

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

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SE 227 Non-Structural Components Class @ UC San Diego | June 3, 2021

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

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



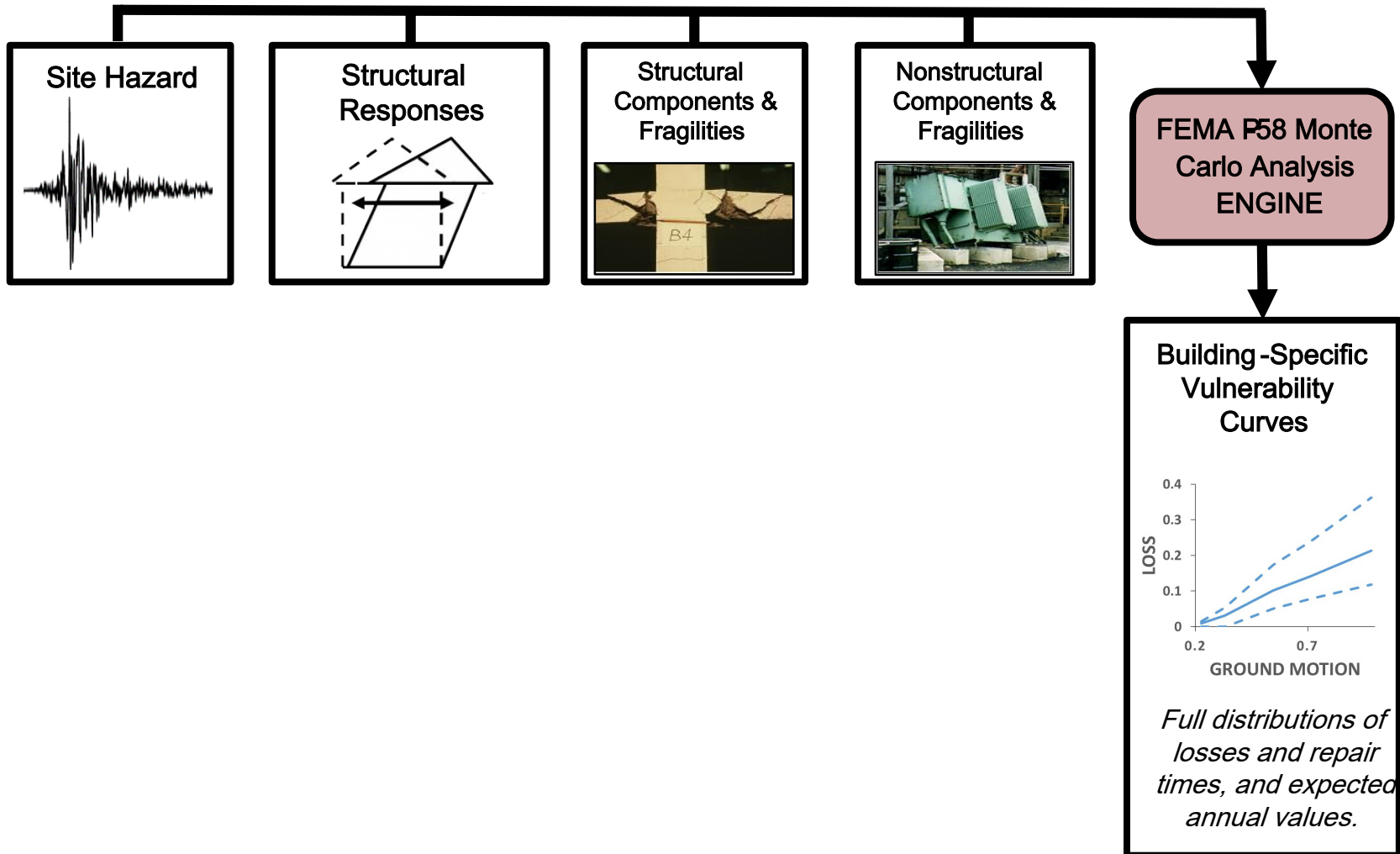
Seismic Performance Assessment of Buildings

Volume 1 – Methodology

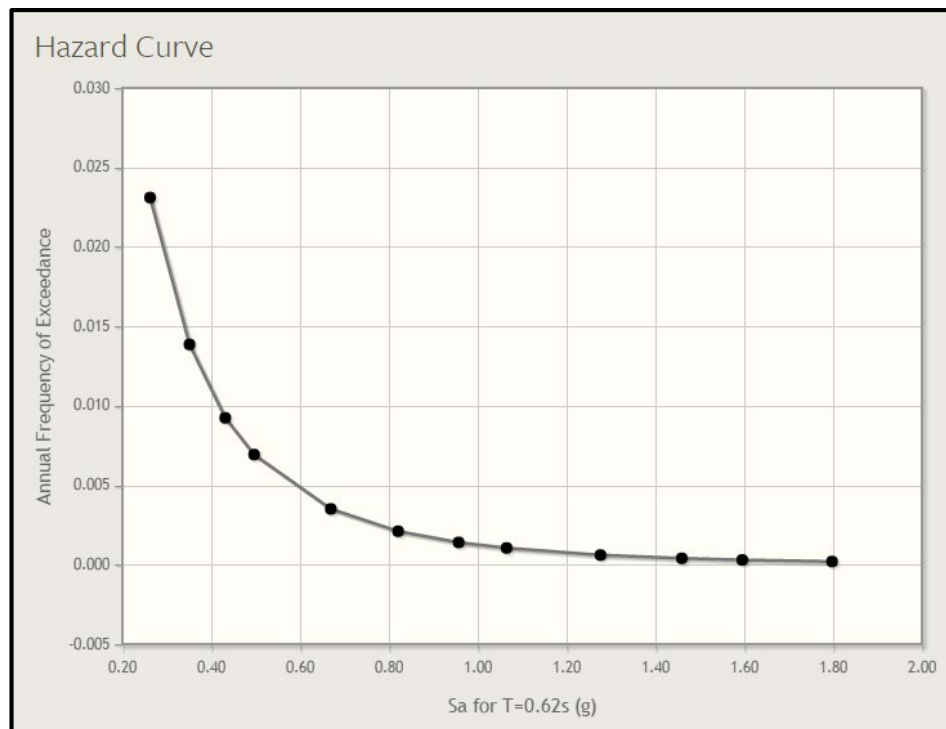
FEMA P-58-1 / September 2012



FEMAP-58: Detailed Steps of Method

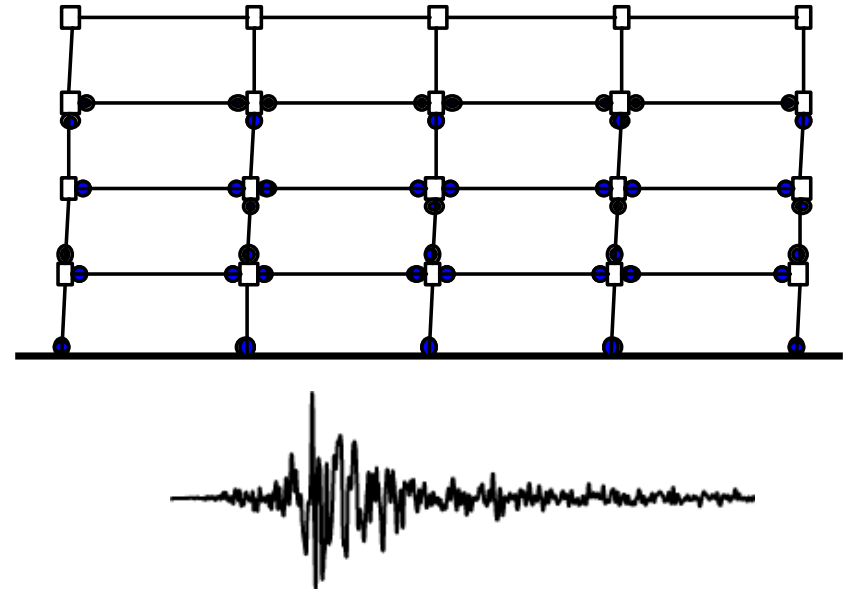


- **Step 1:** Define ground motion hazard (with soil)
 - Option #1: SP3 can provide curve (given an address)
 - Option #2: User-specified curve



■ 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)

■ 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

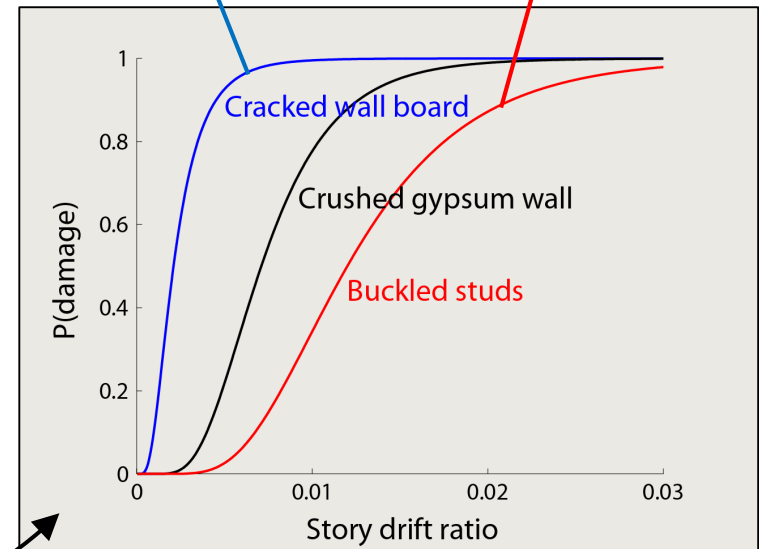
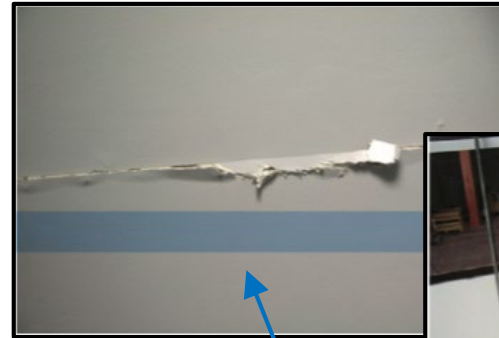
■ Step 3: Quantify component damage

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

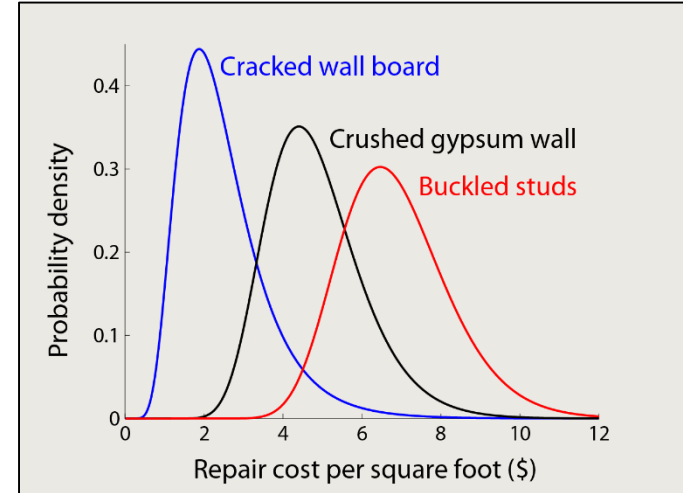
Structural Components				
ACTION	FRAGILITY ID	FRAGILITY NAME	FRAGILITY QUANTITY	FRAGILITY LOCATION
Expand   	B1049.022a	RC Slab Column Connection	16	All stories ▼
Expand   	B1041.082a	Non-conforming MF, Conc Col & Bm	4	All stories ▼
Expand   	B1041.082b	Non-conforming MF, Conc Col & Bm	8	All stories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

■ Step 3: Quantify component damage

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

■ 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.

- **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)**

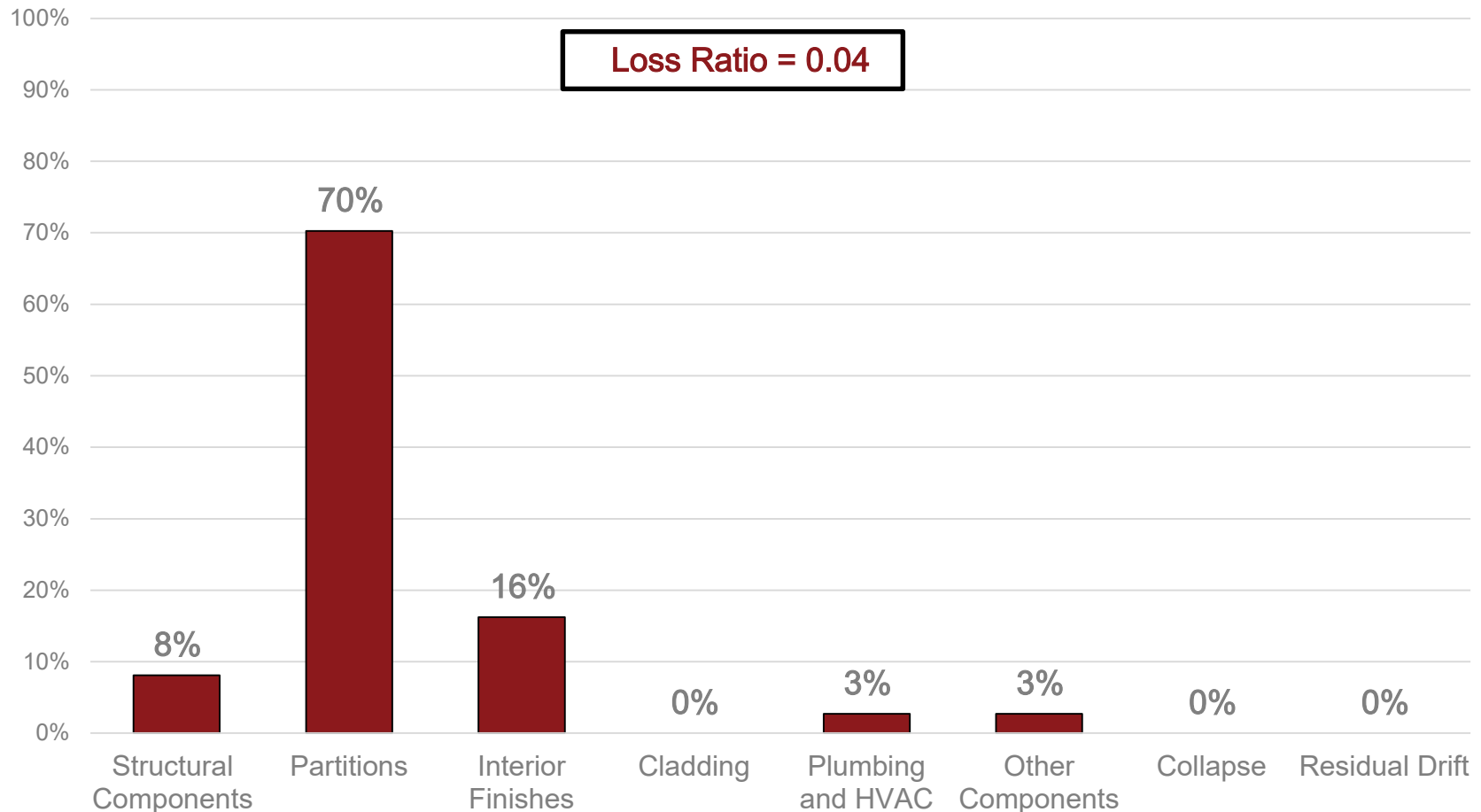
Step 5: Aggregate to building-level consequences

Thousands of Monte Carlo simulations

The simulations provide detailed statistical information on building performance.

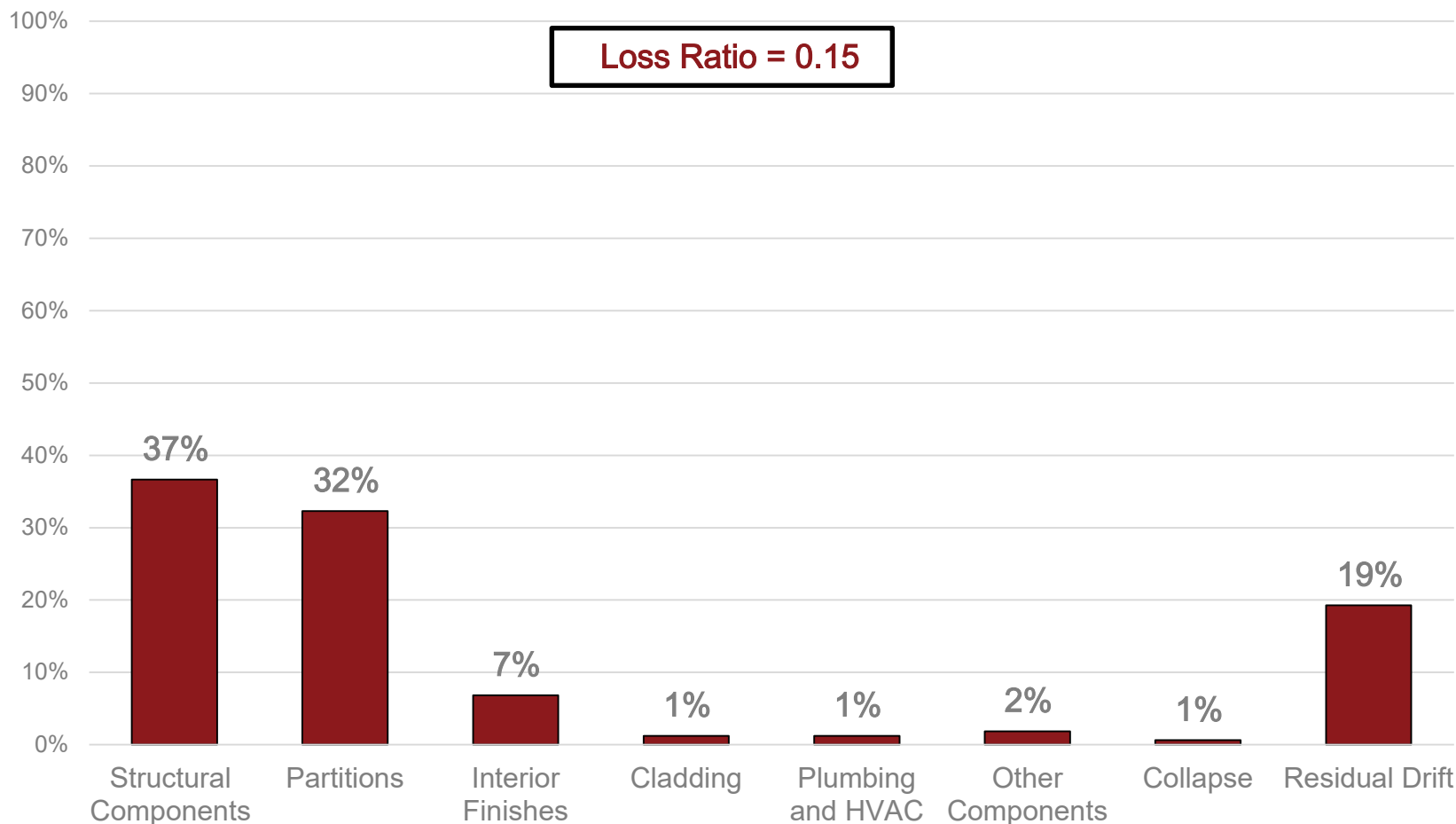
8-story concrete frame in Los Angeles

Loss Contributions by Component Type for a 50 Year Ground Motion



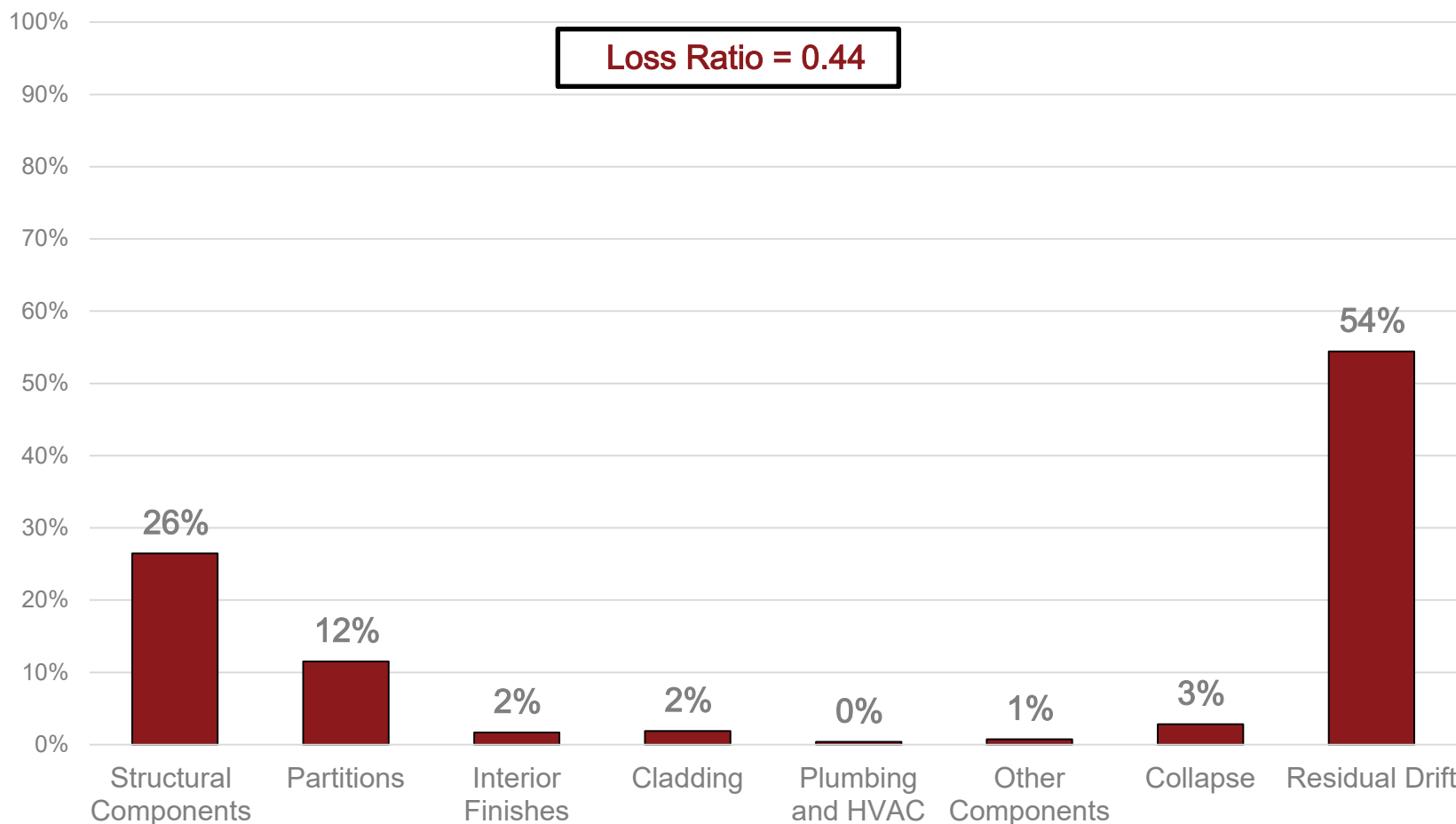
8-story concrete frame in Los Angeles

Loss Contributions by Component Type for a **475 Year** Ground Motion

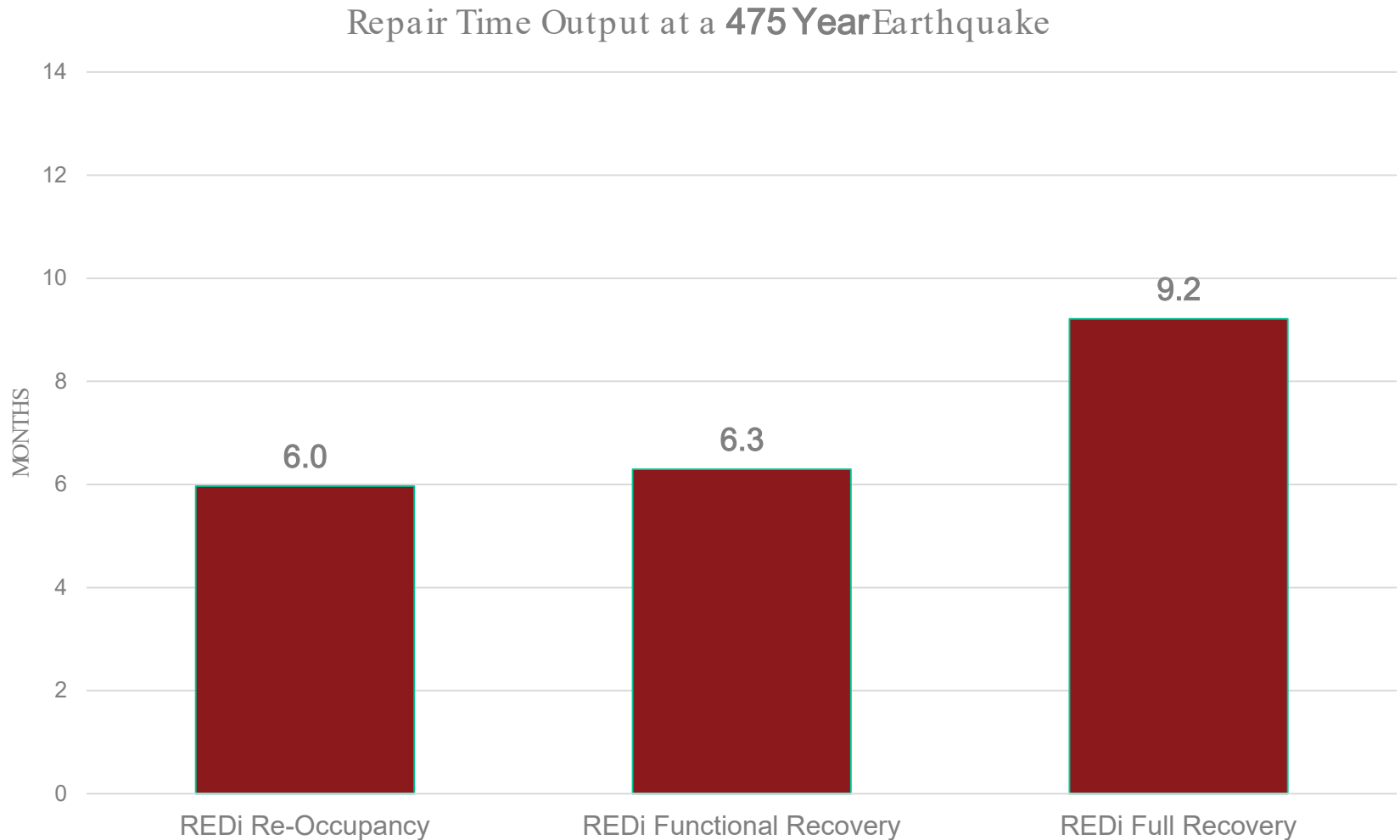


8-story concrete frame in Los Angeles

Loss Contributions by Component Type for a **2475 Year** Ground Motion



■ Average Repair Times (REDi, 2013):



- 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.



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**.

- 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 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

- Overview of FEMAP-58 risk analysis methodology
- **Examples of project uses of FEMA 58**
- SP3 software overview
- SP3-RiskModel demo
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New Design: Long Beach Civic Center and Port Facility



Figure Source: SOM/NYASE 2016 SEAOC presentation

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.]

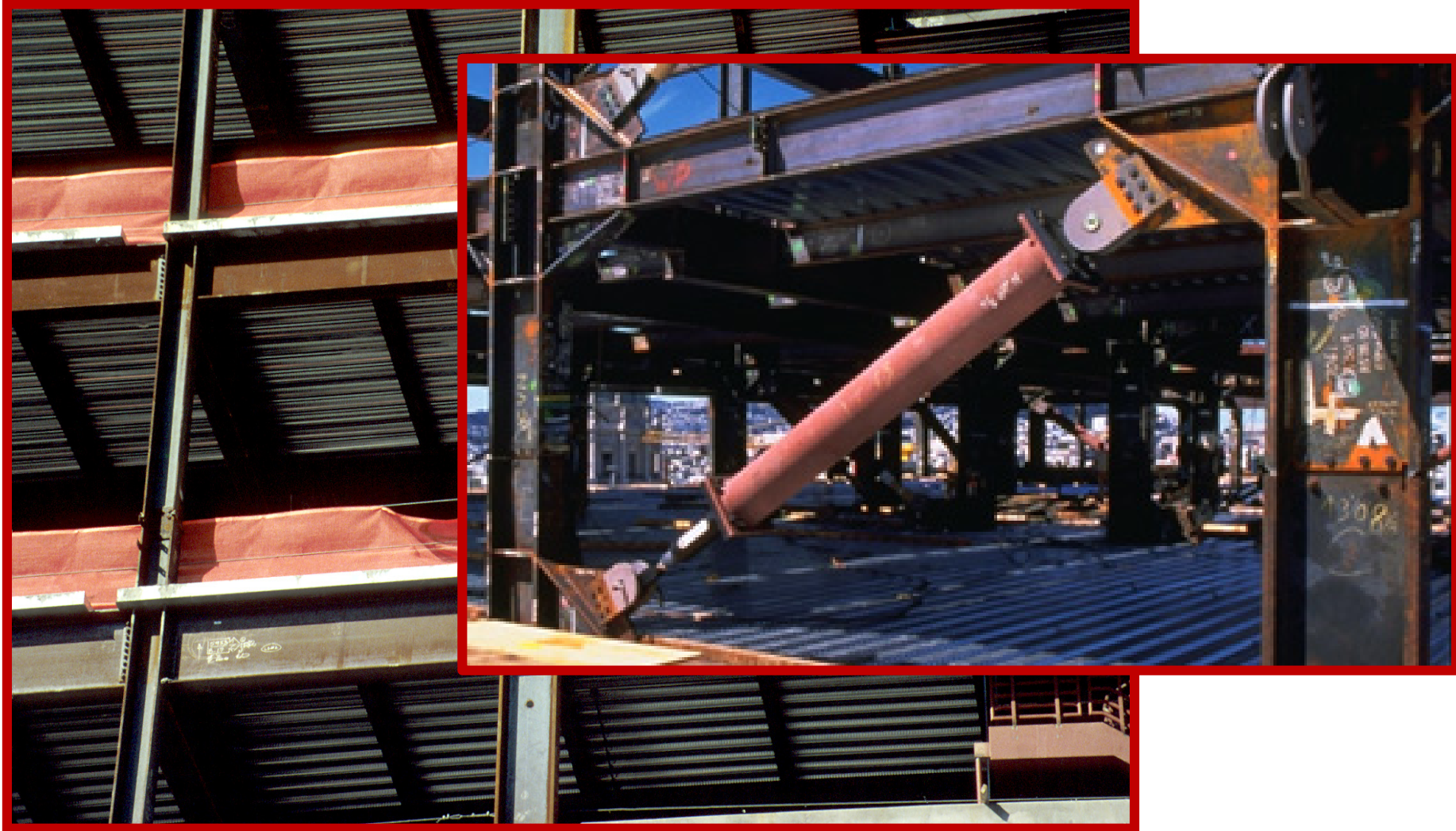
REDi Rating: ~Gold Performance

US Resilience Council Rating: 4-5 Star Performance

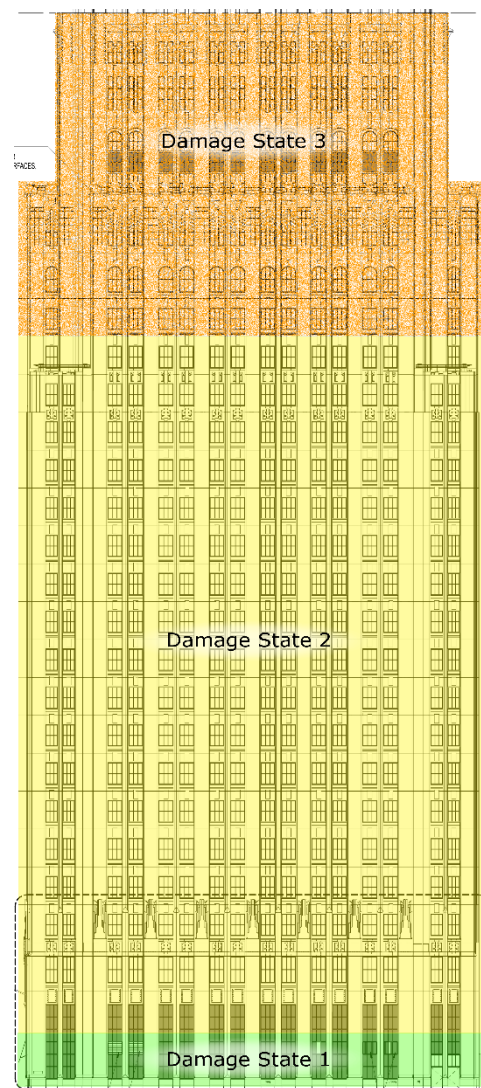
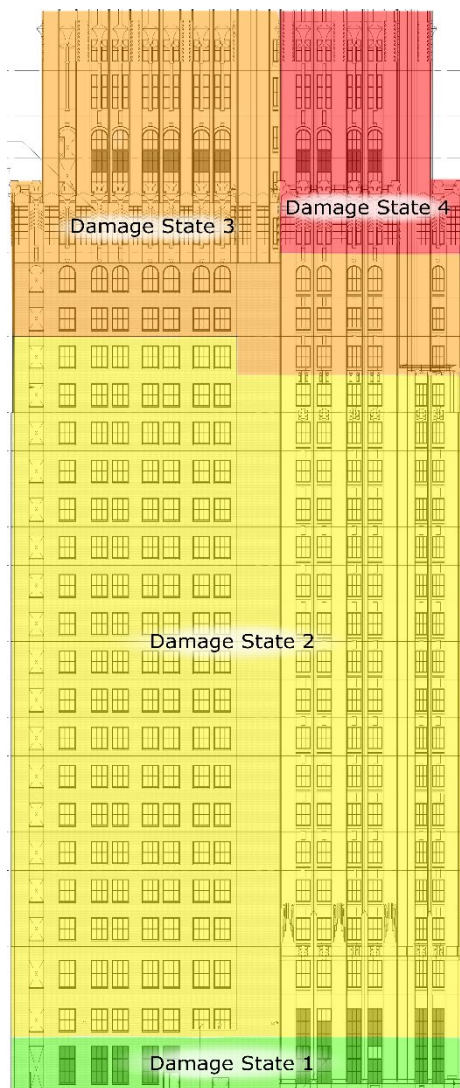
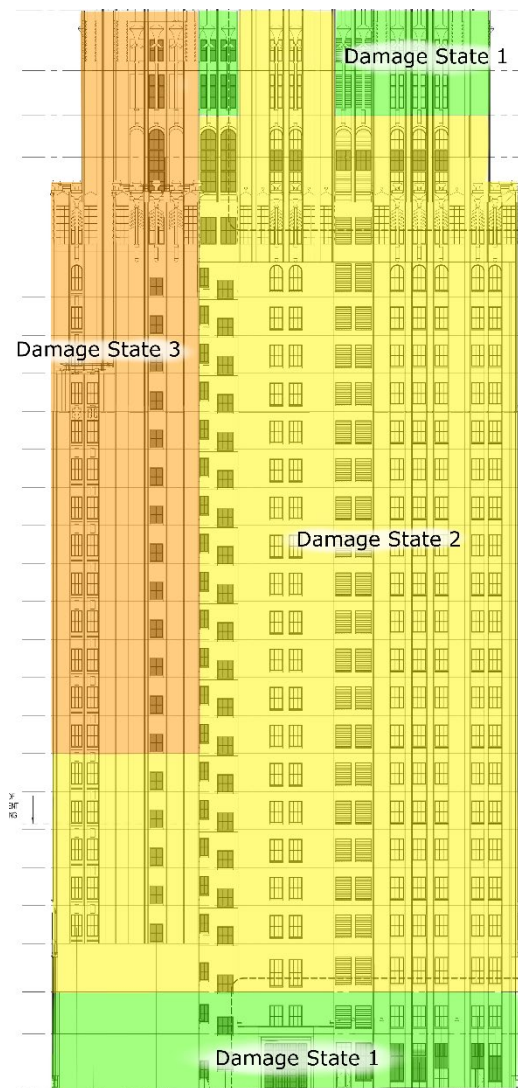


Figure Source: SOM/NYASE 2016 SEAOC presentation

Retrofit Projects: San Francisco, Sacramento, etc.



Risk Assessments: Property Transaction Due Diligence



Risk Assessments: Detailed Assessments of High Value Items



Image: Greater Raleigh CVB

Risk to high-value content.

Risk Assessments: Detailed Assessments of High Value Items



Post-earthquake operability of production facilities.



Risk to



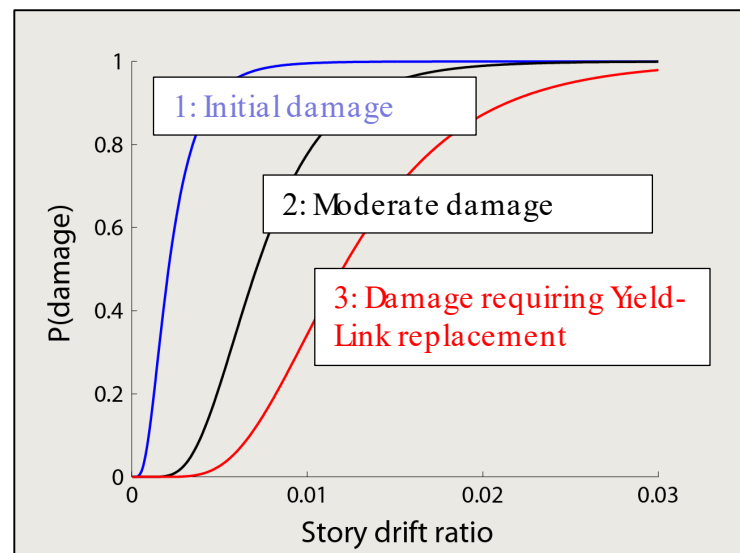
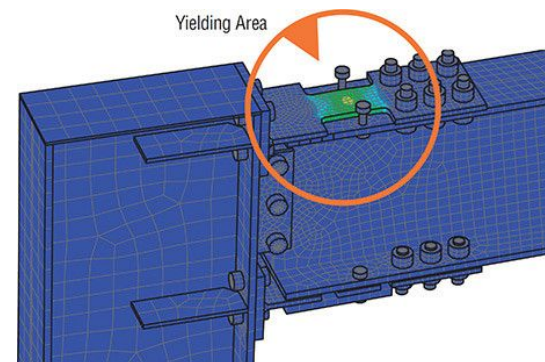
Goals of the Resilient Design:

Reduce risk of loss and downtime, since Watson Land Company owns the buildings.

Allow building customers to resume business operations as quickly as possible.

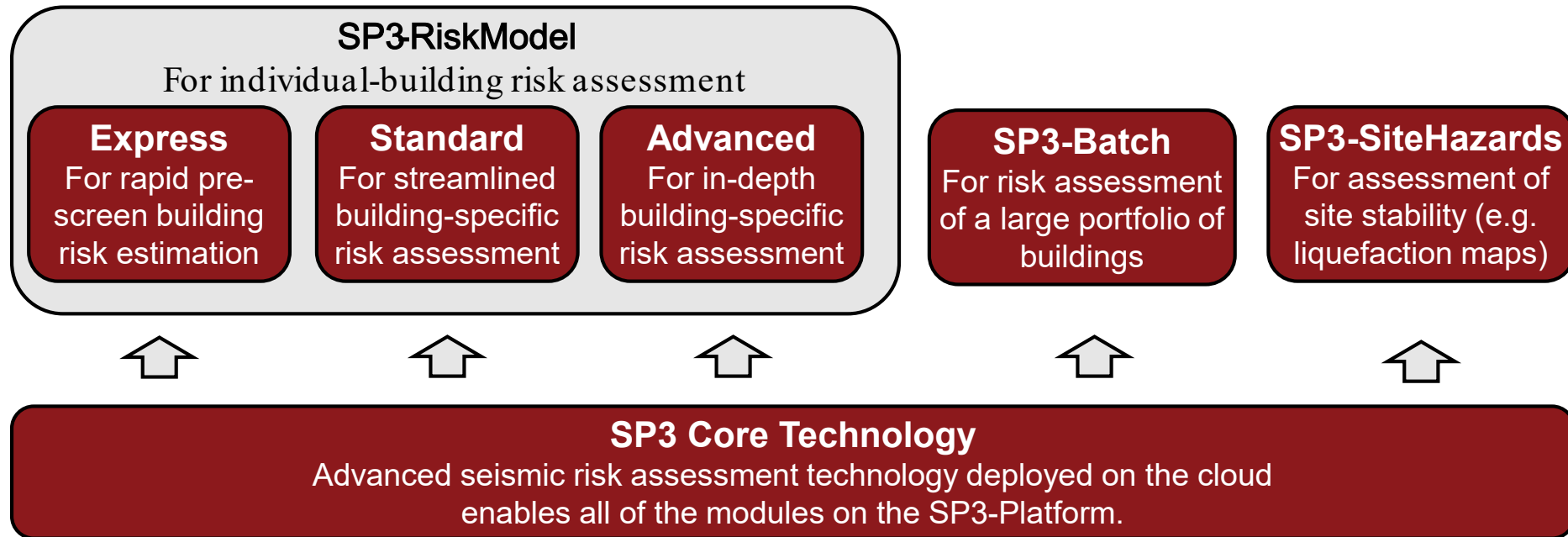
Quantify the reduced risk to hopefully get a discount on earthquake insurance.

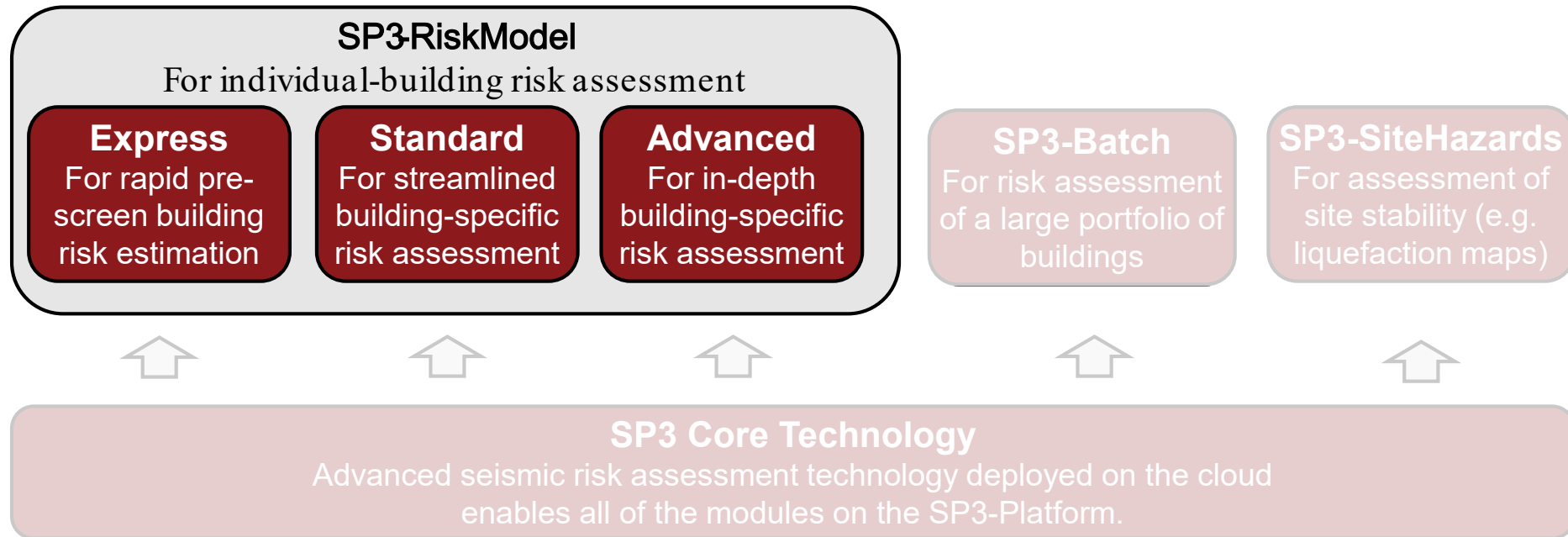
- Risk assessment of resilient structural systems (with Simpson Strong Frame being one example of many)



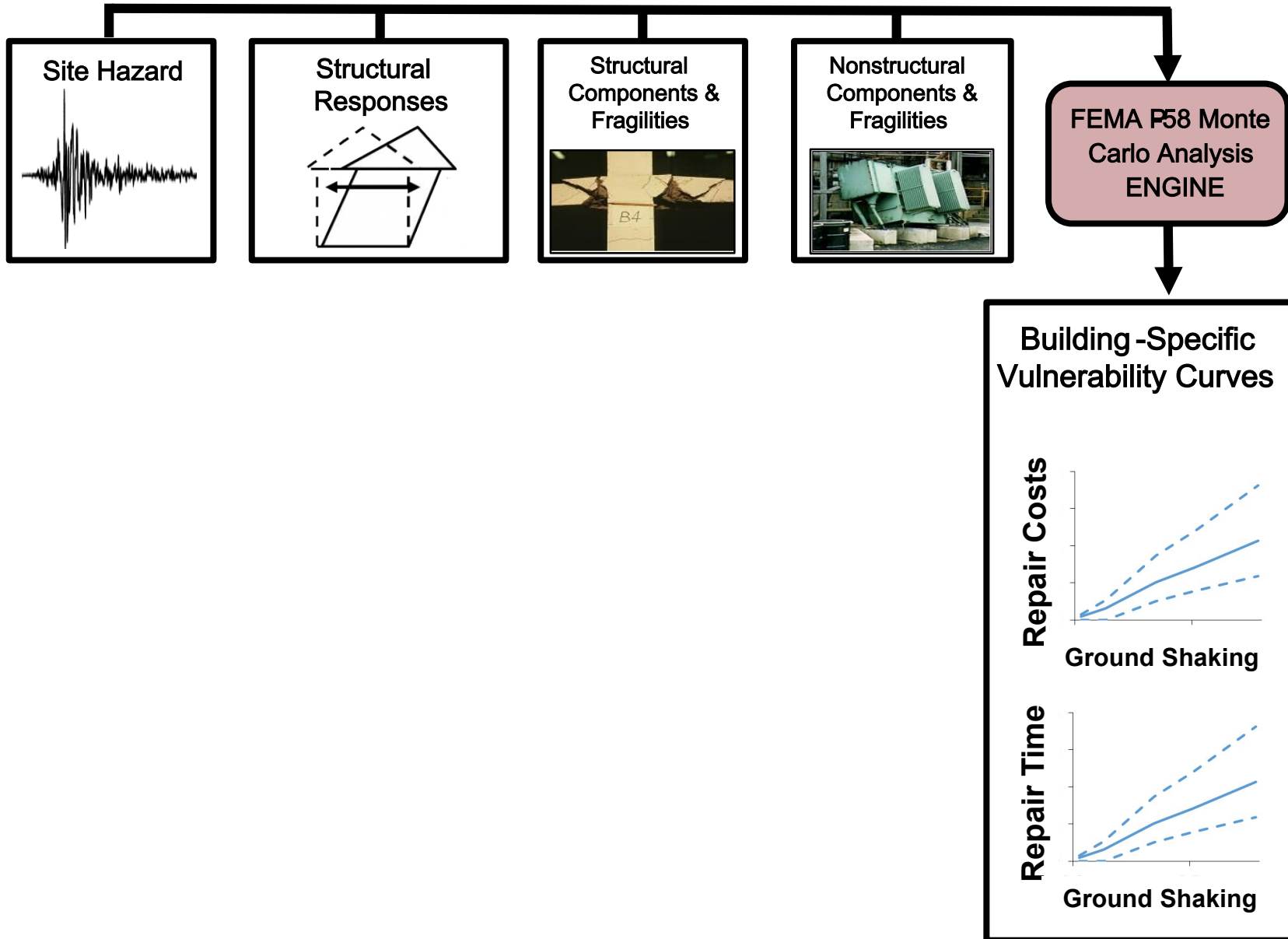
- Resilient design is not a future idea; it is happening now in practice.
- We now have methodologies/tools to quantify resilience in a way that owners can understand and make decisions based on (repair costs and repair times).
- Owners/stakeholders are electively choosing better performance (some requiring 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 unique position to be leaders in pushing resilient design into the mainstream (public interest + analytical tools).

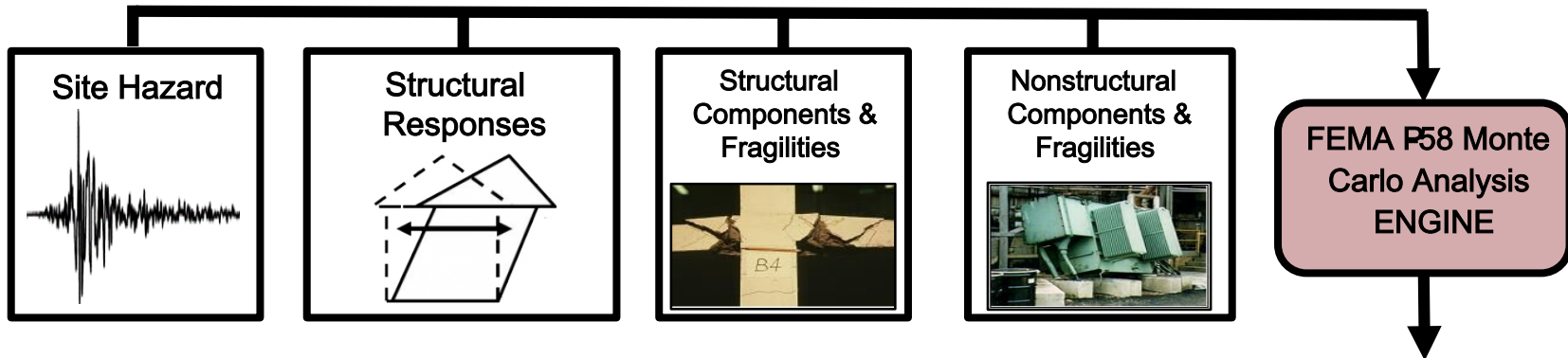
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SP3-RiskModel





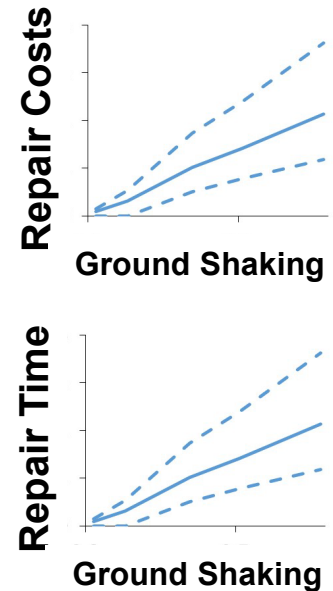
Detailed Building and Site Information

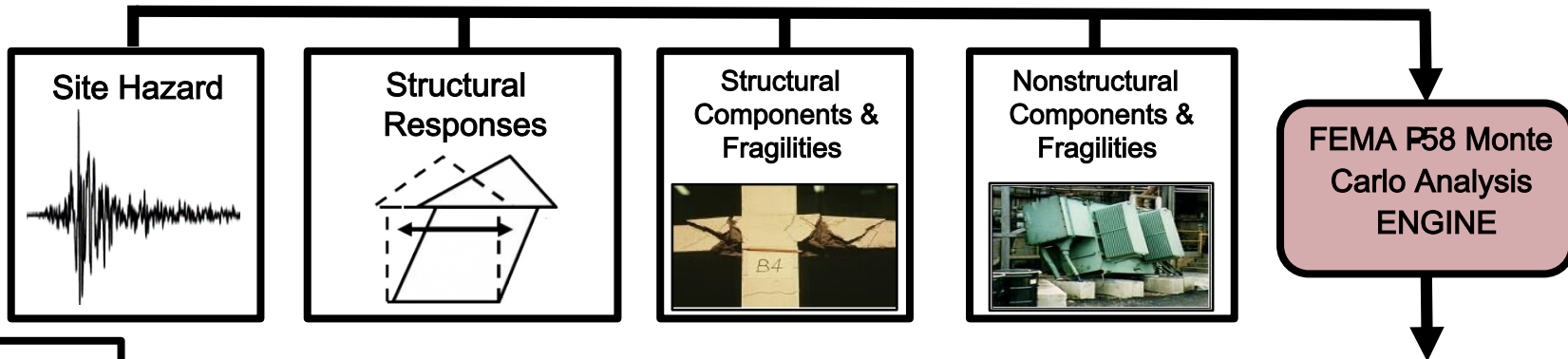
(e.g. building system, strength and stiffness, detailing, user defined structural responses, user defined hazard, etc)

SP3-RiskModel Advanced

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

Building-Specific Vulnerability Curves





Basic Building and Site Information

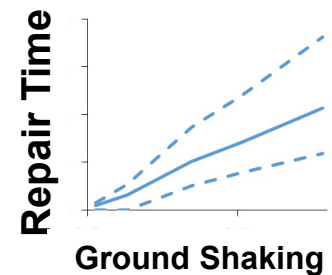
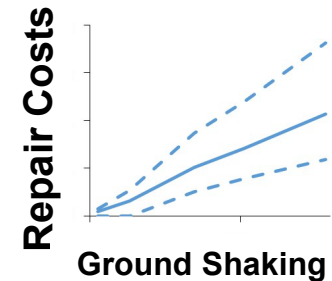
(e.g. location, construction year, structural system, occupancy, etc)

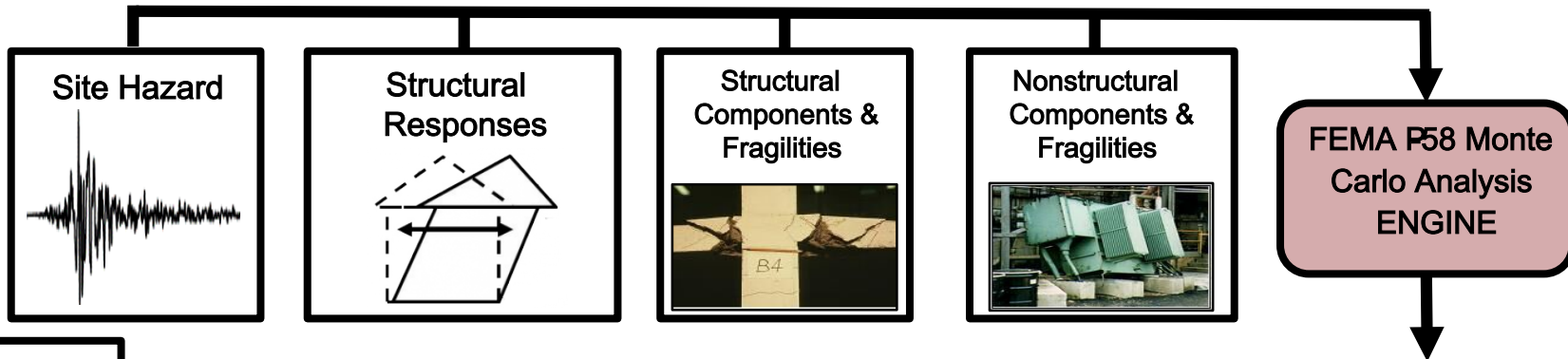


SP3-RiskModel Standard

Standard: Due-diligence risk assessment reports, preliminary resilient design decisions
Still gives full FEMAP-58 risk results (but with some more uncertainty in the estimate).

Building-Specific Vulnerability Curves





Basic Building and Site Information

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

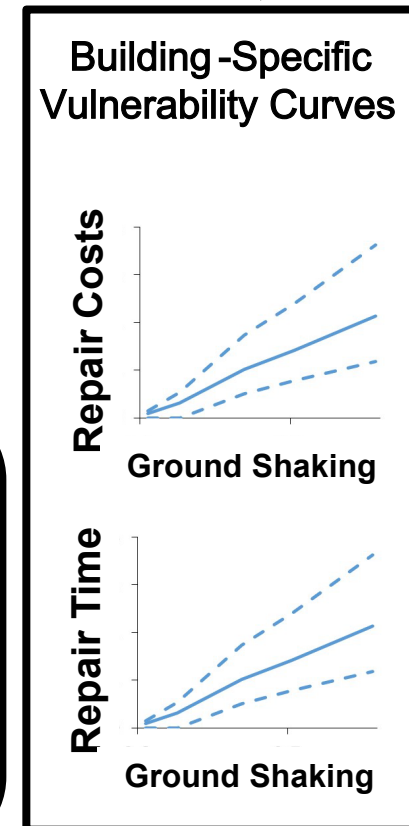


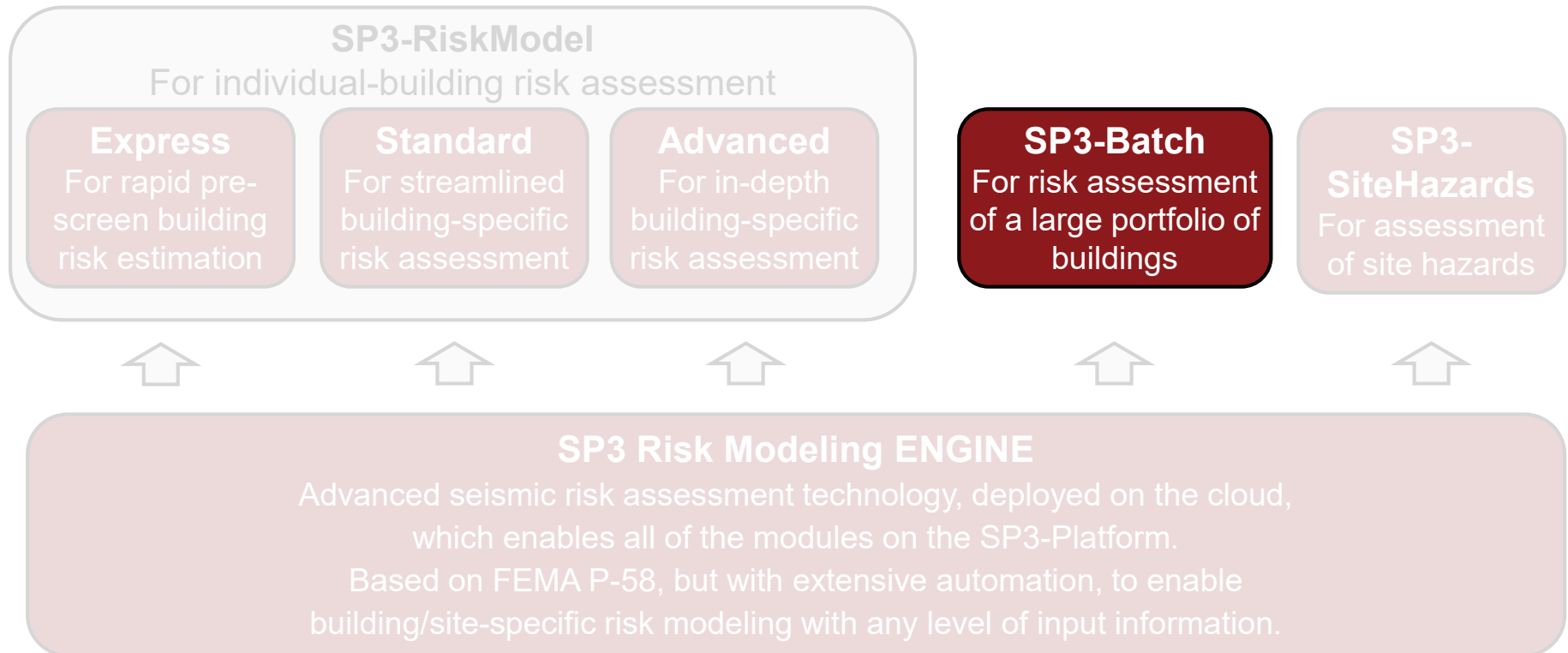
Additional Secondary Modeling

(irregular shapes, building geometric layout, and square footage, etc)

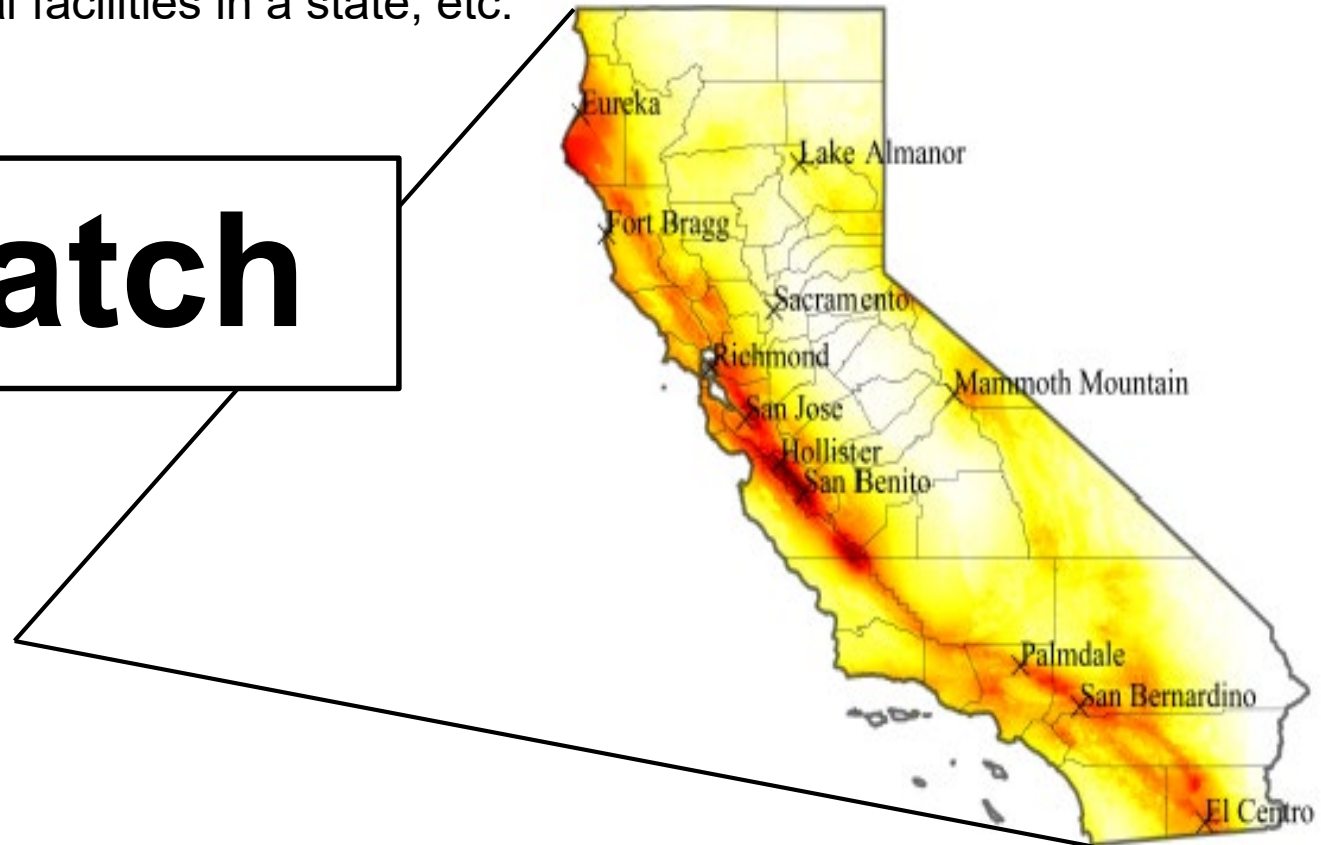
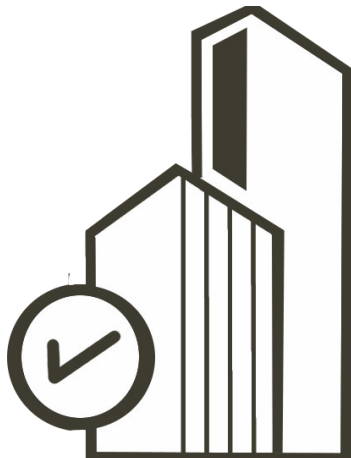
Express Rapid assessments of one building or a portfolio of buildings (using SP3-Batch)

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

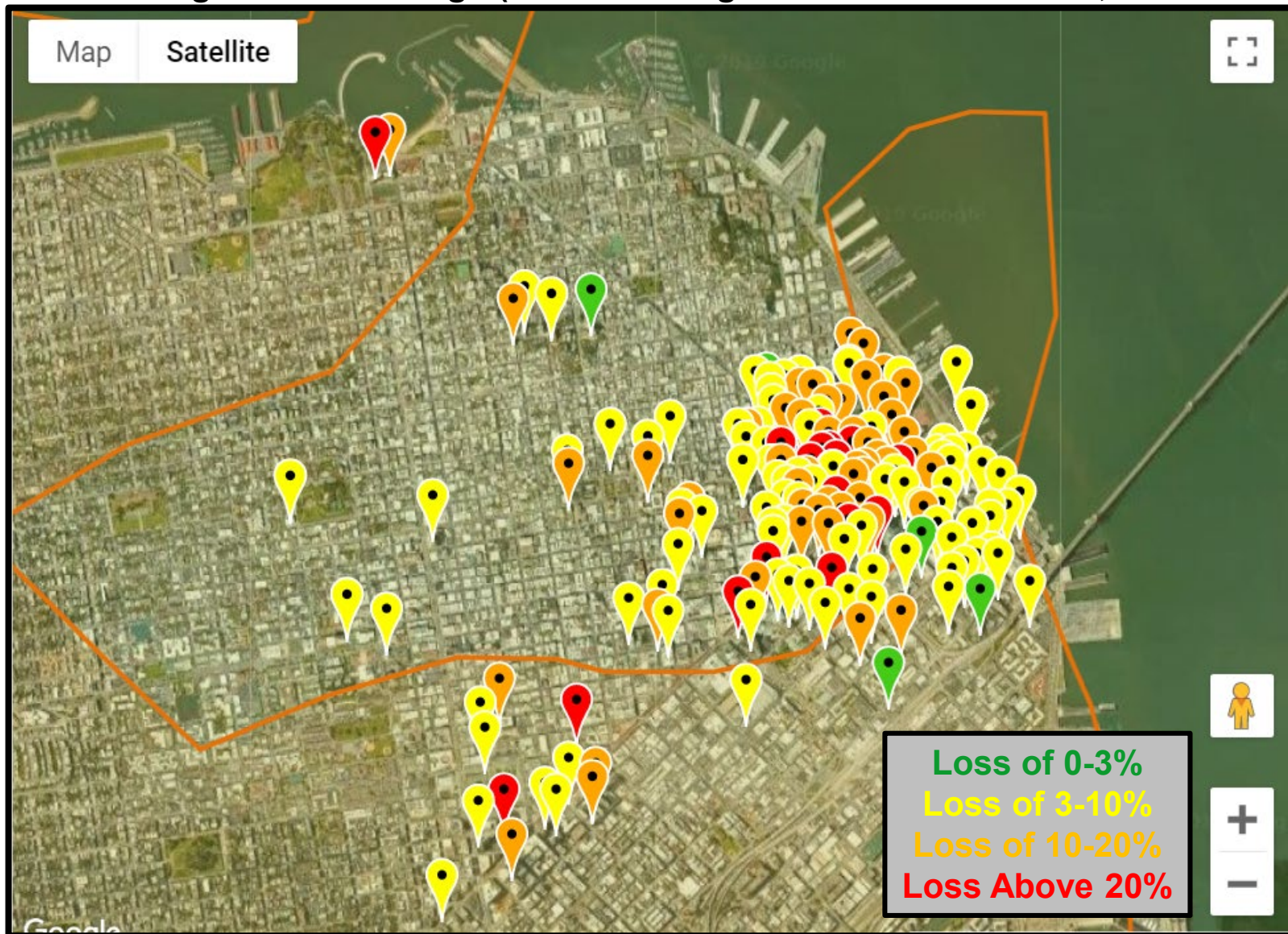


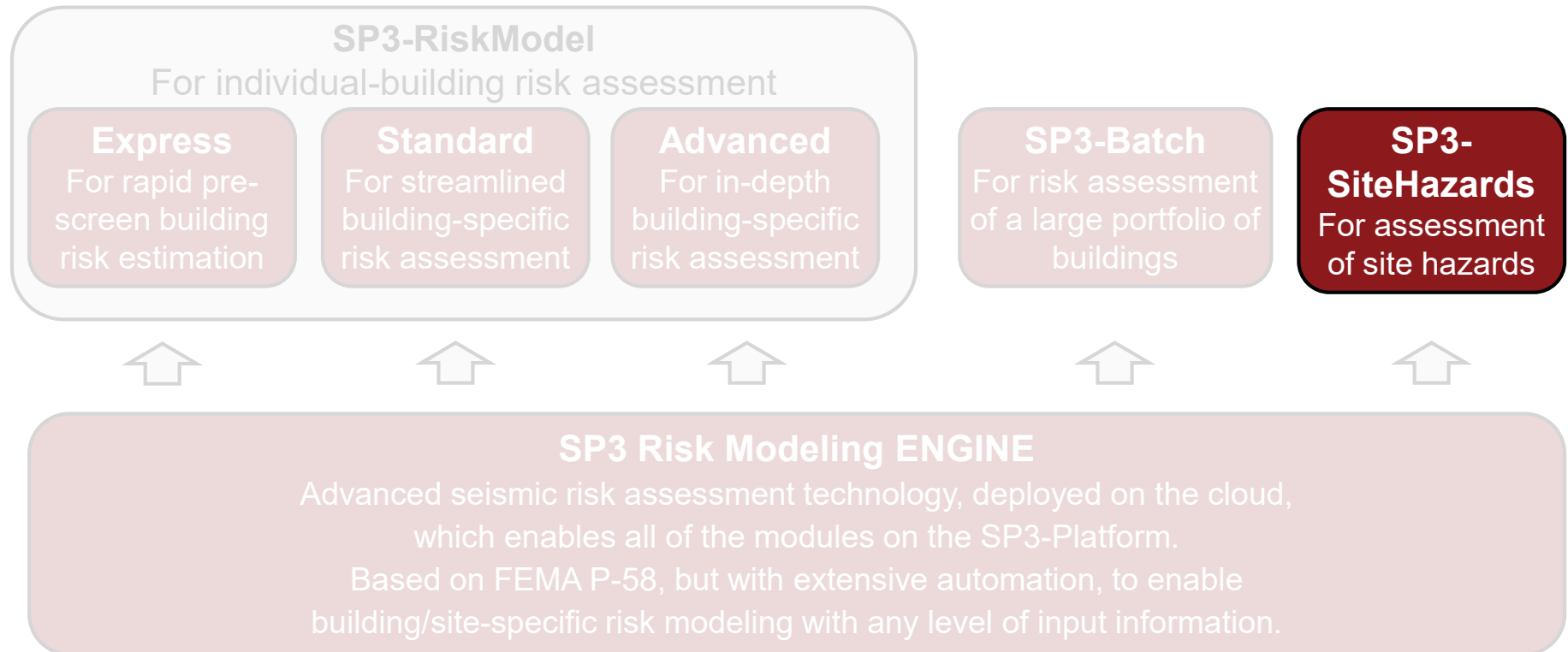


- Runs SP3 building analyses at scale using Amazon Web Services and ~2000 processors (CVS batch input, etc.).
- May Use Case:** San Francisco tall buildings, SF Bay Area non-ductile concrete (~3000 buildings), portfolio of 100+ municipal buildings in a CA county, project starting for a California campus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



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





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)

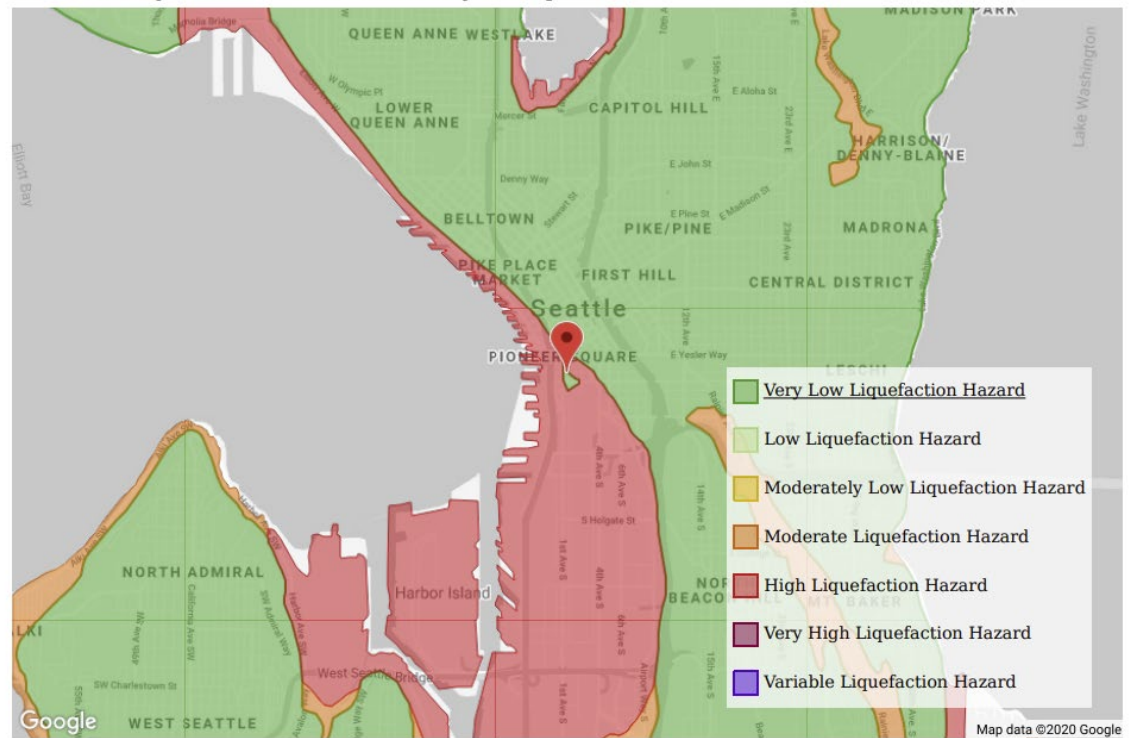


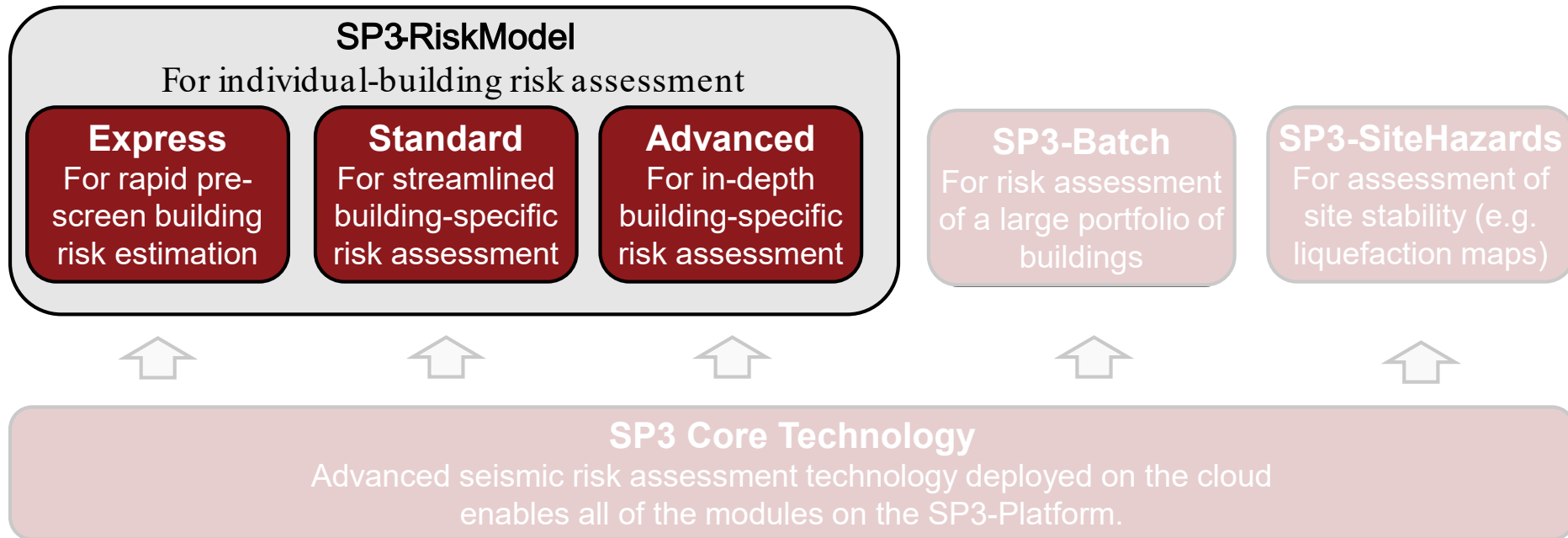
Produced for:

Bosco Inc

Data Source #1 - Washington State Liquefaction

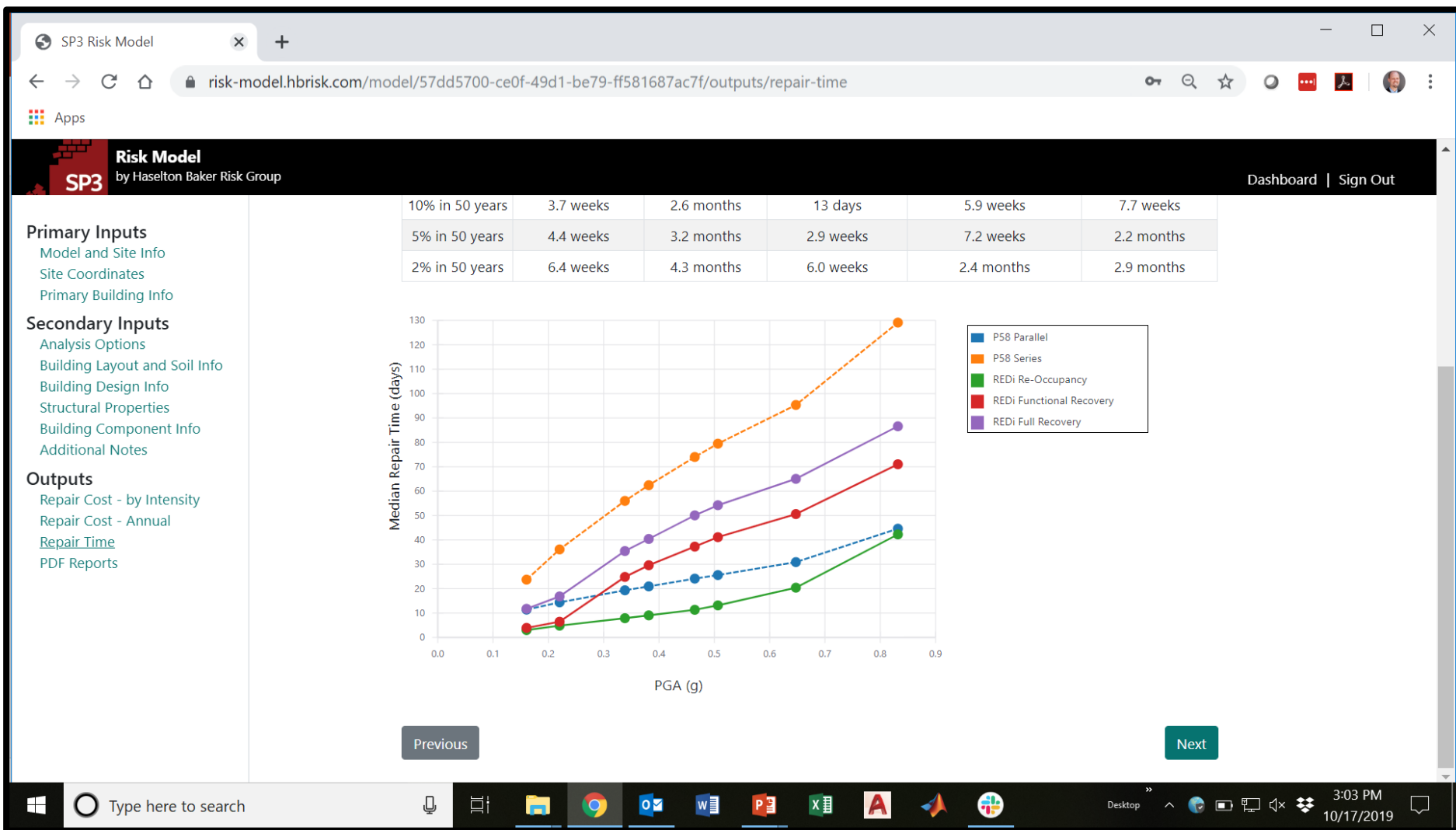
Based on the map below, this site is located in a **Very Low Liquefaction Hazard** zone.



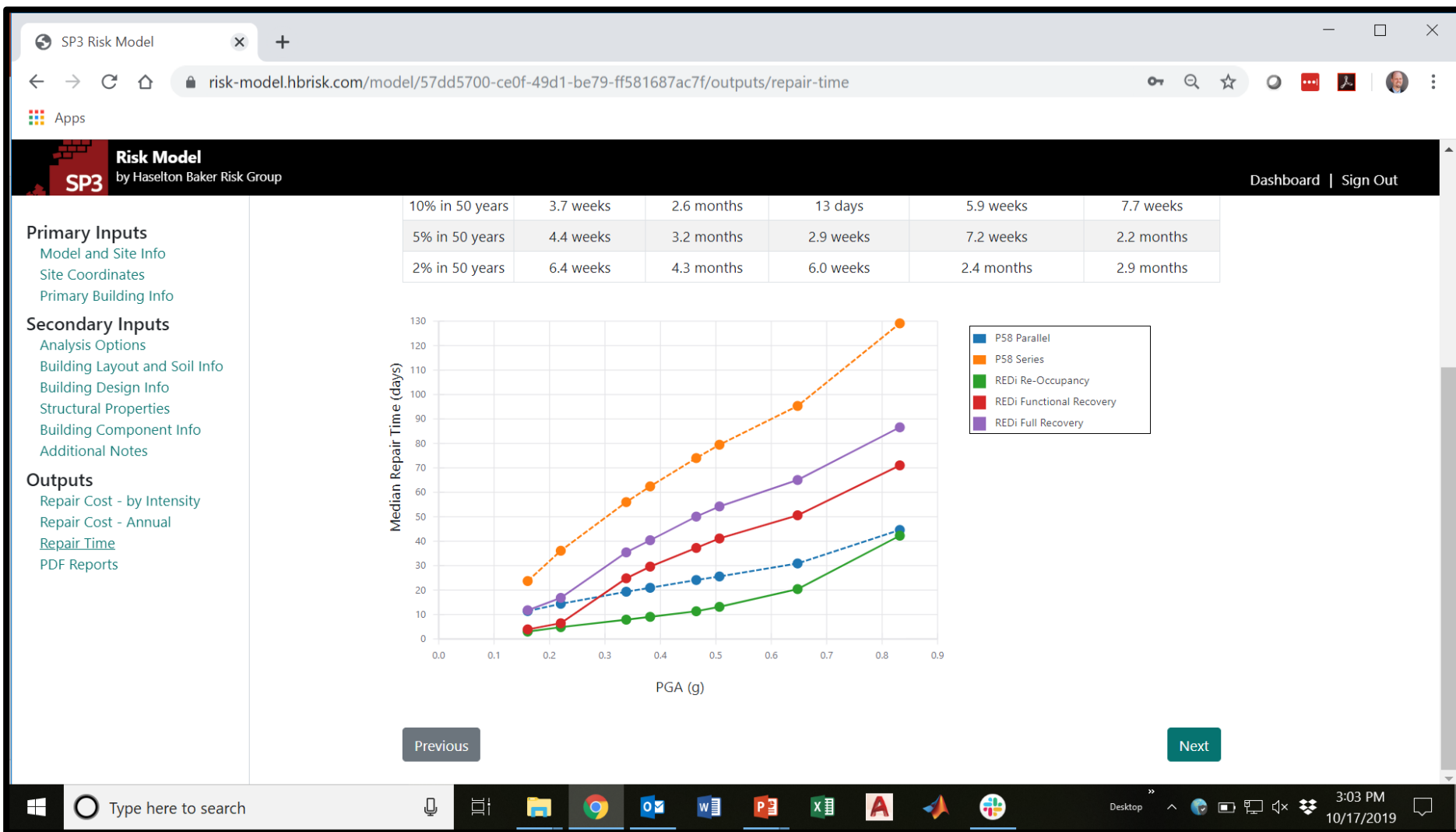


SP3-Portfolio (coming soon)





- Optional 1-2 hour take-home assignment:
 1. Pick a building that you want to do a quick seismic risk assessment for (and in the U.S.).
 2. Run an automated SP3-RiskModel assessment of the building.
 3. Look at the output reports and describe the non-structural damage at three levels of ground shaking:
 - 50% in 50 year
 - 10% in 50 year
 - 2% in 50 year
 4. [optional] Look at the predicted peak floor accelerations demands and compare with other prediction methods you have learned about in class.
 5. [optional] Comment on PFA predictions and component demand predictions (and note that you can view anchorage strength estimates on the component page).



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- 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!

Kendall Anderson (HB-Risk admin): *kendall@hbrisk.com*

Curt Haselton: *curt@hbrisk.com*, Direct: (530) 514-8980

www.sp3risk.com

New Design: Long Beach Civic Center and Port Facility



Figure Source: SOM/NYASE 2016 SEAOC presentation

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.]
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REDi Rating: ~Gold Performance

US Resilience Council Rating: 4-5 Star Performance

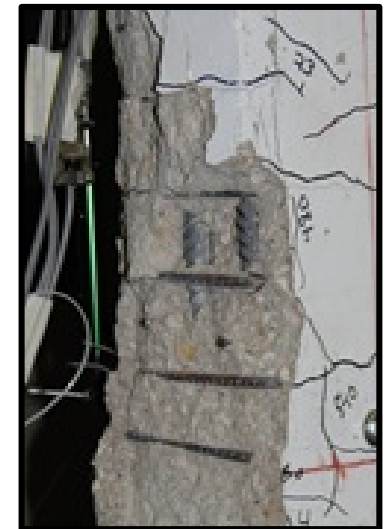


Figure Source: SOM/NYASE 2016 SEAOC presentation

Approach: Iterative design using FEMAP-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)



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

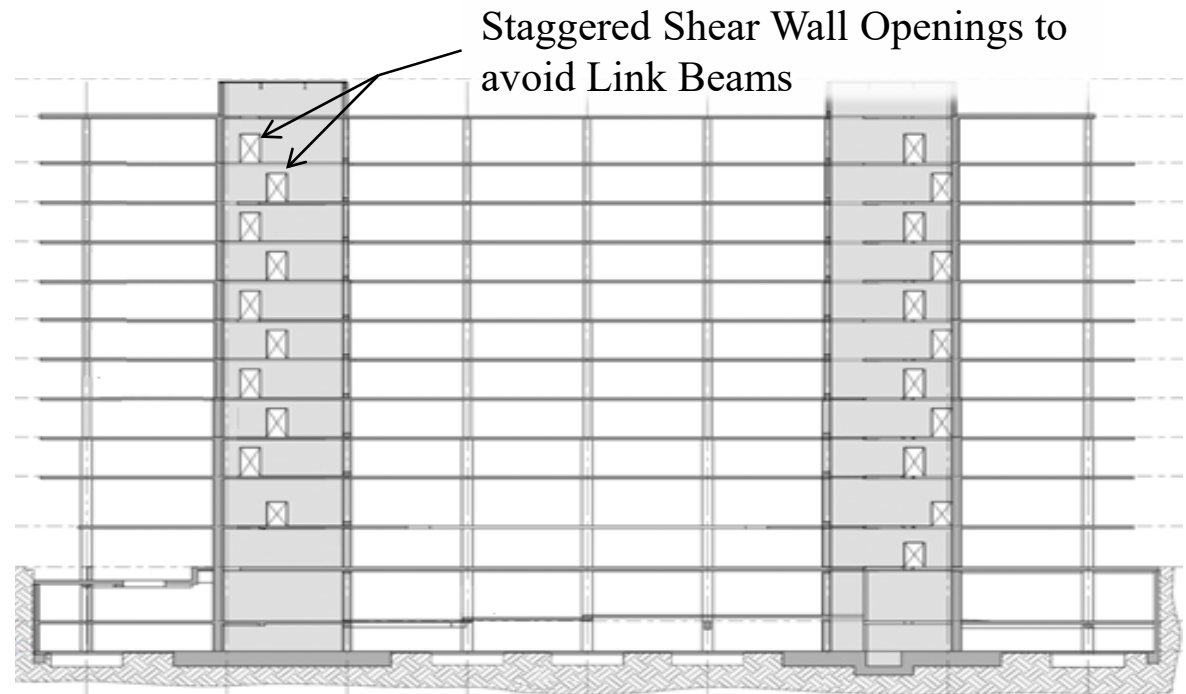
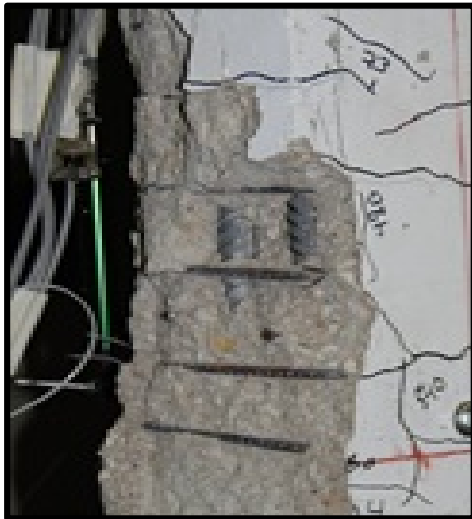


Figure Source: SOM/NYASE 2016 SEAOC presentation

Step #3: Design mechanical and electrical components to be functional at the 10% in 50 year (anchorage, equipment, lighting, etc.).

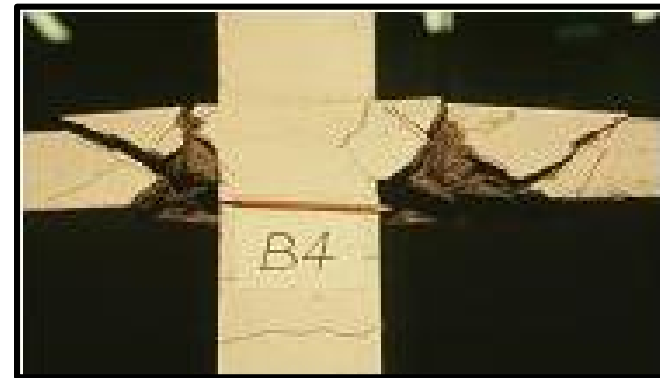
- Result for Steps #2-3:
 - Repair Cost = 5.5% [still 4-star]
 - Recovery Time = 2.5 months [still 3-star]
 - 1.0 month – slab-column connections
 - 1.5 months – partition walls



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



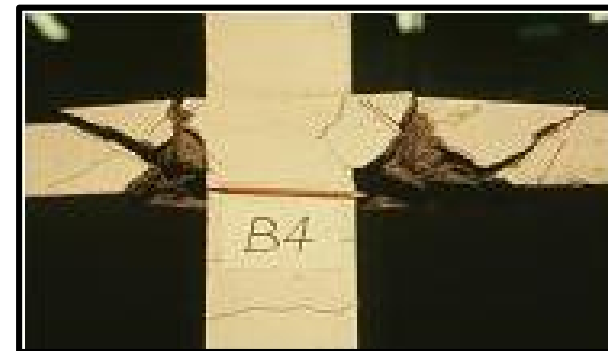
Step #6: Stiffen the building (longer walls, more coupling, etc.). Reduces the maximum drifts from around 1.4% to 1.0%.

- Result:
 - Repair Cost = 2% [5-star]
 - Recovery Time = 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]



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.**





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 FEMAP-58 offers this same level of building-specific detail when doing **performance assessments** as well.