Performance-Based Probabilistic Seismic Slope Displacement Procedure

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Ref: Macedo et al. (2018) EQ Spectra J.

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Seismic Slope Displacement ($D$)

What is the expected seismic slope displacement at a specified return period?
Bray, Macedo & Travasarou (2018) Subduction Zone EQs

1. SLOPE MODEL
   nonlinear soil response
   fully coupled deformable stick-slip stiffness ($T_s$) & strength ($k_y$)
   13 $k_y$ values & 10 $T_s$ values

2. EARTHQUAKE DATABASE
   810 two-component records
   27 subduction interface EQs
   Over 490,000 analyses

   OPTIMAL INTENSITY MEASURES:
   $S_a(1.5 T_s)$ & $M_w$ of outcropping motion below slide

3. VALIDATION
   12 case histories
Approaches for Estimating $D$

**Deterministic**
- Estimate $S_a$ based on governing $M$ & $R$ at an $\varepsilon$
- Estimate $D$ based on $S_a$, $M$, $k_y$, & $T_s$

**Pseudo-Probabilistic**
- Compute $S_a$ hazard curve considering all $M$, $R$ & $\varepsilon$
- Estimate $D$ based on $S_a$, $M$, $k_y$, & $T_s$ at selected return period

**Performance-Based Probabilistic**
- Compute $S_a$ hazard curve considering all $M$, $R$ & $\varepsilon$
- Convolve $S_a$ hazard with displacement model using all $k_y$ & $T_s$
- Estimate $D$ at selected return period

Macedo et al. (2018) *EQ Spectra J.*
Although same $S_a$ value at 475 yr return period, slope displacement hazard differs due to different shapes of hazard curves.

USE SEISMIC SLOPE DISPLACEMENT HAZARD CURVE.
Performance-Based Probabilistic Approach

\[ D = f \left( k_y, S_a, T_s, M_w \right) \]

- Include variability of \( S_a \) & \( D \)
- Include variability of \( k_y \) & \( T_s \)

Mean Seismic Slope Displacement Hazard Curve
Capture Epistemic Uncertainty

\[ \lambda_d = \int_{T_s} \int_{k_y} \int_{M} \int_{0}^{\infty} P(D > d | S_a, M, k_y, T_s) P(M | S_a) (\Delta \lambda(S_a)) f(T_s) dS_a dk_y dT_s \]

Logic Trees also for: \( k_y, T_s, \) & models

Macedo et al. (2018)
Contributions of Different Tectonic Settings

Macedo et al. (2018)
ILLUSTRATIVE CASES

- Case YB: $k_y = 0.1$ & $T_s = 0.66$ s
  San Francisco Bay, CA

- Case SL: $k_y = 0.1$ & $T_s = 0.33$ s
  Salt Lake, Utah

- Case S1: $k_y = 0.1$ & $T_s = 0.33$ s
  Seattle, Washington

- Case S2: $k_y = 0.1$ & $T_s = 0.66$ s
  Seattle, Washington
Influence of Magnitude Dependence (YB case)

Results are insensitive to choice of M from PSHA
Comparison of Variability due to $k_Y$ & $T_s$ (YB case)
### Comparison of Approaches

<table>
<thead>
<tr>
<th>Site</th>
<th>$1.5 T_s$</th>
<th>Spectral Accel. ($g$)</th>
<th>Pseudo-Prob. D (cm)</th>
<th>Perf.-Based D (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(s)</td>
<td>475 years</td>
<td>2475 years</td>
<td>475 Years</td>
</tr>
<tr>
<td>YB</td>
<td>1.0</td>
<td>0.33</td>
<td>0.58</td>
<td>15</td>
</tr>
<tr>
<td>SL</td>
<td>0.5</td>
<td>0.30</td>
<td>1.10</td>
<td>6</td>
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<tr>
<td>S1</td>
<td>0.5</td>
<td>0.47</td>
<td>1.03</td>
<td>25</td>
</tr>
<tr>
<td>S2</td>
<td>1.0</td>
<td>0.25</td>
<td>0.60</td>
<td>11</td>
</tr>
</tbody>
</table>

Difference depends on tectonic setting and hazard level
Pseudostatic Seismic Coefficient \((k)\)

Iterate to find value of \(k\) with desired \(D_a\) (allowable displacement) and \(T_r\) (return period)

\(D_a = 20\text{cm}\)
\(T_r = 475\text{yr}\)
Comparison of Probabilistically based $k$ values (YB & SL cases) 
($D_a = 15$ cm & $T_r = 475$ & 2475 yrs)
CONCLUSIONS

▪ Performance-based probabilistic seismic slope displacement procedures can better capture uncertainty in EQ shaking and slope properties

▪ Difference in performance-based probabilistic and pseudo-probabilistic approaches depends on tectonic setting and hazard level

▪ Performance-based probabilistic approach provides rational basis to select a hazard-compatible seismic coefficient for pseudostatic slope stability analysis