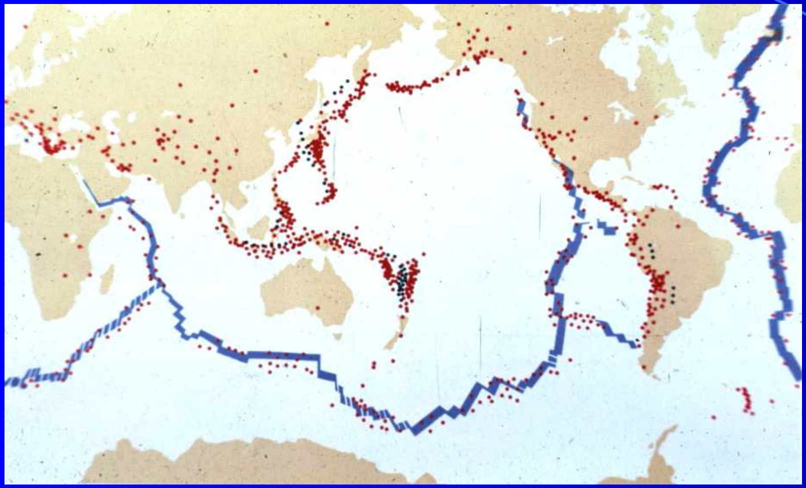
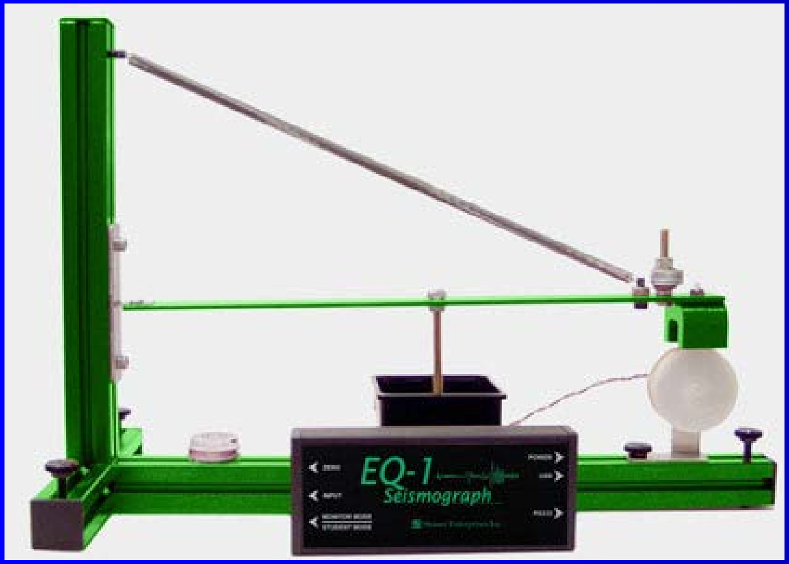
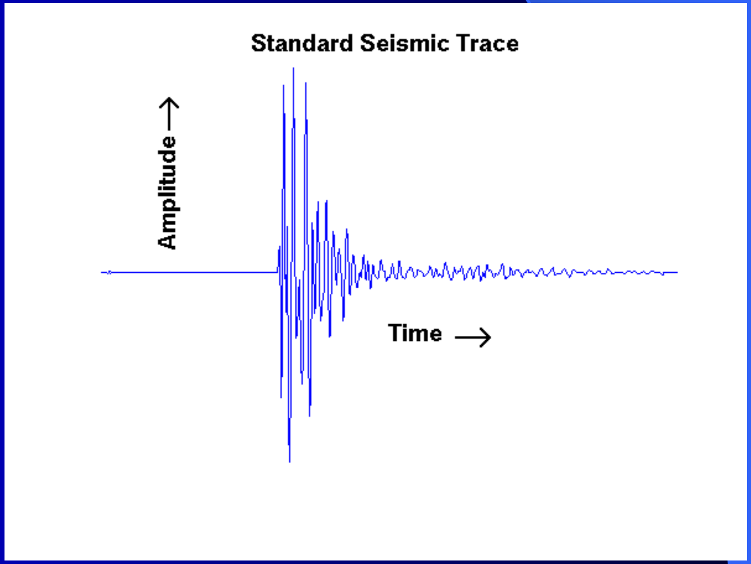
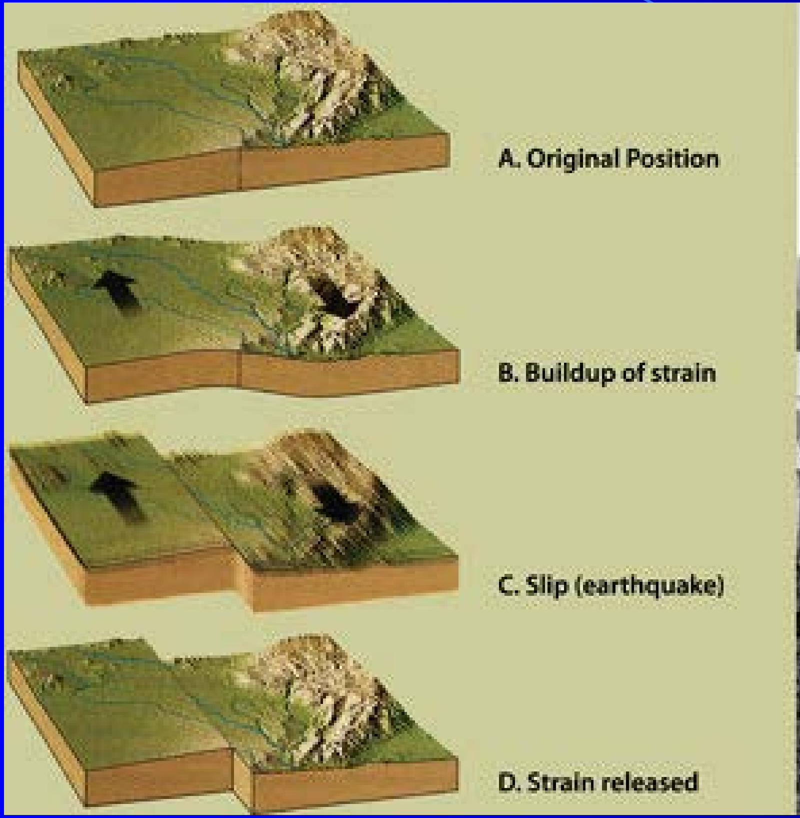
89.325 – Geology for Engineers
Earthquakes



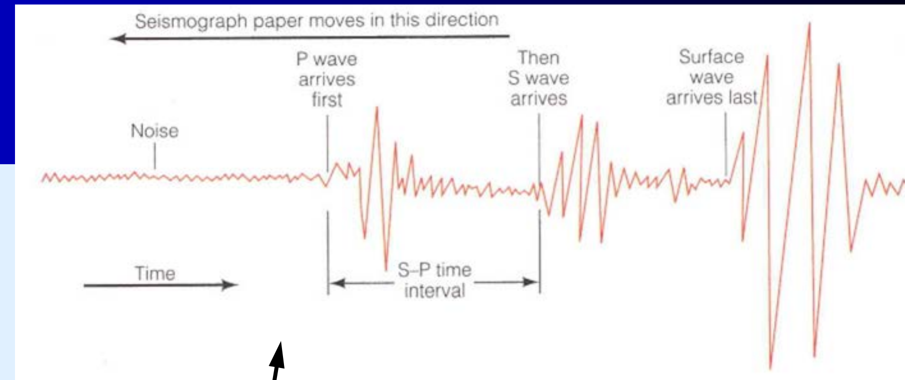




Elastic Rebound Theory

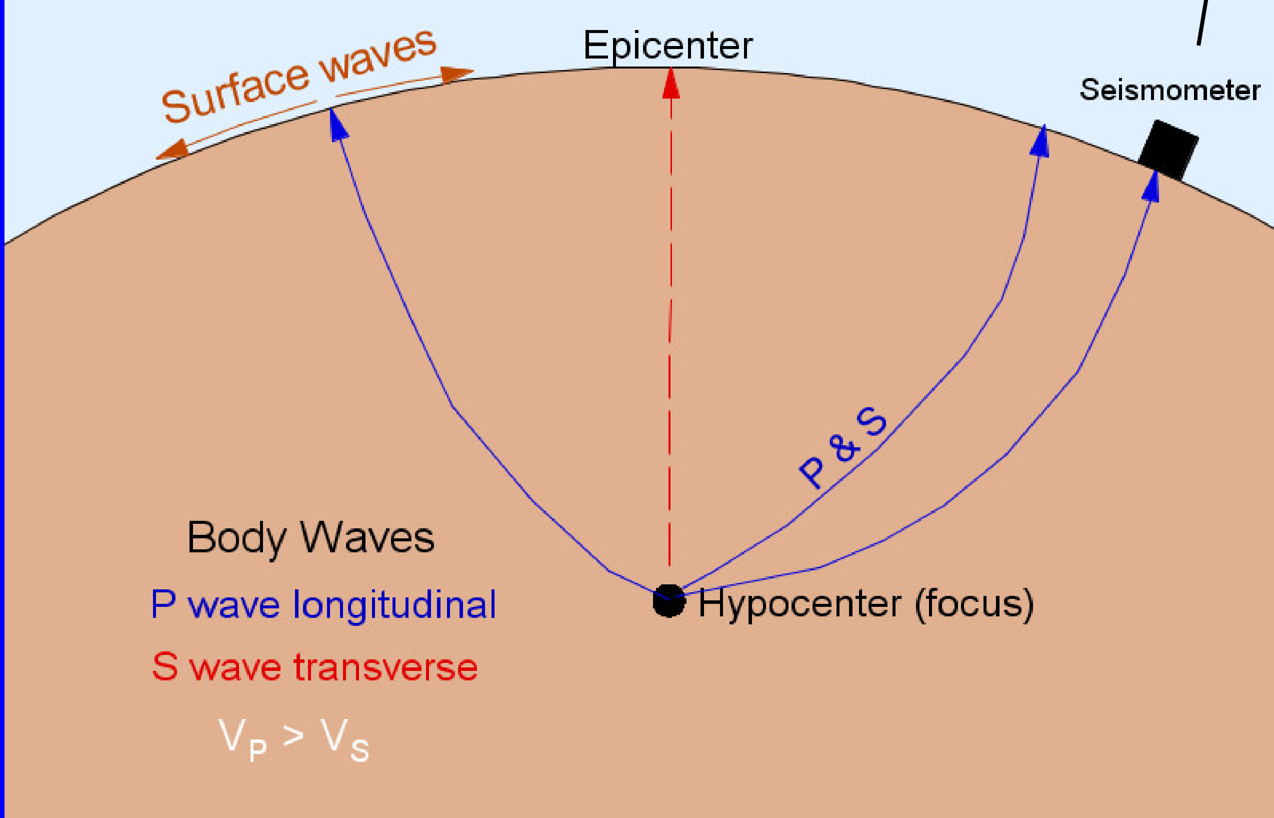


Earthquakes occur when strain exceeds the strength of the rock and the rock fractures.



Surface waves (there are several types) are transverse

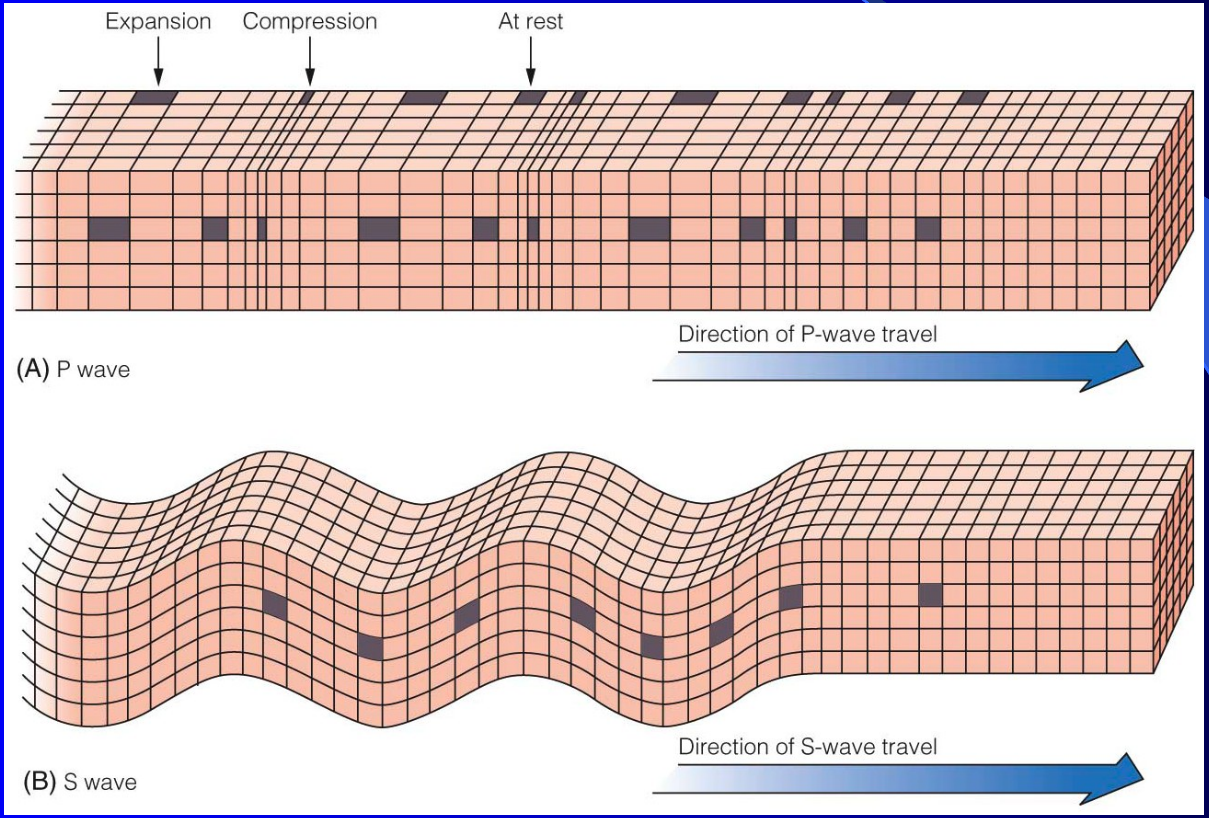
These are the waves that cause earthquake damage



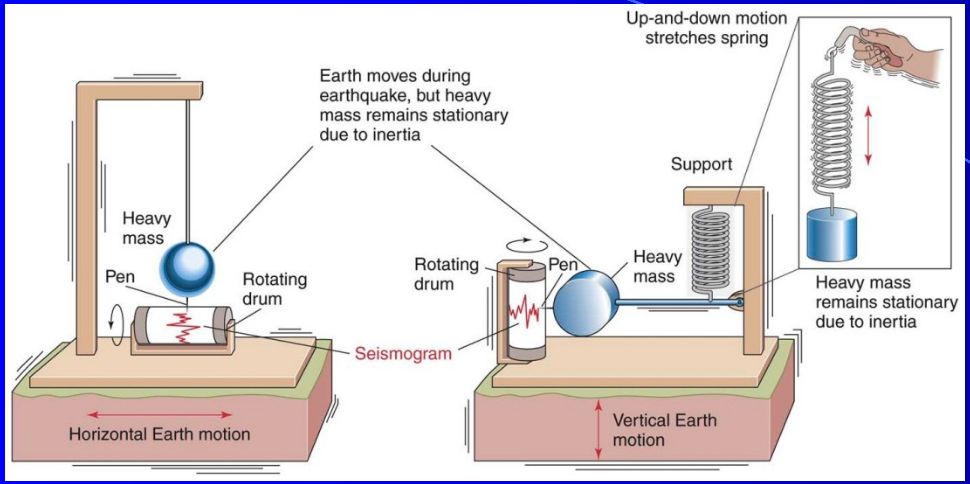
The arrival of earthquakes waves is recorded by a seismograph. The amplitude of the P-wave displacement is used to determine the Richter magnitude.

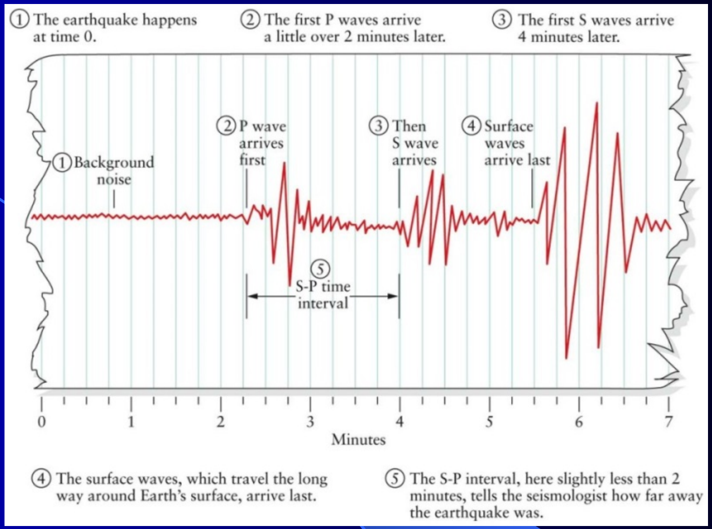
Earthquake Waves

- Body waves – move through the solid earth
  - P-waves - longitudinal
  - S-waves - transverse
- Surface waves - transverse

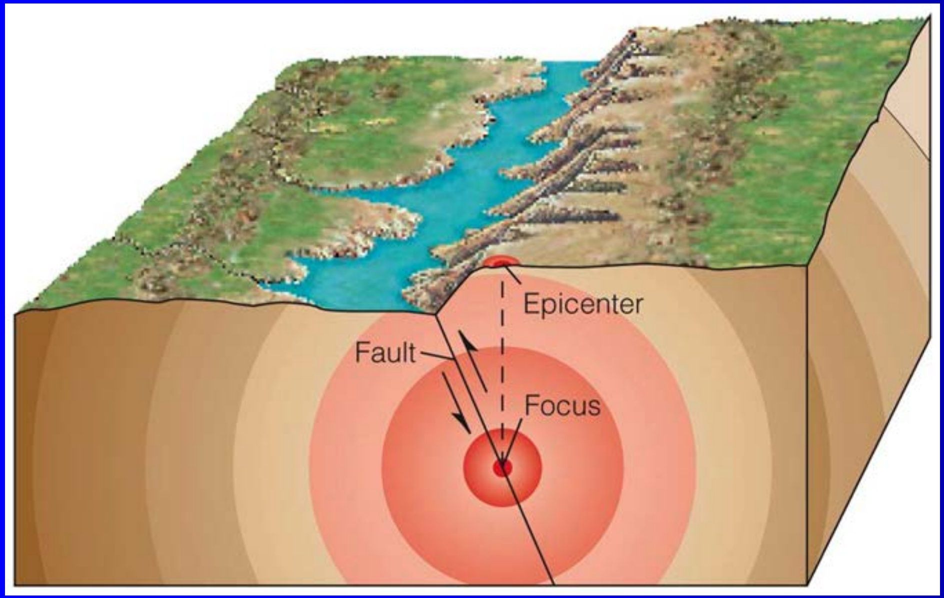


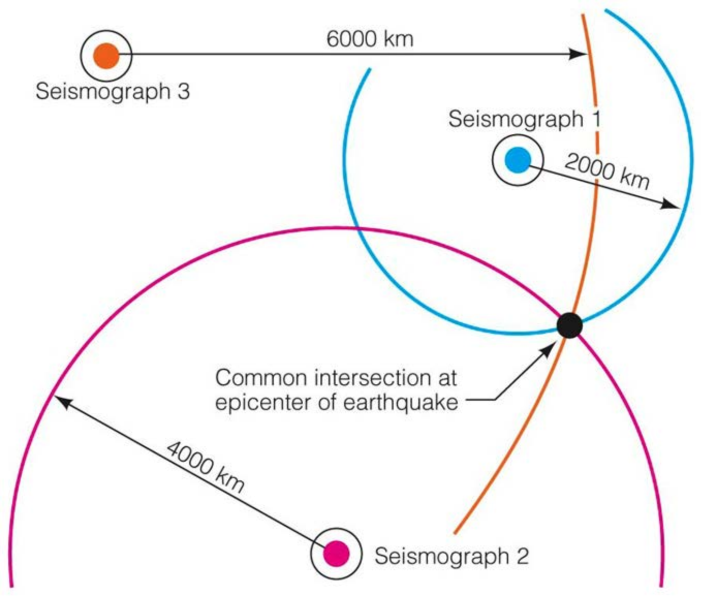
Recording Earthquakes





Locating earthquake epicenter





Earthquake magnitude – amount of energy released

Determination of Richter Magnitude for an Earthquake

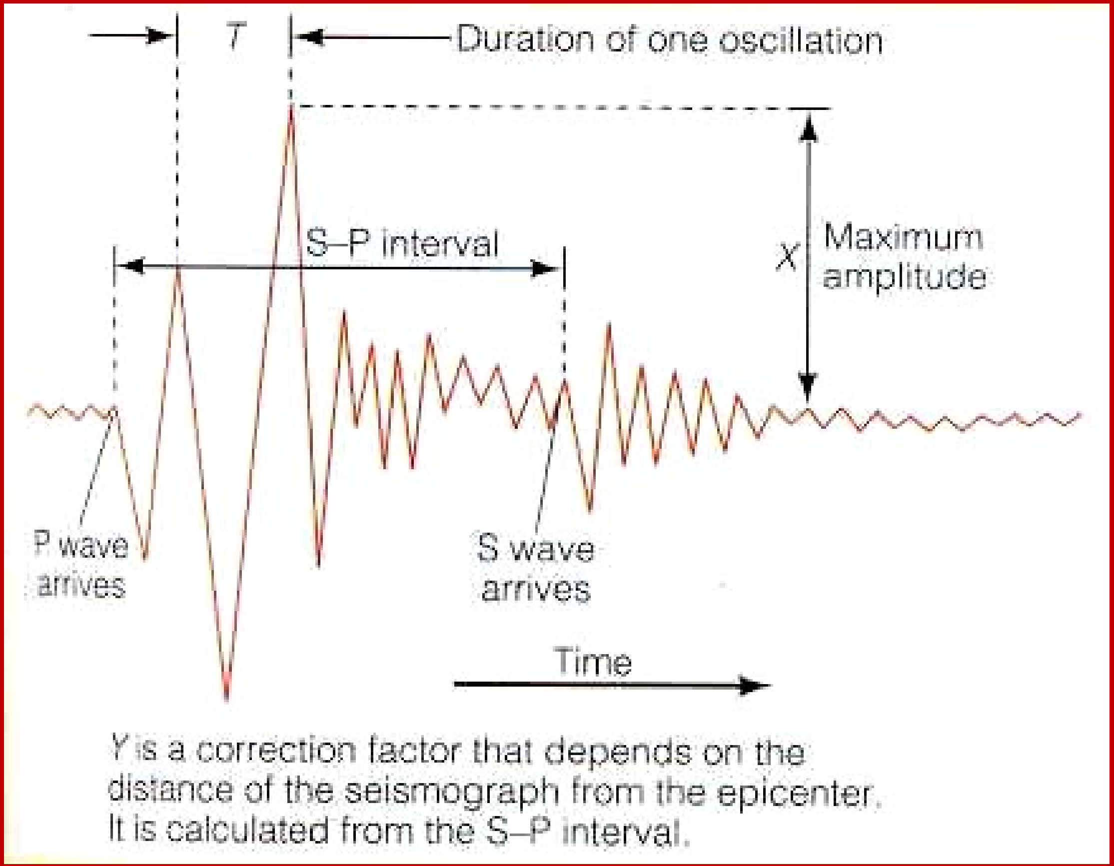
$M = \log(X/T) + Y$

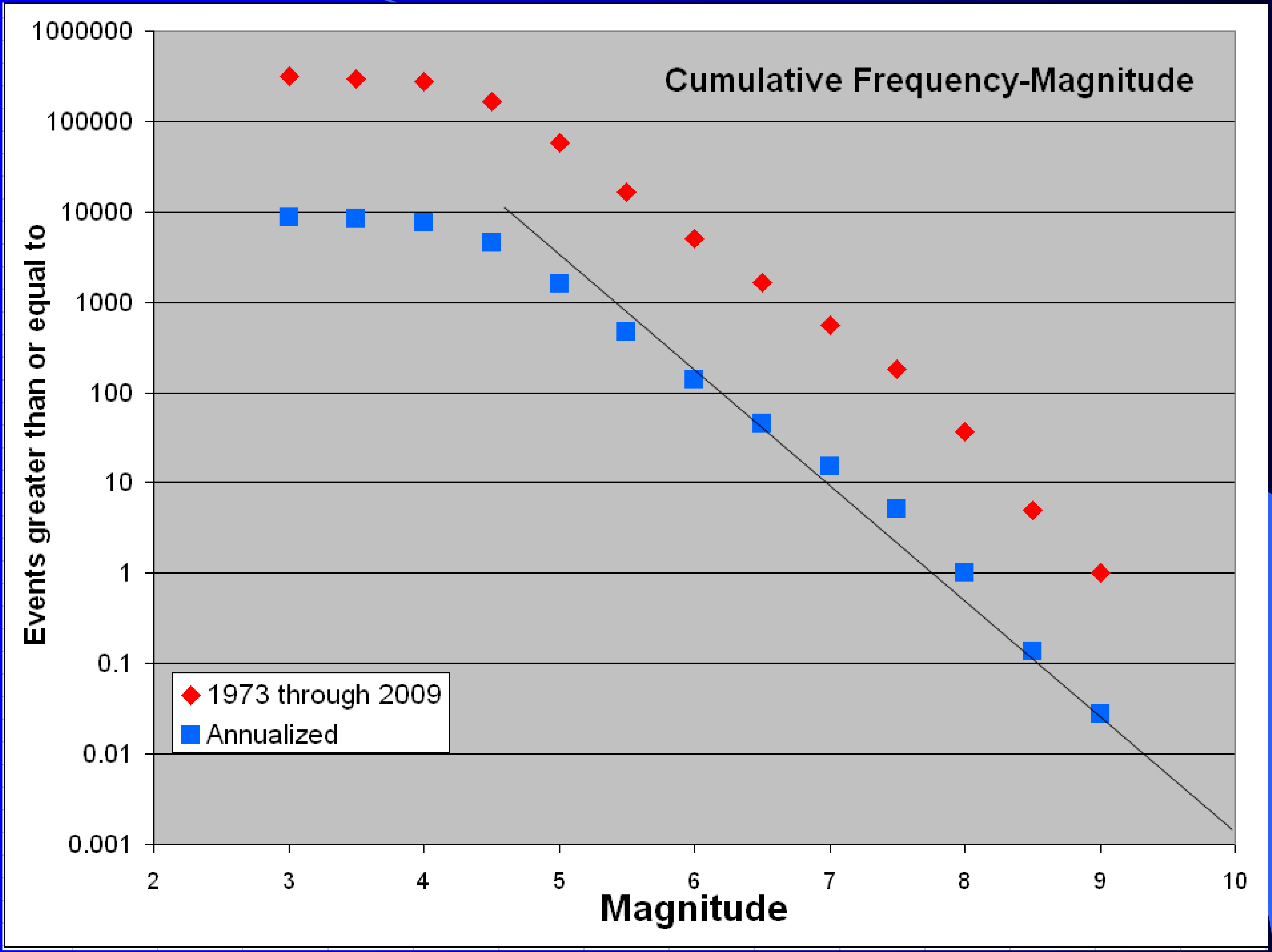
1M ~ 10X

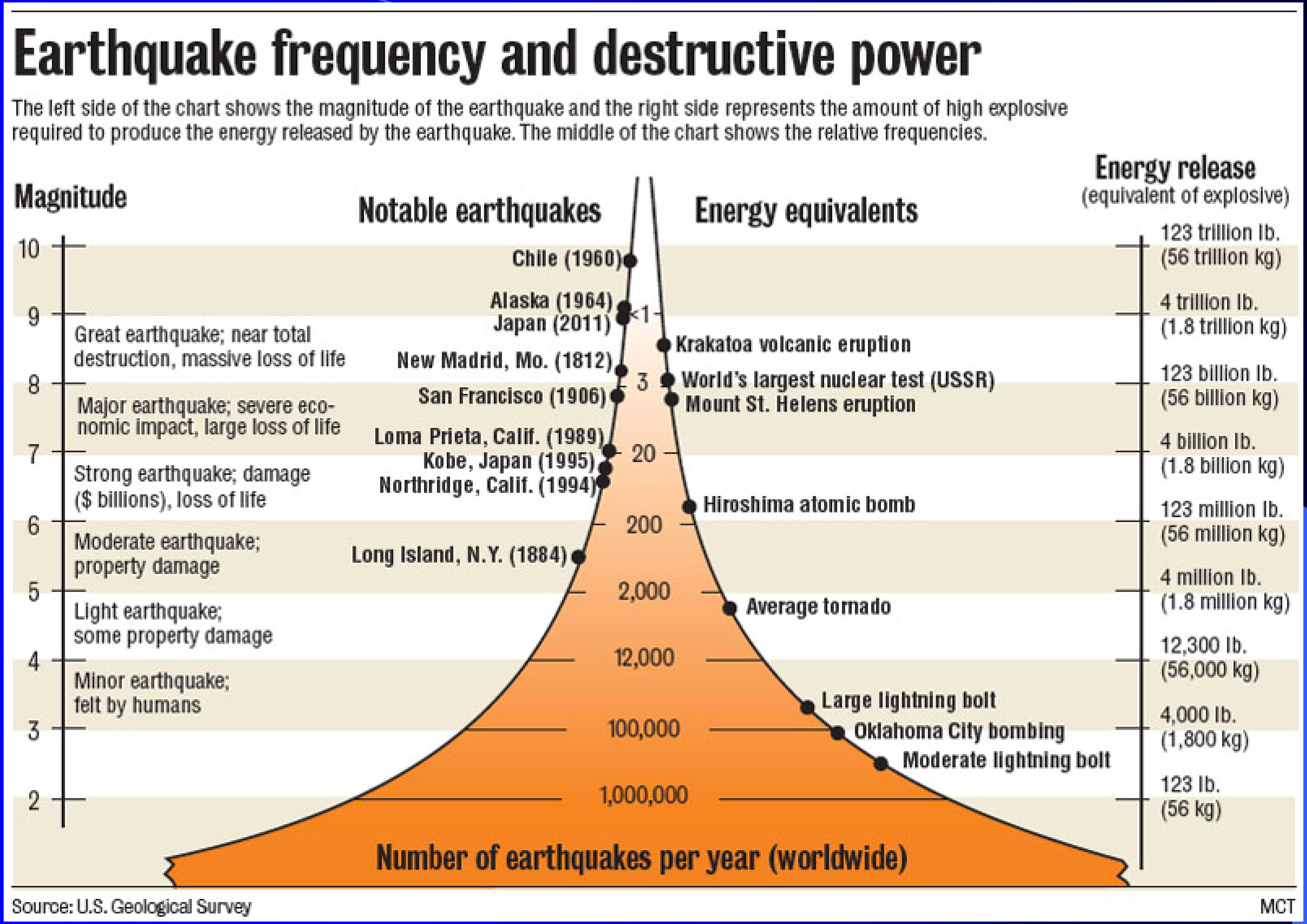
Energy ~ X^2

1M ~ 100x energy

However, energy increase when summed over the whole range of waves in a wave record is only 30x. Confusion time!




Cumulative Frequency-Magnitude
Events greater than or equal to
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
2
3
4
5
6
7
8
9
10
Magnitude
1973 through 2009
Annualized



Earthquake frequency and destructive power
The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.
Magnitude
Notable earthquakes
Energy equivalents
Energy release
(equivalent of explosive)
10
9
8
7
6
5
4
3
2
Great earthquake; near total destruction, massive loss of life
Major earthquake; severe economic impact, large loss of life
Strong earthquake; damage ($ billions), loss of life
Moderate earthquake; property damage
Light earthquake; some property damage
Minor earthquake; felt by humans
Chile (1960)
Alaska (1964)
Japan (2011)
New Madrid, Mo. (1812)
San Francisco (1906)
Loma Prieta, Calif. (1989)
Kobe, Japan (1995)
Northridge, Calif. (1994)
Long Island, N.Y. (1884)
<1
3
20
200
2,000
12,000
100,000
1,000,000
Krakatoa volcanic eruption
World's largest nuclear test (USSR)
Mount St. Helens eruption
Hiroshima atomic bomb
Average tornado
Large lightning bolt
Oklahoma City bombing
Moderate lightning bolt
123 trillion lb. (56 trillion kg)
4 trillion lb. (1.8 trillion kg)
123 billion lb. (56 billion kg)
4 billion lb. (1.8 billion kg)
123 million lb. (56 million kg)
4 million lb. (1.8 million kg)
12,300 lb. (56,000 kg)
4,000 lb. (1,800 kg)
123 lb. (56 kg)
Number of earthquakes per year (worldwide)
Source: U.S. Geological Survey
MCT

Earthquake intensity – damage caused by earthquake

- Subsurface material
- Type of construction
- May not be directly related to earthquake magnitude

TABLE 6.1 Earthquake Magnitudes, Frequencies, and Effects

Richter and Moment Magnitude*	Number per year	Modified Mercalli Intensity Scale*	Characteristic Effects in Populated Areas
<3.4	800,000	I	Recorded only by seismographs
3.5–4.2	30,000	II–III	Felt by some people who are indoors
4.3–4.8	4,800	IV	Felt by many people; windows rattle
4.9–5.4	1,400	V	Felt by everyone; dishes break, doors swing
5.5–6.1	500	VI–VII	Slight building damage; plaster cracks, bricks fall
6.2–6.9	100	VIII–IX	Much building damage; chimneys fall; houses move on foundations
7.0–7.3	15	X	Serious damage, bridges twisted, walls fractured; many masonry buildings collapse
7.4–7.9	4	XI	Great damage; most buildings collapse
>8.0	<1	XII	Total damage; waves seen on ground surface, objects thrown in the air

*The correspondence between Richter and moment magnitudes and the Mercalli intensity is not exact because they are calculated on the basis of very different parameters.

Orientation of present-day US principal stresses

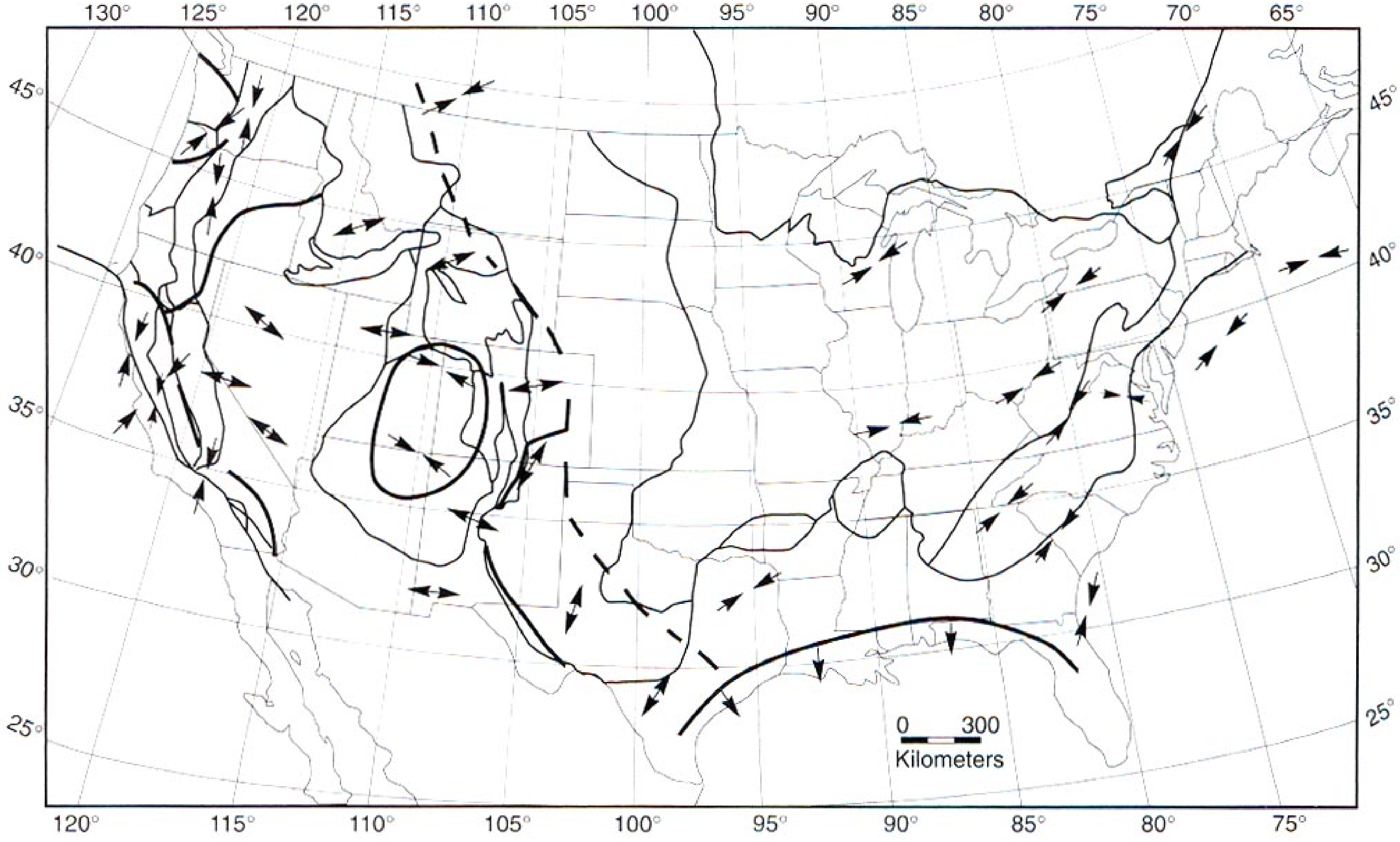
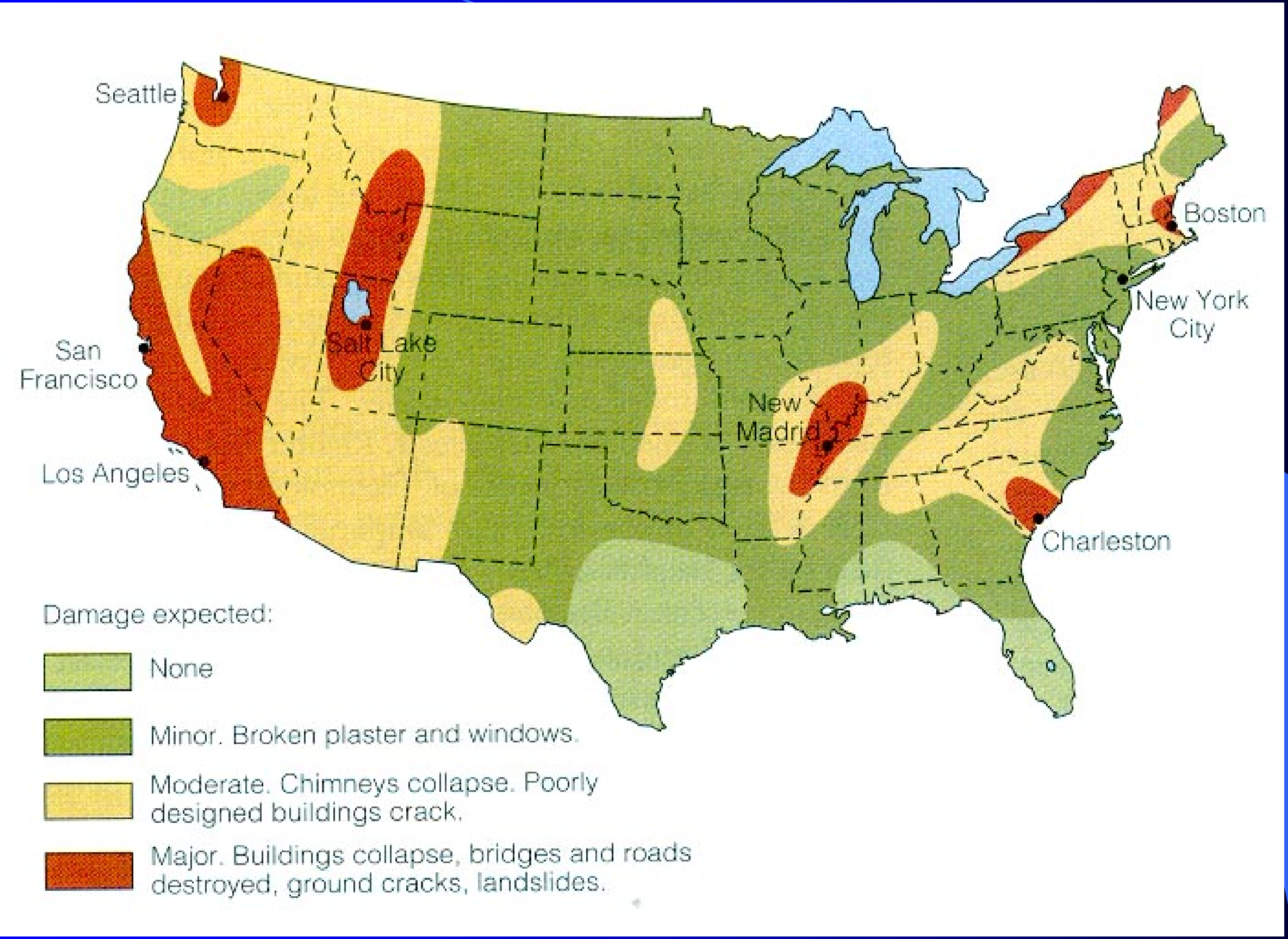


FIGURE 3E–3

Domains of common orientation of present-day maximum (compressional) and minimum (extensional) principal stress in the United States. Arrowheads indicate whether stress is extensional or compressional. (From M. L. Zoback and M. D. Zoback, 1989, Geological Society of America *Memoir 172*.)

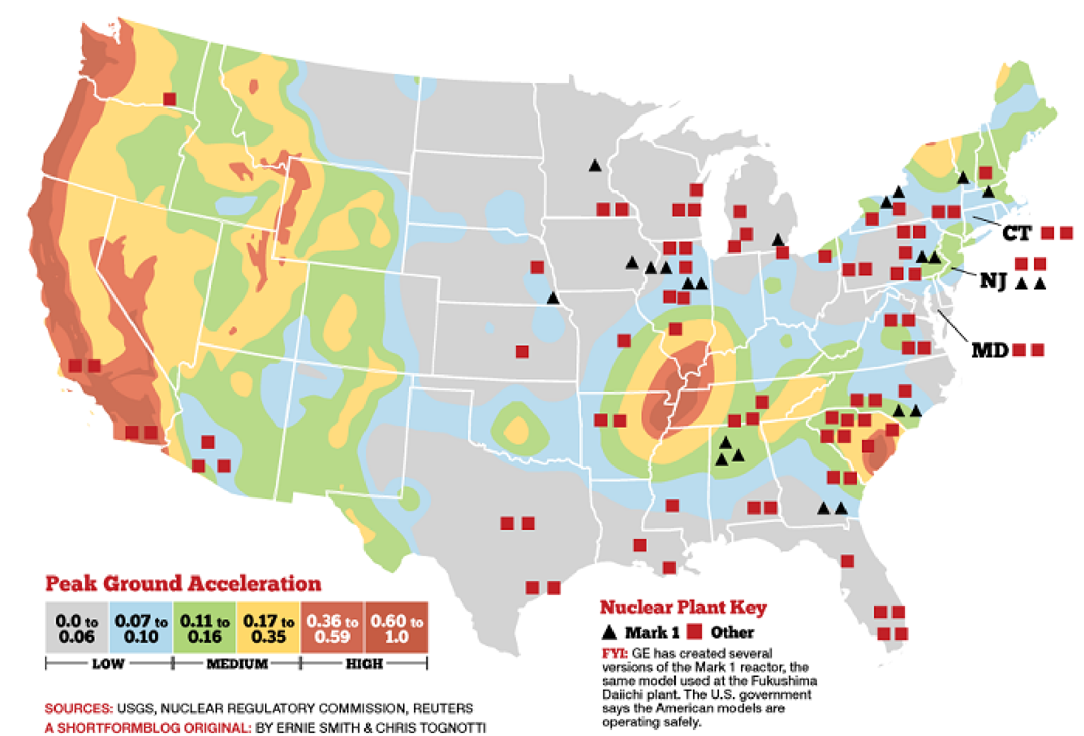
Seismic-risk map for the contiguous United States



Boston is in the same seismic-risk zone as San Francisco

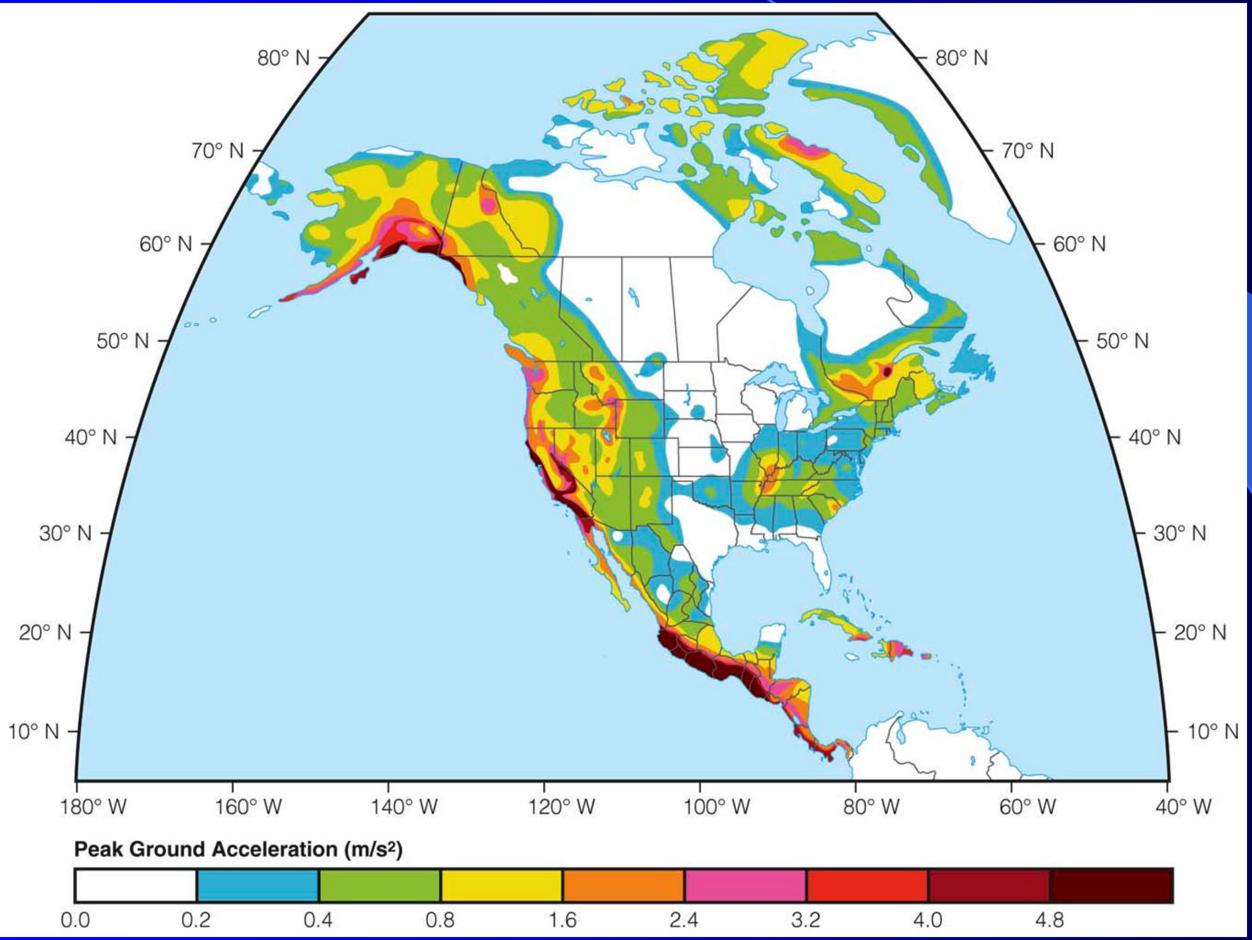
Peak Ground Acceleration (PGA) in m/s^2

Instrumental Intensity	Acceleration (g)	Velocity (cm/s)	Perceived Shaking	Potential Damage
I	< 0.0017	< 0.1	Not felt	None
II-III	0.0017 - 0.014	0.1 - 1.1	Weak	None
IV	0.014 - 0.039	1.1 - 3.4	Light	None
V	0.039 - 0.092	3.4 - 8.1	Moderate	Very light
VI	0.092 - 0.18	8.1 - 16	Strong	Light
VII	0.18 - 0.34	16 - 31	Very strong	Moderate
VIII	0.34 - 0.65	31 - 60	Severe	Moderate to heavy
IX	0.65 - 1.24	60 - 116	Violent	Heavy
X+	> 1.24	> 116	Extreme	Very heavy



Earthquake Hazards

- Primary – ground motion and surface rupture
- Secondary – fires, landslides, liquefaction, tsunamis



Primary effects - most earthquake damage is caused by differential movement of the land surface due to the passage of the transverse surface waves.

Secondary Effects

Liquefaction

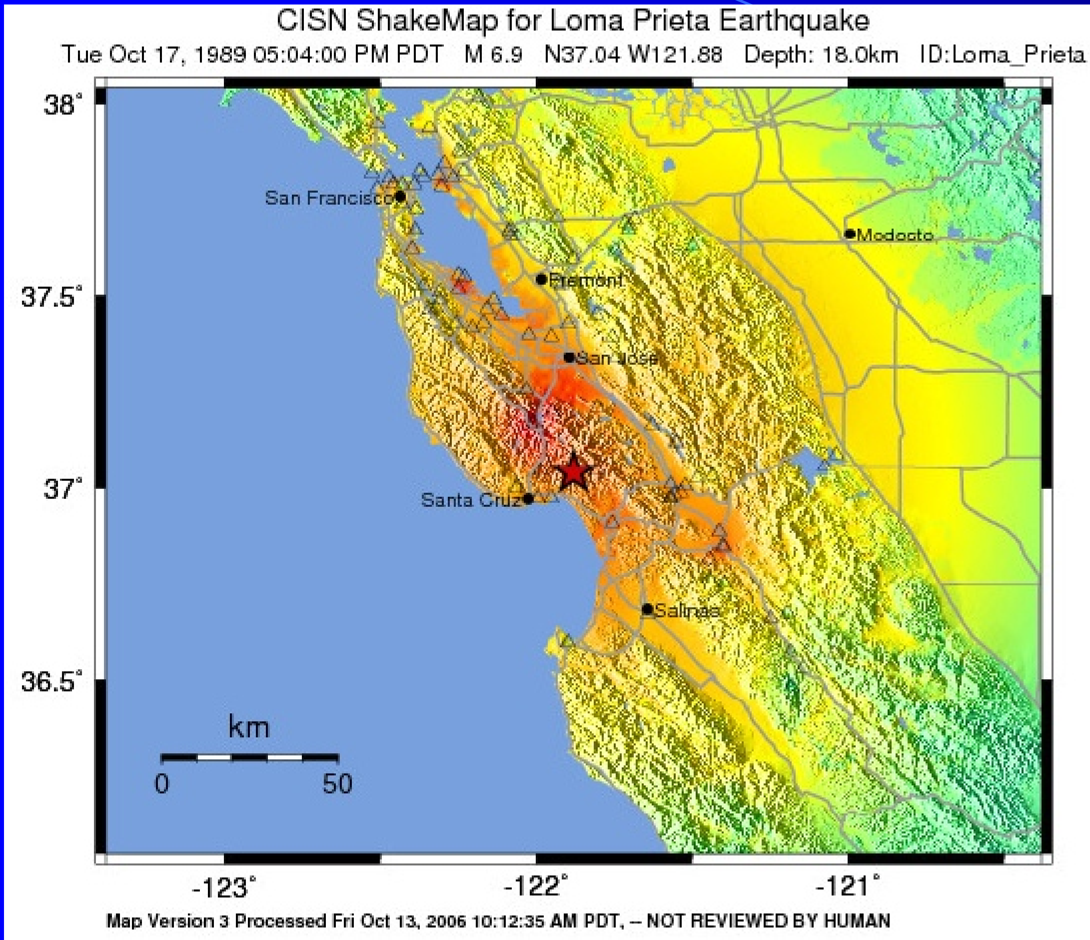
Tsunami

Landslide

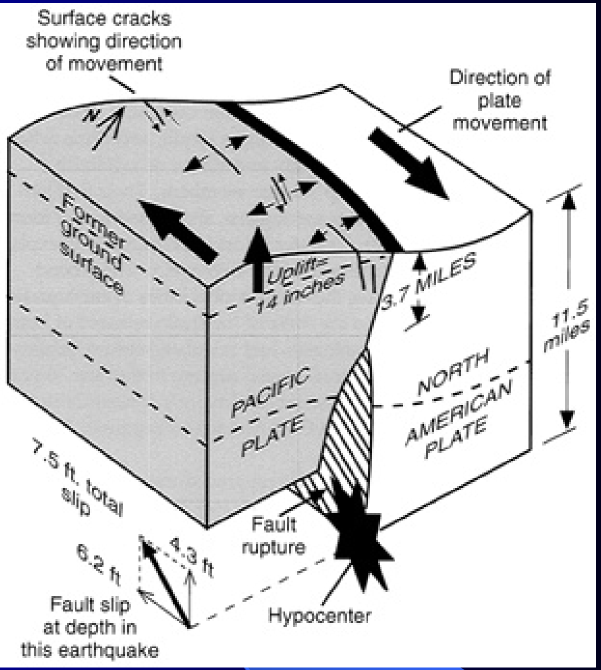
Fire

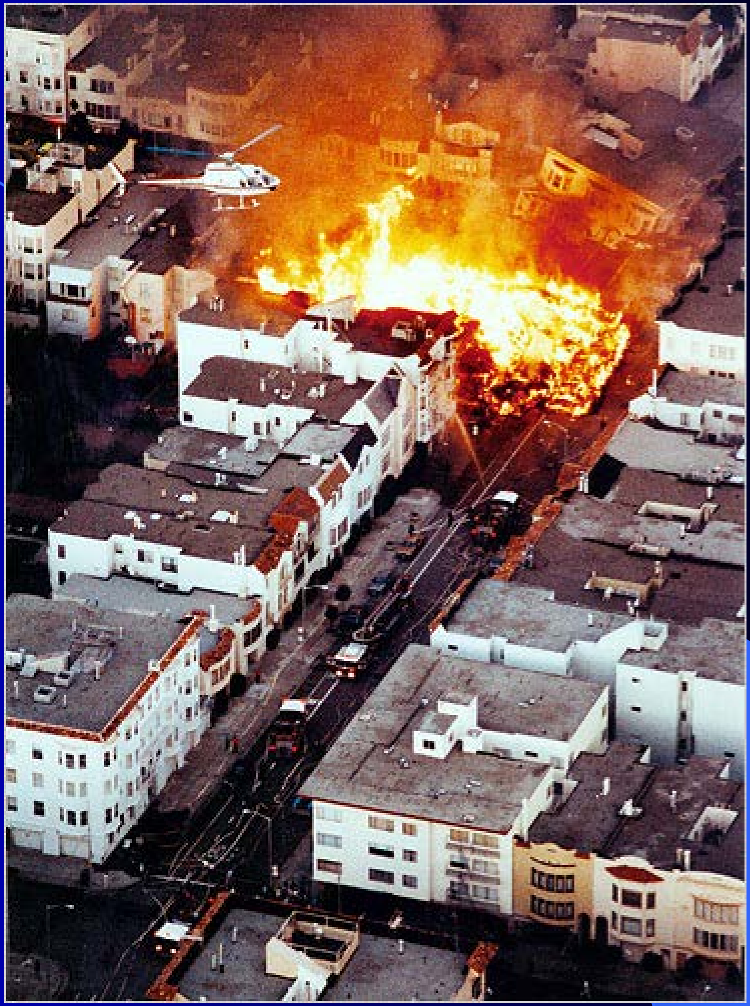
Mud volcano

Loma Prieta Earthquake



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



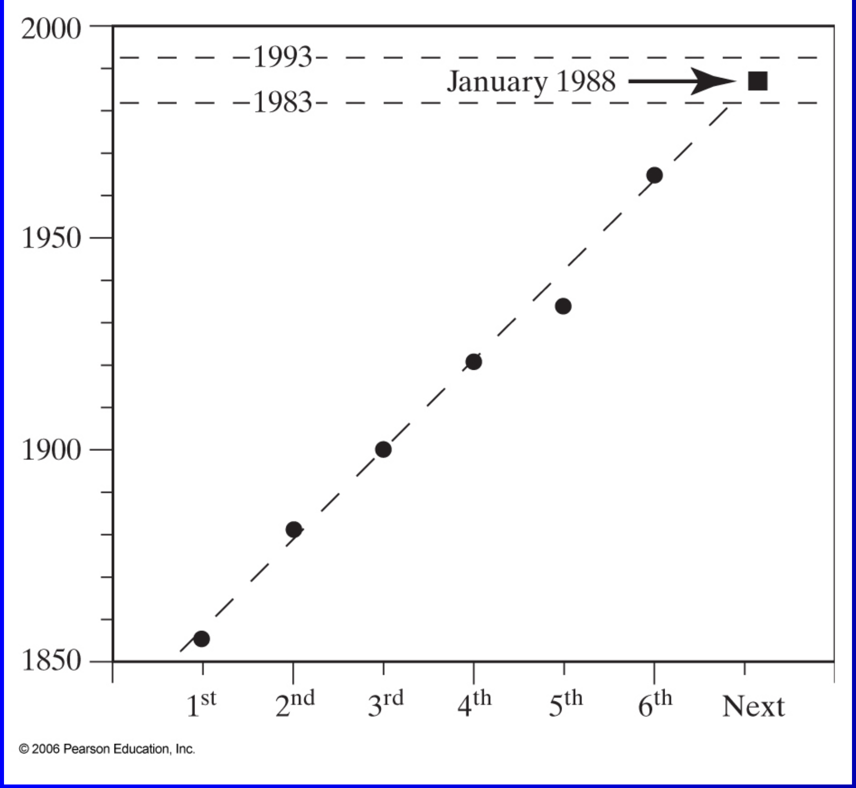


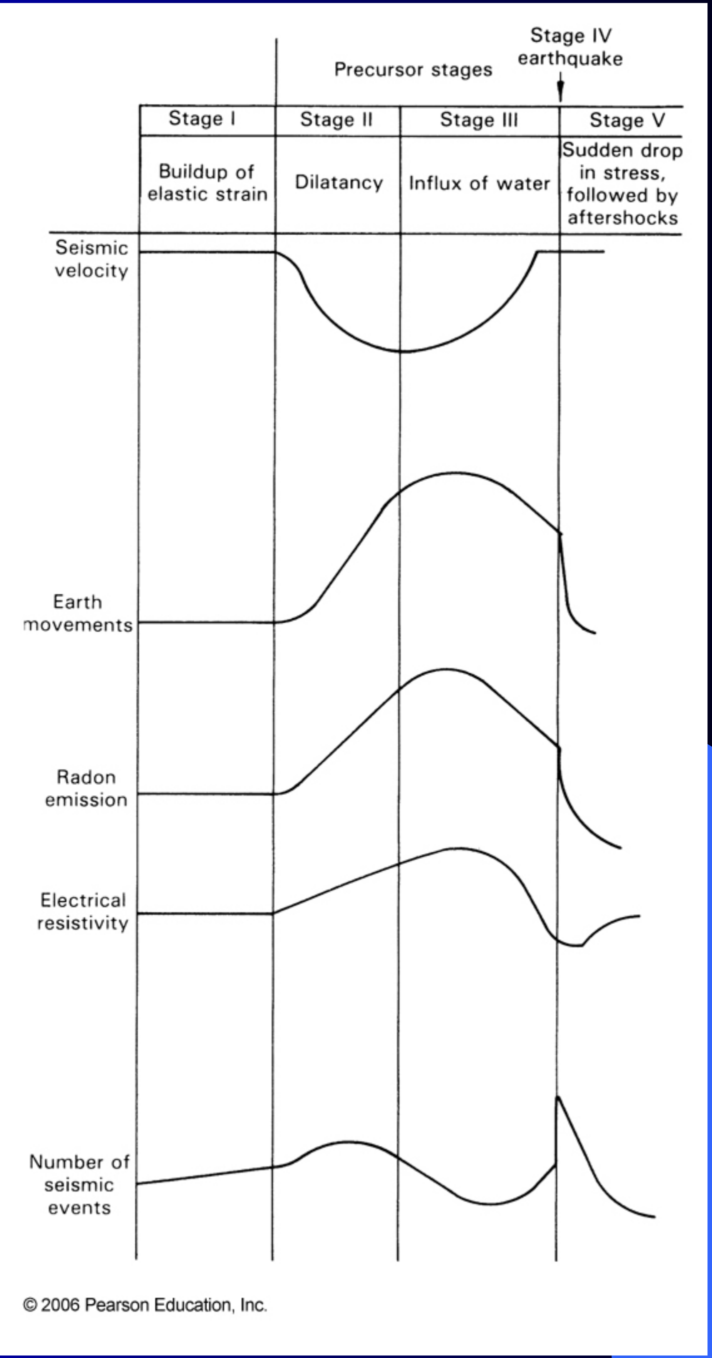
Predicting Earthquakes

1) Recurrence intervals – can only be applied to relatively frequent earthquakes
2) Seismic quiet zones – an inactive area along a fault trace represents a region in which strain is accumulating – a potential locus for failure
3) Changes in water level in wells – as rocks begin to fail voids develop (dilatancy) and groundwater moves into the voids
4) Increase in frequency of small earthquakes – precursor earthquakes
5) Strain measurements – monitor accumulation of strain
6) Folklore

Dilatancy model

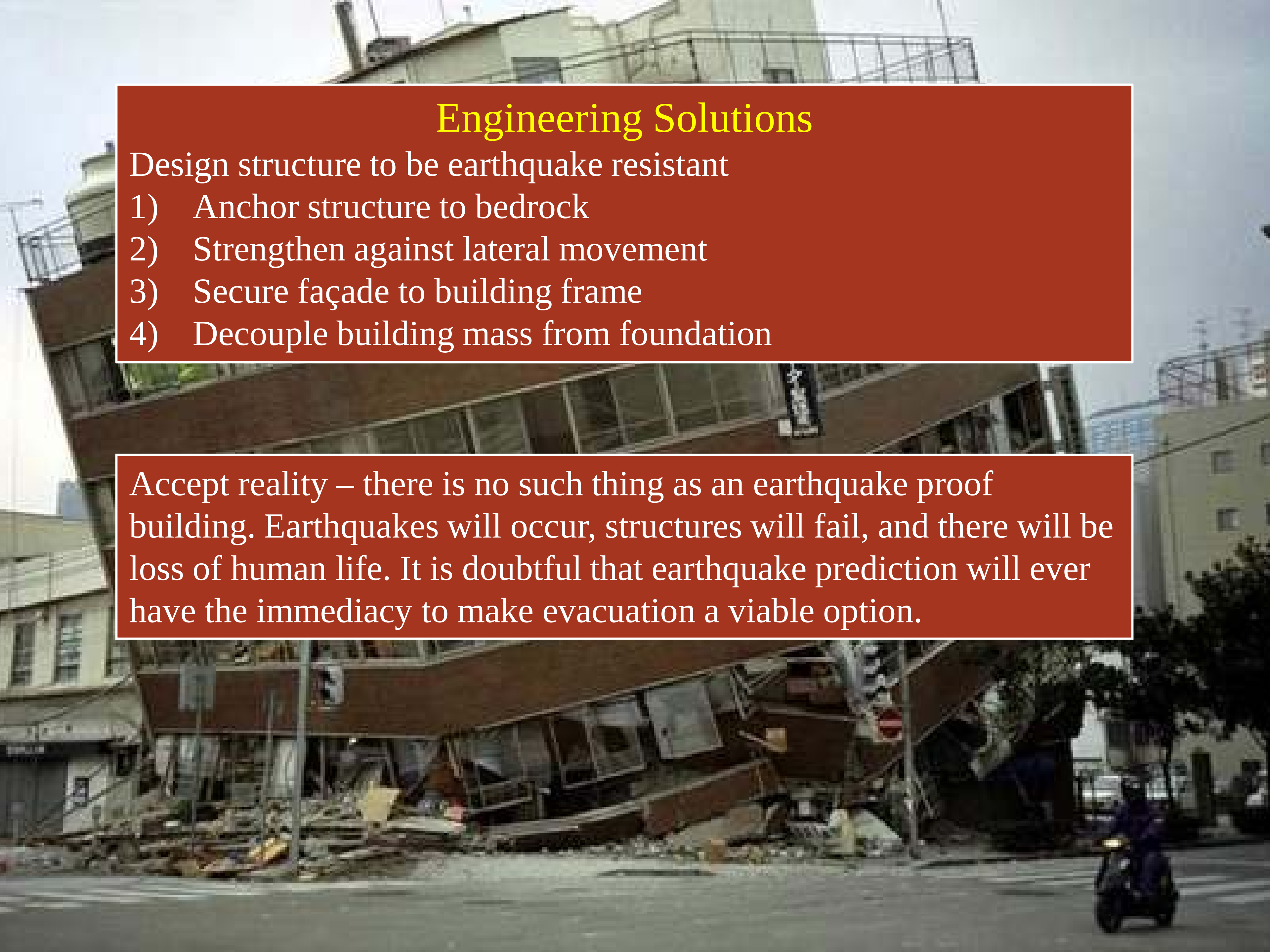
Recurrence Interval





Parkfield, CA

Earthquake occurred in 2004

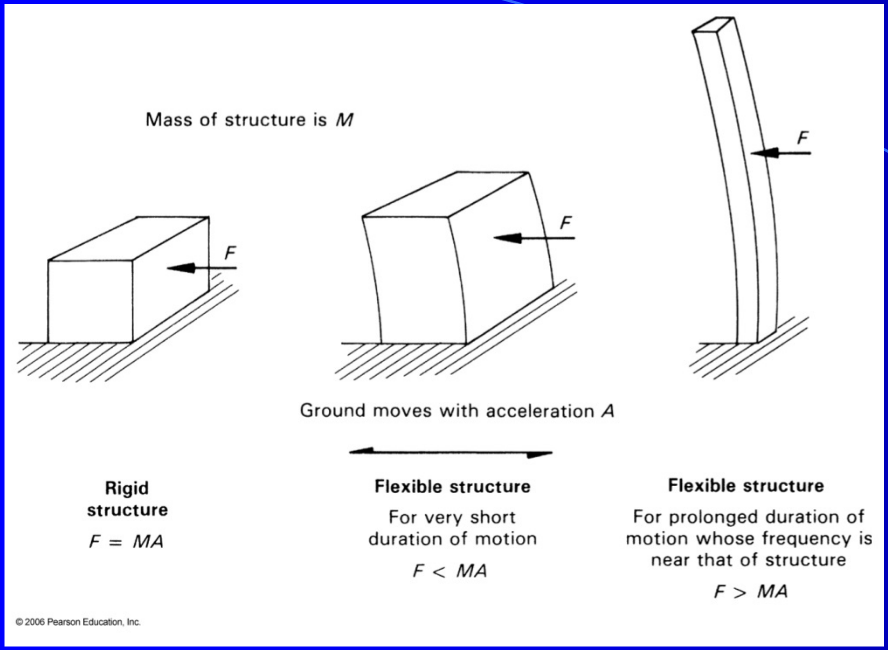


Engineering Solutions

Design structure to be earthquake resistant

1) Anchor structure to bedrock
2) Strengthen against lateral movement
3) Secure façade to building frame
4) Decouple building mass from foundation

Accept reality – there is no such thing as an earthquake proof building. Earthquakes will occur, structures will fail, and there will be loss of human life. It is doubtful that earthquake prediction will ever have the immediacy to make evacuation a viable option.



Mass of structure is M
F
F
F
Ground moves with acceleration A
Rigid structure
F = MA
Flexible structure
For very short duration of motion
F < MA
Flexible structure
For prolonged duration of motion whose frequency is near that of structure
F > MA
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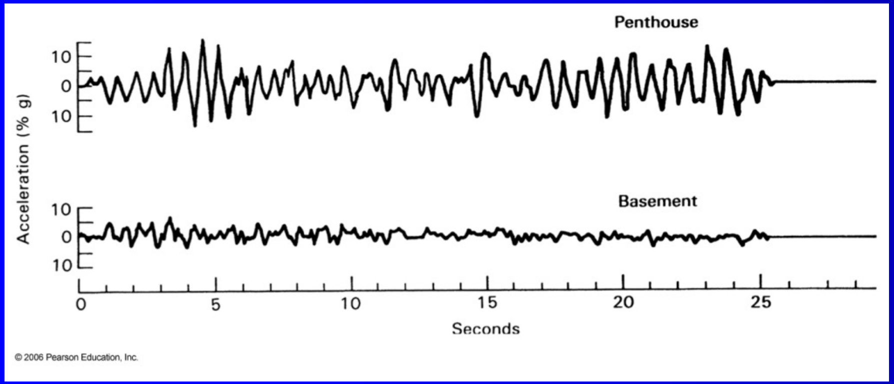

Penthouse
Basement
Acceleration (% g)
10
0
10
0
5
10
15
20
25
Seconds
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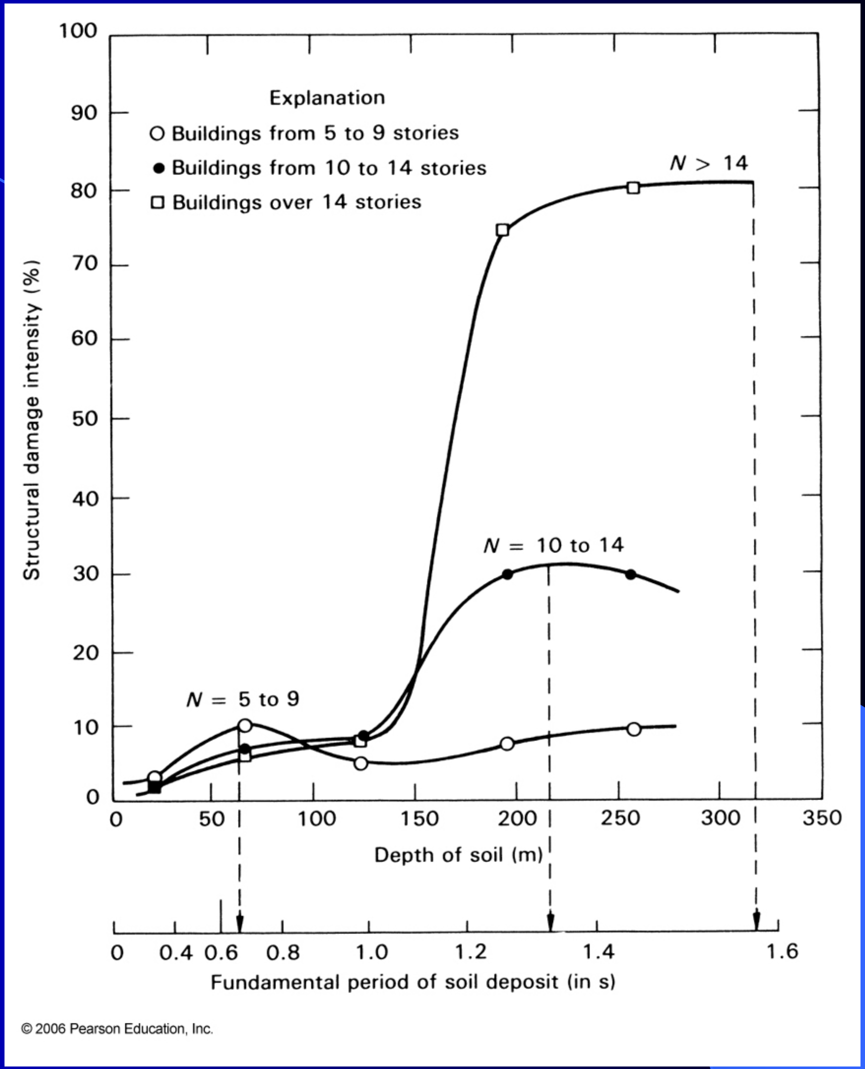


Explanation
Buildings from 5 to 9 stories
Buildings from 10 to 14 stories
Buildings over 14 stories
N > 14
N = 10 to 14
N = 5 to 9
Structural damage intensity (%)
Depth of soil (m)
Fundamental period of soil deposit (in s)
0 0.4 0.6 0.8 1.0 1.2 1.4 1.6
0 50 100 150 200 250 300 350
© 2006 Pearson Education, Inc.

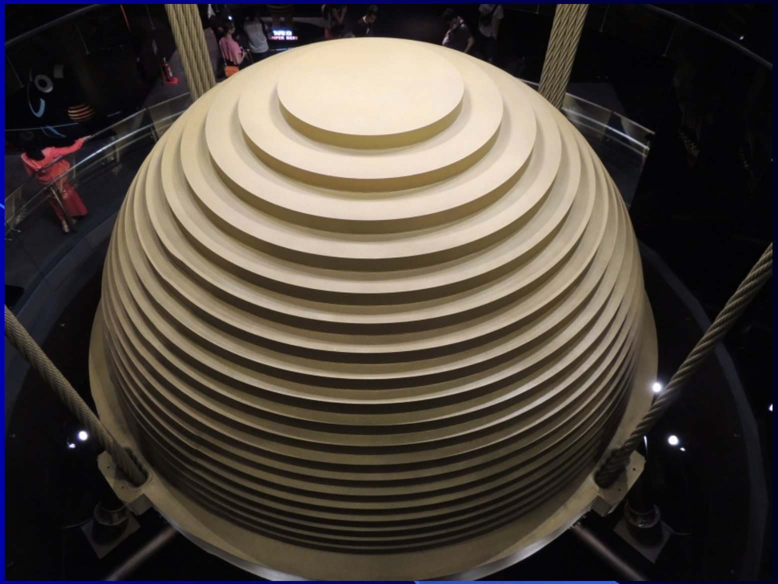
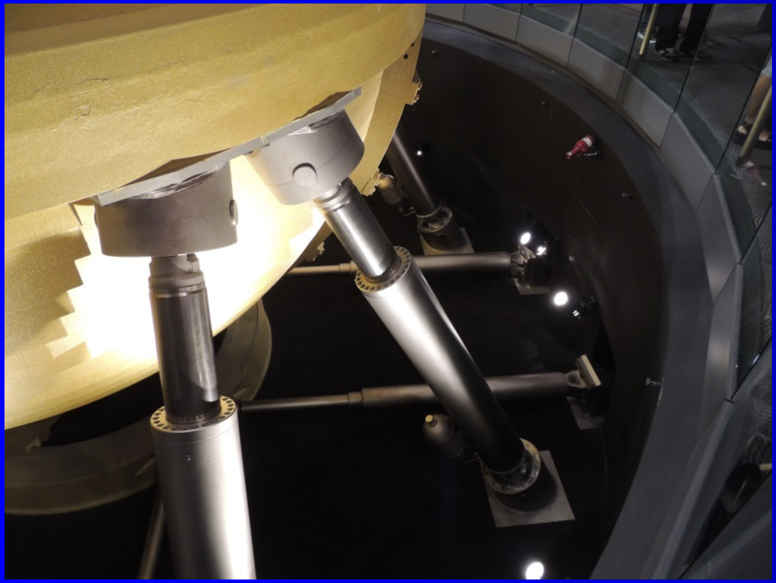
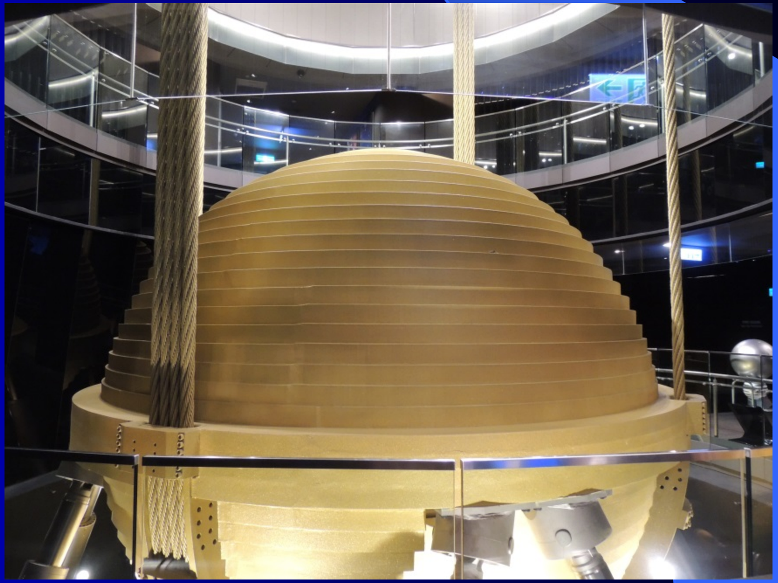

Building 101




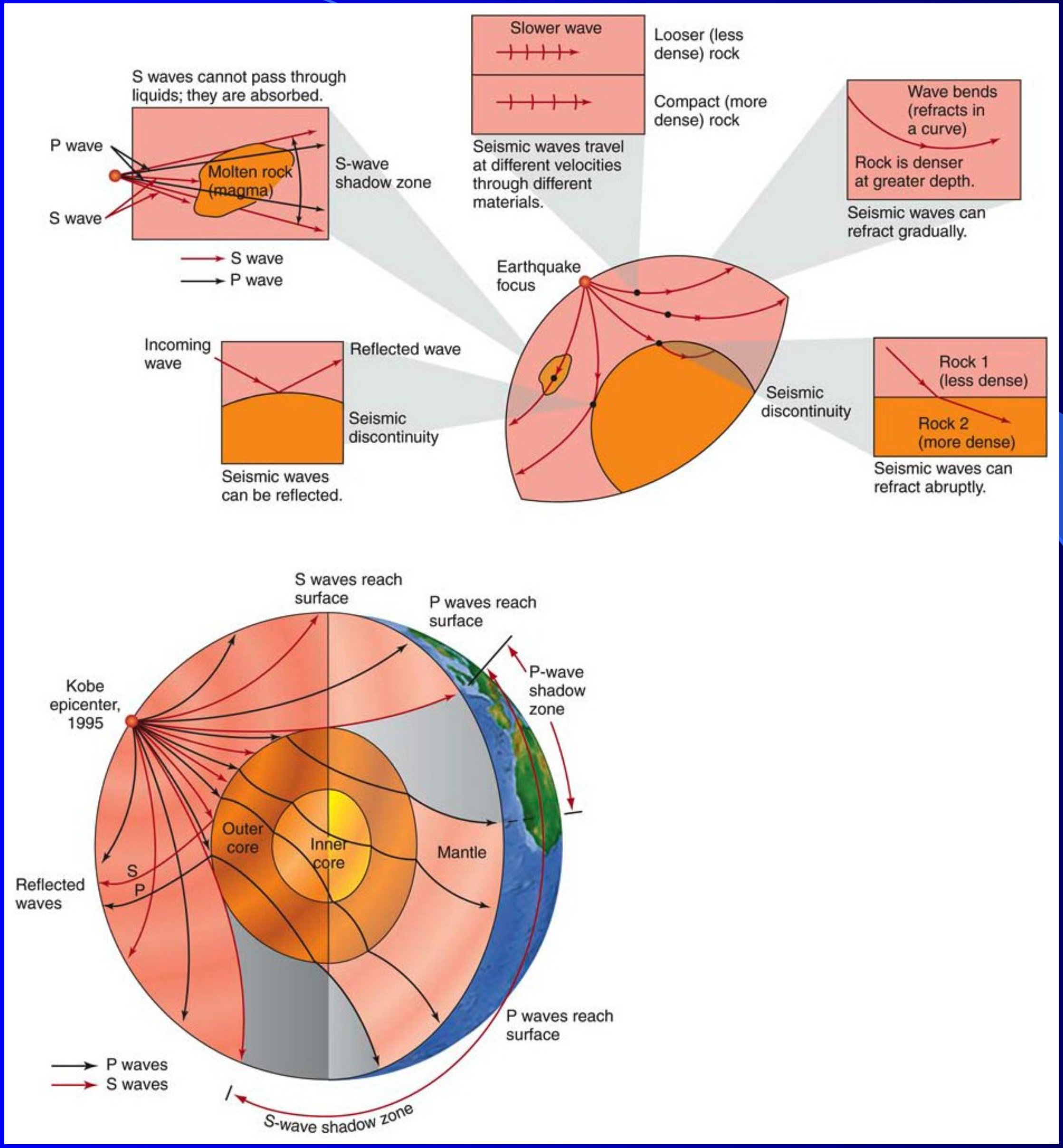
Table 8.4 Earthquake Ratings for Common Building Types

Simplified Description of Structural Types	Relative Damageability (in order of increasing susceptibility to damage)
Small wood-frame structures, i.e., dwellings not over 3000 sq ft, and not over 3 stories	1
Single or multistory steel-frame buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	1.5
Single or multistory reinforced-concrete buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	2
Large-area wood-frame buildings and other wood-frame buildings	3 to 4
Single or multistory steel-frame buildings with unreinforced masonry exterior wall panels; concrete floors and concrete roof	4
Single or multistory reinforced-concrete frame buildings with unreinforced masonry exterior wall panels, concrete floors, and concrete roof	5
Reinforced-concrete bearing walls with supported floors and roof of any materials (usually wood)	5
Buildings with unreinforced brick masonry having sandlime mortar and with supported floors and roof of any materials (usually wood)	7 up
Bearing walls of unreinforced adobe, unreinforced hollow concrete block, or unreinforced hollow clay tile	Collapse hazards in moderate shocks

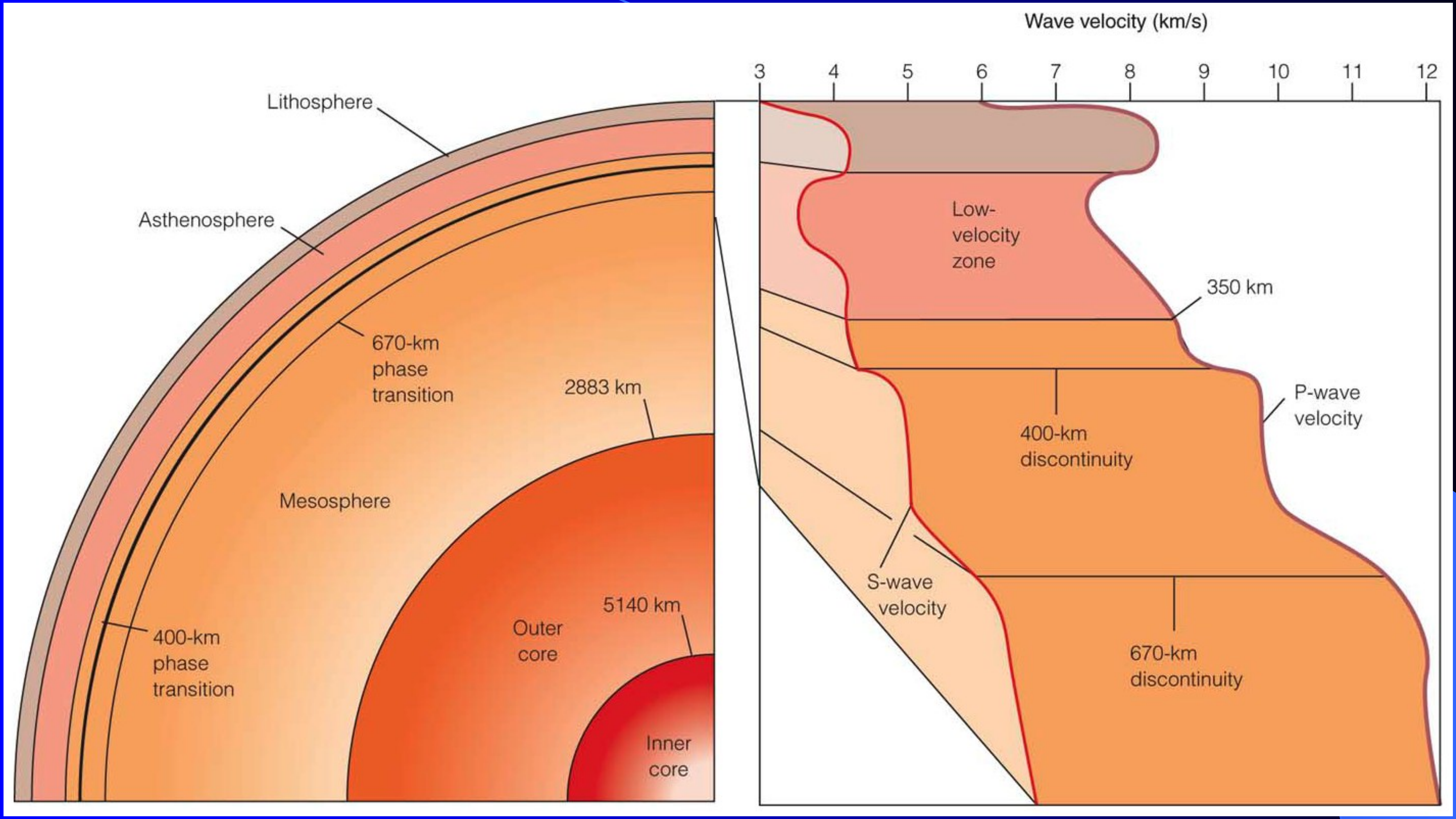
Source: From D. Armstrong, 1973, *The Seismic Safety Study for the General Plan*, Sacramento, Calif.: California Council on Intergovernmental Relations.

Note: This table is not complete. Additional considerations would include parapets, building interiors, utilities, building orientation, and frequency response.

Earthquakes and the Earth's Interior



Seismic Discontinuities



Planet Earth – the megascopic scale