Spectral Damping Scaling Factors (DSF) for Subduction Interface & Intraslab Earthquakes (NGA-Subduction Project)

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Outline

- Background: DSF for NGA-West2
- Database for DSF-Subduction
- Median for DSF-Subduction
- Dependence on Duration, Magnitude, Distance, and Vs30
- Conclusions & Future Direction

(Note: November 2017 Version of NGA-Sub Database is used for this presentation.)
**Motivation:** GMPEs are traditionally developed for 5% damping. Real structures can have damping ratios other than 5%. Two examples:

<table>
<thead>
<tr>
<th>Stress Level</th>
<th>Type and Condition of Structure</th>
<th>Percentage of Critical Damping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working stress, no more than about ½ yield point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Vital piping</td>
<td>1 to 2</td>
<td></td>
</tr>
<tr>
<td>• Welded steel, prestressed concrete, well reinforced concrete (only slight cracking)</td>
<td>2 to 3</td>
<td></td>
</tr>
<tr>
<td>• Reinforced concrete with considerable cracking</td>
<td>3 to 5</td>
<td></td>
</tr>
<tr>
<td>• Bolted and/or riveted steel, wood structures with nailed or bolted joints</td>
<td>5 to 7</td>
<td></td>
</tr>
<tr>
<td>At or just below yield point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Vital piping</td>
<td>2 to 3</td>
<td></td>
</tr>
<tr>
<td>• Welded steel, prestressed concrete (without complete loss in prestress)</td>
<td>5 to 7</td>
<td></td>
</tr>
<tr>
<td>• Prestressed concrete with no prestress left</td>
<td>7 to 10</td>
<td></td>
</tr>
<tr>
<td>• Reinforced concrete</td>
<td>7 to 10</td>
<td></td>
</tr>
<tr>
<td>• Bolted and/or riveted steel, wood structures, with bolted joints</td>
<td>10 to 15</td>
<td></td>
</tr>
<tr>
<td>• Wood structures with nailed joints</td>
<td>15 to 20</td>
<td></td>
</tr>
</tbody>
</table>

PEER/ATC-72-1 (2010)

**2.4.4.1 Selection of Target Damping**

In linear-elastic response history analyses, using either modal response history or direct integration, the magnitude of damping is chosen to represent, in an approximate sense, the amount of energy dissipation at the expected deformation levels. At low deformation levels, prior to significant yielding or damage to structural components, damping values are typically in the range of 0.5% to 5% critical damping in the primary vibration modes. At higher deformation levels, damping values up to 20% of critical (or more).
**Goal:** Develop scaling factors to translate existing GMPEs for spectral ordinates at 5% damping to spectral ordinates at other damping ratios from 0.5 to 30%.

**Definition:**

\[
DSF = \frac{PSA(\beta)}{PSA(5\%)} = \frac{RotD50(\beta)}{RotD50(5\%)}
\]

**Model:**

\[
\ln(DSF) = \mu(\beta, T, \text{earthquake, site, } b) + \varepsilon; \quad \varepsilon \sim N(0, \sigma)
\]

- Distribution?
- Predictor Variables?
- Functional Form?
- Variability?
Over 8,000 records for crustal earthquakes in active tectonic regions & existing models dating all the way back to Newmark & Hall 1982

Parameters:

\[ \beta: \text{11 damping ratios (0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, and 30\%)} \]

\[ T: \text{21 NGA periods (0.01 – 10 s)} \]

\[ D: \text{duration (replaced by } M: \text{magnitude & } R: \text{distance)} \]

Site class (noninfluential)

NGA-West2 Median Model:

\[
\ln(DSF) = b_0 + b_1 \ln(\beta) + b_2(\ln(\beta))^2 \\
+ [b_3 + b_4 \ln(\beta) + b_5 (\ln(\beta))^2 ]M \\
+ [b_6 + b_7 \ln(\beta) + b_8 (\ln(\beta))^2 ]\ln(R_{rup} + 1) \\
+ \epsilon
\]

\((b_0, \ldots, b_8 \text{ are tabulated regression coefficients for all periods})\)
Over 8,000 records for crustal earthquakes in active tectonic regions & existing models dating all the way back to Newmark & Hall 1982

**Parameters:**

- $\beta$: 11 damping ratios (0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, and 30%)
- $T$: 21 NGA periods (0.01 – 10 s)
- $D$: duration (replaced by $M$: magnitude & $R$: distance)
- Site class (noninfluential)

**NGA-West2 Median Model:**

$$\ln(DSF) = b_0 + b_1 \ln(\beta) + b_2 (\ln(\beta))^2$$
$$+ [b_3 + b_4 \ln(\beta) + b_5 (\ln(\beta))^2] M$$
$$+ [b_6 + b_7 \ln(\beta) + b_8 (\ln(\beta))^2] \ln(R_{rup} + 1)$$
$$+ \epsilon$$

($b_0, \ldots, b_8$ are tabulated regression coefficients for all periods)
Background: NGA-West2 Model

- Over 8,000 records for crustal earthquakes in active tectonic regions & existing models dating all the way back to Newmark & Hall 1982

- **Parameters:**
  - $\beta$: 11 damping ratios (0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, and 30%)
  - $T$: 21 NGA periods (0.01 – 10 s)
  - $D$: duration (replaced by $M$: magnitude & $R$: distance)
  - Site class (noninfluential)

- **NGA-West2 Standard Deviation Model:**

  \[
  \sigma_{\ln(DSF)} = \left| a_0 \ln \left( \frac{\beta}{5} \right) + a_1 \ln \left( \frac{\beta}{5} \right)^2 \right|
  \]

  ($a_0$ and $a_1$ are tabulated regression coefficients for all periods)
Selected records used in regression:

- $0 \leq R_{rup} < 50$ km
- $4.2 \leq M \leq 7.9$
- $0.25 \leq D_{5-75} \leq 59.32$ s
- $116 \leq V_{S30} \leq 2016$ m/s

→ 2,250 horizontal records

Model recommended for < 300 km

Regression for < 50 km
Database: Subduction Interface

NGA-Subduction Japan Interface

NGA-Subduction Taiwan Interface

NGA-Subduction Cascadia Interface

NGA-Subduction Alaska Interface

NGA-Subduction Central America Interface

NGA-Subduction South America Interface
Database: Subduction Interface

MR Bins:

- Large M
- Semi-large M
- No data

10 ≤ $R_{rup}$ < 1000 km
4.5 ≤ M ≤ 9.5
Median: Subduction Interface

M 6-7

Japan:

Below 100 km

100-300 km

300-1000 km

Taiwan:
Median: Subduction Interface

M 6-7

Alaska: Not enough data

Cascadia: Not enough data
Median: Subduction Interface

M 6-7

Central America:

South America:

Below 100 km

100-300 km

300-1000 km
Database: Subduction Intraslab

10 \leq R_{rup} < 1000 \text{ km}
3.5 \leq M \leq 8.5

MR Bins:

- 100km
- 300km
- No small M data

NGA-Subduction Japan Intraslab
NGA-Subduction Taiwan Intraslab
NGA-Subduction Cascadia Intraslab
NGA-Subduction Alaska Intraslab
NGA-Subduction CentralAmerica Intraslab
NGA-Subduction SouthAmerica Intraslab
Median: Subduction Intraslab

M 6-7

Japan:

Taiwan:
Median: Subduction Intraslab

M 6-7

Alaska: Not enough data

Cascadia:
Median: Subduction Intraslab

M 6-7

Central America:

Below 100 km

100-300 km

300-1000 km

South America:

Not enough data
Dependence on Duration

NGA-West2 Crustal Earthquakes:
Figures are for data w/ R<50km

NGA-Subduction Interface Earthquakes (Japan):

- Y-axis is the same scale.
- X-axis is not the same scale. Subduction has longer durations (larger M and longer R).

→ Dependence on Duration is very similar!
Dependence on Duration

NGA-West2 Crustal Earthquakes:
Figures are for data with R<50km

NGA-Subduction Intraslab Earthquakes (Japan):

Slightly more dependence than interface.
Dependence on Magnitude

NGA-West2 Crustal Earthquakes:
Figures are for data w/ R<50km

NGA-Subduction Interface Earthquakes (Japan):

Y-axis is the same scale.
X-axis is not the same scale. Subduction has larger M.
→ Not as much dependence on M! (M more influential at longer T, no trend at 0.2s, but significant trend at 7.5s)
Dependence on Magnitude

NGA-West2 Crustal Earthquakes:
Figures are for data with R<50km

NGA-Subduction Intraslab Earthquakes (Japan):

Interaslab more similar to Crustal than Interface.
Dependence on Distance

**NGA-West2 Crustal Earthquakes:**
Figures are for data w/ \( R<50 \text{km} \)

**NGA-Subduction Interface Earthquakes (Japan):**

X-axis is not the same scale. Subduction has much longer \( R \).
More obvious trends at 0.2s (reverse) and 7.5s.
→ Distance could be more important than \( M \) for subduction, but still similar trends!
Dependence on Distance

NGA-West2 Crustal Earthquakes:
Figures are for data w/ R<50km

NGA-Subduction Intraslab Earthquakes (Japan):

Slightly more dependence than interface.
Dependence on Site Parameters (Vs30)

Interface Earthquakes (Japan):

Intraslab Earthquakes (Japan):

Residuals of a preliminary model without site parameters. 
→ May need to include Vs30 as a parameters at short periods!
Dependence on Site Parameters (basin depth)

Interface Earthquakes (Japan):

Intraslab Earthquakes (Japan):

Residuals of a preliminary model without site parameters.
→ May need to include Vs30 as a parameters at short periods!
Conclusions

- NGA-Sub GMPEs will be developed for a 5% damping ratio
- We will develop a DSF-Sub model that can adjust GMPEs for damping ratios 0.5% to 30%
- DSF-Sub shows more dependence on T, compared to NGA-West2 events (except Taiwan):
  - At short distance (<100km), long T DSF very different from NGA-West2
  - At mid distance (100 to 300km) not too different
  - At long distance (>300km), short T DSF very different from NGA-West2
  - Intraslab closer to NGA-W2 than Interface (could be due to different frequency content)
- Dependence on duration, magnitude, and distance are very similar to NGA-West2. Intraslab closer to NGA-W2 than Interface. Differences seem to be due to the larger M and longer R of data.
- Overall, DSF-Sub is similar enough to NGA-West2 to retain the same functional form
- Coefficients need to be updated using the latest NGA-Sub database
- May consider adding Vs30 as a parameter
The proposed model is plotted for all 11 damping ratios from 0.5 to 30%.
(0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, 30)

Newmark and Hall (1982) is plotted for
$\beta = 0.5, 1, 2, 3, 5, 7, 10, 15, 20\%$. It is applicable to $T = 0.125 - 10\text{s}$, and
is not a function of $M$ or $R_{\text{rup}}$. 