The Financial Benefit of Earthquake Retrofitting in Different Hazard Environments

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Structural engineers believe (falsely) that the purpose of seismic strengthening is to upgrade the structure to maximum extent practical. The latter incorporate levels of conservatism and performance objectives which may not be appropriate for the use of existing structures due to economic limitations […] 

source R. Hamburger. (2012)
Limitations of Seismic Evaluation and Retrofitting Provisions

- Current US seismic provisions regarding older-buildings (ASCE-31, ASCE-41) are characterized by high conservatism
  - Deem a building deficient if single component fails
  - Lead to economically inefficient solutions

- ATC-78 Project Initiative offers a guideline to identify a subset of concrete buildings highly likely to collapse
  - Understand the relative importance of common deficiencies
  - Reduce conservatism in assessment and retrofit of older RC structures
  - Focused on the assessment of only the collapse risk for older RC structures

"killer building" Reduced benefit of seismic upgrading

![Graph showing probability of collapse for different building heights]
Towards Evaluating the Financial Benefits of Seismic Upgrading

Current Approach

- **Advantages**
  - State of the art seismic analysis
  - Can identify deficiencies that drive the non-satisfactory performance

- **Disadvantages**
  - Essentially deterministic
  - Structure specific (hard to generalize)
  - Iterative
  - Hard to optimize degree of seismic upgrading balancing cost and safety
Towards evaluating the financial benefits of seismic upgrading

Challenges:

- Can we establish a framework to quantify, on a preliminary basis, the financial benefits of seismic upgrading for different hazard environments?

- Similarly to ATC-78, can we identify a sweet spot in seismic upgrading after which marginal financial benefits are minimal?
A Framework to Quantify the Seismic Loss to a Single Structure

- Extends the PEER PBEE framework using the frequency-severity actuarial approach to estimate the loss probability distribution
- Allows estimation of a complete probability distribution (both aggregate and occurrence based) of earthquake losses (important for long time horizons)

Mathematical expression:

\[
P(D_k | S_{\alpha \alpha}) = \Phi \left( \frac{1}{\beta} \ln \left( \frac{(1 + \frac{S_{\alpha \alpha}}{\alpha_y} - 1) \times T_A / \lambda_k}{2} \right) \right)
\]

<table>
<thead>
<tr>
<th>Damage State</th>
<th>Damage Description</th>
<th>( \lambda_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slight</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Extensive</td>
<td>0.3(1+14)</td>
</tr>
<tr>
<td>4.5</td>
<td>Heavy - Complete</td>
<td>( \mu )</td>
</tr>
</tbody>
</table>

Graphs and tables illustrating the relationship between spectral acceleration and probability of damage, as well as the failure of existing and code-compliant buildings.
Measuring Earthquake Risk Exposure

Expected Loss
quantile risk measure,
insurance/cost-benefit analysis

Expected Shortfall
tail risk measure
what-if analysis

\[ EL = \]
Measuring the Degree of Seismic Upgrading and Upgrading Benefit

- **Yield Strength:**
  \[ a_y (dsu = 1) = S_{a_e (10\% / 50 yr)} (T_1) / q \]

- **Degree of Seismic Upgrading:**
  \[ dsu = \frac{a_y (dsu) - a_y (0)}{a_y (1) - a_y (0)} \]

- **Loss Risk Measure:**
  \[ \rho (L | dsu) \quad \rho \in \{ EL, ES_\alpha \} \]

- **Upgrading Benefit:**
  \[ UB_\rho (dsu) = \rho (L | dsu = 0) - \rho (L | dsu) \]

- **Normalized Upgrading Benefit:**
  \[ NUB_\rho (dsu) = \frac{UB_\rho (dsu)}{UB_\rho (dsu = 1)} \]
Normalized Upgrading Benefit (NUB) Curves

- NUB curves are concave
- A “sweet spot” lies approximately at 30% $dsu$

- Shape of the NUB curves:
  - Similar for all regions considered
  - Independent of the retrofit cost function
  - Insensitive to uncertainties in vulnerability and cost functions

![Normalized Upgrading Benefit (NUB) Curves](image)
Normalized Upgrading Benefit (NUB) Curves

- NUB curves are concave
- A “sweet spot” lies approximately at 30% $dsu$
- Allow preliminary cost-benefit analysis for retrofit decision-making
- Give insurance companies a tool to quickly evaluate discounts in insurance premiums for given $dsu$
Normalized Upgrading Benefit (NUB) Curves

- Expected Shortfall risk measure focuses only on the events in the tail of the loss curve
- NUB curves are concave up to confidence levels of 99%
  - NUB curves are similar up to this confidence level for all considered hazard environments
  - NUB curves become convex only for events “far” in the tail of the loss curve
Normalized Upgrading Benefit (NUB) Curves

- Expected Shortfall risk measure focuses only on the events in the tail of the loss curve
- Focus on the “far” end of the loss curve tail endows seismic risk evaluation with “risk aversion” by considering only severe and infrequent events

\[
\text{Expected Shortfall} = \alpha = 98\% \\
\text{Expected Shortfall} = \alpha = 99\% \\
\text{Expected Shortfall} = \alpha = 99.9\%
\]
Conclusions

- A framework to evaluate the financial benefits of seismic retrofitting of individual structures in different seismic environments is proposed.
- Normalized Upgrade Benefit (NUB) curves are a powerful tool for financial decision-making in preliminary seismic evaluation of existing buildings.
- NUB curves have similar shape for all seismic hazard regions considered using the expected loss or the expected shortfall with confidence level up to 99% as risk measures.
- The shape of the NUB curves is in general concave, demonstrating that a partial retrofit (with respect to a new building structure requirements) could be financially optimal.
Questions?
thank you