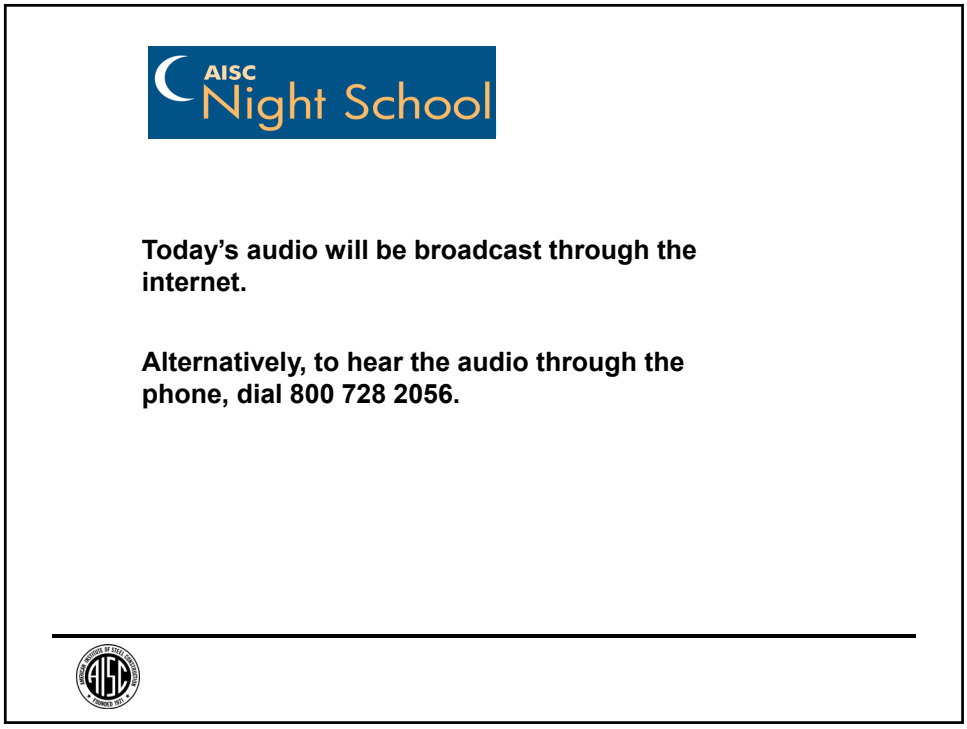

AISC Night School

Today's live webinar will begin shortly.
Please standby.
As a reminder, all lines have been muted. Please type any questions or comments through the Chat feature on the left portion of your screen.

Today's audio will be broadcast through the internet.
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Course Description

Session 1: Seismology and Earthquake Effects

February 24, 2014

This lecture discusses plate tectonics as the source of seismic energy release and addresses earthquake measures and the concepts of magnitude and intensity. As well, local and widespread earthquake effects will be presented. Probability concepts, return periods and risk in addition to issues of related hazards, including tsunamis will be presented.

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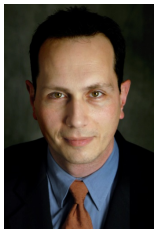
Learning Objectives

- Gain familiarity with seismology and plate tectonics.
- Learn and understand how earthquakes are measured and the effect on building structures.
- Gain an understanding of earthquake effects and their influence on structures.
- Learn and understand the probability of earthquakes and how this influences the design of steel buildings.

There's always a solution in steel.

Fundamentals of earthquake engineering for building structures



Rafael Sabelli, SE

structural STEEL

Course objectives

- Understand the principles of earthquake engineering
- Understand the application of those principles in the fundamental procedures of seismic design
- Understand how the material properties of steel are utilized in seismic design

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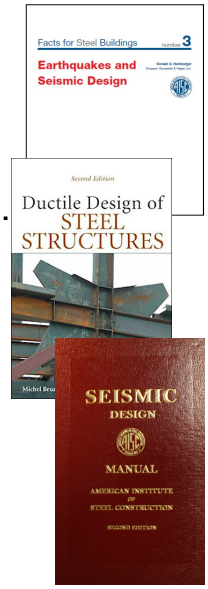
Resources

- *Earthquakes and Seismic Design,* Facts for Steel Buildings #3. Ronald O. Hamburger, AISC.
- *Ductile Design of Steel Structures*, Bruneau, Uang, and Sabelli, McGraw Hill.
- AISC *Seismic Design Manual*
- Other publications suggested in each session



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Resources

- AISC Seismic Design Manual Seminar
  - Offered live in cities across the US
    - Consult AISC.org for locations and dates
  - Introduces the *Seismic Design Manual*
  - Introduces the reorganized 2010 AISC *Seismic Provisions*
    - Introduces key technical changes in the *Seismic Provisions*
    - Presents key provisions
    - Explains commonly misapplied provisions
  - Presents selected design examples
- Seismic Night School (this course)
  - Principles
  - Concepts
  - Lays groundwork for Seismic Design Manual Seminar

www.aisc.org/seminars

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Other resources

- AISC Solutions Center
  - 866.ASK.*AISC* (866-275-2472)
  - Solutions@AISC.org
- AISC Night School
  - Nightschool@AISC.org

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Course outline

1. **Seismology and earthquake effects**
2. Dynamics and response
3. Building dynamics and response
4. Steel behavior
5. System ductility and seismic design
6. Steel systems
7. Building configuration
8. Building codes

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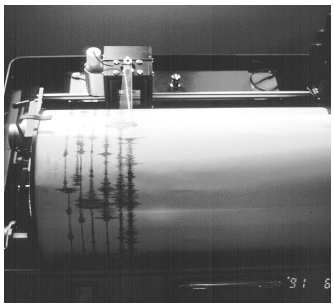
Session 1: Seismology and earthquake effects



Session topics

- Plate tectonics
- Seismic waves
- Earthquake measures
- Major earthquakes
- Earthquake effects
- Related hazards
- Hazard, risk, and probability

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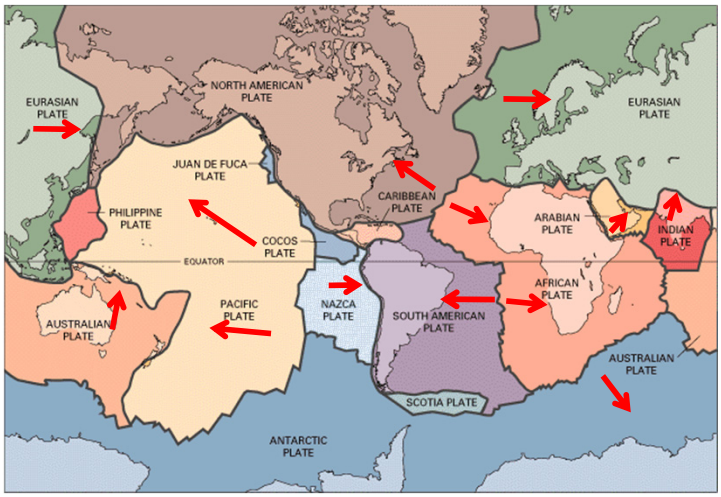
Plate tectonics

Major Tectonic Plates



Plates move relative to each other continuously. Near plate boundaries strain energy is built up and released as an earthquake.

USGS

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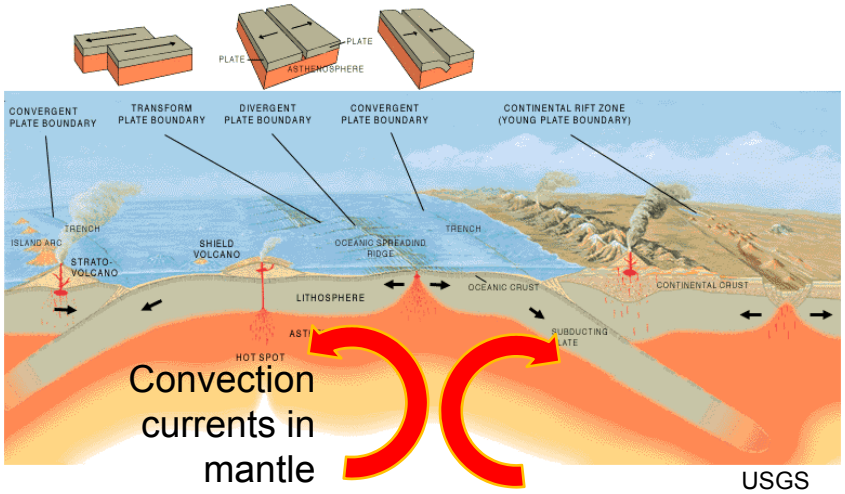
Tectonic plate movement



Convection currents in mantle

USGS

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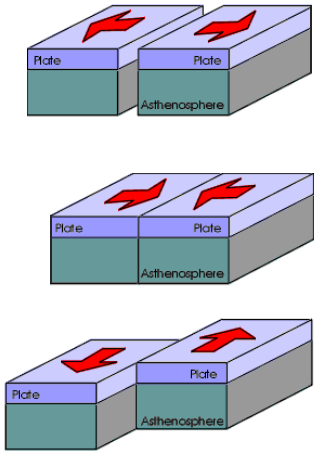
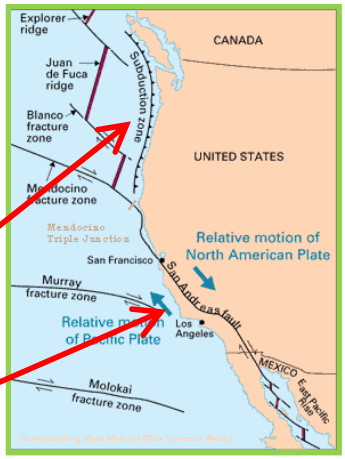
Interactions at plate boundaries



Divergent

Convergent

Transform



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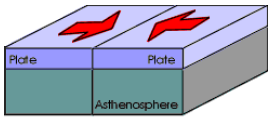
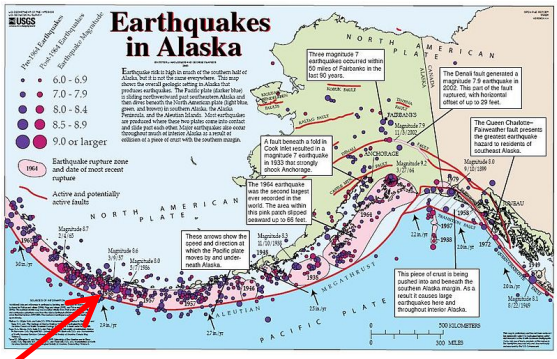
Interactions at plate boundaries





Convergent

USGS

Plate movement

- San Andreas Fault Zone
  - 2 in/year (56 mm/year)
  - Los Angeles and San Francisco are 15 million years apart

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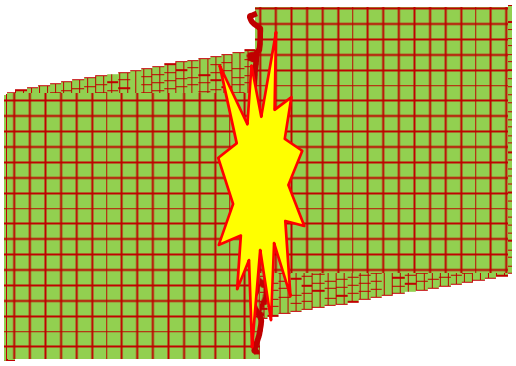
Stored energy



Plates motion is stored as strain energy, and released as an earthquake.

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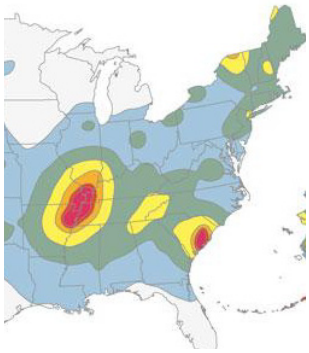
Intraplate earthquakes

- New Madrid
- Charleston
- Indian Ocean
- Underlying mechanisms not clear



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Seismic waves

Seismic waves

- Earthquakes cause sudden release of strain energy
- The release of strain causes high-energy waves to radiate from the hypocenter
- At the surface, the waves change direction and radiate from the epicenter
- Surface waves are high amplitude and cause damage

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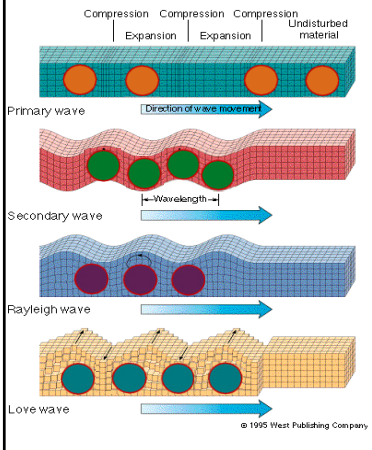
Seismic waves



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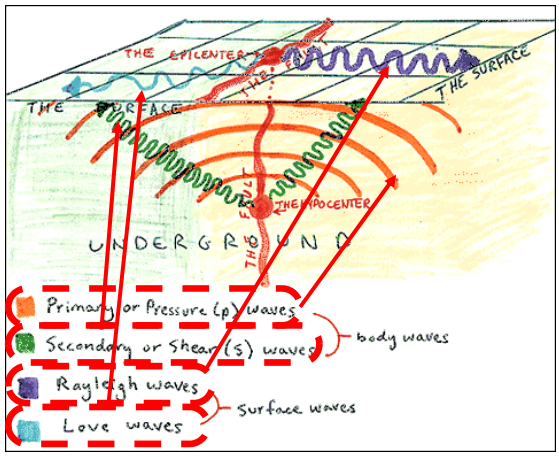

eGFI teacher resources

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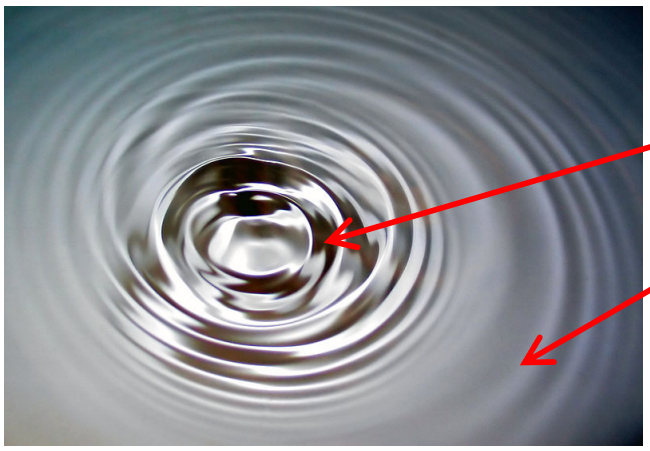
Effect of distance



Highest amplitude

Amplitude diminishes with distance

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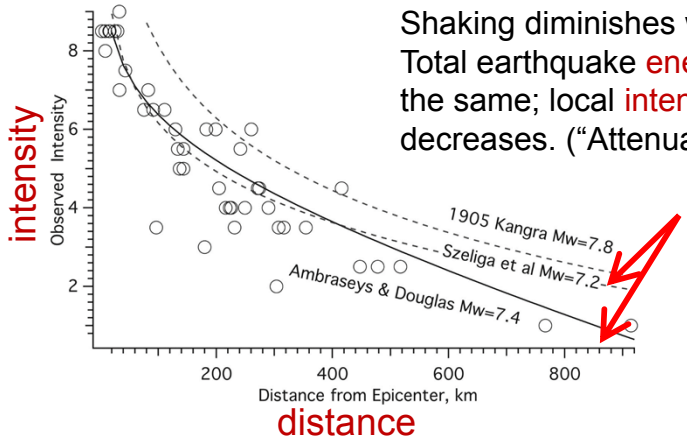
Effect of distance



Shaking diminishes with distance. Total earthquake energy remains the same; local intensity decreases. ("Attenuation")

Attenuation models

USGS

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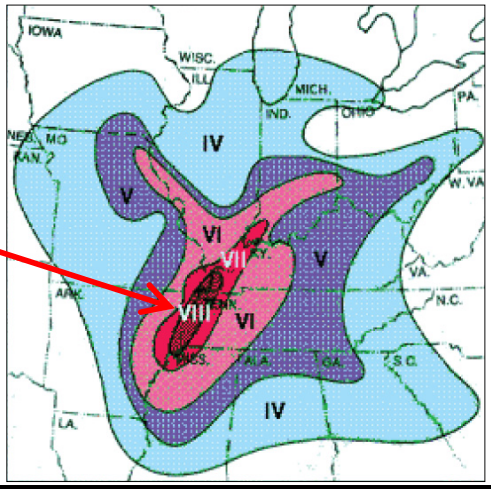
Effect of distance



Highest intensity

The earthquake has a single magnitude, but a range of intensities.

USGS

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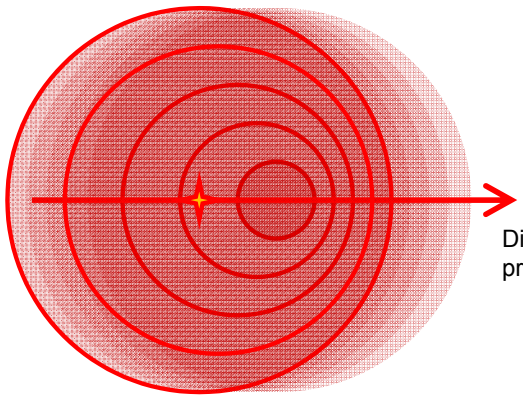
Directivity

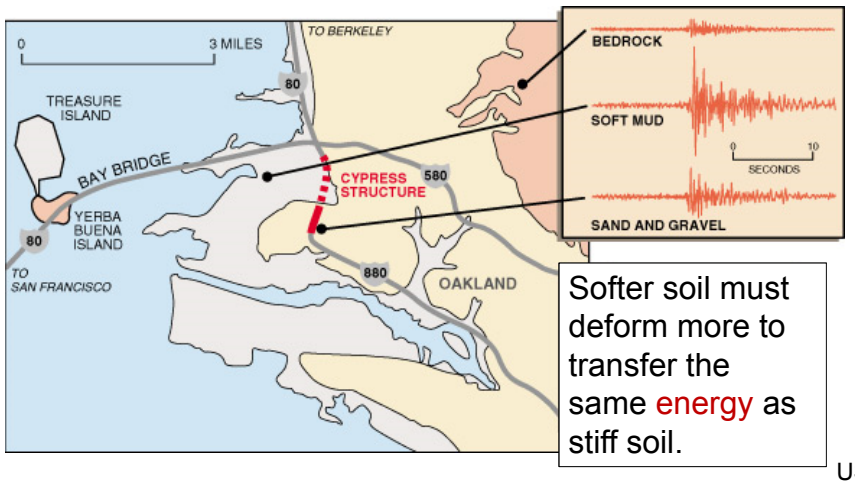


Direction of rupture propagation

Initial rupture

30

Effect of soil stiffness



Softer soil must deform more to transfer the same energy as stiff soil.

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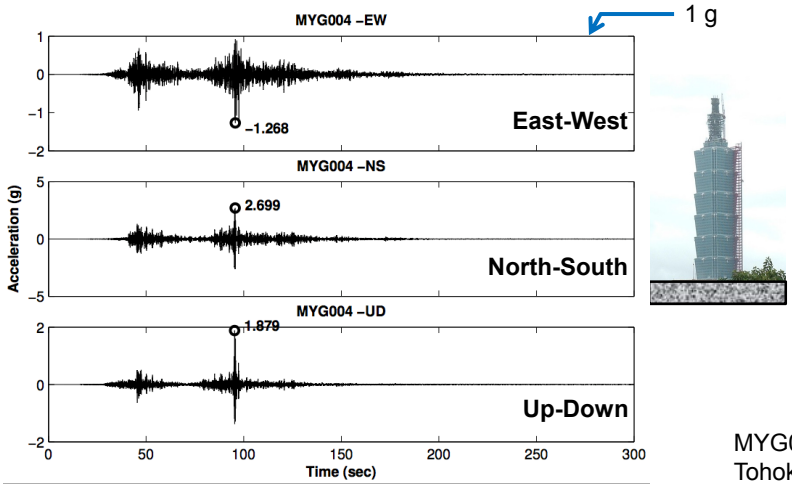
Ground motion



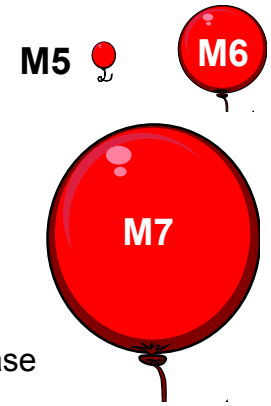
MYG04 station
Tohoku earthquake

There's always a solution in steel.

Earthquake measures

Earthquake measures

- Richter Magnitude
  - Logarithmic
    - M6.0=32*M5.0
  - Energy-based
  - Difficult to establish accurately
    - Based on standard instrument at standard distance
    - Very large earthquakes may release more energy than is recorded



Earthquake measures

- Moment magnitude
  - Energy-based
  - Based on:
    - Surface area of fault
    - Slip
    - Rock modulus of rigidity
  - Similar to Richter

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Earthquake measures

- Modified Mercalli Intensity (MMI)
  - Based on effects
    - Subjective
    - Based on conventional construction
  - Some correlation to intensity of acceleration

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Modified Mercalli Intensity

I. Not felt except by a very few under especially favorable conditions.

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

III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

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Modified Mercalli Intensity

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

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Modified Mercalli Intensity

VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken

VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

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Chimney damage. MMI ~VIII

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Modified Mercalli Intensity

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.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

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Long Beach, 1933: MMI = IX

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Lisbon, 1755: MMI = XI

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Seward, AK, 1964: MMI = XI

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Modified Mercalli Intensity

Table 1-2 Intensity and Peak Ground Acceleration	
Modified Mercalli Intensity	**Peak Ground Acceleration, *g***
VI	0.05–0.10
VII	0.10–0.20
VIII	0.20–0.30
IX	0.30–0.60
X	> 0.60

Hamburger

Accelerations are used in design

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Magnitude & Intensity

Magnitude	**Typical <u>Maximum</u> Modified Mercalli Intensity**
1.0 - 3.0	**I**
3.0 - 3.9	**II - III**
4.0 - 4.9	**IV - V**
5.0 - 5.9	**VI - VII**
6.0 - 6.9	**VII - IX**
7.0 and higher	**VIII** or higher

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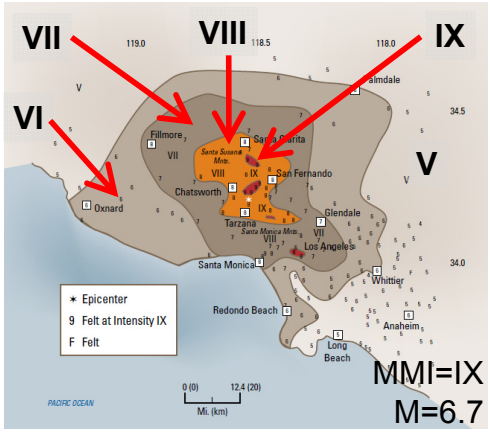
1994 Northridge MMIs



Intensity is useful to describe the local effects.

Magnitude is useful to describe the event as a whole

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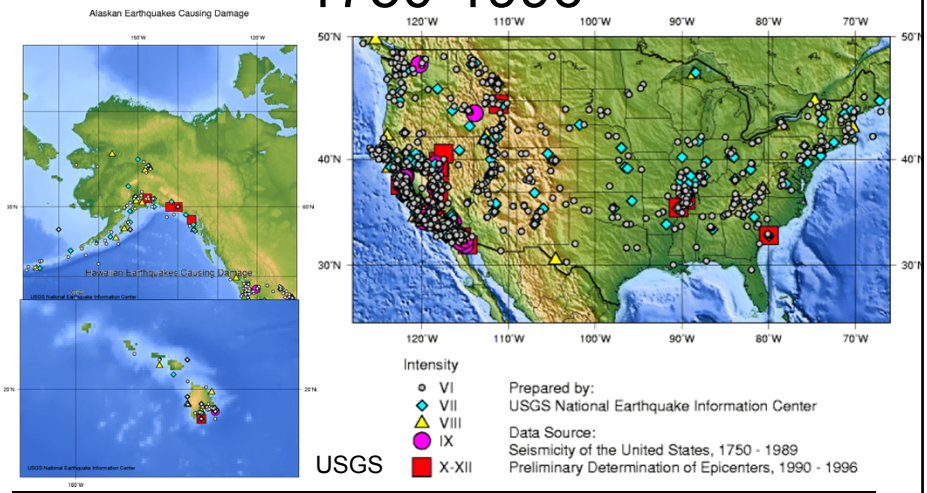
US earthquakes causing damage 1750-1996



USGS

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Major earthquakes

Earthquake frequency

Magnitude	Estimated #/Year
2.5 or less	900,000
2.5 to 5.4	30,000
5.5 to 6.0	500
6.1 to 6.9	100
7.0 to 7.9	20
8.0 or greater	One every 5 to 10 years

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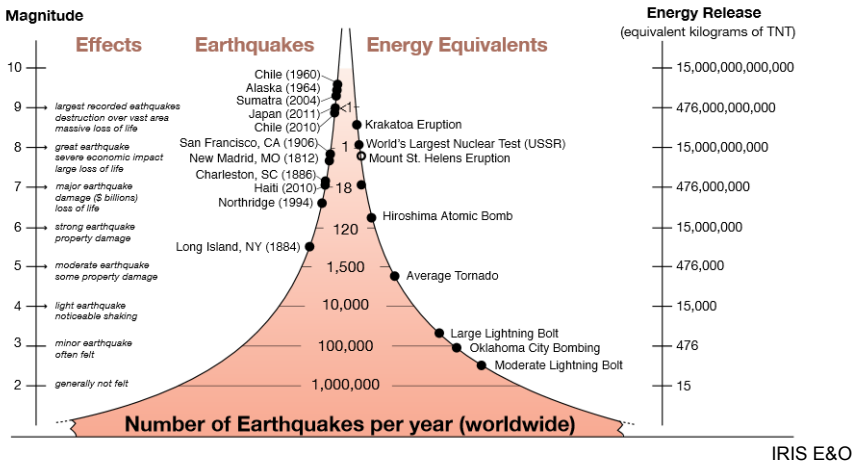
Largest earthquakes

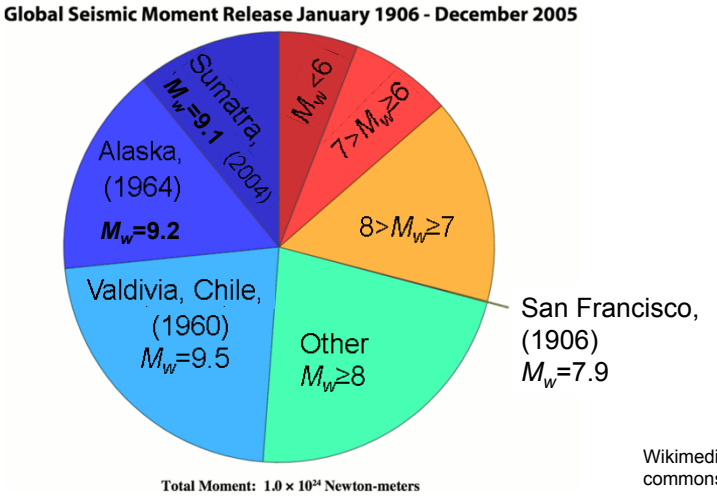
Date	Location	Magnitude
May 22, 1960	**Valdivia, Chile**	**9.5**
March 27, 1964	**Prince William Sound, Alaska, USA**	**9.2**
December 26, 2004	**Indian Ocean, Sumatra, Indonesia**	**9.1–9.3**
November 4, 1952	Kamchatka, Russia (then USSR)	9
March 11, 2011	Pacific Ocean, Tōhoku region, Japan	9.0
September 16, 1615	Arica, Chile	8.8 (est.)
November 25, 1833	Sumatra, Indonesia	8.8–9.2 (est.)
January 31, 1906	Ecuador – Colombia	8.8
February 27, 2010	Valdivia , Chile	8.8
January 26, 1700	Pacific Ocean, North America	8.7–9.2 (est.)
July 8, 1730	Valparaiso, Chile	8.7 (est.)
November 1, 1755	Atlantic Ocean, Lisbon, Portugal	8.7 (est.)
February 4, 1965	**Rat Islands, Alaska, USA**	**8.7**
July 9, 869	Pacific Ocean, Tōhoku region, Japan	8.6-9.0 (est.)
September 20, 1498	Pacific Ocean, Nankai Trough, Japan	8.6 (est.)
October 28, 1707	Pacific Ocean, Shikoku region, Japan	8.6 (est.)
August 15, 1950	Assam, India – Tibet, China	8.6
March 9, 1957	**Andreanof Islands, Alaska, USA**	**8.6**
April 1, 1946	**Aleutian Islands, Alaska, USA**	**8.6**
March 28, 2005	Sumatra, Indonesia	8.6

Earthquake frequency



IRIS E&O

Largest earthquakes



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Valdivia, Chile, 1960 M=9.5

- >2,000 killed
- >3,000 injured
- >2,000,000 homeless
- >$550 million damage
- Tsunamis
  - 61 deaths, $75 million damage in Hawaii
    - $500,000 damage in the United States west coast
  - 138 deaths and $50 million damage in Japan
  - 32 dead or missing in the Philippines

Valdivia, Chile, 1960 M=9.5

- Earth's day shortened 1.26 microseconds
- Concepción moved 3.0 meters (10 ft)
- Chile may have expanded ~ 1.2 km²

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Costliest earthquakes

Name	Magnitude	Property loss (US 2013 $)
2011 Tōhoku earthquake, Japan	**9**	**$235 billion**
1995 Great Hanshin (Kobe) earthquake, Japan	6.9	$100 billion
2008 Sichuan earthquake, China	8	$75 billion
2010 Chile earthquake, Chile	8.8	$15–30 billion
1994 Northridge earthquake, United States	**6.7**	**$20 billion**
2012 Emilia earthquakes, Italy	5.9 (est.)	$13.2 billion
2011 Christchurch earthquake, New Zealand	6.3	$12 billion
1989 Loma Prieta earthquake, United States	7	$11 billion
921 earthquake, Taiwan	7.6	$10 billion
1906 San Francisco earthquake, United States	7.7 to 7.9 (est.)	$9.5 billion

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Northridge, CA, 1994, M=6.7

- $20 billion in losses
- 60 people killed
- > 7,000 injured
- 20,000 homeless
- >40,000 buildings damaged
- 1.8g maximum recorded acceleration
  - High local intensities

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Deadliest earthquakes

Date	Location	Fatalities	Magnitude
January 23, 1556	Shaanxi, China	820,000–830,000 (est.)	8.0 (est.)
December 16, 1920	Ningxia–Gansu, China	273,400	7.8
July 28, 1976	Hebei, China	242,769	7.8
May 21, 526	Antioch, Turkey (Byzantine Empire)	240,000	7.0 (est.)
December 26, 2004	Indian Ocean, Sumatra, Indonesia	230,210	9.1–9.3
October 11, 1138	Aleppo, Syria	230,000	Unknown
January 12, 2010	**Haiti**	**222,570-316,000**	**7**
December 22, 856	Damghan, Iran	200,000 (est.)	7.9 (est.)
March 22, 893	Ardabil, Iran	150,000 (est.)	Unknown
September 1, 1923	Kantō region, Japan	142,800	7.9
December 28, 1908	Messina, Italy	123,000	7.1
October 6, 1948	Turkmenistan	110,000	7.3
December 31, 1703	Edo, Japan	2,300-12,000	8.2
November 1, 1755	Lisbon, Portugal	15,000–60,000	8.5–9.0 (est.)

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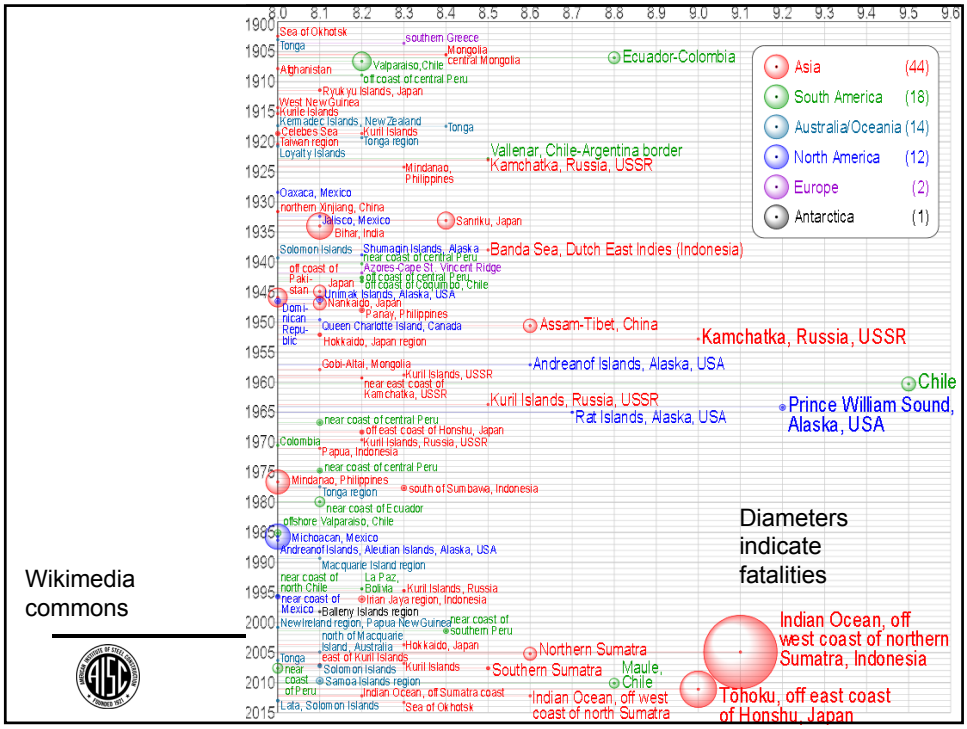

Haiti, 2010, M=7.0

- 200,000-316,000 people killed
- 300,000 injured
- 1.3 million displaced
- Port-au-Prince
  - 97,294 houses destroyed
  - 188,383 houses damaged
- Felt as far as southern Florida, northern Colombia and northwestern Venezuela.

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There's always a solution in steel.

Earthquake effects

Earthquake effects

- Local effects
  - Epicenter
    - Fault thrust
    - Sliding/shearing
  - Soil effects
    - Liquefaction
    - Slope instability
- Widespread effects
  - Horizontal shaking
  - Vertical shaking
  - (This is what we typically design for!)

Surface Faulting

Fig. 1-6. Fault scarp created by the 1954 Dixie Valley earthquake in the Nevada desert. (Photo by K.V. Steinbrugge)

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Surface Faulting

USGS

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Surface Faulting

USGS

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Surface Faulting

USGS

Codes proscribe construction on sites subject to surface rupture

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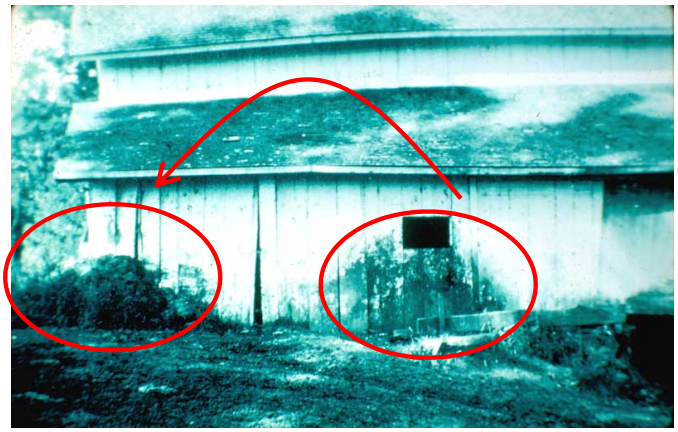
Surface Faulting



Manure pile moved 10 feet (along with ground next to barn).

USGS

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Landslides

USGS

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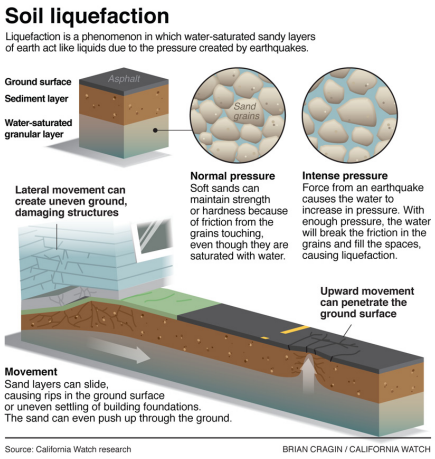
Liquefaction

- Loss of strength
- Ground shaking loosens water-saturated sands
- Soil flows laterally and vertically under pressure



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Liquefaction

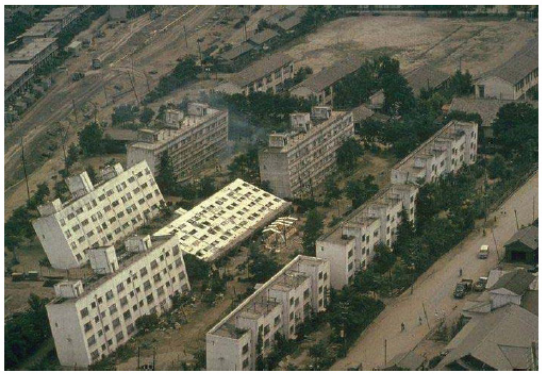

Fig. 1-8. Settlement in apartment buildings due to soil liquefaction, 1964 Nigata, Japan, earthquake. (Photo courtesy of University of Washington)

Codes proscribe construction on unimproved liquefiable sites

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Liquefaction

USGS

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Lateral spreading

Fig. 1-9. Lateral spreading damage to highway pavement near Yellowstone Park, 1959 Hegben Lake earthquake. (Photo courtesy of U.S. Geologic Survey)

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Earthquake effects

- Surface faulting
  - Building is not permitted over known faults
  - Bridges, railways, and roads must have displacement capacity
- Soil effects
  - Soil can be remediated
  - Deep foundations can bypass liquefiable layers

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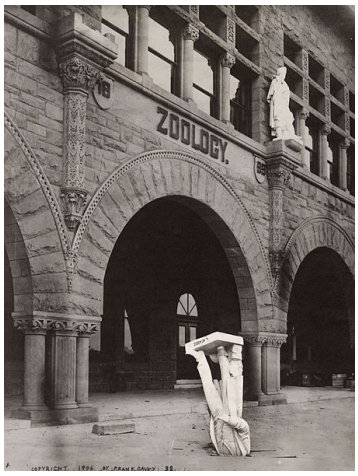
Horizontal shaking



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Horizontal forces

USGS

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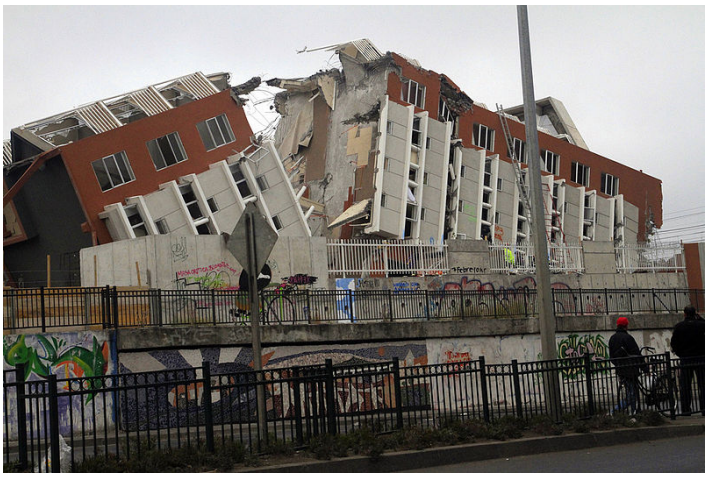
Overturning



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Earthquake effects

- Horizontal shaking
  - Buildings must be designed to resist horizontal shaking, and related overturning
  - Strategies include:
    - Strength
    - Stiffness
    - Displacement capacity
    - Energy absorption

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There's always a solution in steel.

Related hazards

Tsunami

Wikimedia commons

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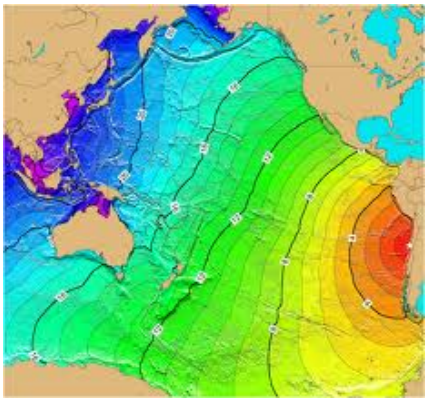
Tsunami

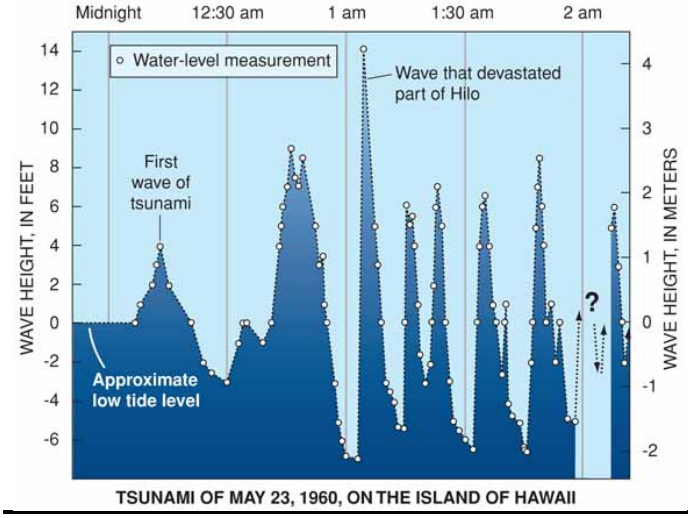


Tsunamis open-sea amplitude gradually attenuates.

Local shoreline effects can be many times open-sea amplitude.

80

Tsunami



TSUNAMI OF MAY 23, 1960, ON THE ISLAND OF HAWAII

USGS

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Tsunami

Tsunamis are caused by undersea fault movement.

Current design codes do not address tsunamis.

Evacuation and refuge are typical strategies.

Wikimedia commons

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Cascading events

- Fires
  - 1906 San Francisco fire

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Cascading events

- Power loss
  - Critical equipment
  - Elevators
    - How to evacuate 50-story buildings?
- Gas leaks
- Disrupted transportation
- Homelessness

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Hazard, risk, and probability

Hazard

- "Hazard" is used to correlate probability and intensity
  - The earthquake intensity for which there is a specified probability of exceedance
  - Probability of exceedance can be converted to return period.
    - Similar to 500-year wind, 100-year flood, etc.

Deterministic approach

- Known seismic source
  - Estimated maximum magnitude
    - Or based on other criteria (return period, historical)
  - Attenuation over distance calculated
- Example:
  - "The earthquake hazard for X site is a peak ground acceleration of 0.65g resulting from an earthquake of magnitude 6.8 on the San Andreas fault at 10 mile distance."

Codes use deterministic methods near well understood faults

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Probabilistic approach

- Known seismic sources:
  - Estimated maximum magnitude
  - Attenuation over distance
- Intensity/return periods for faults combined to form a single intensity at a given return period
- Example:
  - "The earthquake hazard for X site is a peak ground acceleration of 0.35g with 2 % probability of being exceeded in 50 years."

Codes use probabilistic methods where earthquake risk is not dominated by well understood faults

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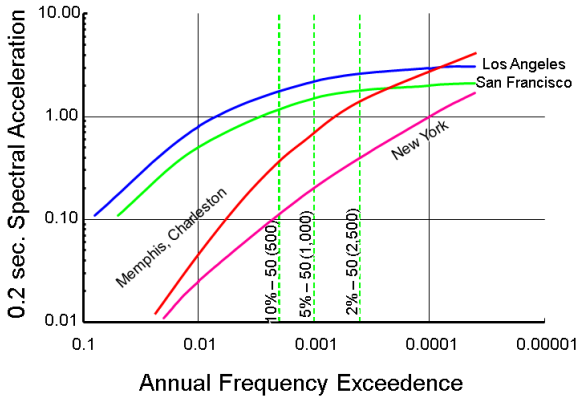
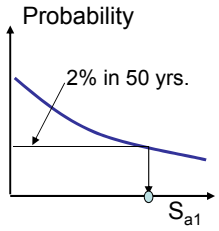
Probability





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Probabilities

P_1 = annual exceedance probability

$1 - P_1$ = annual non-exceedance probability

R = return period

$R = -1/\ln(1 - P_1)$

P_n = exceedance probability for period n

$R = -n/\ln(1 - P_n)$

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Probabilities

$[1-P_1]$ = Probability of non-exceedance in 1yr

$[1-P_1]*[1-P_1]*[1-P_1]$
= Probability of non-exceedance in 3yrs

$P_1*P_1*P_1$
= Probability of exceedance in every year!
(Don't do this!)

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Probabilities

$[1-P_1]^n$ = Probability of non-exceedance in *n* yrs

P_n = $1-[1-P_1]^n$
= Probability of exceedance in *n* yrs

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Probabilities

Given: 10% probability of exceedance in 50 yr
→R=475 years
(T=500 years = 9.5% / 50 yr)

Given: 2% probability of exceedance in 50 yr
→R=2475 years
(T=2500 years = 1.98% / 50 yr)

Past codes have used 475 year and 2475 year return periods

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Multiple sources

Probabilities are not additive

Maintain chance of non-exceedance of acceleration X

$[1- P_a]^{50} * [1- P_b]^{50} * [1- P_c]^{50} \ldots. = 98\%$

P_a = probability of acceleration X from source A

P_b = probability of acceleration X from source B

P_c = probability of acceleration X from source C

Therefore, a 2% chance in 50 years of exceeding the intensity

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Multiple sources

Small or distant events have very low probability of exceeding the intensity

Do not reduce the chance of non-exceedance much

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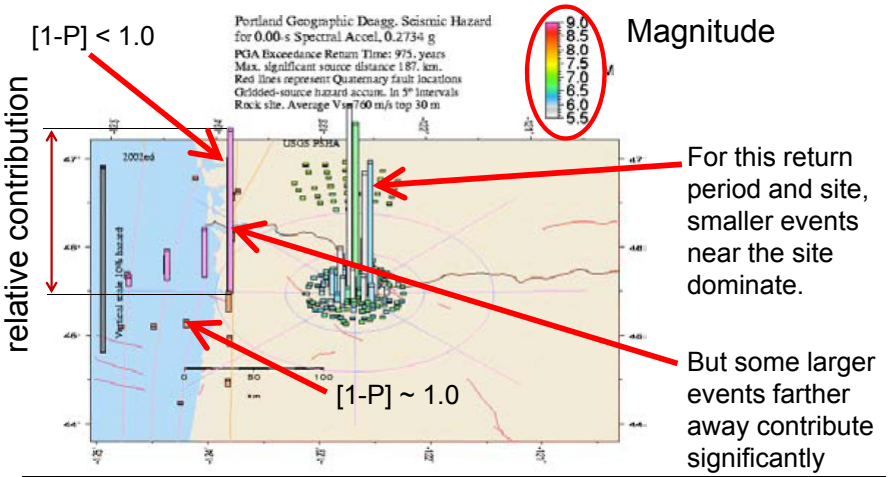
Hazard "de-aggregation"



State of Oregon

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Seismic hazard

- How is the seismic hazard determined?
  - Deterministic method used near major faults
    - Based on characteristic earthquake on known fault
  - Probabilistic methods used elsewhere
    - 2475 year return period
      - Past seismicity
      - Slip rate
      - By USGS
  - Probabilistic methods less relevant near faults with frequent events

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Determining seismic hazard

- Maps examine each location
  - Shaking caused by multiple events
  - Attenuation models used
- Maps created considering:
  - Significant damaging earthquakes
    - Smaller earthquakes
  - Historical intensities
  - Historical seismicity information
  - Geologic (prehistoric) information
  - Geodetic (slip rate) information

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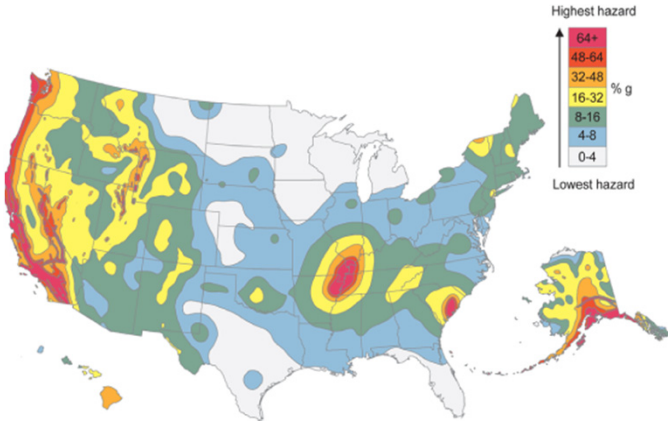
USGS Hazard maps



Periodically reviewed and updated to include:

- new fault data
- new attenuation relations
- new geodetic data
- more seismic data

USGS

USGS acceleration maps are used for design

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Hazard vs risk

Hazard

- Uniform hazard
- "Maximum Considered Earthquake" (MCE)
- 2475 yr return period
  - Given the MCE…
  - 10% chance of collapse

Risk

- Uniform risk
- Risk-targeted MCE = MCE_r
  - Given the MCE_r …
  - 10% chance of collapse
- MCE_r selected
  - 1% chance of collapse in 50 years (maximum risk)
    - Assumed fragility of structures

Current ASCE 7 2010 code uses "uniform risk" concept

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Risk

- Uniform hazard
  - Standard return period considered
- Uniform risk
  - Different return period considered at each location
  - Risk of not meeting performance goal is uniform
  - Assumes similar structural fragility

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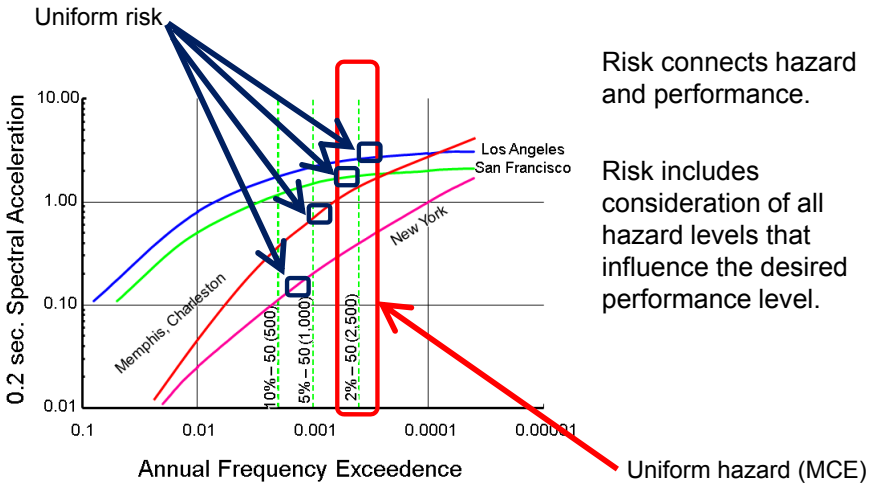
Risk



Risk connects hazard and performance.

Risk includes consideration of all hazard levels that influence the desired performance level.

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Uncertainty

- "Maximum Considered Earthquake" is an arbitrary cut off
- Larger events are possible
- Earthquake demands introduce far more uncertainty than most other loadings
  - Intensity
  - Dynamic characteristics
  - Unmapped faults (e.g., Christchurch)

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Summary

Summary

- Tectonic plate movement results in release of energy
- Seismic waves carry this energy and affect buildings
- Magnitude describes the event
- Intensity describes the local manifestation
- Very large earthquakes are rare but represent a significant risk

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Parting thought

How do structures respond to earthquake-induced shaking?

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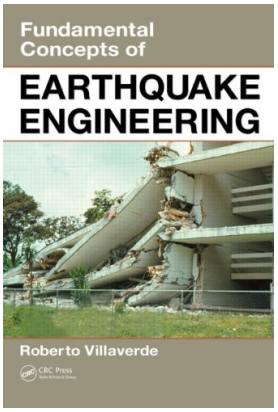
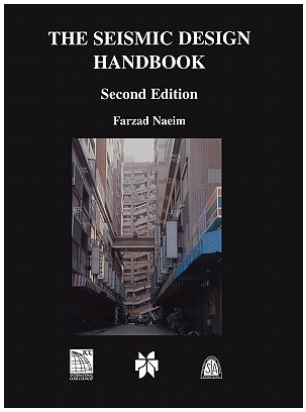
End of session 1

Next:

Session 2: Dynamics and response

Additional resources





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Question time

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: ceu@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

8-Session Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

8-Session Registrants

Access to the quiz: Information for accessing the quiz will be emailed to you by Thursday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

Quiz and Attendance records: Posted Tuesday mornings. www.aisc.org/nightschool - click on Current Course Details.

Reasons for quiz:

- **EEU** – must take all quizzes and final to receive EEU
- **CEUs/PDHS –** If you watch a recorded session you must take quiz for CEUs/PDHs.
- **REINFORCEMENT** – Reinforce what you learned tonight. Get more out of the course.

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHs.

8-Session Registrants

Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available until March 10. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

CEUs/PDHS – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHs.

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Thank You

Please give us your feedback!
Survey at conclusion of webinar.

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