Assessing the Post-Earthquake Reduction and Recovery of the Shelter-In-Place Housing Capacity of a Residential Community in NOIDA India

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3ICUDR Presentation

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Research Project Overview

Component Modeling

- Infill Frame Modeling
  - Beam flexural hinge
  - Column flexural hinge and shear spring in series
  - Column flexural hinge, shear and compression-only axial springs in series at column base
  - Off-diagonal compression-only infill strut
  - Central compression-only infill strut

Cyclic Behavior of Infill Frame

- Normalized Lateral Displacement ($\Delta/\Delta_u$)
- Normalized Lateral Force ($F/F_y$)

System Development and Performance Assessment

- Rocking Spine System
  - Uniform distribution of damage along building height
  - Uplift at spine footing

- Idealized Backbone Curve
  - Overturning Moment
- Spine Gravity Loads
- Adjacent Infill Yielding/Cracking
- Adjacent Infill Complete Degradation
- Adjacent Beams Complete Degradation

- Housing Capacity Recovery Curve
  - Housing Capacity (# of people)
  - Time (months)

Community Resilience Assessment

- Residential Community
- Scenario Earthquake Study
  - Fault
  - Infill frame residential buildings
  - Epicenter

- Housing capacity recovery curve
  - Immediate post-earthquake housing capacity
  - Pre-earthquake housing capacity
Residential Community Resilience Assessment Objectives

1. Identify and assess building performance limit states that are explicitly linked to recovery

2. Incorporate the assessment of those limit states into a community scale recovery model

3. Apply framework to model the reduction and recovery of the shelter-in-place capacity of a residential community
Resilience-Based Building Performance Limit State Event Tree

- Collapse $LS_5$
  - Clear and rebuild

- Irreparable damage $LS_4$
  - Demolish and rebuild

- Building unsafe $LS_3$
  - Vacate until repaired
  - Occupy during repairs

- Loss of functionality $LS_2$
  - Continued function

- Safe to occupy
  - Functionality maintained $LS_1$
  - Continued function

- Repairable damage
  - Continued function

- Inspection triggered

- Inspection not triggered $LS_0$
Assessing Building Performance Limit State

\[ P(\text{LS} \geq l_s|\text{IM}) = \begin{cases} 1 - P(\text{LS} \geq l_{s+1}|\text{IM}) & i = 0 \\ P(\text{LS} \geq l_s|\text{IM}) - P(\text{LS} \geq l_{s+1}|\text{IM}) & 1 \leq i < 5 \\ P(\text{LS} \geq l_s|\text{IM}) & i = 5 \end{cases} \]
Modeling Recovery at the Building Level

Residential Building Occupancy

- 100% Occupiable Fully Functional (OccFull)
- 0-100% Occupiable Loss of Function (OccLoss)
- 0% Not Occupiable (NOcc)

Functional State

Time (days)

Recovery Path

$T_{NOcc}$ $T_{OccLoss}$ $T_{OccFull}$ $T_{LC}$
Modeling Recovery at the Building Level

Recovery Curve Given Damage State $LS_i$

Recovery Path Given Damage State $LS_i$

Functionality

Residential Building Occupancy (%)
Computing Expected Recovery Function

\[
E[q(t)|IM] = \sum_{i=1}^{n_{LS}} [q(t)|LS_i] \cdot P( LS_i | IM)
\]

“Expected” Recovery Function

Number Of Occupants

Time (days)
Accounting for Externalities and Socioeconomic Factors

- **Examples of External Effects and Socioeconomic Factors**
  - Utility disruption
  - Loss of access
  - Availability of labor for repairs and/or reconstruction
  - Availability of financing

- **Accounting for Externalities and Socioeconomic Factors**
  - Incorporate the effect of externalities in the assessment of building performance limit states and building level recovery models
  - Develop statistical model linking time parameters (repair time, time to inspection etc.) used in recovery model to externalities and socioeconomic factors
Resilience Assessment of Residential Community in NOIDA, India

- Acquire inventory through field and remote sensing data
- Develop set of surrogate and structural models (3D) buildings representative of inventory
- Use surrogate models to develop limit state fragility curves
- Assess the immediate post-earthquake and recovery trajectory of shelter-in-place capacity for existing building stock
- Evaluate the effect of enhanced seismic performance mitigation strategy
Results: Recovery of Housing Shelter-In-Place Capacity
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- **Time to 95% pre-earthquake capacity**
  - Existing Inventory: 633 days
  - Enhance Seismic Performance Buildings: 337 days

- **Cumulative loss of occupancy**
  - Existing Inventory: $9.3 \times 10^6$ person-days
  - Enhance Seismic Performance Buildings: $4.5 \times 10^6$ person-days
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Conclusions

• Developed performance-based framework that incorporates key building performance limit states in modeling recovery

• Framework applied to model the recovery of the shelter-in-place housing capacity of a residential community

• Slope of recovery curve at various stages linked to distribution of damage

• Measured impact of enhanced seismic performance mitigation strategy

• Current work is focused on incorporating the effect of externalities and socioeconomic factors