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

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www.sp3risk.com

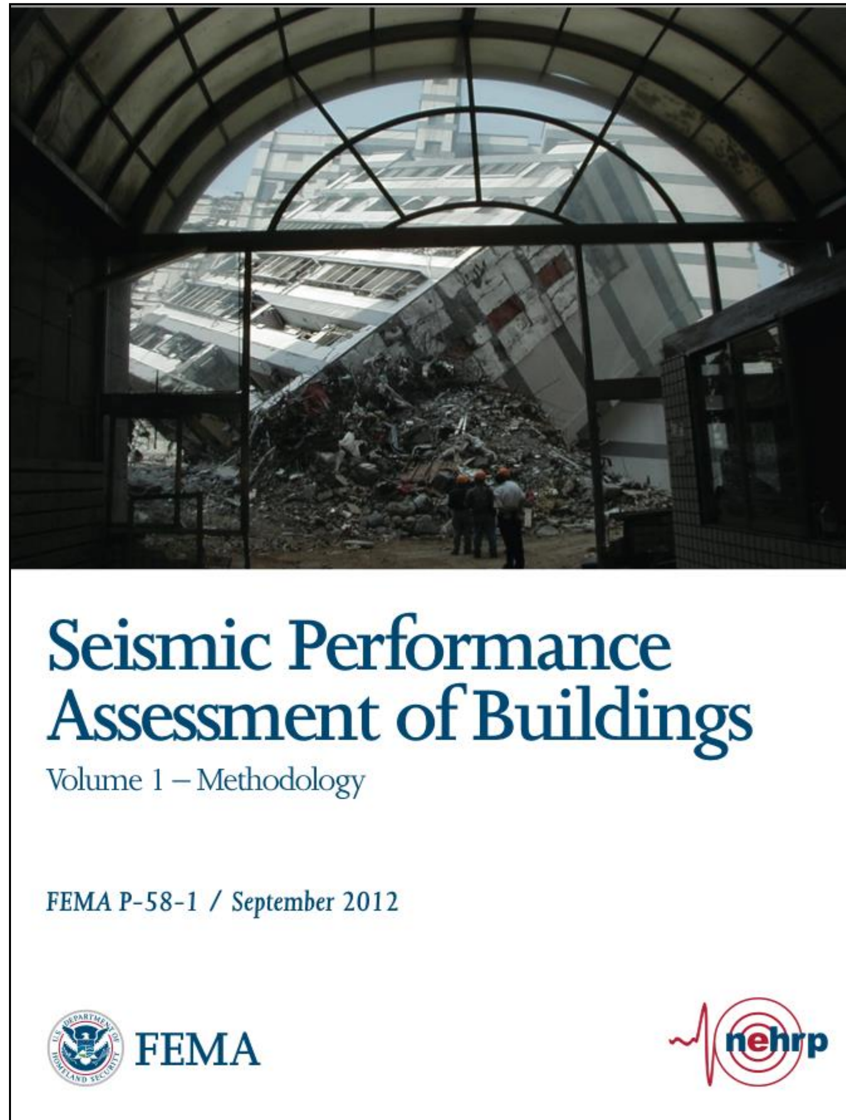
Engineering Risk Analysis Class @ Texas A&M | April 29, 2021

Planned Agenda for Today

- Overview of FEMA P-58 risk analysis methodology
- Examples of project uses of FEMA P-58
- SP3 software overview
- SP3-RiskModel demo
- Resilient design example (if time permits)
- Discussion Q&A

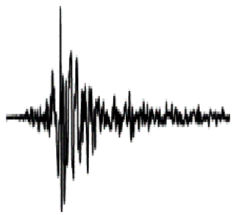
FEMA P-58: Overview

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

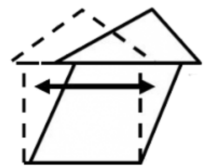


FEMA P-58: Detailed Steps of Method

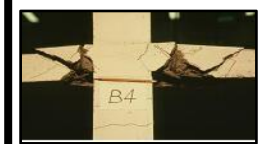
Site Hazard



Structural Responses



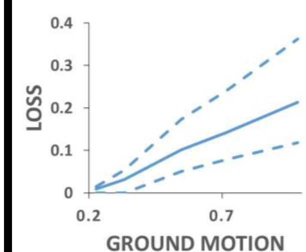
Structural Components & Fragilities



Nonstructural Components & Fragilities

FEMA P-58 Monte Carlo Analysis ENGINE

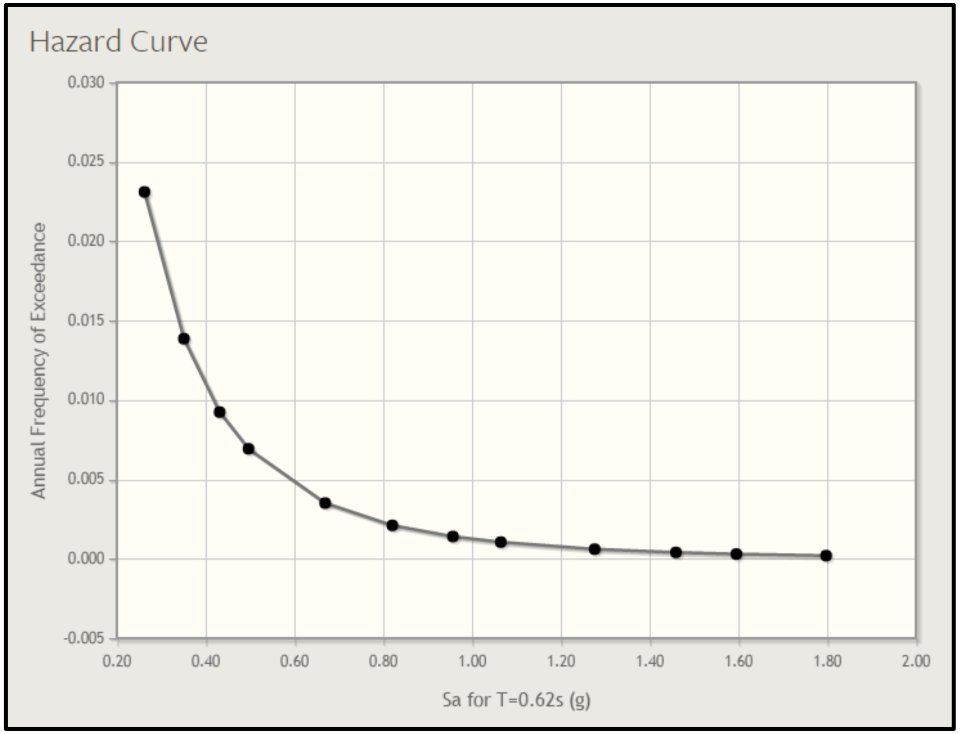
Building-Specific Vulnerability Curves



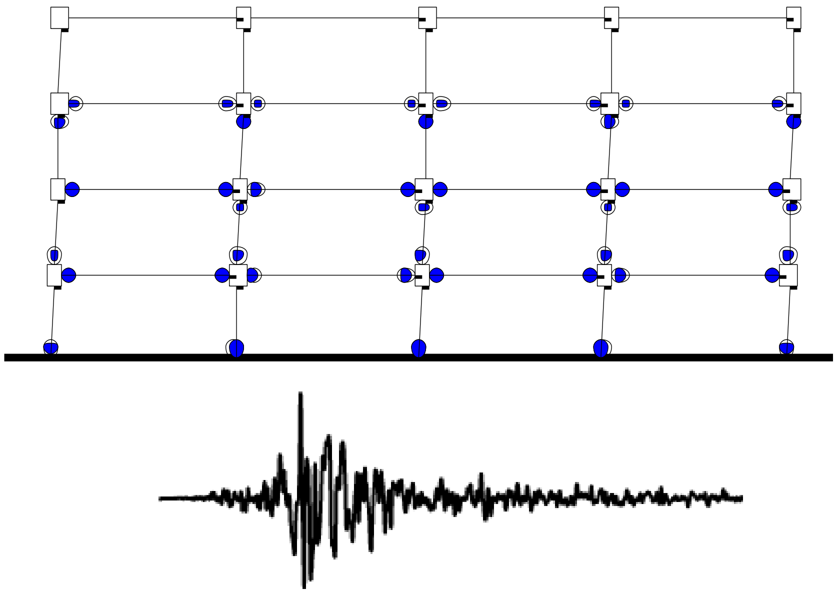
Full distributions of losses and repair times, and expected annual values.

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



- **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)

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

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

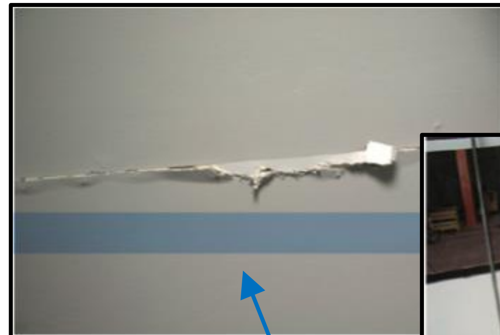
Non-structural Components

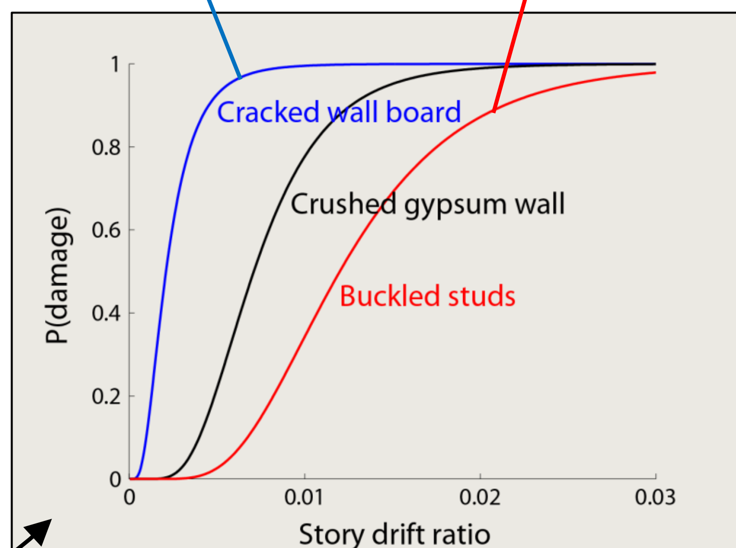
ACTION	FRAGILITY ID	FRAGILITY NAME	FRAGILITY QUANTITY	FRAGILITY LOCATION
Expand | | |	B2022.002	Curtain Walls	38.567	All stories
Expand | | |	B2022.002	Curtain Walls	38.567	All stories
Expand | | |	C1011.001a	Wall Partition, Metal Stud	4	All stories

FEMA P-58: Component Damage

- **Step 3:** Quantify component damage

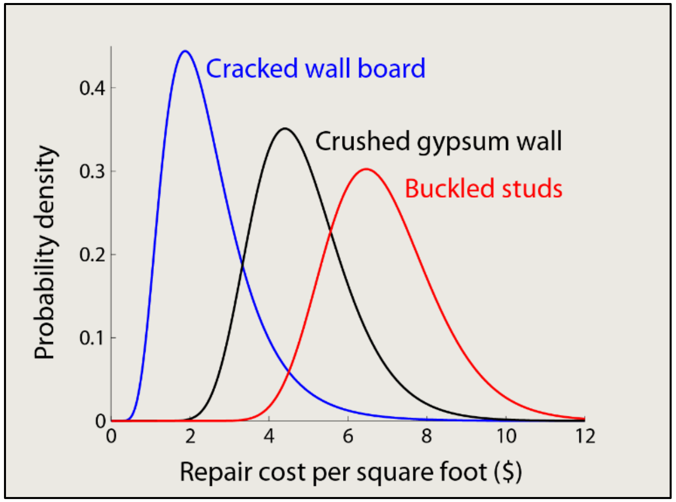
Each component type has a “fragility function” that specifies the probability that a structural demand causes damage





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.

FEMA P-58: Building-Level Consequences

- **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, …)

- **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.

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)

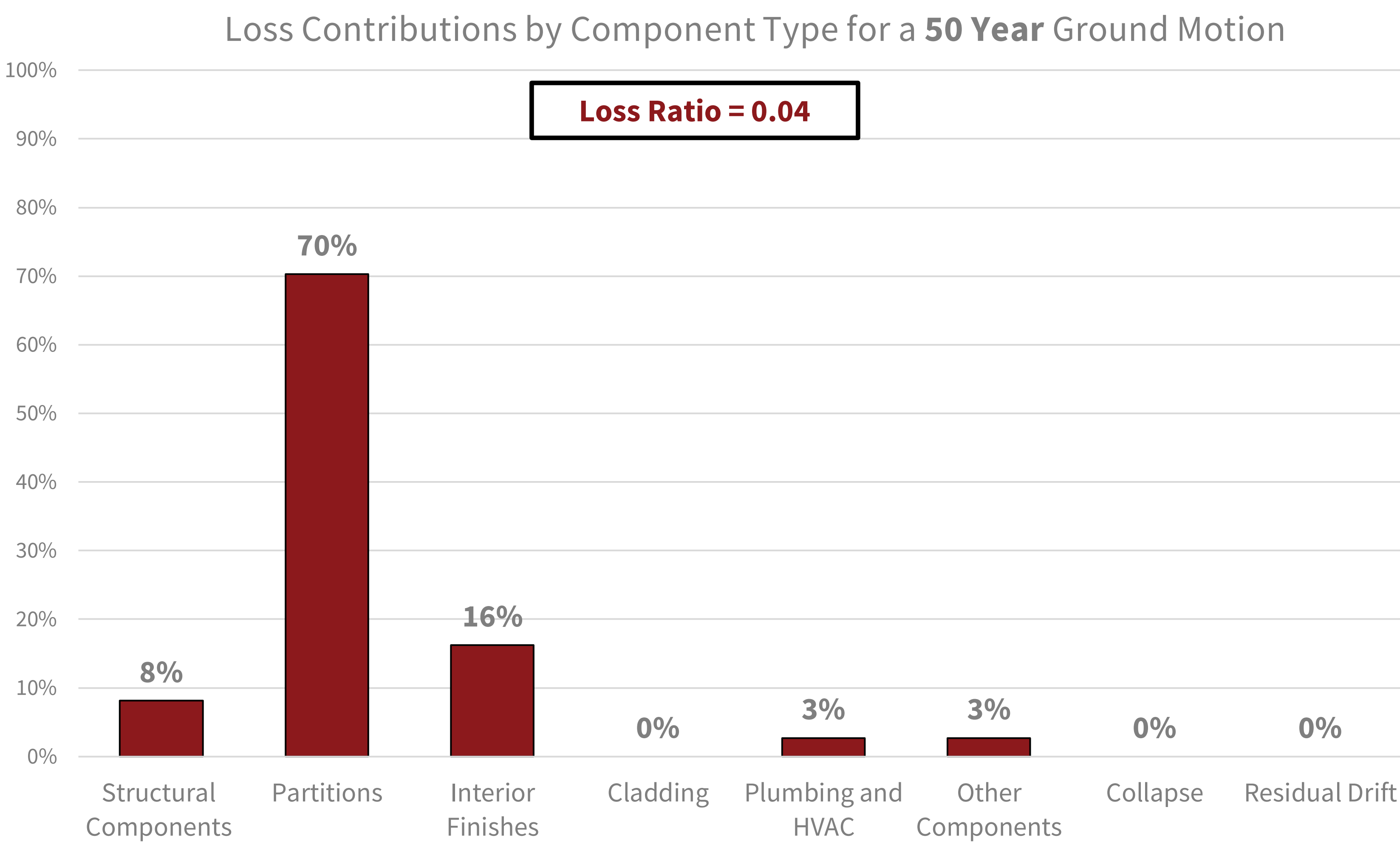
Step 5: Aggregate to building-level consequences

Thousands of Monte Carlo simulations

The simulations provide detailed statistical information on building performance.

Output Examples: Repair Cost

8-story concrete frame in Los Angeles



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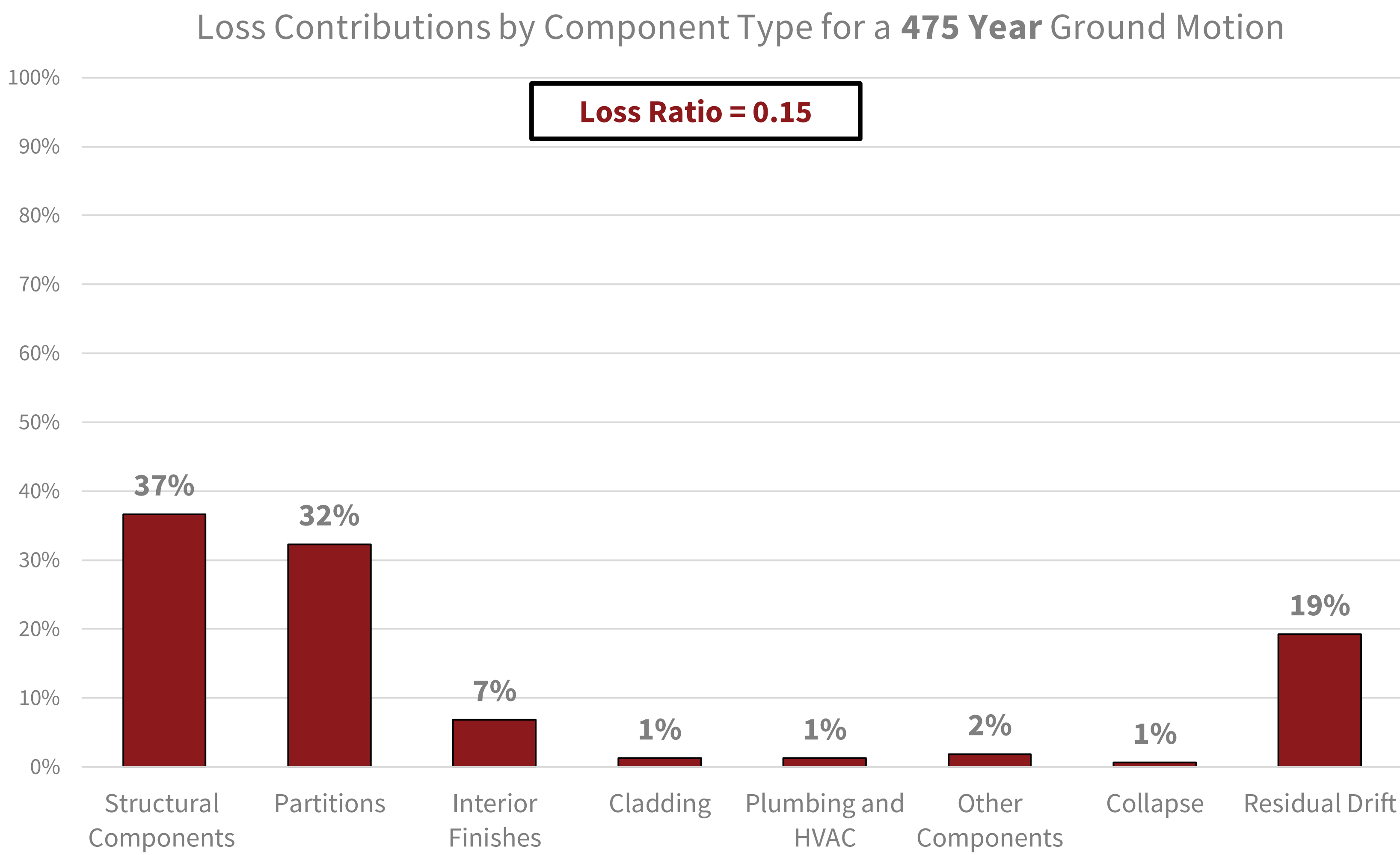

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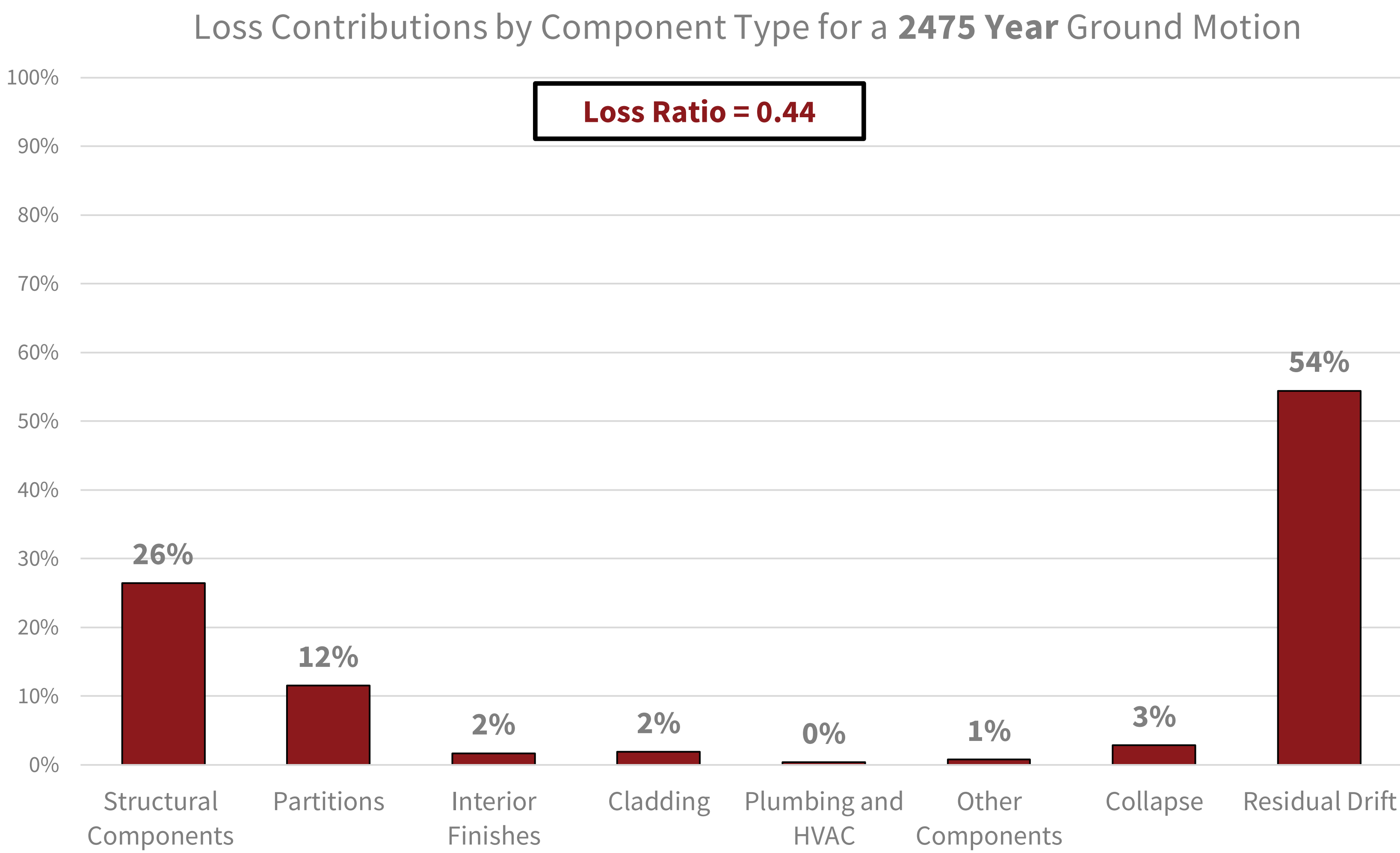
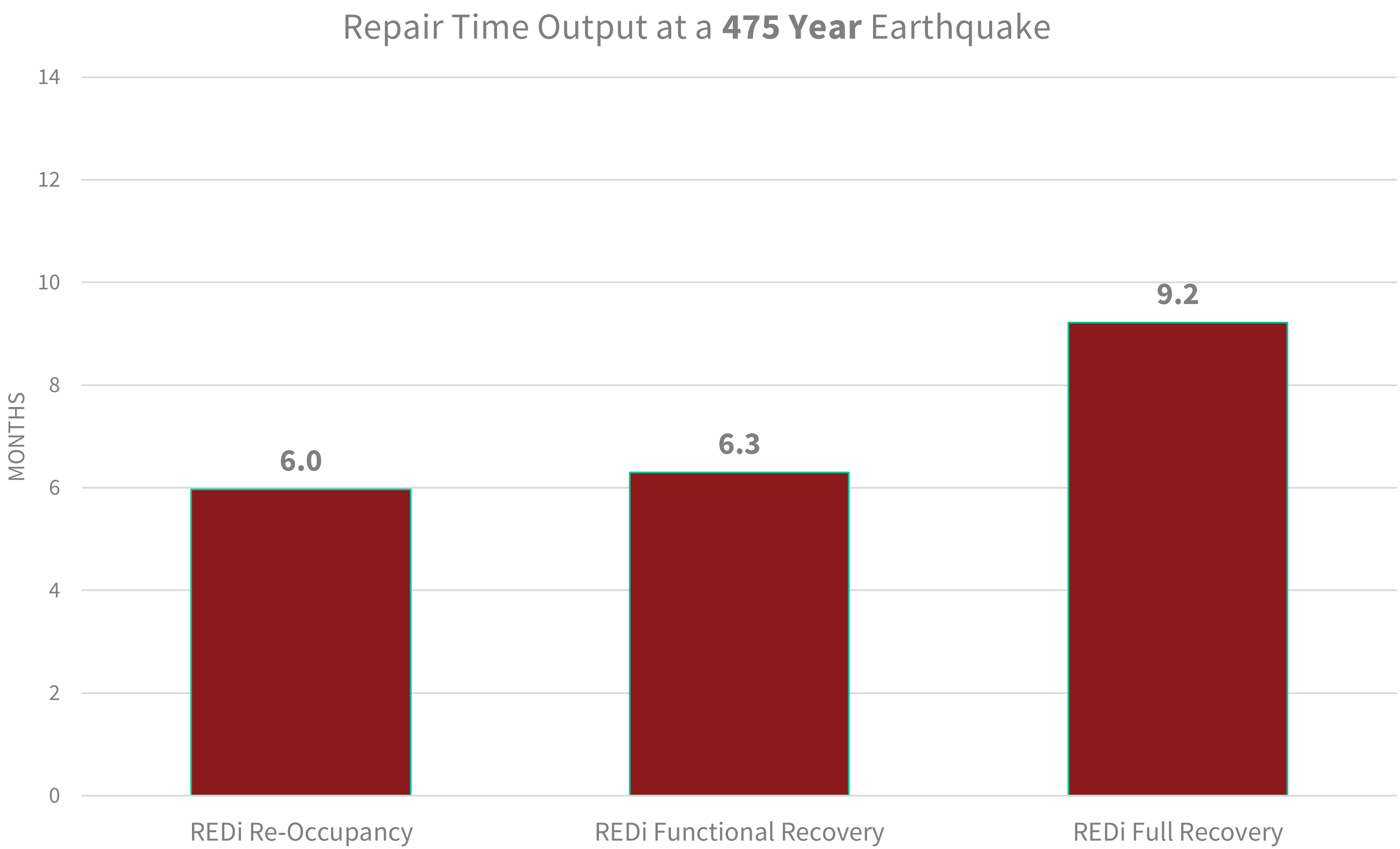


Output Examples: Repair Times

- Average Repair Times (REDi, 2013):



The Need for a Software Solution

- FEMA P-58 was released in 2012 and a barrier to widespread adoption was related to software and ease-of-use.
- FEMA P-58 is a great methodology but FEMA is expressly not in the business of maintaining software. Software has been barrier to adoption.
- **Need:** To better enable use of FEMA P-58, a commercial-grade software was needed.

SP3 Software Compliments FEMA P-58

FEMA P-58 provides the **comprehensive** and **standardized** building-specific risk assessment (with ~$16M to develop).

SP3 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**.

National Science Foundation Funding

- The NSF funding and training has been amazing!
  - ✓ **2014:** $50k seed grant and focused summer of research commercialization training.
  - ✓ **2015:** $150k Phase I NSF Small Business Innovation Research grant (+$30k matching)
  - ✓ **2016-2018:** $750k Phase II NSF Small Business Innovation Research grant
  - ✓ **2018:** $150k supplement
  - ✓ **2019-2021 (awarded):** $500k of matching funds
  - ✓ **$1.63M awarded to date**

Current Adoption of the SP3 Software

- **Current uses of SP3:**
  - Licensed by 80+% of the large west-coast structural engineering firms, and has been expanding from there (across the US and firms in other countries).
  - Also beginning adoption in the mortgage risk and insurance risk markets.
  - Currently being used for:
    - Resilient design of new buildings (municipal buildings, court houses, etc.)
    - Retrofit of existing buildings
    - Assessments of special facilities (emergency operation centers, manufacturing, museums, etc.)
    - Investment risk assessments
    - Mortgage risk assessments
    - Insurance risk assessments

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Recent Innovative Projects with P-58/SP3

New Design: Long Beach Civic Center and Port Facility

Figure Source: SOM/NYASE 2016 SEAOC presentation

Resilient Design Example

New Design: Long Beach Civic Center and Port Facility

Design Objectives (for design earthquake):

- Safe (few or no injuries)
- Minimal repair cost (<5%) [vs. ~15%]
- Minimal reoccupancy time (<1 week) [vs. 4-6 mo.]
- Minimal functionality time (<1 month) [vs. 6-9 mo.]

REDi Rating: ~Gold Performance

US Resilience Council Rating: 4-5 Star Performance

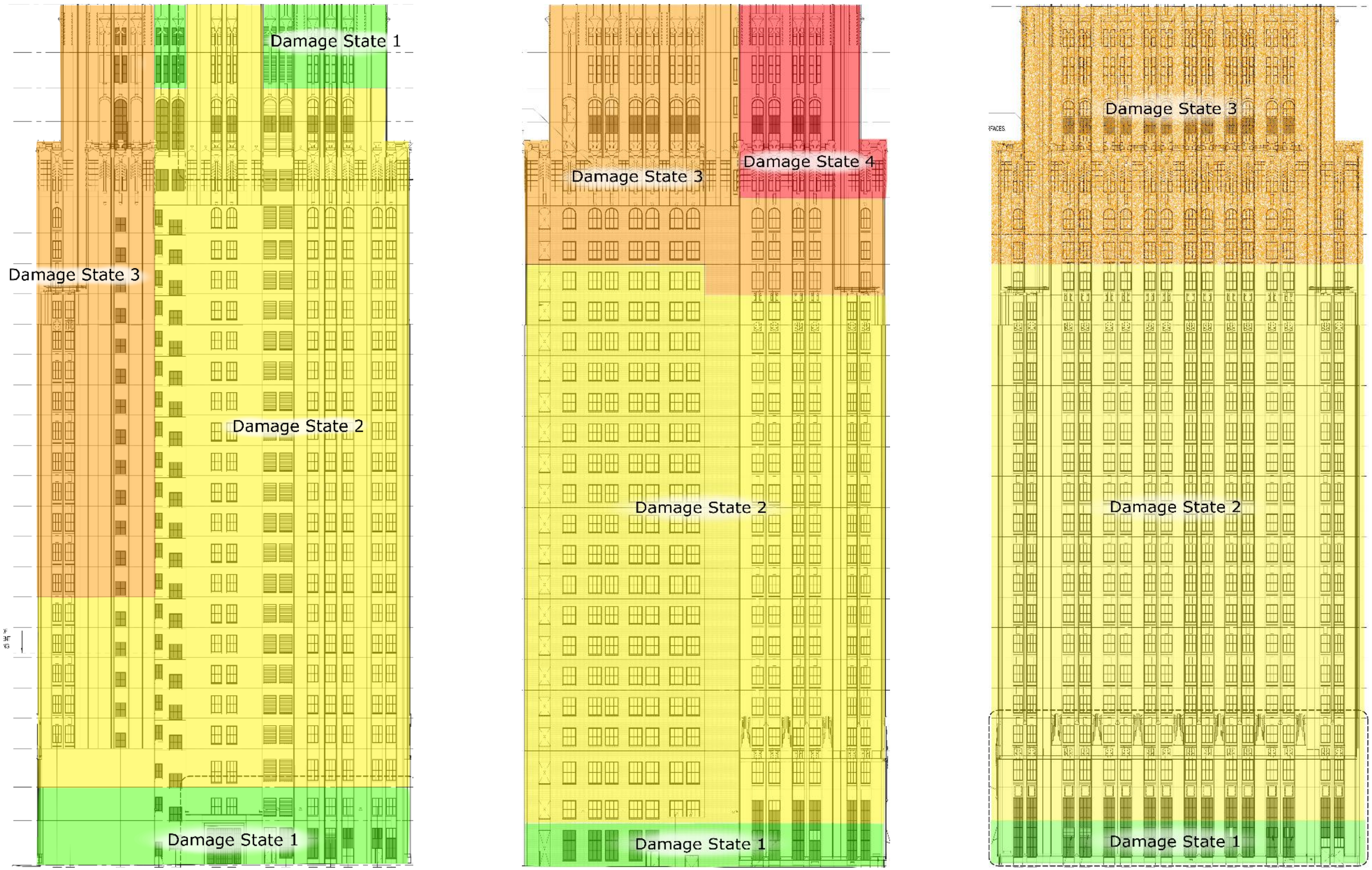
Figure Source: SOM/NYASE 2016 SEAOC presentation

Retrofit Projects: San Francisco, Sacramento, etc.

http://www.forell.com/pre-northridge/

Recent Innovative Projects with P-58/SP3

Risk Assessments: Property Transaction Due-Diligence



Risk Assessments: Detailed Assessments of High-Value Items

Risk to high-value content.

Recent Innovative Projects with P-58/SP3

Risk Assessments: Detailed Assessments of High-Value Items

Risk tc

Post-earthquake operability of production facilitates.

Recent Innovative Projects with P-58/SP3

WATSON
LAND COMPANY

Goals of the Resilient Design:

- Reduce risk of loss and downtime, since Watson Land Company owns the buildings.
- Allow building customers to resume business operations as quickly as possible.
- Quantify the reduced risk to hopefully get a discount on earthquake insurance.

Recent Innovative Projects with P-58/SP3

Approach

Design by ASCE 41 for Immediate Occupancy

Then use FEMA P-58/SP3 to quantify the improved resilience (i.e. reductions in loss and downtime); future designs could use FEMA P-58/SP3 directly to design for specific loss and repair time objectives (or a building rating).

Recent Innovative Projects with P-58/SP3

The Team:

- **Watson Land Company**
- **HSA Associates**
- **SP3 software team (HB-Risk) as consultants**

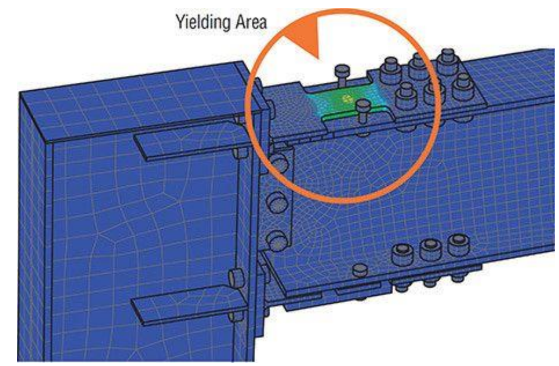
Recent Innovative Projects with P-58/SP3

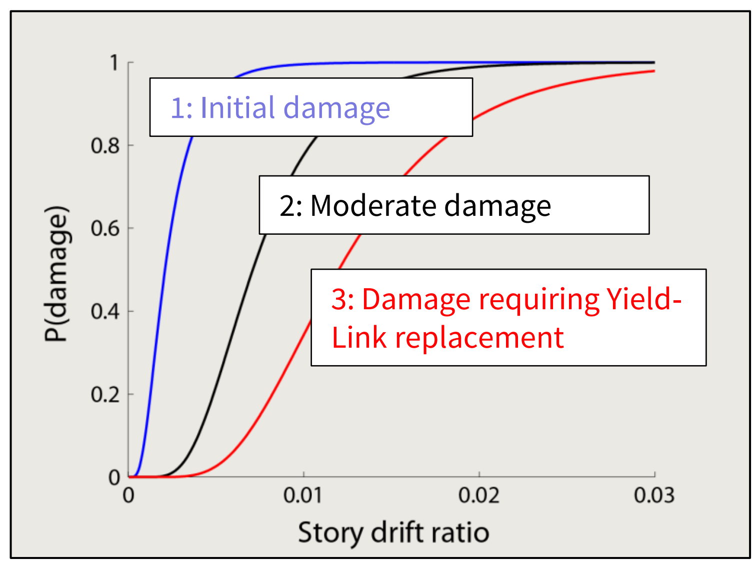
Costs:

Only $1.27 per square foot to get Immediate Occupancy performance, when compared with a standard code-compliant design.

Recent Innovative Projects with P-58/SP3

- Risk assessment of resilient structural systems (with Simpson Strong Frame being one example of many)





Legislative Pushes for Resilient Design

- Resilient design is not a future idea; <u>it is happening now in practice</u>.
- We now have methodologies/tools to quantify resilience in a way that owners can understand and make decisions based on (repair costs and repair times).
- Owners/stakeholders are electively choosing better performance (some requiring it), and we have been finding that quickly-functional buildings can be often achieved with little-to-no added cost.
- This has led to public/government interest and legislative efforts for resilient design (more than safety), including:
  - NIST/FEMA 2021 Report to Congress: *FEMA P-2090/NIST SP-1254: Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time*
  - California Assembly Bill 1329 legislation: *California AB-1329: Building Codes – Earthquakes – Functional Recovery Standard*
- We as structural/earthquake engineers are in a <u>unique position</u> to be leaders in pushing resilient design into the mainstream (public interest + analytical tools).

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SP3-Platform Overview

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 stability (e.g. liquefaction maps)

SP3 Core Technology
Advanced seismic risk assessment technology deployed on the cloud enables all of the modules on the SP3-Platform.

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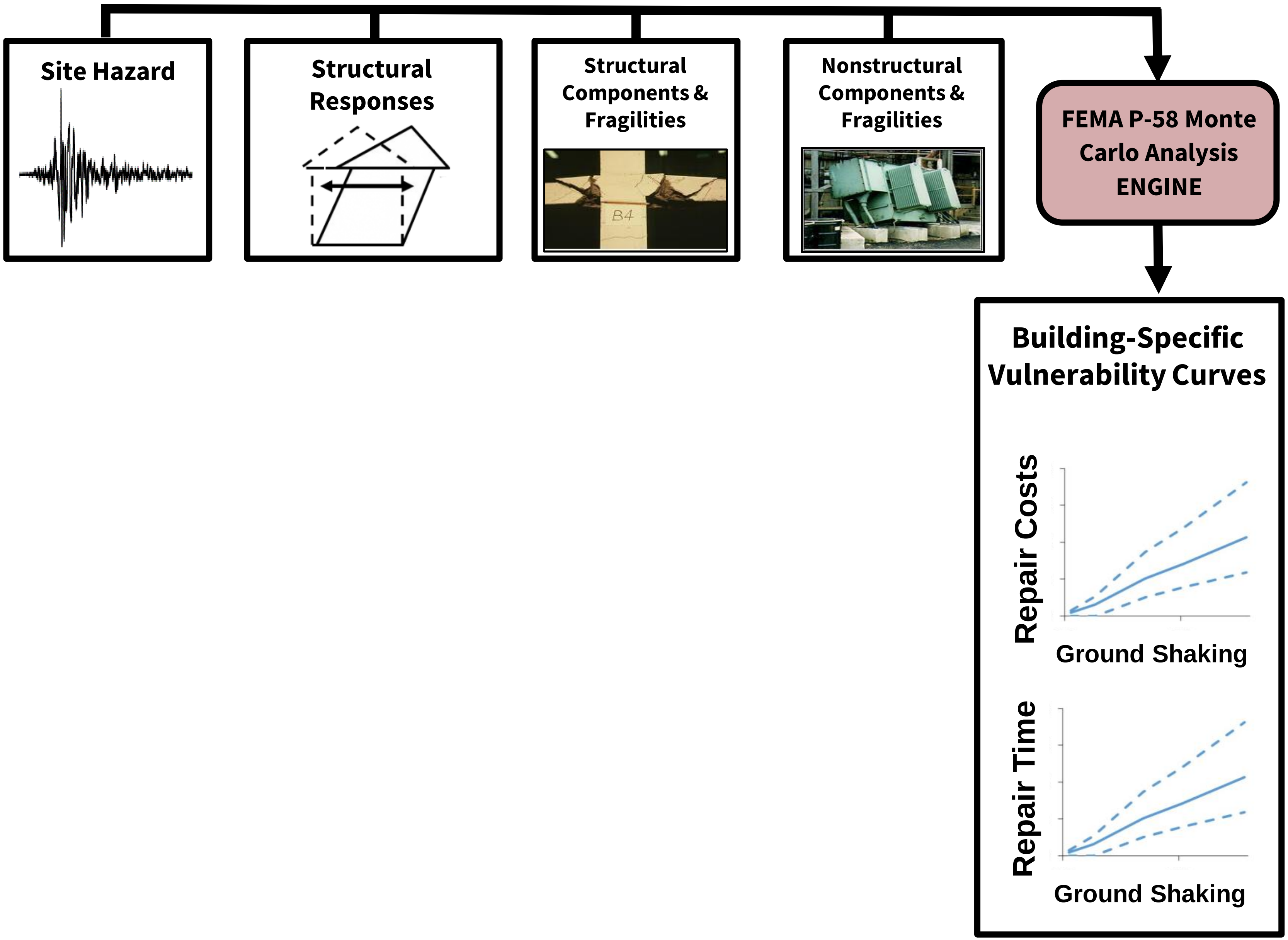
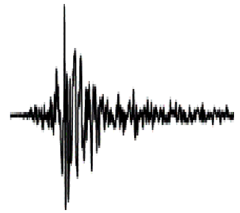
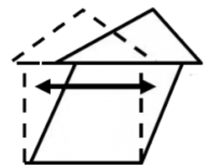


SP3-RiskModel

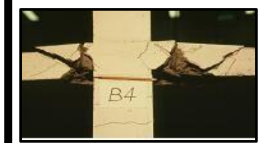
Site Hazard



Structural Responses



Structural Components & Fragilities



Nonstructural Components & Fragilities

FEMA P-58 Monte Carlo Analysis ENGINE

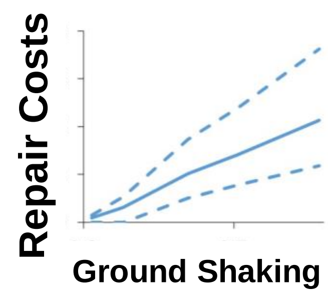
Detailed Building and Site Information

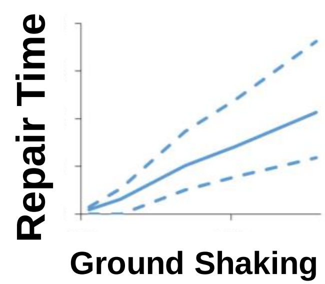
(e.g. building system, strength and stiffness, detailing, user-defined structural responses, user-defined hazard, etc.)

SP3-RiskModel Advanced

Advanced: Detailed analysis of new/existing buildings with full control of all modeling parameters.

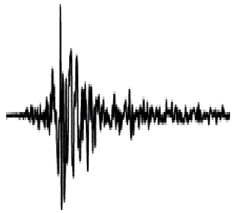
Building-Specific Vulnerability Curves





SP3-RiskModel

Site Hazard



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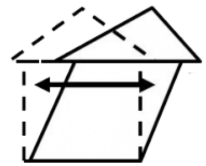

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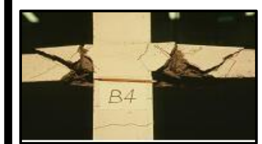


Nonstructural Components & Fragilities

FEMA P-58 Monte Carlo Analysis ENGINE

Basic Building and Site Information

(e.g. location, construction year, structural system, occupancy, etc.)

Additional Secondary Modifiers

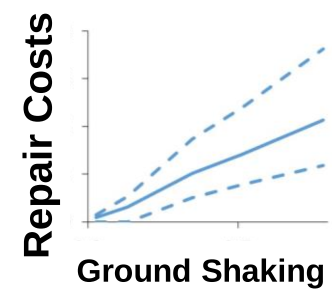
(irregularities, building geometric layout and square footage, etc.)

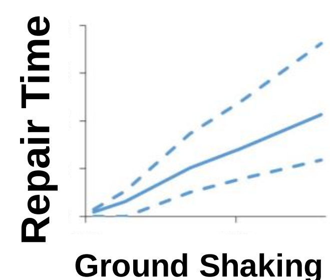
SP3-RiskModel Standard

Standard: Due-diligence risk assessment reports, preliminary resilient design decisions

Still gives full FEMA P-58 risk results (but with some more uncertainty in the estimate).

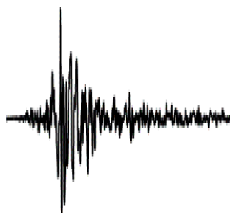
Building-Specific Vulnerability Curves





SP3-RiskModel

Site Hazard



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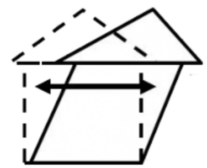

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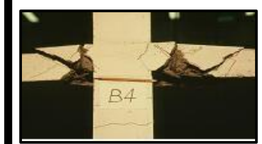

Nonstructural Components & Fragilities

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Basic Building and Site Information

(e.g. location, construction year, structural system, occupancy, etc.)

~~**Additional Secondary Modifiers**~~

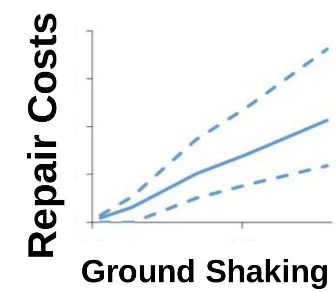
~~*(irregularities, building geometric layout and square footage, etc.)*~~

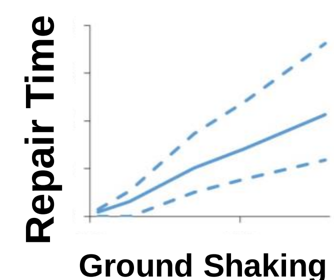
SP3-RiskModel Express

Express: Rapid assessments of one building or a portfolio of buildings (using SP3-Batch)

More approximate than other levels, but still gives full FEMA P-58 results to quantify building/site-specific risk in terms of dollars and downtime.

Building-Specific Vulnerability Curves





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For assessment of site hazards

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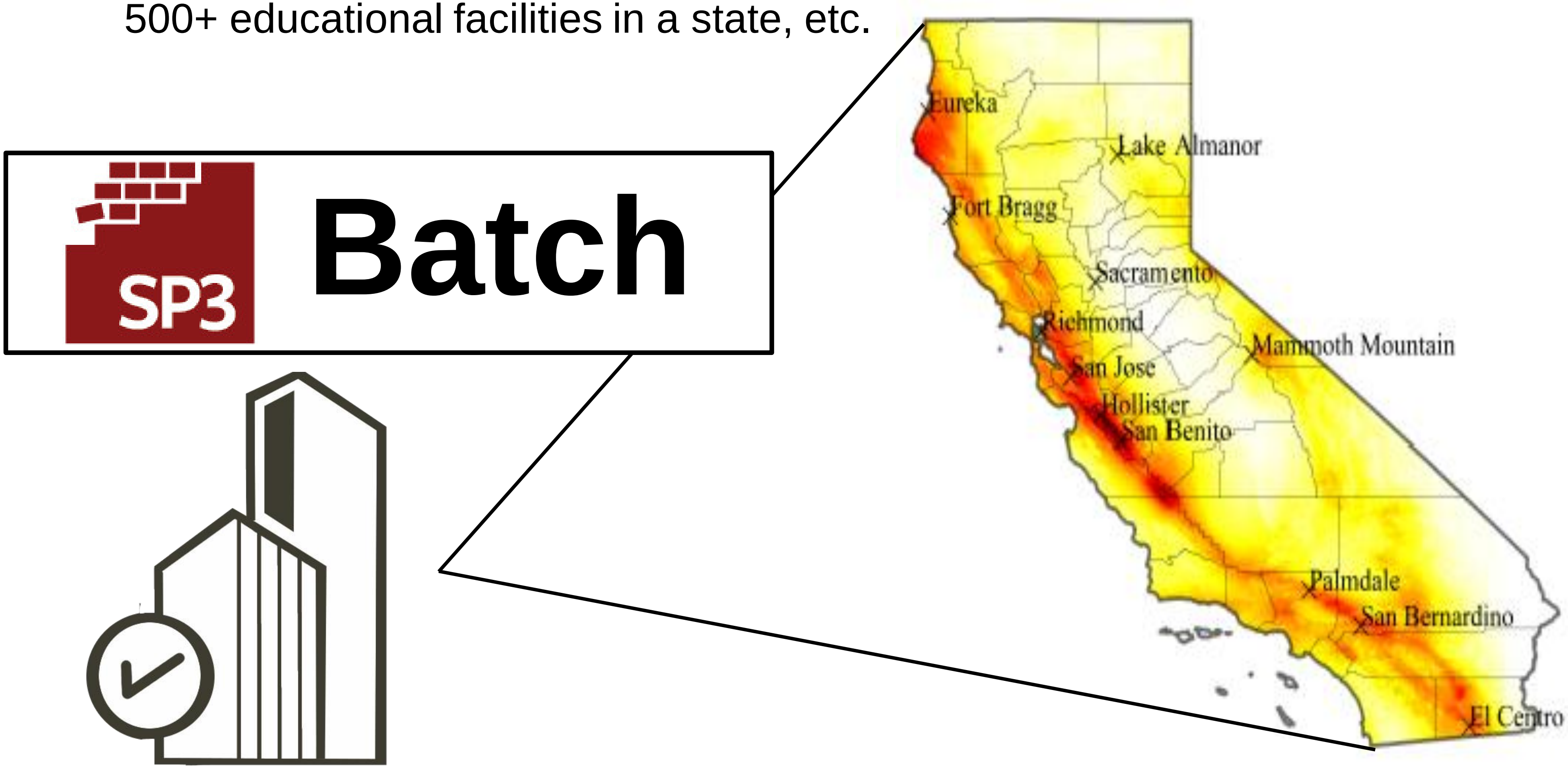
Advanced seismic risk assessment technology, deployed on the cloud, which enables all of the modules on the SP3-Platform.
Based on FEMA P-58, but with extensive automation, to enable building/site-specific risk modeling with any level of input information.

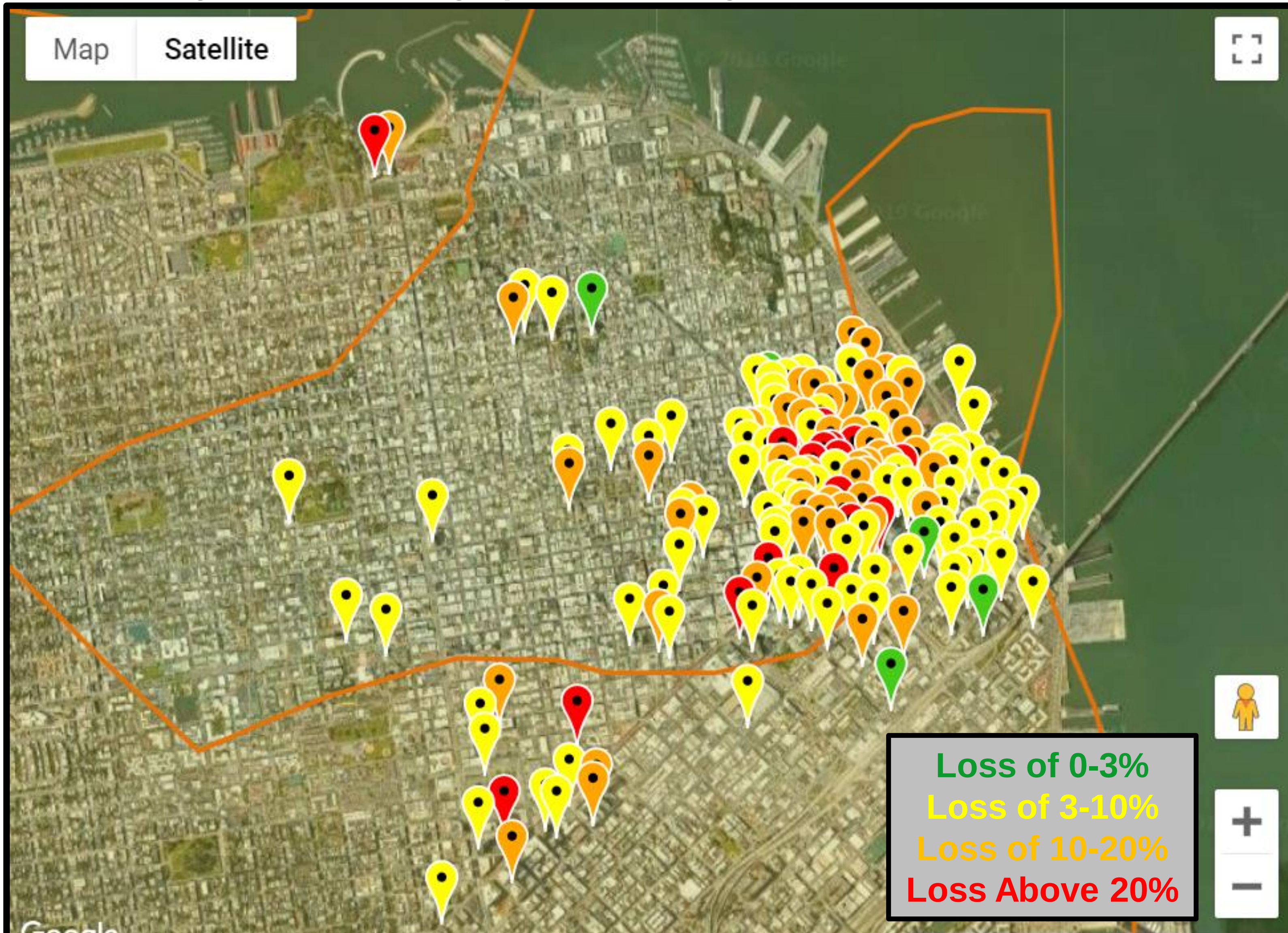
SP3-Batch

- Runs SP3 building analyses at scale using Amazon Web Services and ~2000 processors (CVS batch input, etc.).
- **May Use Case:** San Francisco tall buildings, SF Bay Area non-ductile concrete (~3000 buildings), portfolio of 100+ municipal buildings in a CA county, project starting for a California campus of 500+ buildings, project on 500+ educational facilities in a state, etc.



SP3-Batch for San Francisco Tall Buildings

Current existing SF tall buildings (mean shaking from San Andreas M8, not 10% in 50 yr):



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SP3-SiteHazards

SITE SEISMIC HAZARDS REPORT

Report Generated for:

123 Mission St

SF, CA 94105

Lat / Long: 37.7917688°, -122.3944272°

Date:

April 23, 2020

Report Generated by:

The Site Hazards Module of the

Seismic Performance Prediction Program (SP3)

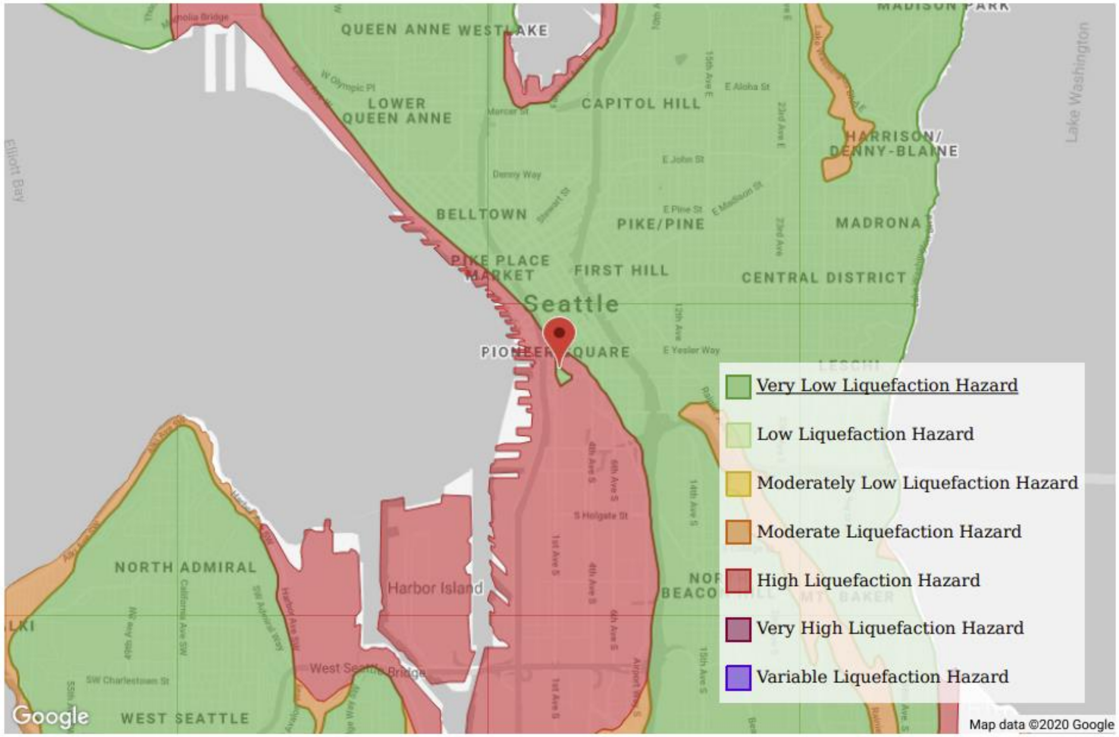
Seismic Performance Prediction Program by Haselton Baker Risk Group

Produced for:

Bosco Inc

Data Source #1 - Washington State Liquefaction

Based on the map below, this site is located in a **Very Low Liquefaction Hazard** zone.



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For rapid pre-screen building risk estimation

Standard
For streamlined building-specific risk assessment

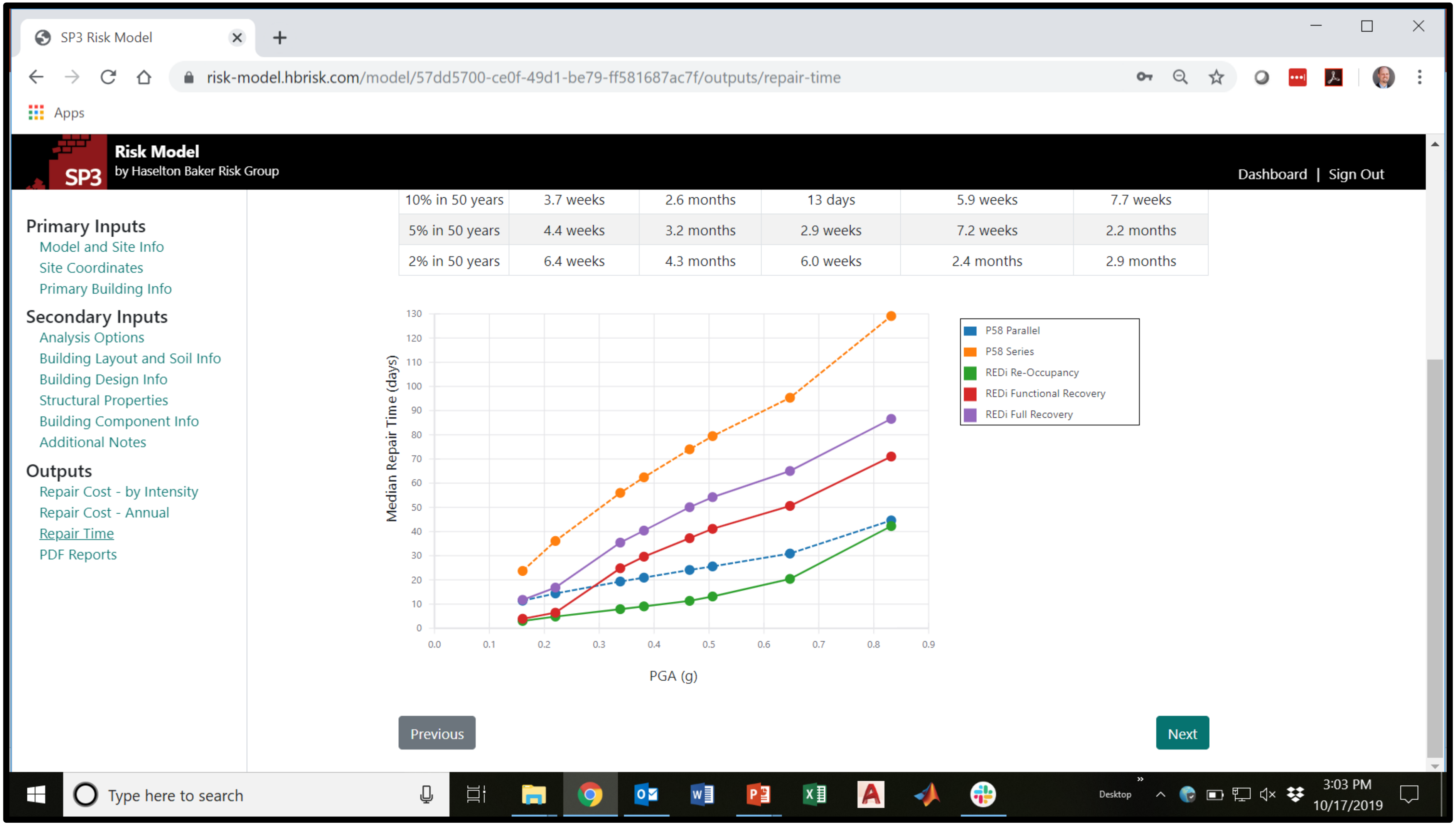
Advanced
For in-depth building-specific risk assessment

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

SP3-SiteHazards
For assessment of site stability (e.g. liquefaction maps)

SP3 Core Technology
Advanced seismic risk assessment technology deployed on the cloud enables all of the modules on the SP3-Platform.

SP3-RiskModel Demo



Planned Agenda for Today

- Overview of FEMA P-58 risk analysis methodology
- Examples of project uses of FEMA P-58
- SP3 software overview
- SP3-RiskModel demo
- **Resilient design example (if time permits)**
- **Discussion Q&A**

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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IF TIME PERMITS

Resilient Design Example

New Design: Long Beach Civic Center and Port Facility

Figure Source: SOM/NYASE 2016 SEAOC presentation

Resilient Design Example

New Design: Long Beach Civic Center and Port Facility

Design Objectives (for design earthquake):

- **Safe (few or no injuries)**
- **Minimal repair cost (<5%) [vs. ~15%]**
- **Minimal reoccupancy time (<1 week) [vs. 4-6 mo.]**
- **Minimal functionality time (<1 month) [vs. 6-9 mo.]**

REDi Rating: ~Gold Performance

US Resilience Council Rating: 4-5 Star Performance

Figure Source: SOM/NYASE 2016 SEAOC presentation

Resilient Design Example

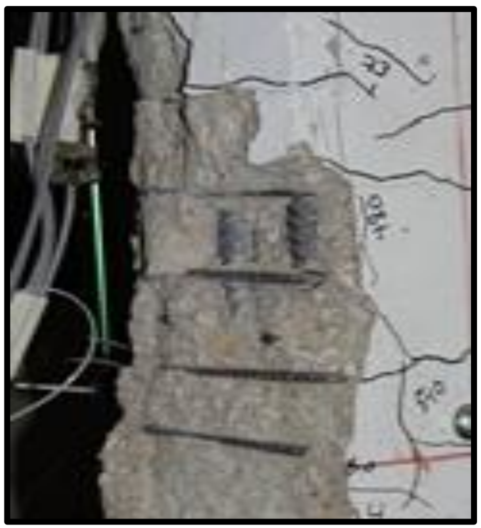
Approach: Iterative design using FEMA P-58.

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)

Resilient Design Example

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



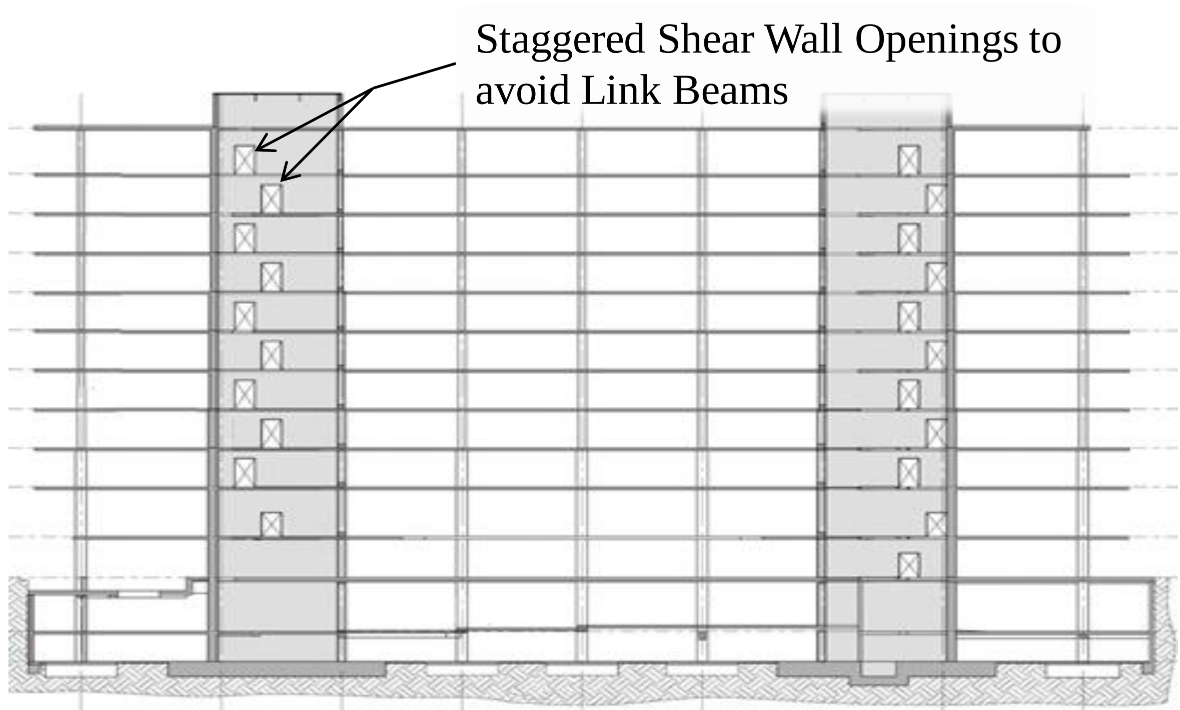
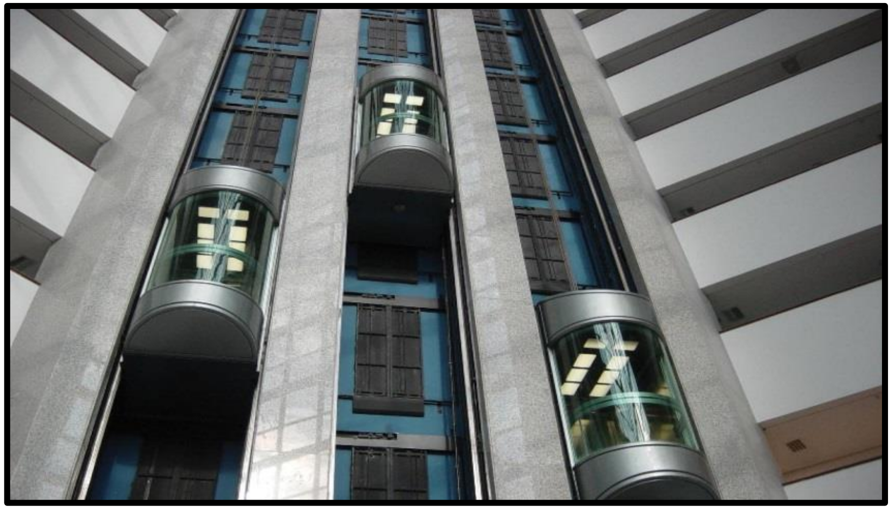


Figure Source: SOM/NYASE 2016 SEAOC presentation

Resilient 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

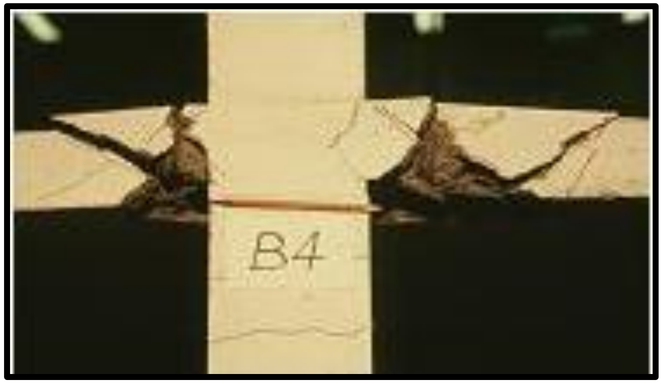


Resilient Design Example

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

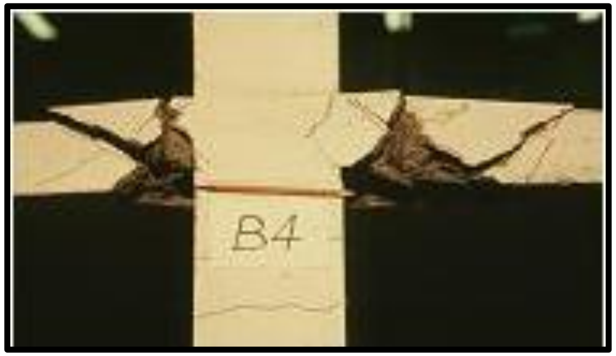


Resilient Design Example

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]

Resilient 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.

Resilient Design Example

Figure Source: SOM/NYASE 2016 SEAOC presentation

- 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.