Building Seismic Performance Assessment Under Sequential Seismic Events

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Outline

- Why aftershocks matter?
- A probabilistic framework for quantifying seismic risk under sequential seismic events
- Ground motion pairing for sequential response history analysis
- A framework for seismic loss assessment under sequential seismic events
- Mainshock-aftershock seismic risk and loss evaluation for Los Angeles County
Why Examining Seismic Risk under Sequential Seismic Events is Important?

- ASCE 7-10 seismic design criteria
- Collapse risk of 1%
- The seismic design maps are derived for single mainshock events
- The role of aftershocks is not incorporated
- Decision making in the post-mainshock environment
Why Aftershocks Could Potentially be Damaging?

- Two sources of extra hazard in the post-mainshock environment
  - Elevated seismic hazard during a short period after a major mainshock event
  - Reduction in the structural capacity
A Probabilistic Framework for Quantifying MS and MS-AS Seismic Risk

- Markov process is capable of addressing these uncertainties

\[ \Pi_k = \begin{bmatrix} p_{11}^k & p_{12}^k & \ldots & p_{1r}^k \\ 0 & p_{22}^k & \ldots & p_{2r}^k \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \ldots & p_{rr}^k \end{bmatrix} \]

\[ p_{ij}^k = \int (P_{i,j}[EDP > edp_j|IM] - P_{i,j+1}[EDP > edp_{j+1}|IM]) \alpha_{IM}^k(im) \]

- Probability of transition between limit states at time step \( k \) after mainshock

- APSHA curve at time step \( k \) after mainshock

- \( \lambda_{IM}^k \) is the APSHA curve at time step \( k \) after mainshock.

- \( i \): damage state under 1\(^{\text{st}}\) event

- \( j \): damage state 2\(^{\text{nd}}\) event
Numerical Models

- RC frame buildings
- Ductile, non-ductile and infill frames
- 2 to 20 stories
- Models developed in OpenSees by Haselton and Raghunandan
- Plastic hinge for beams and columns with stiffness and strength degradation
- Maximum story drift ratio (SDR) as the EDP

Plastic hinges at the ends of beams and columns

Joint shear panel

@ 13 ft.

15 ft.

20 ft.

P – Δ Columns
Ground Motion Pairing

- With suitable consideration of source and path differences between mainshocks and aftershocks, can records mainshocks replace aftershocks?

- Larger, more inclusive databases for mainshocks

Chiou and Youngs (2008)

Constant-ductility response spectra for $\mu = 8$
Ground Motion Pairing

- Collapse fragility curves for 2-, 8- and 20-story buildings
- Record-pairs with aftershocks as second ground motions result in higher collapse probabilities
- A result of both higher spectral values at longer periods and scaling
Seismic Risk in Pre-Mainshock Environment

- Pre-mainshock MS-AS seismic risk assessment
- Insightful when designing or retrofitting a building
- A lifespan of 50 years
- Aftershocks are significant for 30 days after each mainshock
- Collapse is between 1.5 to 3.5 times more likely when the contribution of aftershocks is considered
Aftershock-Induced Losses

Up to 7% extra losses due to aftershocks within a period of 30 days after mainshock

Incorporating aftershocks increases the life-cycle loss by 30%
Mainshock-Aftershock Seismic Risk Assessment for Los Angeles County

- RC Frames
- Ductile and non-ductile moment frames
- Nonductile frames with masonry infills
- Stochastic ground motion maps
- Both expected annual and scenario-based metrics
- Magnitude 7 mainshock on Puente Hills
Seismic Risk and Loss
Thank you