Earthquake Response and Preparedness: Modeling Human/Structure Interaction

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Introduction

- Earthquake response – humans/building interaction
- Assess the preparedness of Los Angeles to
  - Mass evacuation
  - Healthcare response
- Structural and non-structural building response
- Effect of damage and injury on evacuation
- Agent-based simulations of human activity and evacuation

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Outline

- Project Approach
- Site Information
- Ground Motion Input
- Structural Simulations
- Non-Structural Layout
- Non-Structural Damage Analysis
- Test Structure Evacuation Model
- Evacuation of City Block
- Casualty Modeling
- Regional Modeling and Animation
- Future Work
Approach - City

Region Information

Building Information

Ground Motion

Casualty Modeling

Building Response Modeling

Visualization

Region Evacuation

City Evacuation

Hospital Response

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Approach – Test Structure

- Ground Motions
- Non-Structural Layout
- Structural Damage Modeling
- Non-Structural Damage Modeling
- Building Evacuation
- Casualty Modeling
Site Information
Approach - City

- Approach
- Region Information
- Building Information
- Ground Motion
- Casualty Modeling
- Building Response Modeling
- Visualization
- Region Evacuation
- City Evacuation
- Hospital Response

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Region

Red numbers are square footages. Black are the year built (19--)

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Ground Motion Input
Approach - City

Region Information → Building Information → Building Response Modeling → Visualization

Region Information → Ground Motion → Casualty Modeling → Region Evacuation → City Evacuation → Hospital Response

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Approach – Test Structure

- Ground Motions
- Structural Damage Modeling
- Non-Structural Damage Modeling
- Non-Structural Layout
- Casualty Modeling
- Building Evacuation
Ground Motion Input (Northridge earthquake 1994)

- Far field record
- PGA 0.52 g
- Vs30 355.8 m/s
Structural simulations

High resolution
Approach – Test Structure

- Ground Motions
- Non-Structural Layout
- Structural Damage Modeling
- Non-Structural Damage Modeling
- Building Evacuation
- Casualty Modeling
3 story archetypical building

- Typical 3-story office-building
- Employed in seismic study by Gupta and Krawinkler
- Moment-resisting steel framed structure
- Light composite concrete decks
- Dead load, \( D = 4 \text{ [kPa]} \)
  - Deck self-weight \( \approx 3 \text{ [kPa]} \)
  - Ceilings/fireproofing, etc. \( \approx 1 \text{ [kPa]} \)
- Office live load, \( L = 2.5 \text{ [kPa]} \)

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Physics based simulations

- Methodology from studies on progressive collapse

- Large strains and geometric nonlinearities

- Contact and impact of falling members
3 story building. Case study
3 story building - Visualization
Damage assessment

[Diagram of a structural layout with dimensions and material specifications]
Floor damage

- Damage resulting in partial collapse

2nd floor slab (effective plastic strain)
Accelerations and displacements

2nd floor slab (effective plastic strain)
Response of buildings to a strong earthquake
detailed dynamic, time-history simulations
contact and collapse
Structural damage enables estimates of post-earthquake:
obstacles in evacuation routes
collapsed slabs
buckled columns
damaged staircases
Time floor accelerations and drifts for assessment of non-structural damage
Non-Structural Layout
Approach – Test Structure

- Ground Motions
- Structural Damage Modeling
- Non-Structural Damage Modeling
- Building Evacuation
- Casualty Modeling
- Non-Structural Layout
Design of Non-Structural Layout

- Non-structure elements for the test structure only.
- Designed in Google Sketchup according to fire code.
- Non-structural elements present inside walls and ceilings:
  - 1: Evenly distributed with constant density
  - 2: Amounts calculated using ATC 58
- Two floor plans commercial occupancy:
  - a ground floor
  - upper story, repeated for all higher stories.
Non-Structural Damage Analysis

Assembly based vulnerability
Approach – Test Structure

- Ground Motions
- Non-Structural Layout
- Structural Damage Modeling
- Casualty Modeling
- Building Evacuation
- Non-Structural Damage Modeling
Method

- Step 1: Fragility functions
- Step 2: Location/number of the components
- Step 3: Structural responses from simulation
- Step 4: Run probabilistic non-structural damage analysis
- Step 5: Create damage distribute map.
Example: Glazing Damage

<table>
<thead>
<tr>
<th>Floor</th>
<th>Structural Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0308</td>
</tr>
<tr>
<td>2</td>
<td>0.0474</td>
</tr>
<tr>
<td>3</td>
<td>0.0346</td>
</tr>
</tbody>
</table>

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Damage distribution map
(Dry wall partition and Acoustic Ceiling)
Test Structure Evacuation Model

Implement agent based modeling
Approach – Test Structure
What is agent-based modeling?

- Agents are purposeful, rational, perceiving and decision making artificial life forms that interact with the surroundings.

   ![Diagram showing the flow of information between Perceiving module, Rational Module, and Action Module.]

   - **Perceiving module**
     - Status of environment and other agents in vicinity
   - **Rational Module**
     - Decision, based on simple rules
   - **Action Module**
     - Interact with environment

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ABM of test structure
Assumptions and capabilities

- Each person tries to evacuate individually using shortest distance to exit.
- It is assumed that most of people know the shortest path to exit.
- Some confused people are modeled.
- Because the building is designed using high standards no injury or dead was assumed.
- People will never path walls, and avoid each other.
Evacuation of City block

Implement agent based modeling
Approach - City
Partial map of region from ABM

Legend

City:
- Street
- Alley

- Building stock:
  - One story
  - Two stories
  - Three story
  - Four story
Model assumptions and capabilities

- Model is expandable to any city size and population
- Mapped the exact building stock in the model
- Exit and stair cases are approximately located
- Includes traffic flow, cars never run over people, two way streets
- People recognize each other and form queues at exits
- Walking speed is based on health status
- Some people use private cars to evacuate using two exit points provided
- Each injured individual if can make it to out of building will have a chance to get assisted by healthy persons near them
Casualty Modeling
Approach – Test Structure
Approach - City

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Methodology

1. Visually assess structure load bearing system

2. Based on ATC 13, estimate central damage factor: $0 \leq cdf \leq 100$

3. Below table is the mapping between people and building

<table>
<thead>
<tr>
<th>CDF</th>
<th>Minor injury</th>
<th>Serious injury</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>1.90</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>85.10</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>45</td>
<td>13.00</td>
<td>5.30</td>
<td>0.03</td>
</tr>
<tr>
<td>80</td>
<td>0.00</td>
<td>14.60</td>
<td>0.3</td>
</tr>
<tr>
<td>100</td>
<td>0.00</td>
<td>14.70</td>
<td>0.4</td>
</tr>
</tbody>
</table>

| P[Minor] | 0.65 | 1.36 | 27.91 | 30.04 | 6.76 | 10.03 | 13.24 |
| p[Seroius] | 0.18 | 6.04 | 9.10 | 0.90 | 1.34 | 1.76 | 0.17 |
| P[Dead] | 2.18 | 3.75 | 0.23 | 0.33 | 0.44 | 0.08 | 0.08 |

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Automating Casualty Calculation

### Building Information Generator

**Occupancy Type**
- Multi-Unit Residential
- Commercial
- Healthcare
- Retail

**Building Class**

**Square Footage:**

**CALCULATE**

### Earthquake

- Weekday
- Weekend

**Month**

**Time**

**Modified Mercalli Intensity (Richter Magnitude)**

**Save Building Data**
- Building Name: `building_X`
- Save Building

### Occupancy Details

<table>
<thead>
<tr>
<th>Total Occupants</th>
<th>Minor Injuries</th>
<th>Major Injuries</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>C. W. Pipe &gt;2.5&quot;</td>
<td>1000 If</td>
<td>HVAC VAV Box</td>
</tr>
<tr>
<td>Gross Wall Area</td>
<td>H. W. Pipe &lt;2.5&quot;</td>
<td>1000 If</td>
<td>HVAC Coils</td>
</tr>
<tr>
<td>Windows/Glazing</td>
<td>Gas Piping</td>
<td>1000 If</td>
<td>St/Ch Pipe &lt;2.5&quot;</td>
</tr>
<tr>
<td>Roof Area</td>
<td>Waste Piping</td>
<td>1000 If</td>
<td>St/Ch Pipe &gt;2.5&quot;</td>
</tr>
<tr>
<td>Int. Partit. Length</td>
<td>Proc. Pipe &lt;2.5&quot;</td>
<td>1000 If</td>
<td>Heat. Pipe &lt;2.5&quot;</td>
</tr>
<tr>
<td>Ceram. Floor Tile</td>
<td>Proc. Pipe &gt;2.5&quot;</td>
<td>1000 If</td>
<td>Heat. Pipe &gt;2.5&quot;</td>
</tr>
<tr>
<td>Ceram. Wall Tile</td>
<td>Acid Piping</td>
<td>1000 If</td>
<td>Electrical Load</td>
</tr>
<tr>
<td>Cell. Gypsum</td>
<td>HVAC Tow. Cap.</td>
<td>TN</td>
<td>Elec. Cable Tray</td>
</tr>
<tr>
<td>Cell. Exposed</td>
<td>HVAC Boiler Cap</td>
<td>BTU</td>
<td>Ele. Switch Gear</td>
</tr>
<tr>
<td>Cell. Other</td>
<td>HVAC Air Handl.</td>
<td>cf/min</td>
<td>Lay-in Flu. Light</td>
</tr>
<tr>
<td>Stairs</td>
<td>HVAC Fans</td>
<td>cf</td>
<td>Stem Flu. Light</td>
</tr>
<tr>
<td>Elevators</td>
<td>HVAC Ducts &lt;6&quot;</td>
<td>1000 If</td>
<td>Generator Cap</td>
</tr>
<tr>
<td>Plumb. Fixtures</td>
<td>HVAC Ducts &gt;6&quot;</td>
<td>1000 If</td>
<td>Sprinkler Piping</td>
</tr>
<tr>
<td>C. W. Pipe &gt;2.5&quot;</td>
<td>HVAC Ducts/Diff</td>
<td>Each</td>
<td>Sprinkler Drop</td>
</tr>
</tbody>
</table>

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Regional Modeling and Animation

Single degree of freedom
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Example (Single Block)

Steel moment frame
Eccentrically braced steel frame
Concrete moment frame
Others

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Example (Multi Blocks)

Steel moment frame
Eccentrically braced steel frame
Concrete moment frame
Others
Future Work
Needed Connections and Modules

Connections:

- From building response to casualties
- From casualties to regional agent-based models
- From region to city
- From city to hospital

Modules

- Whole city response
- Hospital response
Other Avenues of Exploration

- Traffic and transportation
  - Greater literature review needed
  - Estimated flow of cars
- Cooperative/competitive evacuation
- Incorporation of GIS into Netlogo
- Ambulances and health responders
Questions?