Development of U. S. National Seismic Hazard Maps and Implementation in the International Building Code

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http://earthquake.usgs.gov/hazmaps/
Seismic hazard analysis has two model components:

(1) Earthquake-Rupture Forecast (ERF)

Probability of all possible fault-rupture events ($M \geq \sim 5$) for region & time span

(2) Intensity-Measure Relationship (IMR)

Gives $\text{Prob}(\text{IMT} \geq \text{IML})$ for a given site and fault-rupture event

### Attenuation Relationships

- **(traditional)**
  - (no physics)

### Full-Waveform Modeling

- **(developmental)**
  - (more physics)
To calculate the hazard curve (annual rate of exceeding ground motions) we:

1. Determine magnitude, and distance, and rate of earthquake

2. Calculate ground motion distribution for that m and d.

3. Calculate the product:
   
   annual rate of earthquake * probability that earthquake will exceed certain ground motion level

4. Sum these rates for all earthquakes in the model at each ground motion to get a hazard curve. This curve shows the rate of exceedance of each ground motion.
What is the annual rate that ground motion will exceed 0.05 g pga given M 6.5 earthquake occurs?

Almost all earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.05g

0.02 (ann. rate of M 6.5) * 0.99 (probability of exceeding 0.05) = 0.02

Ground motion: 0.05g
Rate of 0.05 g exceedance: 0.02
What is the annual rate that ground motion will exceed 0.4 g pga given M 6.5 earthquake occurs?

Only 10% of earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.4g

Rate of exceeding 0.4 g:
0.02 (ann. rate of M 6.5) * 0.1 (probability of exceeding 0.2) = 0.002

Ground motion: 0.05g 0.4g
Rate of 0.4 g exceedance: 0.02 0.002
Ground motion: 0.05g 0.4g
Rate of Ground motion exceedance: 0.02 0.002

HAZARD CURVE

10% probability of exceedance in 50 years

PGA
DATA FOR DEVELOPING SEISMIC SOURCES

EARTHQUAKES

GEODETIC DATA

QUATERNARY FAULTS

Synthetic Aperture Radar Techniques
Paleo-tsunami studies
Paleo-seismology studies
From fault data we can estimate magnitude from potential Rupture area and recurrence from slip rate or paleoseismic data.
USGS Magnitude-frequency model

Parameters

- Slip rate
- Characteristic or maximum magnitude
- Epistemic and aleatory uncertainty
- Ratio of Characteristic to Floating Rupture moment rate
- Minimum magnitude
- b-value

Moment rate $2 \times 10^{17}$/yr (2/3) split into three magnitudes
Moment rate $6.7 \times 10^{16}$/yr (1/3) used for floating ruptures (GR)
Moment rate $2 \times 10^{16}$/yr used for background earthquakes
Time-dependent hazard analysis

- Time dependent hazard considers the time since the last earthquake:
  - USGS has produced preliminary time-dependent maps for Alaska, California, Utah, and New Madrid region. These models are combinations of time-dependent and Poisson recurrence.
  - Currently, the USGS considers these maps as research products.
  - These products will be posted at our website.
  - For 2007 building codes the USGS will continue to use the Poisson maps.
  - The largest contribution of uncertainty in the 2002 report was due to the recurrence model used.
Time-dependent hazard maps

Probability for Cascadia Subduction Zone Interface Earthquake

Return Period

50-year probability

BPT a=0.2
BPT a=0.5
Lognormal a=0.5

Current Time
300/500 = 0.6

Time-independent (Poisson)
How do stress changes influence time-dependent earthquake probabilities?

- Time-dependent conditional probability with stress changes
Ground motion attenuation relations

M 7.5 comparison of attenuation relations

Distance (km)

pga (g)

Deep intraslab
Youngs interface unmodified
Youngs interface modified
Frankel soft rock
Sadigh rock
Sadigh rock M 6.5
Katch India (M 7.7) rock and soil
IRIS DMC rock (M 6.7-7.3)
IRIS DMC soil (M 6.7)
General Functional Form of Crustal Interplate Ground Motion

Attenuation relations

\[
\ln Y = f_1(M) + f_2(R) + f_3(F) + f_4(HW) + f_5(S) + f_6(D) + \varepsilon
\]

- \( f_1(M) \) = magnitude scaling term
- \( f_2(R) \) = distance scaling term
- \( f_3(F) \) = style-of-faulting term
- \( f_4(HW) \) = hanging-wall term
- \( f_5(S) \) = shallow site conditions term
- \( f_6(D) \) = shallow sediment and basin depth term
- \( \varepsilon \) = random error term
HAZARD PRODUCTS

2002 Hazard Maps - PGA-rock
2% probability of exceedance in 50-years

Purple - 0.3g and greater
Yellow - 0.1g and greater

http://eqhazmaps.usgs.gov
Figure 6. Comparison of predicted and historic seismicity rates for most of California.
How the Hazard Maps are used in the International Building Code
BUILDING SEISMIC SAFETY COUNCIL AND USGS WORKED TOGETHER IN AN ITERATIVE PROCESS

• The end result was a series of USGS probabilistic maps and a series of MCE ground motion maps prepared in response to BSSC requests.
MCE MAPS

• Maps of Maximum Considered Earthquake Ground Motion
• Based on probabilistic maps 2% probability of exceedance in 50 years, firm rock, 0.2s and 1.0 SA.
PERFORMANCE GOAL

- Minimize the risk to occupants,
- Increase the performance of higher occupancy structures,
- Improve the capability of essential structures to function, and
- Ensure a low likelihood of collapse for ground motions in excess of the design levels
PROBABILITIES CONSIDERED

- 10% P.E. in 50 years
- 5% P.E. in 50 years
- 2% P.E. in 50 years
SITE CONDITION OF PROBABILISTIC MAPS

B/C BOUNDARY - FIRM ROCK, shear wave velocity of 760 m/sec in the top 30 m (B/C Boundary)
PARAMETERS CONSIDERED

- PGA
- Spectral Accelerations:
  0.1, 0.2, 0.3, 0.5, 1.0, and 2.0 sec
WHY 2% P.E. IN 50 YEARS?
HAZARD CURVES FOR SELECTED CITIES

CITIES
- Los Angeles
- San Francisco
- Seattle
- Salt Lake City
- New York City
- New York City
- Charleston
- Memphis

0.2 sec Spectral Acceleration, %g

Annual Frequency of Exceedance

10 years
5 years
2 years
UNIFORM HAZARD RESPONSE SPECTRA
San Francisco, CA

PROBABILITY OF EXCEEDANCE
2% in 50 years
10% in 50 years

Spectral Response Acceleration, g

Period, sec

Spectral Response Acceleration, g
WHERE DID 2/3 COME FROM?

- **Fundamental Design Requirement to Prevent Collapse**
  
  \[ \text{Collapse Structural Resistance} \geq \text{Collapse Load} \]

- **Conservative estimate of Collapse Structural Resistance**
  \[ \text{Collapse Structural Resistance} \geq 1.5 \times \text{Code Structural Resistance} \]

- **Estimate of rare but possible ground motion for collapse conditions**
  \[ \text{Collapse Load} = 2\% \text{ PE in 50 yr Ground Motion} \]

- **Substituting into Design Requirement to Prevent Collapse**:
  
  \[ 1.5 \times \text{Code Structural Resistance} \geq 2\% \text{ PE in 50 yr Ground Motion} \]

  \[
  \text{Code Structural Resistance} \geq \frac{1}{1.5} \times (2\% \text{ PE in 50 yr GM}) \\
  \geq \frac{2}{3} \times (2\% \text{ PE in 50 yr GM})
  \]
Effect of Multiplying by 2/3

Normalized at 2% Probability of Exceedance in 50 Years

0.2 sec Spectral Acceleration

Annual Frequency of Exceedance

2% in 50 years
2/3 x 2% in 50 years
10% in 50 Years
5% in 50 Years
2% in 50 Years
In regions of high seismicity, such as coastal California, the hazard is typically controlled by large-magnitude events occurring on a limited number of relatively well defined fault systems.

Ground shaking calculated at a 2% in 50 years likelihood would be much larger than that which would be expected based on the characteristic magnitude of earthquakes on these active faults, because these faults can produce characteristic earthquakes every few hundred years.

General rule is applicable in all regions.
CONSTRAINS

• Near well-defined faults transition from probabilistic ground motion (GM) to deterministic GM

• Use the median GM times 1.5 (intended to approximate one sigma) as the deterministic GM for the maps
CONTRAINTS

- Use a plateau equivalent to current UBC Zone 4 design practice (x 1.5) as a transition from the probabilistic GM to the deterministic GM
- If the deterministic GM (x 1.5) exceeds the probabilistic GM, retain the probabilistic GM
U.S. Geological Survey
National Seismic Hazard Mapping Project
Based on:
2. USGS Open-File Report 96-532, 1996

Horizontal Spectral Response Acceleration (%g) for 0.2 Sec Period (5% of Critical Damping)
With 2% Probability of Exceedance in 50 Years
Firm Rock - 760 m/sec shear wave velocity

Scale - 1:45000000
Albers Equal-Area Conic Projection
Standard Parallels 29.5°N and 45.5°N
EXCEPTION FOR LOW-RISE
REGULAR-SHAPED BUILDINGS

- Regular structures five stories or less in height with $T \leq 0.5$ sec
- Seismic Design Category D, E, or F
- Design ground motions (Site Class B) need not exceed
  - $T = 0.2$ sec  $S_s = 1.5$ g  ($S_{DS} = 1.0$ g)
  - $T = 1.0$ sec  $S_1 = 0.6$ g  ($S_{D1} = 0.4$ g)
Design/Hazard curve tool

CD available, Internet version available about December, 2005
Maximum Considered Earthquake Ground Motion
Site Class B \( F_a = 1.00 \) \( F_v = 1.00 \)
Zip Code = 94111
Central Lat. = 37.798211 deg Central Long. = -122.398062 deg

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Time-history for dynamic analysis

DGML=Design Ground Motion Library
Process for 2007 Maps

- CA: June or Sept. 2006
- PacNW: Mar. 2006
- InterMtn West: May 2006
- CEUS: May 2006

Comments From Outside Community

Draft maps 1st round
On web

External Review Panel

Draft maps 2nd round
On web

External Review Panel

Comments From Outside Community

Final Maps Mid-2007


eqhazmaps.usgs.gov
Conclusions

- PSHA requires estimate of source magnitude, fault type, site conditions, distance
- International Building Codes based on 2% probability of exceedance in 50 years, firm rock, 0.2 and 1s Spectral Acceleration
- Web-tools available for use by engineers and other end-users