Implications of the FEMA P-58 Methodology for Structural System Selection and Design

John Hooper
Magnusson Klemencic Associates
John Gillengerten
OSHPD (Retired)
David Bonneville
Degenkolb Engineers

Brief Background on FEMA P-58

- FEMA funds ATC in 2001 to develop:

  "Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings"
- 10-Yr effort to develop the first guidelines
  - Seismic Performance Assessment of Buildings:
    - Volume 1—Methodology
    - Volume 2—Implementation Guide
    - Volume 3—Supporting Electronic Materials and Background information
      - Includes Performance Assessment Calculation Tool (PACT)

Brief Background on FEMA P-58

- Subsequent 5-yr Effort (FEMA P-58-1)
  - Develop performance-based seismic design guidelines and stakeholder guidelines
- Determine likely performance of code-designed buildings
- Provide guidance on structural system selection and design based on FEMA P-58-1
- FEMA P-58-1 Completion: Soon!

Technical Basis for the FEMA P-58 Methodology

- PEER Framework for Performance-Based Earthquake Engineering
- PEER Framework applies the Total Probability Theorem to determine earthquake consequences:

$$v(DV) = \iiint G\langle DV \mid DM \rangle \mid dG\langle DM \mid EDP \rangle \mid dG\langle EDP \mid IM \rangle \mid d\lambda(IM)$$

FEMA P-58-1 Building Evaluation Overview

- FEMA P-58-1 evaluated the probable performance of a large number of building archetypes
  - Representing Risk Categories II and IV
  - Structures of different height
  - Different structural systems
  - Designed with a variety of occupancies
  - Designed to a range of Site Seismic Hazards

FEMA P-58-1 Building Evaluation Overview

- Systems Evaluated:
  - Special Steel Moment-resisting Frames
  - Special Concrete Moment-resisting Frames
  - Special Reinforced Concrete Shear Walls
  - Steel Special Concentrically Braced Frames
  - Steel Buckling-restrained Braced Frames

FEMA P-58-1 Building Evaluation Overview

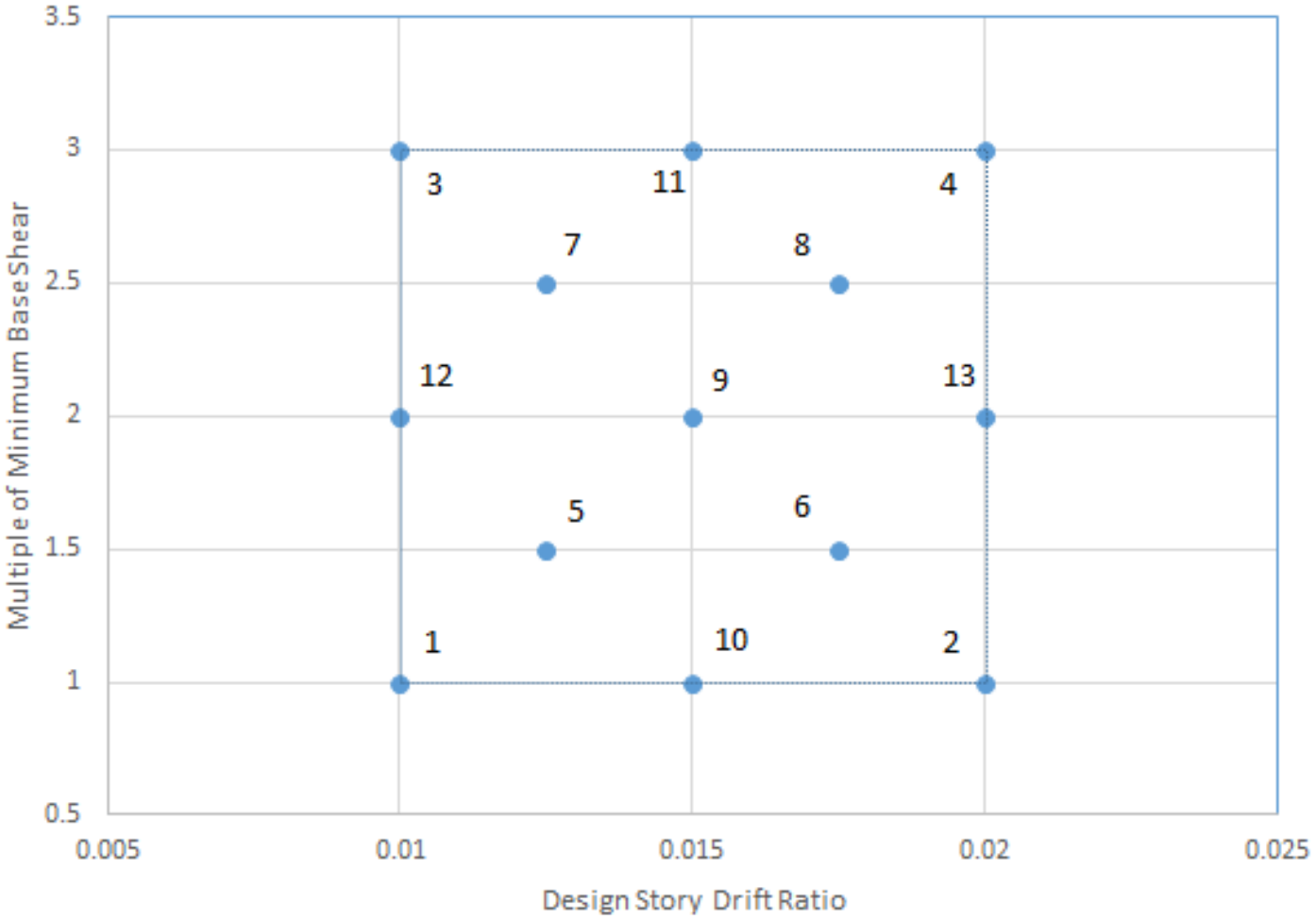
- Building Archetypes Evaluated
  - Office and non-acute clinics (Risk Category II)
    - Low-, mid-, and high-rise structures
  - Healthcare and Emergency Operations Center (Risk Category IV)
    - Low and mid-rise structures

FEMA P-58-1 Building Evaluation Overview

- Site Seismic Hazards Evaluated

Site Seismic Hazard	S_{DS}	S_{D1}
High SDC D	**1.33g**	**0.75g**
Medium SDC D	**1.00g**	**0.6g**
Low SDC D	**0.50g**	**0.35g**

ASCE-7-Based Design Space



FEMA P-58-1 Building Evaluation Results

- Casualties: Mid-rise Office Buildings, Risk Category II, Medium SDC D

Lateral Force-Resisting System	Casualty Risk				
	20% MCE	40% MCE	67% MCE	80% MCE	100% MCE
Steel SMRF	0.0%	0.0%	0.2%	0.5%	0.8%
Steel SCBF	0.0%	0.3%	2.2%	3.8%	5.5%
Steel BRBF	0.0%	0.2%	0.9%	1.7%	3.2%
SRCSW	0.0%	0.0%	0.2%	0.6%	1.5%
Concrete SMRF	0.0%	0.0%	0.2%	0.7%	1.5%

FEMA P-58-1 Implications for Design

- The majority of injuries caused by ceiling systems
- Suspended lay-in tile ceiling systems have prescriptive requirements identical across SDC D through F
  - Low SDC D archetypes had significantly lower probabilities of injuries compared to those in Medium and High SDC D
- Archetypes designed to Risk Category IV have somewhat better performance

FEMA P-58-1 Building Evaluation Results

- Median Repair Costs: Mid-rise Office Buildings, Risk Category II, Medium SDC D

Lateral Force-Resisting System	Predicted Median Losses				
	20% MCE	40% MCE	67% MCE	80% MCE	100% MCE
Steel SMRF	0%	1%	7%	13%	17%
Steel SCBF	1%	8%	17%	22%	26%
Steel BRBF	0%	2%	9%	16%	48%
SRCSW	0%	1%	4%	7%	8%
Concrete SMRF	0%	1%	5%	12%	20%

FEMA P-58-1 Implications for Design

- Residual drift is a major contributor at strong shaking intensities
  - Dominates losses for structures in Risk Category II if the system is designed near the maximum story drift limits
  - Design for lower drift limits to reduce residual drift losses
- Flooding is another major contributor to loss
  - Predicted to occur in shaking intensities of 67% MCE and higher in most archetypes

FEMA P-58-1 Implications for Design

- Damage to exterior walls is common in higher shaking intensities
  - Occurs in all lateral systems, since the curtain wall is designed to accommodate the specified story drift.
  - Where the design drift ratio is less than about 0.005, most curtain wall systems can accommodate story drift with little damage.

FEMA P-58-1 Building Evaluation Results

- Repairability: Mid-rise Office Buildings, Risk Category II, Medium SDC D

Lateral Force-Resisting System	Percent Realizations the Building is Repairable				
	20% MCE	40% MCE	67% MCE	80% MCE	100% MCE
Steel SMRF	100%	100%	97%	93%	83%
Steel SCBF	100%	100%	100%	99%	97%
Steel BRBF	100%	98%	86%	69%	55%
SRCSW	100%	100%	100%	100%	100%
Concrete SMRF	100%	100%	98%	100%	100%

FEMA P-58-1 Implications for Design

- Repairability is measured by the severity of residual drift
  - Archetypes sustaining residual drifts in excess of 1% deemed unrepairable
- Archetypes designed to Risk Category IV benefited from the more restrictive drift limits
- Reduce design story drifts to improve repairability

FEMA P-58-1 Building Evaluation Results

- Unsafe placard: Mid-rise office buildings, Risk Category II, low SDC D

Lateral Force-Resisting System	Percent Realizations, Unsafe Placard Triggered				
	20% MCE	40% MCE	67% MCE	80% MCE	100% MCE
Steel SMRF	0%	0%	3%	10%	23%
Steel SCBF	3%	29%	53%	65%	73%
Steel BRBF	0%	3%	27%	44%	58%
SRCSW	0%	0%	1%	3%	8%
Concrete SMRF	0%	0%	3%	11%	23%

FEMA P-58-1 Implications for Design

- Unsafe placards most commonly resulted from residual drift or damage to structural elements
- Unsafe placard estimates made using FEMA P-58-1 tend to be higher than those estimated
  - "Unseen" structural damage is accounted when evaluating the potential of unsafe placards
- Reduce design story drifts to improve potential of unsafe placards

FEMA P-58-1 Building Evaluation Results

- Median Repair Time: Low-rise Office Buildings, Risk Category II, Medium SDC D

Lateral Force-Resisting System	Median Repair Time, Days				
	20% MCE	40% MCE	67% MCE	80% MCE	100% MCE
Steel SMRF	0	5	15	22	26
Steel SCBF	21	34	52	63	286
Steel BRBF	0	11	30	44	281
SRCSW	0	14	29	37	46
Concrete SMRF	0	5	17	23	27

FEMA P-58-1 Building Evaluation Results

- Methodology focuses on the length of time to make necessary repairs
- Repair time is measured by the number of days required to restore damaged components to their pre-earthquake condition
- Parallel repair was assumed, allowing repair work to occur on all floors simultaneously

FEMA P-58-1 Implications for Design—Summary

- Results show, in general, performance aligns with traditional views of expected performance
- Selection of the lateral force resisting system has a significant influence on performance
- All of the systems can meet the traditional performance expectations, with careful selection of the design story drift and lateral strength

FEMA P-58-1 Implications for Design—Summary

- ASCE 7 drift limits provide life safety protection; may not provide protection to property in stronger ground motion
  - Especially for buildings designed near the maximum permitted story drift limits
- Designing to Risk Category IV provides improvement in structural performance due to the lower drift limits, and higher design forces for nonstructural components