IDA Capacity Curves: The Need for Alternative Intensity Factors

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Presentation Outline:

1) Incremental-Dynamic-Analysis (IDA)
2) Evaluation study
   • Analytical model description
   • Ground motion data set
   • Typical response of steel-frame building to near-fault records
   • NTH analyses results: Common Seismic demand parameters
   • Correlation of IDA curves with observed response
   • Common intensity measures (IMs) and their critical evaluation
3) Alternative IM to account for system inelastic behavior
4) Conclusion
Comparison of recorded and computed response (a) at channel 2 (EW direction) at 6th storey level
Ground Motion Database

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<th>No.</th>
<th>Year</th>
<th>Earthquake</th>
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<th>Mech. *</th>
<th>Station</th>
<th>Component</th>
<th>Site Class</th>
<th>PGA (g)</th>
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<tr>
<td>(a) Far-Fault Recordings</td>
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<td>(b) Near Fault Recordings (Forward-Rupture Directivity)</td>
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Ten ordinary far-fault and ten near-fault records are used in IDA study.

Near-fault records are characterized by forward-directivity, and exhibit coherent-long period velocity pulses.

Pseudo-spectral acc. spectra and mean spectra of far-fault and near-fault records
Six-Story Building Response to Typical Near-Fault Ground Motions

Response dominated by higher modes

Response dominated by first mode
NTH Analysis Results:
Far-Fault and Near-Fault Records

- Largest demand concentrated at first and fifth story levels showing large interstory drift.
- While the dispersion is almost similar, near-fault records yielded larger demand.
Progressive change in interstory drift and story ductility demands during IDA analysis

- IDA curves show hardening being inconsistent with the observed inelastic response
Variation of base shear coefficient with increase in $S_a(T_{1,5\%})$

**Far-Fault Records**

**Near-Fault Records**
IDA curves plotted as a function of base shear coefficient

- Base shear coefficient during IDA analyses are well correlated with static pushover analysis
# Common Intensity Measures

<table>
<thead>
<tr>
<th>Intensity Measure</th>
<th>Unit</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>1 Peak ground acceleration</td>
<td>g</td>
<td>PGA</td>
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<tr>
<td>2 Peak ground velocity</td>
<td>cm/sec</td>
<td>PGV</td>
</tr>
<tr>
<td>3 First mode spectral acceleration</td>
<td>g</td>
<td>( PSA(T, \alpha) )</td>
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<tr>
<td>4 Root mean square acceleration</td>
<td>g</td>
<td>[ A_{rms} = \sqrt{\frac{1}{T_D} \int_0^T [u_g(t)]^2 dt} ]</td>
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<td>5 Cordova predictor</td>
<td>g</td>
<td>[ IM_{1eff} = S_a(T_1, \xi) \left[ \frac{S_a(cT_1, \xi)}{S_a(T_1, \xi)} \right]^{\alpha} ] ( c = 2; \alpha = 0.5 )</td>
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<tr>
<td>6 Effective peak acceleration</td>
<td>g</td>
<td>[ EPA = \frac{S_{a,avg}(T_1, \xi)}{2.5} ] ( 0.5 )</td>
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</table>

[ATC 3-06, 1978]
IM-1: IDA curves plotted against PGA

Far-Fault Records

Near-Fault Records
**IM-2: IDA curves plotted against PGV**

**Far-Fault Records**

- Graph 1: *Roof Drift Ratio* vs. PGV (cm/sec)
- Graph 2: *Interstory Drift Ratio* vs. PGV (cm/sec)
- Graph 3: *Story Ductility* vs. PGV (cm/sec)

**Near-Fault Records**

- Graph 4: *Roof Drift Ratio* vs. PGV (cm/sec)
- Graph 5: *Interstory Drift Ratio* vs. PGV (cm/sec)
- Graph 6: *Story Ductility* vs. PGV (cm/sec)
**IM-3: IDA curves plotted against $Sa(T_1, 5\%)$**

**Far-Fault Records**

**Near-Fault Records**
IM-4: IDA curves plotted against RMS-Acc.

Far-Fault Records

Near-Fault Records

\[ A_{rms} = \frac{1}{T_D} \int_0^D \left[ \ddot{u}_g(t) \right]^2 dt \]
**IM-5: IDA curves plotted against Cordova Predictor**

**Far-Fault Records**

**Near-Fault Records**

\[ IM_{\text{eff}} = \frac{S_a(T, \xi)}{S_a(T, \xi)} \odot, \alpha = 2, \alpha = 0.5 \]
IM-6: IDA curves plotted against EPA

Far-Fault Records

Near-Fault Records

$$EPA = \frac{S_{a,\text{avg}}(T_1, \xi)}{2.5}$$
IM-3: IDA curves plotted against $S_{a}(T_1, 5\%)$

Far-Fault Records

- Show hardening
- Pushover

Near-Fault Records

- Show softening
- Pushover

- Long period pulses contained in NF records dominantly triggered the first mode response
Progressive change in fundamental period ($T_1$) during inelastic response

In the inelastic range, the period of building deviates dramatically from its elastic counterpart.
An Alternative Intensity Measure, Accounting for Inelastic Response

An IM based on inelastic spectral acceleration is used to account for change in system attributes during inelastic response.

By using the global yield point approximated from static pushover, system ductility can be computed at any level of IDA.

With approximated ductility, secant period is obtained from ESDOF representation.

Inelastic spectrum is generated with known ductility.

IM based on inelastic spectral acceleration is obtained with known secant period.
IM Based on Inelastic Spectrum and ESDOF System Secant Period: Preliminary Results

Far-Fault Record

Desert Hot. Spr.

Near-Fault Record

Rinaldi Rec. Stn.
Conclusions

1) Evaluation of the most common IMs for six-story steel building showed that there exist significant dispersion and none of the IMs are well correlated to the inelastic system behavior.

2) There is therefore a need for alternative IM to be used in performance-based engineering.

3) The IM based on inelastic spectrum and ESDOF secant period seems was developed, and tested using a near-fault and far-fault records.

4) On the basis of preliminary results, IM utilizing inelastic spectral acceleration seems to be promising. A more comprehensive evaluation considering different seismic source characteristics and building models is currently underway.