Resilient Design for Functional Recovery using FEMA P-58/SP3 (+ ATC-138)

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Acknowledgement of Many Collaborators on Resilient Design:

Many visionary Structural Engineers in our profession, SP3 Team, ATC-138 Project Team (FEMA-funded), NIST project by Liel/Cook, Building Seismic Safety Council Functional Recovery Task Committee, and many more….!

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www.sp3risk.com

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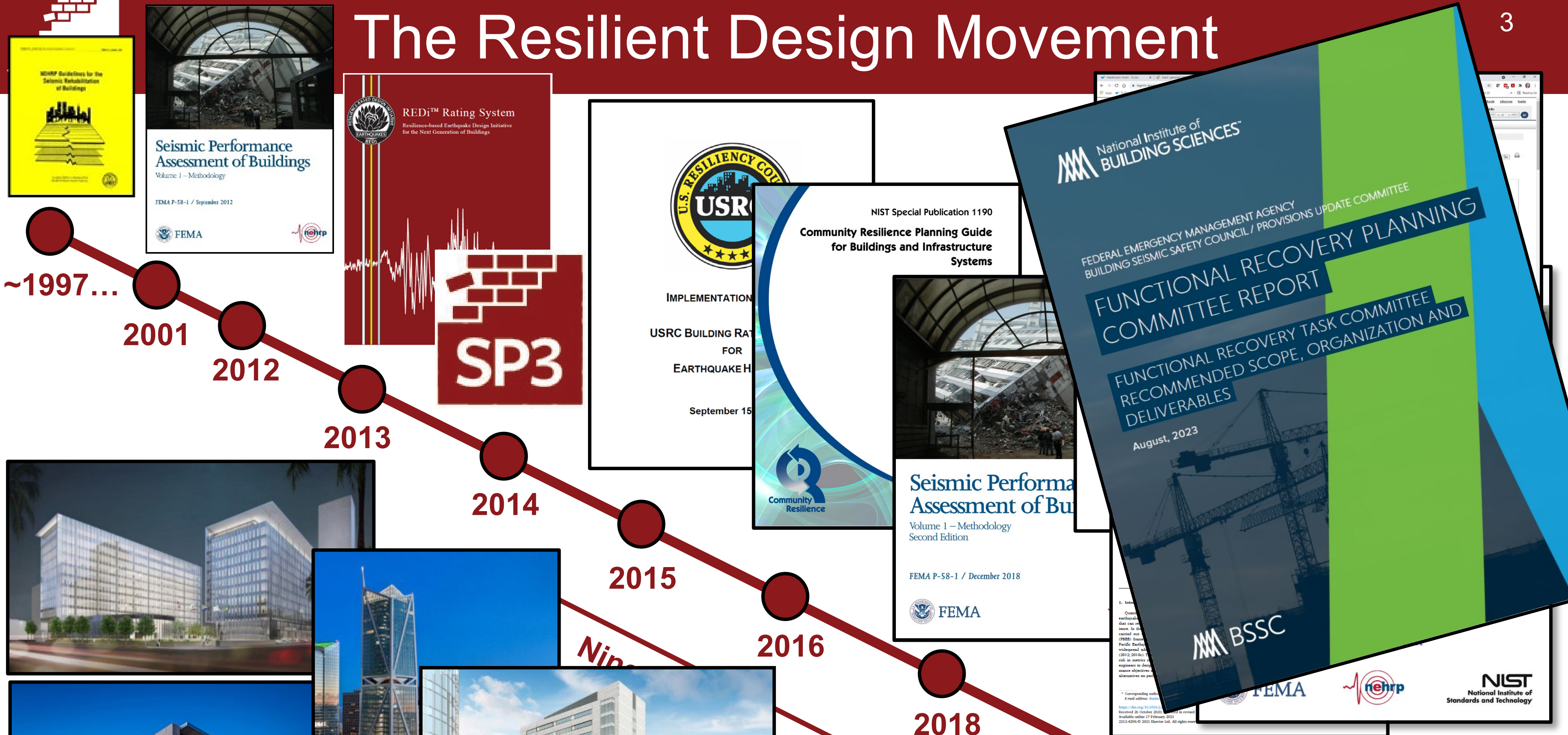
Outline

- Overview of the Resilient Design Movement
- FEMA P-58 Method and new Functional Recovery Module
- Illustrative Resilient Design Example (quick)
- Codification of Resilient Design for Functional Recovery
- Summary and Next Steps
- Time for Q&A (~10-15 minutes)

The Resilient Design Movement



~1997…

2001

2012

2013

2014

2015

2016

2018

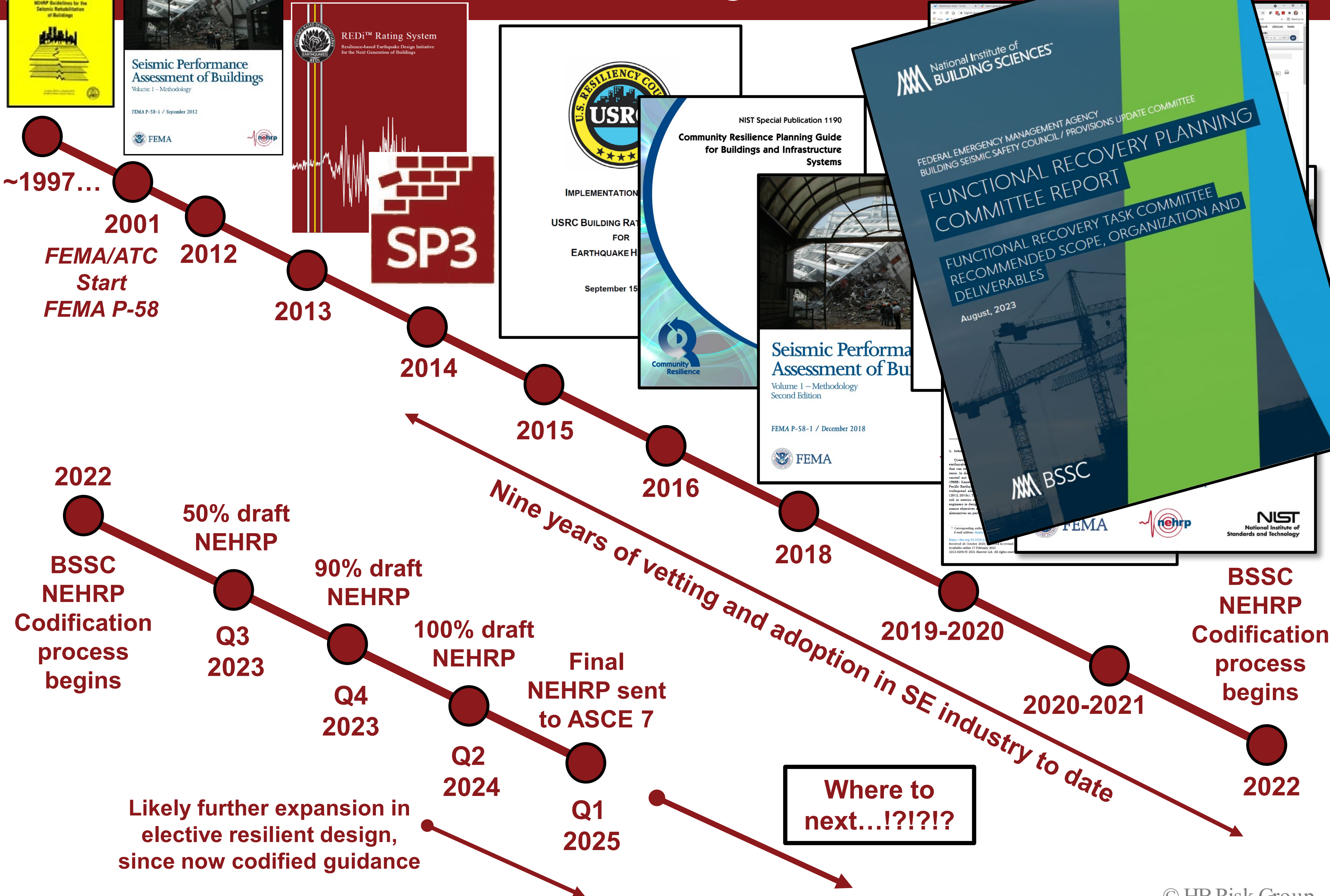
2019-2020

2021

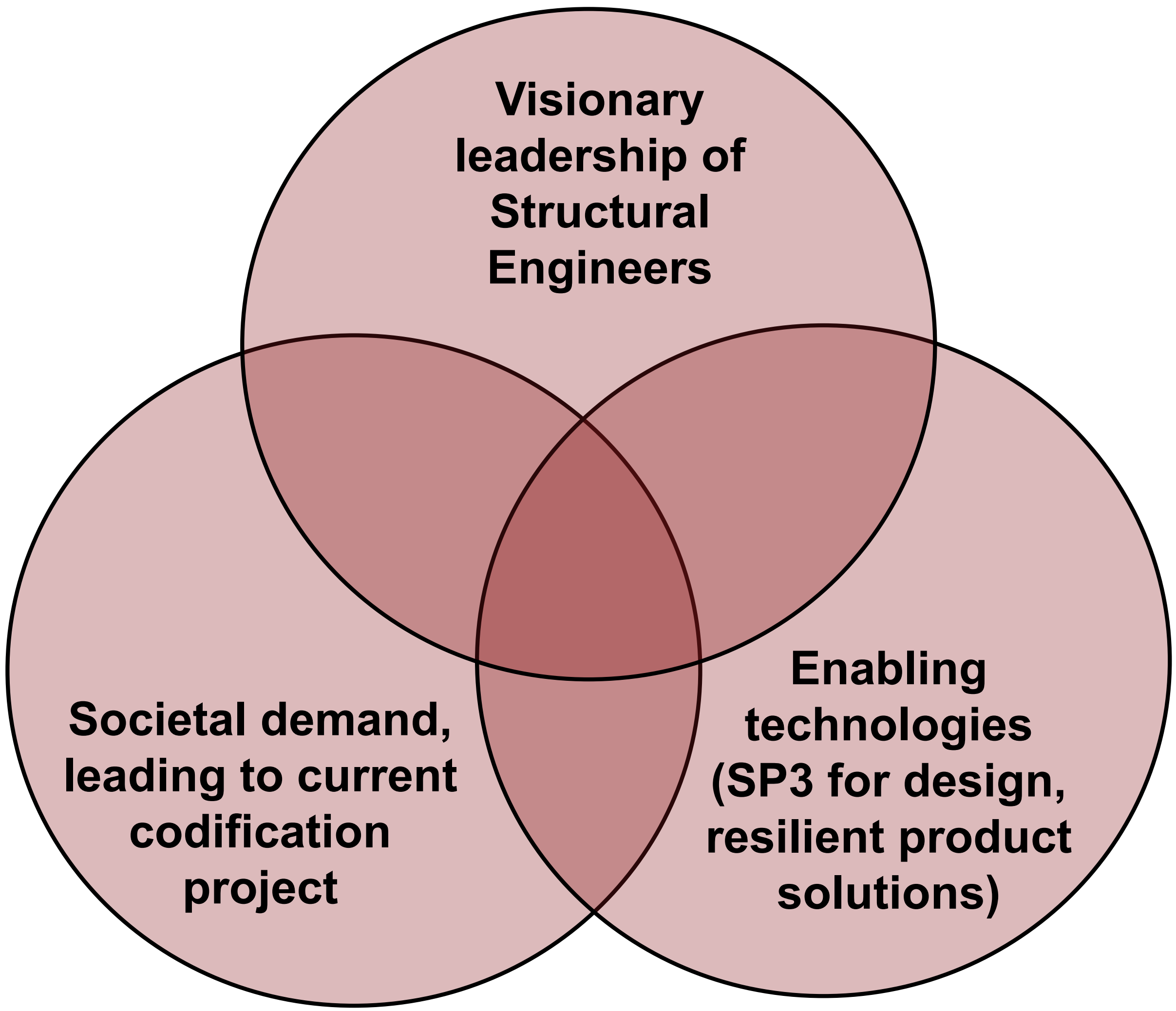
2022

BSSC
NEHRP
Codification
process
begins

The Resilient Design Movement



The Resilient Design Movement



The Resilient Design Movement

Bottom-Up Push for Resilient Design:

- Visionary structural engineers are leading by doing this electively on projects, both to better serve their clients, and to differentiate themselves in the marketplace.
- Typical goals of resilient design projects:
    - **Time:** Reduce time for building to regain function (business disruption); aiming for function in "days to weeks".
    - **Cost:** Reduce damage and needed repair costs; aiming for less than 5% repair cost.

The Resilient Design Movement

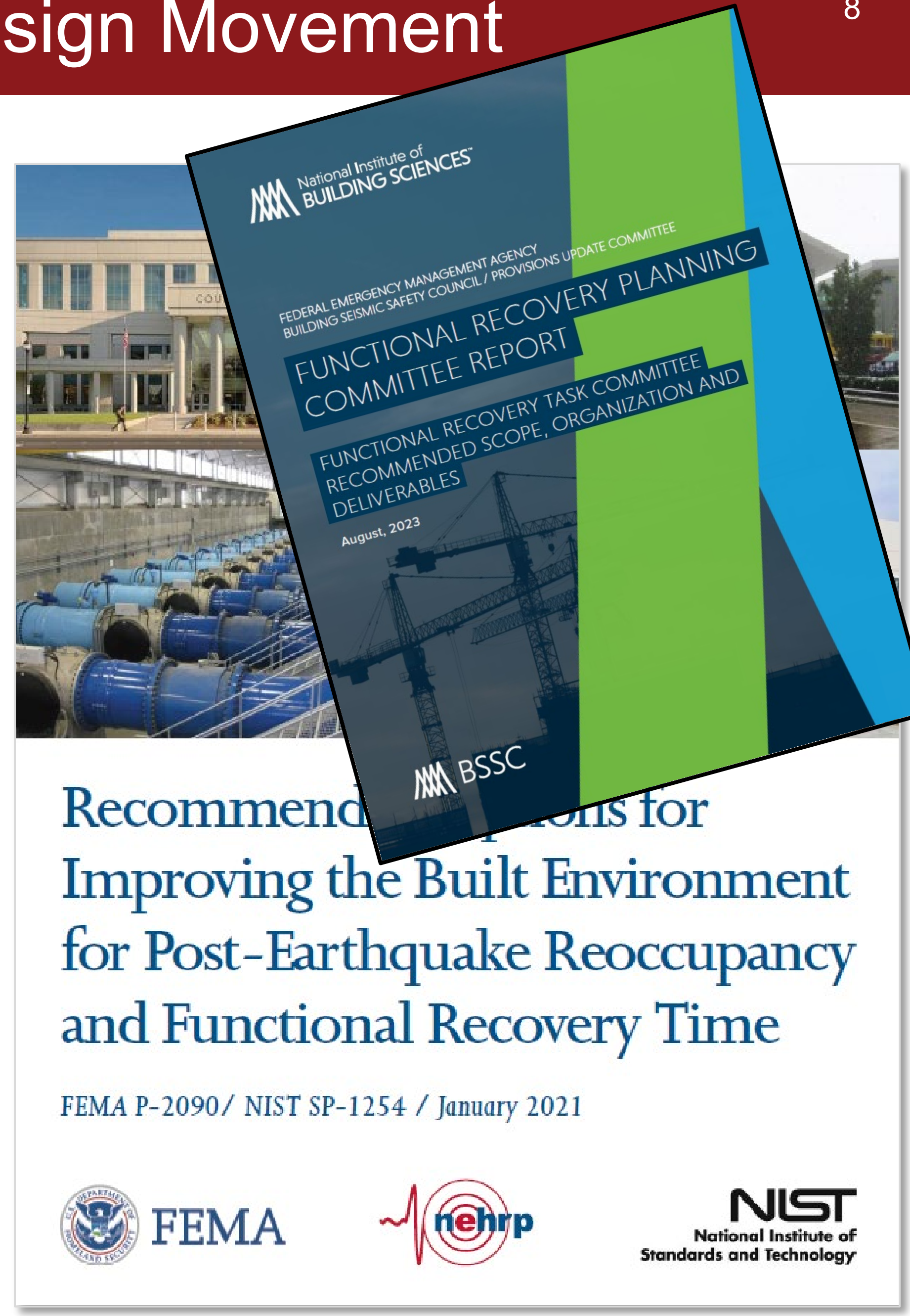
- These elective/visionary projects have been a <u>critical component</u> of the Resilient Design Movement, showing us that:
  - ✓ Resilient design is feasible.
  - ✓ Resilient design is cost effective, ~0-1% cost.
  - ✓ Resilient design can be done at the rapid pace of a design office.
  - ✓ Overall, we have learned that we need to just need to target quick functional recovery in design (beyond safety-only design), and let a creative engineer do it at little cost!
- The learning from these projects is also informing the BSSC functional recovery building code efforts (showing how prescriptive requirements can be created).

The Resilient Design Movement

Top-Down Push for Resilient Design:

- **Federal:** NEHRP Reauthorization with mandate to look at building function, NIST Immediate Occupancy report, NIST/FEMA Functional Recovery report.

*"**Functional recovery** is a post-earthquake performance state in which a building or lifeline infrastructure system is maintained, or restored, to safely and adequately support the **basic intended functions** associated with the pre-earthquake use or occupancy of a building…"*

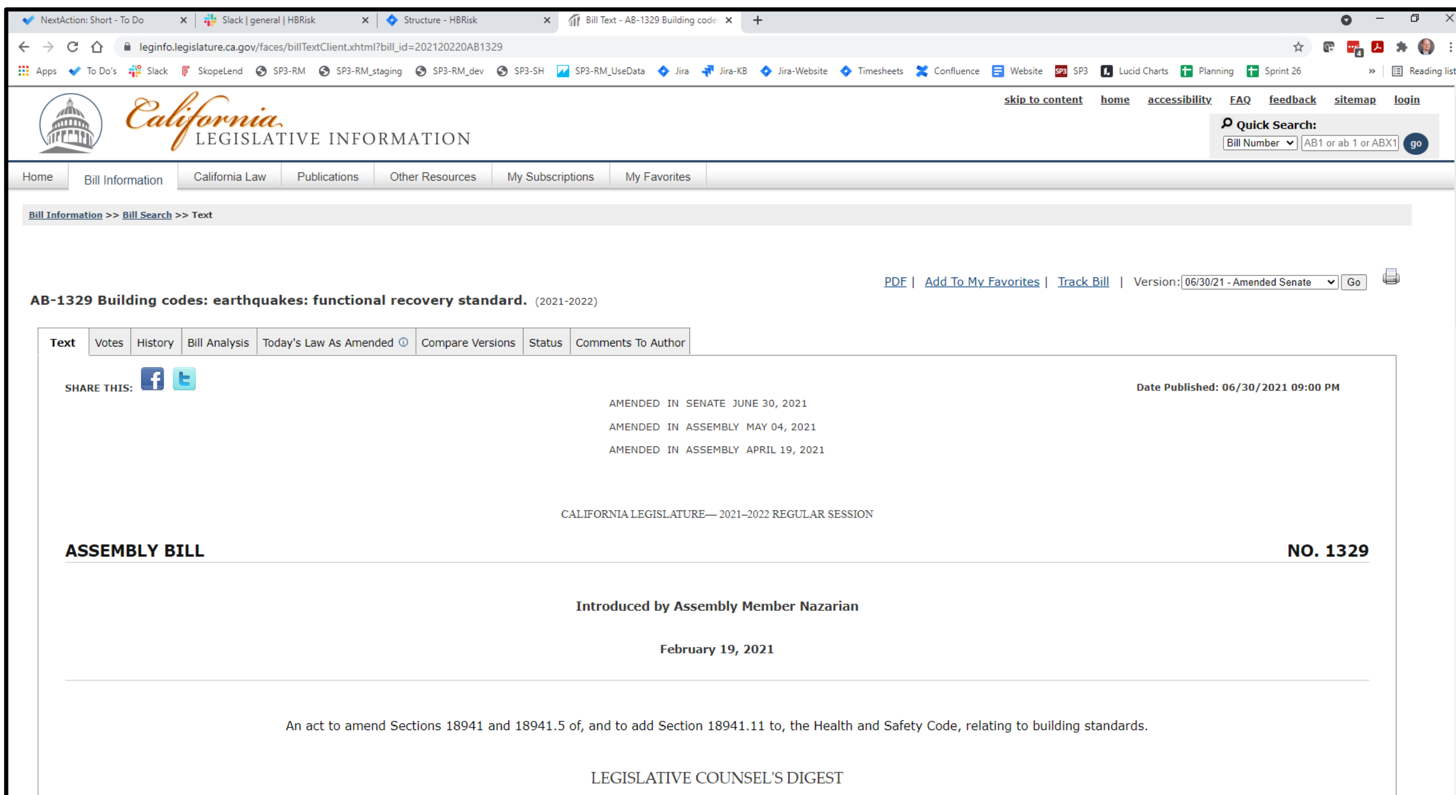


The Resilient Design Movement

Top-Down Push for Resilient Design:

- **State:** California Assembly Bill AB-1329, entitled *"Functional Recovery Standard"*.

"(b) (1) ***During the 2024 triennial code adoption cycle****, the California Building Standards Commission and the Department of Housing and Community Development, acting in accordance with Section 17921, shall develop, adopt, approve, codify, and publish building standards that require buildings not already under the authority of a different state agency* ***to be designed and built to a functional recovery standard for earthquake loads****."*



Outline

- Overview of the Resilient Design Movement
- **FEMA P-58 Method and the New Functional Recovery Module**
- Illustrative Resilient Design Example
- Codification of Resilient Design
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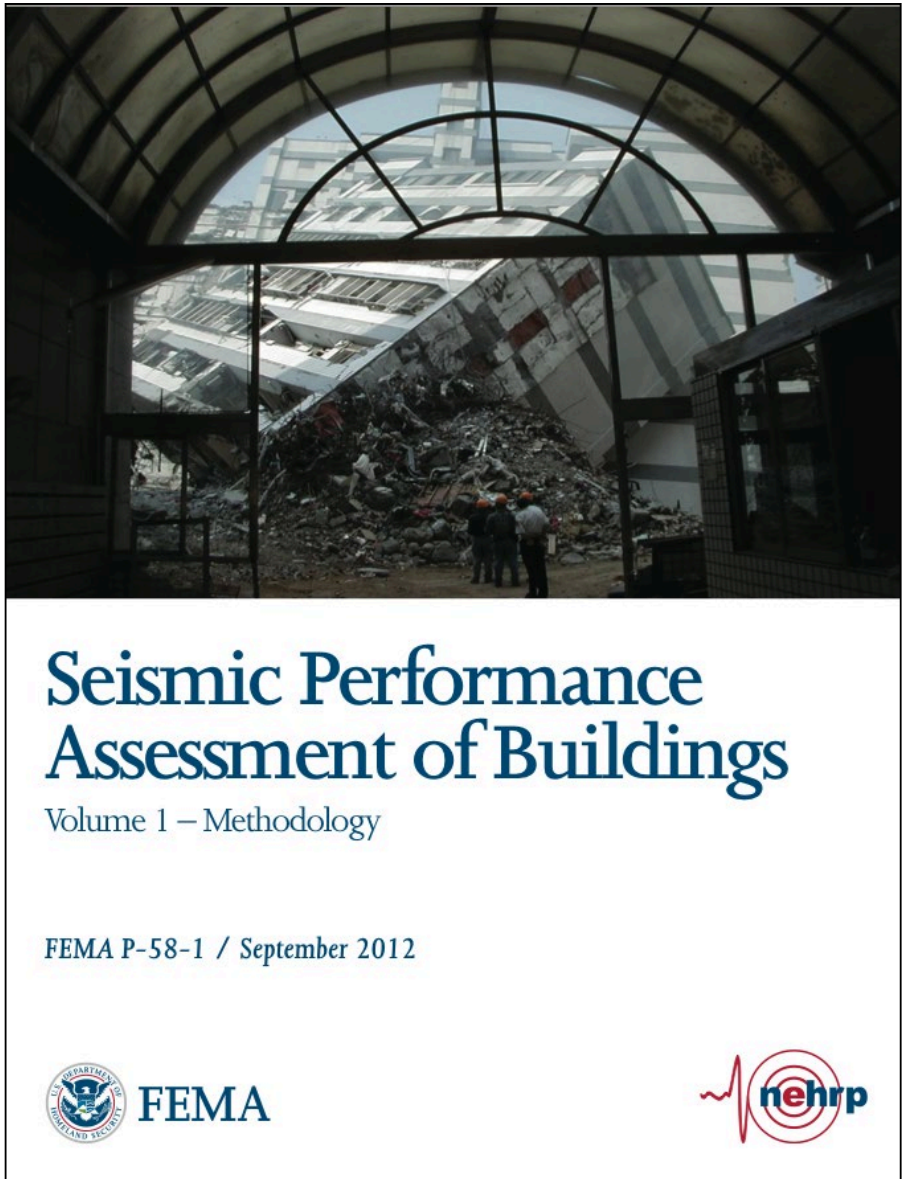
FEMA P-58 and New Developments


Seismic Performance Assessment of Buildings

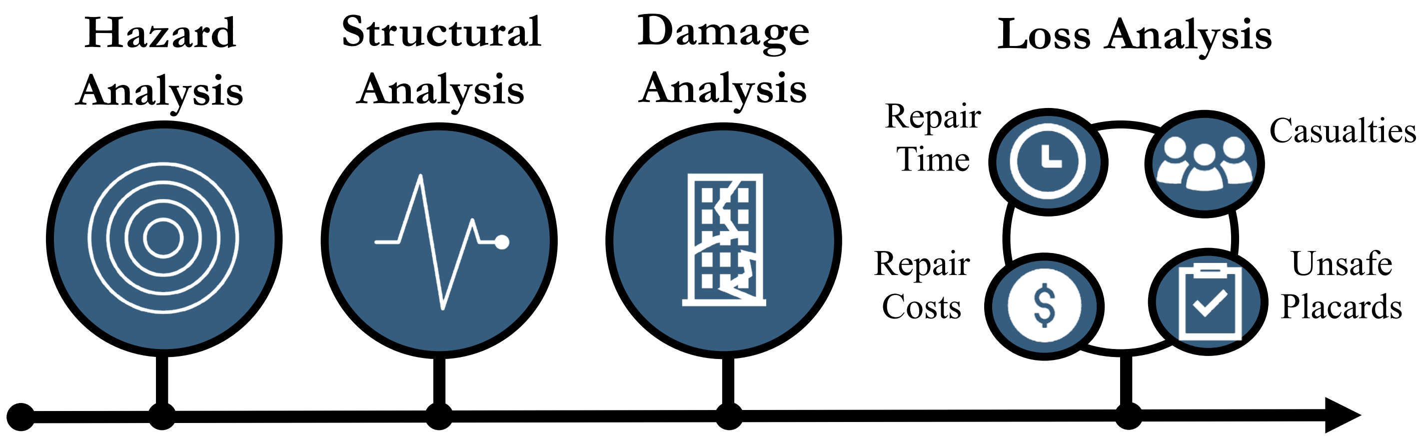
Volume 1 – Methodology

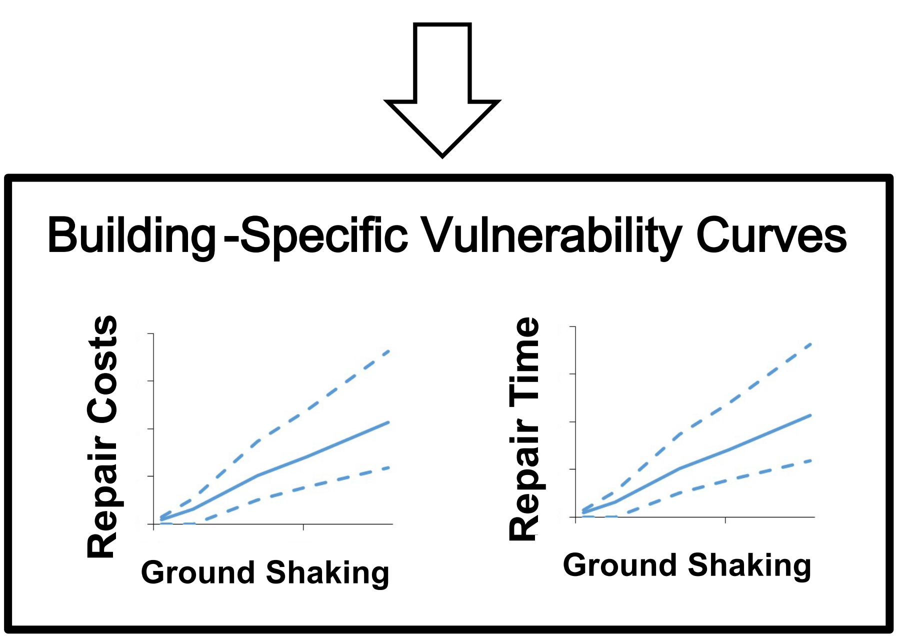
FEMA P-58-1 / September 2012

FEMA

nehrp

FEMA P-58 and New Developments





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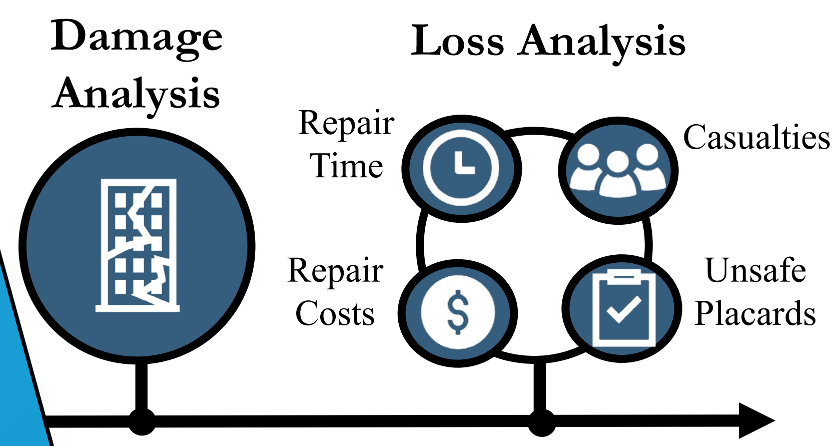

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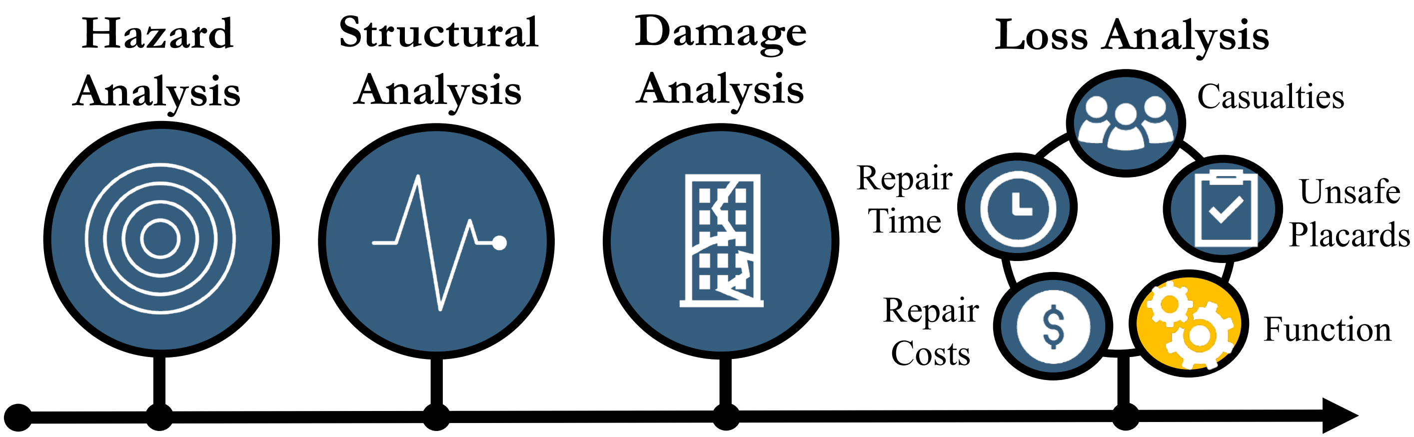
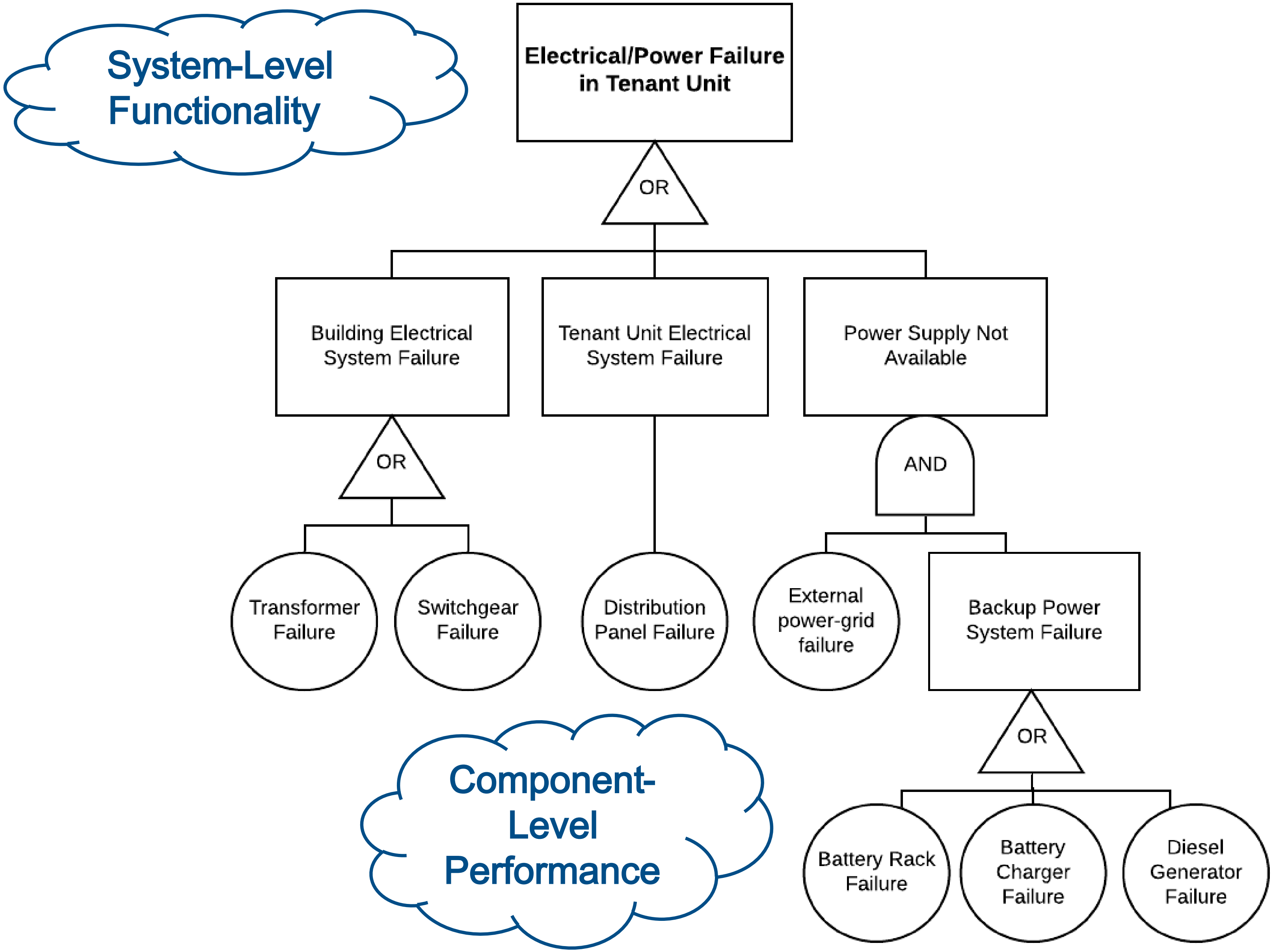


The **FEMA P-58 Functional Recovery Module** now directly assesses:

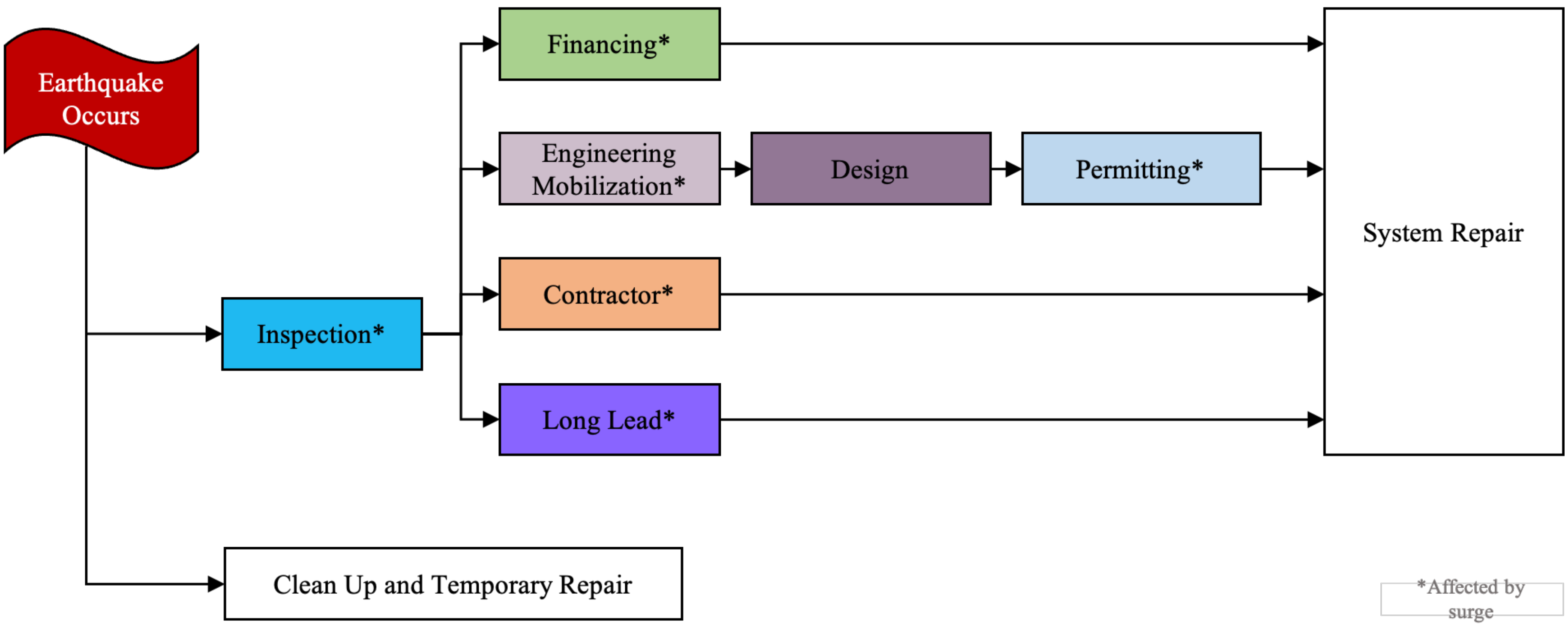
(a) Reoccupancy time, and

(b) Functional Recovery time.

FEMA P-58 and New Developments



FEMA P-58 and New Developments



SP3 Software Compliments FEMA P-58

FEMA P-58 (with FR Module) provides the **comprehensive** and **standardized** approach to evaluate functional recovery times (with ~$20M to develop).

SP3 provides a user-friendly software to integrate all steps of FEMA P-58 (with Functional Recovery Module).

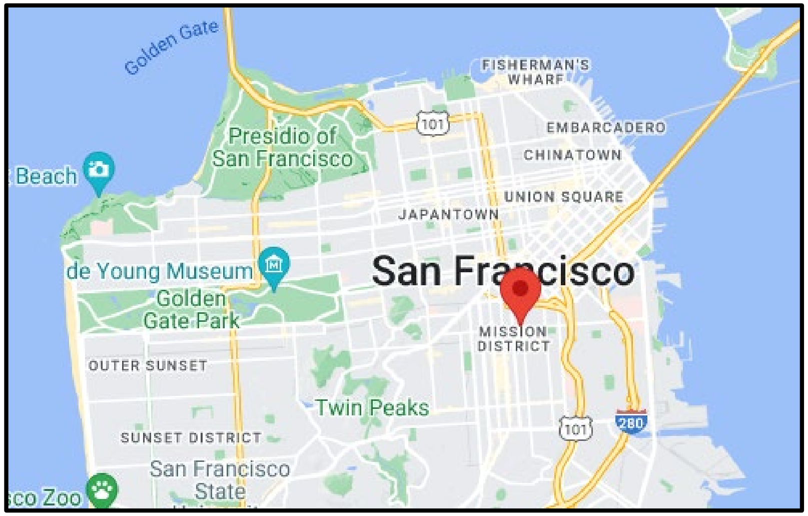
The initial assessment should take a couple **hours** and **not weeks**.

Outline

- Overview of the Resilient Design Movement
- FEMA P-58 Method and Extensions for Functional Recovery
- **Illustrative Resilient Design Example (quick)**
- Codification of Resilient Design
- Summary and Next Steps
- Time for Q&A (10-15 minutes)

Illustrative Example

- New 12-story multi-unit residential building in San Francisco (Mission District)
- Example resilient design goals:
  - ✓ DE: Expected functional recovery of < 1 week (median, 50% chance).
  - ✓ DE: Low probability of functional recovery loss for > 6 months (<20%), so need to limit red tagging and damage to long-lead components.
  - ✓ To illustrate how to handle, require all systems to be functional (e.g. HVAC).
  - ✓ Do "core and shell" assessment, so this does not include user-installed equipment (but could!).
  - ✓ Allow temporary repairs.
- Note: The goal is not no damage; it is no damage that impedes function and not quickly repairable.



Process of Resilient Design using P-58/SP3

- Design is obviously iterative, but there are some rough steps and considerations in the resilient design process.
  - ✓ **Step #1: Select Structural System and Design -** Select trial system, assess code-minimum performance, iterate as needed.
  - ✓ **Step #2: Identify Problem Components -** Identify systems/components with functionality issues in the trial design.
  - ✓ **Step #3: Design Components for Function -** Design all problem components to remain functional (as needed).
    a) Design drift-sensitive components
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  - ✓ **Step #4: Confirm Design Goals are Met –** Run the full building performance model again to ensure that building-level goals are met.

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Step #1: Select/Design the Structural System

- Not necessarily design for no ductility/damage.
- Design such that there is <u>no damage that inhibits function</u>.
- Basic approaches:
  - ✓ Essentially-elastic low-damage.
  - ✓ Allow ductility, but in a fuse that is easy to repair or doesn't need repair.
- Selection considerations for structural performance:
  - ✓ Need to have low chance of red tag.
  - ✓ Control damage to gravity system.
  - ✓ Control residual drifts.
- Selection considerations for non-structural performance:
  - ✓ Drifts (reduce, or design components for them)
  - ✓ Floor accelerations (reduce, which is harder if not using dampers, or design components to withstand the accelerations)

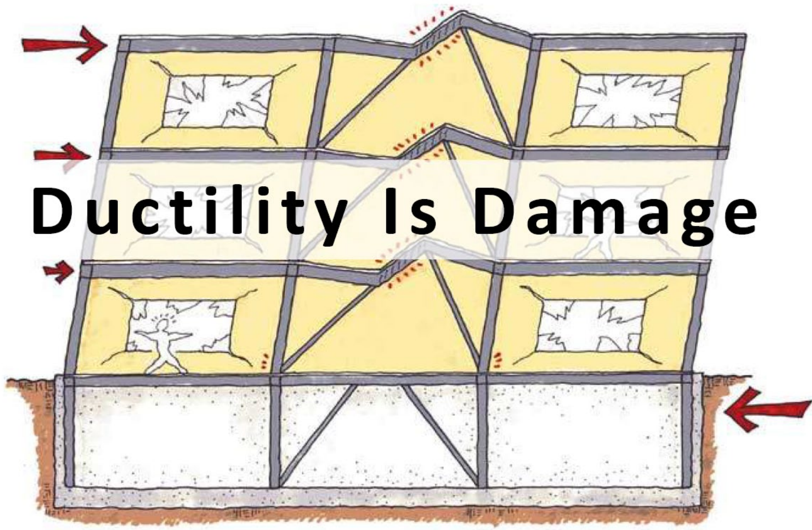
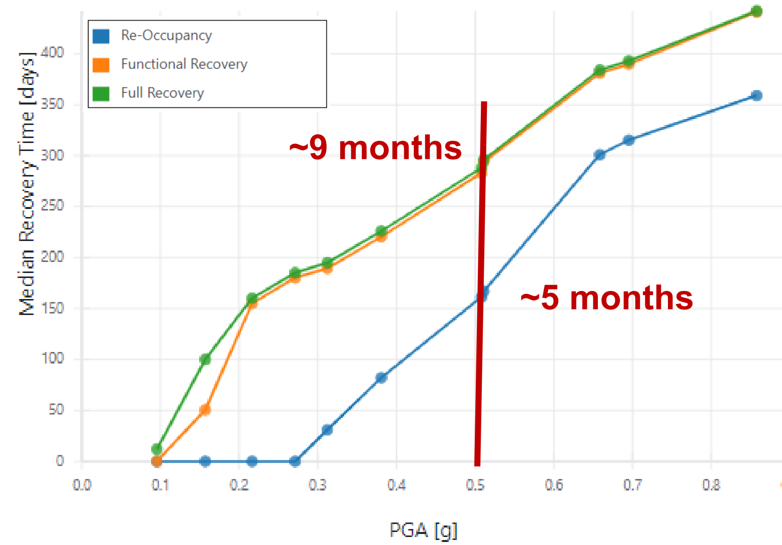
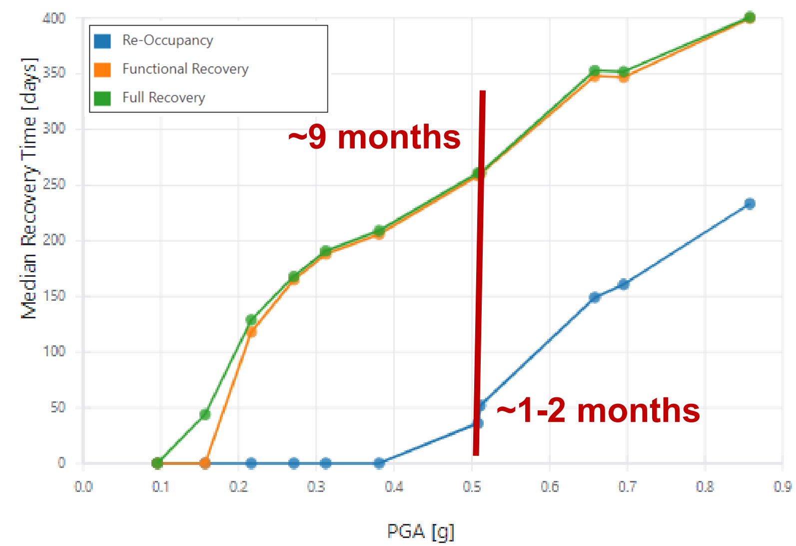


Figure courtesy of David Mar

Step #1: Select Structural System

- Selection and design of the structural system is obviously a critical step, but we will keep it rather short here.
- Trial Design #1:
  - ✓ RC Special Moment Frame designed for RC II.
  - ✓ Gives red-tagging probability at DE of 28%.
  - ✓ Results in 5 months reoccupancy and 9 mo. FR.
- Trial Design #2:
  - ✓ Switch to an RC shear wall.
  - ✓ Red-tagging at DE still too high for RC II (15%).
- Trial Design #3:
  - ✓ Design shear wall for RC IV structural requirements (1% drift, Ie = 1.5), ensure flexural-controlled.
  - ✓ Red-tagging at DE now works better (4%).
  - ✓ Results in 1-2 mo. reoccupancy and 9 mo. FR.
  - ✓ Note: Generally, 1% drift is often used in design for functional recovery, added strength sometimes needed.





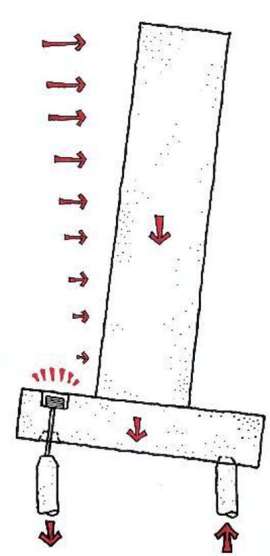
[Walls and damper figures courtesy of David Mar]

Step #1: Select Structural System

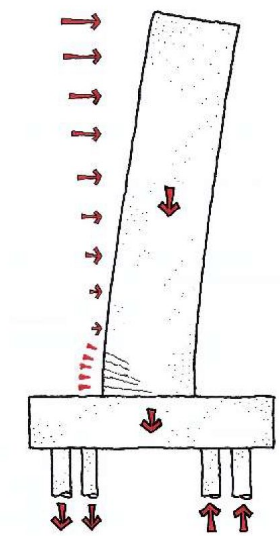
Resilient Design Options:

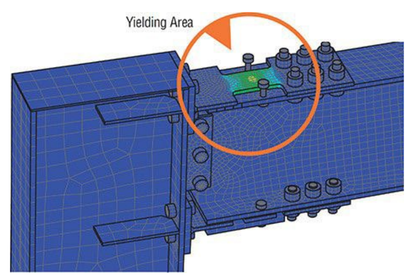
1) In this example, we will used an RC Shear wall with RC IV design, and ensured flexural-controlled (conventional system).
2) Can also use performance-based design, such as rocking systems, but this is more work (peer review), and is the exception for approach.
3) Can also use code-compliant systems that are low-damage or easy-to-repair (typically proprietary, since designed specifically to be resilient).

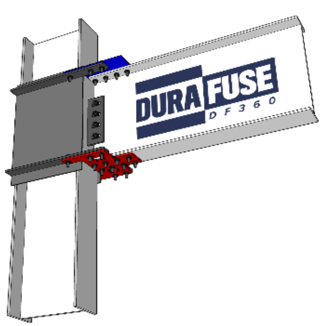
Performance-Based Rocking Wall

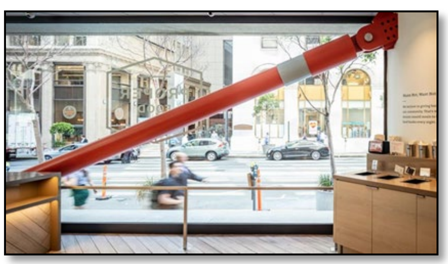


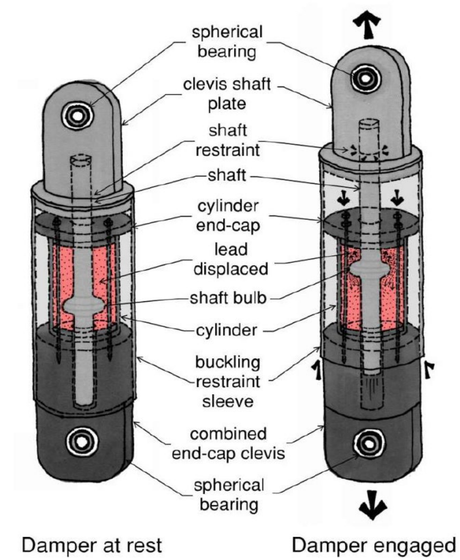
Conventional Wall











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    - d) Discussion of QA/QC considerations and effects
  - ✓ **Step #4: Confirm Design Goals are Met –** Run the full building performance model again to ensure that building-level goals are met.

Step #2: Identify Problem Components

Table 3.4. Percent of realizations affecting building reoccupancy/function per system check - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	3.3	3.3	3.3	3.3	3.3	2.2	0.1
Shoring	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire Suppression	16	16	16	16	15	2.3	0.0
Entry Door Access	20	20	19	16	15	0.9	0.0
Exterior Falling Hazard	19	19	19	16	15	0.9	0.0
Entry Door Racking	0.8	0.6	0.2	0.0	0.0	0.0	0.0
Stairs	38	38	38	38	38	8.5	0.2
Stairway Doors	84	69	22	1.3	0.0	0.0	0.0
Flooding	21	21	13	4.1	0.0	0.0	0.0
Horizontal Egress	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	16	16	16	16	14	1.6	0.1
Interior Falling Hazards	1.9	1.9	1.9	1.9	1.9	1.5	0.1
All Loss of Reoccupancy	**53**	**53**	**52**	**52**	**50**	**9.8**	**0.2**
Building Function (affects function only, not reoccupancy)							
Elevators	63	63	63	63	63	51	15
Exterior Enclosure	0.6	0.6	0.6	0.6	0.6	0.1	0.0
Interior Space	19	8.8	2.7	2.7	2.7	2.2	0.2
Electrical	45	45	45	45	45	25	4.4
Flooding	21	21	21	21	21	7.3	1.1
Potable Water	13	13	13	13	13	1.8	0.0
Sanitary Plumbing	13	13	13	13	13	1.8	0.0
HVAC Ventilation	77	77	77	77	76	45	8.4
HVAC Heating	77	77	77	77	76	45	8.4
HVAC Cooling	78	78	78	78	77	46	8.6
HVAC Exhaust	66	66	66	66	66	42	8.0
All Loss of Function	**97**	**95**	**90**	**88**	**87**	**70**	**23**

Observation: The prior design step to resolve red-tagging has taken care of a lot of drift-sensitive items (1% drift limit)

Step #2: Identify Problem Components

Table 3.6. Percent of realizations affecting building reoccupancy/functionality per component - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Concrete							
B1044.091	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.2 / 1.2	0.0 / 0.0
†Red Tag							
B1049.011	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9	1.6 / 1.6	0.1 / 0.1
†Red Tag, Interior Falling Hazards, Interior Space							
Envelope							
B2011.201a	3.1 / 3.1	3.1 / 3.1	3.0 / 3.0	2.7 / 2.7	2.3 / 2.4	0.4 / 0.4	0.0 / 0.0
†Exterior Falling Hazard, Exterior Enclosure (function)							
B2011.201b	12 / 13	12 / 12	12 / 12	12 / 12	12 / 12	0.9 / 0.9	0.0 / 0.0
†Exterior Falling Hazard, Exterior Enclosure (function), Interior Space, Exterior Enclosure (safety)							
B2022.002	13 / 13	13 / 13	13 / 13	13 / 13	11 / 11	1.5 / 1.5	0.1 / 0.1
†Exterior Falling Hazard, Exterior Enclosure (function), Interior Space, Exterior Enclosure (safety)							
Interior							
C1011.001b	0.0 / 19	0.0 / 8.6	0.0 / 2.4	0.0 / 2.4	0.0 / 2.4	0.0 / 2.0	0.0 / 0.2
†Interior Space							
C3011.001b	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0
†No Reoccupancy/Functionality Consequences (Repair Time Only)							
Stairs							
C2011.011b	38 / 38	38 / 38	38 / 38	38 / 38	38 / 38	8.5 / 8.5	0.2 / 0.2
†Stairs							
Conveying							
†All components in this group: Elevators							
D1014.141	0.0 / 15	0.0 / 15	0.0 / 15	0.0 / 15	0.0 / 15	0.0 / 9.8	0.0 / 2.1
D1014.142	0.0 / 38	0.0 / 38	0.0 / 38	0.0 / 38	0.0 / 38	0.0 / 30	0.0 / 6.7
D1014.143	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 23	0.0 / 7.8
D1014.144	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 25	0.0 / 24	0.0 / 8.0
D1014.151	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 36	0.0 / 11

†System checks that are affected by this component

Continued on next page

Process of Resilient Design using P-58/SP3

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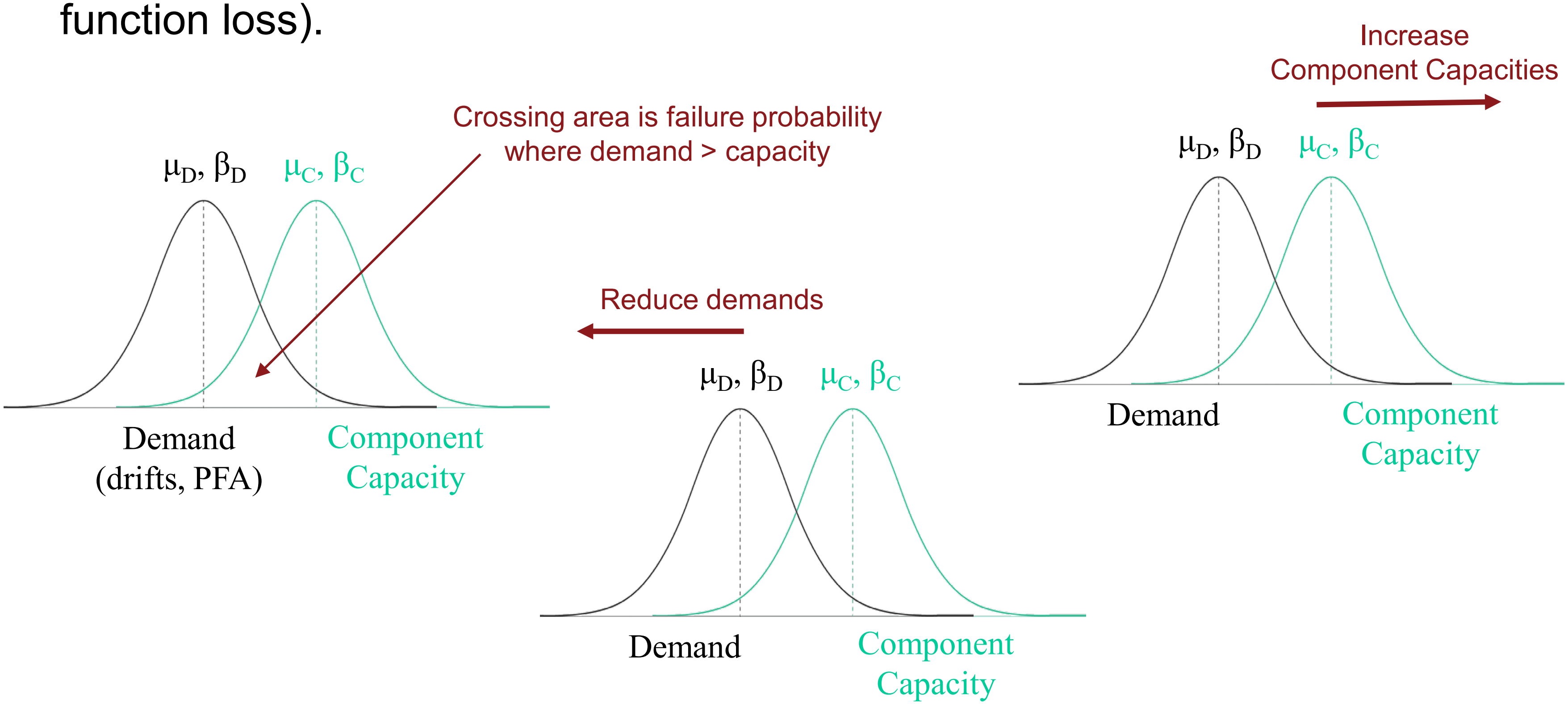
    - c) Design elevators
    - d) Discussion of QA/QC considerations and effects
  - ✓ **Step #4: Confirm Design Goals are Met –** Run the full building performance model again to ensure that building-level goals are met.

Step #3: Design Components for Function

- We now have a list of components that we need to redesign to meet building function requirements.
- We can iteratively run FEMA P-58/SP3 to make these design changes, but it is much easier to "uncouple" the design.
- We really just need to design the problem components for a D/C ratio that gives low probability damage at DE shaking (only for damage that causes function loss).



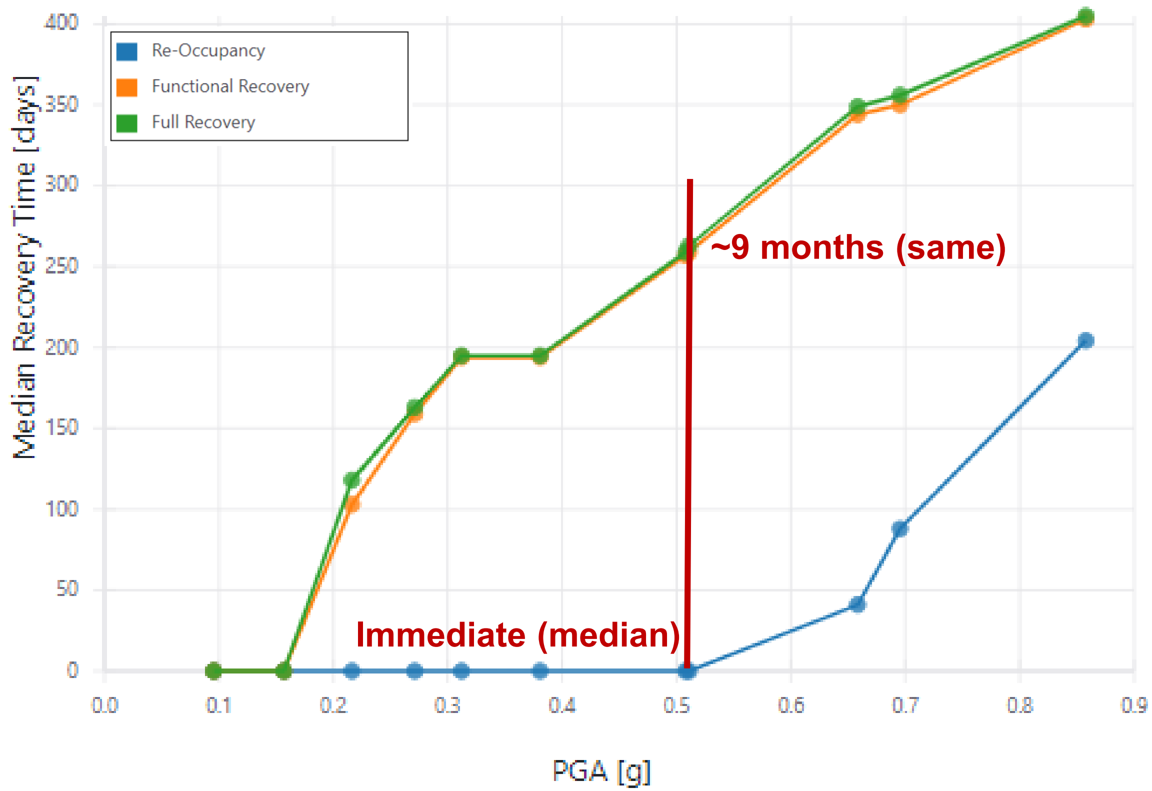
Graphics/ideas courtesy of Dr. Carlos Molina-Hutt of University of British Columbia

Step #3a: Drift-Sensitive Components

- Let's fix the drift-sensitive components first (to get fast reoccupancy)
  - ✓ Note that the wall was already designed for a 1% drift limit and Ie = 1.5; this took care of most drift-sensitive items (e.g. slab damage, in-plane cladding damage, etc.).
  - ✓ Last need for this example is just to <u>add a seismic gap</u> to the stairs!

Step #3a: Drift-Sensitive Components

- Let's fix the drift-sensitive components first (to get fast reoccupancy)



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Step #3b: Acceleration-Sensitive Components

- Let's fix the components needed for function (which are mostly acceleration-sensitive)

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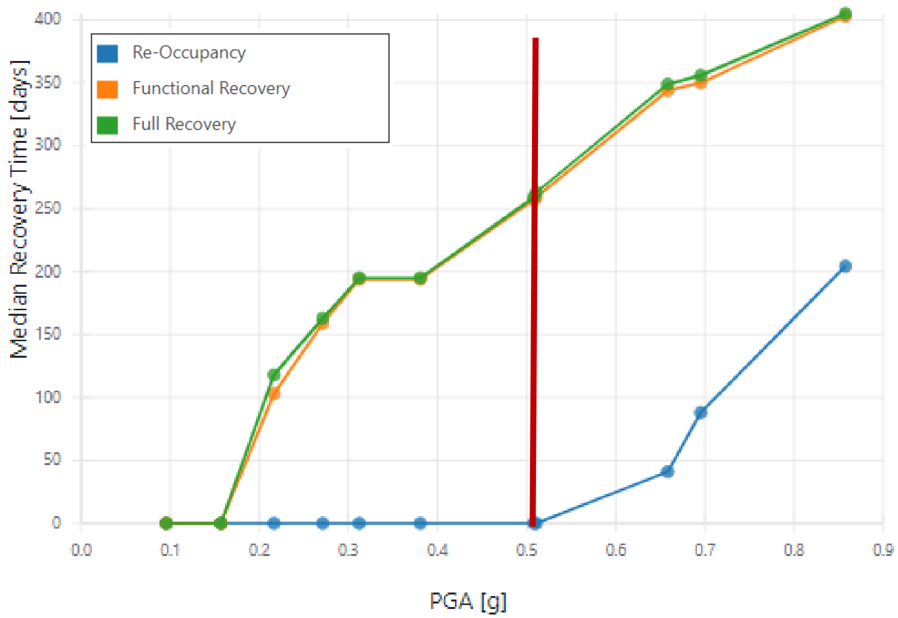
	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	3.6	3.6	3.6	3.6	3.6	2.6	0.2
Shoring	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire Suppression	15	15	15	15	15	2.5	0.0
Entry Door Access	19	19	18	15	13	1.1	0.1
Exterior Falling Hazard	19	19	18	15	13	1.1	0.1
Entry Door Racking	0.6	0.4	0.1	0.0	0.0	0.0	0.0
Stairs	4.5	4.5	4.5	4.5	4.5	1.7	0.2
Stairway Doors	85	67	21	1.3	0.0	0.0	0.0
Flooding	32	31	18	4.3	0.0	0.0	0.0
Horizontal Egress	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	16	16	16	16	15	2.0	0.1
Interior Falling Hazards	1.9	1.9	1.9	1.9	1.9	1.5	0.1
All Loss of Reoccupancy	**42**	**42**	**38**	**33**	**30**	**5.0**	**0.3**
Building Function (affects function only, not reoccupancy)							
Elevators	64	64	64	64	63	50	17
Exterior Enclosure	0.7	0.7	0.7	0.7	0.7	0.2	0.0
Interior Space	19	8.6	2.8	2.8	2.8	2.5	0.3
Electrical	45	45	45	45	45	25	4.4
Flooding	32	32	32	32	32	12	1.1
Potable Water	11	11	11	11	11	2.0	0.0
Sanitary Plumbing	26	26	26	26	25	3.9	0.0
HVAC Ventilation	64	64	64	64	64	40	8.1
HVAC Heating	64	64	64	64	64	40	8.1
HVAC Cooling	70	70	70	70	70	43	8.6
HVAC Exhaust	67	67	67	67	67	42	8.5
All Loss of Function	**96**	**93**	**86**	**82**	**81**	**66**	**25**

The damage to elevators and lots of MEP systems is impeding function.

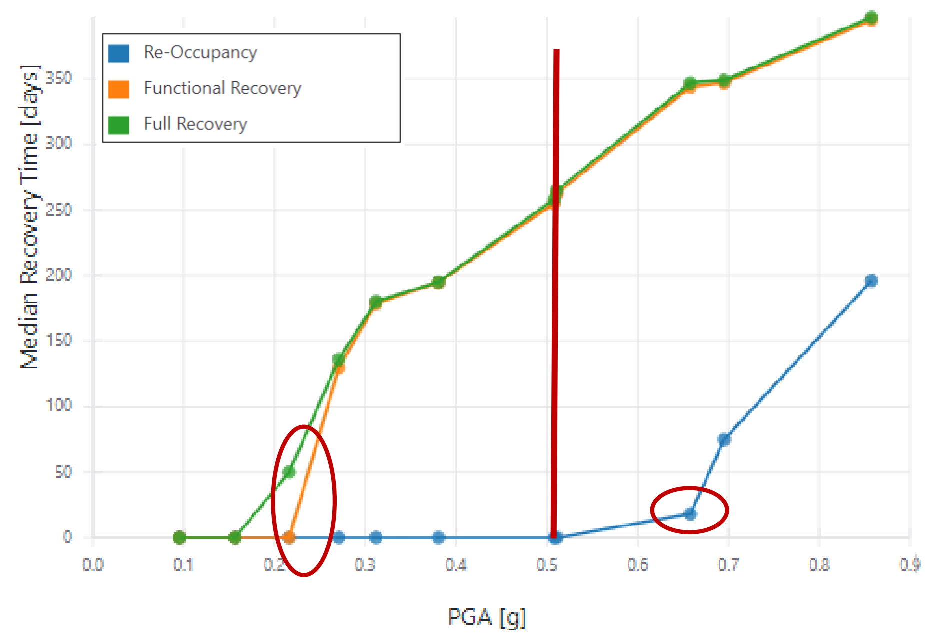
Step #3b: Acceleration-Sensitive (RC II vs. IV)

- Try Risk Category IV for non-structural components first, since we already used RC IV requirements for the structural design step (1% drift, Ie = 1.5).
- Let's see what this gets us (using Ip = 1.5, pre-qualified equipment)….

Current Baseline



Current Baseline + RC IV



- Result: RC IV helps some, delaying onset of function loss, but little impact at DE level.
- Clarification Necessary:
  - This **<u>does not</u>** mean that RC IV did not fix **<u>anything</u>**. It did with pre-qualified equipment, etc.
  - This just means that RC IV <u>did not fix **everything**</u> that impedes function.
  - We will probe this more in this design example, and show that **<u>RC IV gets us close</u>**.

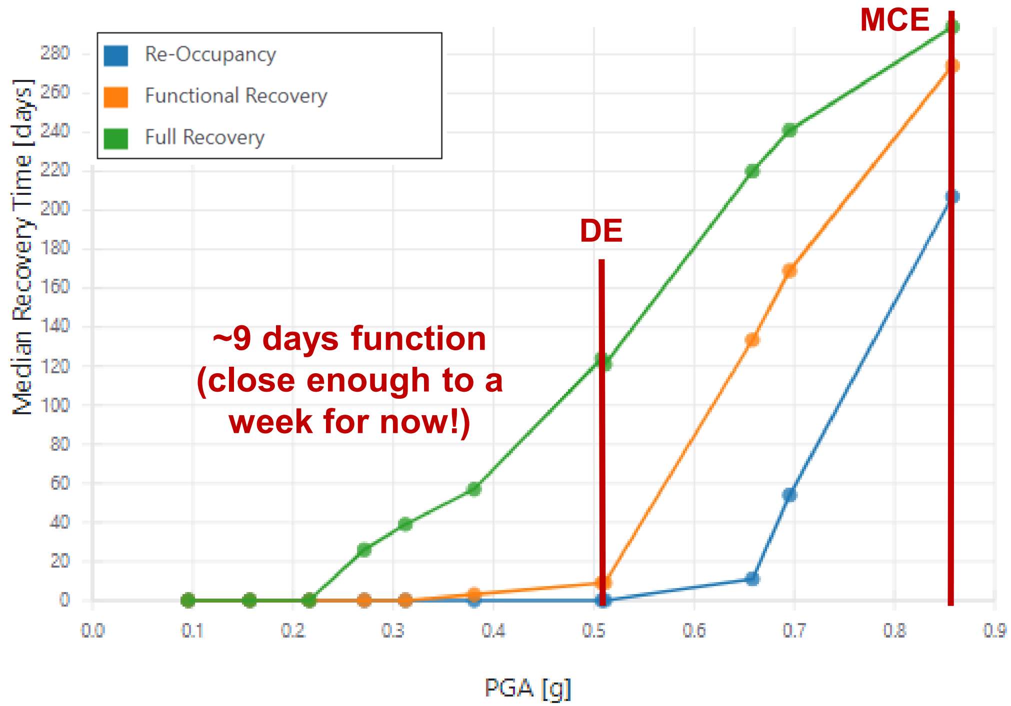
Step #3: Design Components for Function

- Let's now do what is needed to fix the components required for function (which are typically acceleration-sensitive)
  - ✓ Elevators – design for 2x strength required in current ASME (more precise design resilient design requirements development) [above RC IV]
  - ✓ Specify pre-qualified equipment, per ASCE7 Chapter 13. [same as RC IV]
  - ✓ Design anchorages to not need repair - using Ip/Rp = Ip/Rpo =~ 1.5); optimized capacity increases for this example were ~1.25-2.0x of code minimum values). [some are above RC IV]

Process of Resilient Design using P-58/SP3

- Design is obviously iterative, but there are some rough steps and considerations in the resilient design process.
  - ✓ **Step #1: Select Structural System and Design -** Select trial system, assess code-minimum performance, iterate as needed.
  - ✓ **Step #2: Identify Problem Components -** Identify systems/components with functionality issues in the trial design.
  - ✓ **Step #3: Design Components for Function -** Design all problem components to remain functional (as needed).
    - a) Design drift-sensitive components
    - b) Design acceleration-sensitive components
    - c) Design elevators
    - d) Discussion of QA/QC considerations and effects
  - ✓ **Step #4: Confirm Design Goals are Met –** Run the full building performance model again to ensure that building-level goals are met.

Step #4: Confirm Design Goals are Met



Primary Resilient Design Goals Achieved (for DE):

- Median <u>9 day</u> functional recovery (clean-up and temp repairs) [vs. <u>9 months</u> for code-minimum]
- Probability of losing function for > 6 months is <20% (computed as 18%) [vs. 90% for code-min]

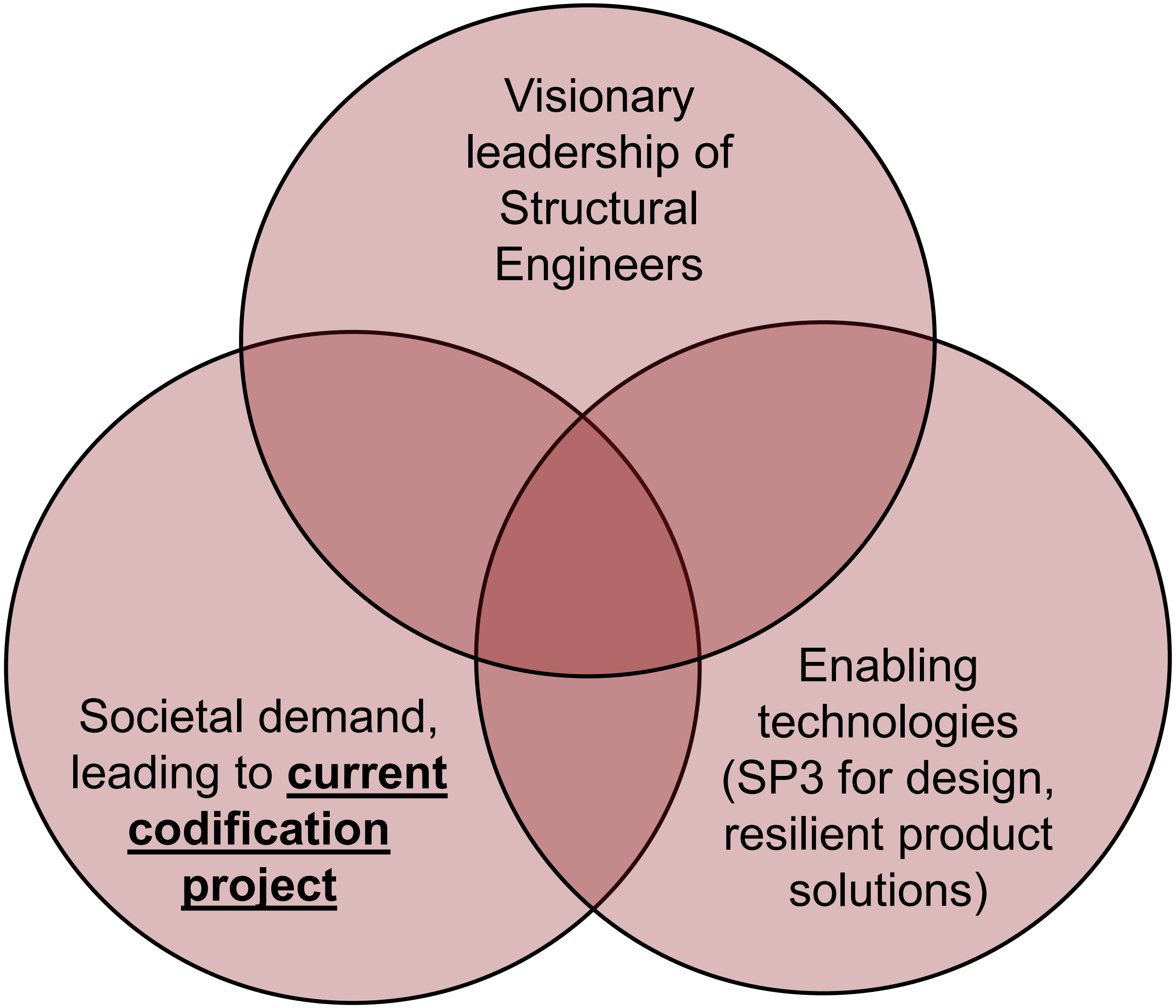
Notes on Accuracy and Uncertainty:

- <u>I don't believe</u> that these numbers are exact (earthquakes have a lot of uncertainty).
- <u>I do believe</u> resilient design will perform much better than code-minimum (<u>designed for function!</u>).
- FEMA P-58 Functional Recovery Module provides a <u>comprehensive and repeatable design tool</u> for resilient design for functional recovery.

Outline

- Overview of the Resilient Design Movement
- FEMA P-58 Method and Extensions for Functional Recovery
- Illustrative Resilient Design Example
- **Codification of Resilient Design**
- Summary and Next Steps
- Time for Q&A (10-15 minutes)

Codification of Resilient Design (BSSC FRTC)



Codification of Resilient Design (BSSC FRTC)

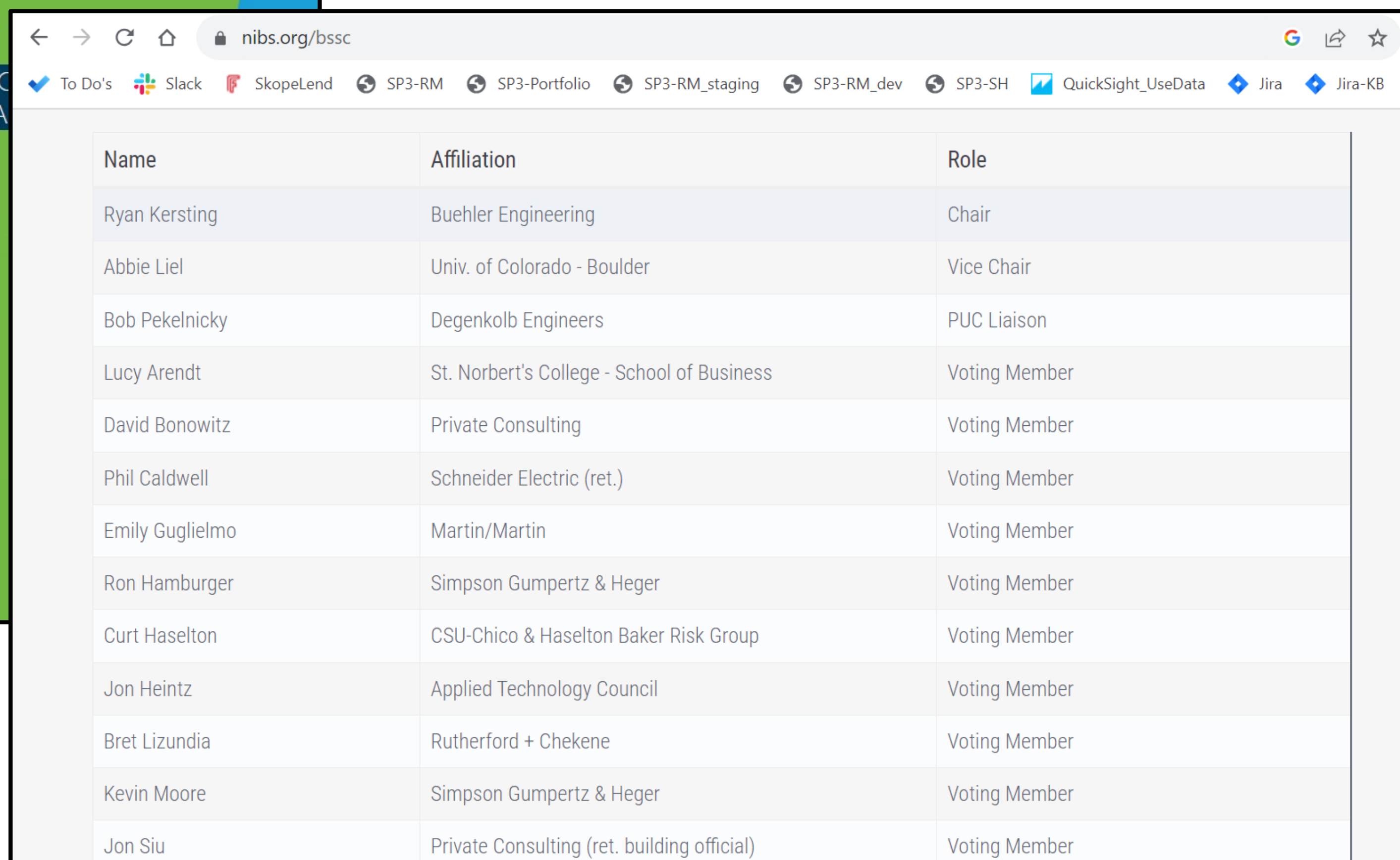
Hurricane Ike, Houston 2008, Reuters Pictures, Dunya News

1) Our current **early-adopter projects** only help the building being designed to be resilient (kind of).
2) Community resilience requires a **majority of buildings** to remain functional.
3) Building **code requirements are necessary** for broad resilient design for most/all buildings!

Lahaina Maui Fire, 2023, Courtesy CBS News

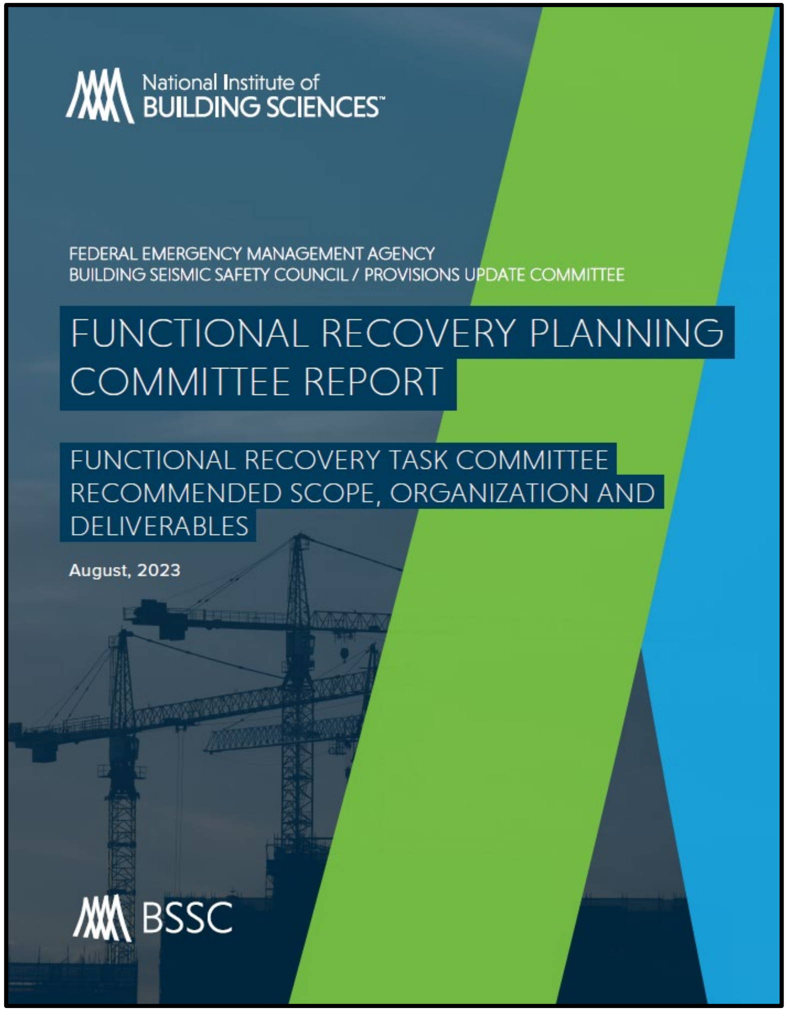
Codification of Resilient Design (BSSC FRTC)

Building Seismic Safety Council (BSSC) Functional Recovery Task Committee (FRTC), FEMA-funded



Name	Affiliation	Role
Ryan Kersting	Buehler Engineering	Chair
Abbie Liel	Univ. of Colorado - Boulder	Vice Chair
Bob Pekelnicky	Degenkolb Engineers	PUC Liaison
Lucy Arendt	St. Norbert's College - School of Business	Voting Member
David Bonowitz	Private Consulting	Voting Member
Phil Caldwell	Schneider Electric (ret.)	Voting Member
Emily Guglielmo	Martin/Martin	Voting Member
Ron Hamburger	Simpson Gumpertz & Heger	Voting Member
Curt Haselton	CSU-Chico & Haselton Baker Risk Group	Voting Member
Jon Heintz	Applied Technology Council	Voting Member
Bret Lizundia	Rutherford + Chekene	Voting Member
Kevin Moore	Simpson Gumpertz & Heger	Voting Member
Jon Siu	Private Consulting (ret. building official)	Voting Member

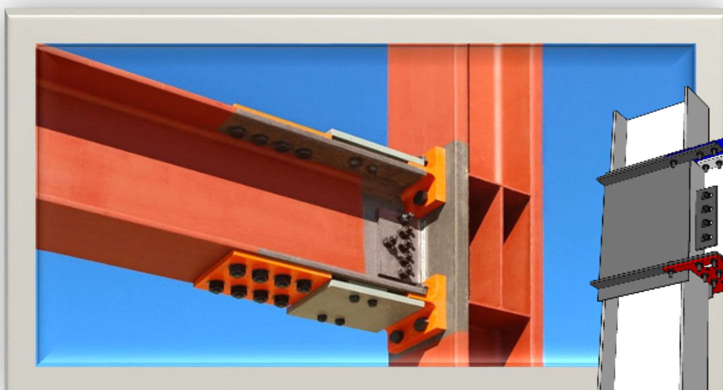
Codification of Resilient Design (BSSC FRTC)

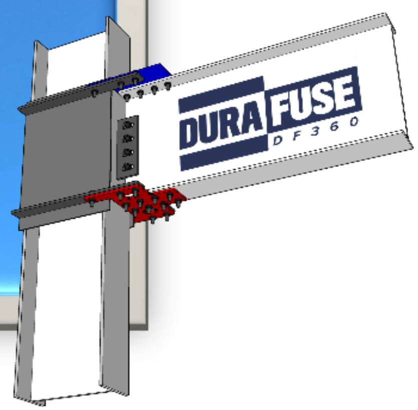


- Large BSSC FRTC building code effort underway to codify resilient design for functional recovery:
  - ✓ Planned in spring 2022, launched in fall 2022.
  - ✓ Composed of ~75-100 people in 7 teams.
  - ✓ Draft requirements are done, completed requirements expected ~Q2 of 2024, final to ASCE7 in 2025, published NEHRP 2025/6.
  - ✓ FEMA P-58/SP3 resilience assessment studies are being run now, for all structural systems, to determine necessary strength factors (R) and drift limits for each structural system.
- This is also being supported through analytical work funded by FEMA through the ATC-138 (FEMA P-58) project.
- The overall idea is to extend building code goals to design for both safety & quick function.
- More mainstream use expected after code adoption (and some during); in the meantime, early-adopter use continues to expand.

Codification of Resilient Design (BSSC FRTC)

Current ASCE7 Safety Design	**New Design for Quick Functional Recovery**
R = 8 Drift Limit = 2%	R = ?? Drift Limit = ??





R = 8 Drift Limit = 2%	R = ?? Drift Limit = ??

Summary and Next Steps

- We are in a **pivotal moment** in our SE profession, as we are starting to change the design paradigm from **safe-only** to **safe+functional**.

- The Resilient Design Movement has now moved to the **codification phase**.
- Codification is key to move us from the early-adopter voluntary phase (few buildings) to the mainstream phase (most/all buildings), to achieve **community resilience**.
- Resilient design code requirements are drafted now, 75-90% draft Q4-Q1, completed in mid-2024, and published in 2025/6 as the BSSC NEHRP Seismic Provisions.
- I see this movement having a huge impact on our society recovery after a large earthquake.

- We can continue to work together to move resilient design forward:
  - ✓ **P-58/SP3:** Methods/software to enable resilient design for functional recovery.
  - ✓ **Structural Engineers:** Leaders keep leading! More SEs doing visionary projects to vet resilient design methods and lead the way!

- Enabling resilient design has been my focus for the past 10+ years, so please reach out to further collaborate and/or provide any constructive feedback. Thank you!

Questions and Discussion!

- Thank you for your time.
- Time for questions and discussion!

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

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

www.sp3risk.com

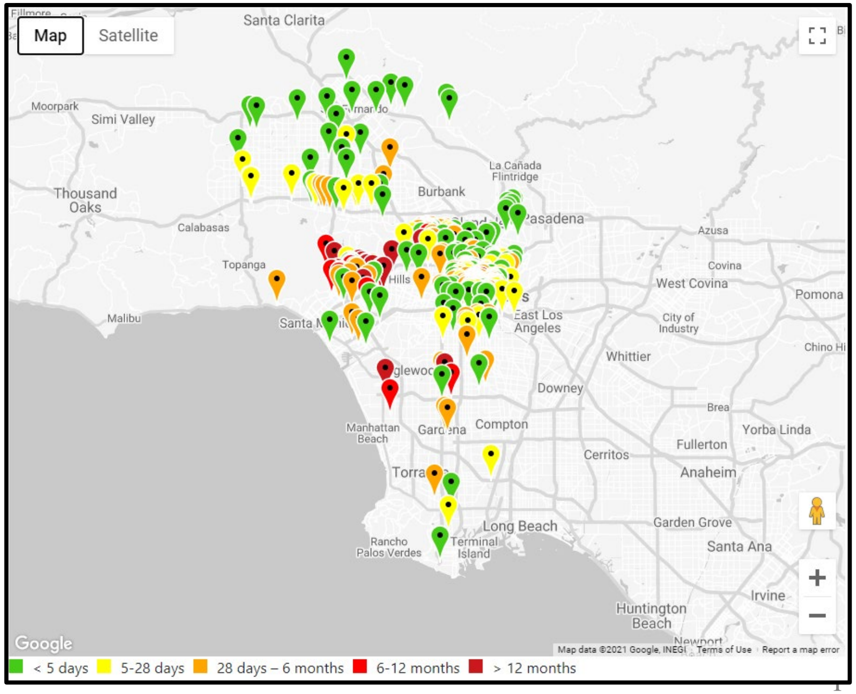
EXTRA

FEMA P-58 and SP3 Use Cases

- We are focusing today on use of FEMA P-58/SP3 for resilient design of new buildings.

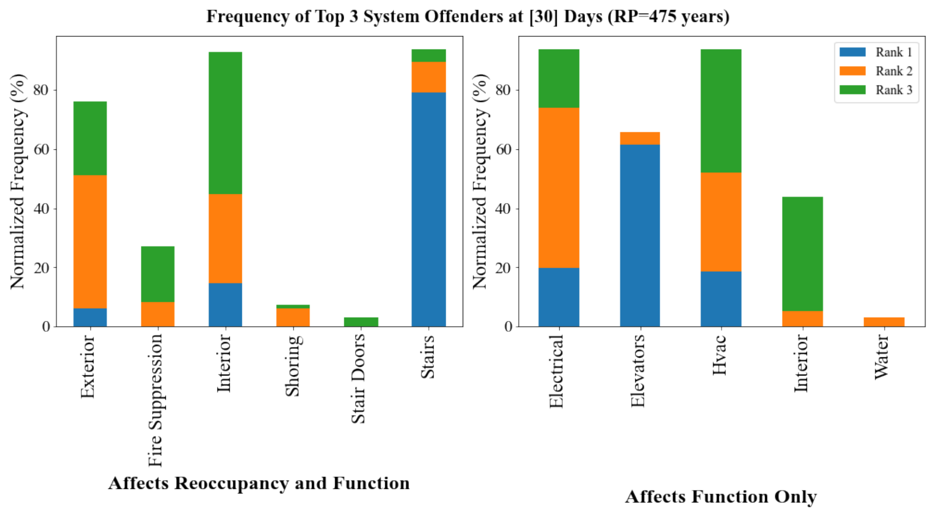
Keep slide?

- Quick note that many other common use cases also:
  - ✓ Building-specific risk assessment for mortgage risk (PML+)
  - ✓ Building-specific risk assessment for insurance risk
  - ✓ Business disruption assessment
  - ✓ Retrofit of existing buildings
  - ✓ Portfolio risk assessment (with automation of SP3-Batch)
  - ✓ SP3-SiteHazards



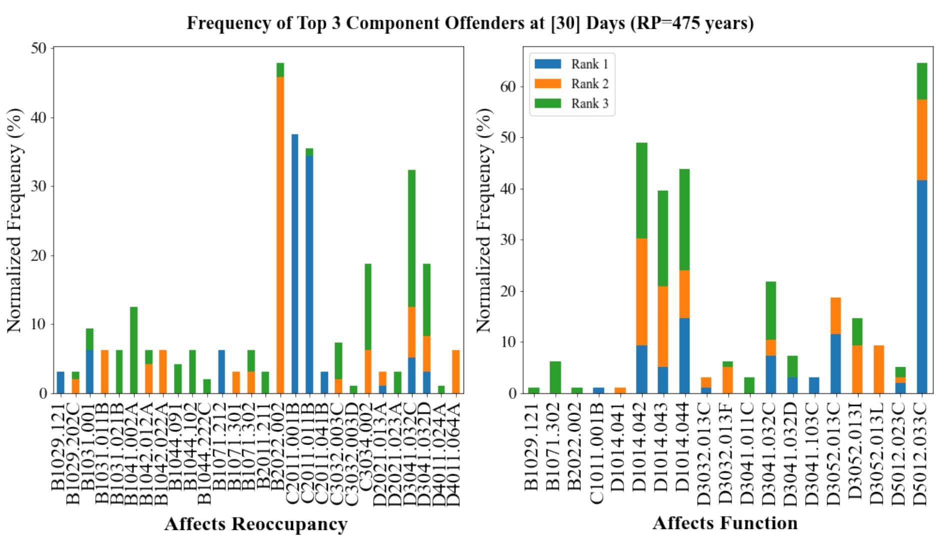
Step #2: “Common Offender” Components

- To generalize this, the ATC-138 project also ran ~600 building cases and assembled a list of “common offender” components.



Reoccupancy offenders (ordered):

- Structural lateral/gravity elements (red tag)
- Stairs when no seismic joint (C2011)
- Curtain/exterior walls (falling) (B2022/B1071)
- HVAC components (falling) (C3041)
- Pendant lighting (C3034.002)
- Suspended ceilings (C3032.003c)



Functional Recovery (ordered):

- Electrical distribution panel (D5012)
- Elevators (D1014)
- HVAC components – ducting, drops, VAV boxes (D3041)
- Air handling units (D3052)
- Cooling tower (D3031)
- Exterior walls (B1071)

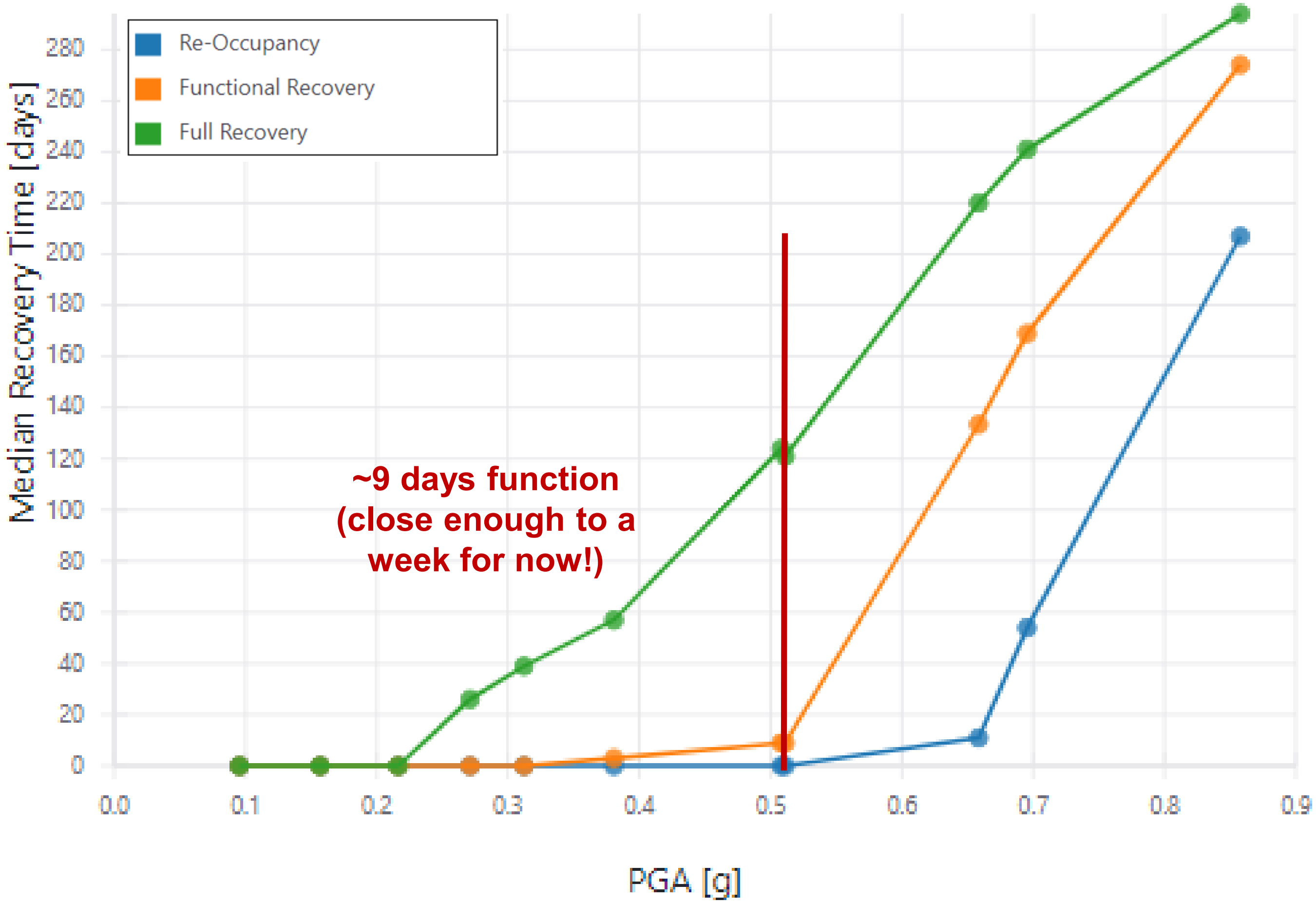
Step #3a: Drift-Sensitive Components

Table 3.4. Percent of realizations affecting building reoccupancy/function per system check - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	3.3	3.3	3.3	3.3	3.3	2.2	0.1
Shoring	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire Suppression	16	16	16	16	15	2.3	0.0
Entry Door Access	20	20	19	16	15	0.9	0.0
Exterior Falling Hazard	19	19	19	16	15	0.9	0.0
Entry Door Racking	0.8	0.6	0.2	0.0	0.0	0.0	0.0
Stairs	38	38	38	38	38	8.5	0.2
Stairway Doors	84	69	22	1.3	0.0	0.0	0.0
Flooding	21	21	13	4.1	0.0	0.0	0.0
Horizontal Egress	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	16	16	16	16	14	1.6	0.1
Interior Falling Hazards	1.9	1.9	1.9	1.9	1.9	1.5	0.1
All Loss of Reoccupancy	**53**	**53**	**52**	**52**	**50**	**9.8**	**0.2**
Building Function (affects function only, not reoccupancy)							
Elevators	63	63	63	63	63	51	15
Exterior Enclosure	0.6	0.6	0.6	0.6	0.6	0.1	0.0
Interior Space	19	8.8	2.7	2.7	2.7	2.2	0.2
Electrical	45	45	45	45	45	25	4.4
Flooding	21	21	21	21	21	7.3	1.1
Potable Water	13	13	13	13	13	1.8	0.0
Sanitary Plumbing	13	13	13	13	13	1.8	0.0
HVAC Ventilation	77	77	77	77	76	45	8.4
HVAC Heating	77	77	77	77	76	45	8.4
HVAC Cooling	78	78	78	78	77	46	8.6
HVAC Exhaust	66	66	66	66	66	42	8.0
All Loss of Function	**97**	**95**	**90**	**88**	**87**	**70**	**23**

Observation: The prior design step to resolve red-tagging has taken care of a lot of drift-sensitive items (1% drift limit)

Step #4: Confirm Design Goals are Met



Step #4: Confirm Design Goals are Met

Initial Code-Minimum Design:

Table 3.4. Percent of realizations affecting building reoccupancy/function per system check - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	3.3	3.3	3.3	3.3	3.3	2.2	0.1
Shoring	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire Suppression	16	16	16	16	15	2.3	0.0
Entry Door Access	20	20	19	16	15	0.9	0.0
Exterior Falling Hazard	19	19	19	16	15	0.9	0.0
Entry Door Racking	0.8	0.6	0.2	0.0	0.0	0.0	0.0
Stairs	38	38	38	38	38	8.5	0.2
Stairway Doors	84	69	22	1.3	0.0	0.0	0.0
Flooding	21	21	13	4.1	0.0	0.0	0.0
Horizontal Egress	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	16	16	16	16	14	1.6	0.1
Interior Falling Hazards	1.9	1.9	1.9	1.9	1.9	1.5	0.1
All Loss of Reoccupancy	**53**	**53**	**52**	**52**	**50**	**9.8**	**0.2**
Building Function (affects function only, not reoccupancy)							
Elevators	63	63	63	63	63	51	15
Exterior Enclosure	0.6	0.6	0.6	0.6	0.6	0.1	0.0
Interior Space	19	8.8	2.7	2.7	2.7	2.2	0.2
Electrical	45	45	45	45	45	25	4.4
Flooding	21	21	21	21	21	7.3	1.1
Potable Water	13	13	13	13	13	1.8	0.0
Sanitary Plumbing	13	13	13	13	13	1.8	0.0
HVAC Ventilation	77	77	77	77	76	45	8.4
HVAC Heating	77	77	77	77	76	45	8.4
HVAC Cooling	78	78	78	78	77	46	8.6
HVAC Exhaust	66	66	66	66	66	42	8.0
All Loss of Function	**97**	**95**	**90**	**88**	**87**	**70**	**23**

Step #4: Confirm Design Goals are Met

Current Working Resilient Design:

Table 3.4. Percent of realizations affecting building reoccupancy/function per system check - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	4.0	4.0	4.0	4.0	4.0	2.4	0.0
Shoring	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fire Suppression	4.9	4.9	4.9	4.9	4.6	0.6	0.0
Entry Door Access	20	20	20	17	15	1.1	0.0
Exterior Falling Hazard	20	20	20	17	15	1.1	0.0
Entry Door Racking	0.6	0.4	0.1	0.0	0.0	0.0	0.0
Stairs	5.2	5.2	5.2	5.2	5.2	1.3	0.0
Stairway Doors	85	66	21	1.2	0.0	0.0	0.0
Flooding	14	14	8.9	2.0	0.0	0.0	0.0
Horizontal Egress	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	16	16	16	16	15	1.7	0.0
Interior Falling Hazards	1.6	1.6	1.6	1.6	1.6	1.3	0.0
All Loss of Reoccupancy	**32**	**32**	**31**	**28**	**26**	**3.7**	**0.0**
Building Function (affects function only, not reoccupancy)							
Elevators	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	0.7	0.7	0.7	0.7	0.7	0.3	0.0
Interior Space	19	8.2	2.5	2.5	2.5	2.2	0.1
Electrical	16	16	16	16	16	7.8	1.8
Flooding	14	14	14	14	14	4.2	0.6
Potable Water	6.9	6.9	6.9	6.9	6.5	0.8	0.0
Sanitary Plumbing	12	12	12	12	11	1.6	0.0
HVAC Ventilation	10	10	10	10	10	5.1	0.8
HVAC Heating	10	10	10	10	10	5.1	0.8
HVAC Cooling	17	17	17	17	17	7.8	1.4
HVAC Exhaust	15	15	15	15	15	7.5	1.5
All Loss of Function	**89**	**79**	**54**	**43**	**41**	**18**	**4.1**

Final Design Summary and RC IV Comparison

Keep slide?

- Design summary and comparison to RC IV requirements:
  - Overall, this example landed close to RC IV requirements, even though RC IV alone shows very little change to baseline results.
  - Structural design step:
    - ✓ Used RC IV requirements for structural design.
    - ✓ Also, limited what structural system could be selected.
  - Stair gap added
  - Equipment
    - ✓ Pre-qualification required for some equipment and note for others; used slightly higher pre-qualification accelerations in some cases.
    - ✓ Anchorage designed for between 1.25-2.0x.
  - Piping – some 1.5x capacity increases needed
  - “Non-Fp” components – a few items require better performance and aren’t clearly linked to design requirements (e.g. HVAC ducting).
  - Elevators – increased capacity needed (details of exact design interventions to accomplish this are in development).

Final Design Summary and RC IV Comparison

Keep slide?

- Design summary and comparison to RC IV requirements:
  - Overall, this example landed close to RC IV requirements, even though RC IV alone shows very little change to baseline results.
  - Structural design step:
    - ✓ Used RC IV requirements for structural design.
    - ✓ **Also, limited what structural system could be selected.**
  - **Stair gap added**
  - Equipment
    - ✓ Pre-qualification required for some equipment and note for others; **used slightly higher pre-qualification accelerations** in some cases.
    - ✓ Anchorage designed for between 1.25-**2.0x**.
  - Piping – some 1.5x capacity increases needed
  - **"Non-Fp" components** – a few items require better performance and aren't clearly linked to design requirements (e.g. HVAC ducting).
  - **Elevators – increased capacity needed** (details of exact design interventions to accomplish this are in development).