An Introduction to Earthquake-Resistant Design

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The Earthquake Challenge

- Earthquakes provide one of the most challenging problems facing the structural engineering profession
- Important social and economic problem
- Field is rapidly changing
  - Changing demands by society
  - New tools for design and analysis
  - New technologies
- Basic concepts and tools relevant to design to resist other forms of natural and human-induced hazards
Today

- Course Organization
- Sources of Earthquake Damage
- Trends in Earthquake Engineering
  - Evolution of building codes
  - Genesis of performance-based approaches to earthquake engineering
- Scope of Course

Course Organization

Contact Information

- Instructor:
  Stephen Mahin
  777 Davis Hall, 642-4021, mahin@ce.berkeley.edu
  Office Hours: Tentatively TuTh 1-2
  or by appointment

- Teaching Assistant:
  Janise Rodgers
  504 Davis Hall
  janise_r@uclink4.berkeley.edu
  Office Hours: TBD
Course Organization

Lectures
TuTh 11-12:30
534 Davis Hall

Review and Discussion Session
- Weekly session with Graduate Student Instructor or Professor.
- Clarify important points in class or carry out examples.
- Help with homework assignments.
- Time slot to make up missed classes.
  - Time to be determined

Prerequisites
- Advanced course in structural analysis (CEE 220/121)
- Course in structural dynamics through modal analysis and use of linear response spectrum techniques for multiple degree of freedom systems (CEE 225/125).
- Some design background.
- Some familiarity with plastic analysis.

Questions on student background:
- Capacity design concepts (CE 244) and simple plastic analysis (CEE 248)?
On-Line Course Notes

Annotated interactive course outline available at:
http://peer.berkeley.edu/course_modules/eqrd/

Still under construction

Includes class notes, handouts, homework problems, most solutions, review questions, as well as:
- Various analytical tools
- Links
- Other useful information

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FEMA References

FEMA publications available for free by downloading from the web or calling 1-800-480-2520

Useful References

Various Technical Papers
✓ On Reserve in Engineering Library
✓ From course website or other provided URLs.

Frequent reference to:

Reference Texts:

Important Sources of Information

✓ National Information Service for Earthquake Engineering
   http://nisee.berkeley.edu
   ✓ Library, located at Pacific Earthquake Engineering Research Center, Richmond
   ✓ Computer applications-Provides non-proprietary computer software and ground motions library

✓ Earthquake Engineering Research Institute, Oakland, CA
   http://www.eeri.org

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Nonlinear Analysis of Structural Systems

Download: http://www.ce.berkeley.edu/~hachem/bispec/index.html

Bispec
✓ Single-DOF systems subjected to one or two components of one or more earthquake records
✓ Response spectra
✓ Animation
✓ Online and downloadable help manuals

Other programs (NONLIN, CAPP, ETABS, SAP) will be made available later

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Course Organization

Assignments
✓ Reading
✓ Homework Assignments
✓ Sequence of problems related to design and evaluation of a single building
✓ Quantitative as well as discussion type questions
✓ Midterm Quizzes
✓ Equivalent of two 80 minute midterm exams (40 minute or 5-35 minute quizzes)
✓ Term Project
✓ Design or research type project of your choice

Grading
✓ Homework, 25%
✓ Quizzes, 40%
✓ Project, 35%

One of many possible projects
Review Sources of Damage

Damage caused by:
✓ Ground shaking
✓ Fault rupturing
✓ Liquefaction and soil movement
✓ Slope instability and landslides
✓ Tsunami and seiche
✓ Fire
✓ Flooding
✓ Interaction with adjacent structures (pounding)
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Trends in Earthquake Engineering

❖ Rapid evolution of model building codes and ad hoc guidelines for design of special structures and evaluation and rehabilitation of existing structures

❖ Fundamental approaches being developed for performance-based engineering design and evaluation
Rapid evolution of building codes

- Focus is on prevention of major catastrophes associated with structural collapse
- Changes in code provisions usually tied to observed damage in major earthquakes
  - Damage to buildings on soft soil → soil factors
  - Damage to tops of tall structures → concentrated forces applied at top of structures
  - Damage in R/C columns → ductile details

Basic Design Guidelines from Past Earthquakes

1. Avoid unnecessary mass. Achieve a uniform distribution of mass.
2. Preserve symmetry. Avoid significant torsional motions.
3. Use as simple a structural system as possible. Make sure there is a complete load path.
4. Use a redundant structural system. Use a backup structural system where ever possible.
5. Structure should be compact and regular in both plan and elevation. Avoid structures with elongated or irregular plans; having substantial setbacks in elevation; or that are unusually slender.
6. Use a uniform and continuous distribution of stiffness and strength. Avoid nonstructural components that unintentionally effect this distribution. Avoid sudden changes in member sizes or details.
Basic Guidelines (Continued)

7. Permit inelastic action (damage) only in inherently non-critical ductile elements (i.e., in beams rather than columns).
8. Detail the members to avoid premature, brittle failure modes. Utilize capacity design principles to avoid undesired shear, axial or joint failures and to foster ductile flexural failure modes.
9. Avoid hammering (pounding) of adjacent structures.

10. Tie all structural components together. Anchor nonstructural components to structure to avoid falling hazards.
11. Avoid systems with low amounts of viscous damping. Absence of nonstructural components tied to structure may be indication of low damping in steel structures.

Building codes are useful design tools

Define “standard of care” ... important legal and professional concept.
But ... focus is on minimum standards needed for the protection of life safety

"provide minimum standards to safeguard life or limb, health, property and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of buildings."

✓ A detailed, prescriptive “deemed-to-comply” format used.
✓ Contains a mix of empiricism, simplified theory and expert judgment.
✓ Current codes provide little guidance on how various stipulations relate to performance.
Codes improving, but not perfect ...

Uneven performance of model code-compliant buildings noted in recent earthquakes. Some perform very well, while others are inadequate.

- Nearly 70% of new steel buildings shaken by the Northridge earthquake suffered brittle fractures in their welded beam to column connections. More than 10% of new steel welded moment frame buildings in Kobe collapsed.
- Several new reinforced concrete structures collapsed or were severely damaged during the Northridge and Loma Prieta earthquakes.
- Important buildings designed by well respected engineers, under stringent quality control conditions are frequently damaged.

Problems becoming more complex

Expected ground motions more severe and complex than previously assumed.

- Concern for near-source, soft soil, long duration motions ... the big one.
- Public's tolerance for damage has diminished due to apparent increase in the frequency of damaging earthquakes.
- Recent earthquakes
  - Near Los Angeles and San Francisco
  - Turkey, Taiwan and Japan
- Highly publicized probabilistic predictions
- No longer considered a rare "act of god."
- Insurance companies and building owners concerned with maximum probable economic losses
- Minimizing disruption of services important
Situation is in flux!

- Addition of new technologies for seismic resistance (isolation, supplemental damping, buckling restrained bracing, composite members, etc.)
- Quantitative, not qualitative, answers wanted
- Addition of new analysis and design tools (nonlinear static and dynamic analysis, probabilistic hazard maps, etc.)
- Economic and social impacts more important
- Developments do not all have same objectives
  - Life safety. How safe?
  - Stated performance goals may differ
  - What is meant by performance state (e.g., continued occupancy)
- Targeted confidence levels vary

Some considerations

- Traditional Analysis problem
  Given structure and loading, check that
  \[ \text{Demands} < \text{Capacity} \]

Design problem
  Identify attributes of a structure that for given earthquake environment will economically and reliably satisfy stated performance expectations.

Need tool box
  - analysis of demands on structure
  - analysis of capacity of structure

Need to manage risk and uncertainty
  - Rational load and resistance factors
  - Utilize system characteristics inherently insensitive to uncertainties in seismic hazard
  - Focus more on displacement and stability than force
Towards Performance-based Engineering

No need to wait for next earthquake to improve seismic design and evaluation methods

- Probabilistic framework
- Probabilistic seismic hazard assessment
- Integrate research on system and element behavior
- Computational tools for predicting seismic demands on systems and elements
- Computational tools to predict capacity of systems and elements to resist expected demands
- Relate engineering parameters to parameters owners and decision makers can understand (cost, disruption, etc.)

From research to practice

- No longer need to wait until the next earthquake
- Testing has had a big impact on structural engineering knowledge and practice
From research to practice

- No longer need to wait until the next earthquake
- Testing has had a big impact on structural engineering knowledge and practice
- Greatly improved details
- Validated computer models
Structural Engineering Practice

- More and better education
- Regularly use computer simulation models in design
- Rigorous inspection of construction
- Codes include advanced analysis methods
- Introduction of new technologies and devices
  Seismic isolation, supplemental energy dissipation devices
- Performance-based engineering frameworks

Severity of Damage

<table>
<thead>
<tr>
<th>Damage</th>
<th>Operational</th>
<th>Immediate Occupancy</th>
<th>Life Safety</th>
<th>Collapse Prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>99%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Joe's Beer! Beer! Beer! Food! Food! Food! Food!
Damage related to demand parameters

Relate Probabilities of Exceedence to Damage States
Quantification of Earthquake Hazard

Structural Engineering Tools Improve

Greater demands for quantitative design and evaluation methods that realistically and explicitly account for performance

✓ Improving analysis tools
✓ Improving characterization of performance

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Performance-Based Design Approaches

Much activity to improve codes

Improved national codes

- National Earthquake Hazard Reduction Program (NEHRP)
- Tentative Provisions for Seismic Design of Buildings (Building Seismic Safety Council)
- International Building Code (merging of three main model codes used in the US and incorporating NEHRP provisions)

New approaches

- Improved performance and reliability
  - Performance-based design (EERC/FEMA)
  - Vision 2000 (SEAOC)
  - SAC Steel Project (FEMA 350 - FEMA 353)
  - Next generation codes (NSF, FEMA)
- Existing Buildings
  - Guidelines for the Rehabilitation of Existing Buildings (FEMA 356)
Earthquake-Resistant Design

- What's covered
- Course outline

Rational framework needed

Need balanced perspective to integrate information from:
- structural analysis
- structural behavior
- seismology
- geotechnical engineering
- economics and public policy
- risk and reliability analysis

Focus on objectives, not procedures or prescriptions

Rely on first principles
Some basic issues treated in course

- Identify key response parameters
- How to get a structure that behaves as expected?
- How do different ground motion characteristics effect structures?
- How do different structural materials & systems behave?
- How do you change system to improve performance?
- Effect of designer decisions about proportions on response.
- How to characterize reliability of a system?
- What simplified tools should be used in design?
- What analysis tools can be used to assess performance?

Course Overview

- Introduction
- Engineering Characterization of Ground Motions
- Sensitivity of Seismic Response of Simple Systems to Ground Motion and Structural Characteristics
- Development of Design Earthquakes (Linear & Nonlinear)
- Analytical Tools for Preliminary/Conceptual Design
- Design Issues and Approaches
  - Code-related Issues - Interpretation and future trends
  - Performance-based Design
  - Capacity Design / Damage Tolerant Design
- Applications
  - Moment Resisting and Braced Frames (mainly steel)
  - New construction and retrofit
- Special topics
Scope of Course

Questions?