ECI280A: Nonlinear Finite Elements for Elastic–Plastic Problems

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Class meeting: Winter Quarter, 2019, Time: Monday, Wednesday 8:00am - 9:50am, Academic Surge, room 2212.
Office hours: Winter Quarter, 2019, Time: Monday, Wednesday 10:00am - noon, Ghausi Hall, room 3147.
Course WWW: http://sokocalo.engr.ucdavis.edu/~jeremic/ECI280A/

Course objectives: This course will provide students with state of the art finite element methods, tools and models for solving elastic–plastic problems. Presented will be computational formulation, techniques and models for nonlinear, elastic plastic finite element method that are used in professional practice and research. Topics will include:

Week I
Introduction: Course objectives, methodology, computer modeling and simulation
Motivation: Inelastic/nonlinear structures and soils, examples

Introduction: Computational Mechanics field of study, kinematics of deformation, strain, stress, linear and nonlinear elasticity, equilibrium relations, finite element method review, nonlinear analysis cycles;
Examples: model development (finite element model, finite element mesh, boundary conditions, material models, loads) and model verification process, linear and nonlinear elastic FEM with solids and structural elements,
Lecture notes reading: Chapter 1, Chapter 2, Appendix A, Chapter 19

Week II
Theory: Expanding the matrix deformation method, linear elastic truss element, Beams (Bernoulli, Timoshenko), solids, plates, walls (plane stress), shells, stiffness, forces, displacements, interpolating functions for displacements, internal and external forces, global equilibrium.
Examples: Truss, beam, solid bricks, external forces, internal forces (sectional forces, stresses). Generalized nodal displacements and internal deformation (curvature, axial, shear, volumetric, general strains),
Lecture notes reading: Sections 2.5, 2.6, 2.7; Sections 2.2, 2.3, 2.4;

Week III
Theory: Micro-mechanical origins of elasto-plasticity, particles in contact, friction, (Hertz contact, Mindlin-Deresiewicz contact/slip)
Examples: Particle contact problems.
Lecture notes reading: Chapter 3 (yet to be typed/written ☹, however, handwritten notes are available)

Week IV
Theory: Incremental, continuum elasto-plasticity, Material Models (perfectly plastic, hardening and softening. Explicit (forward Euler) and Implicit (backward Euler) constitutive integrations,
Examples: Constitutive integrations (explicit and implicit computations!): Single element response using select elastic-plastic material models: von Mises, Drucker-Prager, Cam Clay. Perfectly plastic, isotropic hardening, kinematic hardening models and cyclic response. Inelastic, fiber (1D) and 3D structural models for concrete and steel.
Lecture notes reading: Chapter 4

Week V
Theory: Continuation: Incremental elasto-plasticity. Material modeling for practical applications. Advanced topics in constitutive elasto-plasticity (stability and accuracy, errors in constitutive integrations, problematic incremental steps, energy dissipation, sub-incorporation, line search, model calibrations.
Lecture notes reading: Chapter 4
Week VI

Theory: Contact modeling: Hard contact, Soft contact. Axial contact stiffness, shear contact stiffness. Contact gap opening and closing. Saturated contacts, effective stress and buoyant forces on foundations.

Examples: Contact: concrete to soil and rock, steel to soil and rock. Normal contact with solids, gap opening and closing. Shear contact, slip and no slip. Contact nonlinearity versus soil nonlinearity.

Lecture notes reading: Sections 4.7

Week VII

Theory: Inelastic structural models, beams, plates, walls and shells.


Lecture notes reading: Sections 4.9, 4.12

Week VIII (to be updated)

Theory: Analysis Progress. Stages, increments, iterations, elastic–plastic stiffness matrix, pure incremental methods, force residuals, Newton iterative algorithm for finite element level iterations, constraints to the global (force residual) system of equations, equilibrium iterations, convergence, load control, displacement control, arc-length, hyper-spherical constraint, convergence criteria, automatic step size control, line search, stability and accuracy.

Examples: Nonlinear analysis of structures and solids, elastic plastic solids, structures and contacts. Staged analysis steps, incremental only analysis with no equilibrium enforcement, incremental-iterative analysis, with equilibrium enforcement, convergence criteria (force, displacement), convergence tolerances, step size control.

Lecture notes reading: Chapter 7

Week IX

Theory: Verification, Validation and Prediction, basic theory, solution verification, manufactured solutions, validation experiments, prediction under uncertainty,

Parallel Computing for elastic-plastic computations (static and dynamic domain decompositions methods,

Examples: Solution verification examples for elements, material models, constitutive integration algorithms, solution advancement algorithms.

Lecture notes reading: Chapters 21

Week X

Theory: Elastic–plastic FEM modeling (practical recommendations for development and analysis of nonlinear (elastic-plastic) finite element models, phased development of general FEM (and ESSI in particular) models. Core Functionality for inelastic/nonlinear modeling.

Examples:

Illustrations of algorithms and models described above, benefits and detriments of different algorithms and models.

Lecture notes reading: Chapters 37, 38, 39, 40, 41, 42, 43, 44, 45


Prerequisites: Consent of Instructor.

Computers: Most of the problems in this course will require numerical simulations. A finite element modeling system called RealESSI/MS-ESSI Simulator system (http://real-essi.info) will be made available through Amazon Web Services (AWS)) and will be used for assignments, examples and term project. Other programs can be used as well, provided that they provide needed 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 elastic–plastic problem of your choice (related to your research interests). Term projects will be presented toward the end of semester to the class (and others interested). Publicly accessible WWW site will be created to archive term projects.

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

Examination: Final exam: a week long, take home
Literature:

- Plasticity for Structural Engineers *W. F. Chen and D. J. Han*, Springer Verlag, 1988 ISBN 0-387-96711-7