III.1 Damaging Effects of Earthquakes

- Damage from Earthquake Shaking
  Seismic Intensity, Strong Ground Motion
- Quantifying Earthquake Shaking
  Attenuation Relations
- Frequency Dependence of Strong Ground Motions
- Site Effects
- Other Damaging Effects of Earthquakes
  Tsunami, Fires, Landslides,
  Ground Deformation, Liquefaction

‘Earthquake don’t kill people, structures do’

The number one cause of damage from earthquakes is due to failures in the built environment from ground shaking

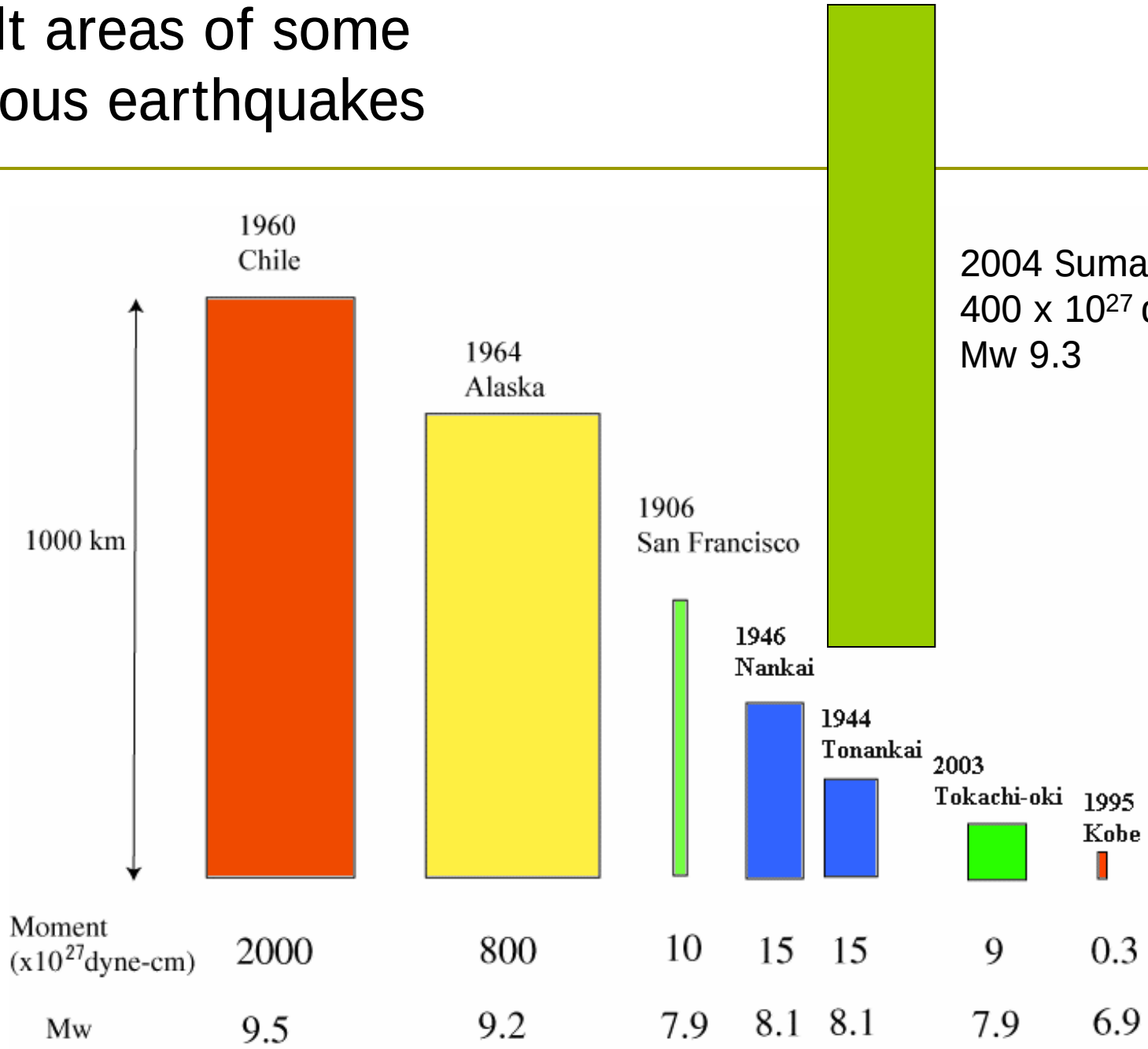
(The number two cause is tsunamis)

1999 Izmit, Turkey earthquake

Modified Mercalli Intensity

I	Barely felt
II	Felt by only few people
III	Felt noticeably, standing autos rock slightly
IV	Felt by many, windows and walls creak
V	Felt by nearly everyone, some dishes and windows broken
VI	Felt by all, damaged plaster and chimneys
VII	Damage to poorly constructed buildings
VIII	Collapse of poorly constructed buildings, slight damage to well built structures
IX	Considerable damage to well constructed buildings, buildings shifted off foundations
X	Damage to well built wooden structures, some masonry buildings destroyed, train rails bent, landslides
XI	Few masonry structure remain standing, bridges destroyed, ground fissures
XII	Damage total

Fault areas of some famous earthquakes

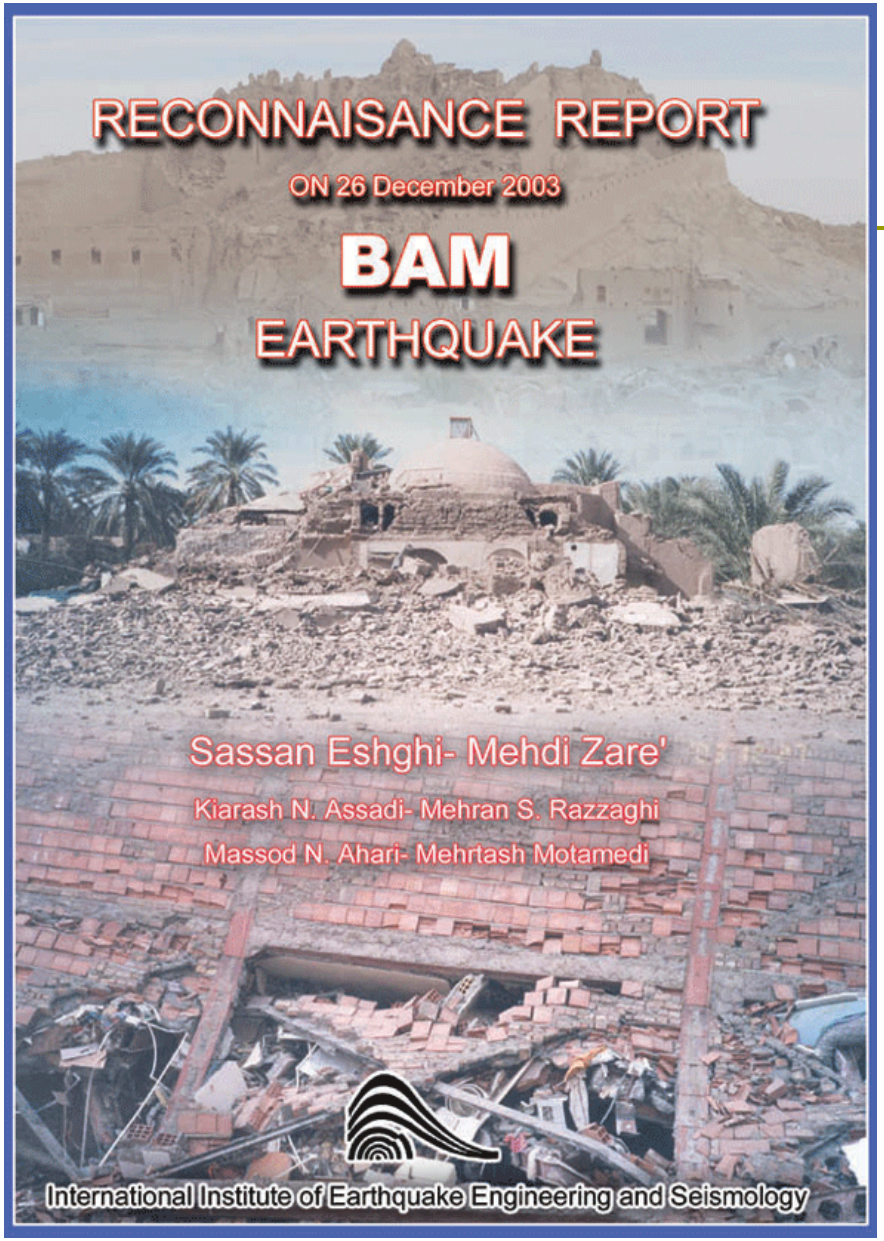


Kashimir, Pakistan Earthquake

October 8, 2005
Mw 7.6

Deaths	>80,000
Injured	>200,000
Homeless	>4,000,000

http://www.eeri.org/lfe/clearinghouse/kashmir/reports/kashmir_eeri_1st_report.pdf



Bam, Iran Earthquake

December 26, 2003
Mw 6.5
Depth 7 km

Deaths	~43,200
Injured	~20,000
Collapsed Buildings	~50,000

http://www.iiees.ac.ir/English/Bam_report_english.html

Latur, India Earthquake

September 30, 1993
Mw 6.1
Depth 7 km

Deaths	7600
Injured	~16,000
Collapsed Buildings	~30,000

1995 Kobe, Japan Earthquake

Hyogo-ken Nanbu (Kobe)
January 17, 1995
Mw 6.9 (M_{jma} 7.3)

Deaths 5096
Injured 26,797
Damage ~US$100 billion

1995 Northridge, California Earthquake

Northridge, California
(Los Angeles)
January 17, 1994
Mw 6.7

Deaths 57
Injured 9,158
Damage ~US$20 billion

Collapsed Bridges in Northridge Earthquake

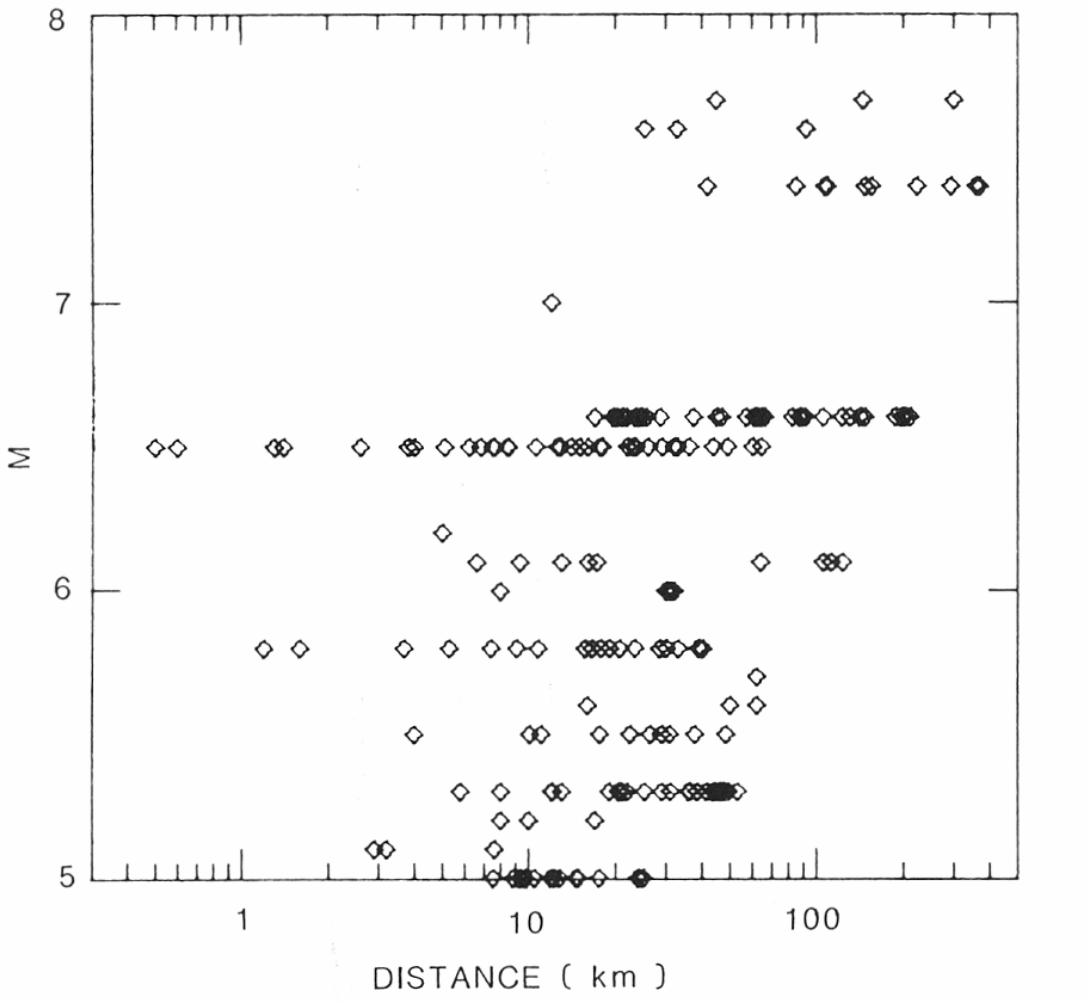
I5-SH14 Interchange

There were 5 collapses and over 170 damaged bridges around Los Angeles

One year later in Japan...

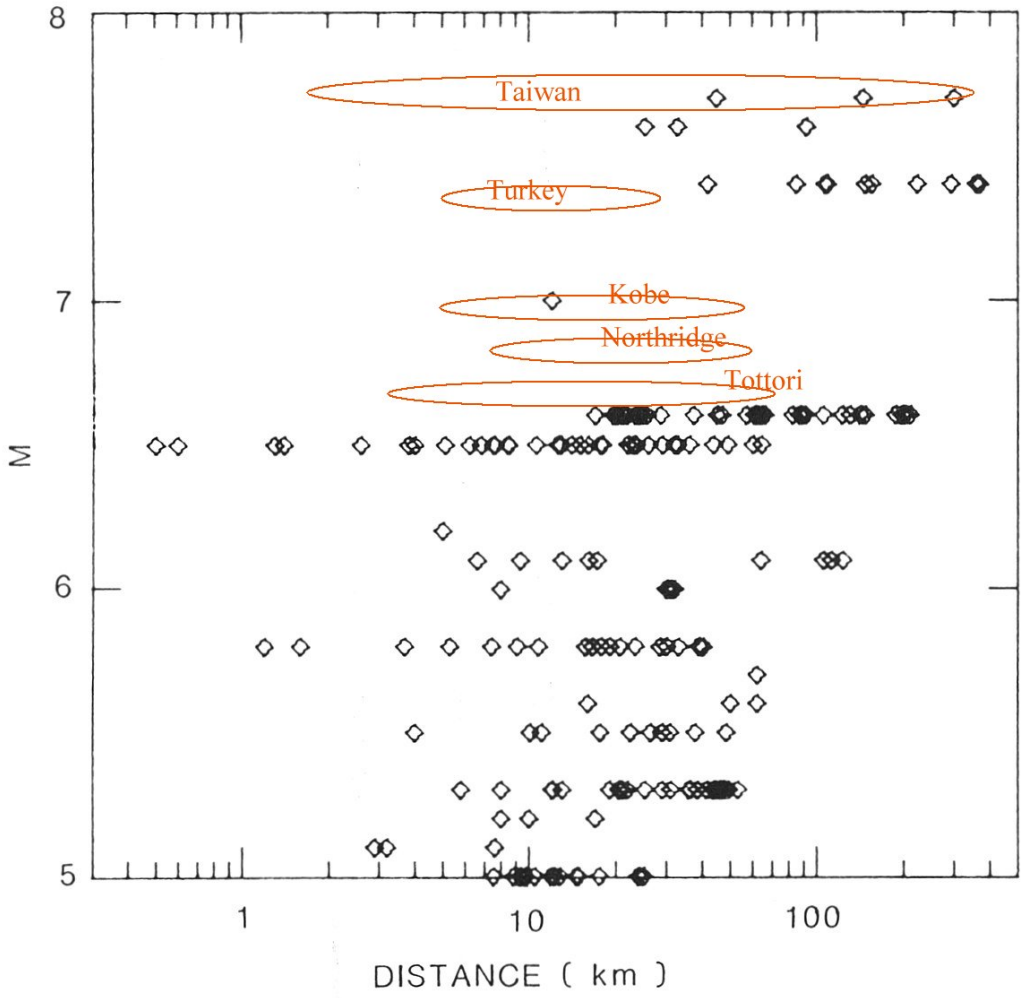
Collapsed Hanshin Highway in Kobe

Strong-motion data in 1982

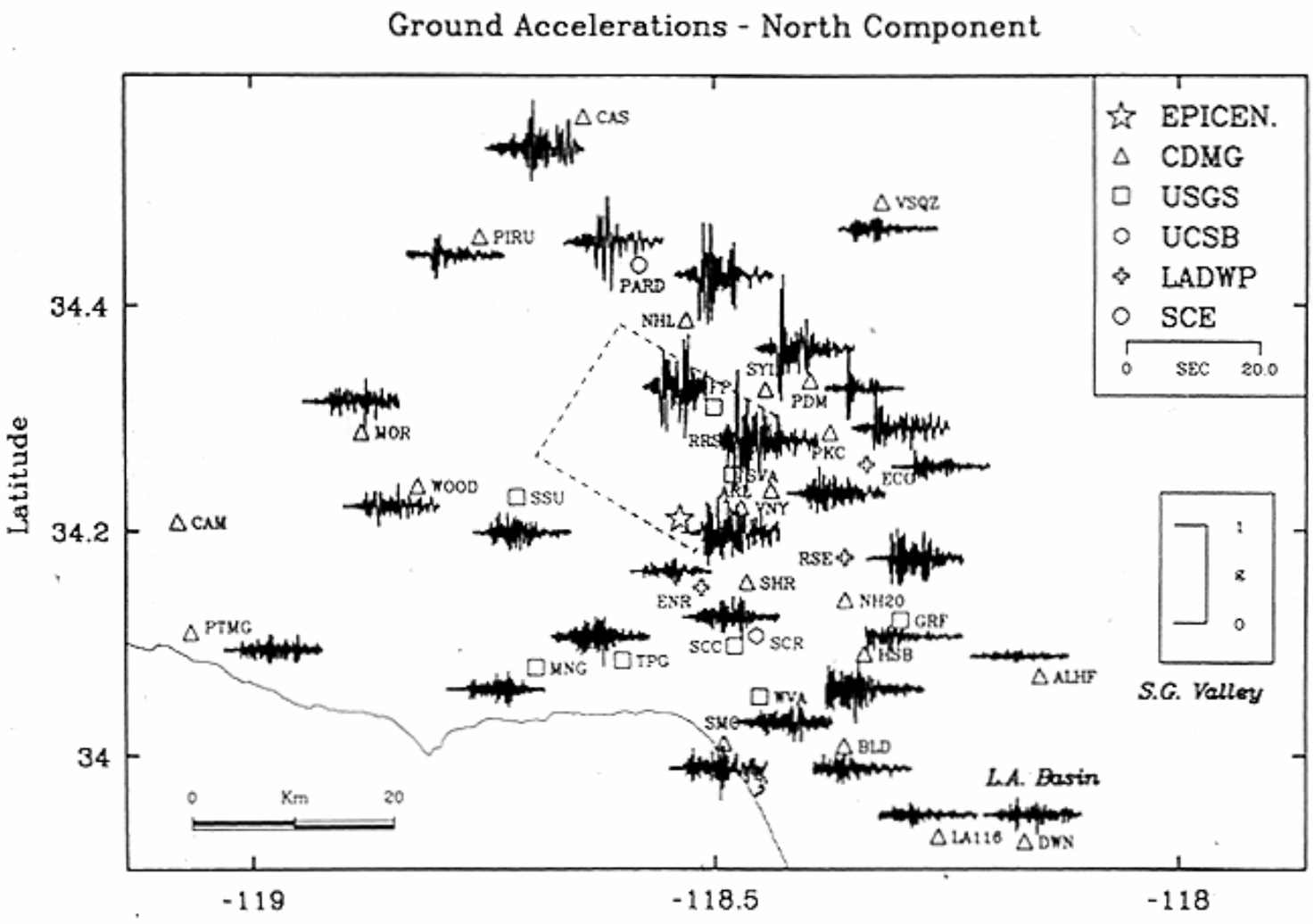


Boore and Joyner, 1982

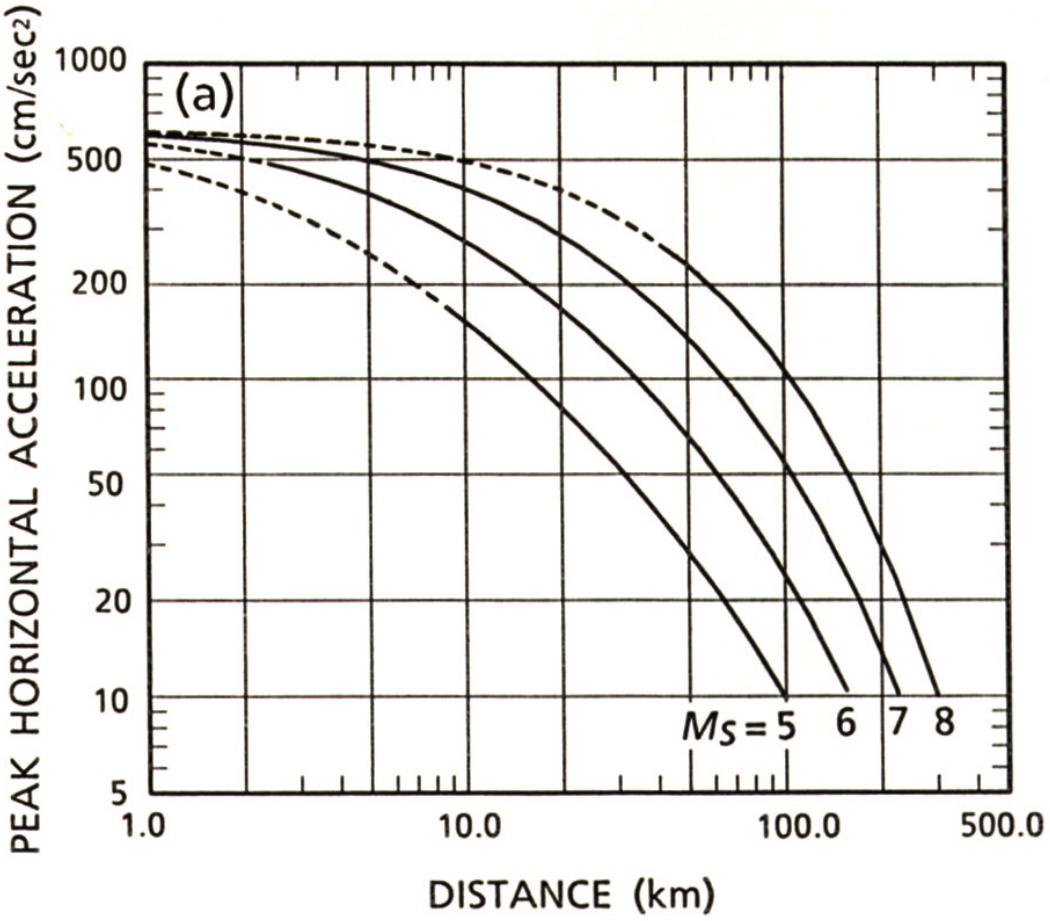
Strong-motion data in 2002



Strong-motion Recordings from the Northridge Earthquake

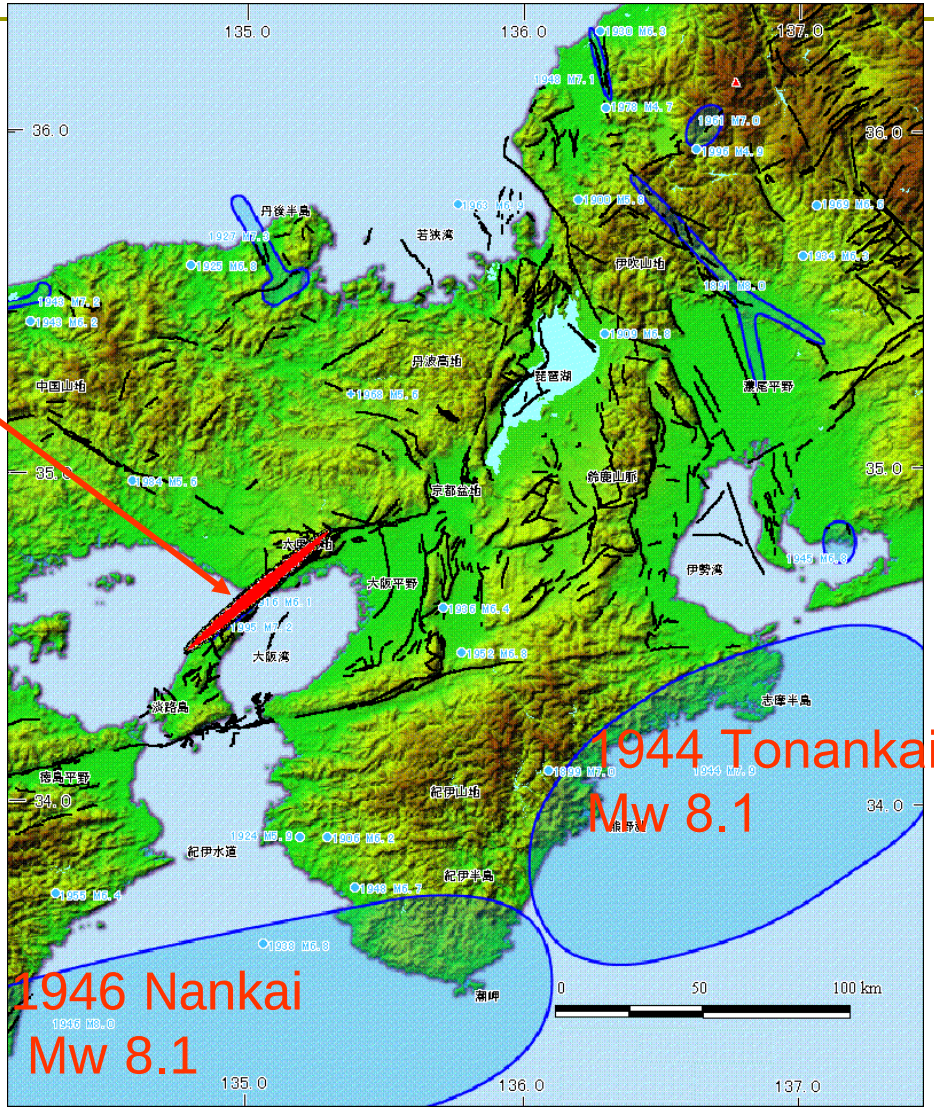


Attenuation Relations



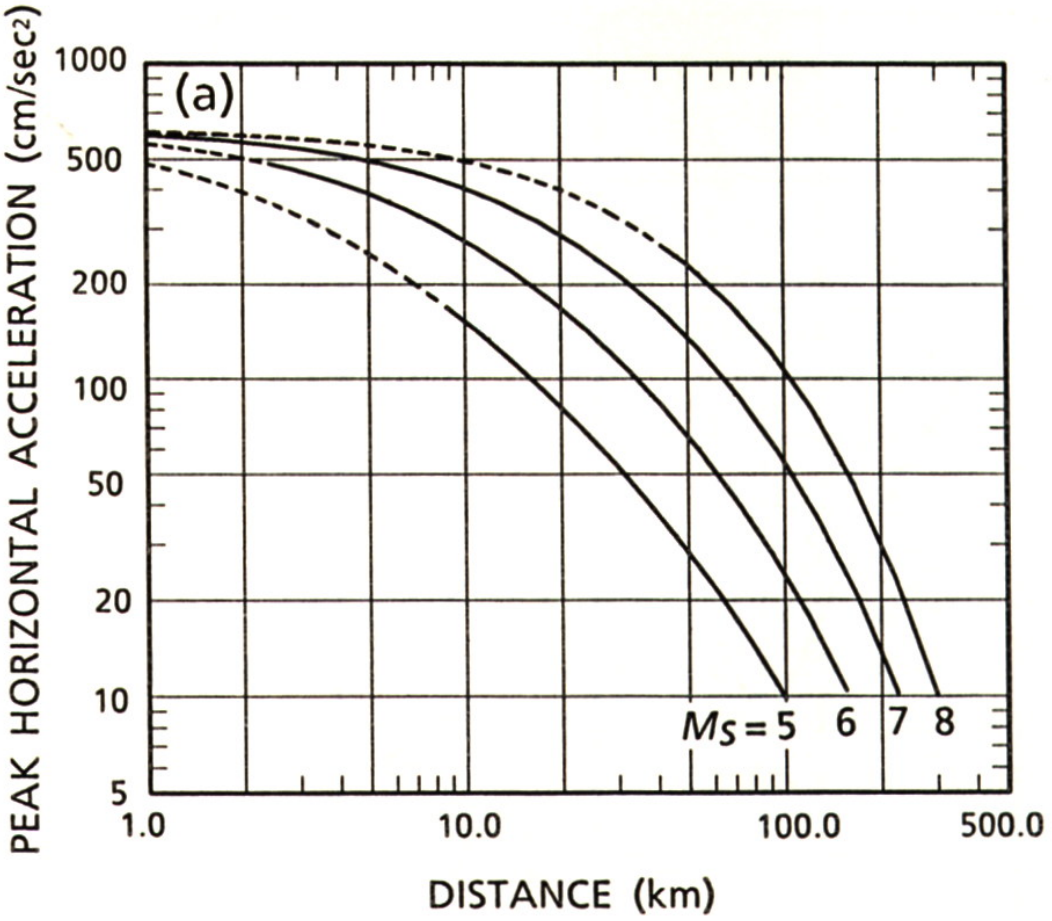
Fukushima and Tanaka, 1990

Distance to Earthquake is Most Important Factor for Shaking Damage



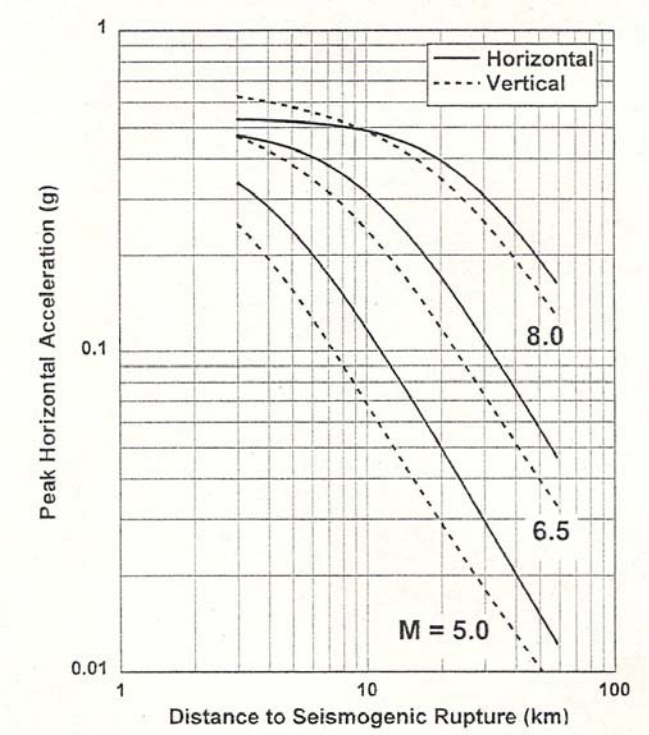
		Deaths
1944	Tonankai	1223
1946	Nankai	1330
1995	Kobe	5310

Attenuation Relations

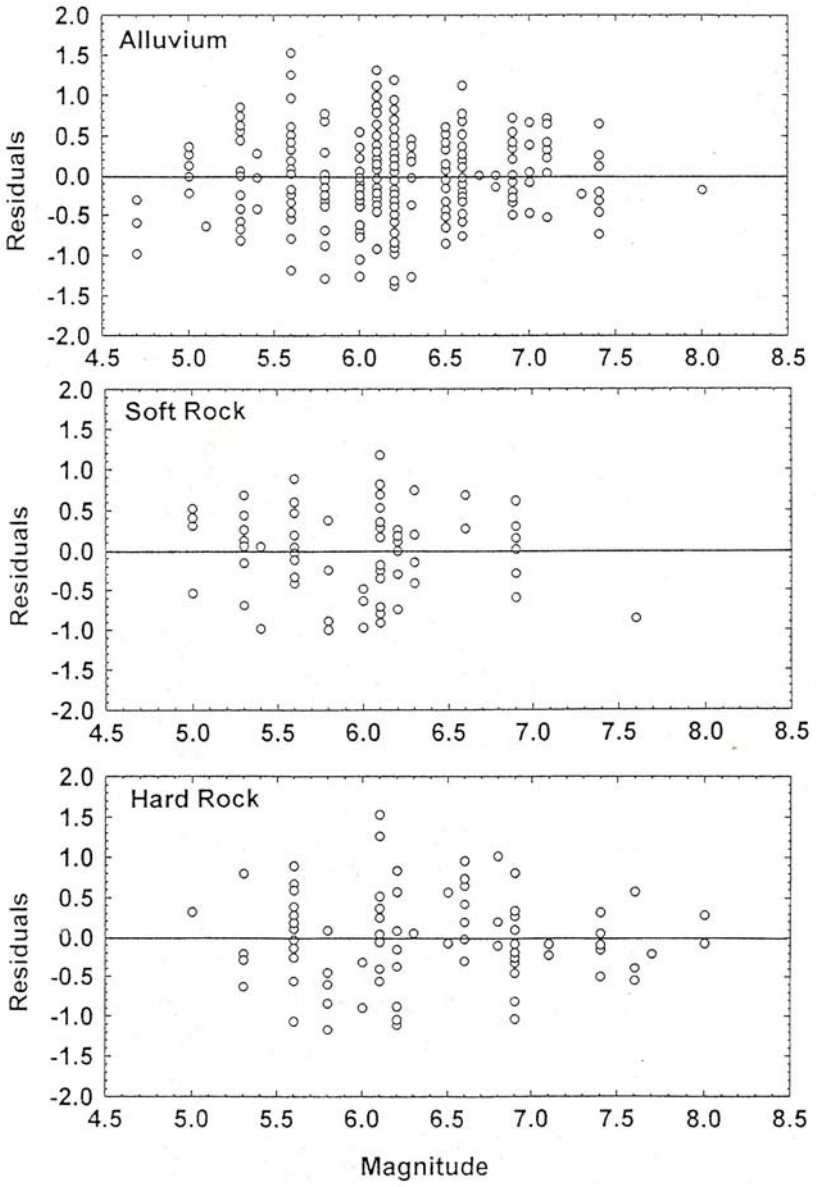


Fukushima and Tanaka, 1990

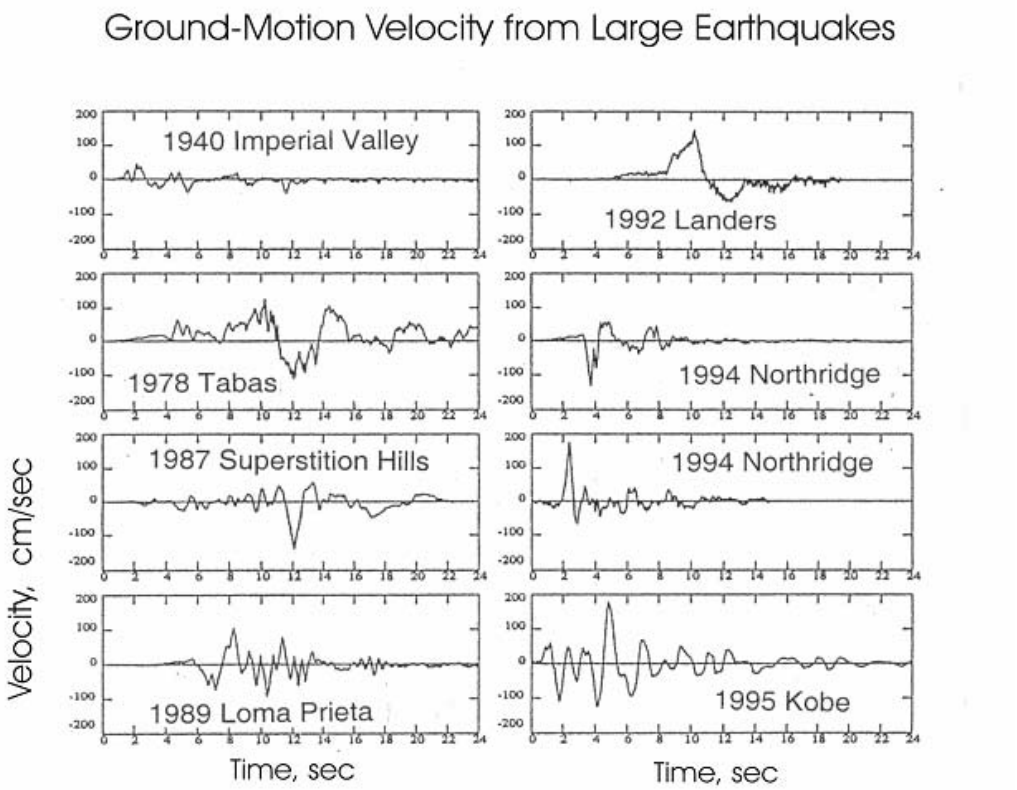
Large Variability in Ground Motions

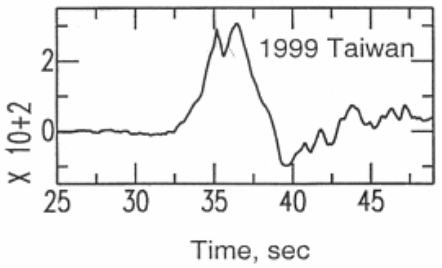


Campbell, 1997



Large Recorded Ground Velocities

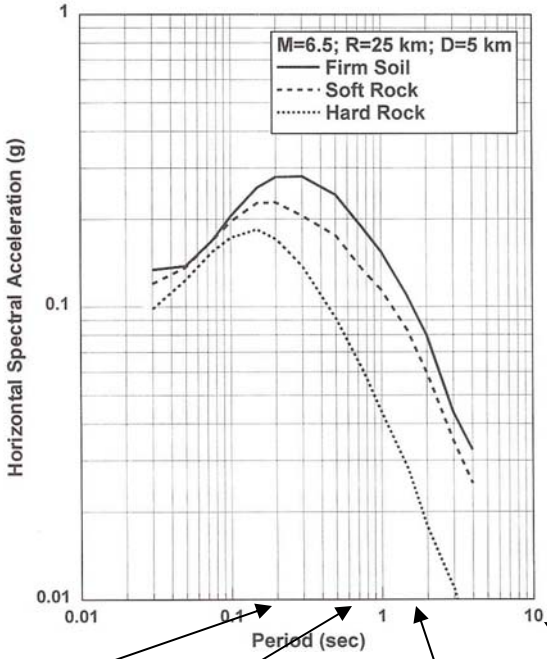




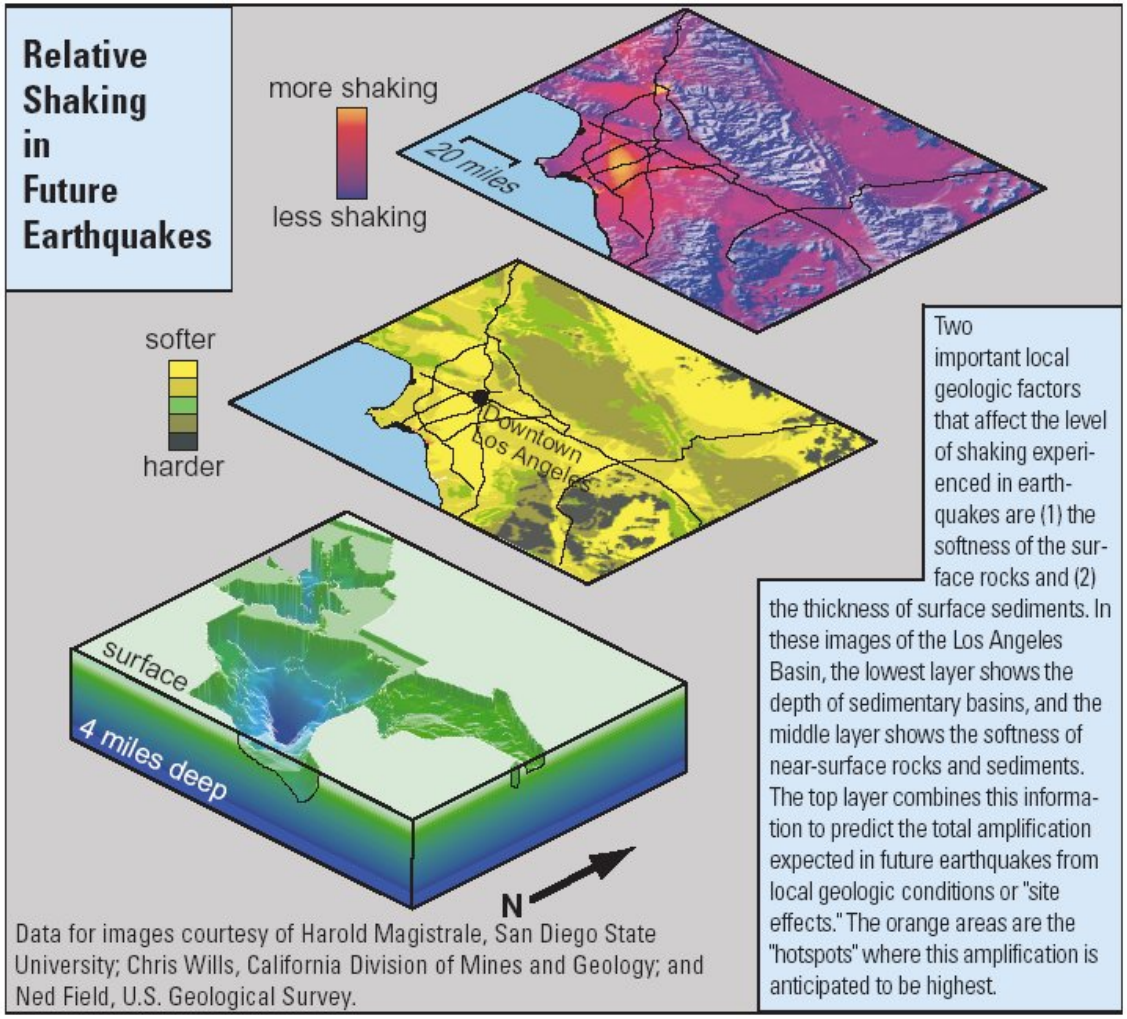
Important Factors for Evaluating Strong Shaking

- Frequency Dependence
- Regional Attenuation
- Site Effects

Frequency Response of Structures



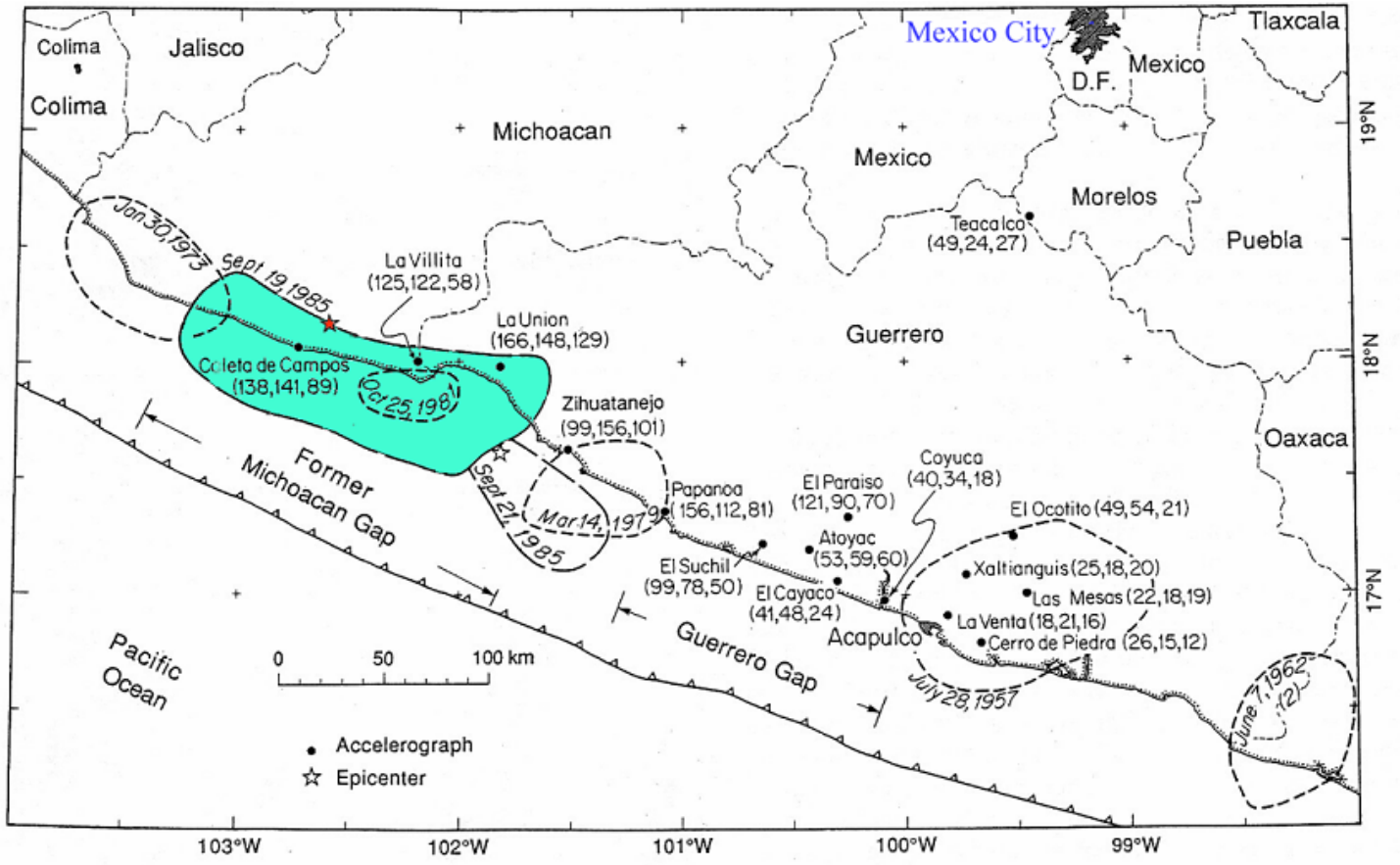
Site Response



Soft surface soils can amplify seismic waves

http://geopubs.wr.usgs.gov/fact-sheet/fs001-01/

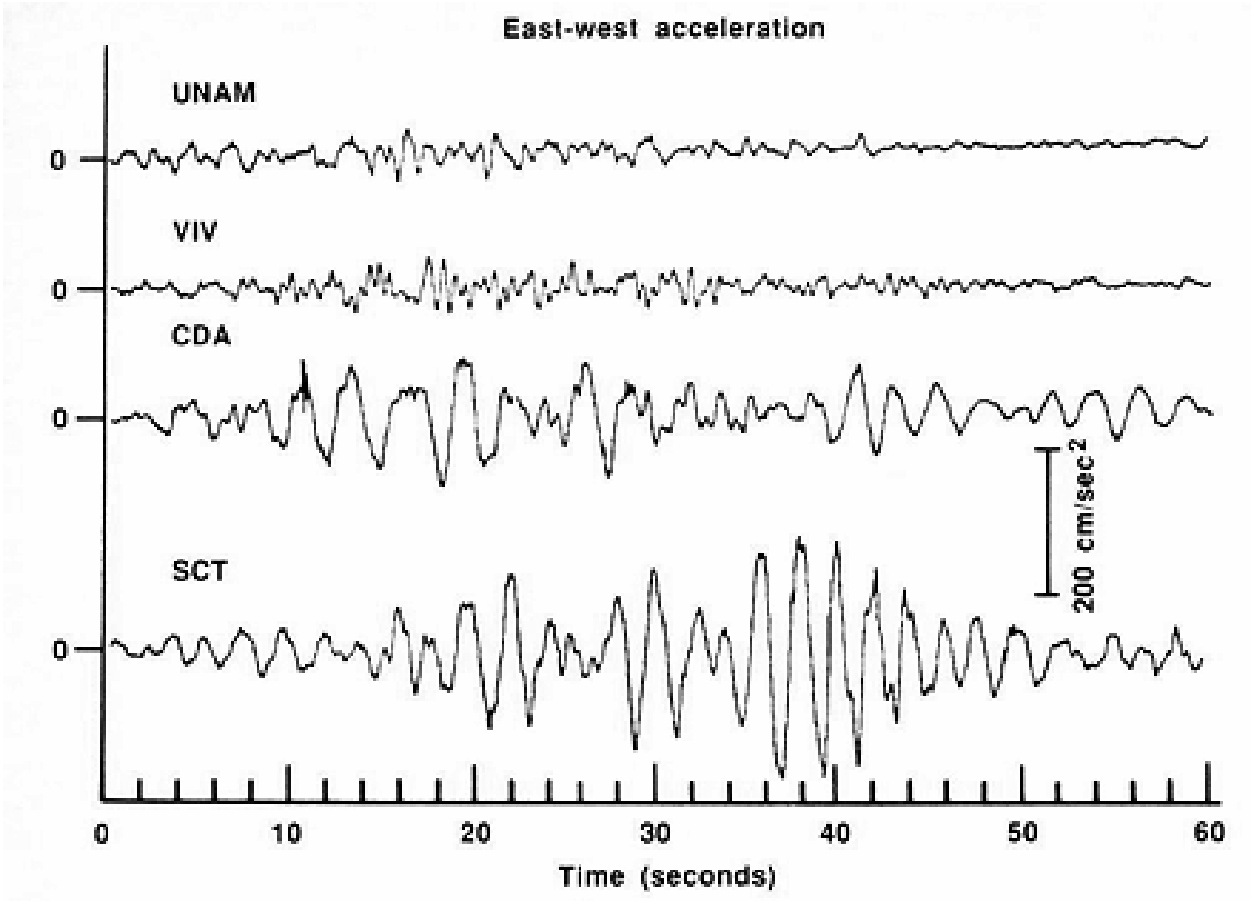
Site Response:
1985 Michoacan, Mexico Earthquake



Mexico City

- 350 km from earthquake
- 9000 deaths
- collapse of 371 high rise structures, especially 10-14 story buildings

Strong-motion Records from Mexico City

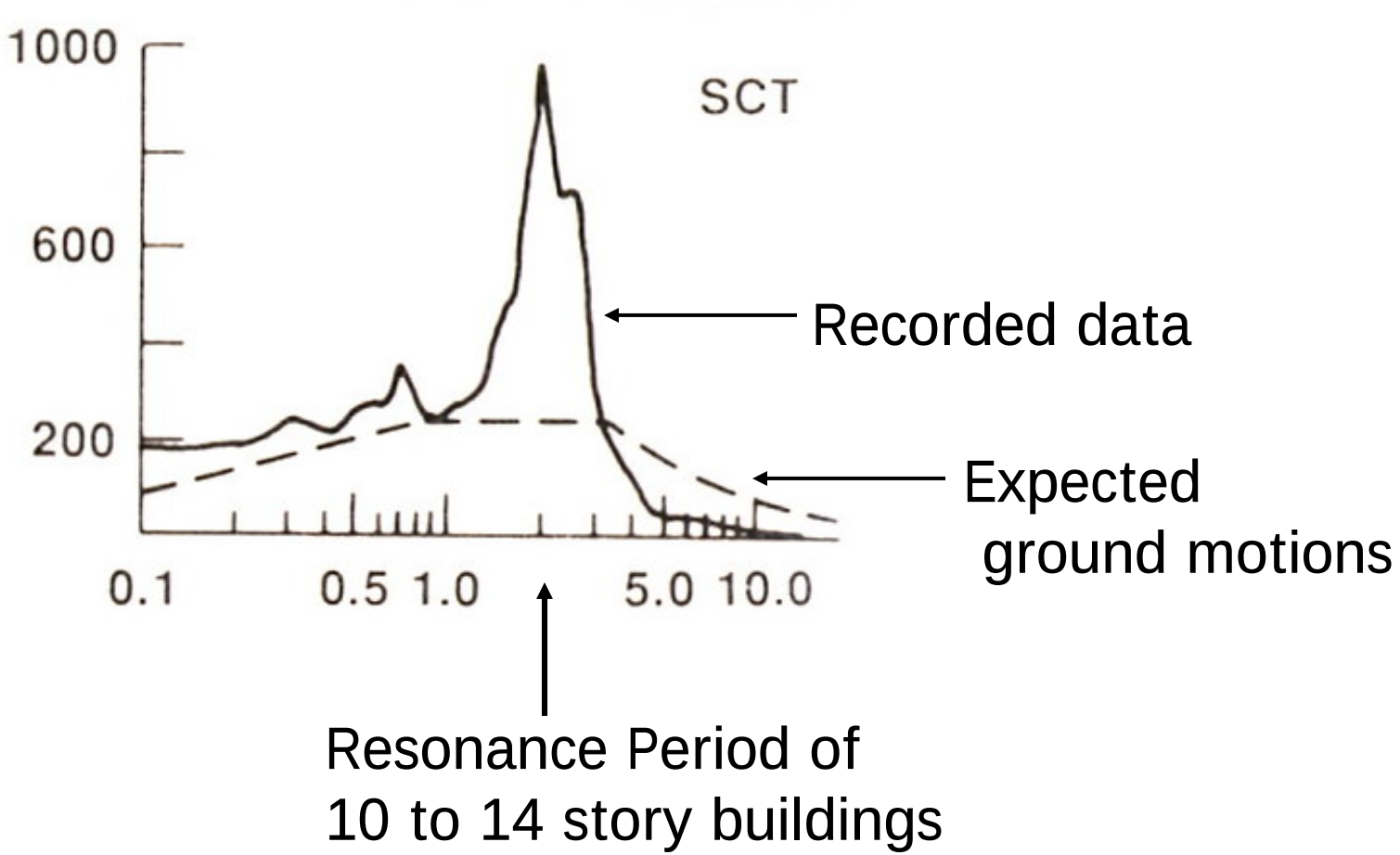


hard rock hills

old lake bed

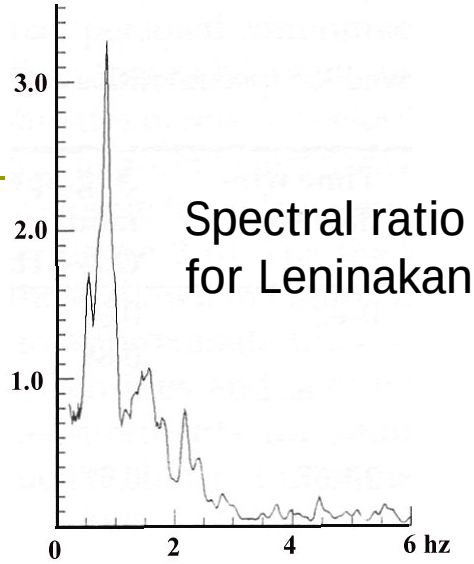
Anderson et al., 1986

Mexico City Acceleration Response Spectrum



1988 Spitak, Armenia Earthquake

Most pre-cast frame buildings in Leninakan and Kirovakan were 9-story Soviet Building Type 111.



Borcherdt et al., 1989

- 95% (127/133) of pre-cast frame buildings in Leninakan were severely damaged or collapsed.
- 0% (0/108) in Kirovakan

Wyllie and Filson, 1989

Other Damaging Effects from Earthquakes

- Tsunamis
- Fires
- Ground Deformations
- Landslides
- Liquefaction

Landslides

Large landslide from the 2005 Pakistan earthquake
http://www.eeri.org/lfe/clearinghouse/kashmir/reports/kashmir_eeri_1st_report.pdf

Landslides

A mother and 2 children rode the landslide for over 1 km in this house

Large landslide from the 1999 Chi-Chi Taiwan earthquake

Fires

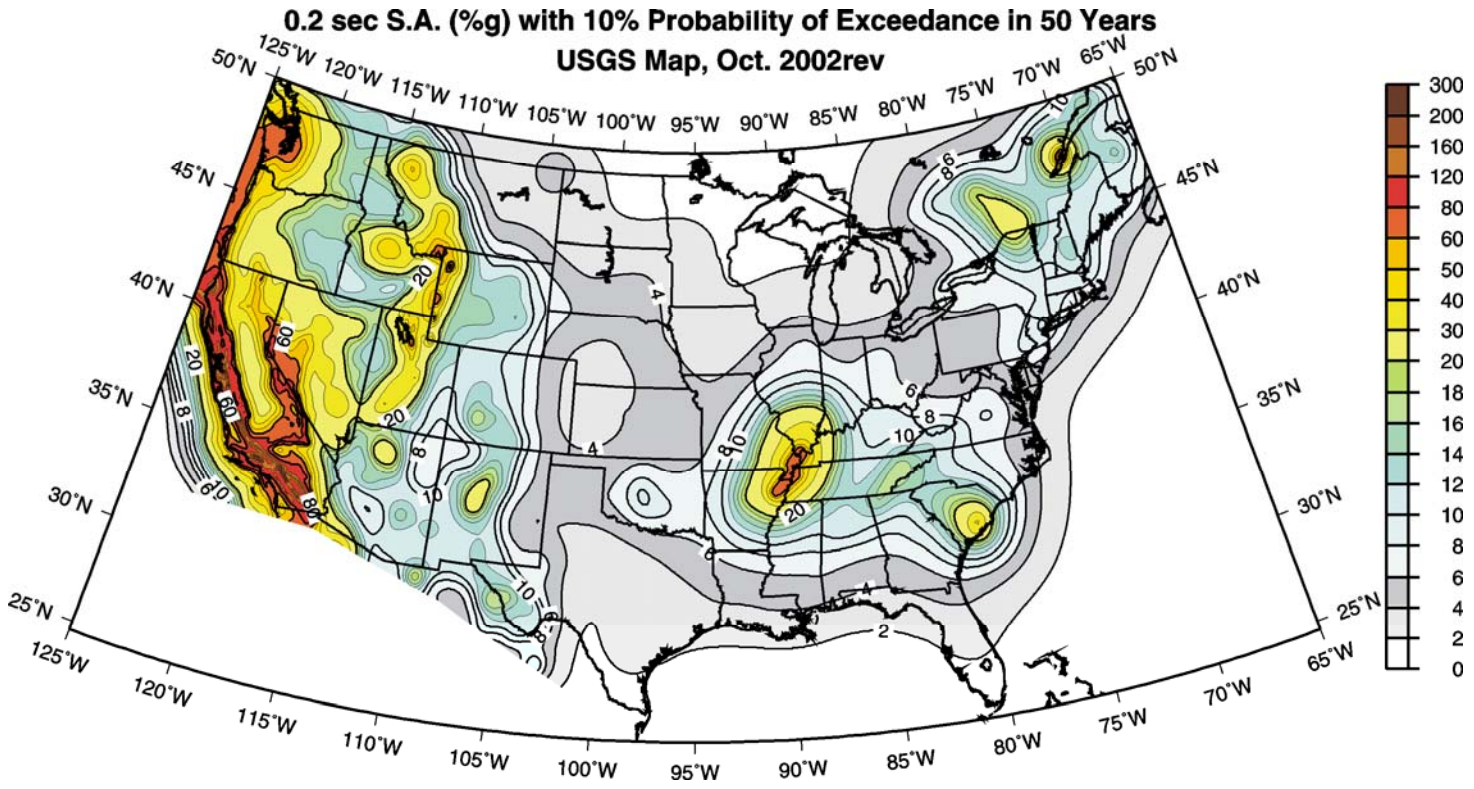
Large fires following the 1995 Kobe earthquake

Liquefaction

Liquefaction causing toppled buildings in the1964 Niigata earthquake

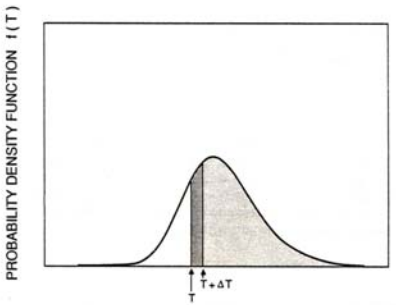
Hazard maps

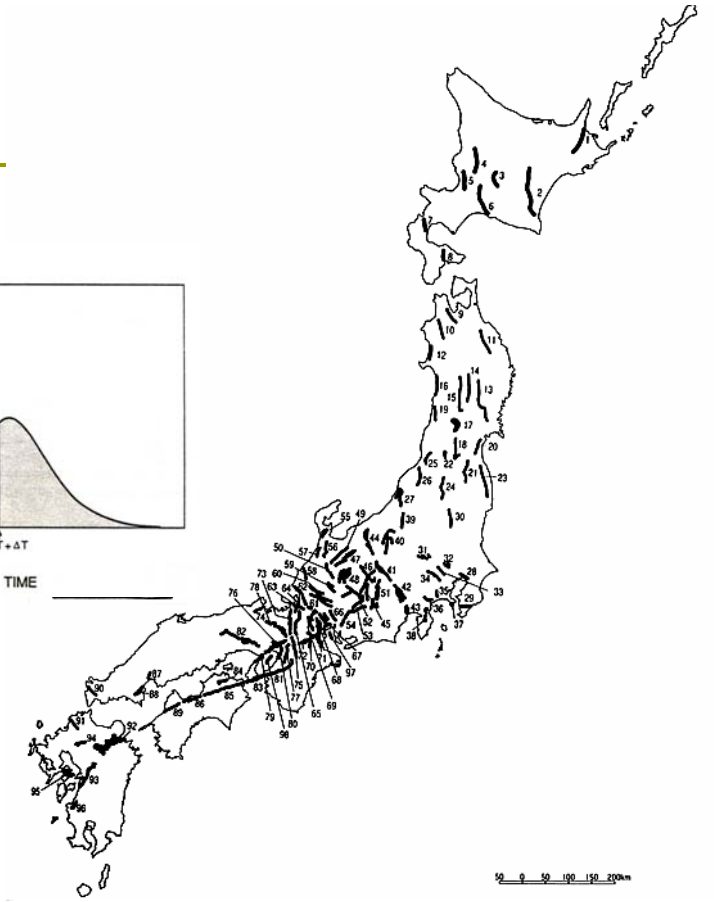
- Show the distribution of shaking that has a certain probability of occurring



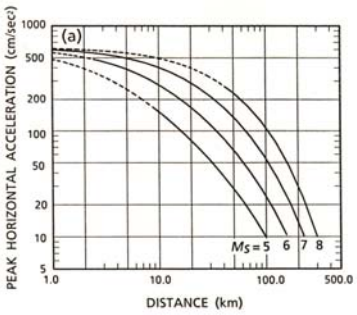
Probabilistic Hazard Maps

Probabilistic Earthquake Occurrence



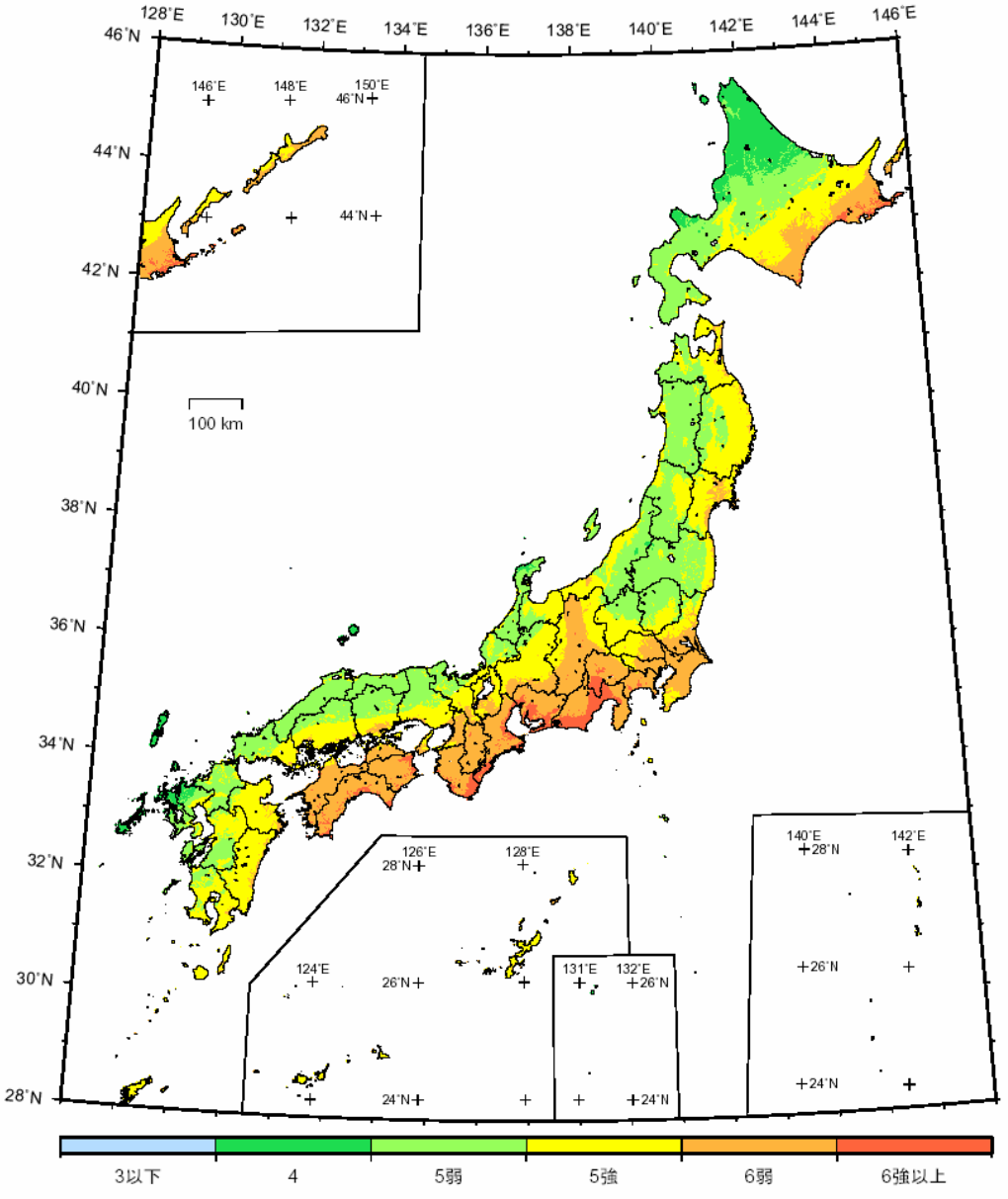


Attenuation Relations



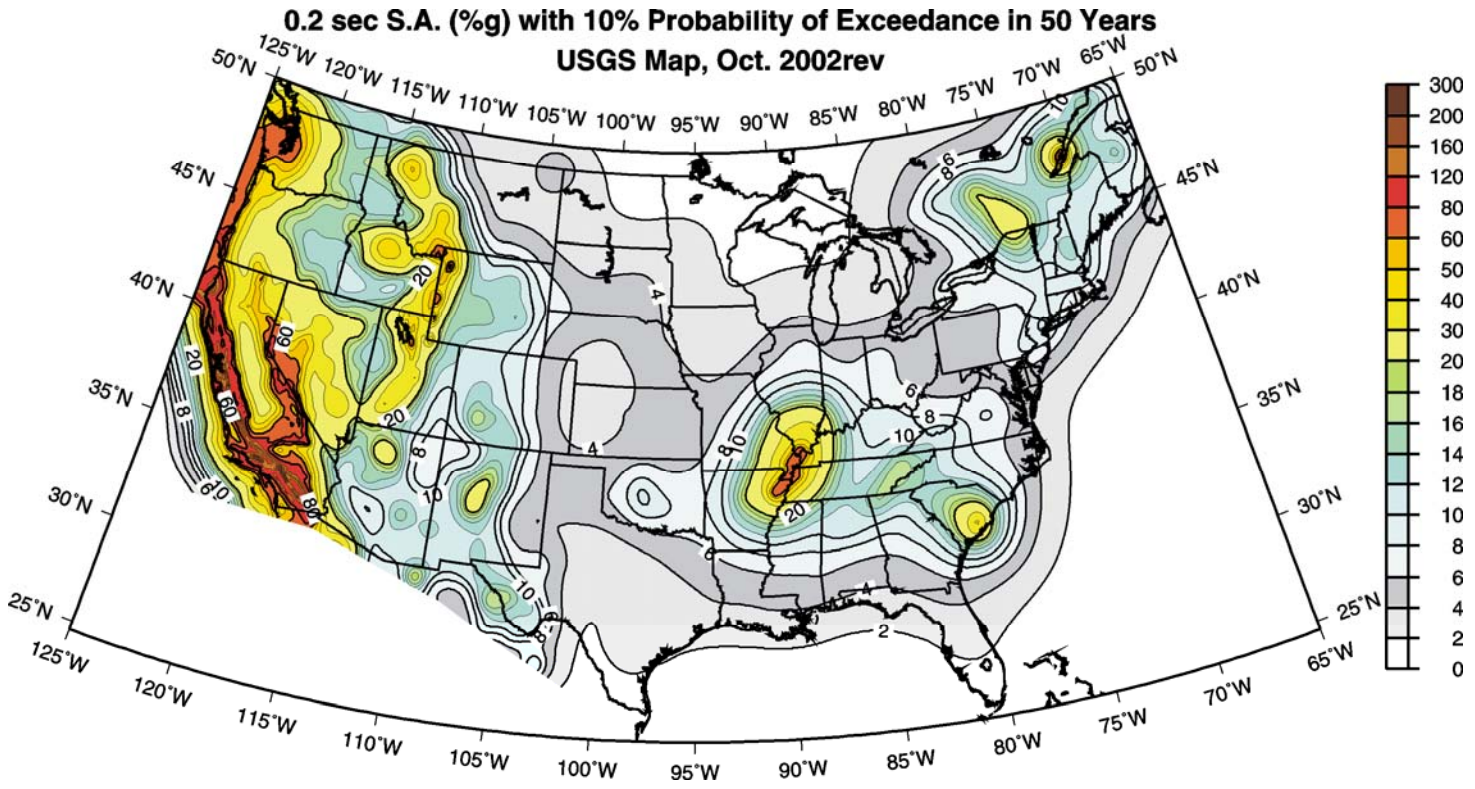
Japan National Seismic Hazard Maps

Probabilty of exceedence
10% in 50 years



Hazard maps

- Map peak ground acceleration (PGA) or spectral acceleration for given frequencies.



Conclusions

- Most severe (high-frequency) shaking is close to the fault, so often smaller earthquakes near populated areas cause huge damage.

- To evaluate the shaking damage, we need information for the amplitudes and frequencies of strong ground motions as a function of distance (attenuation relations).

- Local site effects can be very important (Mexico City).

- Other damaging effects are due to Tsunamis, Fires, Landslides, Ground Deformations, Liquefaction