Seismic Vulnerability Assessment of Buildings Using a Statistical Method of Response Prediction

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Overview

- Vulnerability Function Analytical Framework
- FEMA P-58 Simplified Approach
- Simplified Method Limitations
- Enhanced Simplified Method
Vulnerability Function Analytical Framework

FEMA P-58 Simplified Approach

Simplified Method Limitations

Enhanced Simplified Method
Analytical Evaluation of Vulnerability Functions
Time-Consuming Process of the detailed analytical Models

Ground Motions are scaled by 0.1g incremental until collapse

Total Run Time Per Archetype
\[75 \times 22 \times 2 \times 40 \text{ min} = 3 \text{ months}\]

Total Run Time Per Archetype
\[30 \times 22 \times 2 \times 40 / 60 \text{ min} = 0.7 \text{ day}\]
FEMA P-58
Simplified Approach

Simplified Method Limitations

Enhanced Simplified Method
Simplified Methodology Pseudo IDA Analysis – Base Shear Calculations

\[ V = C_1 \times C_2 \times S_a (T_1) \times W_1 \]

Repeat it for all 2×22 FEMA P-695 ground motions which are scaled by 0.1g incremental until collapse to calculate Base Shear (V).
Simplified Methodology Pseudo IDA Analysis – Uncorrected Displ. Calculations

Equivalent Lateral Forces Method

\[ C_{vi} = \frac{W_i h_i^k}{\sum_{i=2}^{n+1} W_i h_i^k} \]

Structure Design

\[ k_i = \frac{\Delta F_i}{\delta_i} \]

Target Displ. (\( \delta_i \))

ASCE/SEI 41-17

Uncorrected Displacement

\[ \Delta = \frac{F}{K_{\text{Stiffness Matrix}}} \]
Simplified Methodology Pseudo IDA Analysis – Corrected Demands

\[ \Delta_i = \delta_0 + \delta_1 T_1 + \delta_2 S + \delta_3 (h_i+1)^2 + \delta_4 (h_i+1)^3 \times \Delta_i \]

\[ a_i = \delta_0 + \delta_1 T_1 + \delta_2 S + \delta_3 (h_i+1)^2 + \delta_4 (h_i+1)^3 \times PGA \]

\[ v_i = \delta_0 + \delta_1 T_1 + \delta_2 S + \delta_3 (h_i+1)^2 + \delta_4 (h_i+1)^3 \times \left( \frac{S_a(1.0\text{sec})}{2\pi \times 1.65} + 0.3 \frac{T_1 V_1 T_1 \delta_i}{2\pi W_1 \delta_1} \right) g \]

Corrected Residual Displ.:

\[
\begin{align*}
\Delta_r &= 0 & \text{for } \Delta \leq \Delta_y \\
\Delta_r &= 0.3(\Delta - \Delta_y) & \text{for } \Delta_y < \Delta \leq 4\Delta_y \\
\Delta_r &= \Delta - 3\Delta_y & \text{for } \Delta \geq 4\Delta_y
\end{align*}
\]
## Simplified Methodology Archetypes (from HAZUS-MH MR4)

<table>
<thead>
<tr>
<th>Archetype Types</th>
<th>Description</th>
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<tr>
<td>No.</td>
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<tr>
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</tr>
<tr>
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</tr>
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<td>S2H</td>
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<td>16</td>
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Number of Archetypes = \(8 \times 16 \times 4 \times 5 = 2560\)
Vulnerability Function Analytical Framework

FEMA P-58 Simplified Approach

Simplified Method Limitations

Enhanced Simplified Method
Simplified Methodology Conditions/Limitations

- Independent Framing in two directions
- Uncoupled Response
- No torsion
- Regular in plan and elevation
- Less than 15 stories
- Story drifts ratios are limited to 4%

Comparison between Vulnerability Functions of Detailed Models and Simplified Models

- 2-story Wood
- 4-story Wood
- 2-story Concrete
- 12-story Concrete
Vulnerability Function Analytical Framework

FEMA P-58 Simplified Approach

Simplified Method Limitations

Enhanced Simplified Method
IDA Track Archetype Database

- 69 Archetypes
- Different Heights
- Commercial
  - Multi-family
  - Single-family
- Different Seismic Zones

- Light Frame Wood Building
- Concrete Moment Frame Building
- Steel Moment Frame Building
- Steel Braced Frame Building
Modified Parameters to Enhance the Simplified Method

\[ \Delta_i^* = e^{a_0 + a_1 T_1 + a_2 S + a_3 \frac{h_i+1}{H} + a_4 \left( \frac{h_i+1}{H} \right)^2 + a_5 \left( \frac{h_i+1}{H} \right)^3} \times \Delta_i \]

Given from IDA Analyses

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<th>Demand</th>
<th>Frame Type</th>
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<td>-0.030</td>
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<td>1-8 Stories</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
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</table>

Concrete Frame: 20\times1760 = 35200 data point
Wood Frame: 27\times1760 = 47520 data point
Steel Frame: 22\times1760 = 38720 data point
Comparison between Vulnerability Functions of Enhanced Simplified Method and Detailed IDA Track

- 2-story Wood
- 4-story Wood
- 2-story Concrete
- 12-story Concrete
The simplified method proposed by FEMA P-58 restricts its applicability by many assumptions.

The limitation on the inter-story drift has the most significant effect on the demand calculations.

The results revealed noticeable differences between the loss functions developed by original FEMA P-58 simplified methodology.

Generating the vulnerability functions with modified regression parameters generated in this research show improved agreement against the vulnerability functions by IDA analyses.

The enhanced simplified framework can be used to estimate the losses of buildings in a large portfolio of structures with favorable computation times.
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