Resilient Design & Risk Assessment using the FEMA P-58 Analysis Method and SP3 Software

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Stanford University CEE 288 | March 2, 2021

Planned Agenda for Today

- Quick orientation to FEMA P-58 and applications
- Recent innovative projects being done using this new FEMA P-58 method
- More detail on the FEMA P-58 method
- SP3 Demo
- Questions
- Design example (if time permits)

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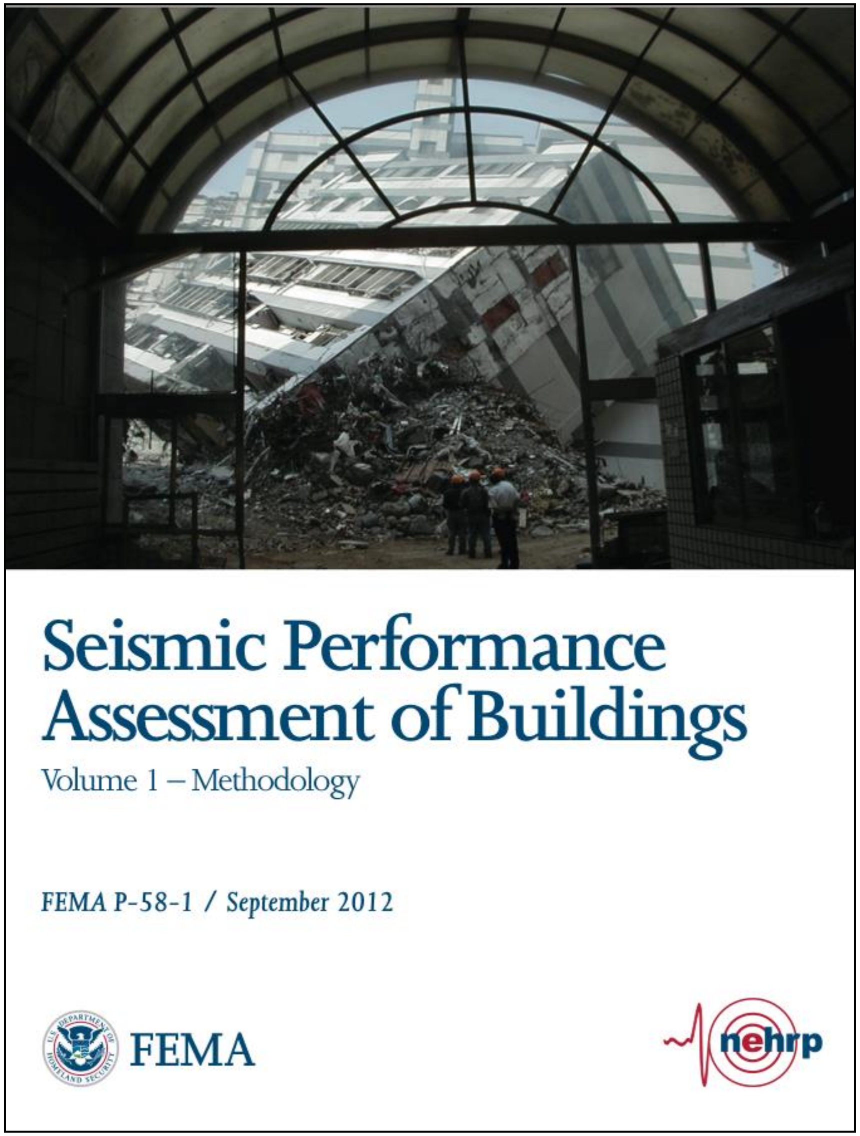
FEMA P-58: Overview

- FEMA P-58 is a probabilistic performance prediction methodology (15 year, $16M+ invested, ~100+ on the team)
- FEMA P-58 is tailored for <u>building-specific</u> analysis (in contrast to most risk assessment methods)
- FEMA P-58 output results:
  - Repair costs
  - Repair time
  - Safety: Fat & Injury



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FEMA P-58 and Enabling Software

FEMA P-58 provides the **comprehensive** and **standardized** building-specific risk assessment.

SP3 software provides a user-friendly software to integrate all steps in a FEMA P-58 risk assessment.

The initial assessment should take a **couple hours** and **not days or weeks**.

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New Design: Long Beach Civic Center and Port Facility

Figure Source: SOM/NYASE 2016 SEAOC presentation

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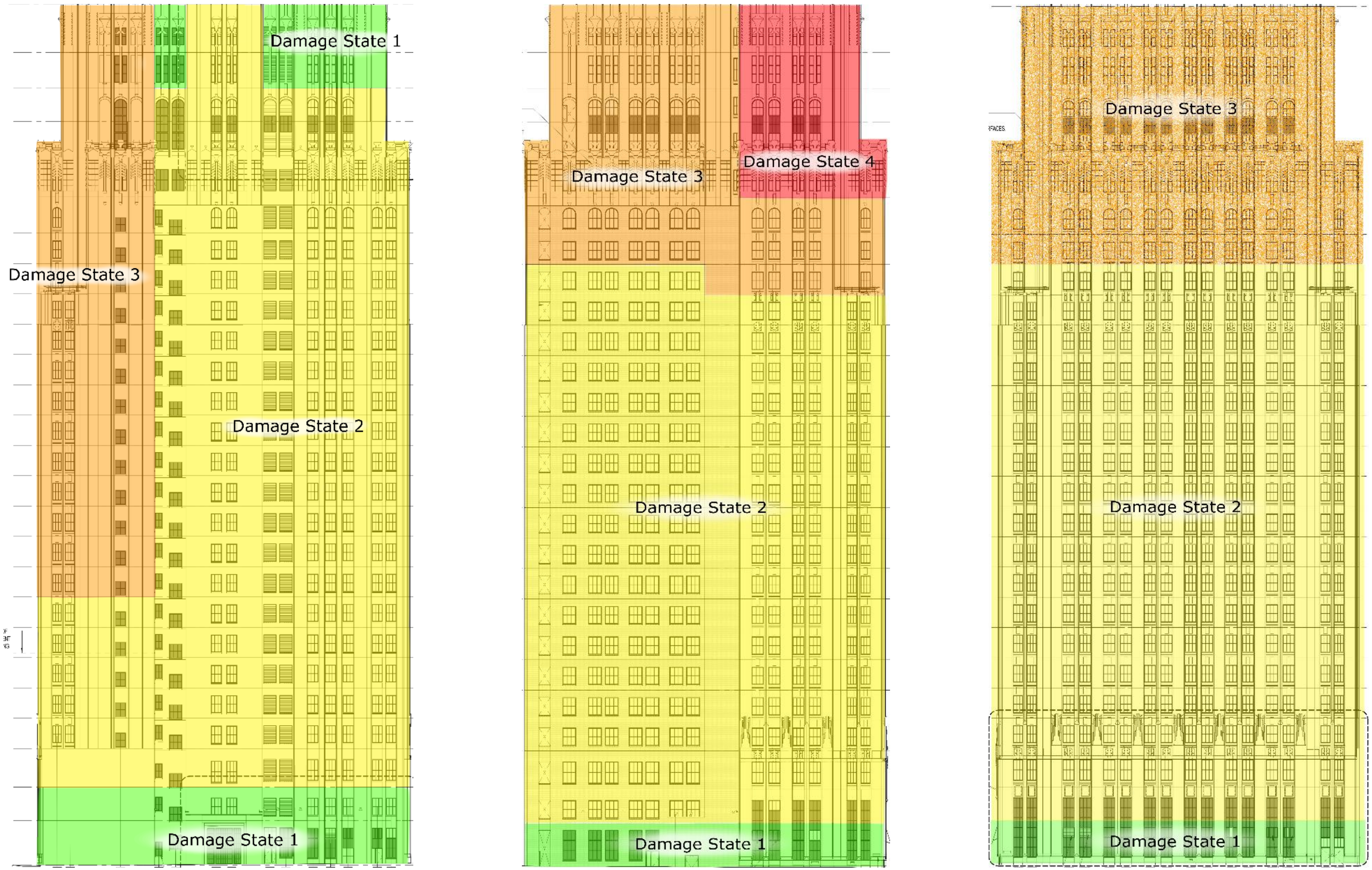
Recent Innovative Projects with P-58/SP3

Risk Assessments: Property Transaction Due-Diligence



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Risk Assessments: Detailed Assessments of High-Value Items

Risk to high-value content.

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Recent Innovative Projects with P-58/SP3

Risk Assessments: Detailed Assessments of High-Value Items

Post-earthquake operability of production facilitates.

Risk t

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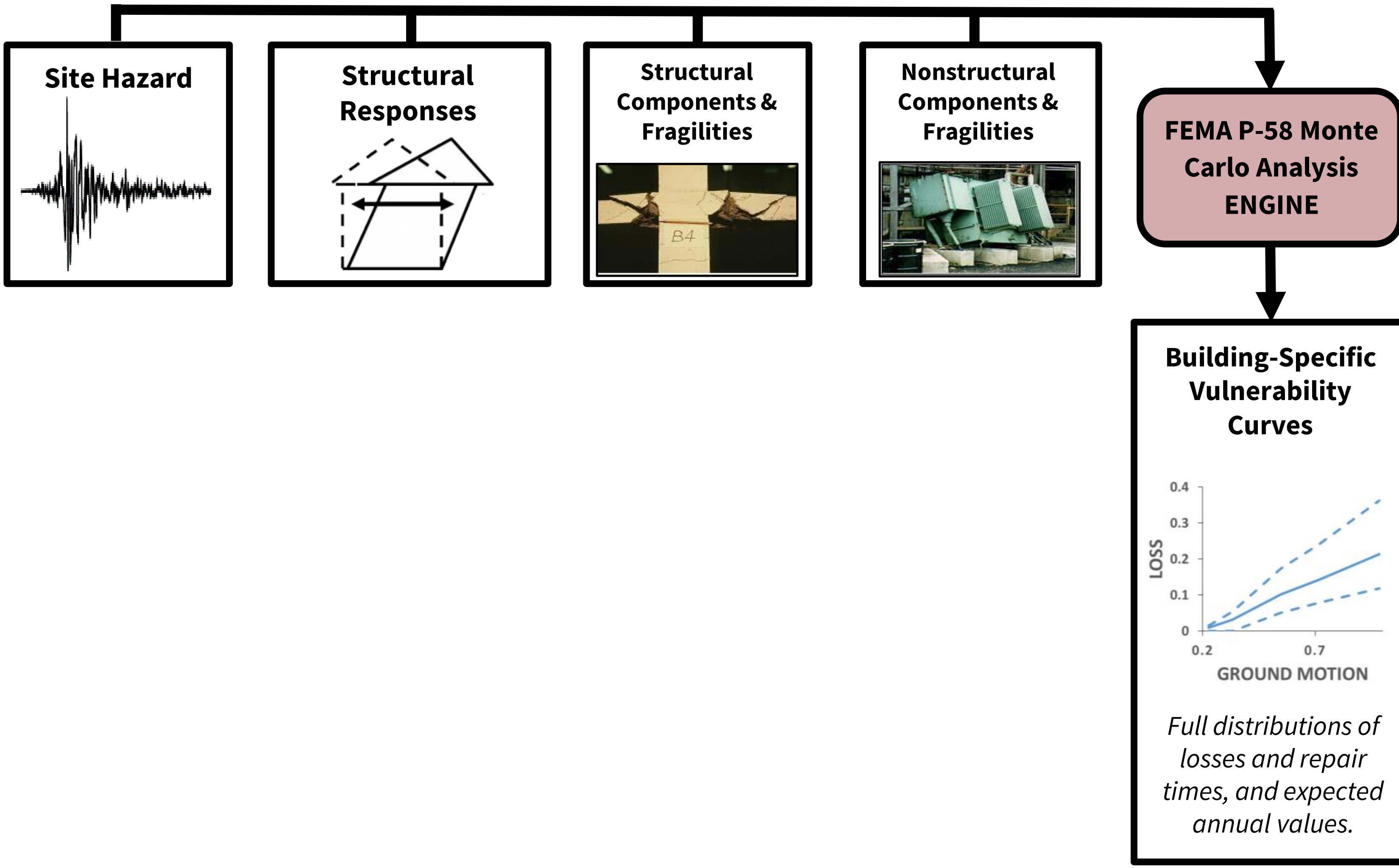
FEMA P-58: Detailed Steps of Method



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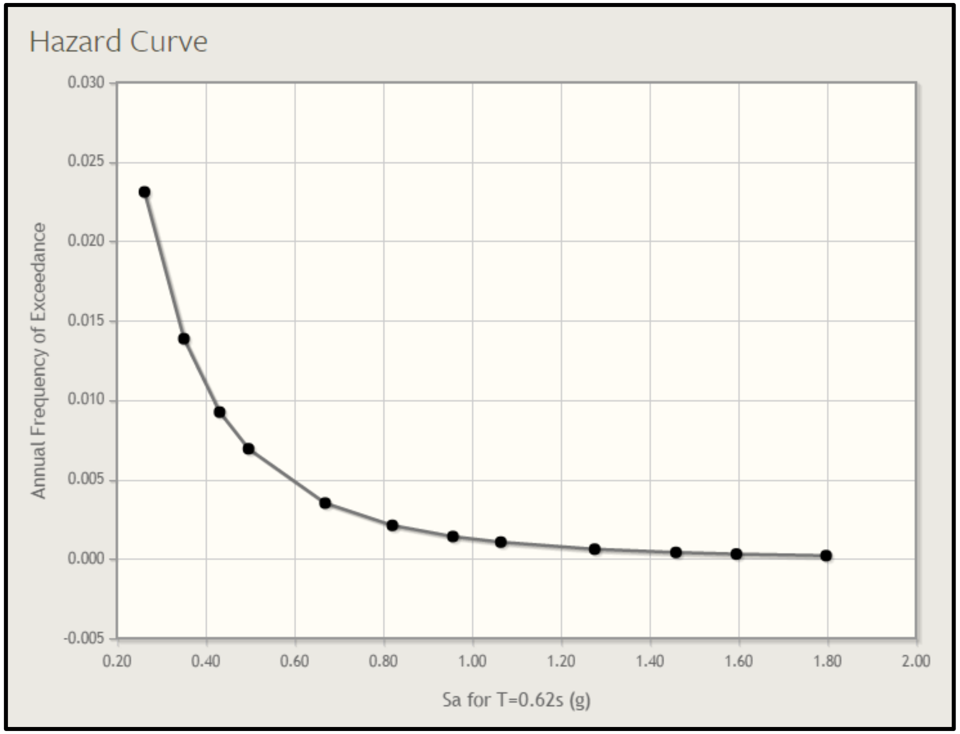
FEMA P-58: Ground Motions

- **Step 1:** Define ground motion hazard (with soil)
  - Option #1: SP3 can provide curve (given an address)
  - Option #2: User-specified curve



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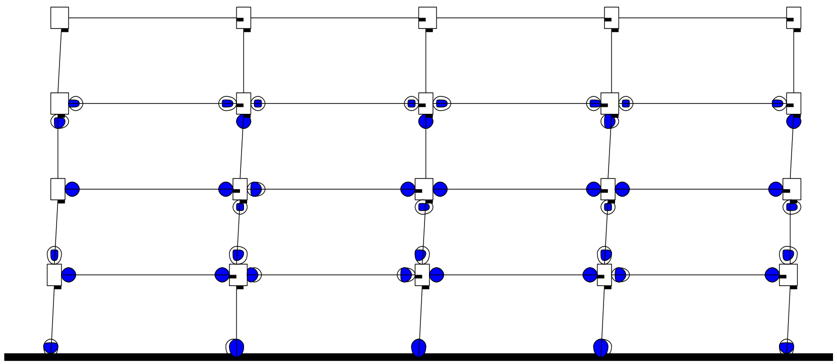
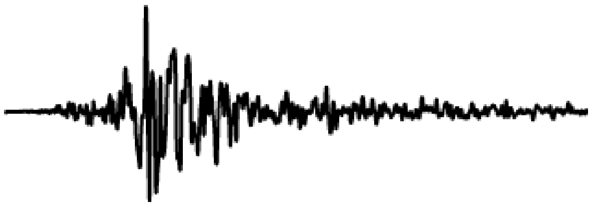
FEMA P-58: Structural Response

- **Step 2:** Predict "engineering demand parameters"
  - Story drift ratio at each story
  - Peak floor acceleration at each floor
  - For wall buildings, also wall rotations and coupling beam rotations





Option #1: Response-history structural analysis

Option #2: Median response results

Option #3: Statistically calibrated predictive equations (SP3 Structural Response Prediction Engine)

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FEMA P-58: Component Damage

- **Step 3:** Quantify component damage

  First, establish what components are in the building. Types and quantities of can be specified or estimated from building size and occupancy type

Windows

Piping

Partitions

Structural components

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FEMA P-58: Component Damage

- **Step 3:** Quantify component damage

We end up with a list of component types, quantities and locations

Structural Components

ACTION	FRAGILITY ID	FRAGILITY NAME	FRAGILITY QUANTITY	FRAGILITY LOCATION
Expand | | |	B1049.022a	RC Slab Column Connection	16	All stories
Expand | | |	B1041.082a	Non-conforming MF, Conc Col & Bm	4	All stories
Expand | | |	B1041.082b	Non-conforming MF, Conc Col & Bm	8	All stories
Expand | | |	B1041.082a	Non-conforming MF, Conc Col & Bm	4	All stories
Expand | | |	B1041.082b	Non-conforming MF, Conc Col & Bm	8	All stories

Non-structural Components

ACTION	FRAGILITY ID	FRAGILITY NAME	FRAGILITY QUANTITY	FRAGILITY LOCATION
Expand | | |	B2022.002	Curtain Walls	38.567	All stories
Expand | | |	B2022.002	Curtain Walls	38.567	All stories
Expand | | |	C1011.001a	Wall Partition, Metal Stud	4	All stories

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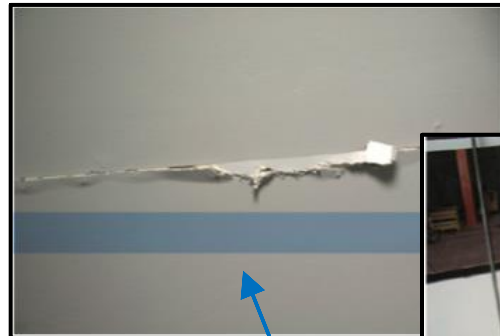
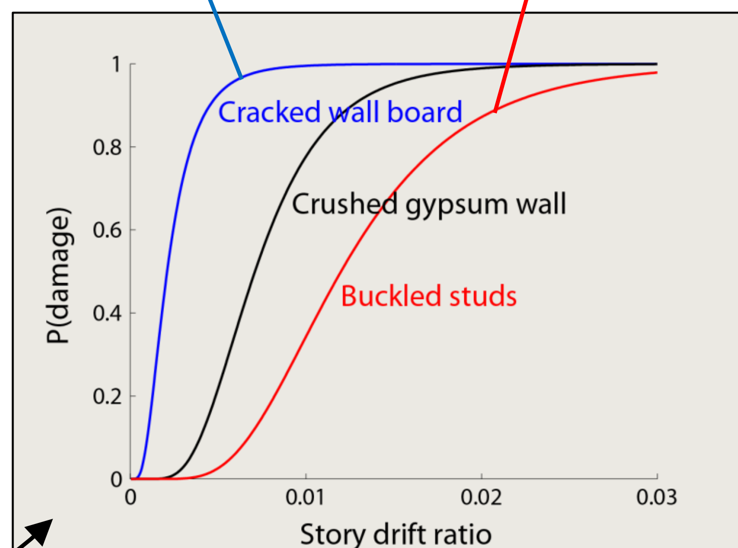
- **Step 3:** Quantify component damage

Each component type has a “fragility function” that specifies the probability that a structural demand causes damage





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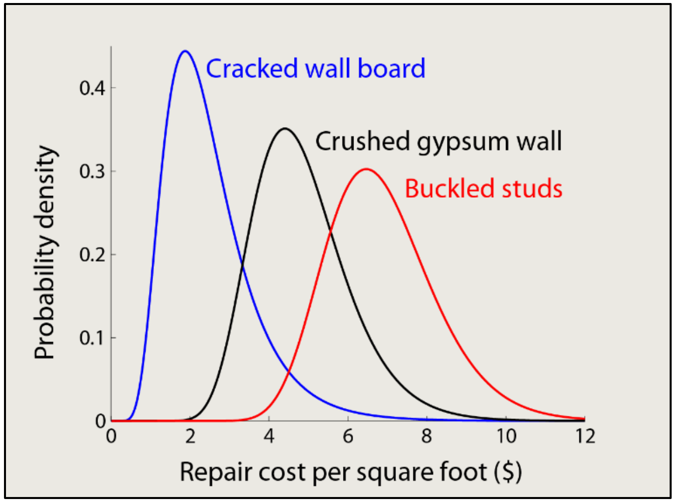
FEMA P-58: Consequences of Damage

- **Step 4:** Quantify consequences of the component damage (component repair costs, repair times, etc.).



	Cost per 100 ft.	Labor per 100 ft.
Cracked wallboard	$2,730	24 person-hours
Crushed gypsum wall	$5,190	45 person-hours
Buckled studs	$31,100	273 person-hours

These are median values—each also has uncertainty

Fragility functions have been calibrated for hundreds of components from test data, and repair cost and labor has been developed by cost estimators.

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- **Step 5:** Aggregate to building-level consequences

Repair costs are the sum of component repair costs (considering volume efficiencies)

Windows	**$26,892**
Partitions	$43,964
Piping	$5,456
Structural Components	$77,920
…	…

Sum = $253,968

Recovery time is aggregated from component damage, but is more complex (mobilization, staffing, construction sequencing, …)

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- **Step 5:** Aggregate to building-level consequences

For a given building and ground shaking intensity, repeat the following steps 2,000-10,000 times!

1. Simulate each structural response parameter
2. Simulate damage to each component
3. Simulate repair costs and repair time for each component
4. Aggregate to compute total repair cost and recovery time

We can then look at the mean cost, 90th percentile, etc.

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FEMA P-58: Summary

- **Step 1:** Site Hazard
  - Soil and hazard curve
  - Ground motions (if needed)
- **Step 2:** Structural Responses
  - Option #1: Response-history
  - Option #2: Median responses
  - Option #3: Predictive equations
- **Step 3:** Damage Prediction
  - Contents
  - Fragility curves
- **Step 4:** Loss Estimation (loss curves & other consequences)

Step 5: Aggregate to building-level consequences

Thousands of Monte Carlo simulations

The simulations provide detailed statistical information on building performance.

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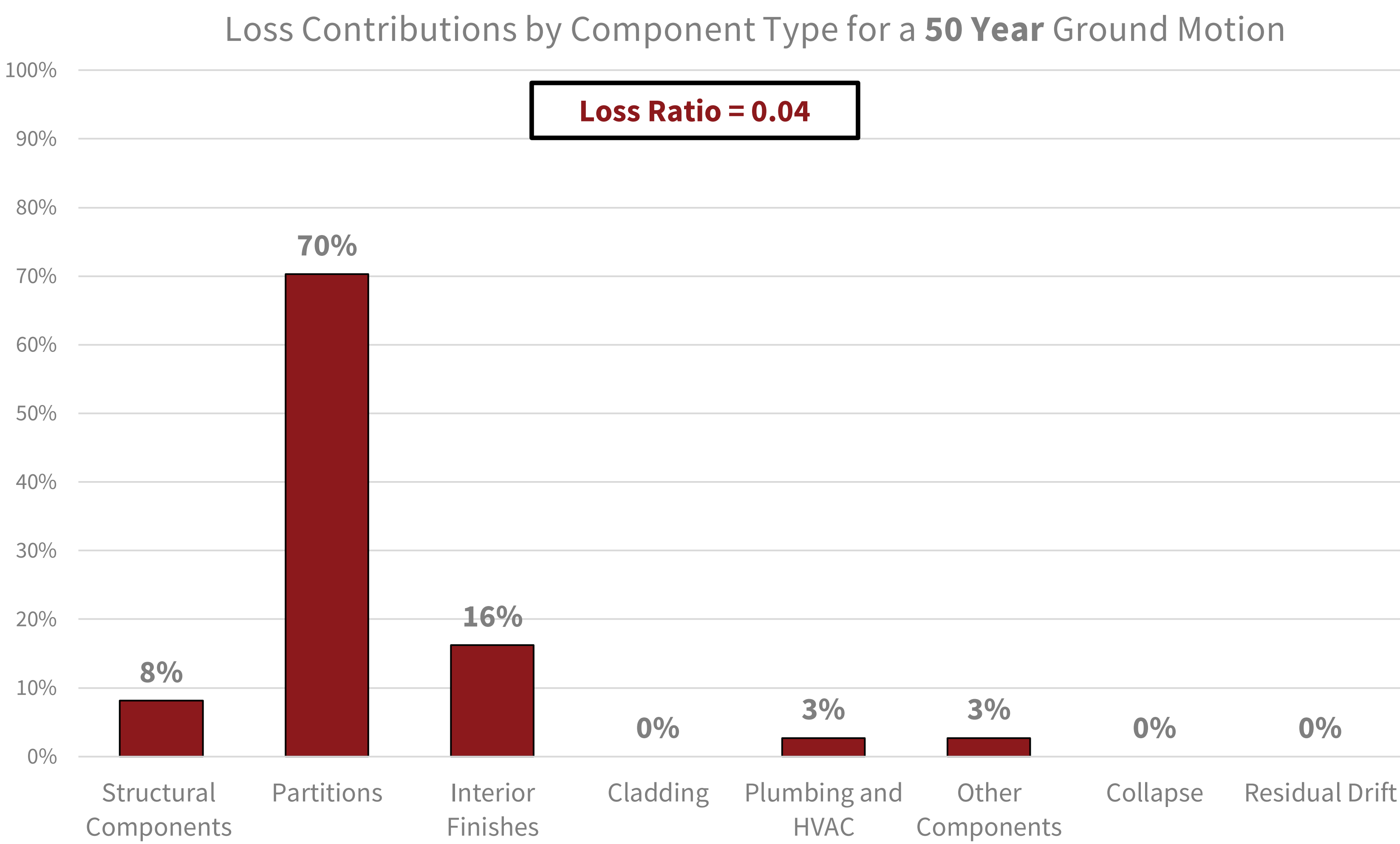
Output Examples: Repair Cost

8-story concrete frame in Los Angeles



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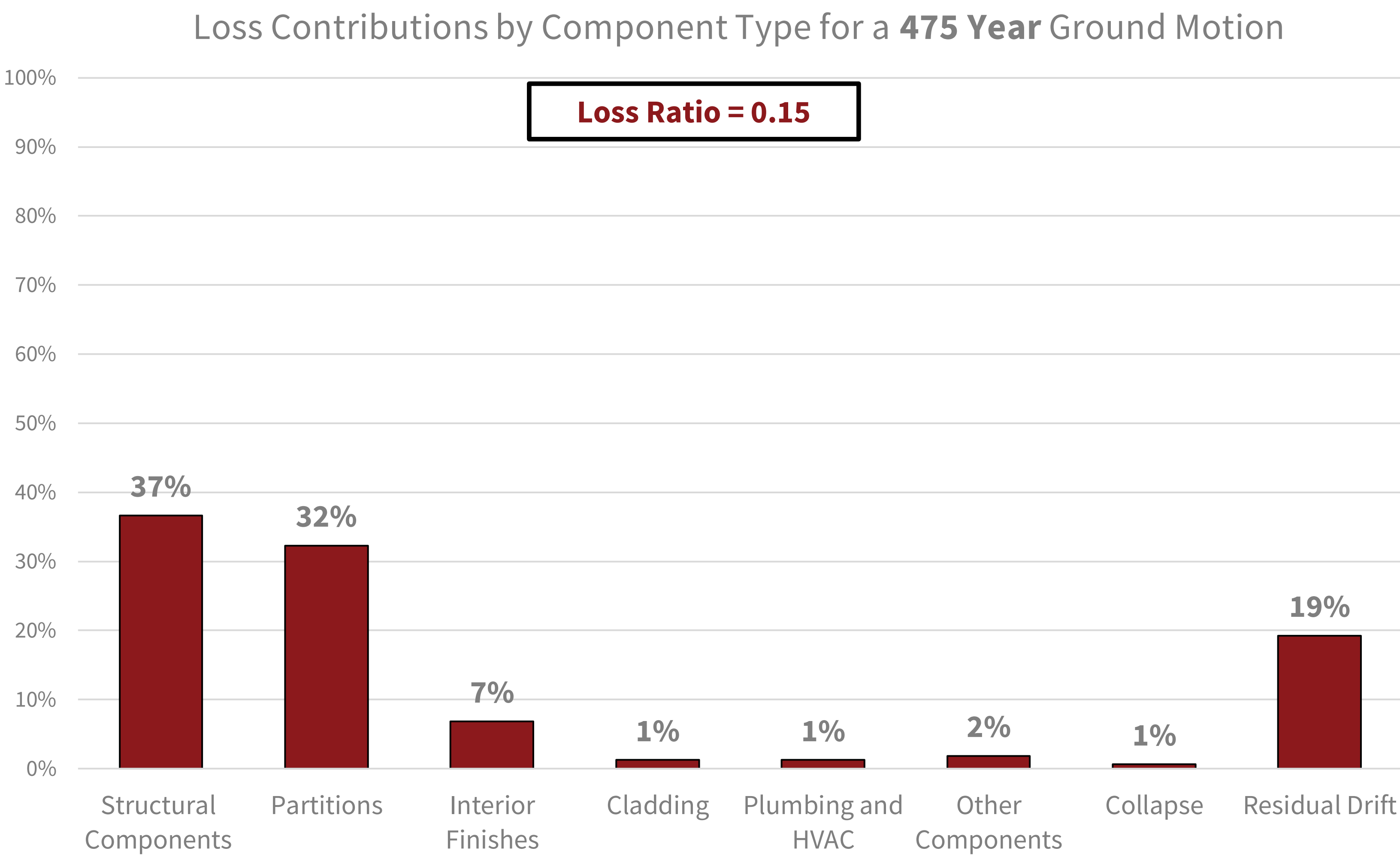
Output Examples: Repair Cost

8-story concrete frame in Los Angeles



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Output Examples: Repair Cost

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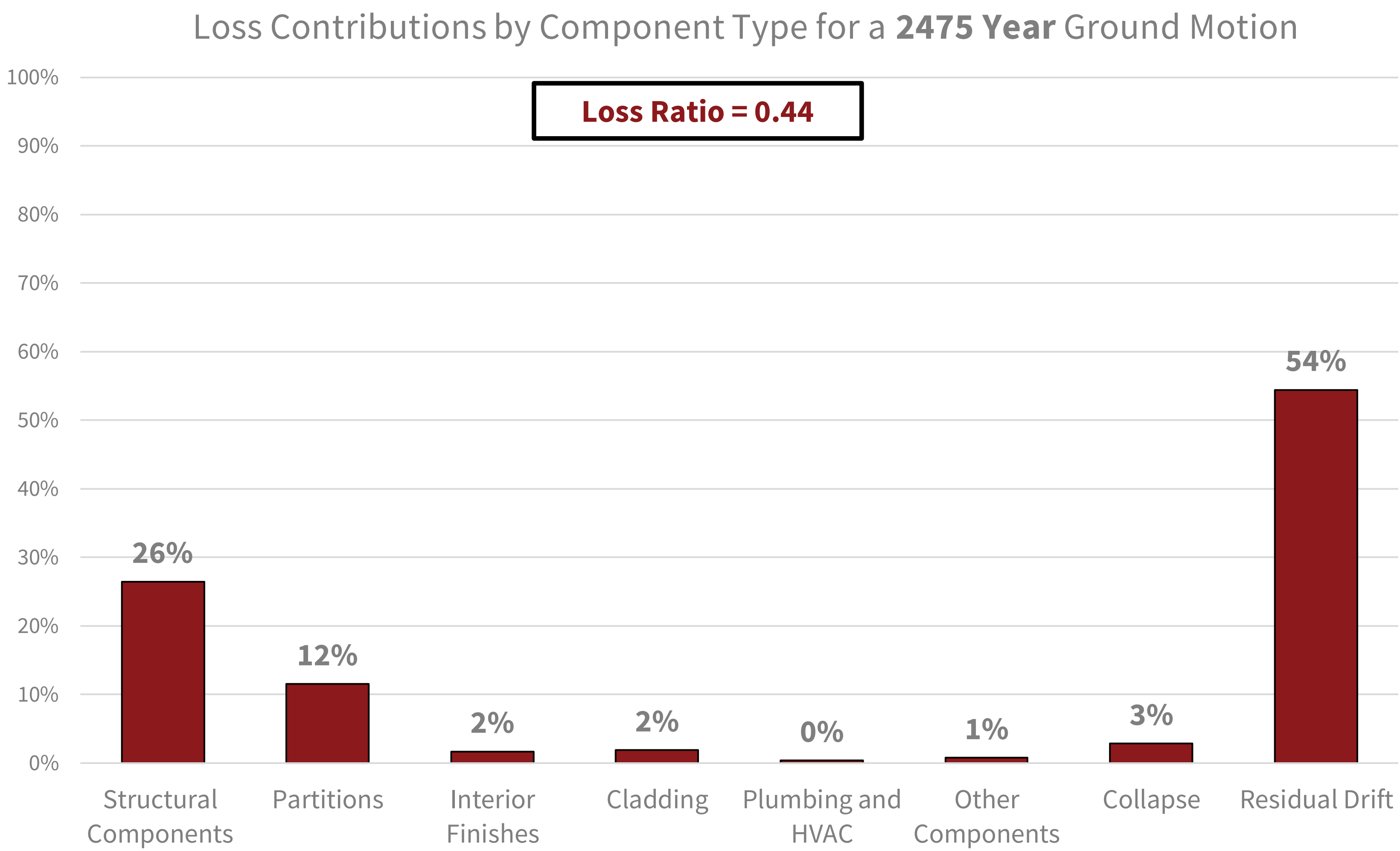

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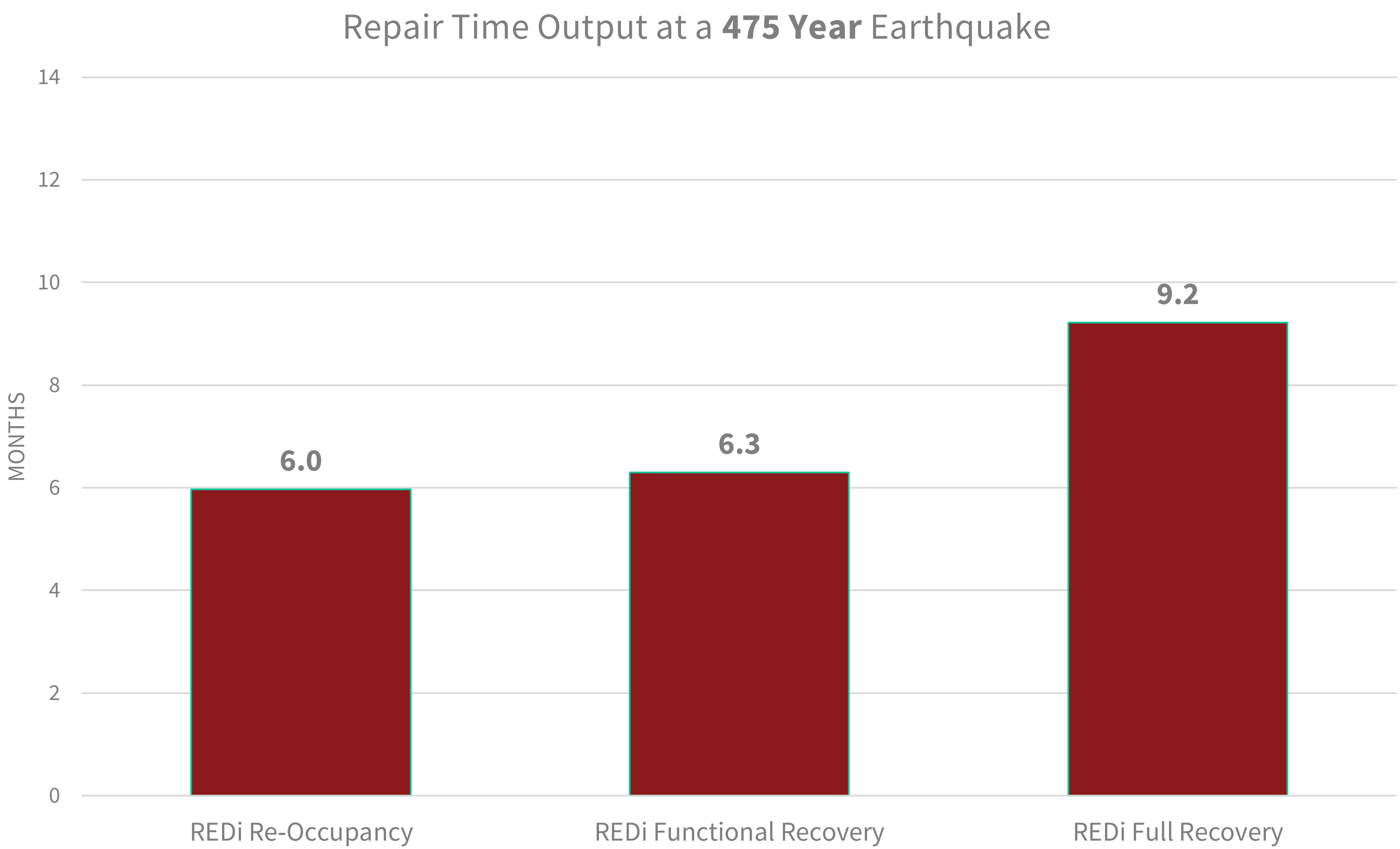
Output Examples: Repair Times

- Average Repair Times (REDi, 2013):



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Overview of SP3

SP3-RiskModel
For individual-building risk assessment

Express
For rapid pre-screen building risk estimation

Standard
For streamlined building-specific risk assessment

Advanced
For in-depth building-specific risk assessment

SP3-Batch
For risk assessment of a large portfolio of buildings

SP3-SiteHazards
For assessment of site hazards

SP3 Risk Modeling ENGINE
Advanced seismic risk assessment technology, deployed on the cloud, which enables all of the modules on the SP3-Platform.
Based on FEMA P-58, but with extensive automation, to enable building/site-specific risk modeling with any level of input information.

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Overview of SP3

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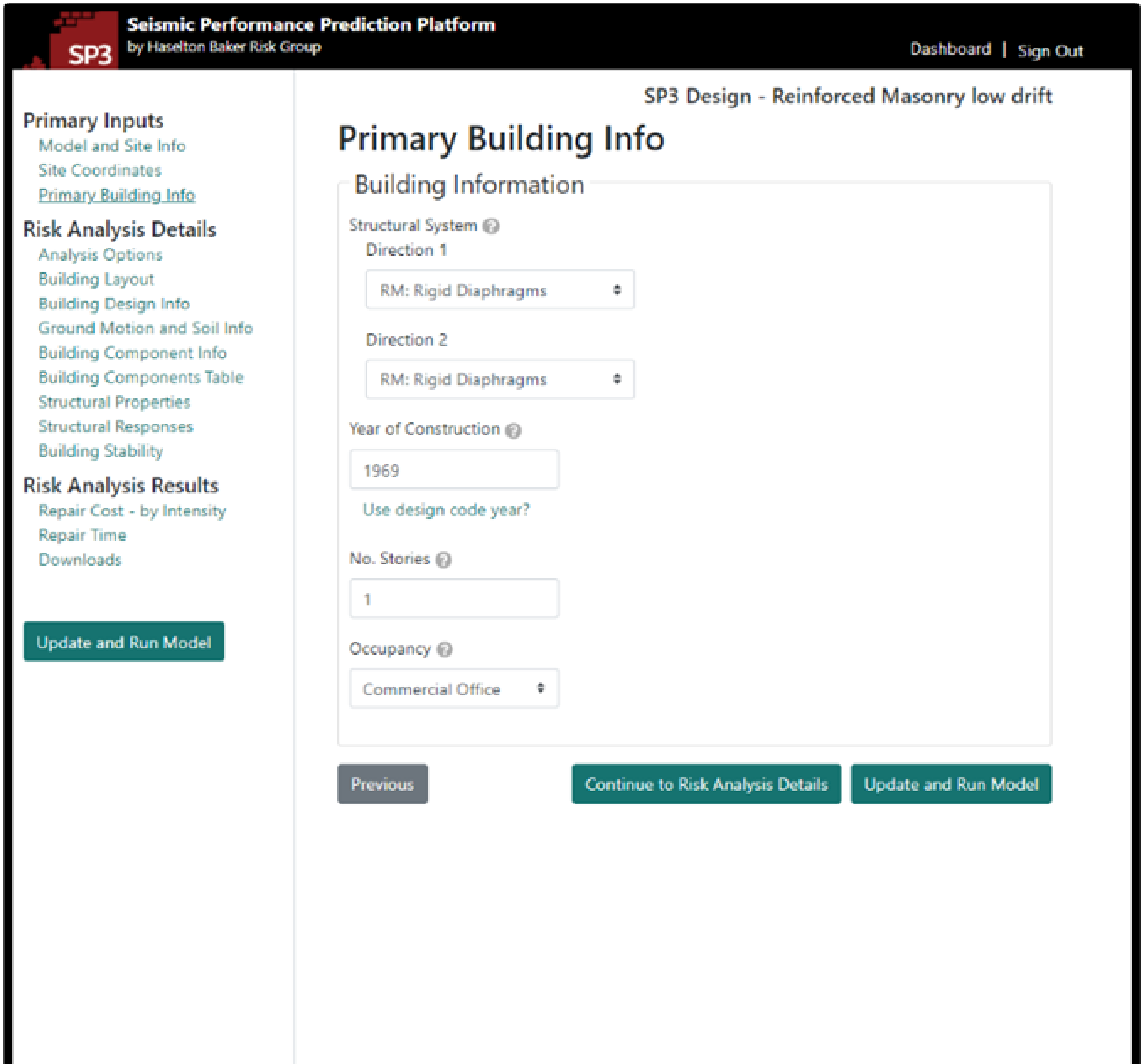
SP3-RiskModel Demo



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Q&A

- Thank you for your time.
- Our goal is to support adoption of resilience-based design and risk assessment, and we welcome feedback and suggestions.

- Time for questions!

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EXTRA

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Quick Resilience-Based Design Example

Approach: Iterative design using FEMA P-58.

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
  - 1.5 months – other non-structural (e.g. partitions, stairs, piping, fire sprinklers)
- Safety [3-star]
  (not discussed here)

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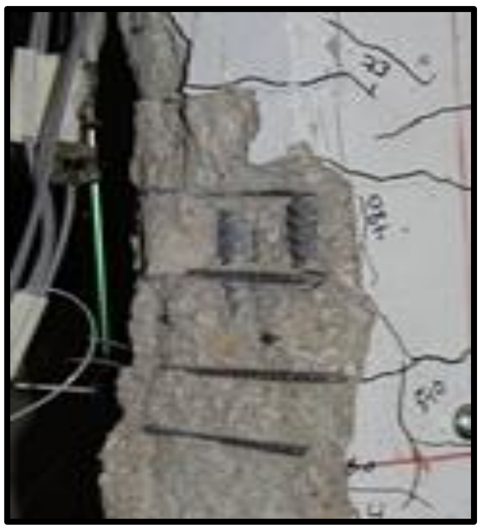
Quick Resilience-Based Design Example

Step #2: Design wall to be "essentially elastic" (very strong) and remove coupling beams (so no structural damage at design level).



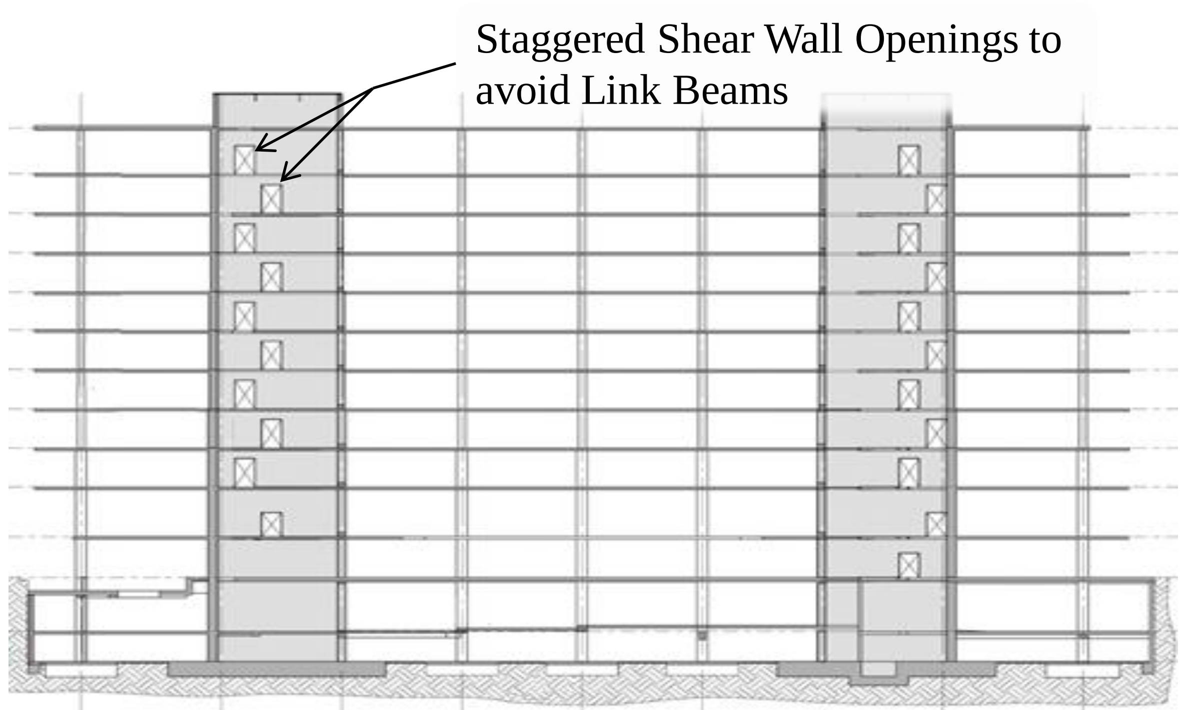


Figure Source: SOM/NYASE 2016 SEAOC presentation

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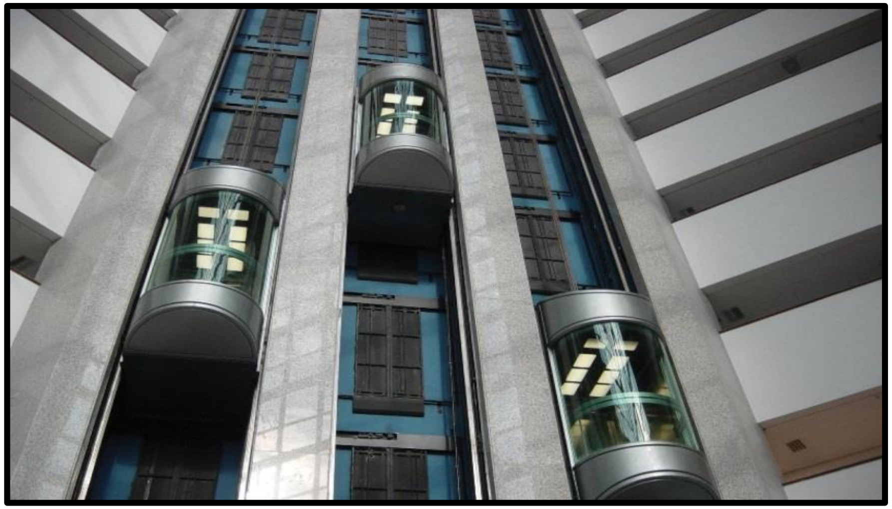
Quick Resilience-Based Design Example

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



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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

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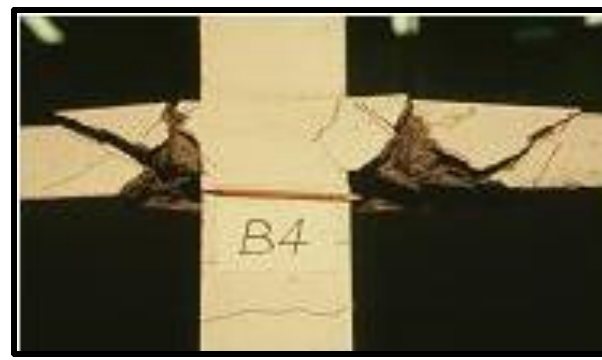
Quick Resilience-Based Design Example

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 = 0 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 0 days [still a 5-star]



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Quick Resilience-Based Design Example

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.

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Direct P-58 Resilience-Based Design Example

- Final Design Outcomes:
  - **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 was a project for **new design**, but FEMA P-58 offers this same level of building-specific detail when doing **performance assessments** as well.

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