PEER/CEA Numerical Modeling Program

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Acknowledgements: PEER-CEA Project

Funding by:

Project Led by:

Yousef Bozorgnia, P.I.

All working group contributors!

PEER-CEA Working Groups

WG1: Literature Review

WG2: Development of Index Buildings

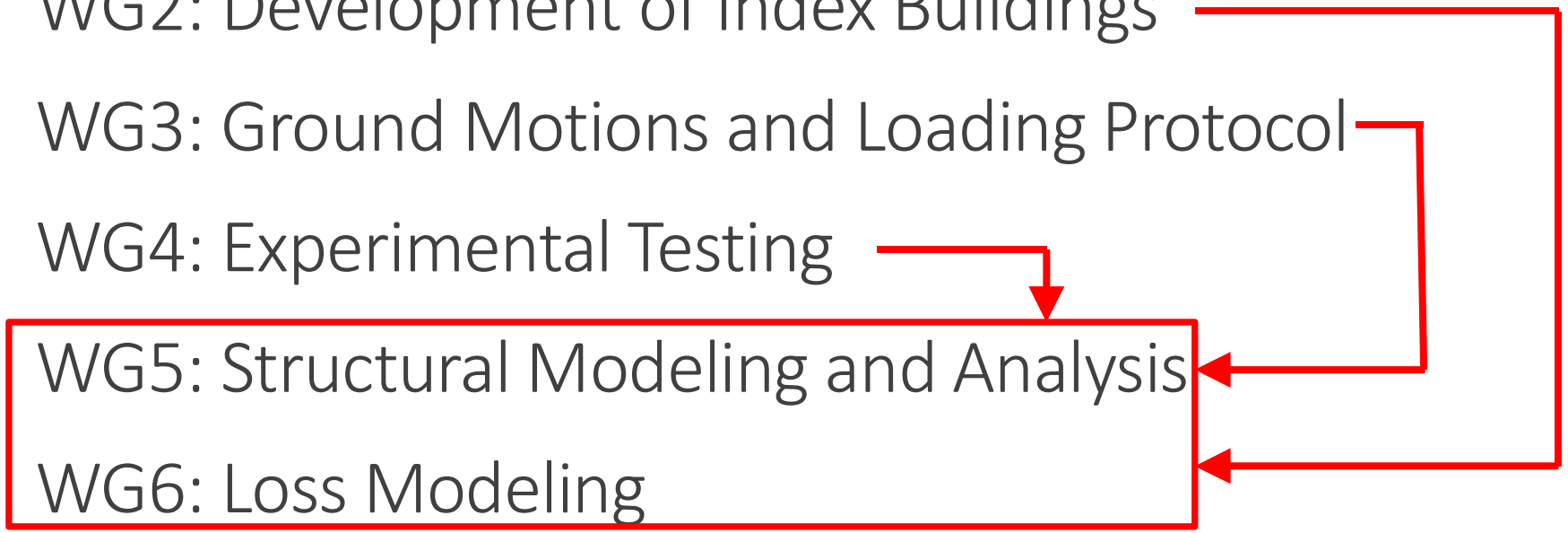
WG3: Ground Motions and Loading Protocol

WG4: Experimental Testing

WG5: Structural Modeling and Analysis

WG6: Loss Modeling

WG7: Reporting



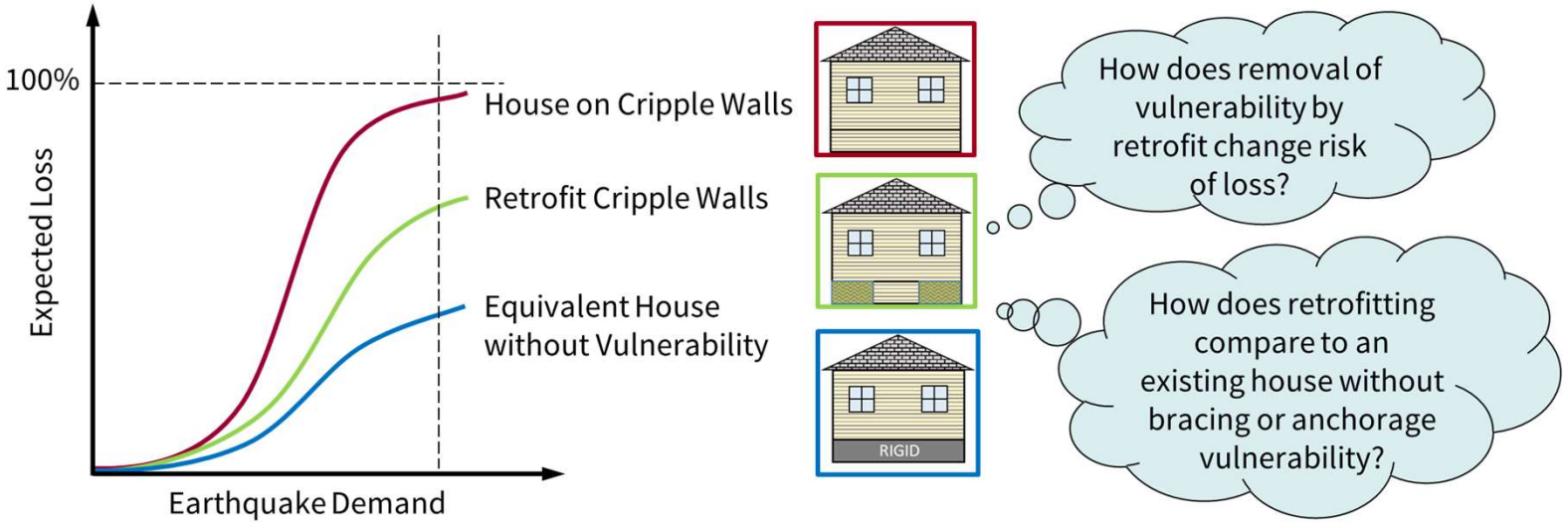
Outline

- End Goals and Numerical Framework
  - ATC-110 to PEER-CEA: Trial Study Results
- What to Analyze?
  - Definition of Building Variants and Index Configurations
- How to Analyze?
  - Selected Sites and Ground Motions
  - Structural Modeling
  - Damage and Consequence Modeling for Older Wood-frame
- Ongoing Efforts and Challenges

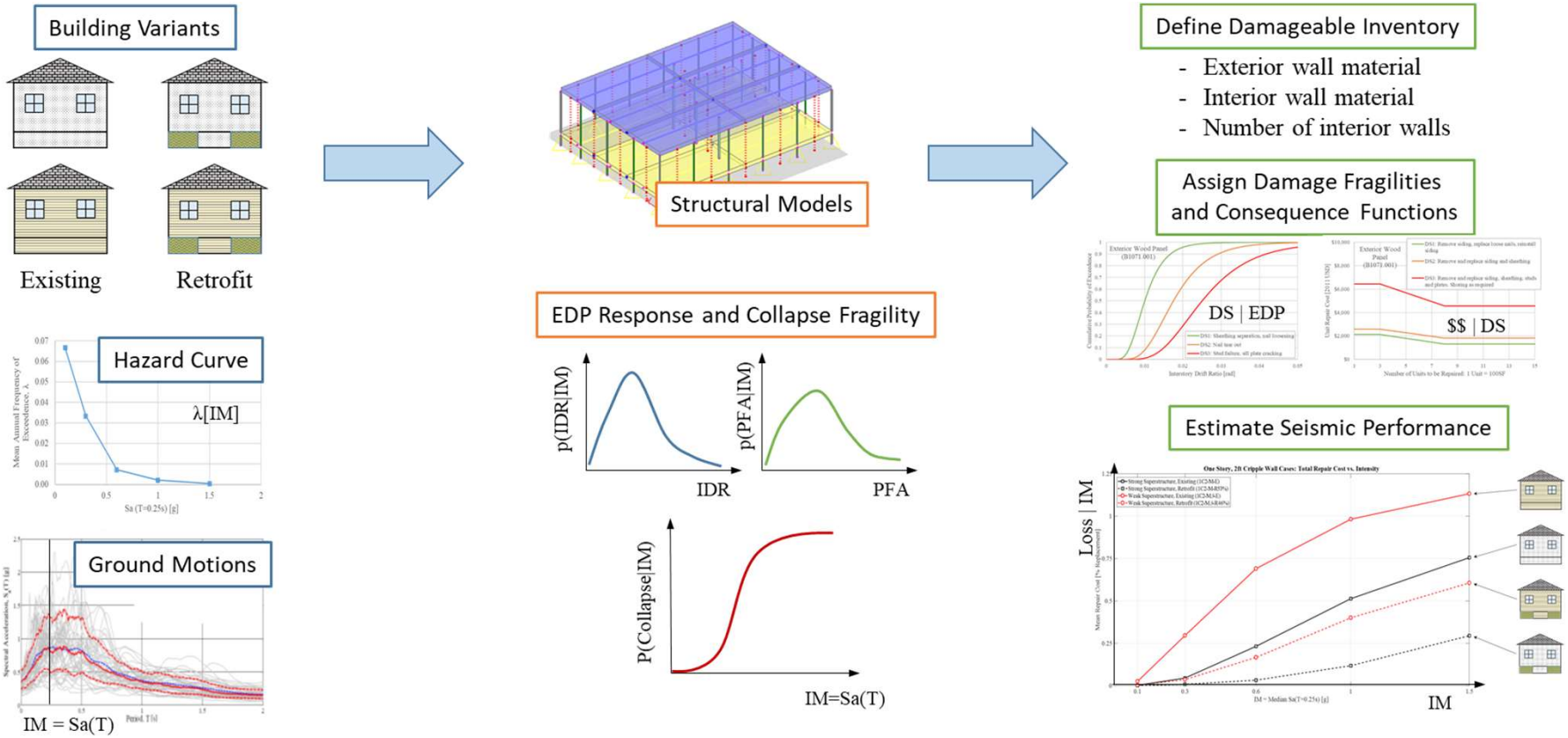
End Goals for Numerical Simulations

- Establish adjustment factors to relate the *change* in seismic loss due to retrofitting at different intensity levels

- Develop loss functions to quantify the effect of retrofit considering observable and unobservable variants used in the insurance industry

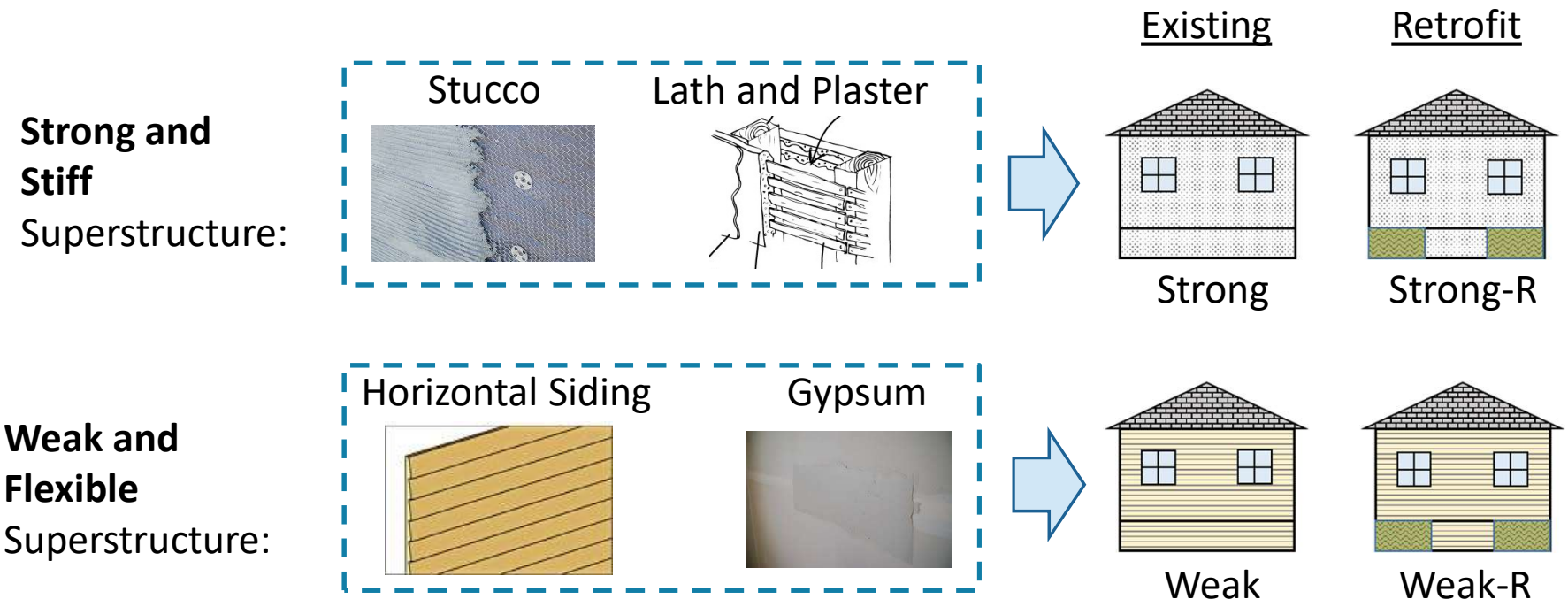


Overview of Building-Specific PBEE Framework (FEMA P-58)

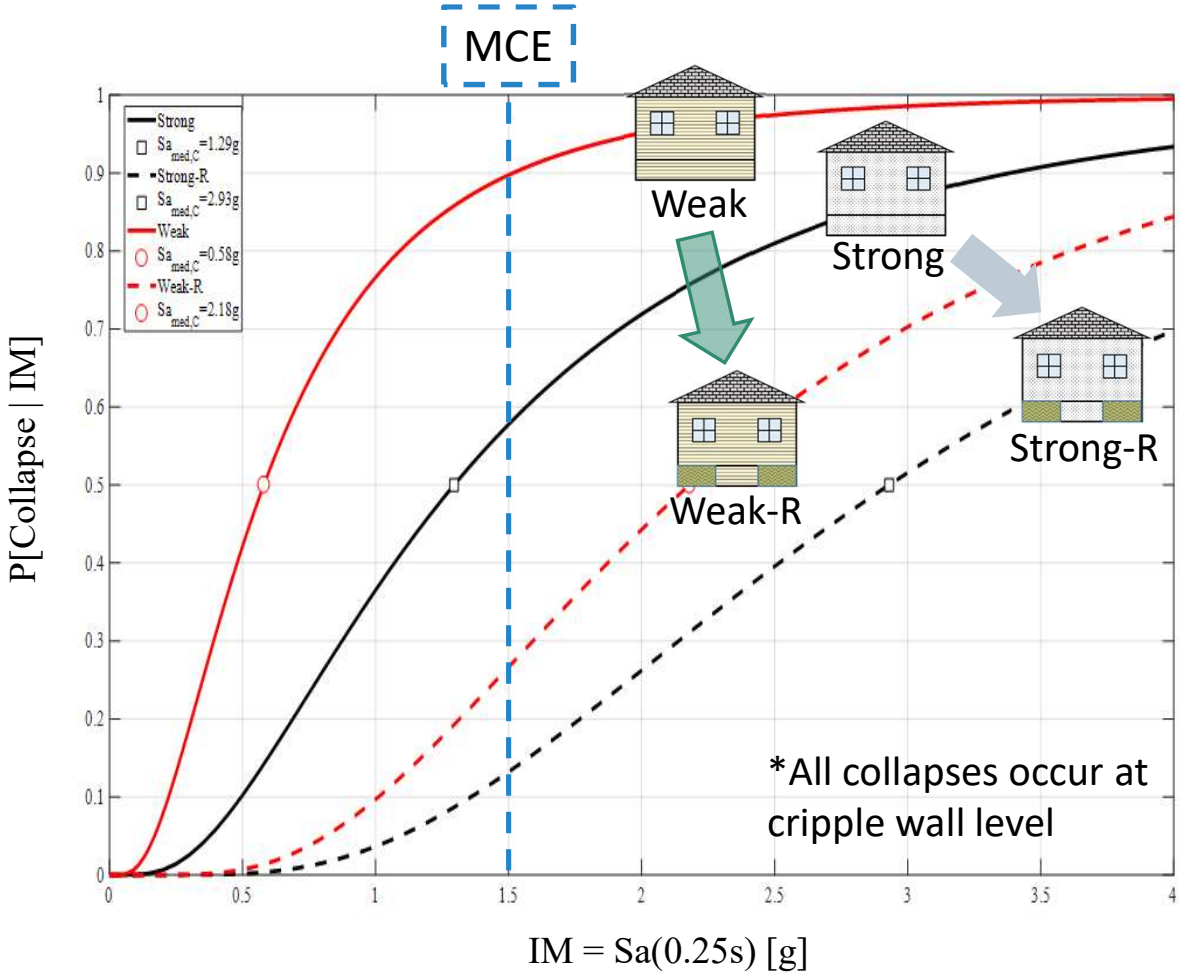


ATC-110 to PEER-CEA: *Trial* Study

- Existing FEMA P-58 fragility and cost functions (SP3) used for initial performance assessment
- ATC-110 analysis conducted using two bounding superstructure definitions
- Both variants are one story houses (1200ft^2) with 2ft cripple walls

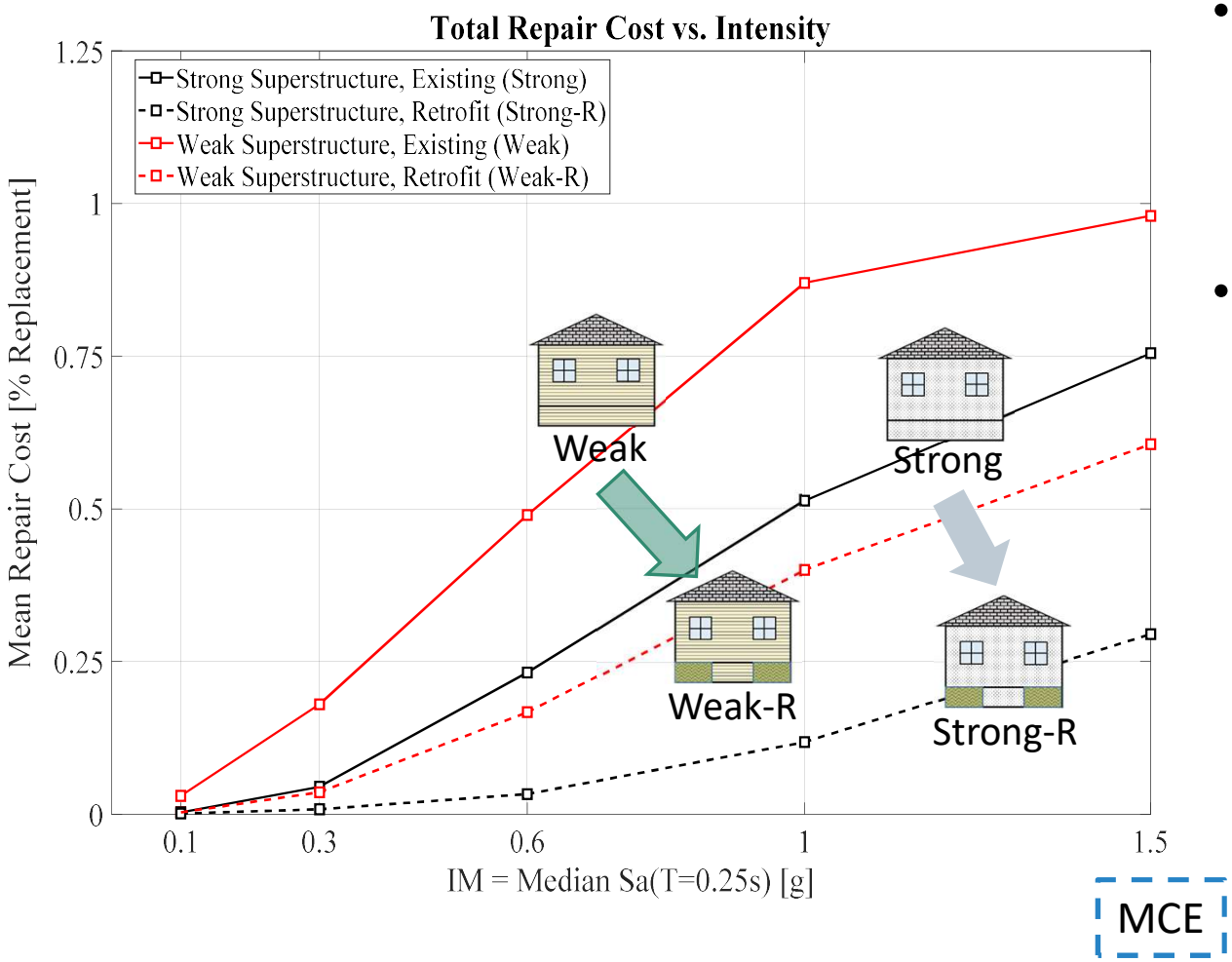


ATC-110 to PEER-CEA: *Trial* Study Collapse Fragility



- ATC-110 focused on reducing P[C|MCE] as a primary objective

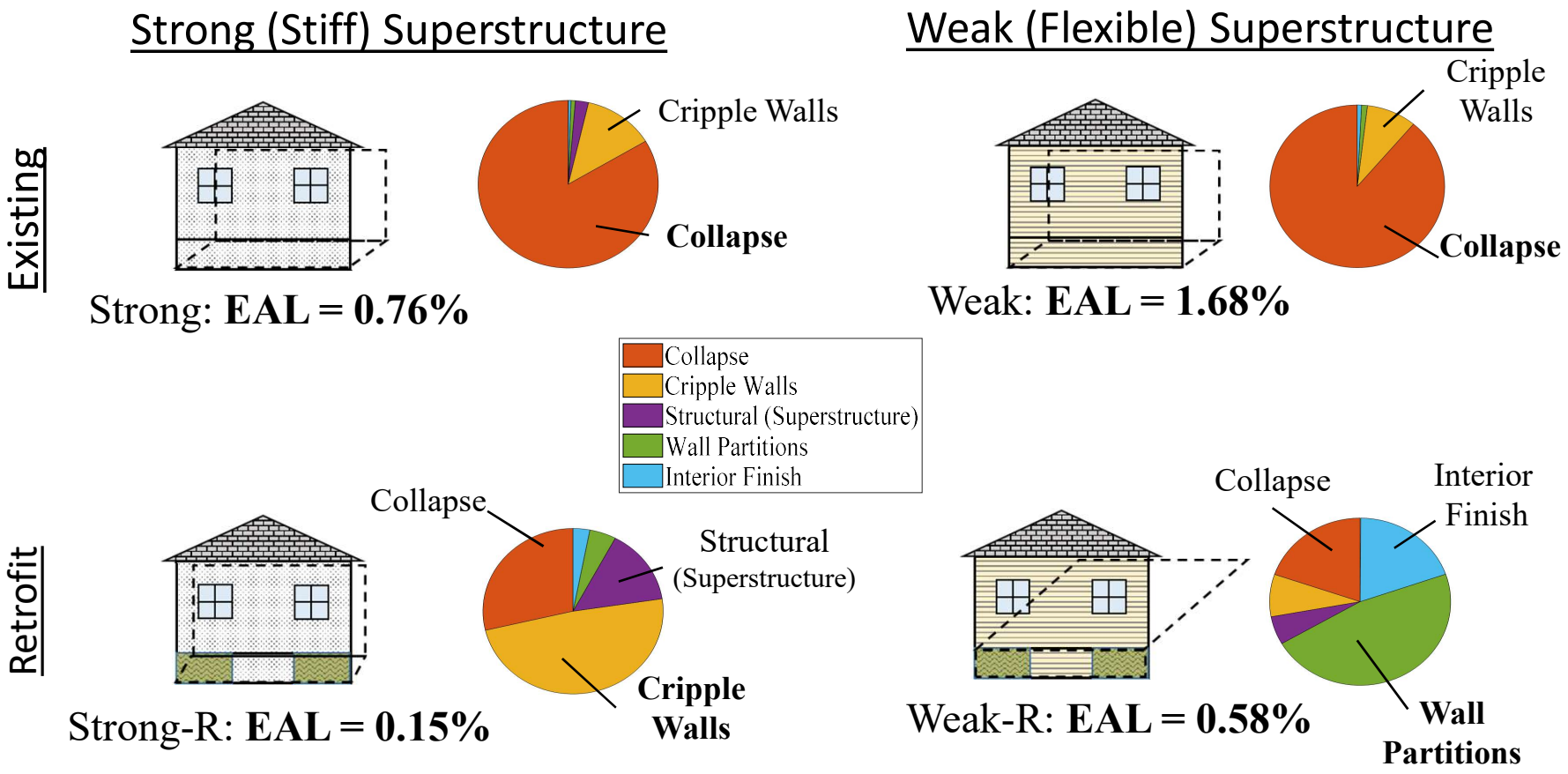
ATC-110 to PEER-CEA: *Trial* Study Loss Functions



- Loss versus Intensity curves are a primary output for the PEER-CEA project
- Modification factors to transition from existing to retrofit is primary objective

ATC-110 to PEER-CEA: *Trial* Study
Expected Annual Loss

- Expected annual loss (EAL) found by integrating loss curve with site hazard



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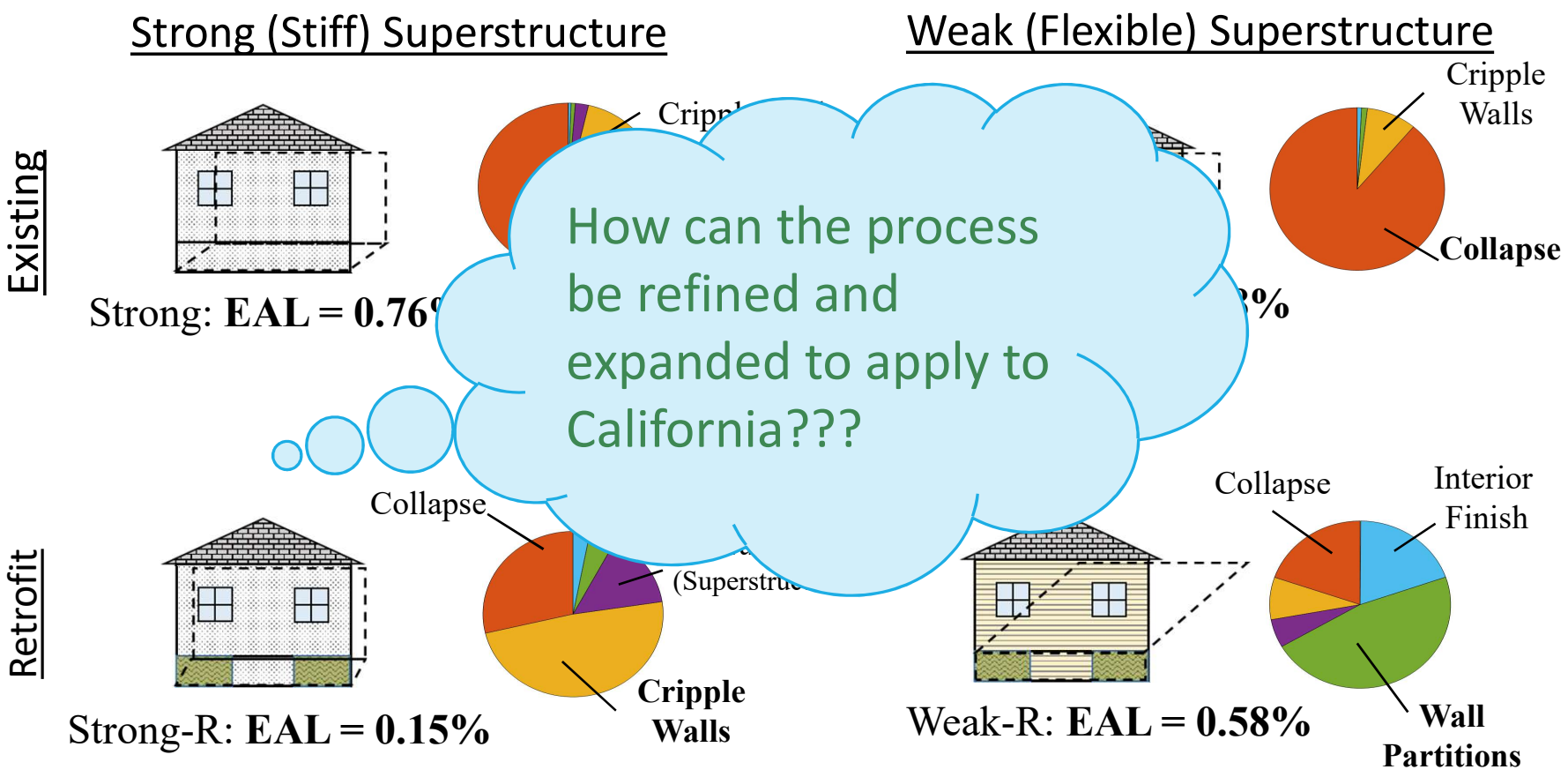


What to Analyze?
Definition of Building Variants

- **Primary Variants - Observable**
  - Age of Construction
  - Number of Stories
- **Secondary Variants - Observable**
  - Exterior material
  - Building (roof) weight
  - Sill bolting
  - Cripple wall height/ slope differential
- **Secondary Variants - Unobservable**
  - Siding/Sheathing Combinations
  - Construction Quality and Condition

Credit: Evan Reis, Working Group 2 - Index Buildings

What to Analyze?
Definition of Building Variants

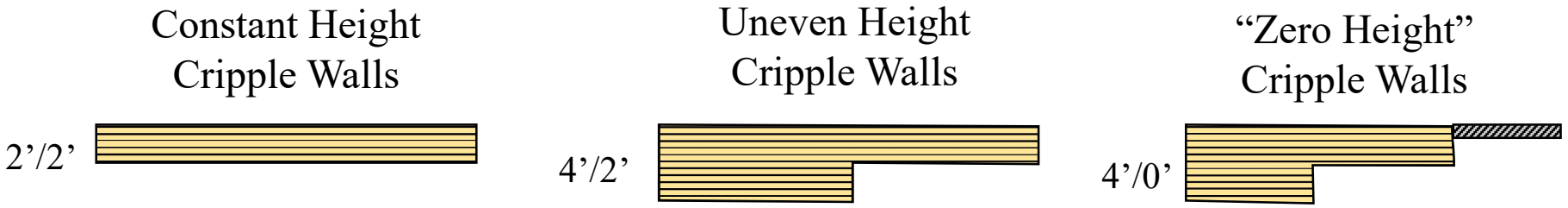
Construction Era (3): Pre-1940 1940-1955 1956-1970

Interior/
Sill Anchorage:

Exterior:

Current Scope:
Over 1000 proposed variants!

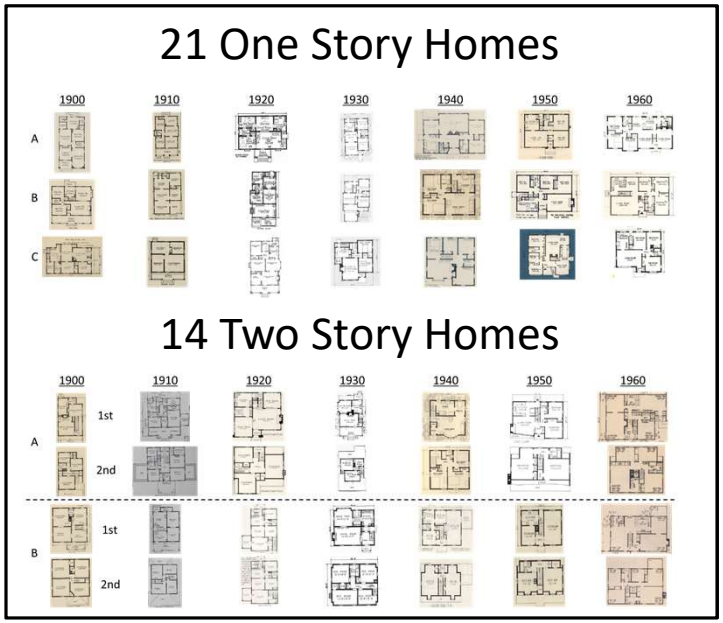
Cripple Wall Classification:

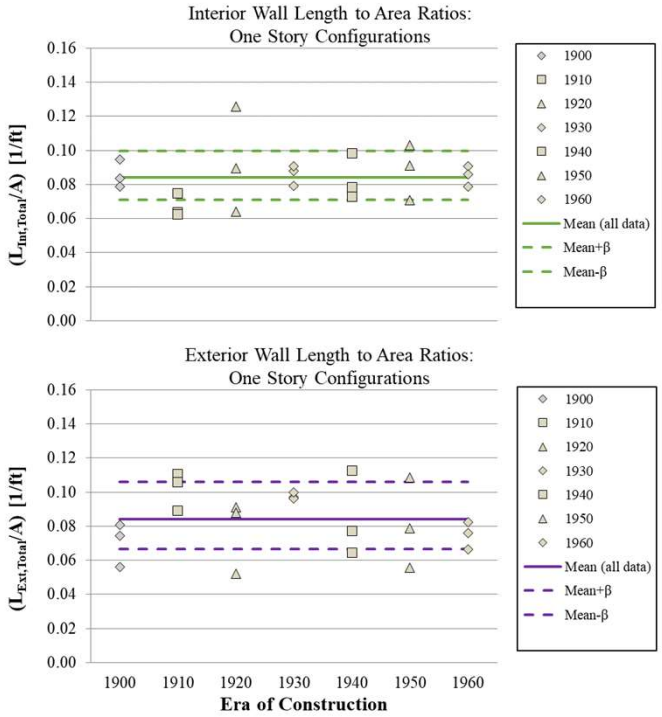


Credit: Evan Reis, Working Group 2 - Index Buildings

What to Analyze?
Baseline Superstructure Configurations

- Wall configuration affects the strength, stiffness, weight and damageable quantities within a home
- ATC-110 configuration collection was used to obtain statistics on interior and exterior wall density

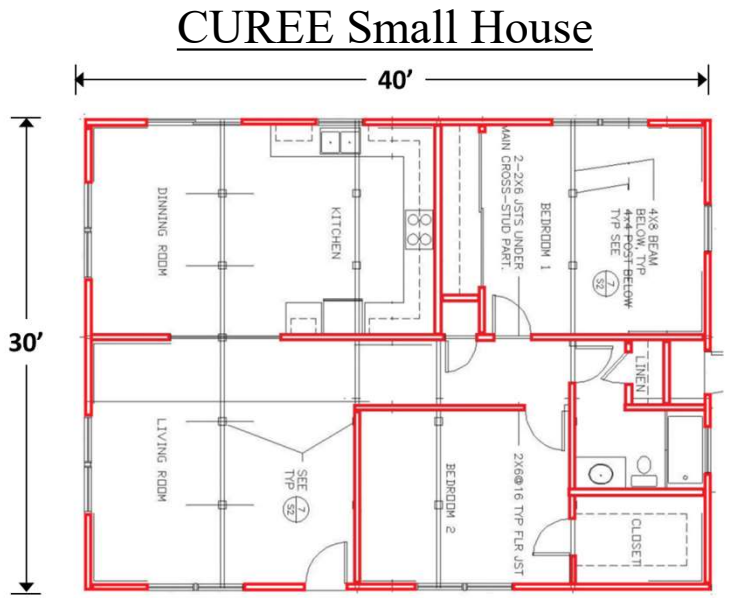




Collaborator: Colin Blaney, ATC-110, PEER-CEA Project Reviewer

What to Analyze?
Baseline Superstructure Configurations

- Wall configuration affects the strength, stiffness, weight and damageable quantities within a home
- ATC-110 configuration collection was used to obtain statistics on interior and exterior wall density
- One Story (1200ft^2) house used in CUREE Wood-Frame project [Isoda *et al.* 2002] was found to be an "average" configuration



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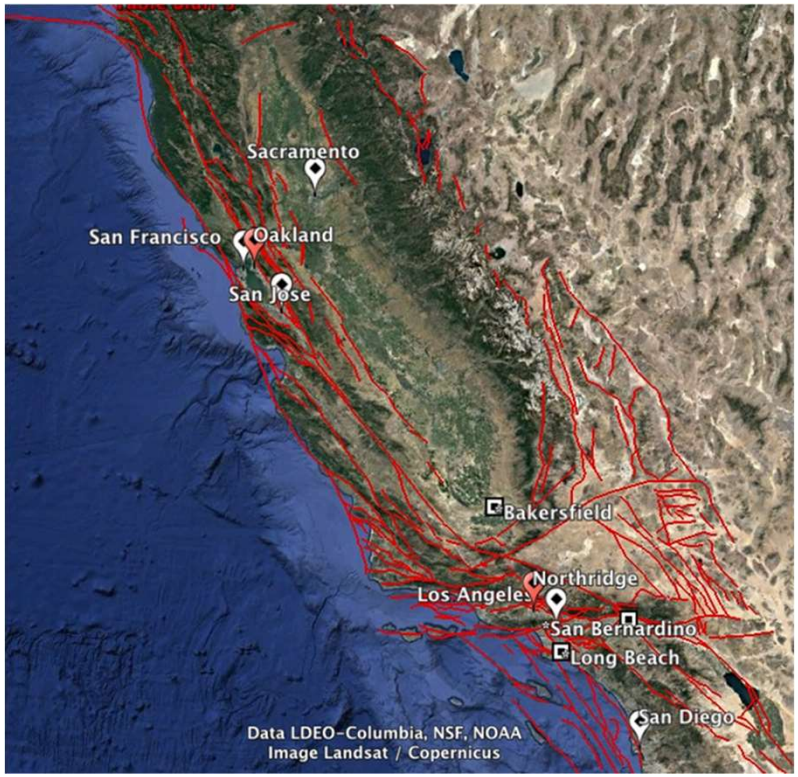
How to Analyze?
Selected Building Sites and Ground Motions

- 10 site locations
- 2 soil types ($V_{S,30}$ = 270 and 760 m/s)



Location	Index	$V_{s,30}$ [m/s]	ATC-110 Plan Set S_{DS} [g]
Oakland	OAK270	270	**1.50**
	OAK760	760	
Sacramento	SAC270	270	**1.00**
	SAC760	760	
San Francisco	SF270	270	**1.20**
	SF760	760	
San Jose	SJ270	270	**1.20**
	SJ760	760	
Bakersfield	BF270	270	**1.00**
	BF760	760	
Long Beach	LB270	270	**1.50**
	LB760	760	
Los Angeles	LA270	270	**1.50**
	LA760	760	
Northridge	NR270	270	**1.50**
	NR760	760	
San Bernardino	SB270	270	**1.50**
	SB760	760	
San Diego	SD270	270	**1.20**
	SD760	760	

Credit: Silvia Mazzoni and Yousef Bozorgnia, Working Group 3 - Ground Motions (Group leaders)

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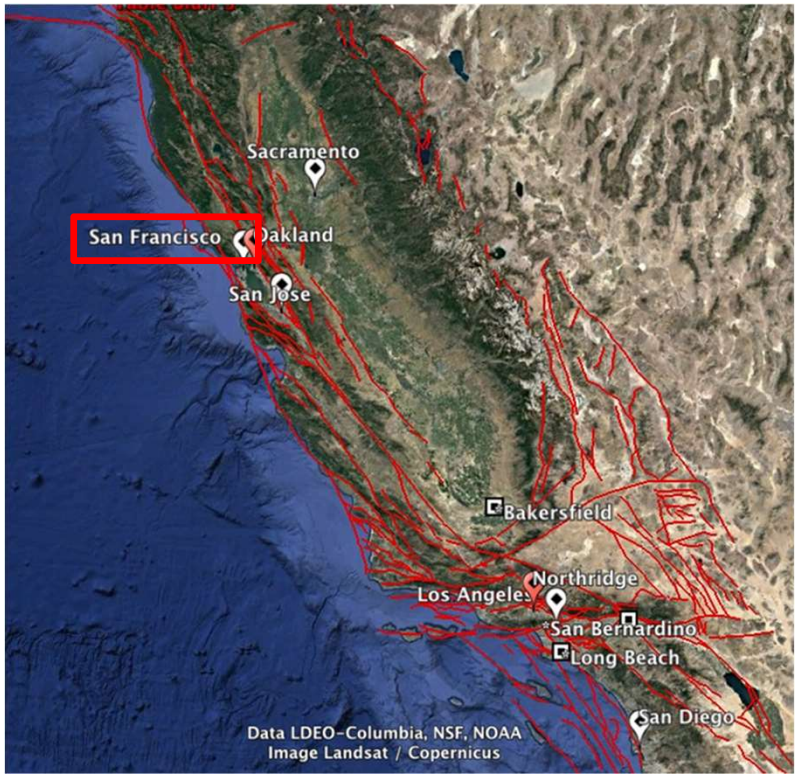
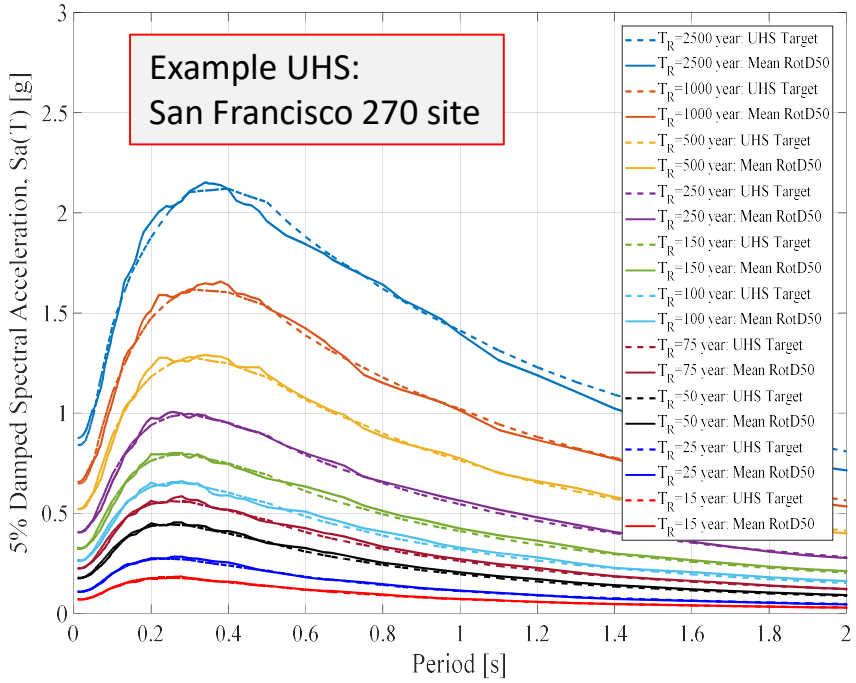


- 10 intensities per site (T_R=15y to 2500y)
- ~50 ground motion pairs per intensity selected to match target Uniform Hazard Spectrum (UHS)



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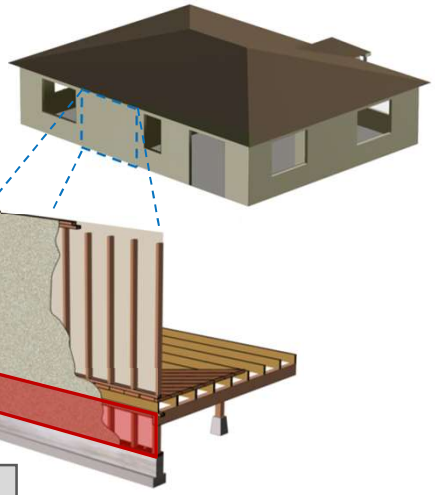
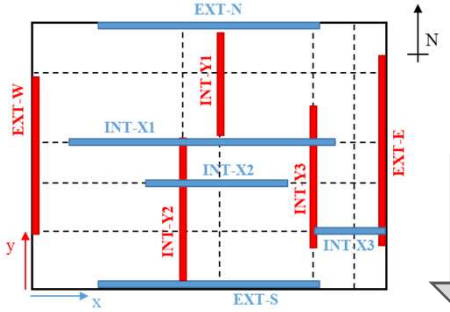
How to Analyze?
Structural Modeling (OpenSEES)

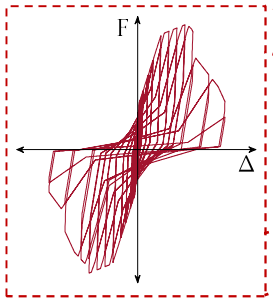
Target Structure

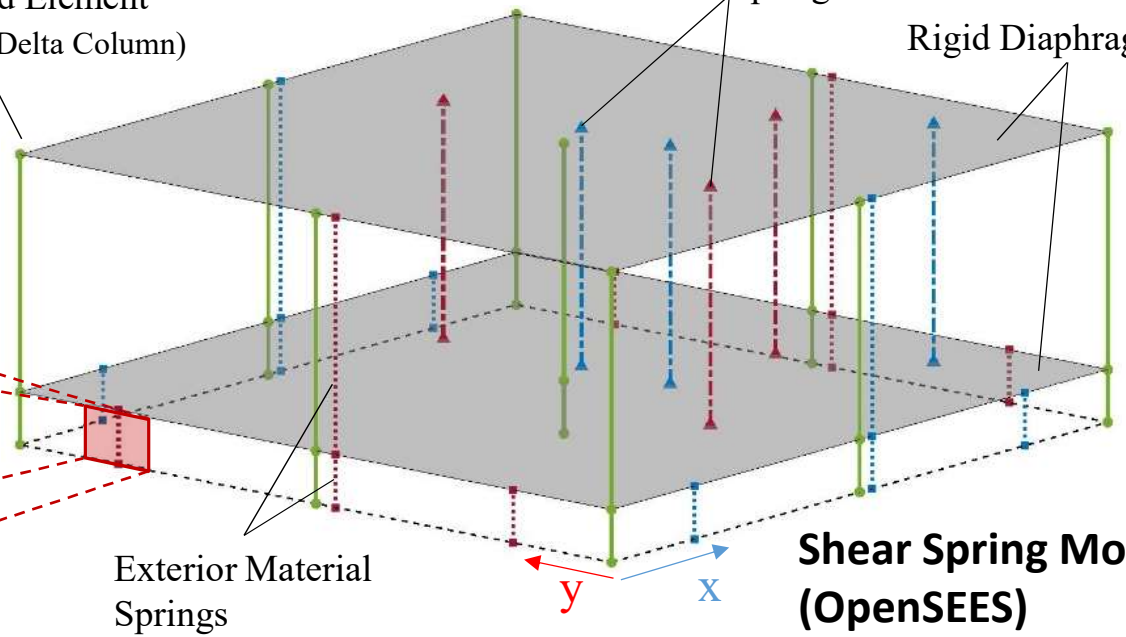


Idealized Floor Plan



Sub-Assembly Testing

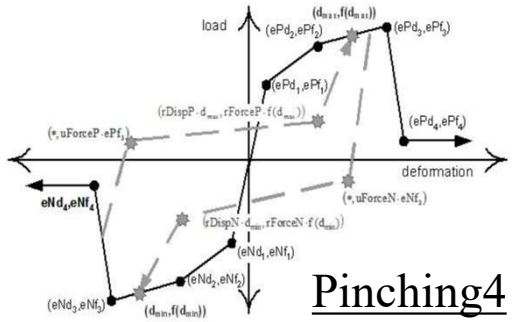




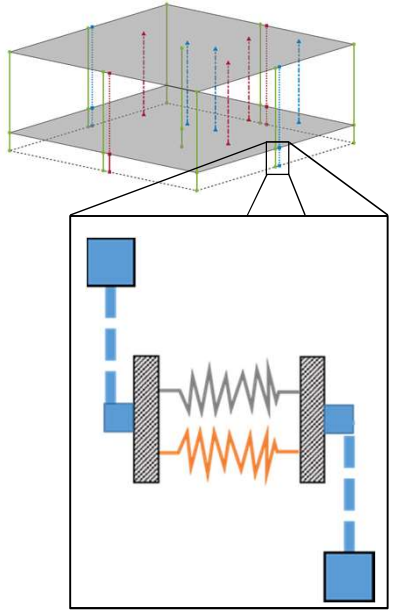
Shear Spring Model (OpenSEES)

How to Analyze?
Hysteretic Modeling of Wall Materials

- The **Pinching4 material model** (OpenSEES) is selected
- **Two spring** (parallel material) **properties** are used to accommodate the importance of cyclic response at both small and large displacements



Pinching4



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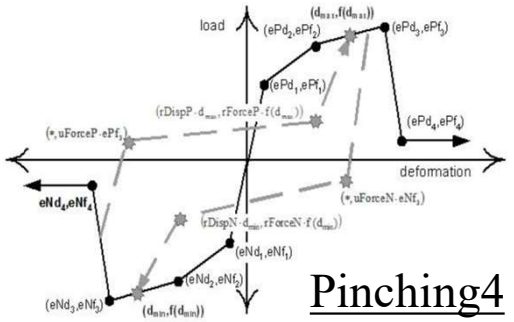
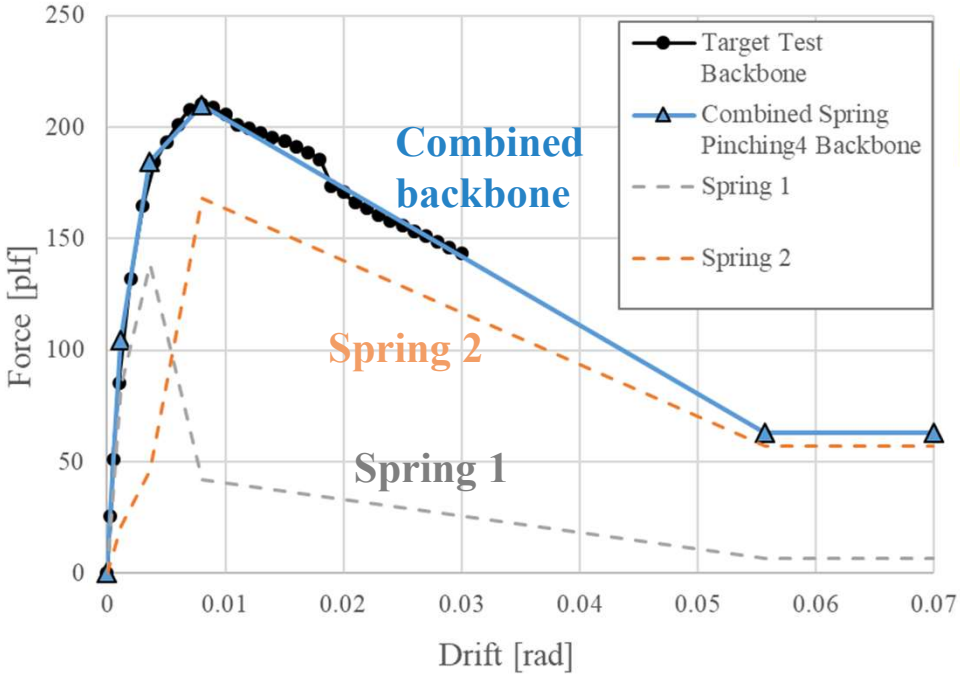
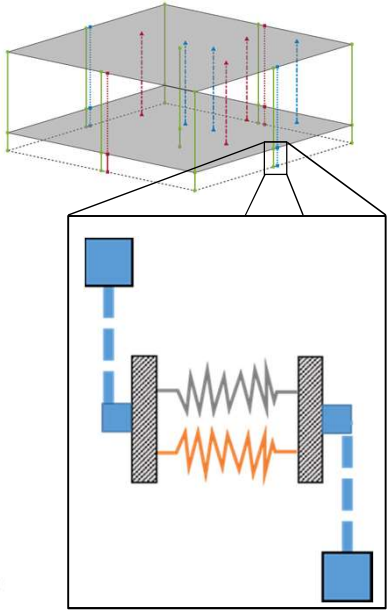


Pinching4

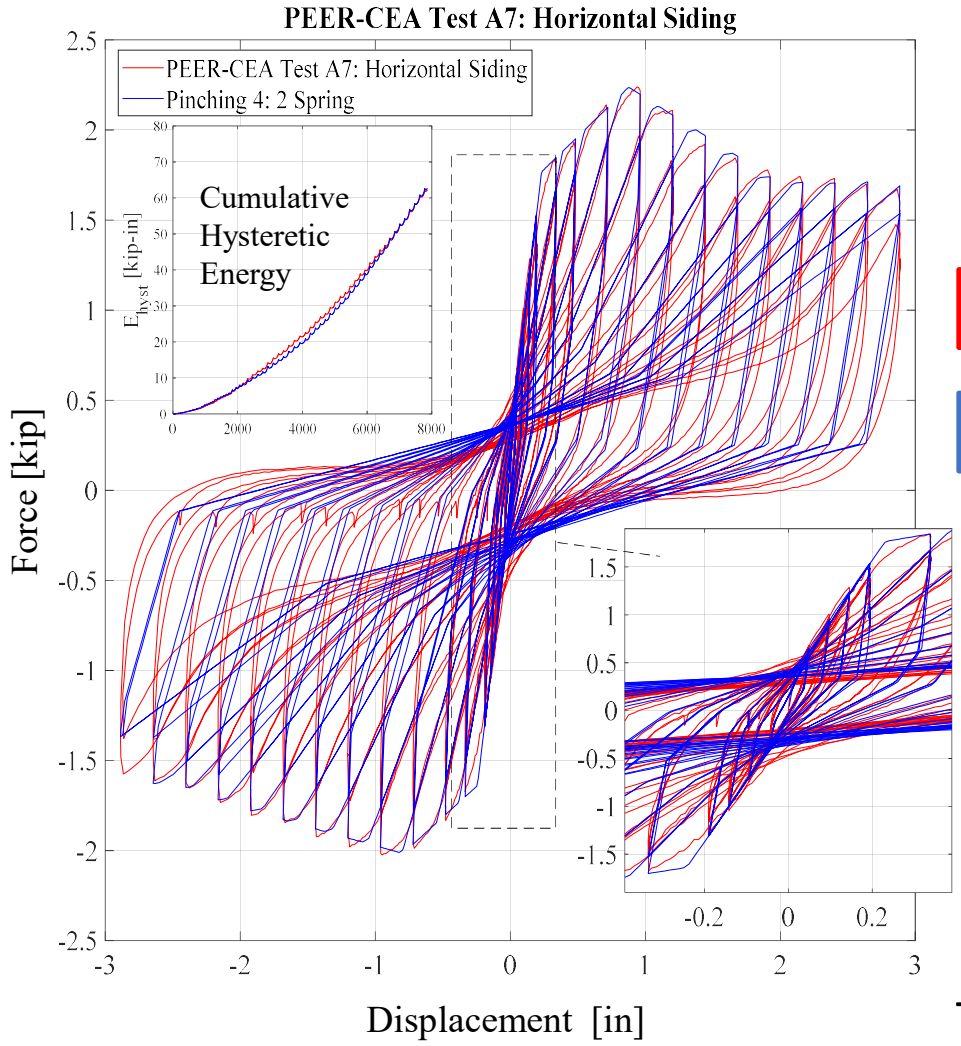




Spring 1 captures small amplitude cyclic behavior up to peak load

Spring 2 captures large amplitude behavior from peak load to residual strength portion

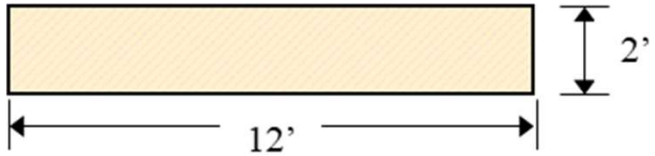
How to Analyze?
Hysteretic Modeling of Wall Materials



2ft X 12ft cripple wall with **horizontal wood siding** (PEER-CEA Test A7)

Experimental

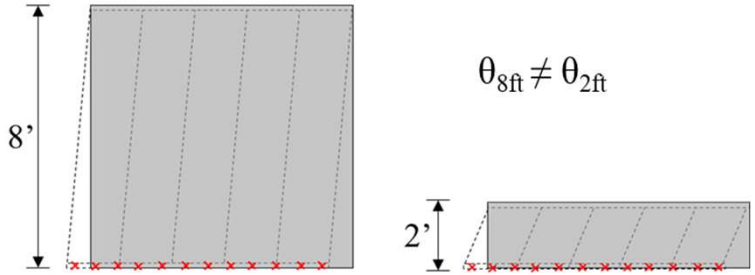
Analytical



Test Data: Schiller & Hutchinson, UCSD

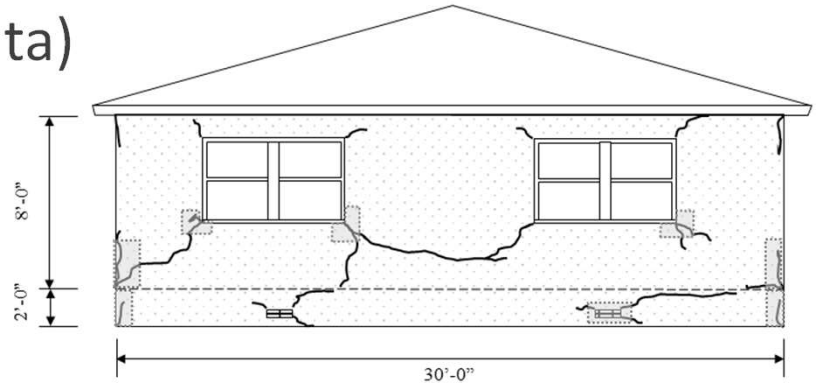
How to Analyze?
Damage Analysis of Older Wood-frame

- **Limited Applicability of FEMA P-58 Database**
  - Geared toward modern construction (e.g. Stucco+OSB, Gypsum)
- **Updating Existing Component Fragilities**
  - Define damage states for older superstructure materials based on available testing (lath and plaster)
  - Adjust damage thresholds (drifts) for walls of varying height and material (cripple walls)



How to Analyze?
Consequence Modeling of Older Wood-frame

- **Claims Adjustor Damage Workshop** (February 2019)
  - Obtain **repair cost estimates** from practicing claims adjustors with earthquake damage experience
  - **Slight Damage to Complete Replacement**
  - Damage states in line FEMA P-58 where applicable (Comparison of existing information)
  - Case studies **target materials with large knowledge gaps** in terms of repair costs (Expand Applicability)
  - Survey questions (Experience data)



Credit: Bret Lizundia, Workshop Organizer

Ongoing Work and Challenges

- **Combining Variants**
  - **Appropriate weighting** for variant combinations to reflect building stock?
  - **CEA sponsored Earthquake Brace and Bolt** (EBB) program **photo database** is currently under review (+5000 homes with cripple walls and anchorage deficiency) (Credit: Joseph Harijanto, Stanford)

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- **Modeling Uncertainty**
  - Influence of **material variation and modeling assumptions**
  - Currently developing surrogate modeling workflows to quantify uncertainty of select variants (Credit: Henry Burton and Zhengxiang Yi, UCLA)

Thank You!

Questions?