YAP 618 – NONLINEAR STRUCTURAL ANALYSIS

Spring, 2016

Instructor

Dr. Barış Erkuş
Room: INB 505; Phone: (212) 385-3849; E-mail: bariserkus@itu.edu.tr.
Web: http://web.itu.edu.tr/bariserkus.
Office Hours: By appointment.
Teaching Assistant: There will be no teaching assistant for this class.

Lectures

Hours: Thursday 13:30-14:30; Location: INB-A2.

Textbook

- Çakıroğlu, A and Özer, E, "Malzeme ve Geometri Bakımından Lineer Olmayan Sistemler", Cilt I, Matbaa Teknisyenleri Basımevi, 1980.

Reference Books and Reports

- PEER/ATC 72-1, "Modelling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings," prepared by ATC and PEER, U.S.A., 2010.
- Li, G and Wong, KKF, "Theory of Nonlinear Structural Analysis: The Force Analogy Method for Earthquake Engineering." Wiley, Singapore, 2014.
- Li, G-Q and Li, J-J, "Advanced Analysis of Steel Frames," Wiley, England, 2007.
- Paz, M. and Leigh, W, "Structural Dynamics: Theory and Computation," Kluwer, U.S.A, 2004.
- Cheng, FY, "Matrix Analysis of Structural Dynamics: Applications and Earthquake Engineering," Marcel Dekker, U.S.A., 2001.
- McGuire, W, Gallagher RH and Ziemian RD, "Matrix Structural Analysis," Wiley, U.S.A., 2000.
- Park, R and Paulay, T, "Reinforced Concrete Structures," Wiley, U.S.A., 1972.
- Giberson, MF, "The Response of Nonlinear Multi-Story Structures Subjected to Earthquake Excitation," PhD Thesis, CalTech, U.S.A., 1967.
- Thom, CW, "The Effects of Inelastic Shear on the Seismic Response of Structures," PhD Thesis, University of Auckland, New Zealand, 1983.
- Citation of research papers and research reports specific to a topic will be provided throughout the course.

Course Description

Nonlinear analysis has recently become an important topic in structural engineering due to several reasons. First, there is a major shift in structural codes towards performance-based design, where structural performance is mostly defined by damage. Evaluation of structural damage for a given structure requires a sound understanding of the structural behavior. While it has certain limitations and validity of its results depends on the assumptions and models used, nonlinear analysis methods can simulate structural behavior better than linear analysis methods. Second, there has been significant research in the past two decades, where nonlinear models for structural elements become more solid, programmable and applicable to practice. Finally, with the advancement of computer technology, nonlinear analysis programs have become more accessible to engineering community where average nonlinear models can be simulated within reasonable times.

Nonlinear procedures require a thorough understanding of the following topics:

- Nonlinear Behavior of Materials, Structural Members and Structures: Nonlinear behavior of materials and structural members is generally best understood by experimental studies and lessons learned from past events, and generally thought in other courses in detail (e.g. reinforced concrete structures, steel structures, structures with base isolation and dampers). Nonlinear behavior of structures can seldom be experimentally investigated in full-scale. Particularly, geometric-type nonlinear behavior of structures mostly investigated by analytical methods and numerical nonlinear analysis.

- Nonlinear Mathematical Models and Their Applicability to the Simulation of Nonlinear Behavior: There is a significant number of mathematical models that can be used for simulation of nonlinear behavior of materials, structural members and structures. Each model has its own limitations, applicability, advantages and disadvantages. These models are generally for material nonlinearity. An engineer or researcher should understand these models very well for an efficient nonlinear modeling and analysis.

- Static and Dynamic Analysis Procedures: Understanding analysis procedures is also very important for nonlinear analysis. Some procedures may be significantly faster than others if suitable models are used, which makes it possible to apply nonlinear analysis in practice and research more frequently and conveniently.

In this course, we will follow the course contents required by the course catalog. However, focus will be given to the following topics:

- The course will review fundamental topics that are thought in other courses to establish a foundation for the nonlinear analysis. These are essential mathematics such as linear algebra, differential equations, equations of motion, linear static and dynamic analysis including, modal and direct time integration, stiffness method, section analysis of reinforced concrete and steel members, energy concepts, damping, damping models such as Rayleigh damping, classical and non-classical damping, fundamental plasticity, yielding, kinematic and isotropic hardening and etc.

- Mathematical models for nonlinear behavior and hysteresis will be covered. Main focus will be material nonlinearity. Continuous models such as Masing model, Ramberg-Osgood model, Wen's model, Bouc-Wen model, Özdemir's model, Menegetto-Pinto model and piece-wise linear models such as elasto-plastic model, rigid-plastic model, bilinear model, tri-linear models such Park model, Takeda model, Ibarra-Krawinkler model, pivot model and ASCE/FEMA models will be covered. Definitions and concepts such as backbone curve, monotonic and cyclic curve, strength deterioration, stiffness degradation, slip and pinching will be introduced.

- Dynamic analysis procedures for nonlinear systems will be covered and reviewed. Since some of analysis methods already thought in undergraduate and graduate courses, emphasis will be given to programming. Explicit methods and implicit methods including predictor-corrector methods, Newmark-β method, Newton-Raphson iteration, Runge-Kutta method (4th order), pseudo-force method, unbalanced force correction method will be covered.

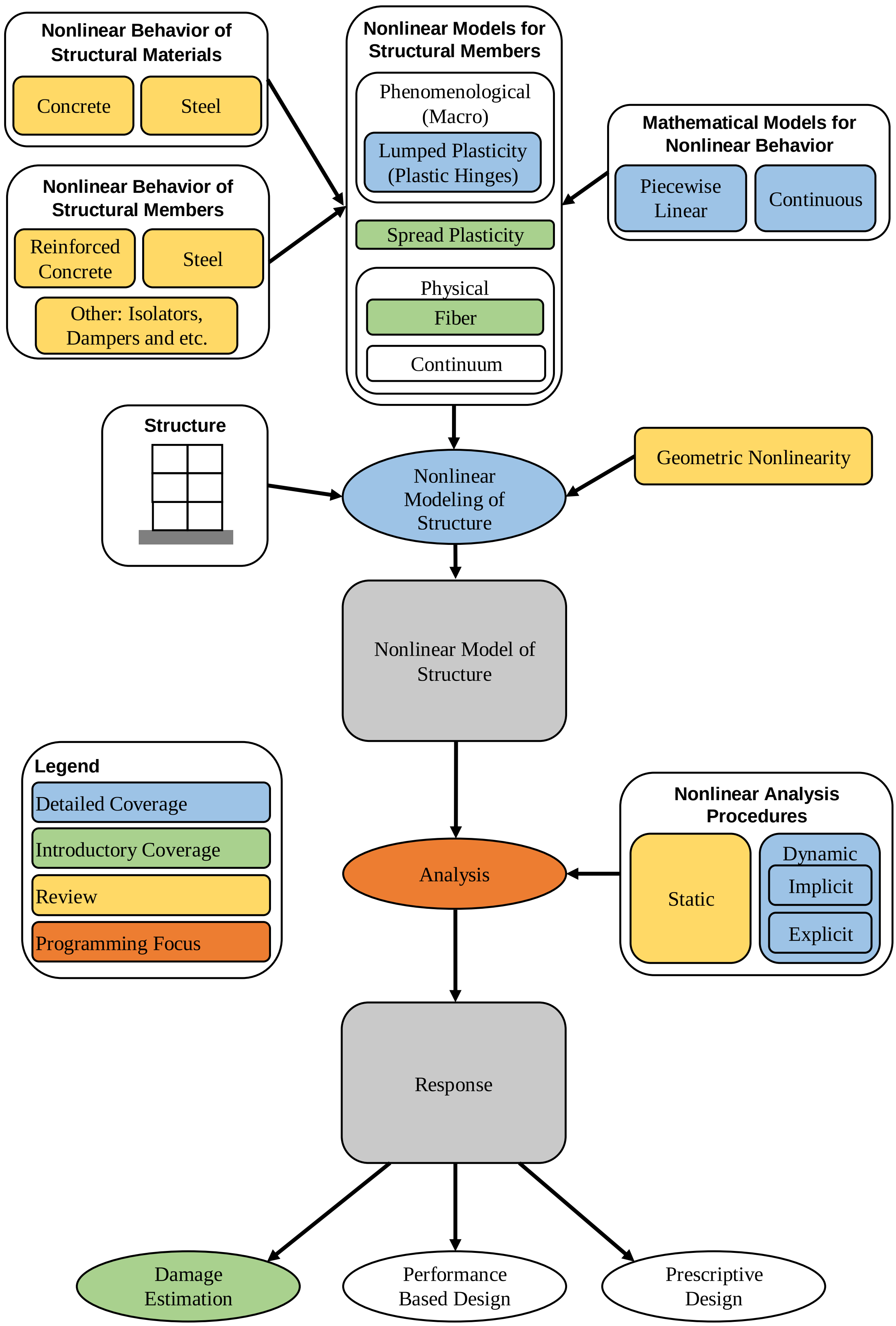
- Plastic hinge concept will be covered. Modelling of a linear beam element with rotational springs and rigid links will be explained. Concepts of rotation and curvature will be emphasized. Based on experimental results or section analysis of given reinforced concrete or steel beam element, development of nonlinear beam elements with rigid-plastic and elastoplastic hinge models will be covered. Modelling of material specific nonlinear behavior will be covered. Matrix methods for nonlinear analysis will be developed. Concepts such as axial force and bending interacting plastic hinges, interaction surface, yielding, hardening and Drucker-Prager criterion will be introduced.

- Advanced topics will be introduced but will not be covered in detail except as noted. These topics include advanced nonlinear models such as distributed plasticity and fiber model, concept of interaction, equivalent frame modeling, energy dissipation and damage. Matrix formulation for a generalized fiber model will be given. Basics of nonlinear modeling of common structural elements will be reviewed. These are reinforced concrete shear walls (flexure and shear), reinforced concrete coupling beams, steel concentric braces, steel eccentric brace link elements, buckling restraints braces, base isolators (elastomer based and friction based) and dampers. Basic damage models will be introduced. Review of FEMA356 and ASCE 41-13 performance levels.

- Students will be asked to familiarize with commercial, educational and scientific programs for nonlinear analysis including, SAP2000, Perform, OpenSEES, Xtract, Seismostruct and Nonlin throughout the course.

Tentative Grading Scheme

Item	Contribution
Midterm	20%
Homework	40%
Final	40%
Total	**100%**



Graphical Representation of the Contents of the Nonlinear Structural Analysis Course

Additional Topics To Be Covered

Week	Topic
1	Review of Fundamental Topics
2	Review of Fundamental Topics
3	Review of Fundamental Topics
4	Mathematical Models for Nonlinear Behavior: Definitions and Concepts
5	Mathematical Models for Nonlinear Behavior: Piecewise Linear Models
6	Mathematical Models for Nonlinear Behavior: Continuous Models
7	Dynamic Analysis Procedures for Nonlinear Systems: Implicit Methods
8	Dynamic Analysis Procedures for Nonlinear Systems: Explicit Methods
9	Plastic Hinges of Structural Members
10	Modeling of Plastic Hinges: Bilinear Hinge Element
11	Modeling of Plastic Hinges: Rigid-Plastic Hinge Element
12	Advanced Topics: Introduction to Fiber Elements
13	Advanced Topics: Introduction to Interacting Nonlinear Hinges
14	Advanced Topics: Other Topics

Programming Assignments

Week	Topic
1	Frame Linear Static Analysis
2	Frame Linear Static Analysis
3	Frame Linear Hinge Model
4	Frame Linear Dynamic Analysis
5	Bilinear Model Static Analysis
6	Bilinear Model Static Analysis
7	Bilinear Model Dynamic Analysis
8	Bilinear Model Dynamic Analysis
9	Bilinear Plastic Hinge Model Static Analysis
10	Bilinear Plastic Hinge Model Static Analysis
11	Bilinear Plastic Hinge Model Static Analysis
12	Bilinear Plastic Hinge Model Dynamic Analysis
13	Bilinear Plastic Hinge Model Dynamic Analysis
14	Bilinear Plastic Hinge Model Dynamic Analysis