FEMA P-807
Guidelines for Seismic Retrofit of Weak-Story Wood-Frame Buildings
Post-Northridge Developments

Large Scale Response History Analysis
FEMA P-695 : Incremental Dynamic Dynamic Analysis
Testing of Archaic Materials
Design of Perforated Walls
FEMA P-807 Innovations

Relative Strength Method
Surrogate Structure Matching
Weak Story Tool
4,400 Dangerous Multi-unit Buildings: 8% of population
Create Seismic Retrofit Program for Weak-Story Wood-framed Apartment Buildings in Western US
The Problem
Inexpensive to Construct
(Work Only In Ground Story)

Inexpensive to Design
(Unsophisticated Engineers)

Performs Well
(Shelter-In-Place)
FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings

Typically:
Non-Engineered
No Plans
Archaic Materials
Archaic Construction Practices
Design for a Population of Buildings, not an Individual Building
Pattern Recognition
Pattern Recognition

Limited Damage to Upper Structure

Damage Concentrated in Lower Structure
RELATIVE STRENGTH METHOD
The Relative Strength Method

![Diagram](image-url)

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
SURROGATE
STRUCTURE
MATCHING
Can a Building's Capacity be Determined from a Few Parameters?
Local Seismicity
Translational Weakness

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Torsional Weakness

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Low Displacement Capacity

Hysteresis of low displacement capacity material

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
High Displacement Capacity

Hysteresis of high-displacement capacity material

FEMA P-807 : Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Create a Controlled Experiment
Determine the Influence of Each Characteristic
Analytical Engine: Surrogate Structure Concept

Material forms:
(2) total

Upper-story strength ratios, \( A_u \):
(4) per mat'l form

Weak-story ratios, \( A_w \):
0.6 to 1.1 by 0.1
(6) per upper-story strength

Retrofit strengths:
\( A_w \) to 1.6
(51) per upper-story strength ratio

TOTAL NUMBER OF BUILDINGS: 612

Time-history seed records:
(22) Bi-directional records = (44) individual
Scaled so that median \( S_a \) (\( T = 0.3 \) sec) = 1.0g

(35) intensities per seed record varying from 0.1 to 3.5 by 0.1

Recover peak interstory drift ratios for each analysis

Given drift criteria, fit log-normal CDF
Simplified Building Model

HORIZ. D.O.F.

| W  | 50 in. |
| H  | 100 in. |
| L  | 111.8 in. |
| q  | 1.107 rad, 63.4 deg. |
| \cos(q) | 0.447 |
| Astrut | 1 in2 |
| Mg | 1 kip (total weight of building) |
Analytical Engine:
Surrogate-Structure Concept

612 surrogate structures x 44 EQs x 35 intensities

1 million nonlinear response-history analyses
Analysis Results

$$S_{c,20} = (0.34 + 1.47 A_{W,x}) A_{U,x}^{0.48}$$

Curve fit for Incremental Dynamic Analysis

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Analysis Results

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Analytical Methodology – Accounting for Torsion

![Graph showing the relationship between torsion coefficient and capacity reduction factor for different ductility and brittleness conditions.](image-url)
Spectral Capacity, \( S_c \)

\[
S_{c1,x} = 0.66 \left( 0.525 + 2.24 A_{W,x} \right) \left( 1 - 0.5 C_T \right) Q_s A_{U,x}^{0.48} \quad C_D = 1.0
\]

\[
S_{c0,x} = 0.60 \left( 0.122 + 1.59 A_{W,x} \right) \left( 1 - 0.5 C_T \right) Q_s A_{U,x}^{0.60} \quad C_D = 0.0
\]

for intermediate values

\[
S_{c,x} = C_D^3 S_{c1,x} + \left( 1 - C_D^3 \right) S_{c0,x}
\]

\[
S_{c,x} \geq S_{MS} \quad \text{if true - no retrofit required}
\]

Onset of Strength Loss drift criteria, OSL

20% Probability of Exceedance, POE
Characteristic Structural Coefficients

**Ground-story Strength**
\[ C_{s,x} = \frac{V_{i,x}}{\sum_{j=1}^{N_s} W_j} \]

**Upper-story Strength**
\[ C_{U,x} = \min \left( \frac{V_{i,x}}{\sum_{j=i}^{N_s} W_j} \right) \]

**Upper to Ground Strength Ratio**
\[ C_{W,x} = \frac{C_{s,x}}{C_{U,x}} \]

**Toughness**
\[ C_{D,x} = \frac{F_{l,x} (\delta = 3\%) }{V_{l,x}} \]

**Torsional Imbalance**
\[ C_T = \frac{\tau}{T} \]
Structural Use of Non-conforming Materials

- Stucco
- Horizontal wood sheathing
- Diagonal wood sheathing
- Brick veneer
- Plaster on wood lath
- Plywood panel siding
- Gypsum wall board
- Plaster on gypsum lath
- Wood structural panel 8d@6
- Wood structural panel 8d@4
- Wood structural panel 8d@3
- Wood structural panel 8d@2
- Wood structural panel 10d@6
- Wood structural panel 10d@4
- Wood structural panel 10d@3
- Wood structural panel 10d@2

Unit Force, plf vs. Drift Ratio, %

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Pushover Curve to Find Peak Strength

\[ f_w(\delta_j) = v_w(\delta_j)L_w Q_{perf} Q_{ot} \]
Weak-Story Wood-Frame Buildings

FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings
Torsion Backbone Curve

Torsional moment that causes a twist of $\theta_j$ for the Ground Story, $t_j(\theta_j)$

Twist Level 2 by the twist angle, $\theta_j$

Center of strength at Ground Story

Wall: 1 2 3 4

$T = \max [t(\theta_j)]$
FEMA P-807: Guidelines for Cost-Effective Seismic Retrofit of Weak-Story Wood-Frame Buildings

Probabilistic Understanding of Retrofit Benefit

- Probability of exceedance before retrofit ($P = 0.87$ in this example)
- Fragility curve before retrofit identified by mean spectral capacity $S_\mu$. ($S_\mu = 0.30$ in this example)
- Fragility curve after retrofit identified by mean spectral capacity $S_\mu$. ($S_\mu = 0.55$ in this example)
- Log-normal standard deviation, $\beta$, determines relevant set of fragility curves. ($\beta = 0.5$ in this example)
- Site-specific seismic intensity, $S_S$ ($= 0.521$ in this example)

$\beta = 0.5$
Needs

More Testing of Archaic Materials
Pre-Engineered Moment Frames
Comprehensive Design & Detailing Examples