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

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Acknowledgement of Many Collaborators on Resilient Design:

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

and many more….

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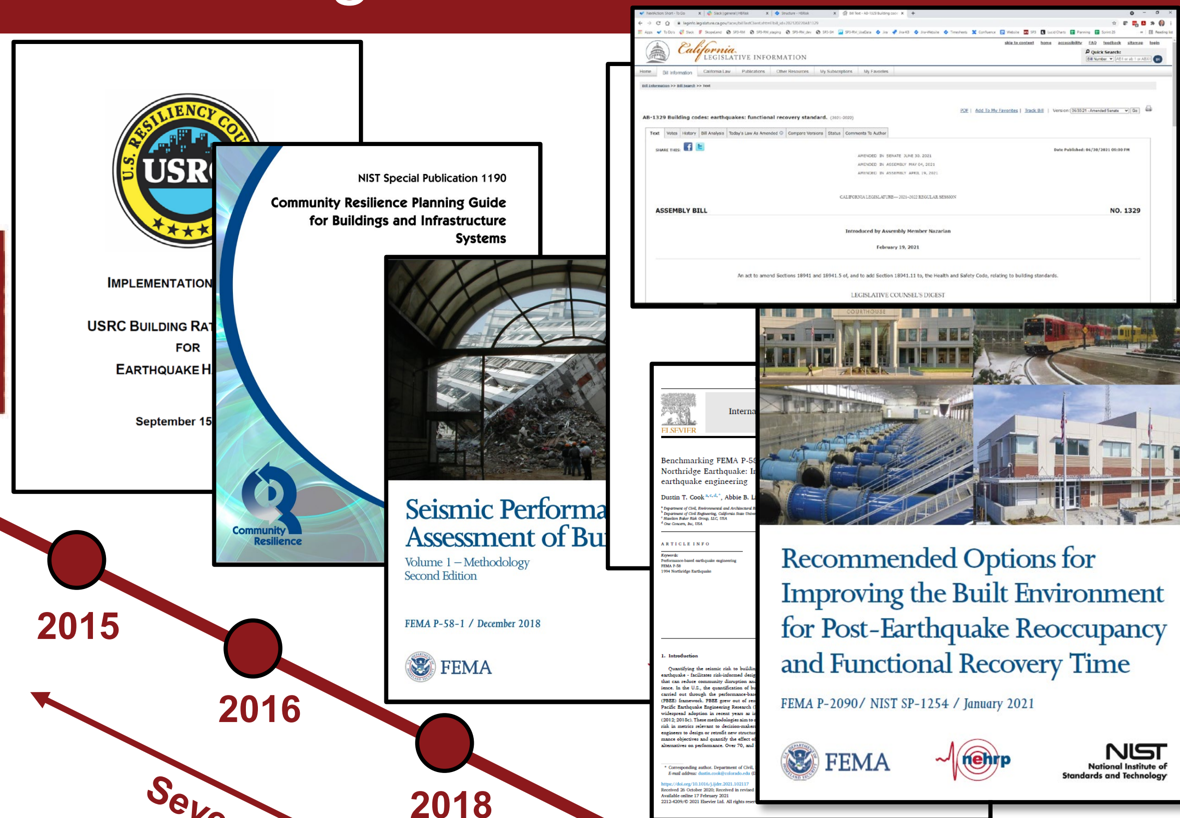
SP3 Webinar Series | March 8, 2023

Outline

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

The Resilient Design Movement

The Resilient Design Movement



~1997…

2001
FEMA/ATC Start FEMA P-58

2012

2013

2014

2015

2016

2018

2019-2020

2020-2021

2022
BSSC NEHRP Codification process begins

Seven years of vetting and adoption in SE industry

2022
BSSC NEHRP Codification process begins

Q3 2023
50% draft NEHRP

Q4 2023
90% draft NEHRP

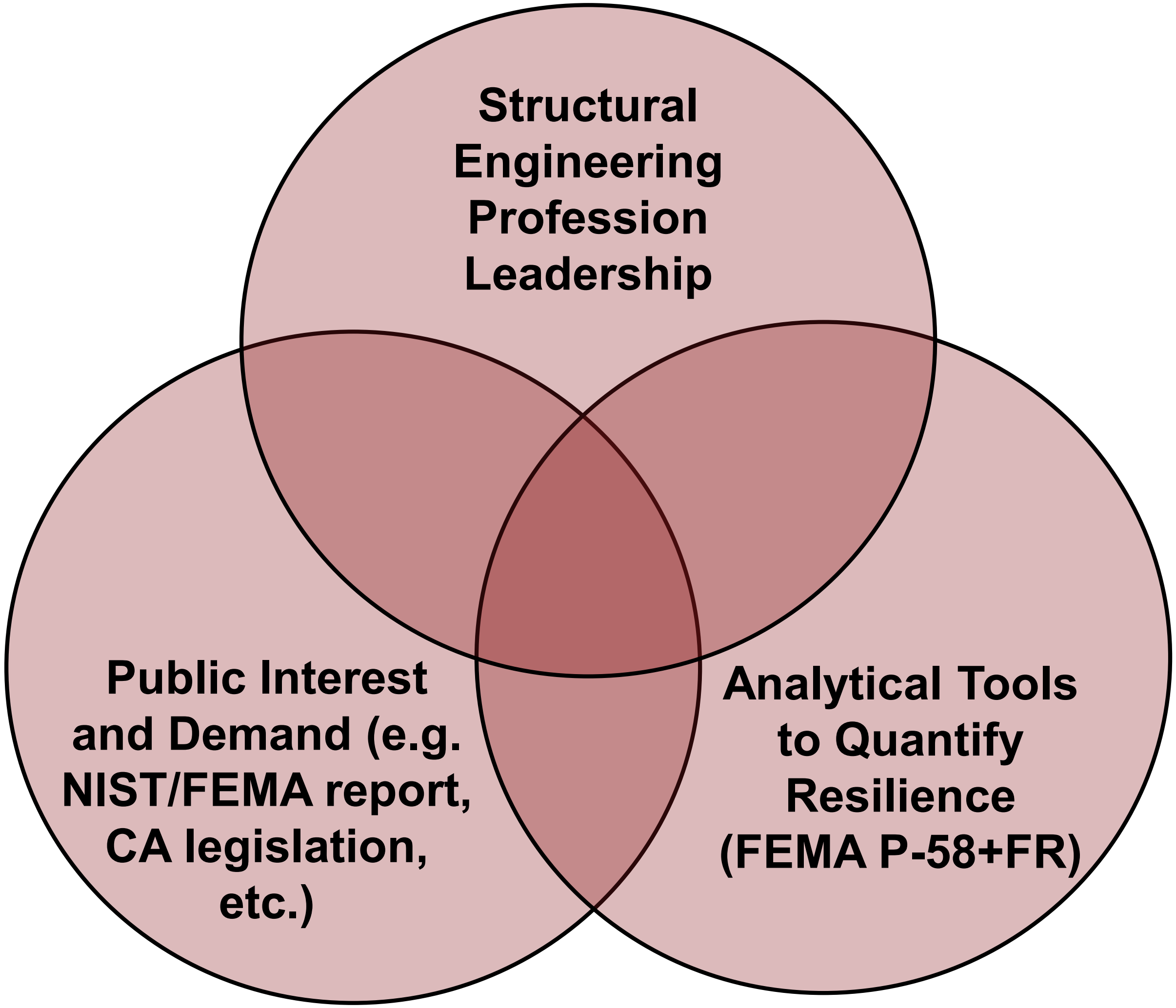
Q2 2024
100% draft NEHRP

Q1 2025
Final NEHRP sent to ASCE 7

Likely further expansion in elective resilient design, since now codified guidance

Where to next…!?!?!?

The Resilient Design Movement



The Resilient Design Movement

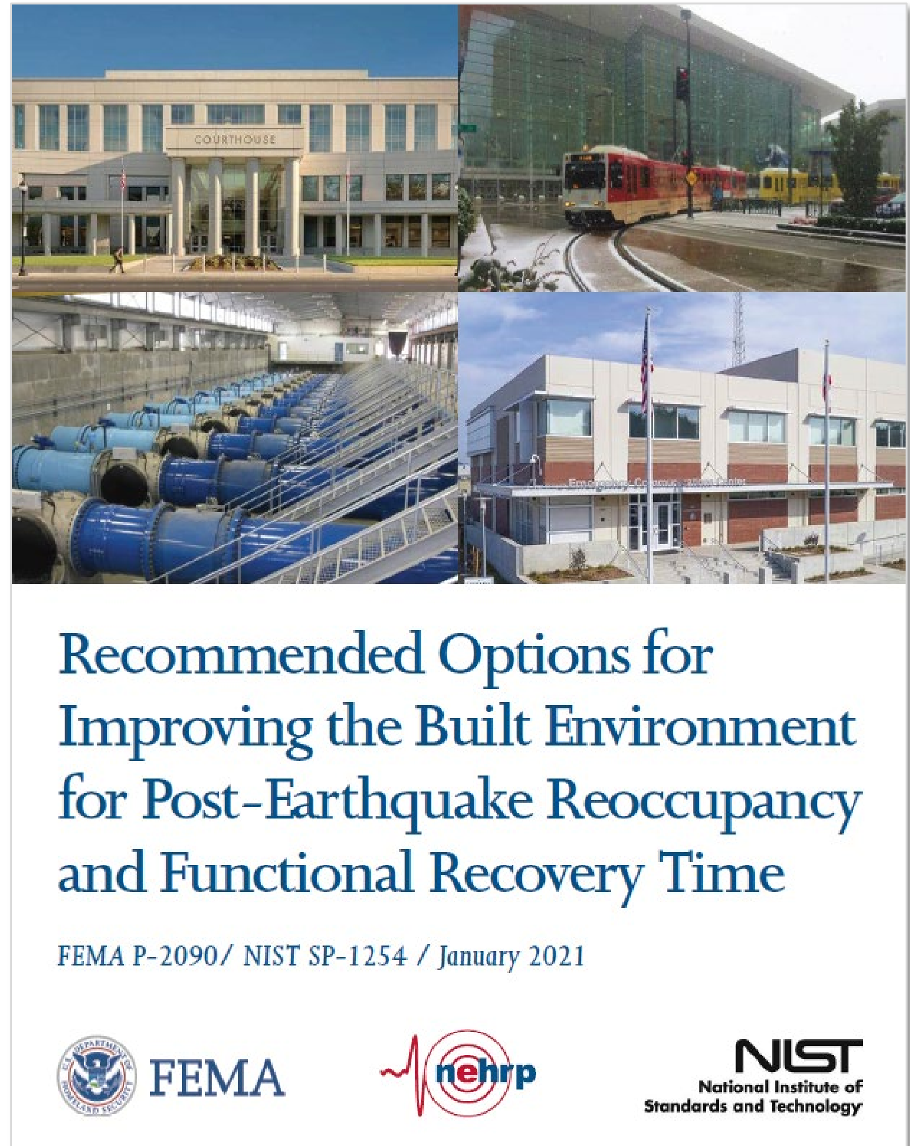
Bottom-Up Push for Resilient Design:

- Visionary structural engineers are leading by doing this electively on projects to better serve their clients.
- 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.

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…"*


Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time

FEMA P-2090/ NIST SP-1254 / January 2021

FEMA

nehrp

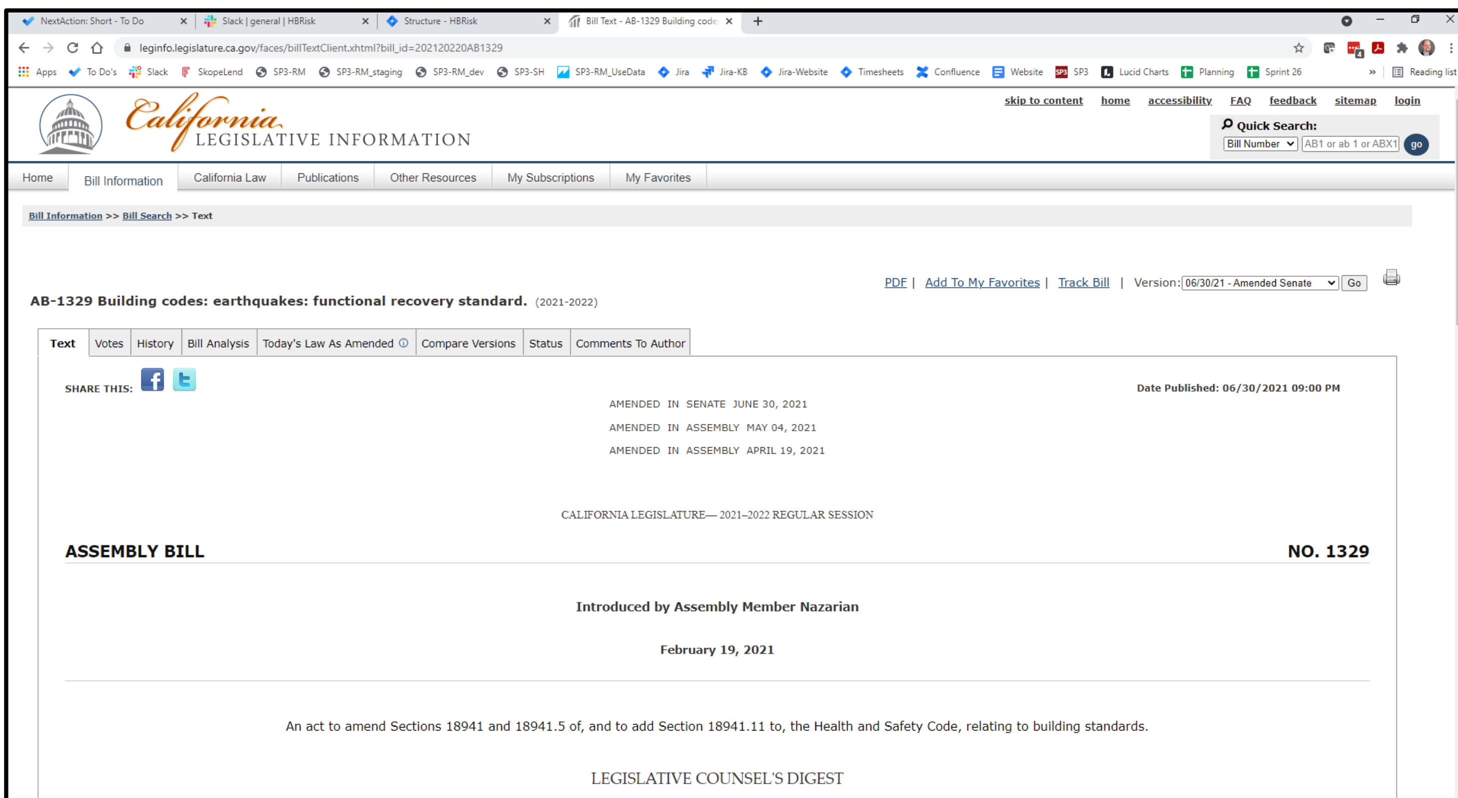
NIST
National Institute of Standards and Technology

The Resilient Design Movement

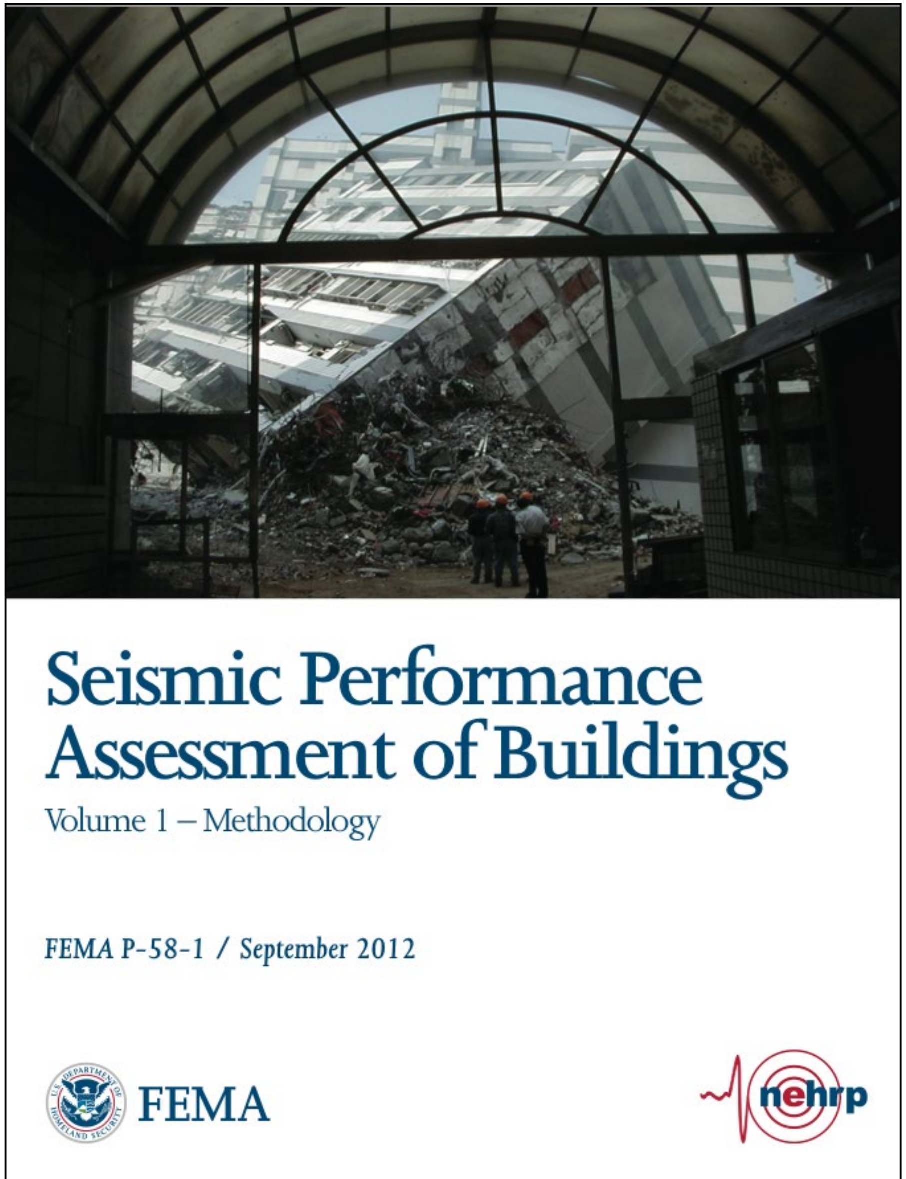
Top-Down Push for Resilient Design:

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

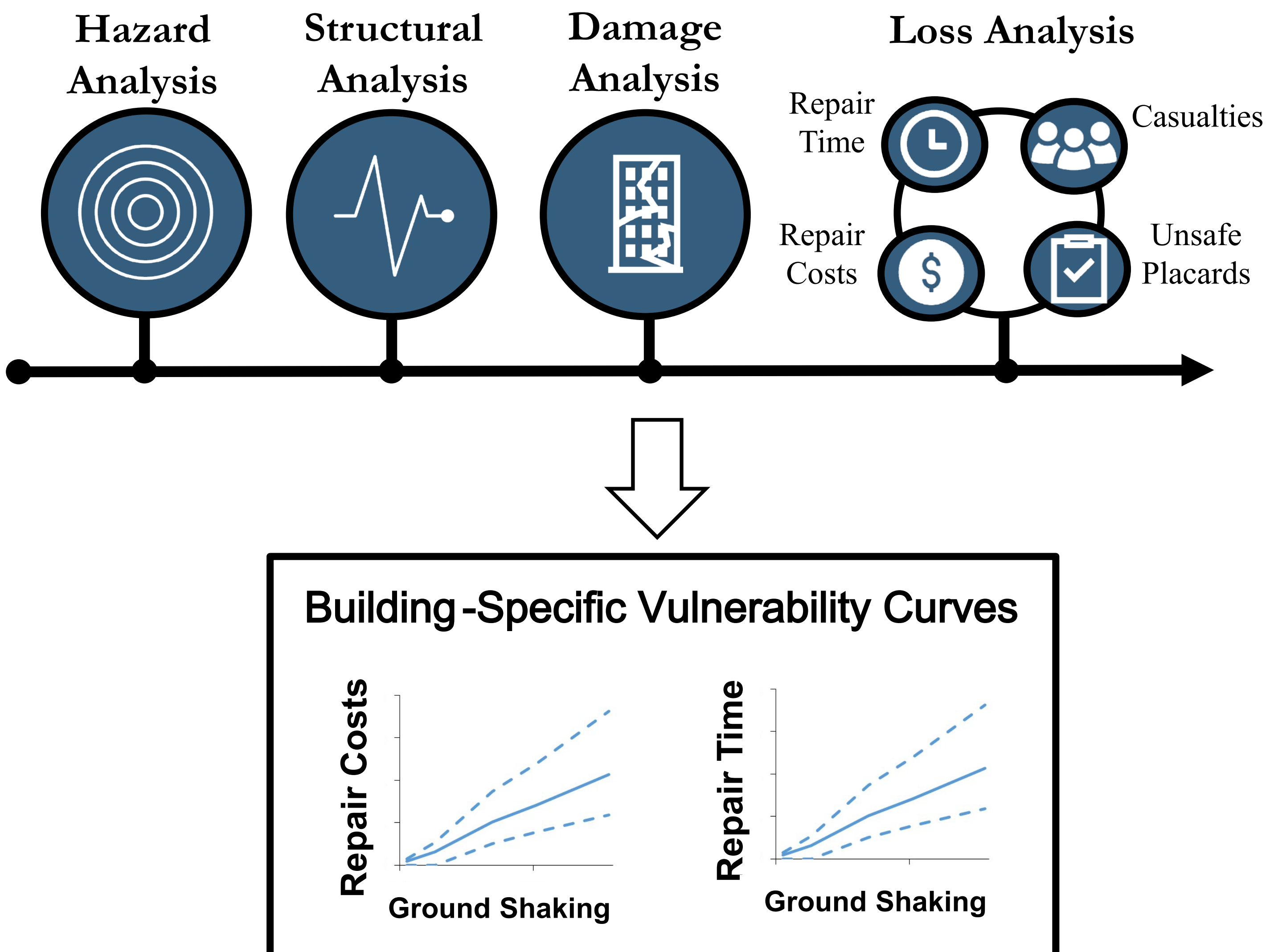
*"(b) (1) **During the 2024 triennial code adoption cycle**, the California Building Standards Commission and the Department of Housing and Community Development, acting in accordance with Section 17921, shall develop, adopt, approve, codify, and publish building standards that require buildings not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



FEMA P-58 and New Developments



FEMA P-58 and New Developments



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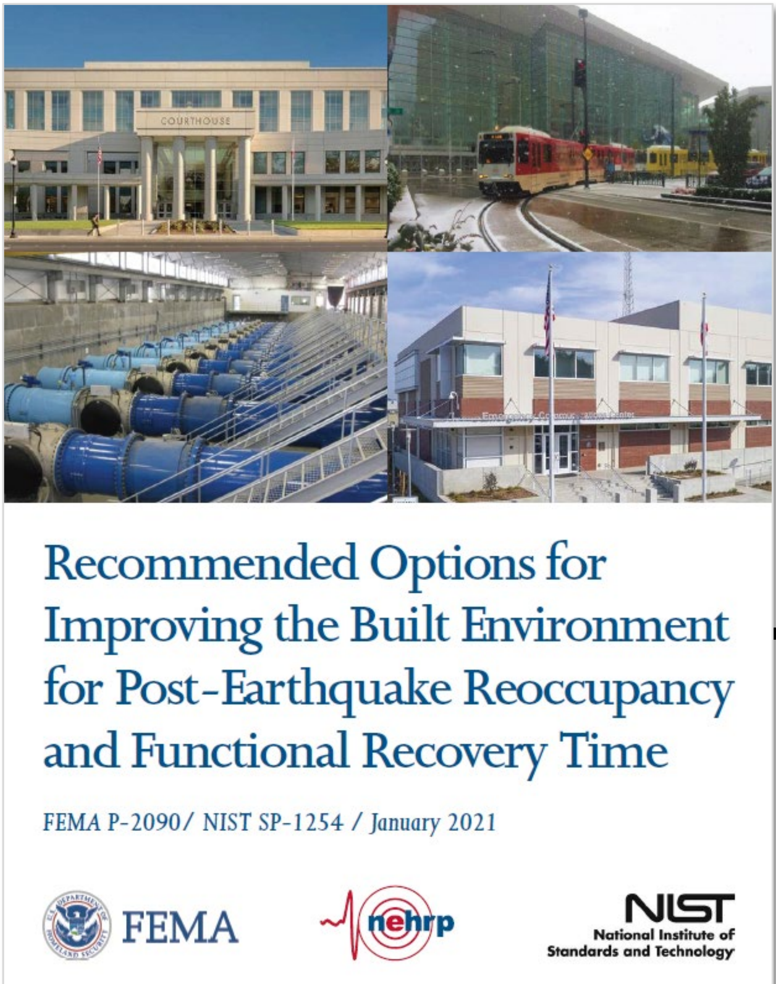
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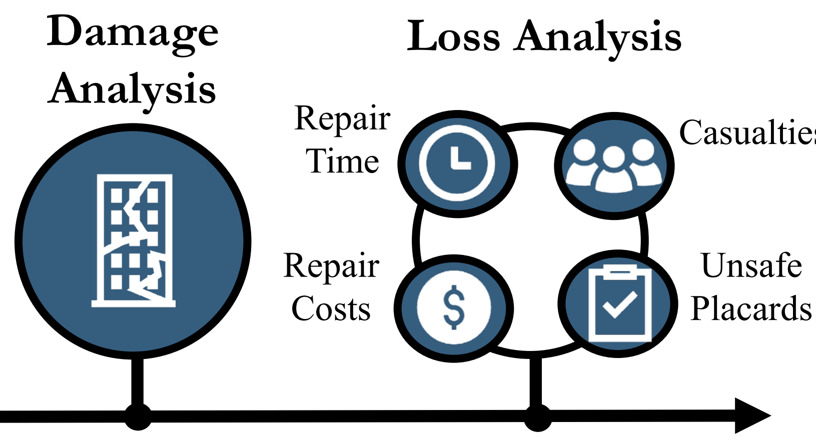
FEMA nehrp NIST National Institute of Standards and Technology



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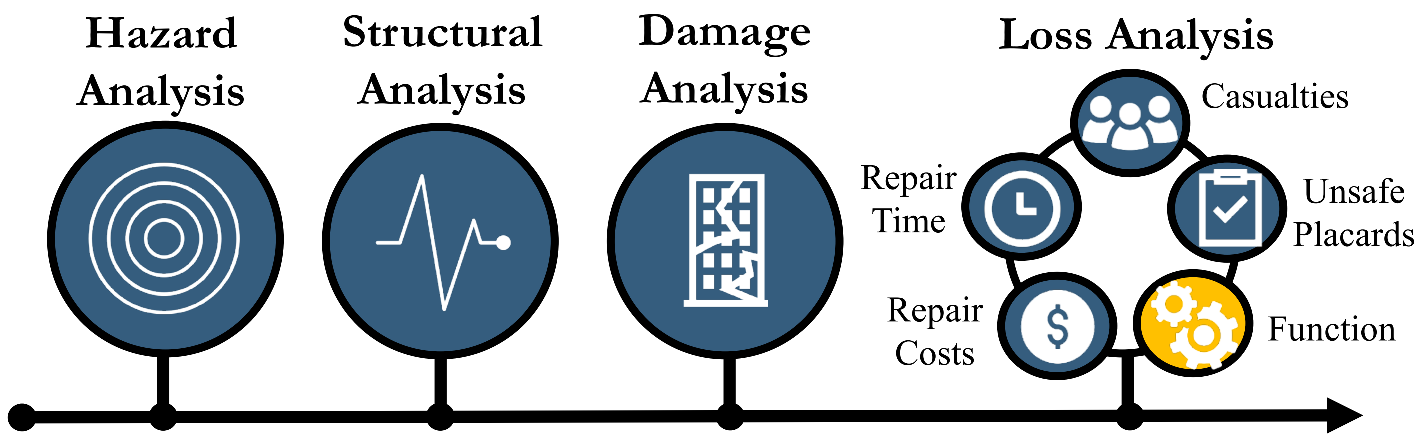
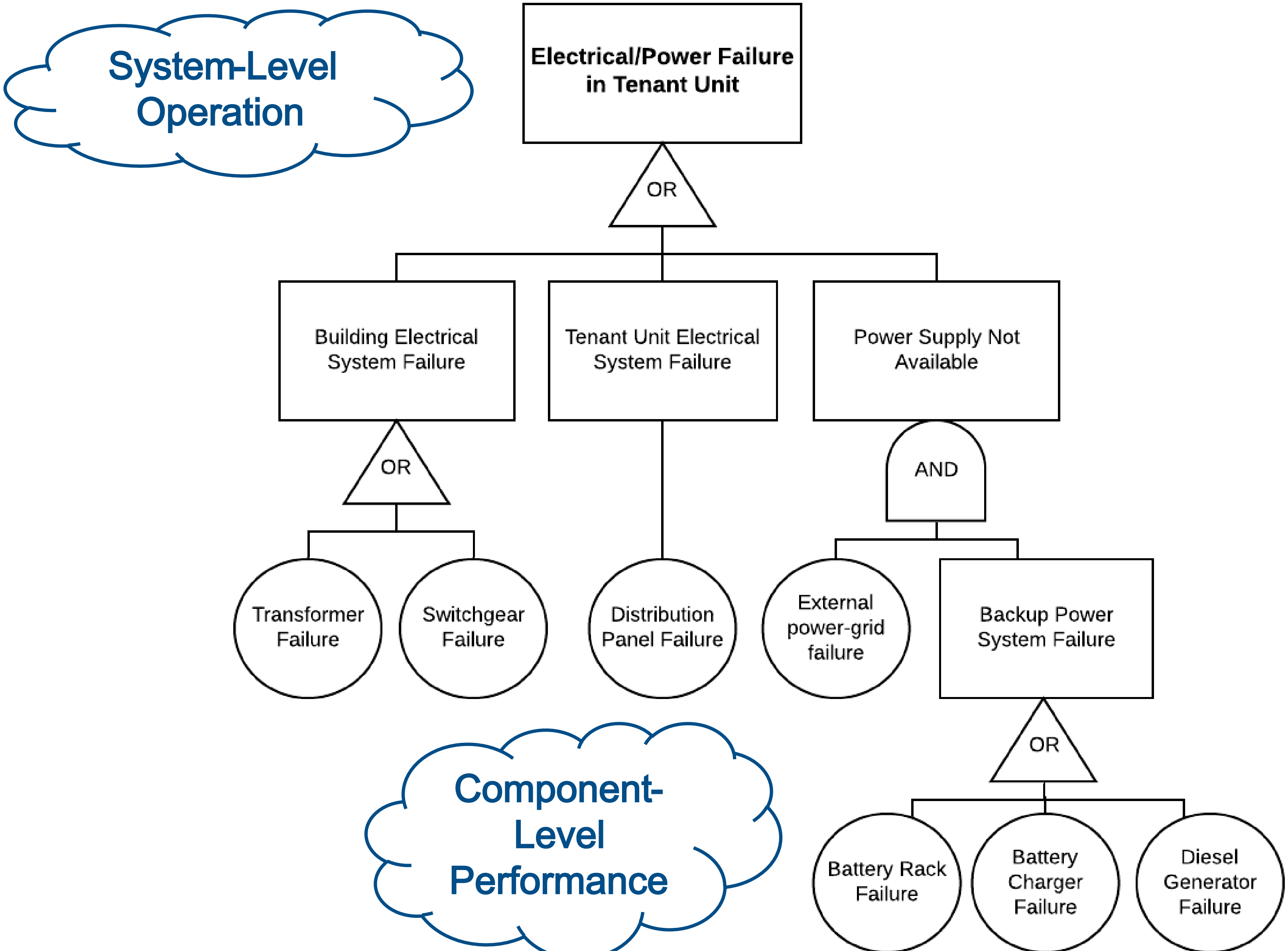


The FEMA P-58 method extensions now assesses:

(a) Reoccupancy time, and

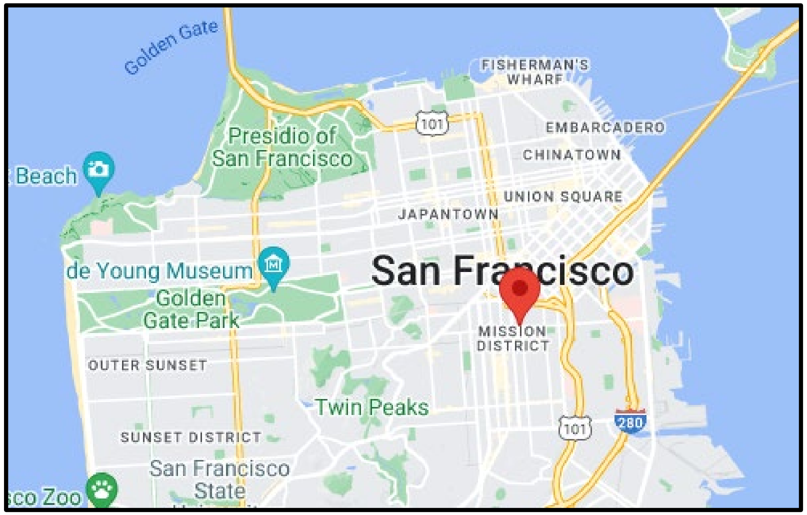
(b) Functional Recovery time.

FEMA P-58 and New Developments



Illustrative Example

- New 9-story multi-family housing in San Francisco (Mission District)
- Patterned after Casa Adelante by Mar Structural Design, but generalized.
- Example resilient design goals:
  - ✓ DE: Expected functional recovery in < 1 week for DE (50/50 chance).
  - ✓ DE: Low probability of functional recovery loss for > 1 mo. (<20%).
  - ✓ MCE: Low probability of being non-repairable at MCE (<10%), rather than just <10% collapse probability.
  - ✓ Include all building systems functioning (even heating/HVAC).
  - ✓ Allow temporary repairs to regain function.
- Note that the goal is not no damage; it is no damage that impedes function and is 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 -** 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, using component-level design targets (related to building-level goals).
    - Including structural and non-structural.
    - Including drift-sensitive and acceleration-sensitive.
  - ✓ **Step #4: Confirm Design Goals are Met –** Run the full building performance model again to ensure that building-level goals are met.

Step #1: Select Structural System

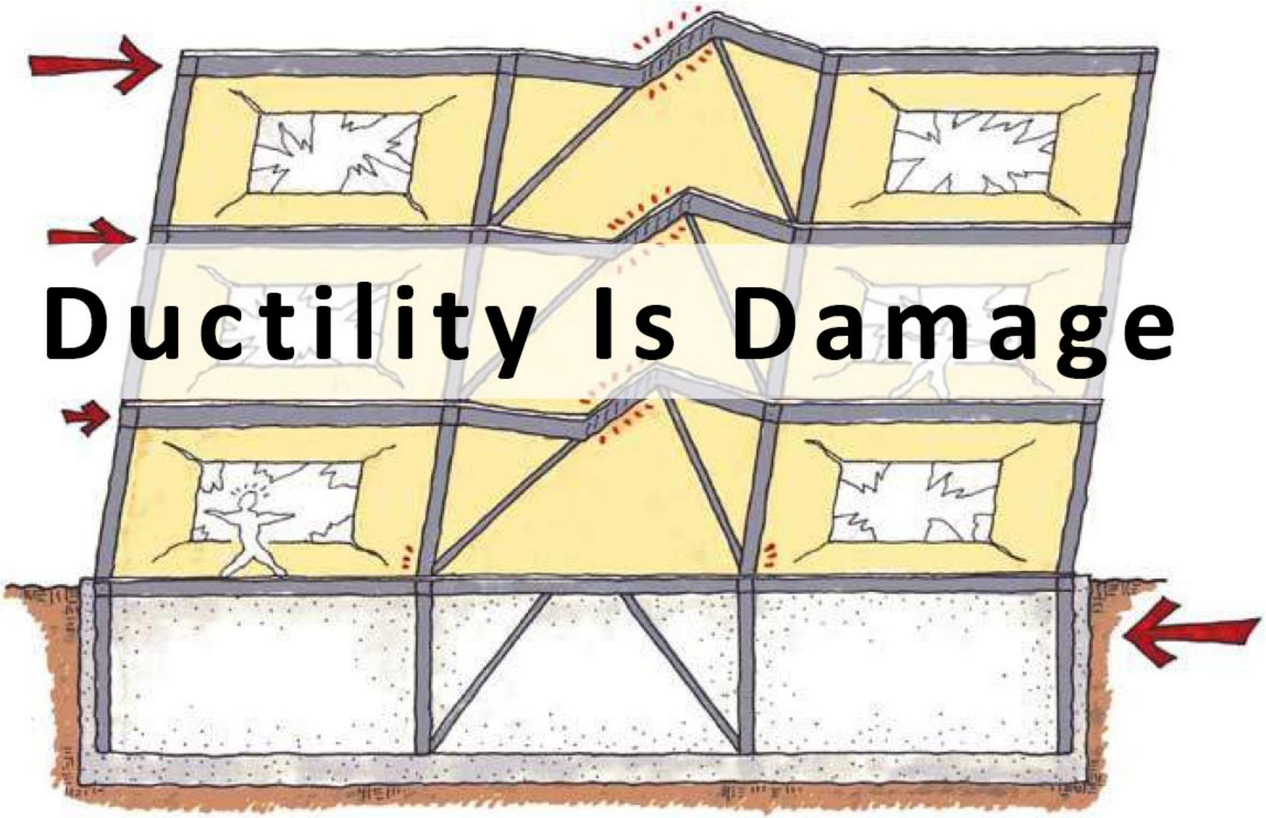


Figure courtesy of David Mar

Step #1: Select Structural System

- Not necessarily design for no ductility/damage.
- Design such that there is no damage that inhibits function.
- 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, or design components for them)

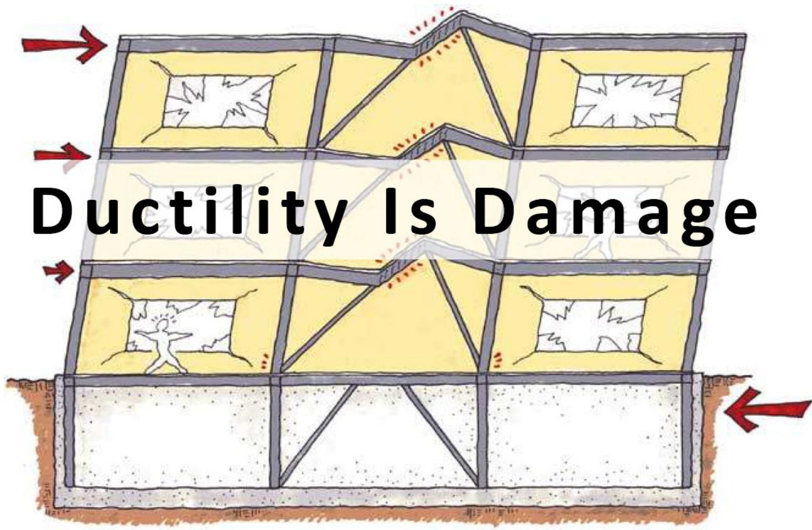
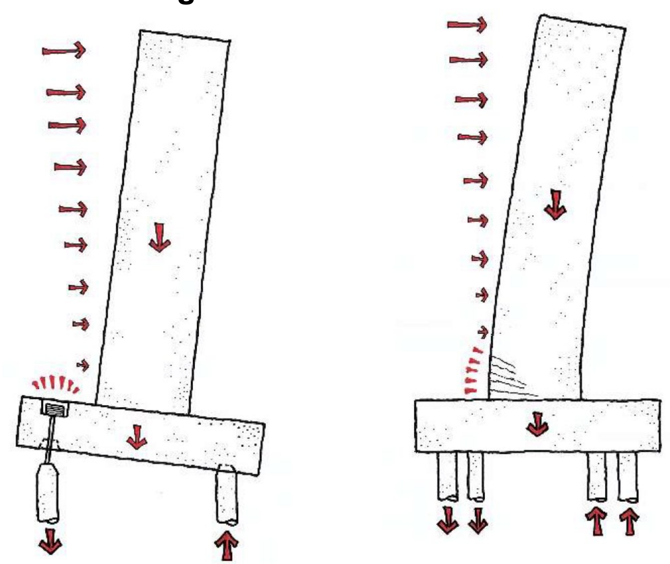
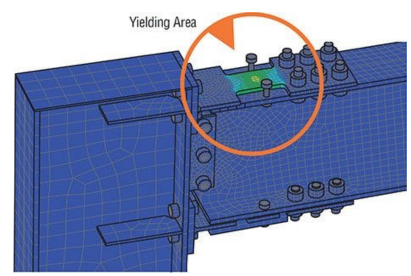


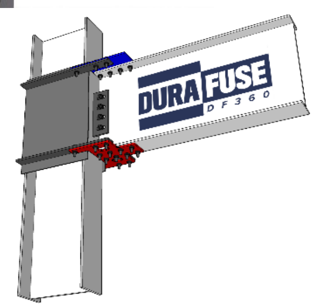
Figure courtesy of David Mar

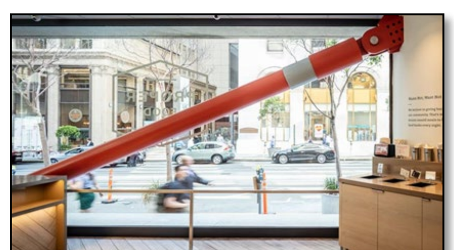
Step #1: Select Structural System

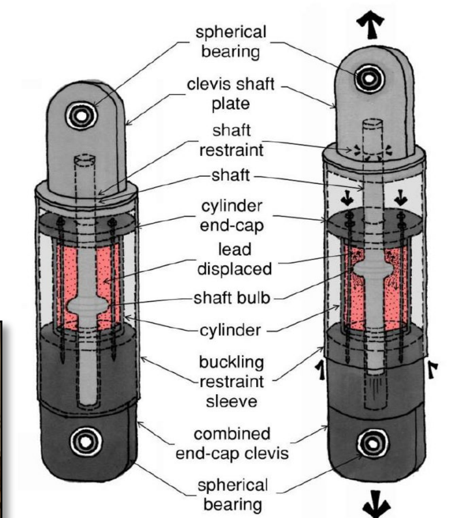
- In this example, we will use rocking wall solution from David Mar (performance-based design).
- Note that performance-based design is not necessary for resilience (it's actually the exception).
- Can use low-damage or easy-to-repair code-compliant systems (typically proprietary, since designed specifically to be resilient).
- Can also use conventional code-compliant systems with higher strength and lower drifts (e.g. conventional RC wall).











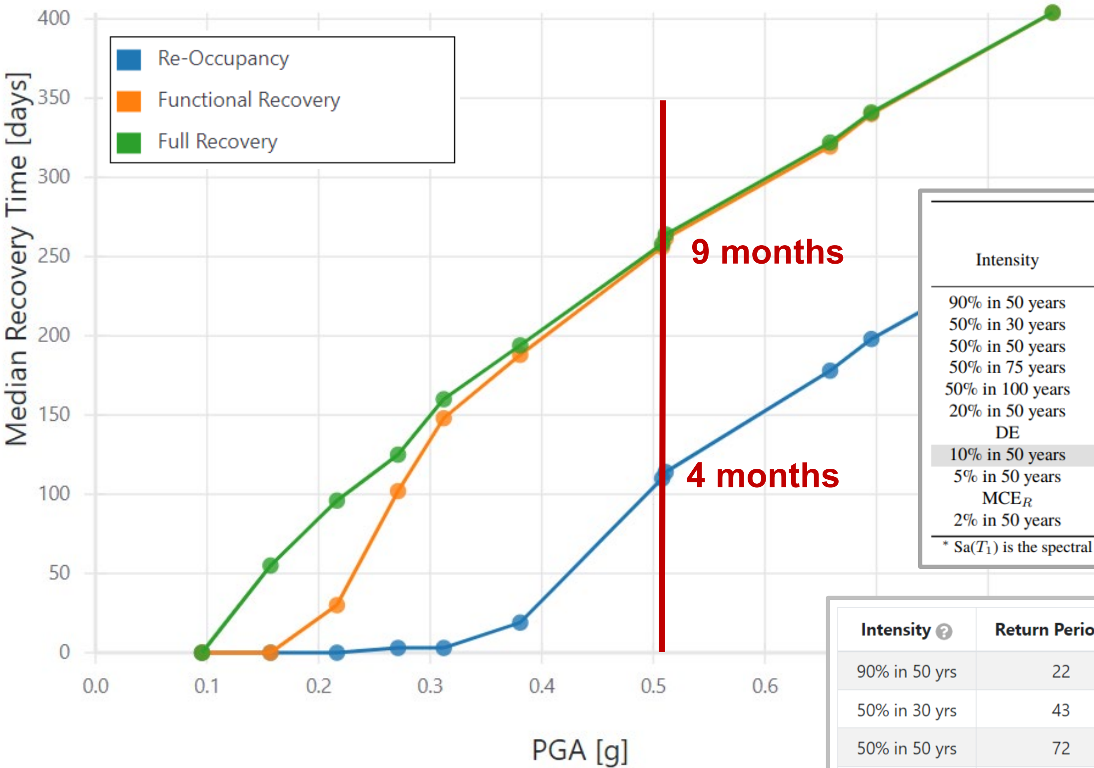
Damper at rest

Damper engaged

[Walls and damper figures courtesy of David Mar]

Step #1: Select Structural System

Now run P-58/SP3 to see current performance for trial design...



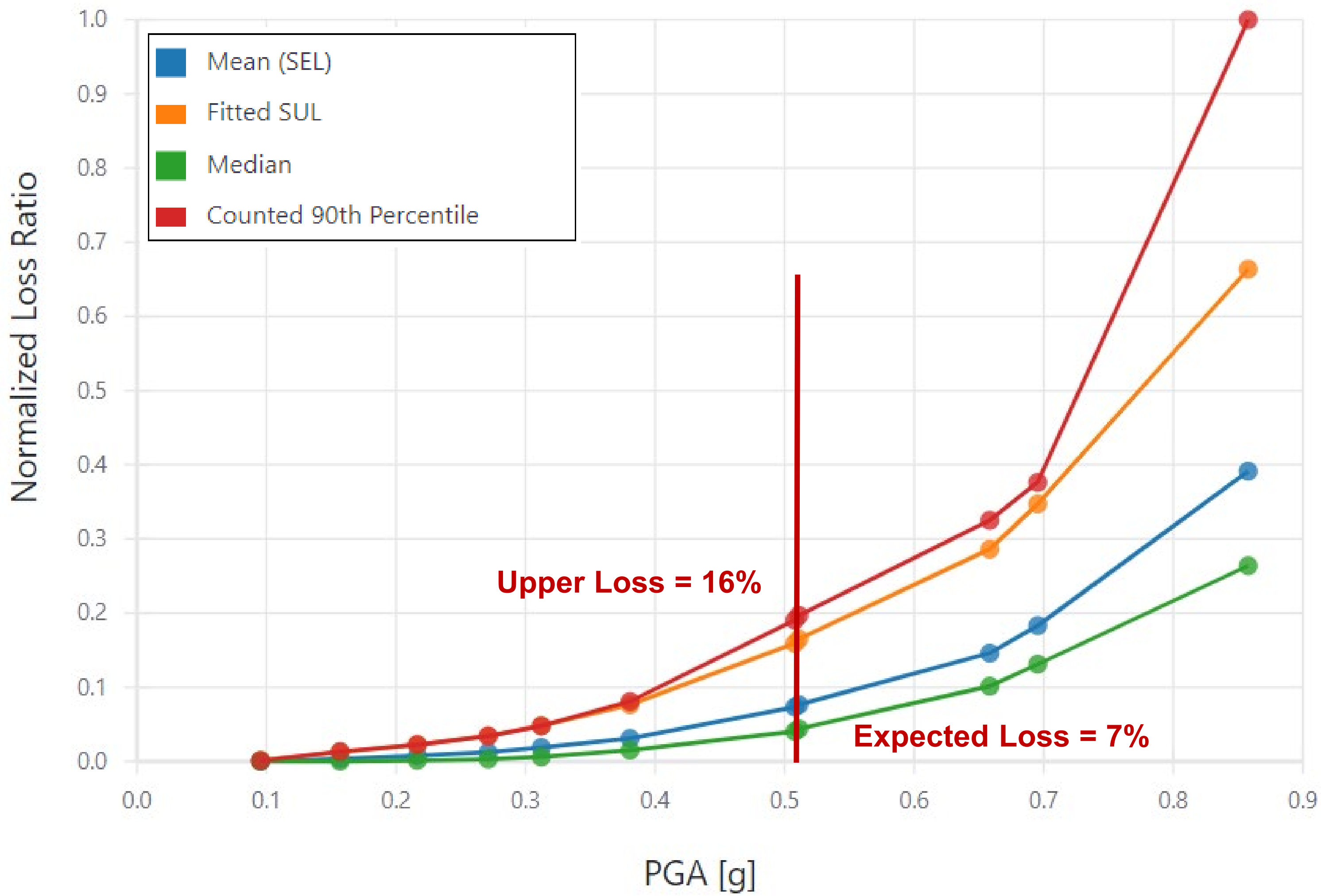
Intensity	Return Period	PGA (g)	$Sa(T_1)^*$	Median Re-Occ.	Median Func.	Median Full	90^{th} Percentile Re-Occ.	90^{th} Percentile Func.	90^{th} Percentile Full
90% in 50 years	22 years	0.10	0.10	0d	0d	0d	0d	3.3m	4.7m
50% in 30 years	43 years	0.16	0.17	0d	0d	7.9w	0d	9.6m	9.7m
50% in 50 years	72 years	0.22	0.25	0d	4.3w	3.2m	3m	12m	12m
50% in 75 years	108 years	0.27	0.33	3d	3.4m	4.2m	3.9m	12m	12m
50% in 100 years	144 years	0.31	0.40	3d	4.9m	5.3m	4.5m	13m	13m
20% in 50 years	224 years	0.38	0.52	2.7w	6.3m	6.5m	5.4m	14m	14m
DE	467 years	0.51	0.77	3.7m	8.5m	8.6m	7.7m	16m	16m
10% in 50 years	475 years	0.51	0.77	3.8m	8.7m	8.8m	7.7m	16m	16m
5% in 50 years	975 years	0.66	1.06	5.9m	11m	11m	10m	17m	17m
MCE_R	1182 years	0.70	1.15	6.6m	11m	11m	11m	18m	18m
2% in 50 years	2475 years	0.86	1.52	8.7m	13m	13m	20m	20m	20m

* $Sa(T_1)$ is the spectral acceleration at T_1 where is the mean of T_1 in both directions

Intensity	Return Period	PGA	Re-Occupancy	Functional Recovery	Full Recovery
90% in 50 yrs	22	0.10	0 days	0 days	0 days
50% in 30 yrs	43	0.16	0 days	0 days	7.9 weeks
50% in 50 yrs	72	0.22	0 days	4.3 weeks	3.2 months
50% in 75 yrs	108	0.27	3 days	3.4 months	4.2 months
50% in 100 yrs	144	0.31	3 days	4.9 months	5.3 months
20% in 50 yrs	224	0.38	2.7 weeks	6.3 months	6.5 months
DE	467	0.51	3.7 months	8.5 months	8.6 months
10% in 50 yrs	475	0.51	3.8 months	8.7 months	8.8 months
5% in 50 yrs	975	0.66	5.9 months	10.7 months	10.7 months
MCE_R	1182	0.70	6.6 months	11.3 months	11.4 months
2% in 50 yrs	2475	0.86	8.7 months	13.5 months	13.5 months

Step #1: Select Structural System

Now run P-58/SP3 to see current performance for trial design...



Step #2: Identify Problem Components

- Check the current code-minimum performance:
  - DE: Median functional recovery time = 9 mo. (goal is 1 week) **[FAIL]**
  - DE: "Worst case" (90^{th}) functional recovery time = 16 mo. (goal is 1 mo.) **[FAIL]**
  - MCE: Reparability = 95% (goal of 90%) **[PASS]**
    - ✓ Controlled residual drifts
    - ✓ Low probability of collapse
    - ✓ Controlled overall level of damage (not a total loss at the MCE)

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)	14	14	14	14	14	13	12
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	5.0	5.0	5.0	5.0	4.8	1.5	1.3
Entry Door Access	48	32	21	5.7	2.9	1.2	1.2
Exterior Falling Hazard	34	32	21	5.7	2.9	1.2	1.2
Entry Door Racking	26	0.0	0.0	0.0	0.0	0.0	0.0
Stairs	61	61	61	61	61	17	12
Stairway Doors	96	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	36	36	36	35	25	11	10
Interior Falling Hazards	13	13	13	13	13	13	12
All Loss of Reoccupancy	**97**	**69**	**68**	**68**	**66**	**19**	**13**
Building Function (affects function only, not reoccupancy)							
Elevators	69	69	69	69	69	55	26
Exterior Enclosure	7.3	7.3	7.3	7.3	7.3	3.2	2.5
Interior Space	52	17	13	13	13	13	13
Electrical	56	56	56	56	56	34	15
Potable Water	32	32	32	32	31	7.2	6.7
Sanitary Plumbing	33	33	33	33	31	7.2	6.7
HVAC Ventilation	54	54	54	54	53	30	14
HVAC Heating	54	54	54	54	53	30	14
HVAC Cooling	54	54	54	54	53	30	14
HVAC Exhaust	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Loss of Function	**99**	**90**	**90**	**90**	**89**	**67**	**33**

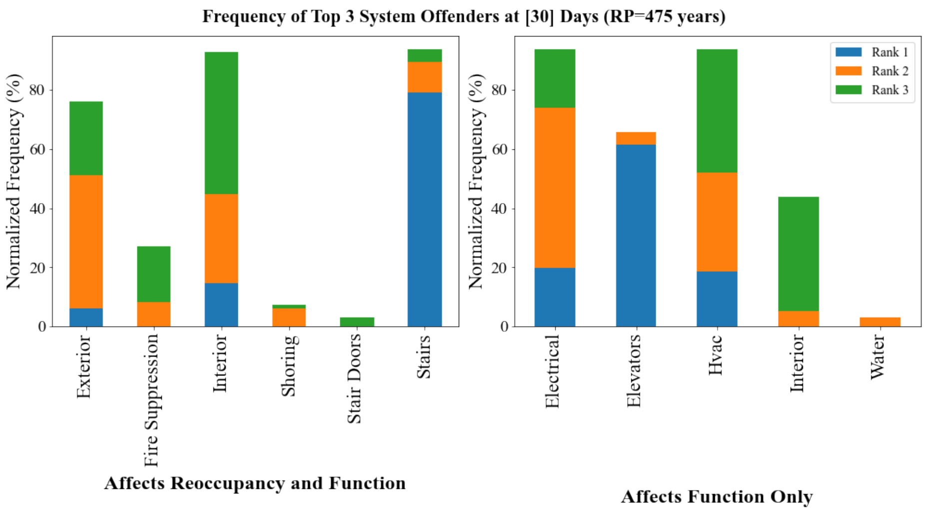
Step #2: Identify Problem Components

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	1.8 / 1.8	1.8 / 1.8	1.8 / 1.8	1.8 / 1.8	1.8 / 1.8	1.8 / 1.8	1.6 / 1.6
†Red Tag							
B1049.011	13 / 13	13 / 13	13 / 13	13 / 13	13 / 13	13 / 13	12 / 12
†Red Tag – Interior Falling Hazards – Interior Space							
Envelope							
B2011.201a	16 / 17	16 / 16	11 / 13	3.7 / 7.6	2.0 / 6.6	1.0 / 3.1	1.0 / 2.5
†Exterior Falling Hazard – Exterior Enclosure (function)							
B2011.201b	3.4 / 3.5	3.3 / 3.3	3.3 / 3.3	3.3 / 3.3	2.8 / 2.8	1.3 / 1.3	1.2 / 1.2
†Exterior Falling Hazard – Exterior Enclosure (function) – Interior Space – Exterior Enclosure (safety)							
B2022.002	36 / 36	36 / 36	36 / 36	35 / 35	25 / 26	11 / 11	10 / 10
†Exterior Falling Hazard – Exterior Enclosure (function) – Interior Space – Exterior Enclosure (safety)							
Interior							
C1011.001b	0.0 / 51	0.0 / 16	0.0 / 13	0.0 / 13	0.0 / 13	0.0 / 13	0.0 / 12
†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	61 / 61	61 / 61	61 / 61	61 / 61	61 / 61	17 / 17	12 / 12
†Stairs							
Conveying							
†All components in this group: Elevators							
D1014.041	0.0 / 16	0.0 / 16	0.0 / 16	0.0 / 16	0.0 / 16	0.0 / 11	0.0 / 5.6
D1014.042	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 42	0.0 / 40	0.0 / 19
D1014.043	0.0 / 40	0.0 / 40	0.0 / 40	0.0 / 40	0.0 / 40	0.0 / 37	0.0 / 17
D1014.044	0.0 / 41	0.0 / 41	0.0 / 41	0.0 / 41	0.0 / 41	0.0 / 38	0.0 / 17
Plumbing							
D2021.013a	0.2 / 1.0	0.2 / 1.0	0.2 / 1.0	0.2 / 1.0	0.2 / 1.0	0.2 / 0.3	0.2 / 0.3
†Potable Water – Interior Falling Hazards – Interior Space							
D2021.013b	0.0 / 28	0.0 / 28	0.0 / 28	0.0 / 28	0.0 / 26	0.0 / 6.5	0.0 / 6.1
†Potable Water							

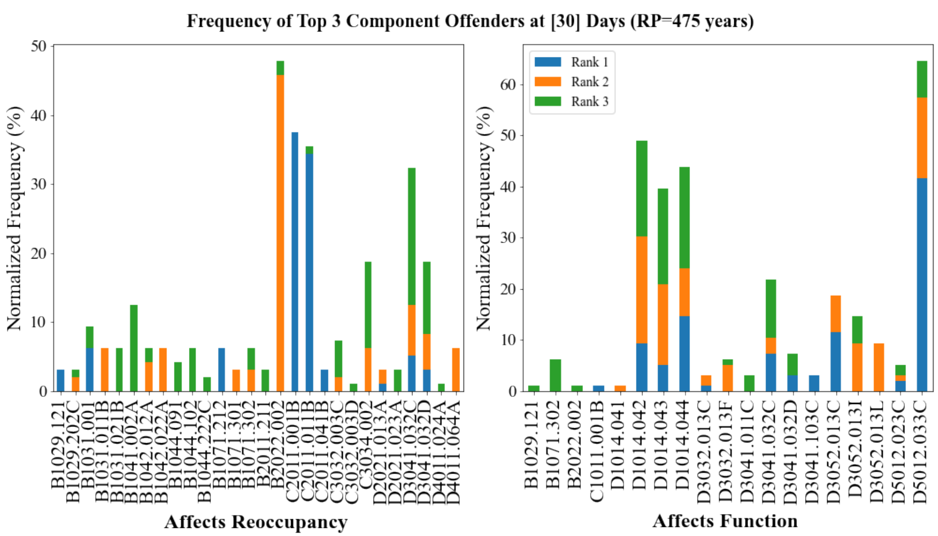
Step #2: “Common Offender” Components

- 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)

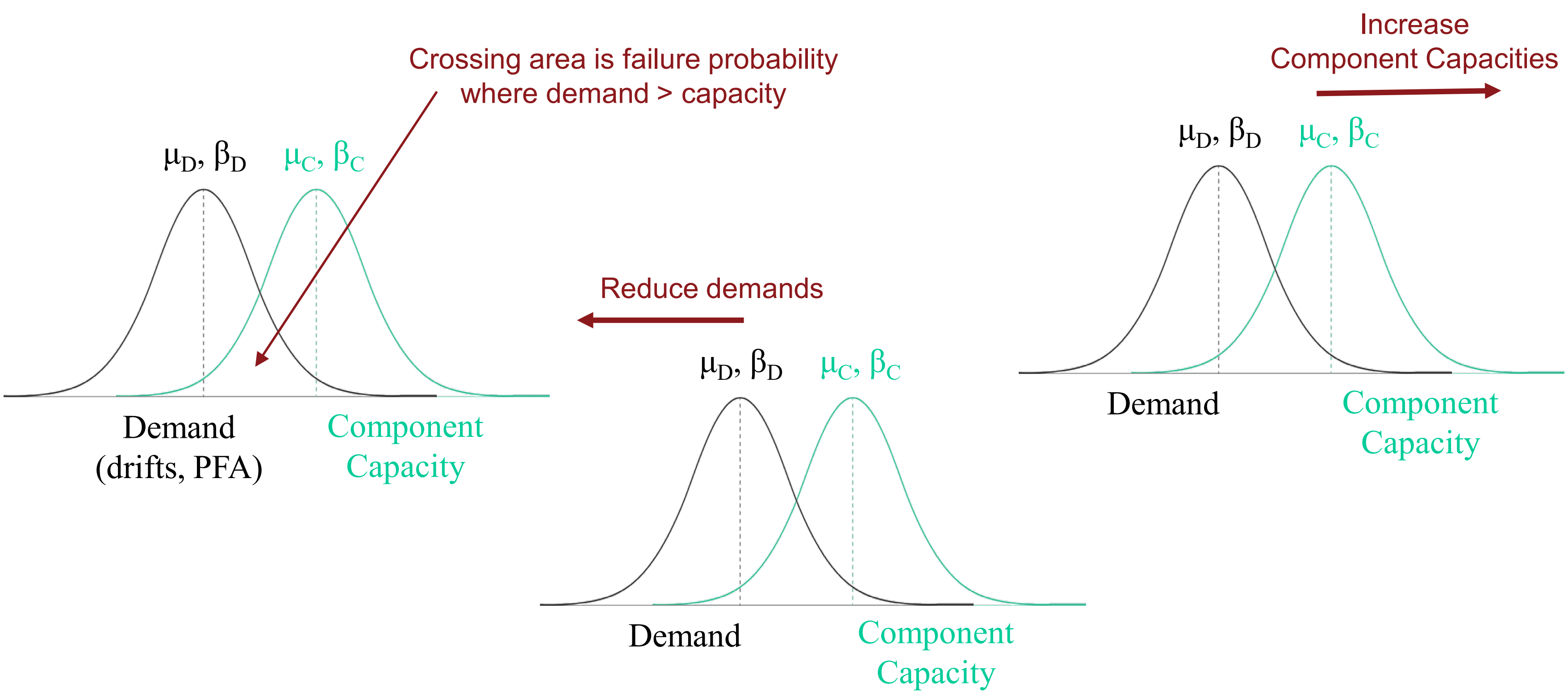


Functional Recovery (ordered):

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

Step #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 now design the problematic components to have a low probability damage at DE shaking (for damage that causes function loss).



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

Step #3: Design Components for Function

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Building Reoccupancy (also affects function)								
Red Tag (Structural)	14	14	14	14	14	13	12	**RC slab damage (drift)**
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	5.0	5.0	5.0	5.0	4.8	1.5	1.3	
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Entry Door Racking	26	0.0	0.0	0.0	0.0	0.0	0.0	
Stairs	61	61	61	61	61	17	12	**Stairs (drift)**
Stairway Doors	96	0.0	0.0	0.0	0.0	0.0	0.0	
Exterior Enclosure	36	36	36	35	25	11	10	**Curtain walls, precast (drift)**
Interior Falling Hazards	13	13	13	13	13	13	12	
All Loss of Reoccupancy	**97**	**69**	**68**	**68**	**66**	**19**	**13**	**RC slab damage (drift)**
Building Function (affects function only, not reoccupancy)								
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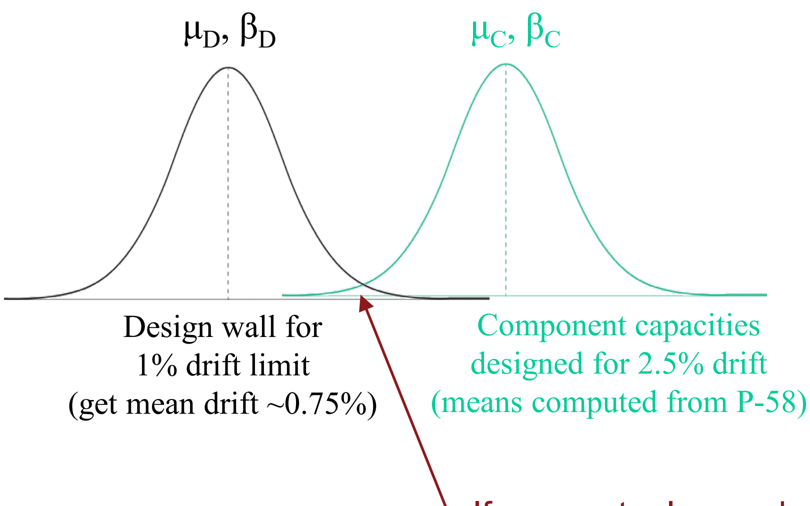
Interior Space	52	17	13	13	13	13	13	
Electrical	56	56	56	56	56	34	15	
Potable Water	32	32	32	32	31	7.2	6.7	
Sanitary Plumbing	33	33	33	33	31	7.2	6.7	
HVAC Ventilation	54	54	54	54	53	30	14	
HVAC Heating	54	54	54	54	53	30	14	
HVAC Cooling	54	54	54	54	53	30	14	
HVAC Exhaust	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
All Loss of Function	**99**	**90**	**90**	**90**	**89**	**67**	**33**	

Step #3: Design Components for Function

- Let's fix the drift-sensitive components first (to get fast reoccupancy)
  - ✓ Stiffen the wall slightly (1% drift limit)
  - ✓ Lower drifts takes care of the RC slab issue (the low chance of red tagging and shoring)
  - ✓ Design stairs with 2.0-2.5% seismic gap (may be overkill)
  - ✓ Design cladding for 2.0-2.5% drift capacity (may be overkill)



If we want a low probability of non-function for building (e.g. 20%), we design individual components for 5-10% probability.

[Note: Exact component-level design targets can be computed from building-level recovery targets.]

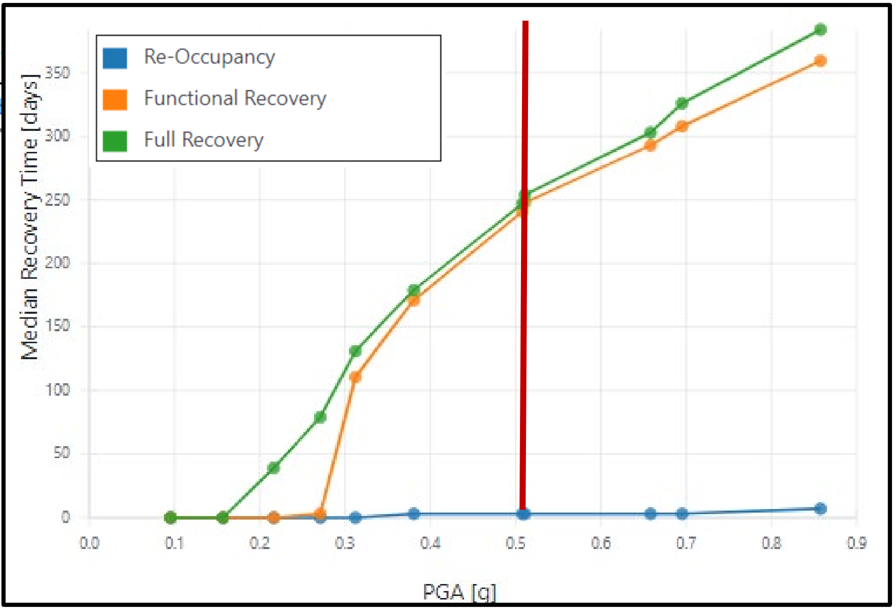
Graphics/ideas courtesy of Dr. Carlos Molina-Hutt of University of British Columbia

Step #3: Design Components for Function

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

Table 3.4. Percent of realizations affecting building reoccupancy/function per s

	Immediate	>3 days	>7 days	>14 days	>1 mont		
Building Reoccupancy (also affects function)							
Red Tag (Structural)	2.0	2.0	2.0	2.0	2.0		
Shoring	0.0	0.0	0.0	0.0	0.0		
Hazardous Material	0.0	0.0	0.0	0.0	0.0		
Fire Suppression	3.4	3.4	3.4	3.4	3.2		
Entry Door Access	20	2.8	2.1	1.5	1.4		
Exterior Falling Hazard	3.0	2.8	2.1	1.5	1.4		
Entry Door Racking	17	0.0	0.0	0.0	0.0		
Stairs	3.6	3.6	3.6	3.6	3.6		
Stairway Doors	86	0.0	0.0	0.0	0.0		
Exterior Enclosure	1.4	1.4	1.4	1.4	1.1		
Interior Falling Hazards	1.5	1.5	1.5	1.5	1.5		
All Loss of Reoccupancy	**87**	**9.6**	**9.3**	**9.1**	**8.6**		
Building Function (affects function only, not reoccupancy)							
Elevators	69	69	69	69	68	54	20
Exterior Enclosure	0.0	0.0	0.0	0.			
Interior Space	23	4.5	1.9	1.			
Electrical	53	53	53	5			
Potable Water	27	27	27	2			
Sanitary Plumbing	27	27	27	2			
HVAC Ventilation	50	50	50	4			
HVAC Heating	50	50	50	4			
HVAC Cooling	50	50	50	5			
HVAC Exhaust	0.0	0.0	0.0	0.			
All Loss of Function	**95**	**78**	**78**	**7**			



Intensity	Return Period	PGA (g)	Sa(T_1)*	Median Re-Occ.	Median Func.	Median Full	90^{th} Percentile Re-Occ.	90^{th} Percentile Func.	90^{th} Percentile Full
90% in 50 years	22 years	0.10	0.14	0d	0d	0d	0d	4.6m	5m
50% in 30 years	43 years	0.16	0.24	0d	0d	0d	0d	9.2m	9.2m
50% in 50 years	72 years	0.22	0.34	0d	0d	5.6w	0d	11m	11m
50% in 75 years	108 years	0.27	0.44	0d	3d	2.6m	0d	12m	12m
50% in 100 years	144 years	0.31	0.52	0d	3.7m	4.4m	3d	13m	13m
20% in 50 years	224 years	0.38	0.67	3d	5.7m	6m	3d	14m	14m
DE	467 years	0.51	0.96	3d	8m	8.2m	3d	16m	16m
10% in 50 years	475 years	0.51	0.97	3d	8.3m	8.5m	3d	16m	16m
5% in 50 years	975 years	0.66	1.30	3d	9.8m	10m	4.3m	18m	18m
MCE_R	1182 years	0.70	1.41	3d	10m	11m	5.7m	18m	19m
2% in 50 years	2475 years	0.86	1.82	7d	12m	13m	20m	23m	23m

* Sa(T_1) is the spectral acceleration at T_1 where is the mean of T_1 in both directions

Step #3: Design Components for Function

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

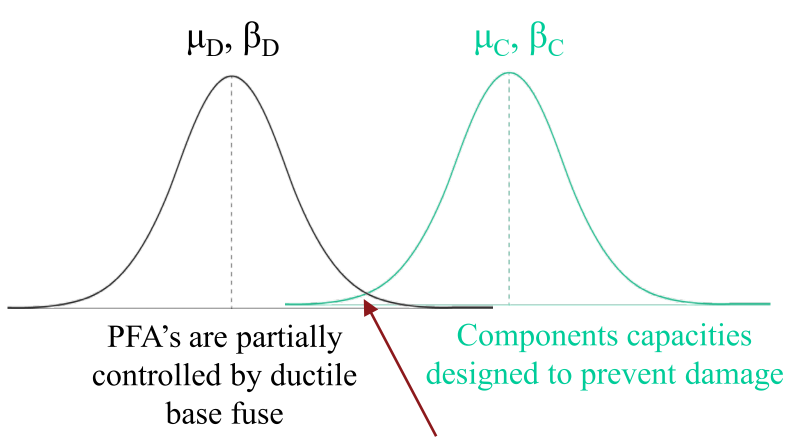
Table 3.4. Percent of realizations affecting building reoccupancy/function per system check - DE

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	2.0	2.0	2.0	2.0	2.0	1.8	1.4
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	3.4	3.4	3.4	3.4	3.2	0.4	0.2
Entry Door Access	20	2.8	2.1	1.5	1.4	0.2	0.2
Exterior Falling Hazard	3.0	2.8	2.1	1.5	1.4	0.2	0.2
Entry Door Racking	17	0.0	0.0	0.0	0.0	0.0	0.0
Stairs	3.6	3.6	3.6	3.6	3.6	0.9	0.6
Stairway Doors	86	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	1.4	1.4	1.4	1.4	1.1	0.5	0.5
Interior Falling Hazards	1.5	1.5	1.5	1.5	1.5	1.5	1.4
All Loss of Reoccupancy	**87**	**9.6**	**9.3**	**9.1**	**8.6**	**2.2**	**1.5**
Building Function (affects function only, not reoccupancy)							
Elevators	69	69	69	69	68	54	20
Exterior Enclosure	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Interior Space	23	4.5	1.9	1.9	1.9	1.8	1.5
Electrical	53	53	53	53	53	29	7.2
Potable Water	27	27	27	26	24	1.3	0.7
Sanitary Plumbing	27	27	27	27	24	1.3	0.7
HVAC Ventilation	50	50	50	49	47	23	5.9
HVAC Heating	50	50	50	49	47	23	5.9
HVAC Cooling	50	50	50	50	48	24	5.9
HVAC Exhaust	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Loss of Function	**95**	**78**	**78**	**78**	**76**	**61**	**24**

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

Step #3: Design Components for Function

- Let's fix the components needed for function (which are typically acceleration-sensitive)
  - ✓ Elevators – design for 2x strength required in current ASME (more precise design resilient design requirements for elevators in development)
  - ✓ Specify pre-qualified equipment, per ASCE7 Chapter 16.
  - ✓ Design anchorages to not need repair, by either:
    - **Designing to be reliably elastic (typical, and done here) [used Ip/Rp = Ip/Rpo = 1.5 in this example]
    - Designing with reliable ductility that does not require repair (since ductility reduces component accelerations substantially)



Design for ~<5% probability of damage (that impeded function)

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right)$$

$$F_p = 0.4 S_{DS} I_p W_p \left[\frac{H_f}{R_\mu}\right]\left[\frac{C_{AR}}{R_{po}}\right]$$

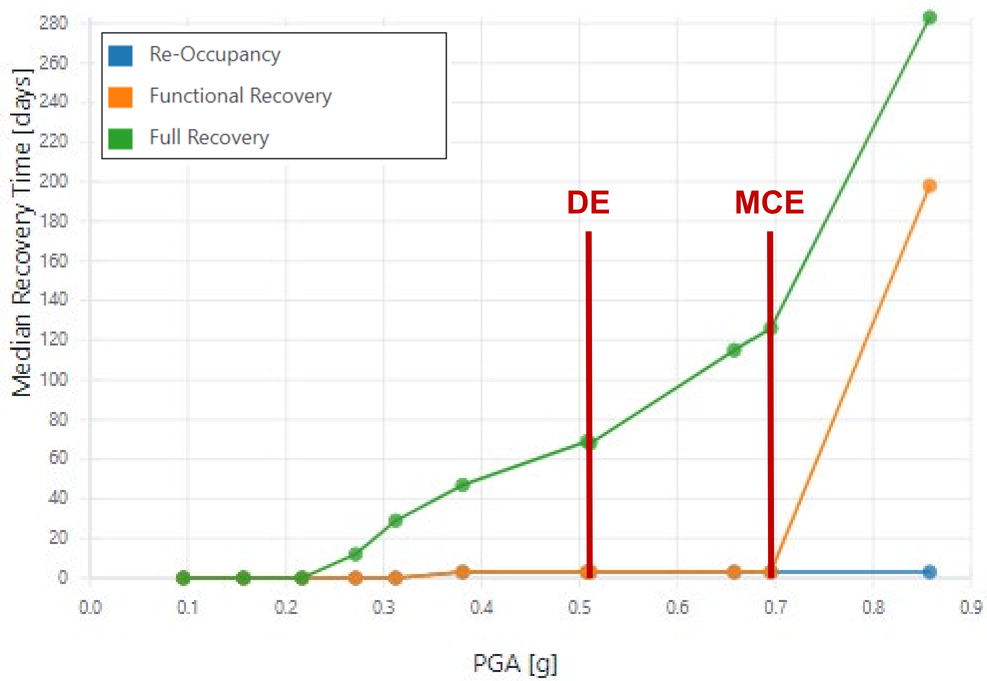
Step #3: Design Components for Function

- All done with designing each individual “problem” component to have a low probability (~5%) of losing function in the DE.

Step #4: Confirm Design Goals are Met

	Immediate	>3 days	>7 days	>14 days	>1 month	>6 months	>12 months
Building Reoccupancy (also affects function)							
Red Tag (Structural)	1.4	1.4	1.4	1.4	1.4	1.2	1.0
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Entry Door Access	18	1.6	1.0	0.3	0.2	0.1	0.0
Exterior Falling Hazard	1.8	1.6	1.0	0.3	0.2	0.1	0.0
Entry Door Racking	17	0.0	0.0	0.0	0.0	0.0	0.0
Stairs	2.8	2.8	2.8	2.8	2.8	0.6	0.4
Stairway Doors	85	0.0	0.0	0.0	0.0	0.0	0.0
Exterior Enclosure	1.4	1.4	1.4	1.3	0.9	0.3	0.2
Interior Falling Hazards	0.9	0.9	0.9	0.9	0.9	0.8	0.6
All Loss of Reoccupancy	**87**	**5.2**	**4.9**	**4.6**	**4.2**	**1.4**	**1.1**
Building Function (affects function only, not reoccupancy)							
Elevators	13	13	13	13	13	10	3.1
Exterior Enclosure	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Interior Space	23	3.7	1.4	1.4	1.4	1.3	1.1
Electrical	3.4	3.4	3.4	3.4	3.2	1.4	0.3
Potable Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sanitary Plumbing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HVAC Ventilation	1.4	1.4	1.4	1.4	1.2	0.2	0.0
HVAC Heating	3.3	3.3	3.3	3.3	3.0	0.2	0.1
HVAC Cooling	3.3	3.3	3.3	3.3	3.0	0.2	0.1
HVAC Exhaust	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Loss of Function	**88**	**20**	**18**	**18**	**17**	**11**	**4.0**

Step #4: Confirm Design Goals are Met



Intensity	Return Period	PGA	Re-Occupancy	Functional Recovery	Full Recovery
90% in 50 yrs	22	0.10	0 days	0 days	0 days
50% in 30 yrs	43	0.16	0 days	0 days	0 days
50% in 50 yrs	72	0.22	0 days	0 days	0 days
50% in 75 yrs	108	0.27	0 days	0 days	12 days
50% in 100 yrs	144	0.31	0 days	0 days	4.1 weeks
20% in 50 yrs	224	0.38	3 days	3 days	6.7 weeks
DE	467	0.51	3 days	3 days	2.3 months
10% in 50 yrs	475	0.51	3 days	3 days	2.3 months
5% in 50 yrs	975	0.66	3 days	3 days	3.8 months
MCE_R	1182	0.70	3 days	3 days	4.2 months
2% in 50 yrs	2475	0.86	3 days	6.6 months	9.4 months

				Median			90^{th} Percentile		
Intensity	Return Period	PGA (g)	$Sa(T_1)$*	Re-Occ.	Func.	Full	Re-Occ.	Func.	Full
90% in 50 years	22 years	0.10	0.14	0d	0d	0d	0d	0d	0d
50% in 30 years	43 years	0.16	0.24	0d	0d	0d	0d	0d	13d
50% in 50 years	72 years	0.22	0.34	0d	0d	0d	0d	0d	2.3m
50% in 75 years	108 years	0.27	0.44	0d	0d	0d	0d	2d	3.2m
50% in 100 years	144 years	0.31	0.52	0d	0d	4w	3d	3d	3.5m
20% in 50 years	224 years	0.38	0.67	3d	3d	6.6w	3d	3d	4.6m
DE	467 years	0.51	0.96	3d	3d	2.2m	3d	6.9m	8.6m
10% in 50 years	475 years	0.51	0.97	3d	3d	2.2m	3d	7.4m	9m
5% in 50 years	975 years	0.66	1.30	3d	3d	3.4m	3.9m	13m	15m
MCE_R	1182 years	0.70	1.41	3d	3d	3.8m	4.6m	14m	16m
2% in 50 years	2475 years	0.86	1.82	3d	5.2m	8.8m	20m	21m	22m

* $Sa(T_1)$ is the spectral acceleration at T_1 where is the mean of T_1 in both directions

Resilient Design Goals Achieved (for DE):

- Expected <u>3 day</u> functional recovery (clean-up and temp repairs) [vs. <u>9 months</u> for code-minimum]
- Probability of losing function for > 1 month is less than 20% (computed as 17%) [vs. 90% for code-min]

Notes on Precision:

- I don’t believed for a minute that these exact numbers are right (lots of uncertainty).
- I do believe this resilient design will perform much better than code-minimum (<u>we designed for function</u>).
- FEMA P-58 provides a reliable and repeatable tool for resilient design for functional recovery (let’s you design each individual component and see it’s impact on overall building performance).

Resilient Design is Feasible and Cost Effective

Similar Cost

to the conventional design

$42M Project Cost

Cost Delta

$100K for Resilience – 0.24%

Figure courtesy of David Mar

Looking Ahead in Resilient Design Movement

- Leaders keep leading! Structural engineering leaders continue to expand doing this electively on current projects.
- BSSC building code language this year (50% draft by August, 90% draft by December), with support of ATC-138 studies.
  - ✓ Benchmark current code-minimum performance for every common structural system (ATC-138).
  - ✓ Develop functional recover time targets (e.g. average functional recovery time < 1 weeks, 90% confidence in < 1 month, reparability).
  - ✓ Identify "common offender" components needing better design for function.
  - ✓ Create <u>component-level</u> design methods for all problem components.
  - ✓ Calibrate component-level design targets (e.g. < 10% damaged) using building-level functional recovery goals (e.g. function < 1mo), confirm with P-58 that component-focused design process meets building-level goals.
- Overall BSSC building code goals this year (90% by December):
  - ✓ Prescriptive FR design requirements for all structural systems.
  - ✓ I would also like to see clear alternative means provisions for how engineers can continue doing creative design like is being done now in practice.

Questions and Discussion!

- Thank you for your time.
- I am really excited about where we are and what is to come in the resilient design movement.
- Our goal is to support adoption of resilience-based design for functional recovery, and we welcome feedback and suggestions.

- Time for questions and discussion!

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