A New Framework for Quantifying Ground Motion Intensity to Estimate Collapse Vulnerability of Buildings

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Motivation

• What makes a ground motion “strong”?  
  – Examine building response (damage, collapse, etc.)
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  – Examine building response (damage, collapse, etc.)

• Traditional ground motion intensity measures
  – Peak ground acceleration (PGA)
  – Peak ground velocity (PGV)
  – Peak ground displacement (PGD)
  – Spectral acceleration ($S_a$)
    • Epsilon ($\varepsilon$)

• Which ground intensity measure(s) best predict building collapse?
P-Δ Collapse

The 20-story building before the C5 ground motion hits. The displacement pulse will be toward the left.

At t=6 seconds, the ground is approaching its maximum horizontal displacement of 182 centimeters.

At t=7 seconds, the ground is returning to its original position, causing the building to “crack the whip.”

This flexure creates a ripple of breaking welds that travels up the building.

By t=16 seconds, the building is hopelessly overbalanced and on its way to oblivion.

- Triangles indicate failure of welded beam-column connections
PGD and PGV to Predict Collapse

- Olsen, Heaton, and Hall (2014, Spectra)
- 64,000 synthetic ground motions
- Classify building response as “repairable,” “not repairable,” or “collapse”
- (PGD, PGV) better predictor of collapse than $(S_a, \varepsilon)$
- Ground motion must have large enough PGD and PGV to induce collapse

- Repairable
- Not Repairable
- Collapse
Collapse due to Sinusoidal Ground Motion

- Song (2014, Ph.D. Thesis)
- Incremental dynamic analysis (IDA) to find minimum amplitude of sinusoidal motion needed for collapse
- “Easier” to induce collapse with long period motion
  - We can low-pass filter ground motions to extract long-period components
Filtered Acceleration and Base Shear

Ground acceleration

$S_a$ (2% damping)

Base shear (Elastic FEM)

Base shear (Elastoplastic FEM)

Filtered acceleration

Building strength $\pm 23\%g$

Force / Weight

Roof Displacement

Displacement

Time (s)

Elastic

Plastic yielding

Elastic
50 Records Scaled to Cause Collapse

U6P in Long-period Ground Motions

- Unfiltered, PGA
- 2nd-order filtered, PFA

50 Collapse Thresholds

- Approach to a constant

U6P Pushover

- Maximum Base Shear

Record

Roof Drift Ratio

Base Shear / Seismic Weight (g)
## Comparison to Traditional Ground Intensity Measures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Best</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGV</td>
<td></td>
<td></td>
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<tr>
<td>$S_a$</td>
<td></td>
<td></td>
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<tr>
<td>PGA</td>
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<tr>
<td>PGD</td>
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### Histogram of Parameters

![Histogram of Parameters](image)

- **Best**
  - $\sigma = 0.0839$
  - $\sigma = 0.1166$
  - $\sigma = 0.1440$
  - $\sigma = 0.1749$
  - $\sigma = 0.2498$

- **Worst**
  - $\pm 0.2$

(Number of records: 50 for best, 100 for worst)

(Logarithm of parameters, base 10)
Conclusions

• Together, PGD and PGV are better collapse predictors than $S_a$ and $\varepsilon$.
• Peak filtered acceleration (PFA) is a better collapse predictor than any single traditional ground intensity measure.

• **BIG IDEA:** Ground motions with large long-period components are most likely to cause P-\(\Delta\) collapse.
Next Project

• How far “beyond-the-code” are buildings designed in the US and in Japan?
  – How do typical existing buildings perform compared to theoretical “to-code” buildings?
    • Apply collapse prediction framework to “as-built” and “to-code” buildings
  • We will need designs of existing Japanese buildings
    – Compare collapse vulnerability of seismic codes and engineering practice in both countries
• Olsen, A. H., et al., 2014, “Characterizing ground motions that collapse steel, special moment-resisting frames or make them unrepairable,” Earthquake Spectra.