Expected Performance of New Code-Compliant Buildings in California

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Current Building Code

- Life safety
- Limit cost
- Limit recovery time
Current Building Code

- Life safety
- Limit cost
- Limit recovery time

Safe but disposable!
Outline

- Methods
  - FEMA P-58
  - REDi
- 8-story office building example
- Enhanced design
- Resilient design
- **Probabilistic** performance prediction
- **Building-specific** analysis
- Output results:
  - Repair costs
  - Repair time
  - Safety
FEMA P-58 Modeling Approach

- Ground Motion Hazard
- Structural Response
- Economic Loss
- Casualties
- Component Damage
- Repair Time
- Recovery Levels
  - Re-occupancy
  - Functional Recovery
  - Full Recovery
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Example Code Conforming Building

- **8-story office building**
  - Northridge, CA
  - New design
  - Steel Special Moment Frame

**Design Event:** 475 yr. return period

**Rare Event:** 2475 yr. return period
- 8-story office building
  - Northridge, CA
  - New design
  - Steel Special Moment Frame

\[
\text{Loss Ratio} = \frac{\text{Repair Cost}}{\text{Building Replacement Cost}}
\]

![Bar chart showing loss ratios for design and rare events]
8-story office building
- Northridge, CA
- New design
- Steel Special Moment Frame

Code Conforming Building Downtime

![Diagram showing Impeding Factors, Repair Time, and Functional Recovery]

- Design Event: 8 mo.
- Rare Event: > 1 yr.
- 8-story office building
  - 12 CA cities

Design Event

- ~5-20%

Rare Event

- ~10-80%
- 8-story office building
  - 12 CA cities

**Design Event**

Downtime (months):
- 7-10 mo.

**Rare Event**

Downtime (months):
- 7-18 mo.
Wide range of building types

- Design Event
  - 5-25%
  - 6-12+ mo.
- Rare Event
  - 10-80%
  - 1.5+ yrs.

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Critical Facility - Risk Category IV

- Seismic Importance Factor, $I_e = 1.5$
- Component Importance Factor, $I_p = 1.5$
- Drift Limit = 1%

Remember: Building strength is increased by $I_e/R$!
Enhanced Repair Cost

~5-20% ~10-45%

Design Event Rare Event
Enhanced Design Downtime

~7 mo.

Design Event

~7-12 mo.

Rare Event
Enhanced vs. Code Conforming

Significant Downtime

- Mean Loss Ratio
  - Design Event
  - Rare Event

- Downtime (months)
  - Design Event
  - Rare Event
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- Resilient design
Resilient Design

- Limit repair cost & downtime
  - Set specific performance goals
  - Assess where damage will occur
  - Strengthen/stiffen as needed
  - Iterate
Quick Resilience-Based Design Example

• Project: Municipal office building
• Building: Design a 10-story RC Wall (coupled core), office occupancy
• Site: LA high-seismic, $S_{DS} = 1.1g$, $S_{DI} = 0.6g$.
• Design Objectives: USRC five-star performance in all categories
  – Repair Cost < 5%
  – Functional Recovery Time < 5 days
  – Safety – high (low collapse, no/few injuries, good egress)
• Showing example for design, but also applicable to risk assessment.
Quick Resilience-Based Design Example

• **Step #1:** Start with code-compliant design to see where that gets us...
  - Repair Cost = 8% [4-star]
  - Recovery Time = 6.5 months [3-star]
    - 3.0 months – mechanical and electrical (HVAC, lighting, switchgear)
    - 2.0 months – structural (mostly walls)
    - 1.5 months – non-structural drift-sensitive (partitions, stairs, piping, fire sprinklers)
  - Safety [3-star]
    (discussed at the end)
Quick Resilience-Based Design Example

- **Step #2:** Design wall to be “essentially elastic” (very strong) and remove coupling beams (need NO DAMAGE THAT WILL REQUIRE REPAIR).

Staggered Shear Wall Openings to avoid Link Beams
Step #3: Design mechanical and electrical components to be functional at the 10% in 50 year (anchorage, equipment, lighting, etc.).

• Result for Steps #2-3:
  – Repair Cost = 5.5% [still 4-star]
  – Recovery Time = 2.5 months [still 3-star]
    • 1.0 month – slab-column connections
    • 1.5 months – partition walls
Quick Resilience-Based Design Example

**Step #4:** Reduce the shear on the slab-column connections.

**Step #5:** Use less damageable partition walls.

- **Result:**
  - Repair Cost = 3.5% [now a 5-star]
  - Recovery Time = 6 weeks [still a 3-star]
  - 3 weeks – slab-column connections
  - 3 weeks – partition walls
**Step #6:** Stiffen the building (longer walls, more coupling, etc.). Reduces the maximum drifts from around 1.4% to 1.0%.

- **Result:**
  - Repair Cost = 2% [5-star]
  - Recovery Time = 2 days [moved from 3-star to 5-star]

**Step #7:** Now that building has less drift, move back to higher shear slab-column connections.

- **Result:**
  - Repair Cost = Still 2% [still a 5-star]
  - Recovery Time = Still 2 days [still a 5-star]
• **Step #8:** Now that building has less drift, see if we can move back more damageable partition walls.

• Result:
  – Repair Cost = 2.5% [5-star]
  – Recovery Time = 2 weeks [would moved down to 4-star]

**Move back to less damageable partition walls to keep a 5-star recovery time.**
• **Step #9**: Safety checks

• Overview of safety checks:
  
  – **Fatalities.** Show good collapse safety (limit fatalities).
  
  – **Injuries.** Check injury prediction from FEMA P-58 (would require additional non-structural bracing to get to 5-star).
  
  – **Residual Drifts.** Very low (essentially elastic).
  
  – **Stairs and Egress.** Check probability of non-functionality (direct outputs from the FEMA P-58 detailed results).
• **Final Design Outcomes (for 10% in 50 year motion):**
  
  – **Repair Cost:** 2% [5-star] (*Typically 10-20% for new code*)
  
  – **Recovery Time:** ~0 days [5-star] (*Typically 6-9mo. for new code*)
  
  – **Safety:** Low fatality+injury risk and good egress [5-star]

• This example was for **new resilient design**, but FEMA P-58 offers this same level of building-specific detail when doing **risk assessments**.