Workshop for the Update of the Pacific Northwest Portion of the National Seismic Hazard Maps

March 28-29, 2006

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USGS
From Science to Mitigation of Risk

Earth Science Information

Seismological: earthquake monitoring (catalogs), ground-motion studies (ANSS+ portable arrays)

Geological: paleoseismology (on-land, offshore), fault studies, geologic mapping

Geophysical: crustal deformation (GPS), seismic reflection and refraction, potential field studies, borehole studies

Quantitative Assessment Of Hazard

Probabilistic seismic hazard assessment: USGS national seismic hazard maps

Site-specific studies

Urban seismic hazard maps

Scenario ground motion maps

Mitigation of Earthquake Risk

Seismic provisions in building codes

Design standards for bridges

Land-use planning

Loss estimation

Earthquake insurance

Emergency management
The national seismic hazard maps are the basis of seismic design maps in the International Building Code (used in 47 states) and International Residential Code (used in 45 states). The maps have a variety of other applications, including:

- new AASHTO design guidelines for bridges
- EPA regulations on landfills
- Loss estimation using HAZUS
- Inputs used for determination of earthquake insurance premiums
- Inputs used for scenarios (e.g., emergency management)
Process for 2007 Maps

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

- National User-Needs Workshop
  - Nov. 2006

Draft maps 1st round
- On web
- External Review Panel

Comments From Outside Community

Draft maps 2nd round
- On web
- External Review Panel

Comments From Outside Community

Final Maps
- Mid-2007


eqhazmaps.usgs.gov
Hazard Methodology Example

Specify recurrence rates of earthquakes for each source that can affect site of interest.

Attenuation relations tell you median ground motions that each potential earthquake will produce at site, and variability.

Hazard curve: describes probability of having ground motions a certain intensity.

San Andreas fault high seismicity zone

Peak ground acceleration ($pga$)

Annual probability of exceeding $pga$

Distance

M 7.6
Line shows 2% Prob. of Exceedance in 50 year; Approx. 2500 yr return time.
This map is used in building codes in 45 states

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
• The national seismic hazard maps represent an average estimate of seismic hazard using alternative models of fault parameters, seismicity, and attenuation relations; they are not worst-case maps

• Website with hazard maps, lookup by lat-lon, input data, deaggregations, documentation: eqhazmaps.usgs.gov
PGA (%g) with 2% PE in 50 yr

62 events
PGA (%g) With 10% PE In 50 years
Did You Feel It? (5 Years)

National Hazard Map (10% PE in 50 years)

yellow= MMI 6

Slide composed by D. Wald
Direct Inputs to Hazard Maps

- Earthquake catalogs (instrumental and historic)
- Fault data (geologic slip rates, dates of past events from trenching, fault geometry, etc.)
- Effects of prehistoric earthquakes: paleoliquefaction (New Madrid, Charleston, Wabash Valley), subsidence and uplift (Cascadia, Seattle flt), turbidites (Cascadia)
- Geodetic data (NV-CA, Puget Lowland)
- Ground-motion attenuation relations
Components of Seismic Hazard Maps for Pacific Northwest

\[ 5.0 \leq M \leq 7.0 \]

Spatially-smoothed shallow seismicity \((h < 35 \text{ km})\)
- M4+ since 1963
- M5+ since 1930
- M6+ since 1850

Spatially-smoothed deeper seismicity \((h \geq 35 \text{ km})\)
- M4+ since 1963
- M5+ since 1940

Background source zones in eastern WA and OR

Puget Lowland areal zone seismicity rate from rate of
- M\(\geq 5.0 \) since 1928;
- Mmax 7.3 [also from GPS]

\[ M \geq 6.0 \]

Crustal faults:
- 0.5 wt characteristic
- 0.5 wt truncated Gutenberg-Richter with Mmin=6.5

For 6.0 \(\leq M \leq 6.5\)
- full weight characteristic

Cascadia subduction zone:
- 0.5 wt M8.3 eqs fill zone every 500 years
- 0.5 wt M9.0 eq every 500 years

Mmax for gridded seismicity adjusted so there is no overlap with faults
Some issues for workshop

• What faults should be added to the maps? Need info on slip rate or earthquake recurrence rate
• What changes should be made for faults already in maps?
• Should the treatment of GPS results be changed?
• What changes should be made in the frequency-magnitude distribution and rupture geometry for great Cascadia subduction zone (CSZ) earthquakes?
• How do we develop time-dependent models for CSZ? Also needed for California Earthquake Authority effort (USGS-SCEC)
• Should changes be made in treatment of deep, intraslab earthquakes?
• What new ground-motion attenuation relations should be used in the maps, such as the Next-Generation of Attenuation (NGA) relations being developed for PEER and new subduction-zone relations?
• Quantifying Uncertainties
• Discussion of engineering issues
Working Group on Washington-Oregon Faults for the National Seismic Hazard Maps

• Provide recommendations to NSHMP about faults to add to the hazard maps, parameters to use for the added faults, and fault parameters to revise.

• Ian Madin, Mark Molinari, Brian Sherrod, Tim Walsh
Crustal faults used in 2002 national maps
Characteristic earthquake completely ruptures entire length of mapped fault

Float rupture zones along fault
Moment rate on single fault
\[ \dot{M}_0 = \mu \dot{u} LW \]

Characteristic Model
rate of characteristic EQ = \[ \frac{\dot{M}_0}{10^{1.5M_{\text{max}} + 9.05}} \]

Gutenberg-Richter Model (rupture zones floated along fault)
\[ \dot{M}_0 = \sum_{6.5 \leq M \leq M_{\text{max}}} \left[ N (M - \delta M/2) - N (M + \delta M/2) \right] 10^{1.5M + 9.05} \]

\[ \dot{M}_0 = \sum_{6.5 \leq M \leq M_{\text{max}}} 10^{a - bM} 10^{1.5M + 9.05} \]

given \( \dot{M}_0, M_{\text{max}}, \) and \( b \), solve for \( a \)

Characteristic magnitude (\( M_{\text{max}} \) here) derived from surface fault length using Wells and Coppersmith 1994
Epistemic and Aleatory Uncertainty for Mchar

Logic tree
Branch 2

Logic tree
Branch 1

Logic Tree
Branch 3

Prob. Density

Moment Magnitude
From 2002 USGS National Seismic Hazard Map
PGA (\%g) with 2\% Prob. Of Exceedance in 50 Years
From 2002 USGS National Seismic Hazard Map

PGA (%g) with 2% Prob. Of Exceedance in 50 Years

Seattle flt

Ursalady Pt. flt

Strawberry Point flt

S. Whidbey Island flt

Devils Mtn flt

Seattle flt
Mean slip rates in mm/yr
3 traces of Seattle fault zone used in 2002 maps from Blakely et al. 2002
Seattle Fault
(treatment in 2002 maps)

• 0.5 wt for characteristic model (northern, frontal fault only) M7.2, 5000 yr recurrence
• 0.5 weight for truncated Gutenberg-Richter from M6.5-M7.2, M 6.5 1000 years, distributed over 3 traces, floating rupture zones along strike
• 45 degree dip, width=21 km, fault reaches surface
• M7.2 derived from Wells and Coppersmith 1994, given length of 71 km
• Used attenuation relations for thrust/reverse faulting
South Whidbey Island Fault (treatment in 1996 and 2002 maps)

- Used slip rate of 0.6 mm/yr (Johnson et al. 1996)
- 0.5 wt Mchar= 7.2 (fault length 63 km), recurrence time of 3100 yr
- 0.5 wt truncated GR, M6.5-7.2, M 6.5 recurrence time of 930 yr
- Fault dip of 60 degrees, width= 17.3 km
- Used attenuation relations for strike-slip faulting
Seattle flt
S. Whidbey Island flt
Strawberry Point flt
Utsalady Pt. flt
Devils Mtn flt
Seattle flt
S. Whidbey Island flt
Strawberry Point flt
Utsalady Pt. flt
Devils Mtn flt
• Change dip from 60° to 45° and seismogenic thickness from 15 km to 20 km

\[
\text{slip rate on fault plane} = \frac{\text{uplift rate}}{\sin (\text{dip})}
\]

\[
\text{fault width} = \frac{\text{seismogenic thickness}}{\sin (\text{dip})}
\]

\[
\text{rate of char. eqs} = \frac{\text{moment rate}}{\text{char. moment}} = \frac{\text{shear modulus} \times \text{length} \times \text{width} \times \text{slip rate}}{\text{char. moment}}
\]

This increases estimate of rate of char. earthquakes by factor of two, if the uplift rate and characteristic moment are unchanged
Results of using proposed SWIF parameters

- 0.6 mm/yr uplift rate, 45° dip, 20 km seism. thickness; 86 km length gives M7.3 (was M7.2): Tchar= 1700 yr, M 6.5 400 yr
- For 0.5 mm/yr strike slip component (derived assuming pure north-south convergence): Tchar= 2900 yr, M 6.5 680 yr
- For ½ wt. (pure reverse faulting), ½ wt (reverse + strike slip): Tchar= 1300 yr, M 6.5 310 yr [much shorter times than used for the Seattle fault]

- Note: trenching finds 2-5 earthquakes during Holocene (T= 2000-5000 yr), in limited sample
- Use reverse faulting term in attenuation relation for reverse faulting model
With revised SWIF parameters, including possible strike-slip component
Caveat

- By revising parameters (e.g., seismogenic thickness, adding assumed strike-slip component, dip) for one fault without changing others, one can derive an incorrect view of the relative hazard of that fault compared to other faults, given the geologic data on those faults.
Portland area faults
Faults used in 2002 maps
PGA (%g) with 2% PE in 50 years
PGA (%g) with 2% PE in 50 years

Mean slip rates in mm/yr
Portland Hills fault  
(treatment in 1996 and 2002 maps)

- 0.1 mm/yr vertical slip rate (from 1995 Geomatrix report for ODOT, cited as I.P. Madin, pers. comm., Pleistocene vertical uplift rate)
- 0.5 wt Char. M7.0, recurrence time 12,000 yr (50 km fault length)
- 0.5 wt truncated GR M6.5-7.0, M 6.5 every 5000 years
- 60 degree dip, 17.3 km width
- Used attenuation relations for reverse faulting
Eastern WA and OR
Map showing seismicity rates for background zones in WUS.
Mean slip rates in mm/yr

- Saddle Mtns 0.052
- Rattlesnake Wallula 0.043
- Hite 0.02
- Horse Heaven Hills 0.031
- Wallowa 0.14

Mill Creek Thrust 0.038
### Comparison of hazard estimates for Hanford (all values in g)

<table>
<thead>
<tr>
<th></th>
<th>Geomatrix 1996, stiff soil sites</th>
<th>USGS 2002 rock sites</th>
<th>USGS 2002 adjusted to stiff soil sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PGA 2000 yr</strong></td>
<td>0.21-0.26</td>
<td>0.20</td>
<td>0.28</td>
</tr>
<tr>
<td><strong>PGA 10,000 yr</strong></td>
<td>0.37-0.48</td>
<td>0.36</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>5 Hz S.A. 2000 yr</strong></td>
<td>0.46-0.58</td>
<td>0.41</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>5 Hz S.A. 10,000 yr</strong></td>
<td>0.87-1.1</td>
<td>0.84</td>
<td>0.97</td>
</tr>
<tr>
<td><strong>1 Hz S.A. 2000 year</strong></td>
<td>0.23-0.26</td>
<td>0.13</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>1 Hz S.A. 10,000 yr</strong></td>
<td>0.43-0.50</td>
<td>0.26</td>
<td>0.49</td>
</tr>
</tbody>
</table>
Using GPS info to get regional moment rate and seismicity rate
Puget Sound: Effect of including areal source zone accommodating 3 mm/yr N-S convergence measured by GPS

PGA (%g) with 2% P.E. in 50 Years
For shear on vertical faults

\[ \dot{M}_0 = \mu hL\dot{u} \]

convergence on 45 deg. dipping faults

\[ \dot{M}_0 \approx 2\mu hL\dot{u} \]
Assumptions used in converting convergence rate to earthquake moment rate

- Convergence rate of 3 mm/yr [faults in our model take up additional convergence]
- Seismogenic thickness of 20 km
- Mmax of 7.3
- b-value of 0.8
- East-west striking faults, dipping at 45°
- Convergence is entirely taken up by earthquake slip
- Used specific areal zone
- Found that derived a-value is consistent with observed rate of M 5.0 earthquakes since 1928 (13 events, 0.18 /yr).
- Change b-value to 0.9, M 5.0 rate increases by 30%
- Change Mmax to 7.4, M 5.0 rate decreases by 10%
Cascadia subduction zone

- Half weight M9.0 rupturing entire CSZ on average 500 years
- Half weight M8.3 earthquakes filling entire CSZ on average 500 years
Components for Frequency-magnitude distribution for Cascadia subduction zone

- M9’s rupturing whole zone
- Cascade of M8’s rupturing whole zone
- Isolated M8’s
- Other events M5-7 (e.g., Petrolia EQ)
Possible configurations for rupture zone of great Cascadia Earthquakes

From Flueck et al. (1997)
Probability for Cascadia Subduction Zone Interface Earthquake

from Petersen et al. (2002)
Cluster of M8’s rupturing whole CSZ

500 yr

| | | | | | | | | | time

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[USGS logo]
For tightly clustered M8.3’s: time-dependent probability of any segment is approximately the time-dependent probability for a M9

Since these are not independent earthquakes, you cannot just add the frequencies of exceeding a specified ground motion for each segment

First find 50-year probabilities of exceeding specified ground motions at each site for rupture of each segment: \( P_1, P_2, P_3, P_4 \).

Then find the probability of having one or more ground motion exceedances in 50 years at each site (union of \( P_1, P_2, P_3, P_4 \))

[after Toro and Silva, 2001]
probability of one or more exceedances of \( u_0 = \)
\[
P_1 + P_2 + P_3 + P_4 - P_1 P_2 - P_2 P_3 \\
-P_3 P_4 - P_1 P_3 - P_1 P_4 - P_2 P_4 \\
+P_1 P_2 P_3 + P_1 P_3 P_4 + P_1 P_2 P_4 + P_2 P_3 P_4 \\
-P_1 P_2 P_3 P_4
\]

where \( P_i \) is the probability of earthquake on segment \( i \) producing ground motion greater than \( u_0 \).
Time independent M8.3’s  Clustersed M8.3’s
Time independent M9

Time-dependent M9
Time independent

With time dependent M8 and M9 equal weight
Probability of segment rupture in next $\Delta t$ years:

$$n \left( \frac{1}{\int_{t_e}^{t_e+\Delta t} P_1(t) dt} + \frac{n-1}{\int_{t_e}^{\infty} P_1(t) dt} \right) + \frac{n}{\int_{t_e}^{\infty} P_1(t) dt}$$

For intra-cluster median of 1 year and inter-cluster median of 500 yr, get 14% probability for next 50 yr, for each segment (assume COV’s of 0.5)

For intra-cluster median of 20 years and inter-cluster median of 500 yr, get 9% probability for next 50 yr, for each segment (assume COV’s of 0.5)

$n$ is number of rupture segments, $t_e$ is time since last earthquake