CEE 282: Nonlinear Structural Analysis

Winter 2015

Instructor

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Lectures

Mon, Wed, Fri, 09:30 to 10:45 in Building 540, Room 108

Course Description

This course covers the theory, computer implementation, and application of methods of geometric and material nonlinear analysis. Geometric nonlinear (or 2^{nd} order) analysis entails solving for equilibrium on the deformed configuration of the structure. Areas where geometric nonlinear behavior has practical design implications include structural stability problems (e.g. P-Δ effects, frame buckling), and the design/behavior of cable and other flexible tension structures. Material nonlinearities involve inelastic behavior of materials: a condition commonly encountered in all structures prior to reaching their strength limit states. Types of inelastic analysis methods that will be discussed include concentrated plasticity (or plastic hinge) methods and spread-of-plasticity methods (fiber analyses, quasi-hinge methods, etc.). Practical design applications of inelastic analysis include static pushover and inelastic time-history analyses in earthquake engineering, and plastic mechanism analysis. Emphasis will be on techniques applied to frame structures comprised of line-type elements, however, the basic concepts equally pertain to general finite element methods.

Prerequisites

CEE 280: Advanced Structural Analysis or equivalent.
An advanced course in structural behavior and design (e.g. CEE 285A, CEE 285B or equivalent).

Grading Basis

Letter grades only (ABCD/NP)

Evaluation

30%: Midterm and final exams
35%: Final project
10%: Programming Assignment
25%: Homework Assignments

Software

Matlab: Accessible for free on corn, Stanford's shared computing environment (instructions to login and access Matlab), and on all computer clusters on campus. Student version is available for purchase from Stanford Bookstore (purchase link).
Mastan2 (Matrix Structural Analysis, 2nd ed.): Free download from www.mastan2.com

Logistics

Piazza

Piazza will be used as a discussion forum. All registered students, as per the first day of class, will be automatically invited to join the course site. If you haven't received an invitation, you can also directly join the course site at piazza.com/stanford/winter2015/cee282/home.
Piazza is the preferred means of asking questions and doubts regarding assignments. You are also encouraged to answer questions posed by your classmates, but please refrain from posting solutions or giving away answers to problems. If you are in doubt, you can post private questions that only the TA and instructors can see. We will answer posted questions as soon as possible.

CourseWork

CourseWork (coursework.stanford.edu) will be used to make all announcements, to distribute course material, to submit assignments, and to view assignment grades. An up-to-date calendar of assignment due dates, exams, etc. will be maintained here as well.

Individual emails

Piazza should be used for general questions that may be of interest to the entire class. Please email the TA or instructor only for personal issues.

Homework Assignments

Homework will be assigned weekly, but may extend over two weeks or more depending on the nature of the assignment. Problems will involve both theoretical and practical problems dealing with nonlinear structural behavior and analysis, with a strong design focus. Many problems will require writing short Matlab scripts, modifying existing scripts, or using Mastan2 to conduct nonlinear structural analysis.

Planning

Start early and plan your time well to ensure timely completion of homework assignments, the programming assignment, and the final project. Experience has shown that you'll make best use of your time if you start assignments early, so that you have sufficient time to ask questions in class or during office hours with the TA or instructor.

Collaboration

You may discuss and collaborate with other students, however, you must submit your own solution. Your solution should not be a copy of work by others, but instead, should reflect your own organization of the calculations and interpretation of the results. Please indicate on your solution, the names of the other students whom you collaborated with.

Submission

All assignments must be submitted before the start of class on the due date. We expect you to submit hardcopies of your homework solutions, but we give you the option of submitting associated Matlab code online to help save the planet. All files related to a homework solution should be uploaded to the Dropbox on the CourseWork site, under a folder called *HomeworkX*, where *X* corresponds to the homework number, before the start of class on the due date. Files uploaded after the start of class will not be considered for grading. All files should be named such that they can be easily identified as being part of the solution to a specific problem. A note should be made in the submitted solution if supporting files are submitted online.

Analysis results should be accompanied by appropriate plots and/or sketches of the structure being analyzed. Plots should have clearly labeled axes and scales. Printed plots should be appropriately titled. Sketches of structures should include key dimensions, boundary conditions, loadings, material properties, etc. Please refrain from submitting long scrolls of analysis results (like the report produced by Mastan2) when a concise summary of important results would suffice.

Grading

Homework problems will be graded to evaluate three main criteria:

- **Completeness**: Have you made a genuine attempt to solve all parts of the problem?
- **Execution**: Have you set up the problem correctly and carried out the necessary calculations without errors?
- **Concept**: Have you understood the theory behind the problem, and are you able to interpret and explain your results?

Although coming up with the right numerical answer to a problem is important, we will place a larger emphasis on your ability to interpret and explain your results. If you have trouble doing so, please don't hesitate to speak with the TA or instructor. And remember, **neatness counts**. This is a professional graduate program and we expect neat and well organized assignment solutions. They not only make a good impression on the instructor and TA, but a well organized assignment is a helpful study and reference aid. Homework grades will be assigned in terms of the following 5 point scheme:

- **0** : No submission or less than 20% on completeness, execution, and concept
- **1** : (Poor) 20% or better combined completeness, execution, and concept
- **2** : (Below average) 50% or better combined completeness, execution, and concept
- **3** : (Average) 75% or better completeness, execution, and concept
- **4** : (Above average) 90% or better on completeness, execution, and concept

Your course grade will largely be determined by your performance on the exams and final project. Your homework grade will, however, influence your course grade in the following way. Consistent homework scores of 3 will be "grade neutral", i.e. they will neither increase nor decrease your course grade; scores above 3 will tend to increase your grade, whereas scores below 3 will tend to decrease your grade.

Programming Assignment

The programming assignment will involve working in groups of two to extend a given Matlab code that conducts a 1^{st} order elastic analysis of an arbitrary 2D framed structure, to conduct a 2^{nd} order elastic analysis, using object-oriented programming (OOP) concepts. You will be given the option of extending your own code from CEE 280 instead of using the given 1st order elastic analysis code. Mastan2 will be used for defining the structural model and viewing the analysis results.

Exams

There will be one midterm exam and an optional final exam. If you choose to take the final exam, your scores from the midterm and final exams will be weighted equally to make up 30% of your course grade. Else, only the midterm exam score will be used.

Final Project

There will be a final project assigned midway through the course that students can work on in groups of two. Topics will be flexible, ranging from computer programming projects to studies of practical applications of nonlinear structural analysis. You are encouraged to be on the lookout for potential project topics through the first half of the course. Students will give oral presentations during the final week of the quarter and submit written reports, due during finals week.

Stanford Honor Code

Students are expected to follow Stanford's Honor Code in all matters related to this course. You are permitted to meet and exchange ideas with your classmates while studying and working on the homework and programming assignments. Ultimately, however, each student is responsible for submitting his/her own work and understanding the material. You are not permitted to copy or otherwise reference another student's assignment solutions, Matlab code, or exams. The only exception to this is when you are given specific permission to work in teams on the programming assignment. In such cases, you are expected to work together and collaborate, such that the submitted solution represents a genuine shared effort. In case you are in doubt, please speak to the TA or instructor, or refer to studentaffairs.stanford.edu/communitystandards/policy.

Textbook

McGuire, W., Gallagher, R. H., & Ziemian, R. D. (2000). *Matrix Structural Analysis* (2nd ed.). New York, NY: John Wiley & Sons, Inc. (TA642 .M25 2000)

Since this textbook is currently out of print, readers will be available for purchase from CopyAmerica for $32. CopyAmerica will sell the readers at the Thornton Center (379 Santa Teresa St) lobby during the first week of the quarter. After that, they can be purchased from 344 S California Ave.

Course Reserves

- Bathe, K.-J. (1996). *Finite Element Procedures.* Upper Saddle River, NJ: Prentice Hall. (TA347 .F5 B36 1996)
- Chen, W. F., & Lui, E. M. (1991). *Stability Design of Steel Frames.* Boca Raton, FL: CRC Press. (TA660 .F7 C45 1991)
- Chen, W. F., & Sohal, I. (1995). *Plastic Design and Second-Order Analysis of Steel Frames.* New York, NY: Springer-Verlag. (TA660 .F7 C44 1995)
- Cook, R. D. (1995). Finite element modeling for stress analysis. New York, NY: Wiley. (TA347 .F5 C665 1995)

- Crisfield, M. A. (1991). *Non-Linear Finite Element Analysis of Solids and Structures.* Chichester, England: John Wiley & Sons, Inc. (TA647 .C75 1991 V.1)
- Sathyamoorthy, M. (1998). *Nonlinear Analysis of Structures.* Boca Raton, FL: CRC Press. (TA646 .S365 1998)
- Simo, J. C., & Hughes, T. J. R. (1998). *Computational Inelasticity.* New York, NY: Springer. (QA931 .S576 1998, free online access from Springer)
- Timoshenko, S., & Gere, J. M. (1961). *Theory of Elastic Stability.* Mineola, NY: Dover Publications. (QA931 .T54 1961, free online access from Knovel)
- Yang, Y.-B., & Kuo, S.-R. (1994). *Theory and Analysis of Nonlinear Framed Structures.* Upper Saddle River, NJ: Prentice Hall. (TA660 .F7 Y36 1994)

Other Resources

- Bathe, K.-J. (2005). *Inelastic Analysis of Solids and Structures.* Berlin, Germany: Springer. (TA652 .K575 2005, free online access from Springer)
- Borja, R. I. (2013). *Plasticity: Modeling and Computation.* Berlin, Germany: Springer. (free online access from Springer)
- Deierlein, G. G., Reinhorn, A. M., & Willford, M. R. (2010). *Nonlinear structural analysis for seismic design.* Gaithersburg, MD: National Institute of Standards and Technology. (available online at www.nehrp.gov/pdf/nistgcr10-917-5.pdf)
- iMechanica: Web of Mechanics and Mechanicians (imechanica.org)
- Lubliner, J. (1990). *Plasticity Theory.* New York, NY: Macmillan. (QA931 .L939 1990, available for free download from www.ce.berkeley.edu/~coby/plas)
- Notes on Nonlinear Finite Element Methods by Prof. Carlos A. Felippa, Professor of Aerospace Engineering Sciences, University of Colorado (available online at www.colorado.edu/engineering/CAS/courses.d/NFEM.d/Home.html)

Tentative Schedule

Week	Date	Topic	Assigned	Due
1	05-Jan	Overview and applications of nonlinear structural analysis, single DOF bar-spring example	HW1	
	07-Jan	Wrap-up single DOF bar-spring example		
	09-Jan	Geometric nonlinear concepts: column and beam-column buckling, Mastan2 demonstration		
2	12-Jan	Derivation of geometric stiffness matrix using PVD		
	14-Jan	Stability (critical load) analysis		
	16-Jan	Wrap-up critical load analysis and design	HW2	HW1
3	19-Jan	*No Class (Martin Luther King Jr. Day)*		
	21-Jan	Element force recovery procedures for geometric nonlinear analysis	Project	
	23-Jan	*No Class (Blume Center Tahoe trip)*		

4	26-Jan	Errors and iterations	Program Assg.	
	28-Jan	Lateral torsional buckling	HW3	HW2
	30-Jan	Introduction to the programming assignment		
5	02-Feb	Principles of stability design		
	04-Feb	Code provisions for stability design, CTL Small Group Evaluation	HW4	HW3
	06-Feb	Wrap-up code provisions for stability design		
6	09-Feb	Uniaxial plasticity		
	11-Feb	Wrap-up uniaxial plasticity		HW4, Project proposal
	13-Feb	**Midterm exam**: emphasis on geometric nonlinear concepts, through HW4		
7	16-Feb	*No Class (Presidents' Day)*		
	18-Feb	Cross section analysis	HW5	
	20-Feb	Wrap-up cross section analysis		
8	23-Feb	Static pushover analysis		Program Assg.
	25-Feb	Multiaxial plasticity		
	27-Feb	Wrap-up multiaxial plasticity	HW6	HW5
9	02-Mar	Fiber beam-column analysis		
	04-Mar	Wrap-up fiber beam-column analysis		
	06-Mar	Guest lecture		HW6
10	09-Mar	Final lecture: Introduction to nonlinear dynamic analysis		
	11-Mar	**Final project presentations**		
	13-Mar	**Final project presentations**		
Exam	18-Mar	**Final exam** (08:30 – 11:30 in 540 108): emphasis on material nonlinear concepts, HW5 and HW6		
	20-Mar	**Final project reports due**		Project report