Resilience-Based Design & Risk Management using FEMA P-58

FEMA P-58 and SP3 Software for Resilient Seismic Design

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What is “Resilience-Based Design”?

Code Design (ASCE7, etc.)

- Safety Goal – Yes
- Not focused on repair cost/time, so designing *disposable buildings*.

“Performance-Based Design” (AB 083, ASCE 41, etc.)

- Safety Goal – Yes
- Can consider other goals, but typically not done in current practice.
- Enhanced modeling and design scrutiny

“Resilience-Based Design“ (or “PBD Generation 2”)

- Safety Goal – Yes
- Repair Time Goal – Yes
- Repair Cost Goal – Yes
- Also enhanced modeling and design scrutiny

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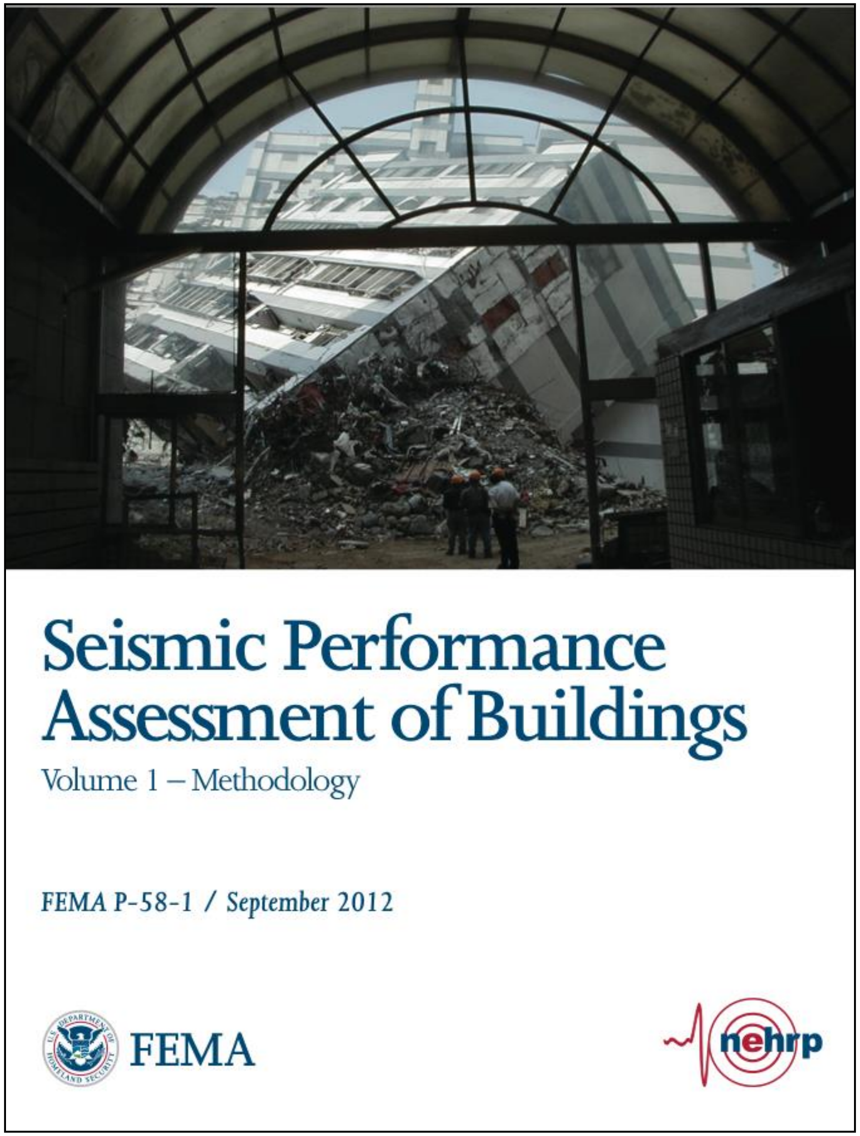
FEMA P-58 Enables Resilience-Based Design

- FEMA P-58 is a probabilistic performance assessment method (10+ years in the making, $12M+ invested, development ongoing)
- FEMA P-58 is tailored for building-specific analysis (in contrast to most risk assessment methods)
- FEMA P-58 output results:
  1) Repair costs
  2) Repair time
  3) Safety: Fatalities & injuries



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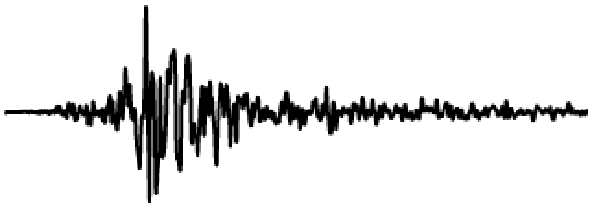
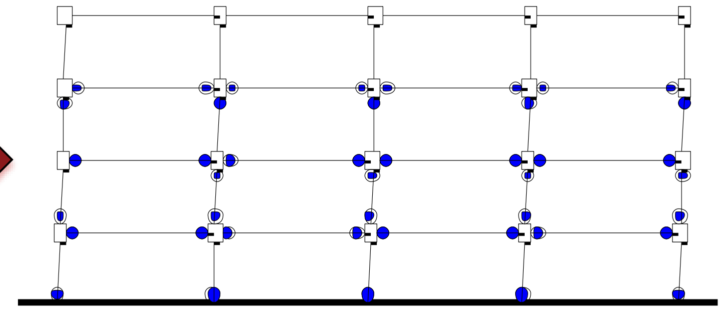
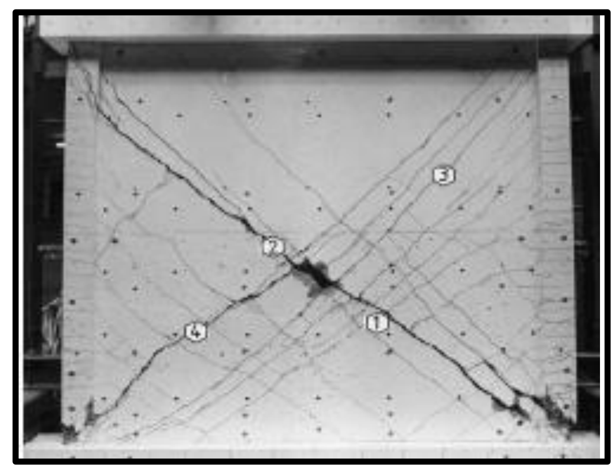
FEMA P-58 Modeling Approach



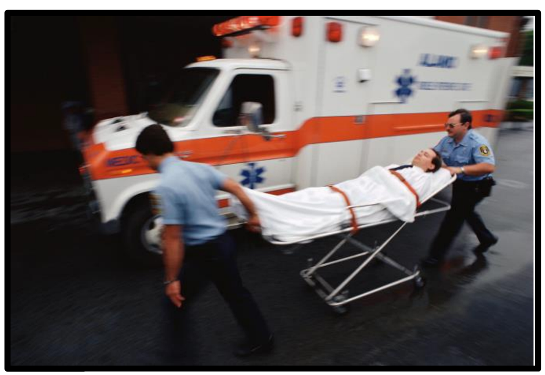
Ground Motion Hazard



Structural Response



Component Damage



Casualties

Repair Time

Economic Loss

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FEMA P-58 Benefits

- **Comprehensive and credible:** $12M, 10 years to develop, team of 100+ really smart researchers and practitioners
- **Transparent and open-source:** FEMA P-58 is open to the public.
- **Building-specific:** The analysis incorporates the specific nuances of the building, rather than being based on building class.
- **Standardized and repeatable:** Consistent FEMA P-58 damage and repair cost databases are used consistently for all analyses (created based on 20+ years of research).

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What can I now do with FEMA P-58?

Applications:

- New design ("resilience-based" design)
- Retrofit
- Risk evaluations for mortgage (PML) and insurance
- Risk evaluations for specialized buildings
- Building ratings

Contrasting Methods:

- Code design (safety-only and prescriptive), performance-based design (typically also safety-only)
- ASCE 41 (mostly safety-only, except for if using IO)
- Experience and judgement-based approaches, which do not handle much building-specific information (e.g. Hazus, ATC-13, ST-Risk, SeismicCat, etc.).
- [same as above]
- Ratings are new; can use FEMA P-58 methods or checklist-based

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New Design: Municipal Center (not named)

Figure Source: SOM/NYASE 2016 SEAOC presentation

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New Design: Municipal Center (not named)

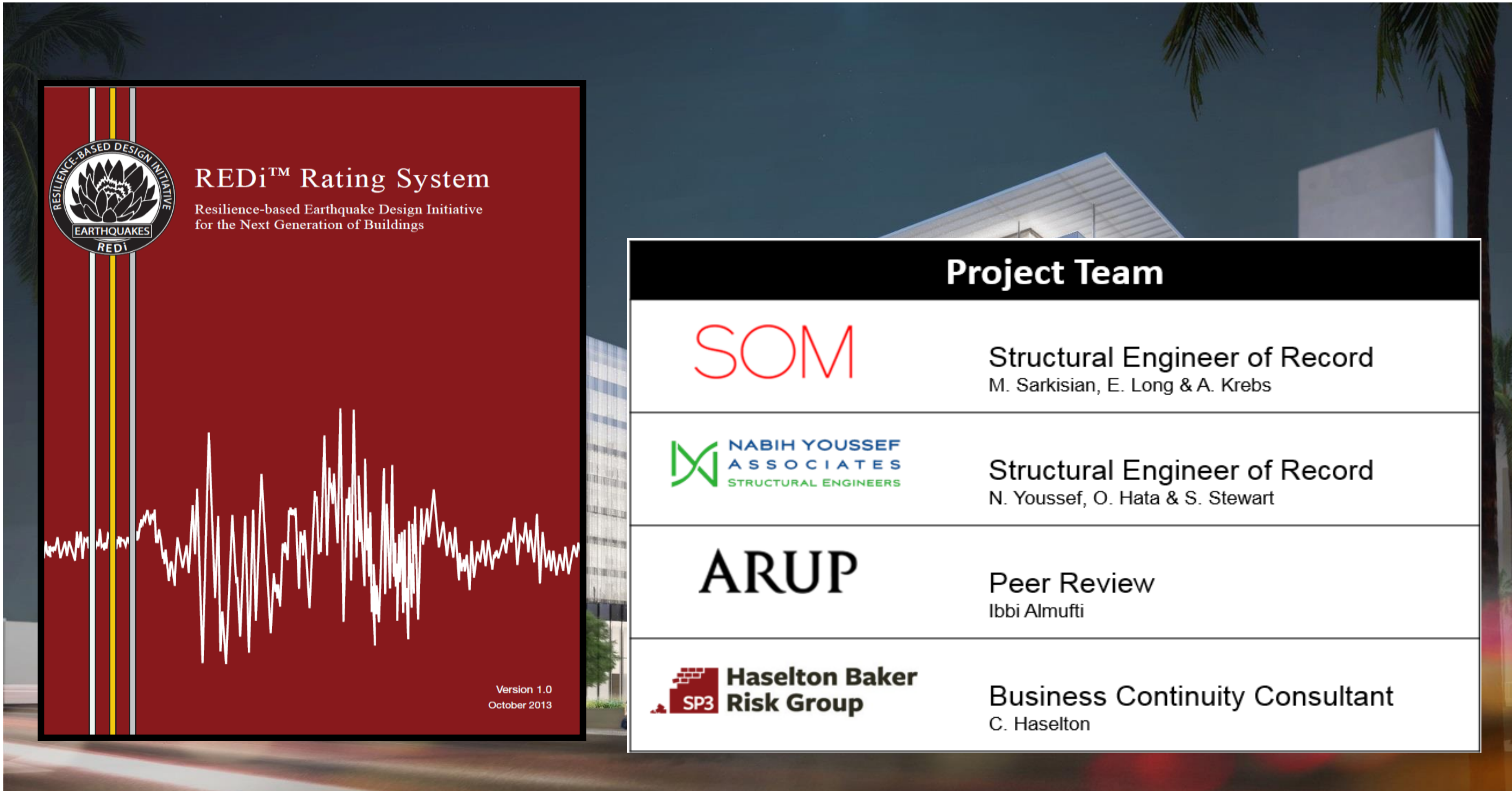

Figure Source: SOM/NYASE 2016 SEAOC presentation

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What can I now do with FEMA P-58?

New Design: Municipal Center (not named)

Design Objectives (for design earthquake):

- Safe (few or no injuries)
- Minimal repair cost (>5%)
- Minimal reoccupancy time (>1 week)
- Minimal functionality time (>1 month)

REDi: ~Gold Performance
USRC: 4-5 Star Performance

Figure Source: SOM/NYASE 2016 SEAOC presentation

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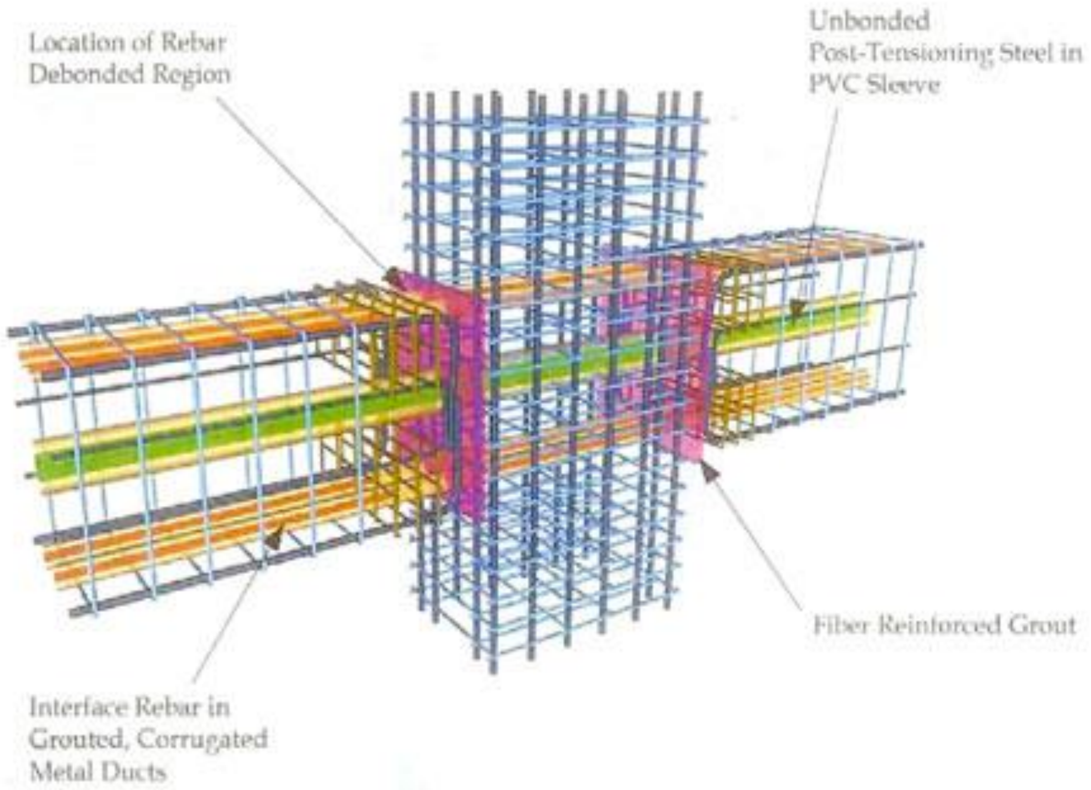
Assessments for Innovating Structural Systems



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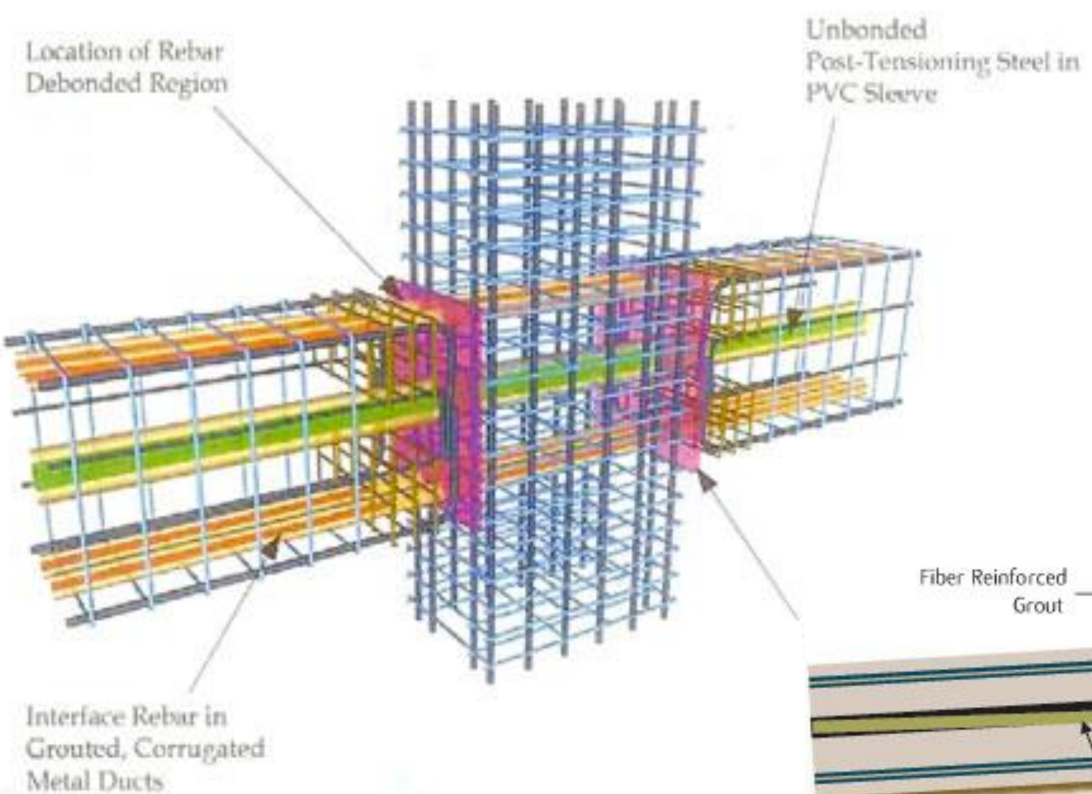
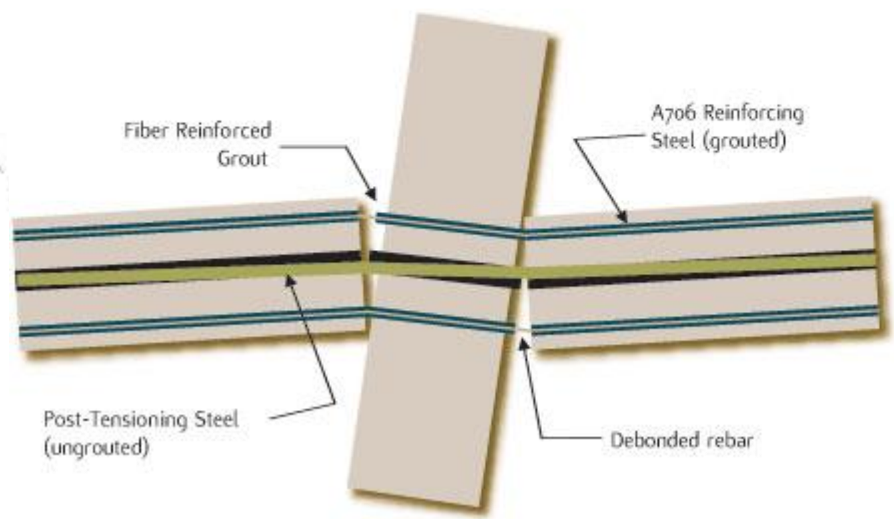
Assessments for Innovating Structural Systems





Figures: http://cenews.com/userfiles/image/SE1111_44.jpg, http://precast.org/wp-content/uploads/2010/09/defying_rubber_band.jpg

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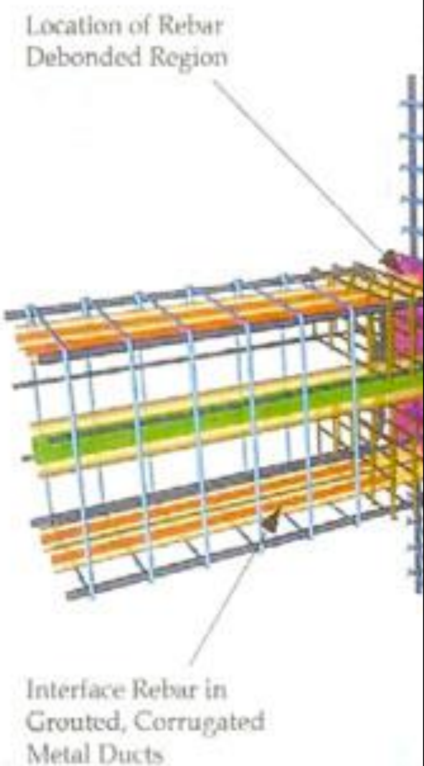
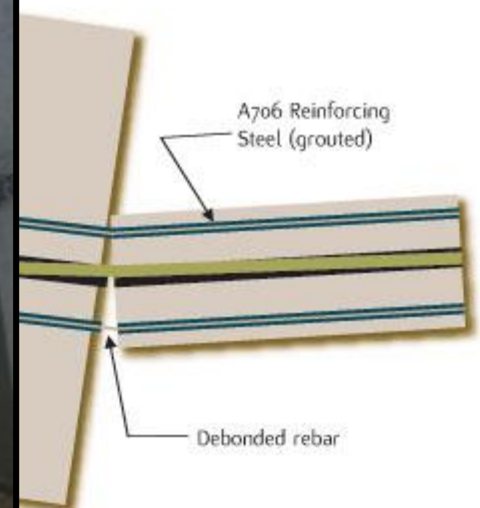
What can I now do with FEMA P-58?

Assessments for Innovating Structural Systems





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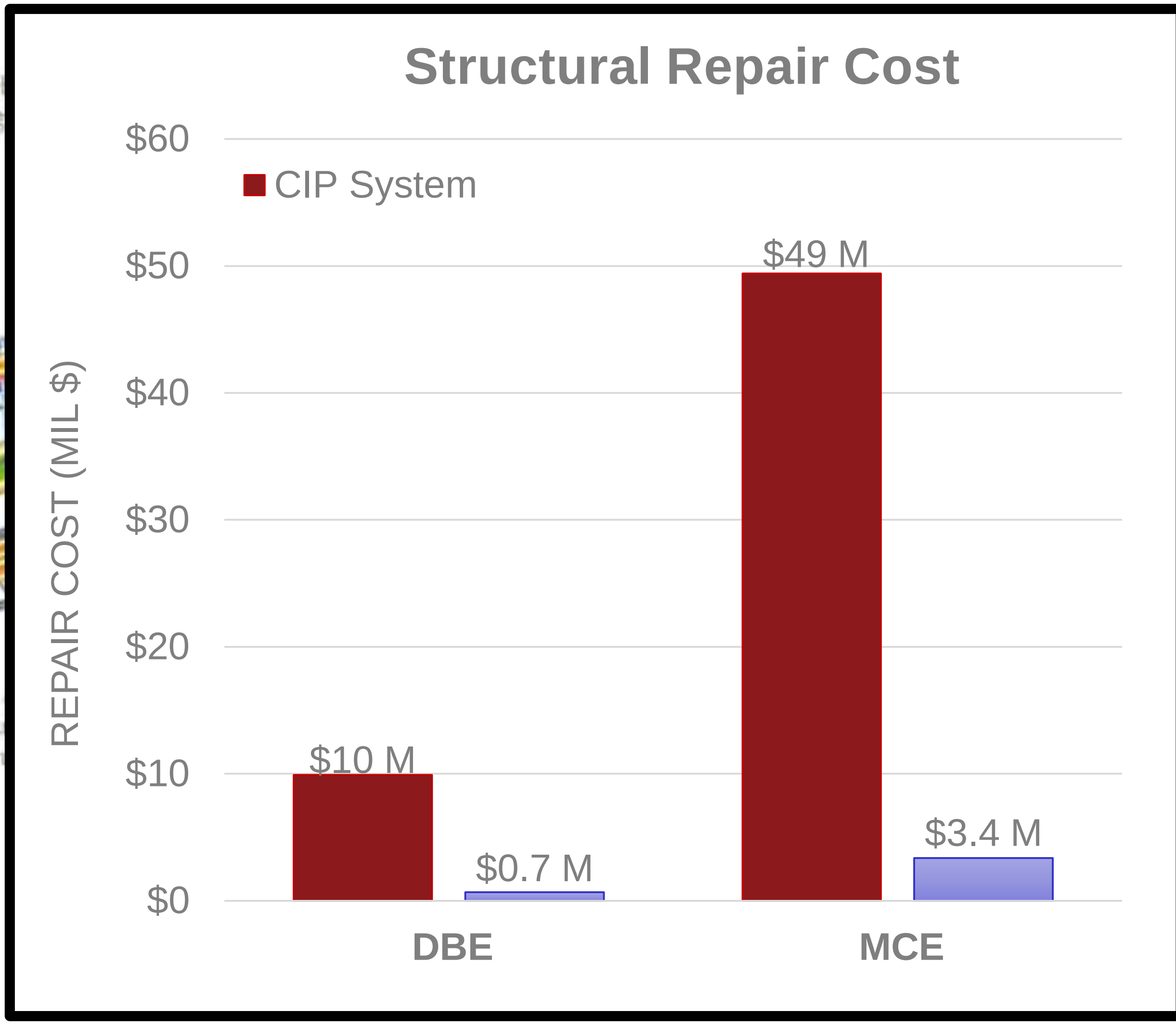
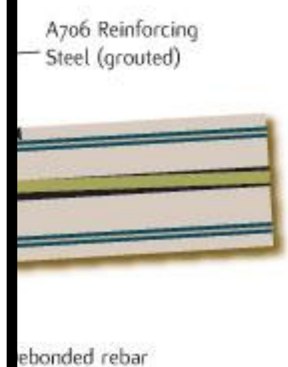
What can I now do with FEMA P-58?

Assessments for Innovating Structural Systems





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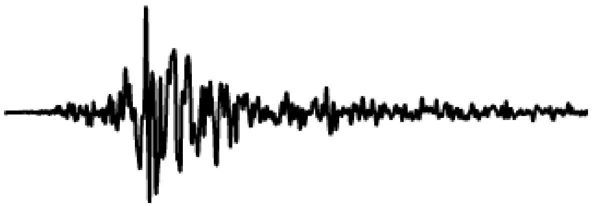
FEMA P-58 Modeling Approach



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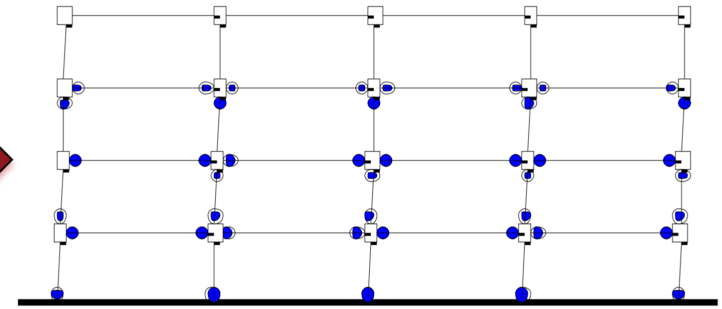

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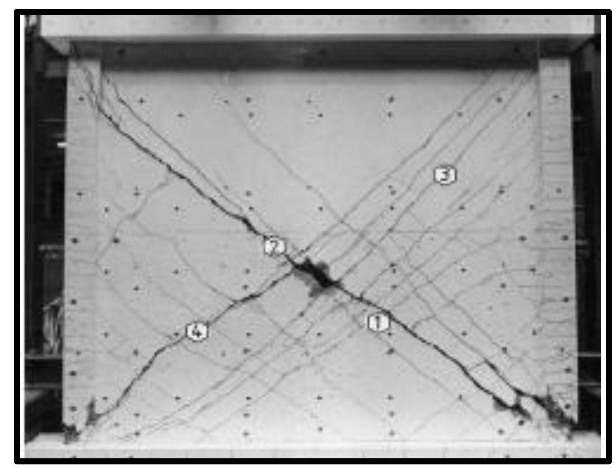
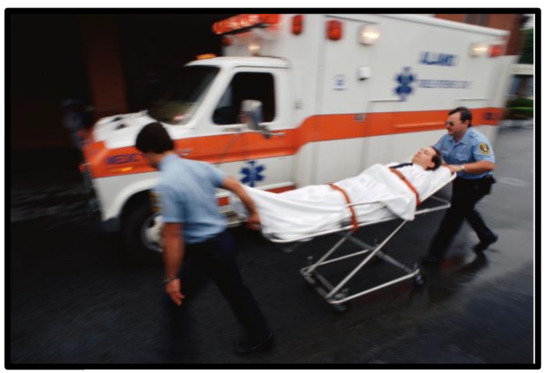


Component Damage



Casualties

Repair Time

Economic Loss

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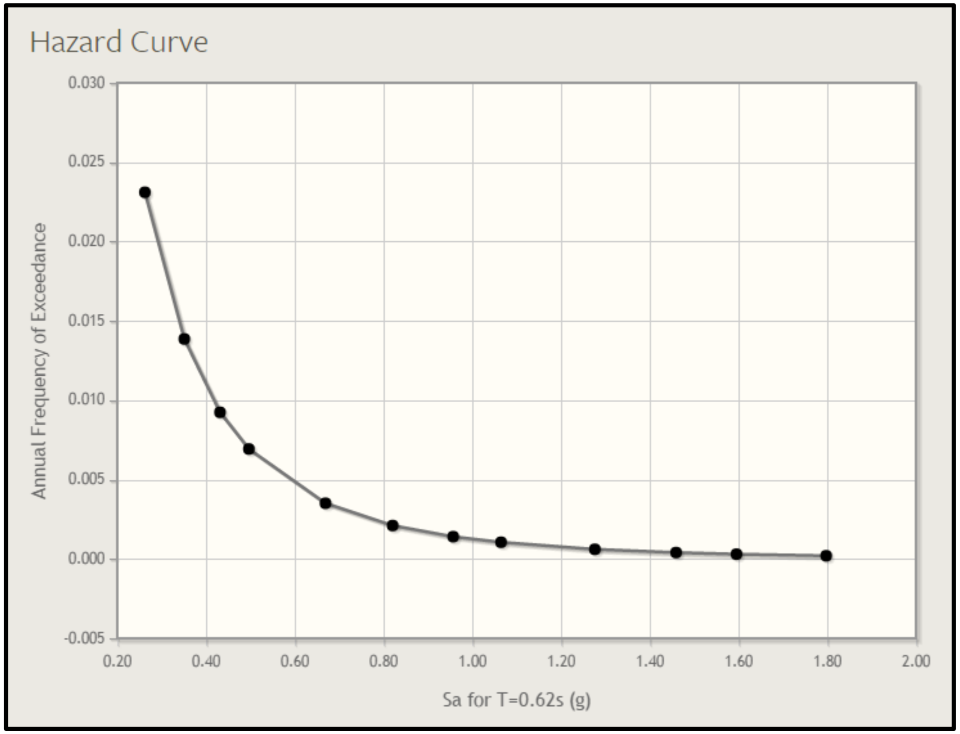
- **Step 1:** Define ground motion hazard curve (with soil type)
  - Option #1: SP3 can provide (given an address)
  - Option #2: User-specified



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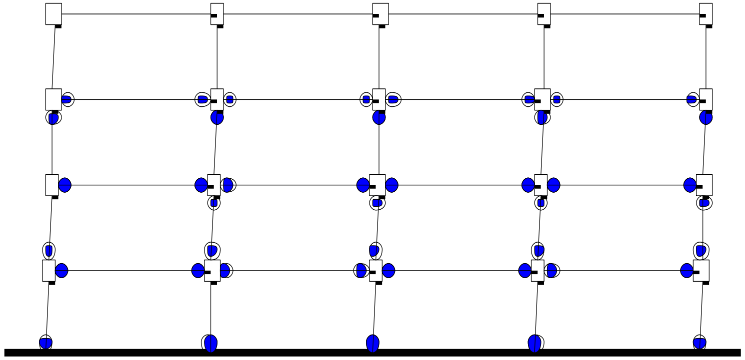
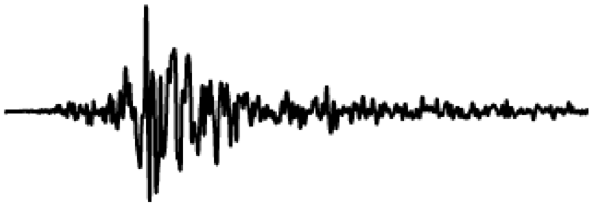
- **Step 2:** Predict "engineering demand parameters"
  - Story drift ratio at each story
  - Peak floor acceleration at each floor
  - For wall buildings, also wall rotations and coupling beam rotations





Option #1: Response-history structural analysis

Option #2: Statistically calibrated predictive equations

Option #3: Modal analysis (soon)

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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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- **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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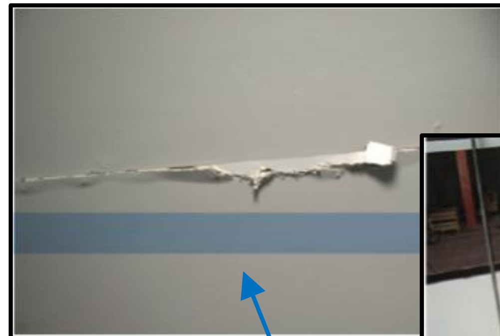
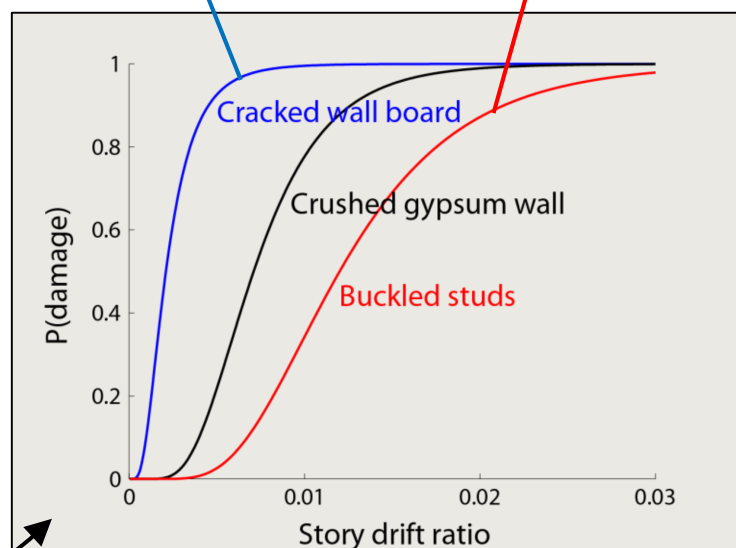
FEMA P-58: Component Damage

- **Step 3:** Quantify component damage

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





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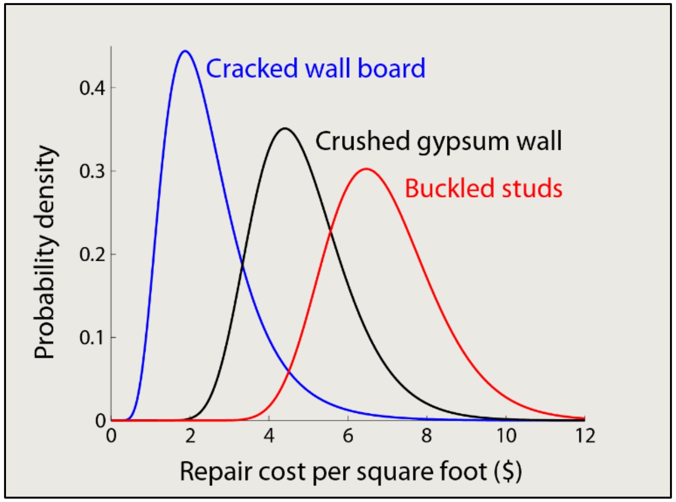
- **Step 4:** Quantify consequences of the component damage (component repair costs, repair times, etc.).



	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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FEMA P-58: Summary of Steps

- **Step 1:** Site Hazard
  - Soil and hazard curve
  - Ground motions (if needed)
- **Step 2:** Structural Responses
  - Option #1: Structural analysis
  - Option #2: Predictive equations
- **Step 3:** Damage Prediction
  - Contents
  - Fragility curves
- **Step 4:** Loss Estimation (repair cost, repair time, etc.)

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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FEMA P-58: Summary of Steps

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Typical Reactions:

Looks extremely complicated!!!

Great method, but it's a Cadillac and I would only use it for special projects!!!

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Enabling SP3 Commercial Software

- **Step 1:** Site Hazard
  - Soil and hazard curve
  - Ground motions (if needed)
- **Step 2:** Structural Responses
  - Option #1: Structural analysis
  - Option #2: Predictive equations
- **Step 3:** Damage Prediction
  - Contents
  - Fragility curves
- **Step 4:** Loss Estimation (repair cost, repair time, etc.)

SP3 implements the FEMA P-58 method, plus a number of other features.

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Enabling SP3 Commercial Software

- **Step 1:** Site Hazard
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- **Step 3:** Damage Prediction
  - Contents
  - Fragility curves
- **Step 4:** Loss Estimation (repair cost, repair time, etc.)

USGS Soil and ground motion database information embedded

Statistically calibrated structural response methods embedded

Full FEMA P-58 fragility database embedded, building contents are auto-populated (with FEMA P-58 methods and enhanced options)

Two-level structure:

1) Use pre-populated values (Goal: Analysis in hours rather than weeks).
2) Modify inputs to dig deeper

Structure: Cloud-based computational platform, flexible reporting options

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Why Does SP3 Exist?

- **The Goal:** Enable widespread and mainstream use of FEMA P-58 for building-specific risk assessment.
- **The Intended Outcome:** We believe that this better understanding of risk will (a) facilitate design of more resilient buildings and (b) enable better decision-making for both mortgage risk and insurance risk.
- **The Strategy:** Provide a software that enables these assessments at a rapid pace, so feasible for nearly all projects (taking hours not weeks).

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Quick Resilience-Based Design Example

- Project: Municipal office building
- Building: Design a 10-story RC Wall (coupled core), office occupancy
- Site: LA high-seismic
- Design Objectives: USRC <u>five-star</u> 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 *assessment*.

Figure Source: SOM/NYASE 2016 SEAOC presentation

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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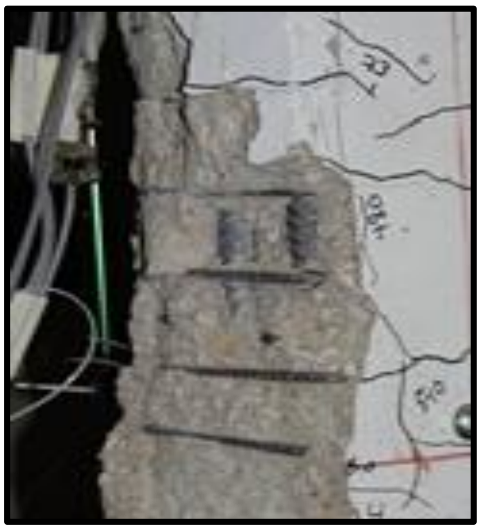
Quick Resilience-Based Design Example

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



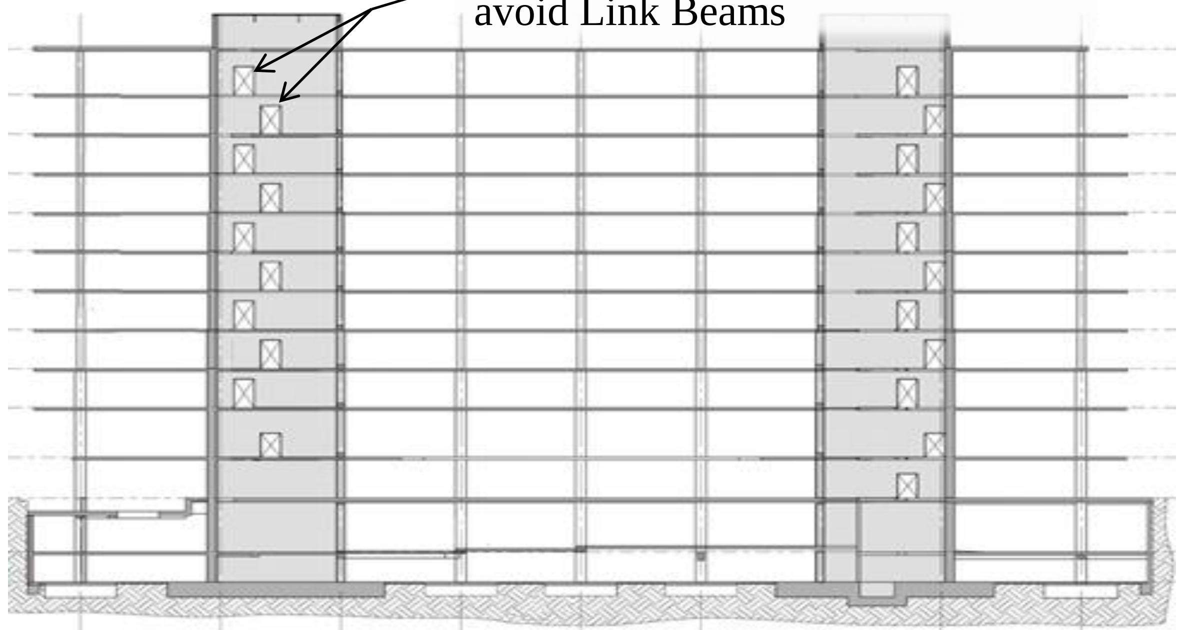


Figure Source: SOM/NYASE 2016 SEAOC presentation

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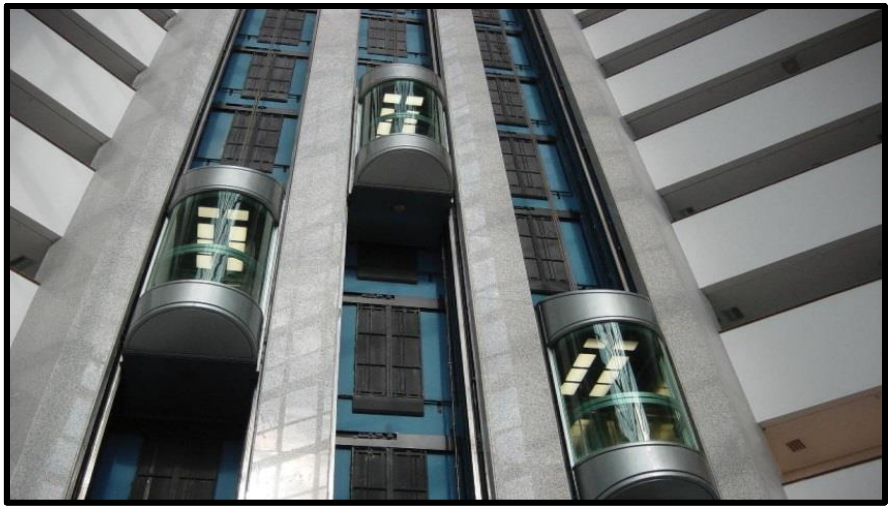
Quick Resilience-Based Design Example

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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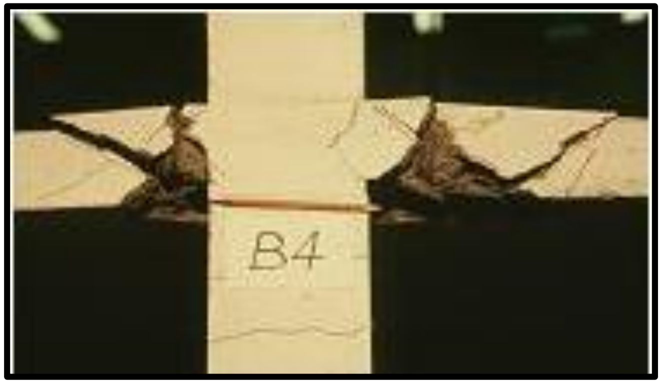
Quick Resilience-Based Design Example

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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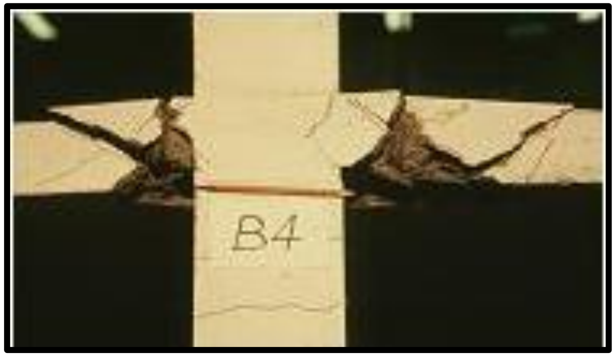
Quick Resilience-Based Design Example

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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Quick Resilience-Based 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 example was 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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Two Options:

- Direct design based on a FEMA P-58 risk assessment
- Prescriptive design, as calibrated based on FEMA P-58 assessments

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Requirements for a Resilient Design

There are several levels of resilient design, and the exact design requirements will depend on the level of resilience desired, but the primary needs to make a building be seismically resilient are as follows:

- Essentially no structural damage (i.e. no red tag and no damage that will inhibit building functionality).
- Residual drifts low enough to not cause red tag and not require repair.
- Peak drifts low enough to prevent damage to non-structural drift sensitive components that would inhibit building functionality.
- Peak floor accelerations low enough to prevent damage to acceleration sensitive components (that would inhibit building functionality), or the anchorages and the equipment being specifically designed to remain functional under the imposed floor accelerations.

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Table 1 - Example performance targets for building resilience

Level of Resilience	Maximum Damage (% value)	Maximum Recovery Time	Safety
Platinum	5%	5 days	Safe
Gold	10%	4 weeks	Safe
Silver	20%	6 months	Safe
Bronze	40%	1 year	Safe

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White Paper on Resilient Design

Table 2 - Example of Resilient Design Process using FEMA P-58

ID	Design Changes	Mean Loss at 10% in 50yr	Mean Loss at 2% in 50yr	Median REDi Functional Recovery at 10% in 50yr
11251	Baseline	17%	43%	37 days
11253	Self-Centering Frame (No Residual Drift)	11%	27%	32 days
11254	Cladding Detailed for No Damage	7%	17%	29 days
11255	Slab-Column Connections Detailed for No Damage	4%	11%	27 days
11256	Lateral Frame Connections Detailed for No Damage	2%	5%	27 days
11257	Elevators Detailed for No Damage	2%	5%	4 days

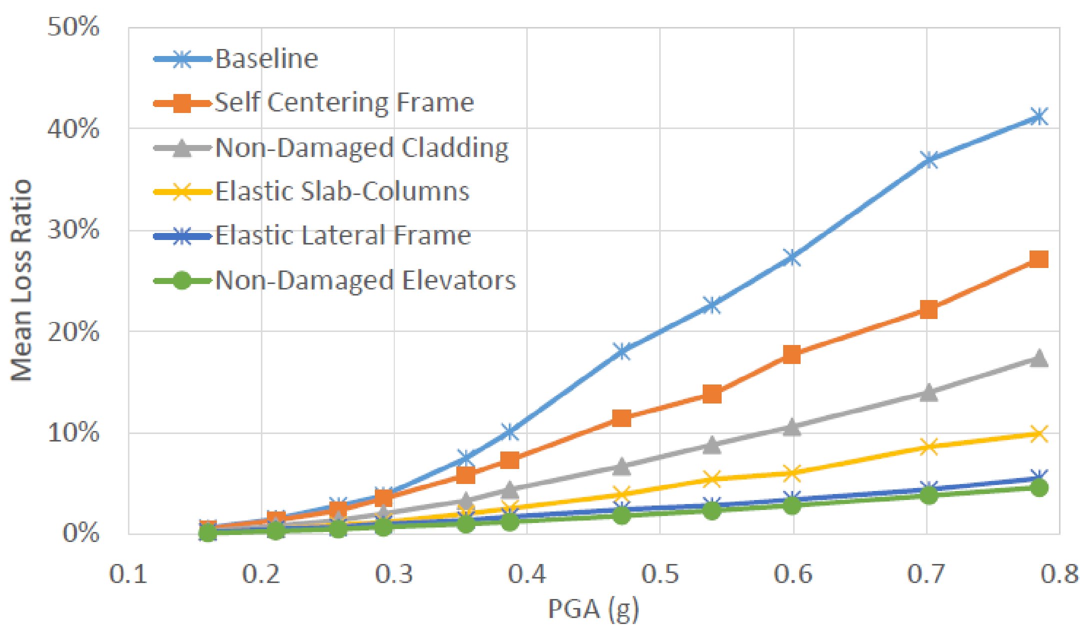

Figure 1 - Example Results from a Resilient Design Process using FEMA P-58

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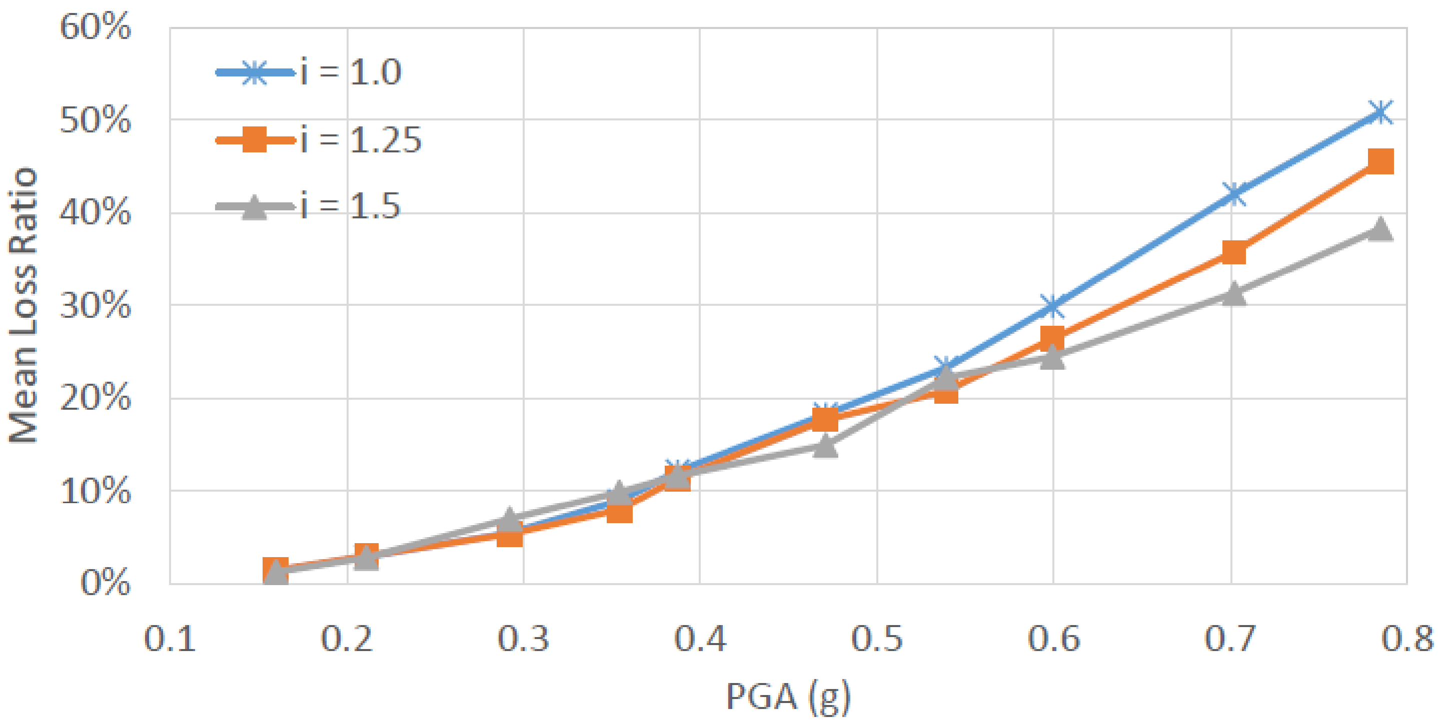

Figure 2 - Effects of Increased Design Strength (Ie > 1.0)

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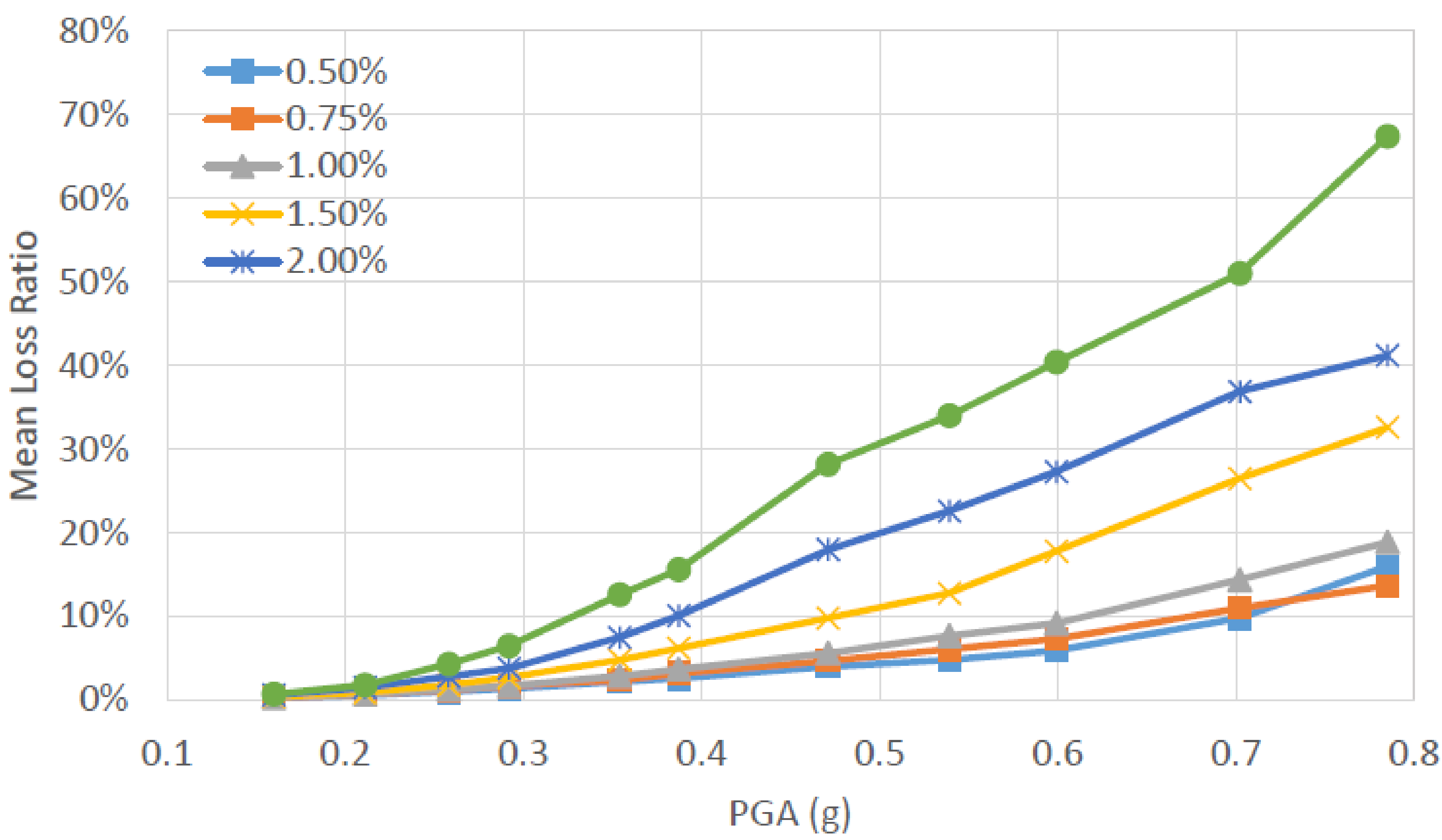

Figure 3 - Effects of Reducing Drift Limits

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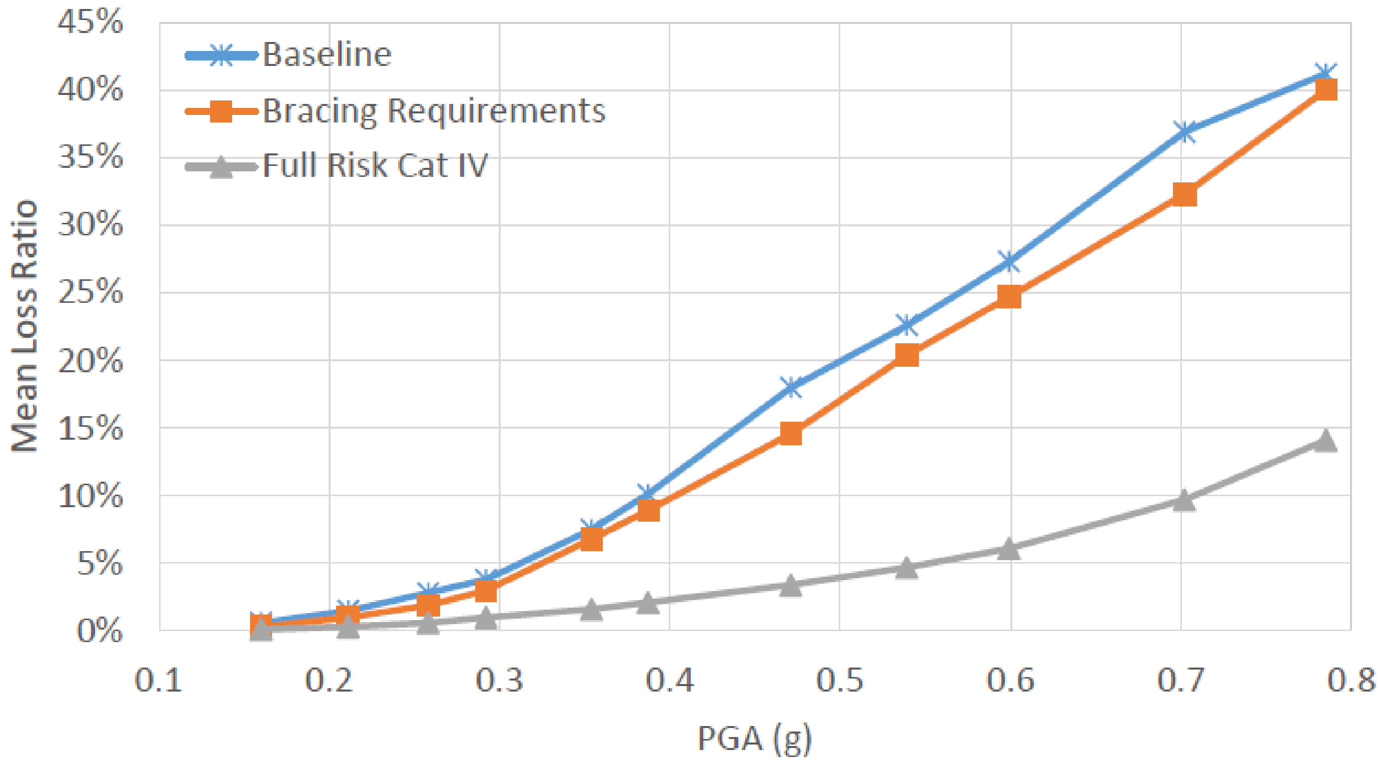

Figure 4 - Effects Risk Category IV Requirements

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REQUIREMENTS FOR A RESILIENT DESIGN

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- Peak floor accelerations low enough to prevent damage to acceleration sensitive components (that would inhibit building functionality), or the anchorages and the equipment being specifically designed to remain functional under the imposed floor accelerations.

Table 6 - Example Prescriptive Requirements for Resilient Design

Level of Resilience	Drift Limit	Maximum R Factor	Maximum Rp Factor	Risk Category for Nonstructural
Platinum	0.75%	3.5	1.5	IV
Gold	1.25%	5.5	4.0	IV
Silver	2.0%	8.5	9.0	III
Bronze	2.5%	8.5	12.0	II

Resilience-Based Design Trend and the Future

- The FEMA P-58 method and SP3 software are complete and ready for use.
- FEMA P-58 method and SP3 are being used increasingly in our structural engineering industry for:
  - New resilient design
  - Retrofit projects
  - PML and more advanced risk assessment
- We are also continuing further SP3 development:
  - Make the methods cover all structural systems and conditions (already covers nearly all of them). Nearly done with wood light-frame and then tilt-up is next.
  - Streamline the analysis methods to make the analysis quicker (structural response prediction methods).

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What are we going to do about this?

- **Cost:** Recent resilience-based design projects have estimated that resilient seismic performance **costed between 0-5%** of the project budget.
- **Performance Results:**
  - Repair cost of ~2% rather than ~10-20%.
  - Repair time of nearly zero rather than ~6-24 months.
  - **With these methods, we can design buildings that are not disposable.

The Question for Us All:

With these resilience-based design methods now available, and with costs being reasonable, why wouldn't we do resilience-based design for all new buildings?

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Questions and Discussion

- 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 and discussion!

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