ECI280B: Dynamic Finite Elements and Earthquakes, Soils, Structures and their Interaction

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Instructor: Boris Jeremić, `Jeremic@ucdavis.edu`

Class meeting: T,Th 12:10pm-1:50pm; Teaching and Learning Complex 3213

Office hours: M,W, 10:00am - noon;

Course WWW: `http://sokocalo.engr.ucdavis.edu/~jeremic/Classes/ECI280B/`

Course objectives: Teach students nonlinear dynamic finite elements and provide state of the art modeling and simulation tools for linear and nonlinear dynamics problems. Focus is on Earthquakes, Soils, Structures and their Interaction (ESSI). Topics will include:

Part One, Dynamic FEM

Week I: **Introduction**: Course objectives, methodology, computer modeling and simulation; Dynamics of nonlinear structures and soils during earthquakes, examples **Preliminary theory, terminology, issues to be addressed**: Deformation, kinematics of moving systems, elasticity, dynamic equilibrium relations, d'Alembert's principle, forces in dynamic equilibrium, mass, damping, stiffness, external force, single degree of freedom systems, **Examples**: Model Development, simple models vs sophisticated models, pre-processing, post-processing, results visualization. **Suggested Reading, Viewing**: Lecture notes: 101, 102;

Week II: **Dynamics 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/energy dissipation, Rayleigh and Caughey viscous damping, linear and nonlinear material behavior. **Examples**: Structural and solid elements and models, dynamic excitations, resonance, linear and nonlinear (elastic and inelastic/elastic-plastic) material models, viscous damping, consistent and lumped mass matrix. **Suggested Reading**: Lecture notes: 102;

Week III: **Nonlinear finite element element theory**: Elasto-plasticity, material models for dynamics of soils and structures, material parameter calibration, uncertainty in material parameters, explicit and implicit constitutive integrations, **Examples**: Elastic plastic solids, beams and shells, material energy dissipation, material damping **Suggested Reading**: Lecture notes: 103, 104;

Week IV: **Nonlinear time domain dynamics 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, stability and accuracy, examples) **Examples**: Nonlinear solid and structural models direct time integration, step size, damping (material, viscous, numerical), stable and unstable computations. **Suggested Reading**: Lecture notes: 108;

Part Two, ESSI Application

Week V: **Theory**: 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 ground motions, 3D vs 1D motions, seismic energy calculations. **Suggested Reading**: Lecture notes: 502;

Week VI: **Theory**: Seismic Motions: Free field vs ESSI motions, incoherent motions, Domain Reduction Method, boundary conditions, radiation damping, 3D inclined wave fields vs 1D vertical motions, nonlinear wave propagation simulations, time step size, element size, earthquake modeling. **Examples**: Real ESSI and SW4 models for free field and local (DRM) motions, element and time step size and propagation of (required) frequencies **Suggested Reading**: Lecture notes: 502, 511, 705;

Week VII: **Theory**: Free field motions development, 1D motions, 3D/6D motions, regional scale models, Geophysical models, **Examples**: Vertical and inclined waves development, and input into SSI models **Suggested Reading**: Lecture notes: 502, 706;

Week VIII: **Theory**: ESSI and Liquefaction, fully coupled, porous solid – pore fluid systems formulation, discretization, basic system of DOFs, coupling damping forces, specialization to slow (consolidation) and fast phenomena (ESSI, liquefaction), boundary conditions, initial conditions, stability and accuracy of various algorithms. **Examples**: 1D and 3D coupled examples, consolidation, liquefaction and de-liquefaction waves, piles in liquefied soil... **Suggested Reading**: Lecture notes: 102, 505;

Week IX: **Theory**: Verification and Validation (definition, procedures, code verification, solution verification, validation experiments, model verification (!)) **Examples**: modeling verification examples, verification for algorithms, elements. Availability of validation data. **Suggested Reading**: Lecture notes: 301-314;

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 **Suggested Reading**: Lecture notes: 503, 504, 509 510, 512;

Textbook: Instructor's lecture notes: `http://sokocalo.engr.ucdavis.edu/~jeremic/LectureNotes/`.

Recorded Lectures: `http://sokocalo.engr.ucdavis.edu/~jeremic/Online-Education`

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.us`) will be made available, for personal computers running Windows, MacOS, Linux, and/or through Amazon Web Services (AWS)) and will be used for assignments, examples and term project. Students will have access to high performance computers from the Real-ESSI Simulator cluster for class assignments and term projects. Other programs can be used as well, provided that they feature requred functionality.

Homeworks: Homeworks will be assigned weekly, and will be due in one week, by the beginning of the lecture. You are encouraged to discuss the approach to homework assignments with other students in the course as well as with the instructor. Late homeworks will not be accepted for credit.

Term Project: Term project will involve work related to developing or using numerical models for numerically simulating physical phenomena of your choice (related to your research interests). Term projects will be presented toward the end of semester to the class (and others interested).

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

Examination: Final exam: a week long, take home

Literature:

- J. Argyris and H.-P. Mlejnek. *Dynamics of Structures*. North Holland (USA Elsevier), 1991.
- M. Hori, Introduction to Computational Earthquake Engineering, Imperial College Press, 2006.
- J.-F. Semblat and A. Pecker. *Waves and Vibrations in Soils: Earthquakes, Traffic, Shocks, Construction works*. IUSS Press, first edition, 2009.
- K. Aki and P.G. Richards. *Quantitative Seismology*. University Science Books, 2nd edition, 2002.
- T.J.R. Hughes. *The Finite Element Method ; Linear Static and Dynamic Finite Element Analysis*. Prentice Hall Inc., 1987.
- K.-J. Bathe. *Finite Element Procedures in Engineering Analysis*. Prentice Hall Inc., 1996.
- B. Jeremić, Z. Yang, Z. Cheng, G. Jie, N. Tafazzoli, M. Preisig, P. Tasiopoulou, F. Pisanò, J. Abell, K. Watanabe, Y. Feng, S.K. Sinha, F. Behbehani, H. Yang, and H. Wang. Nonlinear Finite Elements: Modeling and Simulation of Earthquakes, Soils, Structures and their Interaction. University of California, Davis, CA, USA, 1989-2021. ISBN: 978-0-692-19875-9