Earthquakes Mechanics and Effects

Earthquakes: Cause and Effect
- Why earthquakes occur
- How earthquakes are measured
- Earthquake effects
- Mitigation strategy
- Earthquake time histories

Seismic Activity: 1961-1967

Plate Boundaries

Plate Tectonics: Driving Mechanism

Plate Tectonics: Details in Subduction Zone
Seismicity of North America

Seismicity of Alaska

Faults and Fault Rupture

Types of Faults

Elastic Rebound Theory

Time = 0 Years

Time = 40 Years
Old fence

Time = 41 Years

New road

Old fence

Seismic Wave Forms (Body Waves)

Compression wave (P wave)

Shear wave (S wave)

Seismic Wave Forms (Surface Waves)

Love wave

Rayleigh wave

Arrival of Seismic Waves

P waves  S waves  Love waves

Relationship Between Reservoir Level and Seismic Activity at Koyna Dam, India
Effects of Seismic Waves

- Fault rupture
- Ground shaking
- Landslides
- Liquefaction
- Tsunamis
- Seiches

Cause of Liquefaction

“If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume. If drainage is unable to occur, the tendency to decrease in volume results in an increase in pore pressure. If the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero, the sand loses its strength completely, and liquefaction occurs.”

Seed and Idriss (1971)

Landslide on Coastal Bluff, 1989 Earthquake in Loma Prieta, California
Cause of Tsunamis

Tsunamis are created by a sudden vertical movement of the sea floor.

These movements usually occur in subduction zones.

Tsunamis move at great speeds, often 600 to 800 km/hr.

Tsunami Damage, Seward, Alaska, 1964

Result of Ground Shaking, 1994
Earthquake in Northridge, California

Mitigation Strategies

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<th>Earthquake effect</th>
<th>Strategy</th>
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<td>Liquefaction</td>
<td>Avoid/resist</td>
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<td>Ground shaking</td>
<td>Resist</td>
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Measuring Earthquakes

INTENSITY
- Subjective
- Used where instruments are not available
- Very useful in historical seismicity

MAGNITUDE
- Measured with seismometers
- Direct measure of energy released
- Possible confusion due to different measures

Modified Mercalli Intensity

- Developed by G. Mercalli in 1902 (after a previous version of M. S. De Rossi in the 1880s)
- Subjective measure of human reaction and damage
- Modified by Wood and Neuman to fit California construction conditions
- Intensity range I (lowest) to XII (most severe)
Modified Mercalli Intensity

I. Not felt except by a few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings. Standing automobiles may rock slightly. Vibration like passing truck.

IV. During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. [0.015 to 0.02g]

V. Felt by nearly everyone, many awakened. Some dishes and windows broken. Cracked plaster. Unstable objects overturned. Disturbance of trees, poles and other tall objects. [0.03 to 0.04g]

VI. Felt by all. Many frightened and run outdoors. Some heavy furniture moved. Fallen plaster and damaged chimneys. Damage slight. [0.06 to 0.07g]

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well built ordinary structures, considerable in poorly built or badly designed structures. Noticed by persons driving cars. [0.10 to 0.15g]

VIII. Damage slight in specially designed structures, considerable in ordinary construction, great in poorly built structures. Fall of chimneys, stacks, monuments. Sand and mud ejected is small amounts. Changes in well water. Persons driving cars disturbed. [0.25 to 0.30g]

IX. Damage considerable in specially designed structures, well designed frame structures thrown out of plumb, damage great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. [0.50 to 0.55g]

X. Some well built wooden structures destroyed. Most masonry and frame structures destroyed with foundations badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks. [More than 0.60g]


XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.

Isoseismal Map for the Giles County, Virginia, Earthquake of May 31, 1897.
Isoseismal Map
For New Madrid
Earthquake of
December 16, 1811

Isoseismal Map
for 1886
Charleston
Earthquake

Isoseismal Map for February 9, 1971,
San Fernando Earthquake

Comparison of Isosiesmal Intensity for Four Earthquakes

Comparisons of Various Intensity Scales

Instrumental Seismicity
Magnitude (Richter, 1935)
Also called local magnitude

$M_L = \log \text{ [Maxumum Wave Amplitude (in mm/1000)]}$

Recorded Wood-Anderson seismograph
100 km from epicenter
Magnitude (in general)

\[ M = \log A + f(d,h) + C_S + C_R \]

- \( A \) is wave amplitude
- \( f(d,h) \) accounts for focal distance and depth
- \( C_S \) and \( C_R \) are station and regional corrections

Other Wave-Based Magnitudes

- \( M_s \) Surface-wave magnitude (Rayleigh waves)
- \( m_b \) Body-wave magnitude (P waves)
- \( M_b \) Body-wave magnitude (P and other waves)
- \( m_{bLg} \) (Higher order Love and Rayleigh waves)
- \( M_{JMA} \) (Japanese, long period)

Moment Magnitude

Seismic moment = \( M_o = \mu AD \)

[Units = force times distance]

Where:
- \( \mu \) = modulus of rigidity
- \( A \) = fault rupture area
- \( D \) = fault dislocation or slip

Moment magnitude = \( M_W = (\log M_o - 16.05)/1.5 \)

[Units = dyne-cm]

Approximate Relationship Between Magnitude and Intensity

- \( M_L = 0.67 I_0 + 1 \)
- \( M_{bLg} = 0.49 I_0 + 1.66 \)

Seismic Energy Release

\[ \log E = 1.5 M_S + 11.8 \]
Seismic Energy Release

Ground Motion Accelerograms

Sources:
- NONLIN (more than 100 records)
- Internet (e.g., National Strong Motion Data Center)
- USGS CD ROM

Uses:
- Evaluation of earthquake characteristics
- Development of response spectra
- Time history analysis

Sample Ground Motion Records

Ground Motion Characteristics
- Acceleration, velocity, displacement
- Effective peak acceleration and velocity
- Fourier amplitude spectra
- Duration (bracketed duration)
- Incremental velocity (killer pulse)
- Response spectra
- Other (see, for example, Naiem and Anderson 2002)

Corrected vs Uncorrected Motions

Corrections made primarily:
- To remove instrument response
- To account for base line shift

Base Line Correction for Simple Ground Motion
**Typical Earthquake Accelerogram Set**
- Horizontal acceleration (E-W), cm/sec²
- Vertical acceleration (E-W), cm/sec²
- Horizontal acceleration (N-S), cm/sec²

**Definition of Bracketed Duration**
- Acceleration, cm/sec²
- Bracketed duration

**Definition of Incremental Velocity**
- Acceleration, cm/sec²

**Concept of Fourier Amplitude Spectra**
- Function: \( f_j(t) = a_0 + \sum_{j=1}^{N} a_j \cos(2\pi f_j t) + \sum_{j=1}^{N} b_j \sin(2\pi f_j t) \)
- \( f_j = \frac{d}{d t} \)
- \( \phi_j = \arctan \left( \frac{b_j}{a_j} \right) \)
- \( A_j = \sqrt{a_j^2 + b_j^2} \)

**Ground Motion Frequency Content (1)**
- Horizontal acceleration (E-W), cm/sec²
- Vertical acceleration (E-W), cm/sec²

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**Instructional Material Complementing FEMA 451, Design Examples**

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