PBEE-2 simulation exercise

CVEN 5835-02
SPTPS: Nonlinear Structural Analysis;
Theory and Applications
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Today’s objectives

- Recap 5 stages of PBEE-2
- Repair costs
- Exercise
  - Define the asset
  - Hazard analysis
  - Structural analysis
  - Damage analysis
  - Loss analysis
Recap PEER-style PBEE

Rupture: $M$, mech

Building

Site, $V_s_{30}$

Fault

$A$: location & design

Hazard analysis

$G(IM)$: intensity meas.

EDP: engineering demand param.

Damage analysis

$DM$: damage measure

Loss analysis

$DV$: decision variable

Decision making $D$ OK?

Porter 2006
Repair costs

- Component & damage state \(\rightarrow\) repair effort
- Construction cost estimators judge the unit repair cost for each component & damage state
- They consider economies of scale, uncertain cost
- An example:

Component: D3031.011b, "Chiller - Capacity: 100 to <350 Ton - Unanchored equipment that is anchored or if vibration isolated has seismic snubbers - Equipment fragility only"

Damage state: "Damaged, inoperative"

Repair effort: "Repair chiller and attached piping."
Exercise

- Given: A 20x20x20-ft 1-story woodframe structure built this year next to the Caltech cogen plant, with 7/8-in stucco over 7/16-in oriented strandboard (OSB), a steel door, no windows, a mission-style ceramic tile roof over OSB roof sheathing, no interior finishes, housing two 200-ton chillers hard-mounted on a concrete slab on grade. Construction cost = $350,000.

- Required: repair cost with 10% exceedance probability given shaking with 1/475-yr mean recurrence frequency
1. Hazard analysis, location

[Map of California Institute of Technology with coordinates 34.134331N, -118.127549E]
Site class w/o soil boring


34.1343±0.01N, -118.1275±0.01E
Site class w/o soil boring

- Site class $\approx C$
- $Vs30 \approx 425$ m/sec
- Accuracy similar to Wills et al. (2000)
- A nearby soil boring would be preferred
Hazard deaggregation

http://eqint.cr.usgs.gov/deaggint/2008/

2008 Interactive Deaggregations (Beta)

This is a preliminary version of the 2008 NSHMP PSHA Interactive Deaggregation web site. In this initial release, the 2008 update source and attenuation models of the NSHMP (Peterson and others, 2008) are used with just one exception. For the New Madrid Seismic Zone (NMSZ), the deaggregation source model is set up for the "unclustered" event branches only. These unclustered New Madrid sources are given full weight (50% weight to the 500 year mean recurrence models, 10% weight to the 1000-year mean recurrence models) whereas in the 2008 NSHMP PSHA they are only given 50% weight. Clustered-source models receive the other 50% weight in 2008 NSHMP PSHA. This is a temporary difference. The interactive deaggregation will include the NMSZ clustered-source models when a few software checkups are completed.

Seismic-hazard deaggregations are available for the following spectral periods anywhere in the contiguous U.S.: 0.0 s (PGA), 0.1 s, 0.2 s, 0.3 s, 0.6 s, 1.0 s, 1.9 s, and 2.0 s. This is the same set of periods that has been available at the USGS interactive deaggregation web sites since 1998 (for sites in the contiguous United States).

In the western US, long-period seismic-hazard deaggregations at 3.0 s, 4.0 s, and 5.0 s are also available at this web site. More...
Hazard deaggregation

R = 5 km
M = 6.6
$\epsilon = 0.3$
Ground-motion time histories

http://peer.berkeley.edu/peer_ground_motion_database
Ground-motion time histories
Ground-motion time histories
Ground-motion time histories
Ground-motion time histories
2. Structural analysis

\[ M = \text{roof} + \frac{1}{2} \text{ of wall mass} \]

Roof: \[ W/\text{sf} = 150 \text{ tiles/100 sf} \times 7\text{lb/tile} + 10 \text{ psf for roof, framing, etc.} = 20.5 \text{ psf} \]

Roof mass = \[ 450 \text{ sf} \times 20.5 \text{ psf} / 32.2 \text{ lbm/slug} = 287 \text{ slug} \]

\( \frac{1}{2} \text{ of wall mass: } 15 \text{ psf} \times 10 \text{ ft (high)} \times 80 \text{ ft (perimeter)} / 32.2 \text{ lbm/slug} = 373 \text{ slug} \]

\[ M = 287 \text{ slug} + 373 \text{ slug} = 660 \text{ slug} \]
Stucco sheathing springs from UCI COLA tests

Elastic properties

- $K_0 = 2.5 \text{ kip/in/lf wall}$

Wayne Stewart degrading stiffness parameter values

- $F_Y = \pm 0.168 \text{ kip/lf wall}$
- $r = 0.16$
- $F_U = 0.368 \text{ kip/lf wall}$
- $P_{TRI} = -0.064$
- $F_I = 0.25 \text{ FY, as did Wayne Stewart}$
- $P_{UNL} = 1.45$
- $\beta = 1.09$
- $\alpha = 0.38$

Wayne Stewart Degrading Hysteresis
Structural analysis

- Create springs for each wall, each material
  - E.g., each stucco wall: 20 ft x $K_0$, $F_Y$, & $F_U$
  - Repeat for OSB sheathing

- Create roof diaphragm element

- Perform nonlinear dynamic structural analyses, 1 for each ground-motion time history $i \in \{1, 2, \ldots 20\}$

- Response $R_i = [PTD_{Ei}, PTD_{Wi}, PTD_{Ni}, PTD_{Si}, PGA_i, PRA_i]^T$

- Response $R = [R_1; R_2; \ldots; R_{20}]$
Structural response $R =$

<table>
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<tr>
<th>Sim</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTDE, in/in</td>
<td>0.0028</td>
<td>0.0064</td>
<td>0.0040</td>
</tr>
<tr>
<td>PTDW, in/in</td>
<td>0.0028</td>
<td>0.0064</td>
<td>0.0040</td>
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<tr>
<td>PTDN, in/in</td>
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<td>0.0050</td>
<td>0.0013</td>
</tr>
<tr>
<td>PTDS, in/in</td>
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<td>0.0050</td>
<td>0.0013</td>
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<tr>
<td>PGA, g</td>
<td>0.52</td>
<td>0.55</td>
<td>0.28</td>
</tr>
<tr>
<td>PRA, g</td>
<td>1.48</td>
<td>2.76</td>
<td>1.12</td>
</tr>
</tbody>
</table>
Damage analysis

- Chillers: \( N_D = 1 \); damaged, inoperative; repair chiller and connections
  - \( \theta_1 = 0.72, \beta_1 = 0.2 \);
- Stucco on 7/16-in OSB: \( N_D = 2 \) sequential states
  - Fracture sheathing-framing connection; remove damaged stucco, renail, replace stucco:
    - \( \theta_1 = 0.005, \beta_1 = 0.3 \),
  - Tearout connectors on 2 edges; dem & replace:
    - \( \theta_2 = 0.011, \beta_2 = 0.5 \)
- Roof tile: \( N_D = 2 \) sequential states
  - Minor damage, tiles dislodged; reinstall tiles
    - \( \theta_1 = 1.8g, \beta_1 = 0.3 \)
  - Major portion (>10-20%) of tiles dislodged; replace
    - \( \theta_2 = 2.2g, \beta_2 = 0.3 \)
## Damage analysis

<table>
<thead>
<tr>
<th>Sim</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>u</td>
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</tbody>
</table>

### chiller 1

- **β**: 0.72
- **Pf**: 0.06
- **u**: 0.58
- **f**: 0

### chiller 2

- **β**: 0.21
- **Pf**: 0.06
- **u**: 0.58
- **f**: 0

### Wall E

- **β**: 0.72
- **Pf**: 0.03
- **u**: 0.58
- **f**: 0

### Wall W

- **β**: 0.21
- **Pf**: 0.03
- **u**: 0.33
- **f**: 0

### Wall N

- **β**: 0.72
- **Pf**: 0.08
- **u**: 0.91
- **f**: 0

### Wall S

- **β**: 0.21
- **Pf**: 0.08
- **u**: 0.34
- **f**: 0
Damage analysis: east wall, sim 1

- $R_1 = 0.0028 \text{ in/in}, \ \theta_1 = 0.005, \ \beta_1 = 0.3$
- $P[D \geq 1 | R=0.0028] = \Phi(ln(0.0028/0.005)/0.3) = 0.025$
- $P[D \geq 2 | R=0.0028] = \Phi(ln(0.0028/0.011)/0.5) = 0.003$
- $\text{rand()} = 0.58 > 0.025 \rightarrow \text{not failed DS1 or DS2}$
## Damage summary

<table>
<thead>
<tr>
<th>Sim</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>18.75</td>
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<tr>
<td>Walls 2</td>
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<tr>
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<tr>
<td>Roof 2</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
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</table>

(Units of 64 sf)

<table>
<thead>
<tr>
<th>Sim</th>
<th>1</th>
<th>2</th>
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</thead>
<tbody>
<tr>
<td>Walls 1</td>
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<td>18.75</td>
</tr>
<tr>
<td>Walls 2</td>
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<td>0</td>
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<tr>
<td>Chiller</td>
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<td>1</td>
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<tr>
<td>Roof 1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Roof 2</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

(Units of 100 sf)
Loss analysis: unit costs
i.e., cost to repair 1 “unit”

- Chillers: (as shown earlier)
- Stucco on 7/16-in OSB: \( N_D = 2 \) damage states
  - \( q_1 = \$131/64 \) sf; \( b_1 = 0.2 \); independent of qty
  - \( q_2 = \$742/64 \) sf, \( b_2 = 0.2 \); independent of qty
- Tile roof: \( N_D = 2 \) damage states
  - \( q_1 = \$80/100 \) sf; \( b_1 = 0.3 \); independent of qty
  - \( q_2 = \$800/100 \) sf; \( b_1 = 0.3 \); independent of qty
Loss analysis

\[ C / \text{unit} = q \cdot \exp\left( b \cdot \Phi^{-1} (u) \right) \]
\[ = \frac{131}{64 \text{sf}} \cdot \exp\left( 0.2 \cdot \Phi^{-1} (0.19) \right) \]
\[ = \frac{110}{64 \text{sf}} \]
\[ C = \text{Units} \cdot C / \text{unit} \]
\[ = 18.75 \cdot \$110 \]
\[ = \$2,058 \]

<table>
<thead>
<tr>
<th>Sim</th>
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<tbody>
<tr>
<td>q, $/64sf</td>
<td>$131</td>
<td>$131</td>
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<tr>
<td>b</td>
<td>0.2</td>
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<tr>
<td>rand()</td>
<td>0.73</td>
<td>0.19</td>
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<tr>
<td>Cost/64sf, $</td>
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<td>$110</td>
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<tr>
<td>Count 64 sf</td>
<td>0</td>
<td>18.75</td>
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<tr>
<td>Cost, $</td>
<td>$-</td>
<td>$2,058</td>
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</tbody>
</table>

<table>
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<tr>
<th>Sim</th>
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<tr>
<td>Cost/100sf</td>
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<td>$93</td>
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<tr>
<td>Cost</td>
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# Results

Total cost simulations sorted in increasing order

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<th>Rank</th>
<th>Cost</th>
<th>Percentile</th>
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<tr>
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<td>$ -</td>
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<td>$ -</td>
<td>12.5</td>
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<td>$ -</td>
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<td>6</td>
<td>$ 661</td>
<td>27.5</td>
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<td>18</td>
<td>$ 241,441</td>
<td>87.5</td>
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<td>19</td>
<td>$ 312,759</td>
<td>92.5</td>
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<tr>
<td>20</td>
<td>$ 348,710</td>
<td>97.5</td>
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</tbody>
</table>

90th percentile = \((241,441 + 313,759)/2\)

= $277,100

Call it ≈ $280,000
Results

NB: a lognormal fits the simulations badly; fails Lilliefors goodness-of-fit test.

\[ \hat{c} = 2,850; \sigma_{\ln c} = 5.2; \]  
\[ c_{90} = 2.1 \text{ million} \]
Thanks

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