, beneficial and detrimental effects, balancing input and dissipated energy.
Examples: Analytic development of free field ground motions, 3C vs 1C motions, seismic energy calculations.
Lecture notes reading: Chapters 502, 403, 404.
Week VI
Theory: Seismic Motions: Free field vs ESSI motions, incoherent motions, Domain Reduction Method (DRM), boundary conditions, radiation damping, 3C inclined wave fields vs 1C vertical motions, 1C deconvolution and 1C convolution, nonlinear wave propagation simulations, time step size, element size, earthquake modeling.
Examples: Real-ESSI models for free field and ESSI motions, element and time step size, DRM, Stress test motions, variable inclination, frequency and intensity.
Lecture notes reading: Chapters 502, 403, 404, 707.

Week VII
Theory: Inelastic ESSI Modeling and Simulation: Soil, Rock, Concrete, Steel, Contact/Interface
Examples: Calibration of material parameters for Soil, Rock, Concrete, Steel, Contact/Interface and analysis of inelastic solids and structures
Lecture notes reading: Chapters 502, 401, 403, 404, 707.

Week VIII
Theory: ESSI and Liquefaction, fully coupled, porous solid – pore fluid systems, slow phenomena - consolidation, fast phenomena - liquefaction, coupled contact-interface modeling dynamic buoyant forces.
Examples: 1D and 3D coupled examples, consolidation, liquefaction, ESSI.
Lecture notes reading: Chapter 104, 505.

Week IX
Theory: Verification and Validation, definition, procedures, code, solution and model verification, validation experiments. High Performance Computing (HPC), Coarse grained parallel, fine grained matrix computing.
Examples: modeling verification examples, verification for algorithms, elements. Availability of validation data. HPC Sequential and Parallel analysis.
Lecture notes reading: Chapters 301, 312, 109, 404.

Week X
Theory: ESSI Modeling and Simulation Synthesis: example building structure, boundary conditions, initial conditions, nonlinear contact, gap/slip, nonlinear soil/rock, 1D vs 3D seismic motions development, buoyant forces at foundation level, etc.
Examples: Real-ESSI illustrative examples, hierarchical modeling approach: (a) 1D/1C, 3D/1C models; (b) 3D, structure only, eigen, imposed motions; (c) Full 3D/1C and 3D/3C modeling of ESSI, soil-structure building model.
Lecture notes reading: Chapters 401, 402, 403, 404.


Prerequisites: Introductory finite element course and/or consent of instructor.

Computers: Most of the problems in this course will require numerical simulations. A finite element program Real-ESSI Simulator, http://real-essi.info, will be made available (either local install or through Amazon Web Services (AWS)) and will be used for assignments, examples and term project. Students will have access to AWS supercomputers for class assignments and term projects.

Homeworks: Homeworks will be assigned weekly, and will be due in one week, by the beginning of the lecture.

Term Project: Term project will involve work related to developing or using numerical models for modeling and simulating mechanics phenomena of your choice, related to your research interests. Term projects will be presented toward the end of quarter to the class. Term project reports will be due at the end of quarter.

Grading: Homework assignments 30%, term project 40%, final exam 30%.

Examination: Final exam: a week long, take home

Literature: