# CE 540: Limit Analysis of Structures (3 units)

*Course description and benefits:*

We review the basics of plastic and limit analysis with application in design and evaluation of common structural systems. The course will help you better understand the inelastic behavior of structural systems and will assist you in performing nonlinear inelastic analysis to estimate acceptability of a design for a set of limit-states. Advanced applications in earthquake-resistant design and collapse analysis will be discussed. The goal is to understand and to apply the theorems of plastic analysis to setup limits of design appropriately and to evaluate structural performance accordingly. Definition, estimation, and evaluation of collapse mechanisms of common structural systems are highly emphasized. You will be able to perform nonlinear inelastic analysis and design of simple frames, walls, and bracing systems by the end of the semester successfully.

## Course Outline:

*Background and Review:*

(1) Course Objective, Basics, Definitions, and Applications

(2-3) Hysteresis and constitutive relationships
Yield and fracture criteria

(2-3) Inelasticity at cross section (inelastic pure bending, combined bending and axial, combined flexural and shear)

*Plastic and Limit Analysis:*

(4-7) Simple plastic analysis methods: (event-to-event calculation, equilibrium method, Kinematic method)

(8-11) Fundamental theorems of plastic analysis: (upper-bound theorem, lower-bound theorem, uniqueness theorem)

(12-15) General methods of limit analysis (basic mechanism types, number of basic mechanisms, combination of mechanisms, mechanism analysis by center of rotation)

(16-18) Shakedown theorems (deflection stability)
Methods of shakedown analysis

(19-21) Minimum weight design theorems and applications, optimization methods, linear programming in limit analysis, fully-stressed design

*Applications of Plastic and Limit Analysis:*

(22-24) AISC code provisions
Concrete yield line analysis

(25) Capacity-based design
Pushover analysis

*Advanced topics and Applications (time-permitting):*

(26-28) Mechanisms of inelastic behavior and capacity of modern structural systems: SMRF, CBF, EBF, core wall system, coupled walls and link beams, hybrid wall-frame structure, parallel and serial systems

Design for energy (Professor Anderson's work)

Collapse analysis: (sideway, gravitational, and progressive)

Seismic design (performance-based design and evaluation)

Computational tools (Matlab, Mastan, Arcade, SAP, Perform, OpenSees, ELS)

## Course Learning Outcomes

Objective 1: Learn how to identify and set important limits of design for different structures under various loading conditions

Objective 2: Learn the principles of plastic design for beams and frames and apply them to understand collapse mechanism and strength of structural systems against collapse

Objective 3: Learn the basics of nonlinear structural analysis and its applications in dynamics of structures and earthquake engineering

Objective 3: Learn the concept of capacity-based design and its applications in structural design

Objective 4: Get insight into ductile behavior of common structural systems and their behavior

**Fall Semester 2009:**

| Class | Date | Topic |
|---|---|---|
| 1 | Monday, August 24, 2009 | Course Objective, Basics, and Applications |
| 2 | Wednesday, August 26, 2009 | Hysteresis, constitutive relationships, and yield and fracture criteria |
| 3 | Monday, August 31, 2009 | Inelasticity at cross section |
| 4 | Wednesday, September 02, 2009 | Simple plastic analysis methods |
| | Monday, September 07, 2009 | *Labor Day, University Holiday* |
| 5 | Wednesday, September 09, 2009 | Simple plastic analysis methods |
| 6 | Monday, September 14, 2009 | Simple plastic analysis methods |
| 7 | Wednesday, September 16, 2009 | Review |
| 8 | Monday, September 21, 2009 | Fundamental theorems of plastic analysis |
| 9 | Wednesday, September 23, 2009 | Fundamental theorems of plastic analysis |
| 10 | Monday, September 28, 2009 | Fundamental theorems of plastic analysis |
| 11 | Wednesday, September 30, 2009 | Review |
| 12 | Monday, October 05, 2009 | General methods of limit analysis |
| 13 | Wednesday, October 07, 2009 | General methods of limit analysis |
| 14 | Monday, October 12, 2009 | General methods of limit analysis |
| 15 | Wednesday, October 14, 2009 | Review |
| | Monday, October 19, 2009 | *Mid-term (Tentative)* |
| 16 | Wednesday, October 21, 2009 | Minimum weight design and optimization applications |
| 17 | Monday, October 26, 2009 | Minimum weight design and optimization applications |
| 18 | Wednesday, October 28, 2009 | Minimum weight design and optimization applications |
| 19 | Monday, November 02, 2009 | Mechanism analysis by center of rotation/Computer Methods |
| 20 | Wednesday, November 04, 2009 | Shakedown theorems and methods/Steel Design Example |
| 21 | Monday, November 09, 2009 | Shakedown theorems and methods/Concrete Design Example |
| 22 | Wednesday, November 11, 2009 | AISC code provisions and concrete yield line analysis |
| 23 | Monday, November 16, 2009 | AISC code provisions and concrete yield line analysis |
| 24 | Wednesday, November 18, 2009 | AISC code provisions and concrete yield line analysis |
| 25 | Monday, November 23, 2009 | Capacity-based design and pushover analysis |
| 26 | Wednesday, November 25, 2009 | Advanced topics and applications |
| 27 | Monday, November 30, 2009 | Project presentation |
| 28 | Wednesday, December 02, 2009 | Project presentation, The last lecture |
| | Monday, December 07, 2009 | *Study Day* |
| | Wednesday, December 09, 2009 | **Final Exam** |
| | Wednesday, December 16, 2009 | *End of Session - Winter Recess Dec. 17* |

## Course Information

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| Credits: | 3 |
| Prerequisite<br>By Course:<br>By Topic: | Strength of Materials and Solid Mechanics<br>Structural Analysis (determinate and indeterminate) and Matrix Structural Analysis/Finite Element Method<br>Dynamics of Structures<br>Understanding of Structural Behavior<br>Design of Steel Structures<br>Design of Concrete Structures |
| Course Requirements: | Please attend the lectures regularly. Active participation in discussions is encouraged. |
| Time and location: | Mondays and Wednesdays, 5:00-6:15 pm at KAP163 |
| Instructor: | Arzhang Alimoradi, Ph.D., P.E.<br>Office Hours: before the class at KAP 230D or KAP 209 by appointment<br>Phone: 213-483-6490 Ext. 151 (for emergencies otherwise please use email address below)<br>Email: alimorad@usc.edu |
| Webpage: | On Blackboard |
| Required Text: | Stuart S. J. Moy, *Plastic Methods for Steel and Concrete Structures*, Halsted Press, 1982, ISBN: 978-0470270790 (Available from Bookstore) |
| Course Material: | Class notes, reading materials, and journal papers |
| Suggested References: | Egor P. Popov, *Engineering Mechanics of Solids*, Second Edition, Prentice Hall, 1991<br><br>Milan Jirasek and Zdenek P. Bazant, *Inelastic Analysis of Structures*, Wiley, 2002<br><br>Wai-Fah Chen and Da-Jian Han, *Plasticity for Structural Engineers*, J. Ross Publishing; 2007<br><br>Subhash C. Goel and Shih-Ho Chao, *Performance-Based Plastic Design: Earthquake-Resistant Steel Structures*, International Code Council, 2008 |

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| | Michel Bruneau, Chia-Ming Uang, and Andrew Whittaker, *Ductile Design of Steel Structures,* McGraw-Hill Professional, 1997<br><br>Thomas Paulay and M. J. N. Priestley, *Seismic Design of Reinforced Concrete and Masonry Buildings*, Wiley-Interscience, 1992<br><br>M.J.N. Priestley, G.M. Calvi, and M.J. Kowalsky, *Displacement Based Seismic Design of Structures*, IUSS Press, 2007<br><br>M. Bill Wong, *Plastic Analysis and Design of Steel Structures*, Butterworth-Heinemann, 2009 |
| Course Format: | Two and a half hour lecture per week |
| Assessment and Composition of Grades | Quizzes: 10%<br>Midterm (Monday, Oct. 19h): 30%<br>Final Exam (Wednesday, Dec. 9th): 40%<br>Project and presentation (optional)<br>Due: Monday, November 30, 2009: 05%<br>Homework: 20% |
| Homework: | Please submit your assignments by the due date (a week after they are assigned) |
| Project (Optimal): | Individually or in teams of two. You can choose any subject related to the course but you are encouraged to discuss your topic with the instructor first. A short report and a class presentation conclude your project. |
| First day of classes: | Monday, August 24, 2009 |
| End of session: | Wednesday, December 16, 2009 |