1. Seismic Hazard Analysis (SHA)
   - Probabilistic
   - Deterministic
   - Site-Response Analysis

2. Soil-Foundation-Structure Interaction
   - Kinematic
   - Inertial
   - Input Motion
3. Selection and Scaling of Accelerograms

- Identification of Controlling Seismic Sources
- Accelerogram Selection Guidelines
- Accelerogram Modifications
Two SHA Approaches

1. General Procedure - Ch. 11 of ASCE 7-05

USGS MCE Maps & Site Coefficients

$S_S, S_1, T_L$  $F_a, F_v$

MCE Response Spectrum

$S_a = \frac{S_{M1}}{T}$

$S_a = \frac{S_{M1} \cdot T_L}{T^2}$
Two SHA Approaches (cont.)

2. Site-Specific (Preferred)
   - Probabilistic
   - Deterministic
Uniform Hazard Spectrum

- $S_a (0.2 \text{ sec})$
- $S_a (T)$
- $S_a (1.0 \text{ sec})$
- 2\% in 50-yr

T-sec: 0.2 to 1.0
# Cascadia Earthquake Sources

## Subduction zone earthquakes (1700)
- **Source:** Subduction Zone
- **Affected area:** W.WA, OR, CA
- **Max. Size:** M 9
- **Recurrence:** 500-600 yr

## Crustal earthquakes (900AD, 1872)
- **Source:** Deep Juan de Fuca plate
- **Affected area:** W.WA, OR,
- **Max. Size:** M 7+
- **Recurrence:** 30-50 yr

## Deep earthquakes (1949, 1965, 2001)
- **Source:** Crustal faults
- **Affected area:** WA, OR, CA
- **Max. Size:** M 7+
- **Recurrence:** Hundreds of yr?
Contribution to 2475-yr Ground Motion Hazard

Lavizzo Park, Seattle (47.6° N, 122.3° W)
2008 USGS PSHA

% Contribution

- Sea. flt.
- CSZ M>8

T = 0.2 sec

T = 1.0 sec

T = 3.0 sec

50

CSZ M>8

20

Sea. flt.
Basin Effects

- Amplify long period motions
- Increase duration
Seattle Basin

Ref.: Frankel et al. (2009)
Seattle Basin – EW Profile

Ref.: Pratt et al. (2003)
CSZ M 9.2 Scenario (Yang, 2009)
Simulated CSZ M 9.2 Rock & Soil (Basin) Ground Motions for Seattle

Ref.: Yang (2009)
Response Spectra for Seattle Fault & CSZ Scenarios

Vs30 = 275 m/s, Z1.0 = 1 km, Z2.5 = 6 km
CSZ M9.2 (Yang, 2009) - Geomean

T - sec
Sa - g

C

Map showing seismic zones and faults with Trench 8° and distances.

M 7.2
Z1.0 = 1 km
Z2.5 = 6 km
V_s30m/s = 275

C

PEER
Building Input Motion

400’ Tall Building
$T_1 = 5 \text{ sec}$

$V_s = 650 \text{ fps}$

$V_s = 1,600 \text{ fps}$

$V_{s}^{30} = 1,010 \text{ fps}$

Site Class C

Site Class D

$S_a$ vs $T$

15-20% difference (high seismic areas)
2002 & 2008 USGS $S_{DS}$ & $S_{DI}$, Site Class D, Seattle
Response Spectra for Seattle Fault & CSZ Scenarios

\[ \text{Vs30} = 275 \text{ m/s}, \ Z_{1.0} = 1 \text{ km}, \ Z_{2.5} = 6 \text{ km} \]

CSZ M9.2 (Yang, 2009) - Geomean

\[ C \]

5 km

Vs30m/s = 275

Z_{1.0} = 1 \text{ km}

Z_{2.5} = 6 \text{ km}
Accelerogram Selection and Scaling

- Identify controlling earthquakes
- Select representative accelerograms
- Modify accelerograms to match target $S_a$
Contribution to 2475-yr Ground Motion Hazard

Lavizzo Park, Seattle (47.6° N, 122.3° W)
2008 USGS PSHA

<table>
<thead>
<tr>
<th>% Contribution</th>
<th>T = 0.2 sec</th>
<th>T = 1.0 sec</th>
<th>T = 3.0 sec</th>
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</thead>
<tbody>
<tr>
<td>Sea. flt.</td>
<td>34</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>CSZ M&gt;8</td>
<td>8</td>
<td>33</td>
<td>50 CSZ M&gt;8</td>
</tr>
</tbody>
</table>
CMS – $\varepsilon$ Parameter

\[
\varepsilon = \frac{\ln \frac{Sa_{\text{target}}}{Sa_{50\text{th}}}}{\sigma_{\ln}}
\]

Site Specific

Sa

M_1 - R_1

T_i

M_1, R_1, $\varepsilon$ → select accelerograms

Baker and Cornell (WUS shallow crustal EQ’s)
Number of Accelerograms - N

- 7 (minimum)

- Maximum number
  - SE and GE decision
N depends on:

- # controlling earthquakes
- Median/mean or maximum structural response
- Target Sa
M \geq \sim 8, \text{ Long Duration Motion}

- San Andreas fault M \sim 8

- Cascadia and S. Alaska subduction zone M 9+
Past and Future Seattle Ground Motions

1949 Seattle M 7.1

1965 Seattle M 6.5

1968 Japan M 8.2

M 9+ Simulated

15 Inches

Minutes
Accelerogram Modification

- Constant Scaling
- Spectral Matching
Constant Scaling Method

Sa (g)

- **EQ-IV x 1.3**
- **1940 Imperial Valley, El Centro (2.00)**
- **1971 San Fernando, 8244 Orion Blvd. (1.74)**
- **1979 Imperial Valley, El Centro Diff Array (1.74)**
- **1989 Loma Prieta, Saratoga Aloha Ave. (1.88)**
- **1992 Landers, Yermo Fire Station (2.00)**
- **1994 Northridge, Sylmar Hospital (1.10)**
- **1999 Duzce, Turkey, Duzce Station (1.36)**
Spectral Matching

- Target
- Original
- Matched
Accelerogram Selection and Scaling Recommendations

- $N > 7$ (max $N$ limited by $\$$ and time)
- Use M-R deaggregations $\rightarrow$ controlling EQs
- CMS – use for multiple M-R $\rightarrow$ different $Sa$ shapes
- Scaling (constant or spectral matching) SE’s decision
- Simulated Accelerograms ($M \geq \sim 8$) + - long duration and basin effects
- - very limited no. qualified providers
- Peer Review – Extremely Important
Site Response Analysis

ASCE 7-05; Ch. 21
Site-Specific Ground Motion

SRA

and/or

PSHA/DSHA

Sa

T

Sa
Recommendations

- Don’t do SRA for stiff soil sites; account for local geology through GMPE (i.e., select stiff soil GMPE or appropriate site terms in GMPE)

Possible Exceptions

- Required in ASCE 7-05

\[ V_{s,\text{rock}} \gg V_{s,\text{soil}} \]
SRA (cont.)

Site Response Analysis

(may not be necessary)

Site Class F

Tall Embedded Building

input motion
SRA (cont.)

Site Response Analysis (necessary)

Tall Building on Piles

input motion
Soil-Foundation-Structure Interaction (SFSI)

(a) Complete System

(b) Model for service-level earthquake

(c) Model for maximum-considered earthquake

Rigid “Bathtub”

$U_g$ or $U_{FIM}$
SFSI for MCE

- Linear springs and dashpots model soil-foundation interaction
- Input motion same at all points along foundation
- See FEMA 356 and 440, ASCE 41-06, ATC 40, and other references for details