For more information, contact: EERI
6431 Fairmount Avenue, Suite 7
El Cerrito, CA USA 94530-3624
(415) 525-3668

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
COMMITTEE ON CONTINUING EDUCATION

SLIDES ON EARTHQUAKE-RESISTANT DESIGN

SET I: EARTHQUAKE HAZARDS

Created by: Walter W. Hays, U.S. Geological Survey, Reston, Virginia 22092

PREFACE

The primary physical phenomena (hazards) accompanying an earthquake are horizontal ground shaking and permanent ground failure (landslides, liquefaction, and surface fault rupture). These hazards cause most of the damage and, therefore, are the subject of earthquake-resistant design. The secondary hazards are: regional tectonic deformation, tsunamis, seiches, fire, flooding from dam failure, and aftershocks. They can also cause great losses if they are not considered in the overall design and siting process.

The basic concept of earthquake generation is one of cyclic stress accumulation and an abrupt release along a fault zone. An earthquake is unique in that unlike all other natural hazards it has the potential for causing great socioeconomic impact and loss with little or no warning. In a period of several seconds to a few minutes, the abrupt release of energy can cause economic losses that reach billions of dollars and leave hundreds of thousands dead, injured, and homeless. The impact on human settlements can be so severe that a decade or more may be required for full recovery.

Design and construction are the key elements in the process that transforms empirical data, experimental data, theory, and judgment into lateral-force-resistant buildings and lifeline systems. Design of buildings and lifeline systems requires the best available geologic and seismologic information to define the lateral forces (demand) they will be subjected to. The following questions need answers:

1) Affected Area - What is the size and shape of the geographic area expected to be affected by the occurrence of a damaging earthquake? The near-source region is the most difficult part of the design problem.

2) Severity - How severe are the physical effects expected to be in both the

near-source and far-source regions?

3) Frequency - How often, on the average, is an event large enough to cause damage expected to occur?

4) Impact Time and Duration - How much lead time is expected between the first precursors of the event and its peak impacts? When the event strikes, how long is it expected to last?

5) Primary and Secondary Hazards - What kinds of physical phenomena (hazards) are expected when the event strikes? Which ones will dominate?

Two physical phenomena--vibratory ground motion and permanent ground movements--are the most important considerations in earthquake-resistant design of buildings and lifeline systems. For ordinary buildings governed by a building code and lifeline systems sited above ground, the vibratory ground motion caused by P, S, Love, and Rayleigh waves is of primary importance. For underground structures and buried lifeline systems, consideration of permanent ground movements is more important.

Buildings encompass many categories, including: 1) dwellings, institutional buildings, and public structures, 2) emergency facilities, 3) critical facilities, 4) commercial, financial, and industrial facilities, 4) government facilities and operations. Most people work and live in ordinary buildings (Category 1), whose design is governored by a building code. Other facilities (e.g., hospitals, dams, nuclear power plants) have their own design criteria.

Lifeline systems include energy (electricity, gas, liquid fuel, steam) water (portable, flood, sewage and solid waste, fire-fighting water) transportation (highways, bridges, railways, airports, harbors, transit), and communication (telephone, telegraph, radio, television, telecommunication, mail, press). They provide the essential functions of supply, disposal, transportation, and communication required by a community before and after a damaging earthquake. Criteria for design of lifeline systems have evolved since the 1971 San Fernando earthquake.

The following slides will illustrate some of the important considerations of earthquake hazards in design, emphasizing the input that geology and seismology bring to the design process. Although the emphasis is on the United States, the principles apply worldwide.

References

1. Algermissen, S. T., 1983, An introduction to the Seismicity of the United States: Earthquake Engineering Research Institute Monograph, El Cerrito, California, 148 p.

2. Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., 1982, Probabilistic Estimates of Maximum acceleration and Velocity in Rock in the Contiguous United States: U.S. Geological Survey Open-File Report 82-1033.

3. American Society of Civil Engineers, 1977, The Current State of Knowledge of Lifeline Earthquake Engineering, New York, 478 p.

4. Federal Emergency Management Agency, 1987, Abatement of Seismic Hazards to Lifelines: An Action Plan: Washington, D.C., 6 volumes.

5. Hays, W. W., 1980, Procedures for Estimating Earthquake Ground Motions: U.S. Geological Survey Professional Paper 114, 77 p.

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7. Key, David, 1988 Earthquake Design Practice for Buildings: Thomas Telford, London, England, 217 p.

8. National Academy of Sciences, 1982, Earthquake Engineering Research - 1982, National Academy Press, Washington, D.C. 266 p.

9. U.S. Geological Survey, 1988, Probabilities on Large Earthquakes Occurring

in California on the San Andreas Fault: U.S. Geological Survey Open-File Report 88-398, 62 p.

COMMENTARY FOR SLIDES

Slide Number	Title/Description

Haz 1. Six Options for Mitigation of Earthquake Physical Effects.

Prevention involves controlling the source of the event in a way that changes the physical characteristics of the physical phenomena generated in the event.

Protection is building to withstand the physical phenomena generated in the event. (The building code is the key element.)

Land-use Control encompasses identification and avoidance of sites where an event to expected to have the greatest severity.

Site Modification involves changing the physical properties at the construction site in a way that reduces the vulnerability.

Alert and Warning is providing advance notice of the location, severity, and time of an impending event to the affected populace.

Short-term Protection is response to an alert or warning by performing actions to strengthen existing structures and lifeline systems so that they will be less vulnerable.

Haz 2. Elements of Risk.

Risk (chance of loss) depends of four elements: the location, the buildings and lifelines exposed to the earthquake threat, the physical phenomena (hazards) generated in an earthquake, and the vulnerability of the buildings and lifelines to these hazards.

Haz 3. Example of Poor Siting of Building Creating a Special Design Problem.

This building is sited over an active thrust fault. Design considerations should focus on: 1) the near-field ground shaking, and 2) surface fault rupture. Liquefaction and landsliding might also be a consideration. Each of these hazards is illustrated in slides 4-9.

Haz 4. Horizontal Ground Acceleration and Response Spectra in the Near-Source Region; 1971 San Fernando, California Earthquake.

Designing for sites in the near-source region is the most difficult part of the design process because of focusing, directivity, and fault-related effects. This near-source accelerogram recorded 3-5 km from the epicenter exhibited a peak horizontal acceleration of 1.24 g. The horizontal accelerogram exhibited a "killer" pulse attributed to the fling of the thrust fault and "break out phases" attributed to surface fault rupture. The accelerogram waas controversial because of the effects of topography and the very high ground motion. The 5 percent damped response spectrum approached 200 cm/sec at some periods.

Haz 5. Example of Surface Fault Rupture; 1971 San Fernando, California Earthquake (a thrust fault earthquake).

Buried lifeline systems are especially vulnerable to permanent ground displacement. Buildings and above ground lifelines must also have special design in order to withstand surface fault rupture.

Haz 6. An Important Technical lesson.

Geotechnical considerations in earthquake-resistant design of buildings and lifeline systems are very important. (Reference 8).

Haz 7. Liquefaction

Example of liquefaction; 1979 Imperial Valley, California earthquake. Buried lifeline systems are especially vulnerable to liquefaction. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil.

Haz 8. Effect of liquefaction on Buildings

Example showing the effect of liquefaction on buildings; 1964 Niigata, Japan earthquake.

Haz 9. Landslide

Example of landslide triggered at Turnagain Heights in March 27, 1964 Prince William Sound, Alaska earthquake. The sensitive clay formation, Bootlegger Cove, underlying the area played a major role in the slide.

Haz 10. Regional Tectonic Deformation

Example of regional tectonic deformation; March 27, 1964 Prince William Sound, Alaska earthquake. Location was below sea level before the earthquake. An area of more than 70,000 square miles experienced tectonic deformation in the earthquake.

Haz 11. Dam Failure

Example of near-failure of Van Norman Dam; 1971 San Fernando, California earthquake. Disaster was averted by drawing down the water level immediately after the earthquake. Design criteria for earth dams were reevaluated after the San Fernando earthquake.

Haz 12. Design philosophy: Building Code

Philosophy of earthquake-resistant design for buildings. Damage is allowed but not collapse. Knowledge of the demand is very important. (See slides 14, 15, and 40) (Reference 7).

Haz 13. Design Philosophy: Critical Facilities

Philosophy of earthquake-resistant design for critical facilities differs from that for buildings. A broad-band smooth elastic design response spectrum and a time history are used. Inelastic behavior is not allowed. (Reference 5 and EERI Monograph by Newmark and Hall, "Earthquake Spectra and Design.")

Haz 14. Earthquake ground shaking--The Demand

Comparison of the earthquake bedrock ground shaking hazard in the conterminous United States; 50 year exposure time, 90 percent probability of nonexceedance. Construction of such maps requires analysis of seismicity data, delineation of seismogenic zones, and determination of regional attenuation relations. (Source: Reference 2)

Haz 15. Earthquake Ground Shaking - The Demand in Alaska

The earthquake bedrock ground shaking hazard in Alaska; 50 year exposure time, 90 percent probability of nonexceedance. (Source: Thenhaus, P.C. and others, 1985, Earthquake Spectra, v. 1, pp. 285-305).

NOTE: Maps such as the ones shown in slides 14 and 15 are the basis for the zoning maps in building codes (See slide 40). Soil effects are usually evaluated separately in the context of the building code.

Haz 16. Important Physical Parameters in Design

Important parameters when designing to withstand ground shaking include: 1) the fault, 2) seismicity, 3) attenuation, and 4) soil response. Each parameter influences the ground motion expected at a site in a predictable way which can be incorporated in the design.

Haz 17. The Fault - An Important Technical Lesson

The fault controls the main features of the ground shaking. Three parameters--peak amplitude, spectral composition, and duration--are important.

Haz 18. The San Andreas Fault Zone, California

This 1000-km-long right-lateral strike slip fault system marking the boundary of the North American and pacific plates exhibits different characteristics along its extent. The near-source problem is the most difficult part of the assessment of the ground-shaking hazard for design. The seismic cycle is the most difficult part of the problem for prediction. Paleoseismicity studies provide essential information for both applications.

Haz 19 Earthquake Probabilities Along the San Andreas Fault Zone. (Source: Reference 9).

This slide compares the probability of large earthquakes along segments of the San Andreas fault system. The most eminent earthquake is at Parkfield where a magnitude 6.25 type event has been predicted between 1988 and 1991. In the next 30 years (1988-2018), the probability for a damaging earthquake in Southern California is higher than is Northern California.

Haz 20. Wasatch Fault Zone, Utah

The near-source problem is the most difficult part of the assessment of the ground-shaking hazard for this 370-km-long normal fault system. Ten active fault segments have been identified. Each segment generates earthquakes independent of the others. No large earthquake has occurred since the area was settled in the 1840's.

Haz 21. New Madrid Seismic Zone and Current Seismicity.

The New Madrid seismic zone is buried 3-5 km. It was delineated on the basis of current seismicity and subsurface models derived from gravity, magnetic, and seismic data. The near-source problem is the most difficult part of the assessment of the demand.

Haz 22. An Important Technical Lesson on Earthquake Recurrence.

Earthquakes tend to recur where they have occurred in the past. This fact means that the delineation of seismogenic zones on the basis of geology and historical seismicity (paleoseismicity) is a key part of the design process.

Haz 23. Seismogenic Zones in the Western United States.

the near-source problem is the most difficult part of the assessment of the ground-shaking hazard. (Source: References 2,5). Note that the zones in the Western U.S. tend to be smaller than those in the eastern U.S.--reflecting the greater base of knowledge and the exposure of many active fault systems at the surface in the west.

Haz 24. Seismogenic Zones in the Eastern United States.

The near-field problem is the most difficult part of the assessment of the ground-shaking hazard. (Source: References 2, 5). The zones of the 1811-1812 New Madrid and the 1886 Charleston earthquakes are shown in this slide as fairly large geometrical areas. The fault system generating the Charleston earthquake is still not known unequivocally.

Haz 25. Seismicity - Alaska

Historical earthquakes in Alaska (1899-1976). (Source: Reference 1)

The 1964 Prince William Sound earthquake is the last destructive one to occur.

Haz 26. Seismicity - California and Western Nevada

Historical earthquakes in California and Western Nevada (1812-1983). (Source: Reference 1)

The 1906 San Francisco and 1857 Fort Tejon earthquakes are the last great ones to occur.

Haz 27. Seismicity - Northeastern U.S.

Historical earthquakes in the Northeastern United States (1535-1983). (Source: Reference 1)

Haz 28. Seismicity - Southeastern U.S.

Historical earthquakes in the Southeastern United States (1774-1983). (Source: Reference 1)

The 1886 Charleston earthquake is the last big one to occur.

Haz 29. Seismicity - Central U.S.

Historical earthquakes in the Central United States (1838-1983). (Source: Reference 1)

Significant earthquakes include the three great ones in 1811-1812and the 1895 Charleston, MO earthquake.

Haz 30. Attenuation

Comparison of the same portions of isoseismal maps, Eastern and Western U.S. Earthquakes. Earthquake waves attenuate more slowly in the eastern United States. This fact leads to a larger area of impact in the east, possibly affecting tall buildings far from the earthquake source. The reference of Rankin 1977 is to U.S. Geological Survey Professional Paper 1028.

Haz 31. Seismicity - Western Mountain Region

Historical earthquakes in the western mountain region of the United

States (1852-1983). (Source: Reference 1)

The October 1983 Borrah Peak and August 1959 Hebgen Lake earthquake are the last big earthquakes.

Haz 32. Seismicity - Washington and Oregon

Historical earthquakes in Washington and Oregon (1872-1983). (Source: Reference 1)

The April 1949 and April 1965 earthquakes are the last damaging earthquakes.

Haz 33. Seismicity - Hawaii

Historical earthquakes in Hawaii (1868-1983). (Source: Reference 1)

The April 1868 earthquake had an epicentral intensity of X.

Haz 34. Seismicity - Puerto Rico and Virgin Islands

Puerto Rico - Virgin Island region (1824-1983). (Source: Reference 1)

Both the April 1867 and October 1918 earthquakes generated destructive tsunamis.

Note for slides 25-34: MM intensity VI corresponds approximately with the threshold of ground failure; VII with architectural damage; VIII with structural damage; IX with severe structural damage; and X-XII with severe ground failure and severe structural damage.

When correlating MM intensity with horizontal ground acceleration and velocity:

-- intensity VI corresponds roughly with 8% g and 6 cm/sec;
-- intensity VII corresponds roughly with 14% g and 10 cm/sec;
-- intensity VIII corresponds roughly with 25% g and 21 cm/sec;

-- intensity IX corresponds roughly with 50% g and 50 cm/sec.

Some variation will result as a function of the properties of the underlying soil at the site.

Haz 35. An Important Technical lesson on Earthquake Ground Motion.

Don't underestimate the demand!

Haz 36. Mexico earthquake

This slide of Mexico City shows damaged and undamaged buildings in the background and a collapsed building in the foreground, the result of the September 19, 1985 Mexico earthquake.. Damage was restricted primarily to the lake bed zone which amplified the foundation ground motion and caused the actual demand to exceed the capacity incorporated in the design process (see slide 39).

Haz 37. Mexico Earthquake

Comparison of horizontal accelerograms recorded in lake bed zone (Top) and on rock-like material (bottom), Mexico City, September 19, 1985 earthquake. Two-second period amplification occurred in parts of the lake bed zone, making the ground shaking theremuch more intense.

Haz 38. Mexico Earthquake

Comparison of 2 percent damped horizontal response spectra from 1985 Mexico and 1940 Imperial Valley, California earthquakes. Note that the Mexico City lake-bed zone spectrum is increasing when the Imperial Valley spectrum is decreasing. This atypical effect contributed to the collapse of 5 to 20 story buildings in the lake-bed zone; i.e., not only 20-story buildings having a fundamental period of vibration 2 seconds but shorter ones as well.

Haz 39. Mexico Earthquake

Comparison of actual demand with design spectra; 1985 Mexico Earthquake; lake-bed zone, Mexico City. Since the earthquake, the design level was raised to 0.4.

Haz 40. Seismic Zone Map - United States

This slide shows the ANSI A58.1 seismic zone map for the United States. This map is based on an integration of the best available information on 1) seismogenic zones, 2) historical seismicity, and 3) regional seismic wave attenuation The zones are smoothed values derived from a map such as that shown in slide 14. Zone 4 corresponds with 40% g and greater; Zone 3 with an EPA of 20 to 40% g; Zone 2 with an EPA of 10 to 20% g; Zone 1 with an EPA of 5 to 10% g, and Zone 0 with an EPA of less than 5% g.