National Science Foundation

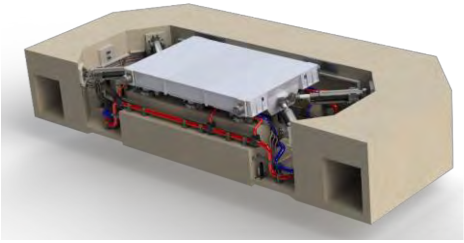
University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Consideration and Planning Strategies for Whole Building Testing at NHERI@UCSD

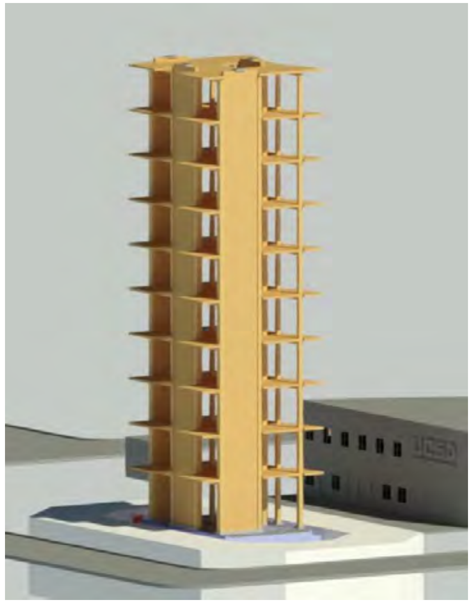
Challenges and Opportunities

John W. van de Lindt, Colorado State University



Joint Academia-Industry NHERI Workshop
NHERI@UC San Diego

September 21-22, 2020
University of California, San Diego

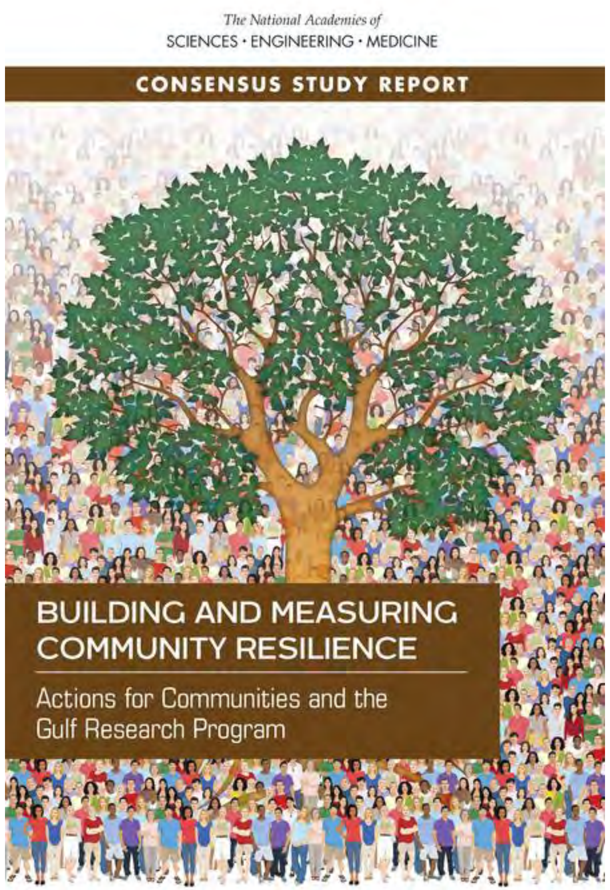


Today's Presentation

- Current status of building-level systems research
- Where should we be going and why? The Grand Challenges
- Academia-industry collaborations
  - NHERI@UCSD – 2013 & 2017
  - Opportunities and challenges
  - Four interrelated grand challenges for building research/practice

A new kind of research is needed …

"A new kind of research is needed that: (1) can address the dynamic state of communities and their changes in risk and resilience over time, and (2) can link information or data from disparate programs with each other and to community resilience priorities, to ultimately (3) link research, data, and information with decision making."

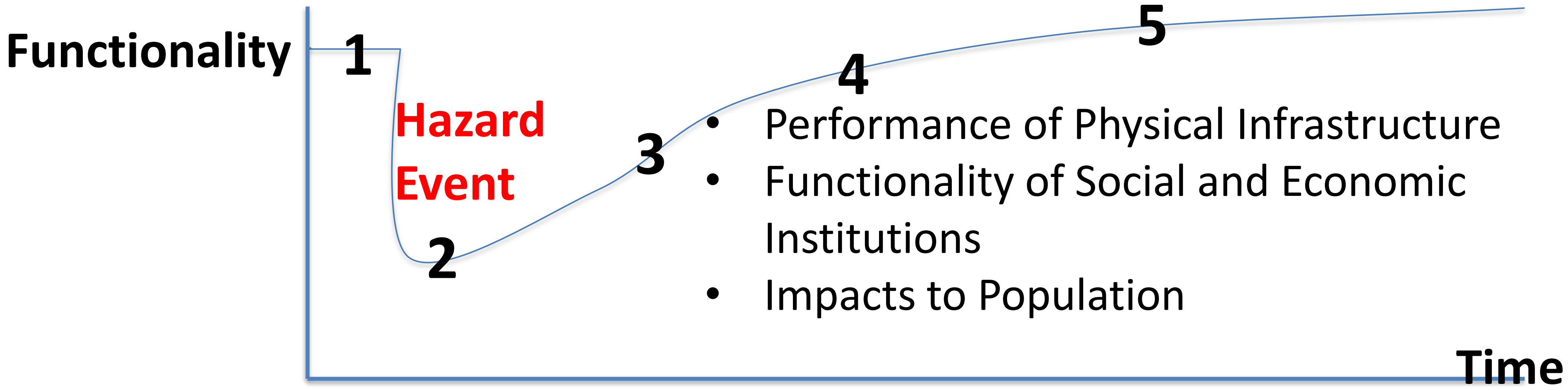


National Academies of Sciences, Engineering, and Medicine 2019. Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program. Washington, DC: The National Academies Press. https:doi.org/10.17226/25383.

Building research is needed …

A new kind of building research is needed that: (1) can address risk and resilience over time, and (2) can link information or data to functionality priorities, to ultimately (3) link building research, data, and information with new design philosophies, innovative technologies, and collective recovery goals.”

Stages of Resilience

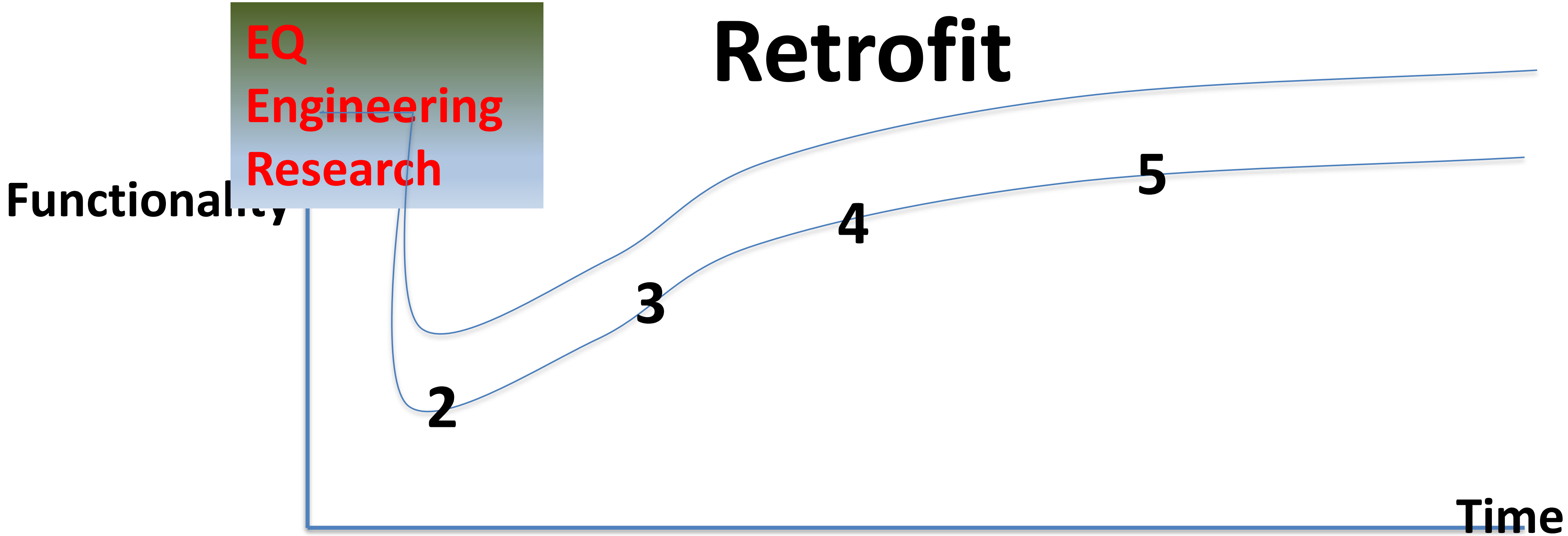


1. Current state
- Existing vs. Desired Performance
- Dependencies

2. Immediate damage
- Loss of Life/Injury
- Physical Damage
- Loss of Function
- Decision Support

3-5. Recovery Stages
- Social and Economic
- Repaired Damage
- Recovered Functions
- Decision Support

Retrofit



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Structural design: where are we currently ?

- Structures are generally designed at the sub-assembly level
- Resulting performance under extreme loading is only implicitly provided.
- Rare events dictate changes in philosophy or corrections in codified design
- Modeling at the system of systems level is becoming more and more accurate

1989 Loma Prieta earthquake
(Bridges, soft-story multi-family buildings)

1992 Hurricane Andrew (Building codes)

1994 Northridge earthquake
(Woodframe, Steel frame)

2005 Hurricane Katrina (Public works, public policy, flood/surge loads)

2011 Great Tohoku tsunami
(Nuclear power plants, evacuation for nearfield tsunamis, ASCE 7 tsunami chapter)

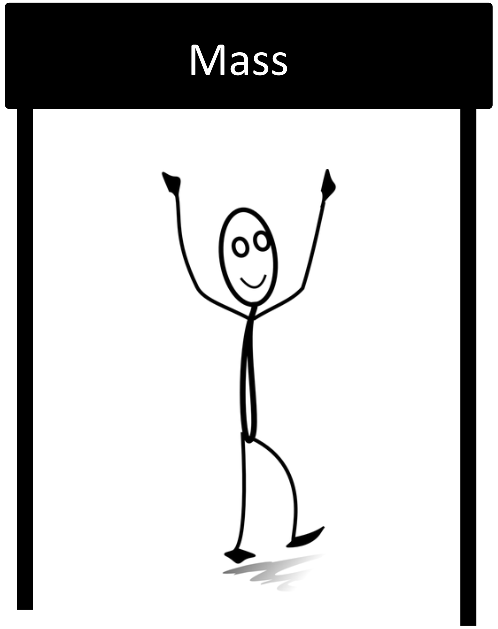
2011 New Zealand earthquake (Resilience, advanced technologies)

2011 Tornado season (ASCE 7 wind loads)

2017 Hurricane Maria (Puerto Rico)

Do we need to test whole buildings ?

- How accurate are our nonlinear numerical models ?
- Trust a SDOF?
- Trust 1000 DOF's ?
- Components and sub-assemblies posses different boundary conditions
  - Difficult to enforce in space and time
- System testing can provide information on how to add components and subassemblies into models
- Effect of retrofits
- Collapse simulation



Earthquakes
Unfortunately, the sum of the part does not always equal the whole! → Experiment

System of Systems

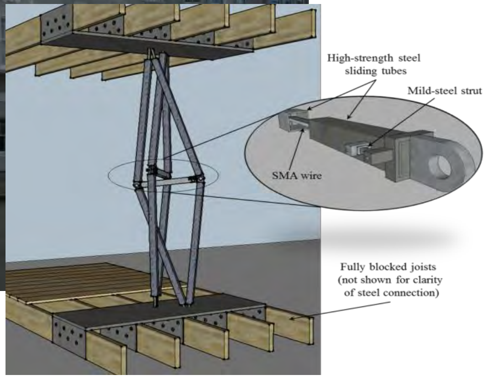
- Recent disasters have revealed shortcomings in building practices that focus on performance of individual facilities.

- Financial limits on public investments in infrastructure renewal

- Presidential Policy Directive 21 (PPD-21): Critical infrastructure security and resilience

Existing Systems

- Performance of buildings
- Resilience of cities



- ASCE 41
- Optimization

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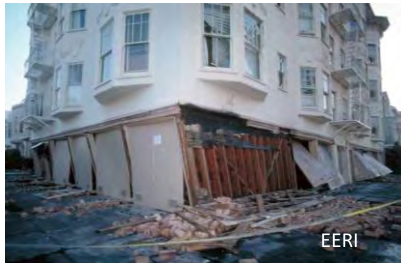
2013: Motivation for NEES-Soft

"Seismic Risk Reduction for Soft-Story Woodframe Buildings"

- Many buildings built prior to the 1970s are prone to collapse during major earthquake event due to insufficient lateral resistance of their first story.
- Community Action Plan for Seismic Safety (CAPSS)
- FEMA P807
- NEES-Soft: Seismic Risk Reduction for Soft-Story Woodframe Buildings
  - **Five-university-industry NSF-funded collaboration**
  - Develop better understanding of soft-story woodframe behavior through numerical analyses and experimental testing
  - Experimental validation of FEMA P807
  - Performance-based retrofit methodology and techniques
  - Develop better models of woodframe collapse mechanisms

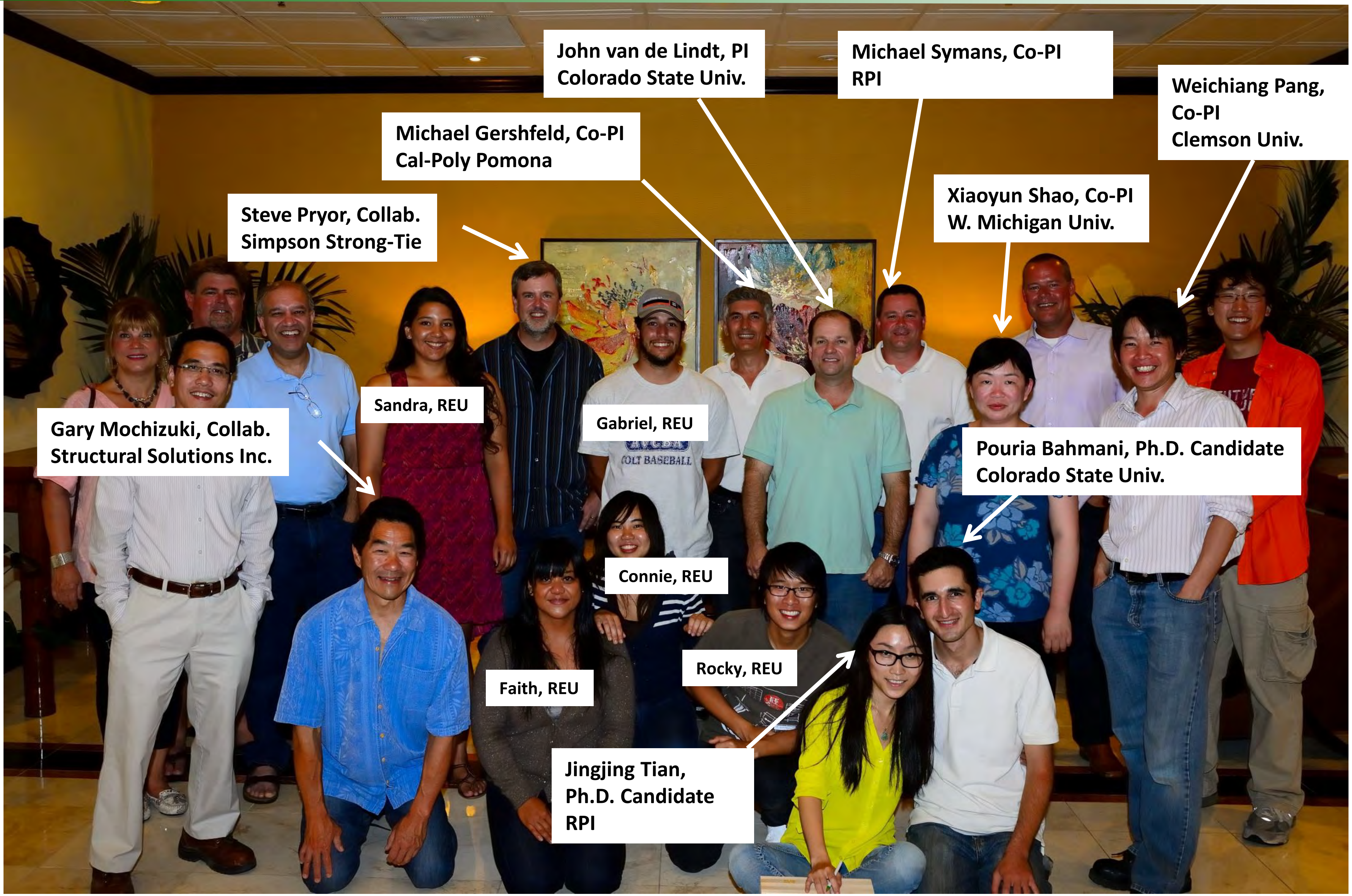


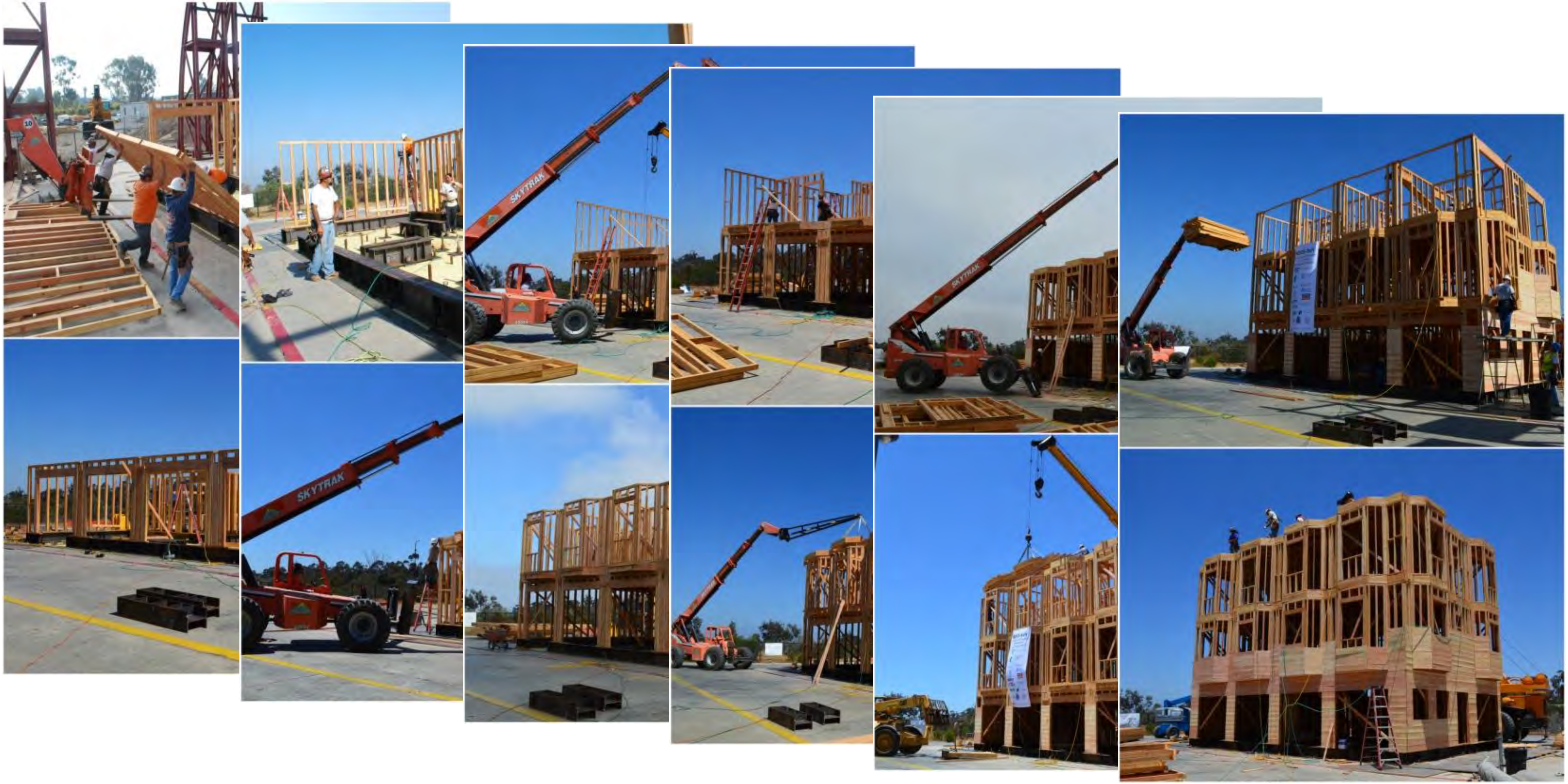
Bahmani, P., J.W. van de Lindt, S.E. Pryor, G. Mochizuki. (2020). "Performance-Based Seismic retrofit Procedure with Shake table Validation.", *Engineering Structures*, 205 (2020) 110012.

Jennings (Sutley), E.N., J.W. van de Lindt, E. Ziaei, P. Bahmani, S. Park, X. Shao, W. Pang, D. Rammer, G. Mochizuki, M. Gershfeld. (2015). "Full-Scale Experimental Verification of the Soft-Story-Only Woodframe Building Retrofits using Hybrid Testing.", *Journal of Earthquake Engineering*, 19 (3).

The lifecycle of the test building

The NEES-Soft UCSD Team




SKYTRAK

Existing Buildings

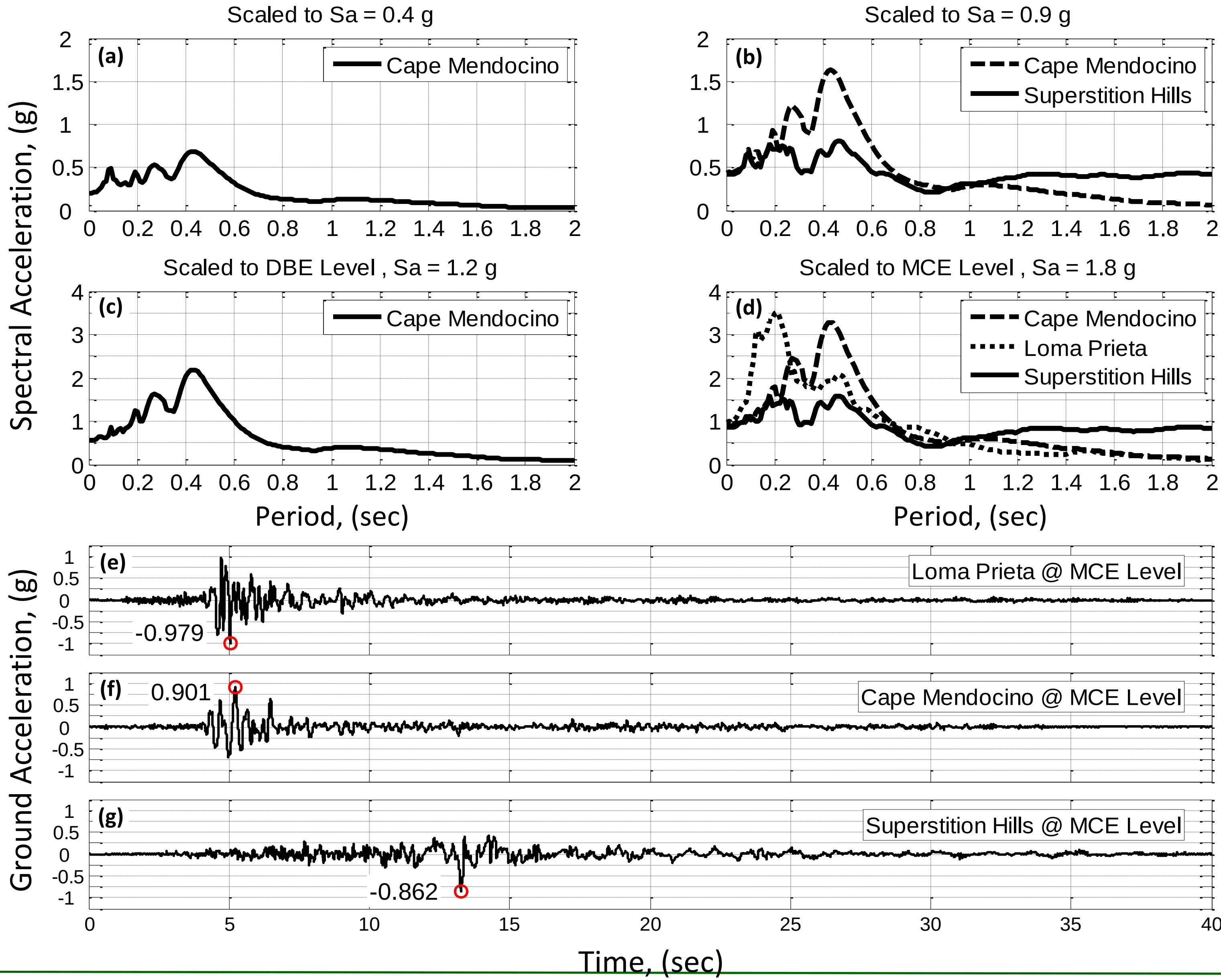
NEES-Soft Test Building

Phase V: Collapse Testing

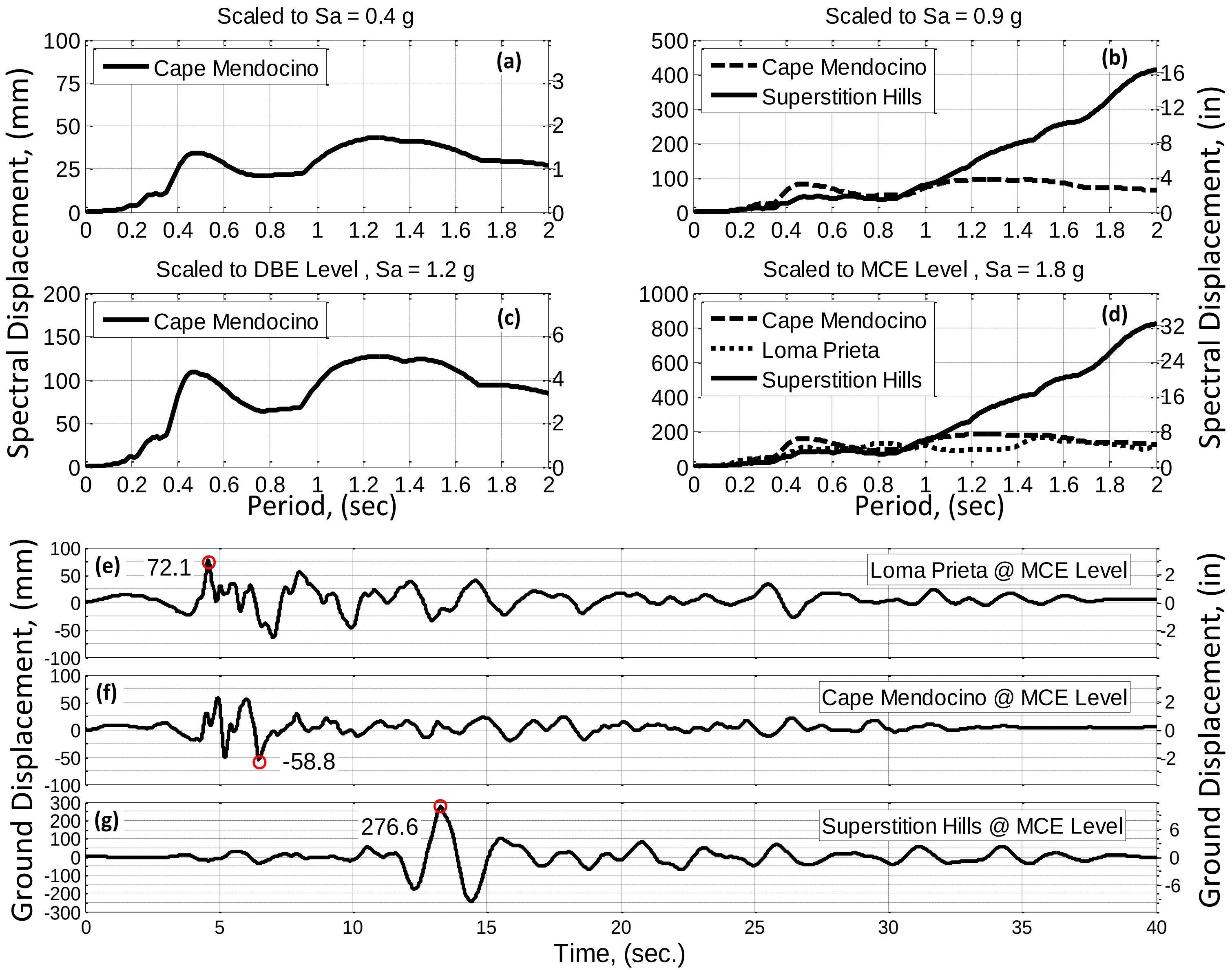
97% of instrumentation and cables removed

Bahmani, P., J.W. van de Lindt, G. Mochizuki, M. Gershfeld, and S.E. Pryor. (2014). "Experimental Seismic Collapse Study of a Full-Scale Four-Story Soft-Story Woodframe Building.", *ASCE Journal of Architectural Engineering*, 10.1061/(ASCE)AE.1943-5568.0000166 , B4014009.

The Collapse Motion, Sa



The Collapse Motion, Sd




2013/08/17 AM11:09:20
CAM4 C1GRGSE


NEES @ UCSD

Phase I: Cross Laminated Timber Rocking Walls

Applying the FEMA P807 Methodology

Phase III: Steel SMF + WSP

Bahmani, P., J.W. van de Lindt, M. Gershfeld, G. Mochizuki, S.E. Pryor, M., D. Rammer. (2013). "Experimental Seismic Behavior of a Full-Scale Four-Story Soft-Story Woodframe Building I: Building Design and Retrofit Methodology.", ASCE *Journal of Structural Engineering*, 10.1061/(ASCE)ST.1943-541X.0001207, E4014003.

van de Lindt, J.W., P. Bahmani, G. Mochizuki, S.E. Pryor, M. Gershfeld, Jingjing Tian, D. Rammer, and M.D. Symans. (2013). "Experimental Seismic Behavior of a Full-Scale Four-Story Soft-Story Woodframe Building II: Shake Table Test Results.", ASCE *Journal of Structural Engineering*, 10.1061/(ASCE)ST.1943-541X.0001206 , E4014004.

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Performance-Based Seismic Design/Retrofit

Priestley, 1998
DDD

→

Filiatrault & Folz, 2002
Modified DDD

→

Pang et al., 2009
Simplified DDD

→

Pang et al, 2010
Applied DDD to a Six Story woodframe building, 2010
(Part of NEES-Wood Project in Miki, Japan, **van de Lindt et al.**)

↓

To this point, the DDD procedure only can be employed for structures which have negligible in-plane torsional moments (i.e., No In-plane Eccentricities) .

↓

Bahmani et al. (2013)
DBDT

Bahmani, P., van de Lindt, J., and Dao, T. (2014). "Displacement-Based Design of Buildings with Torsion: Theory and Verification.", *J. Struct. Eng.*, 140(6), 04014020.

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Shake Table
Access
Beyond this
Point
Authorized
Personnel
ONLY!

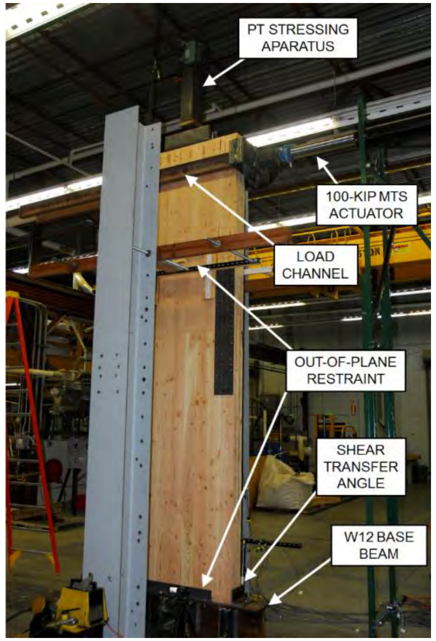
Colorado State University


SIMPSON
Strong-Tie
Strong Frame
MOMENT FRAME
Frame
MOMENT FRAME
BM 2
BM 1

NHERI TallWood

Objective: Develop and validate Resilience-based seismic design for tall CLT buildings

Planning Project 2013~2015 (NSF)



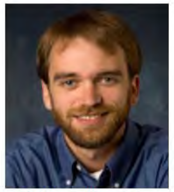
- ☑ Consensus on tall wood building
- ☑ Rocking wall component tested

FPL Mass-Timber Research Workshop 2015

NHERI TallWood Project Funded 2016 (NSF)

Principle Investigators


Shiling Pei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Marjan Popovski


Douglas Rammer


Eric McDonnell

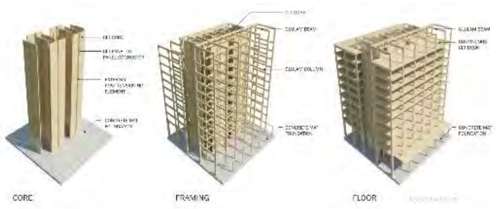

Andre Barbosa

FPInnovations | Forest Service U.S. Department of Agriculture | Holmes | Oregon State University

GAME PLAN

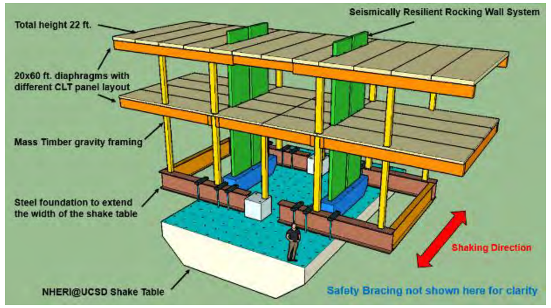
Project duration: 2016~2021

Nheritallwood.mines.edu

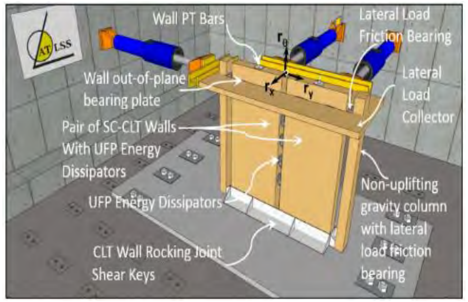


Define Tall Wood Archetypes

Investigative testing at system level



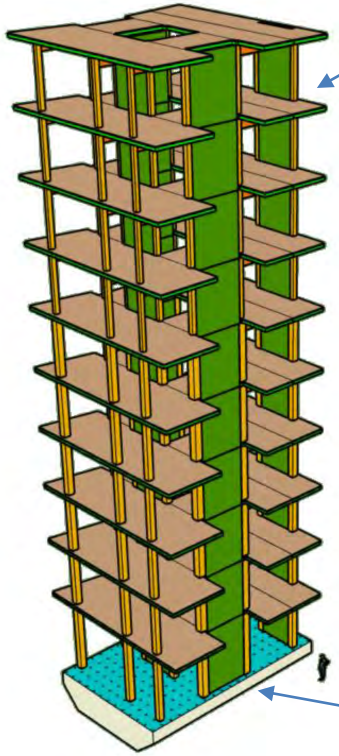
Two-story test at NHERI@UCSD 2017 Summer

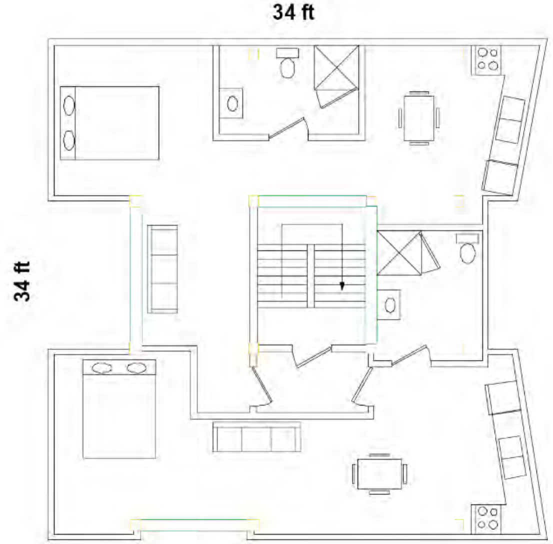


Assembly test at NHERI@Lehigh 2019

Full-scale 10-story validation Test (2021)

Mixed-Use building w/ CLT rocking wall lateral system



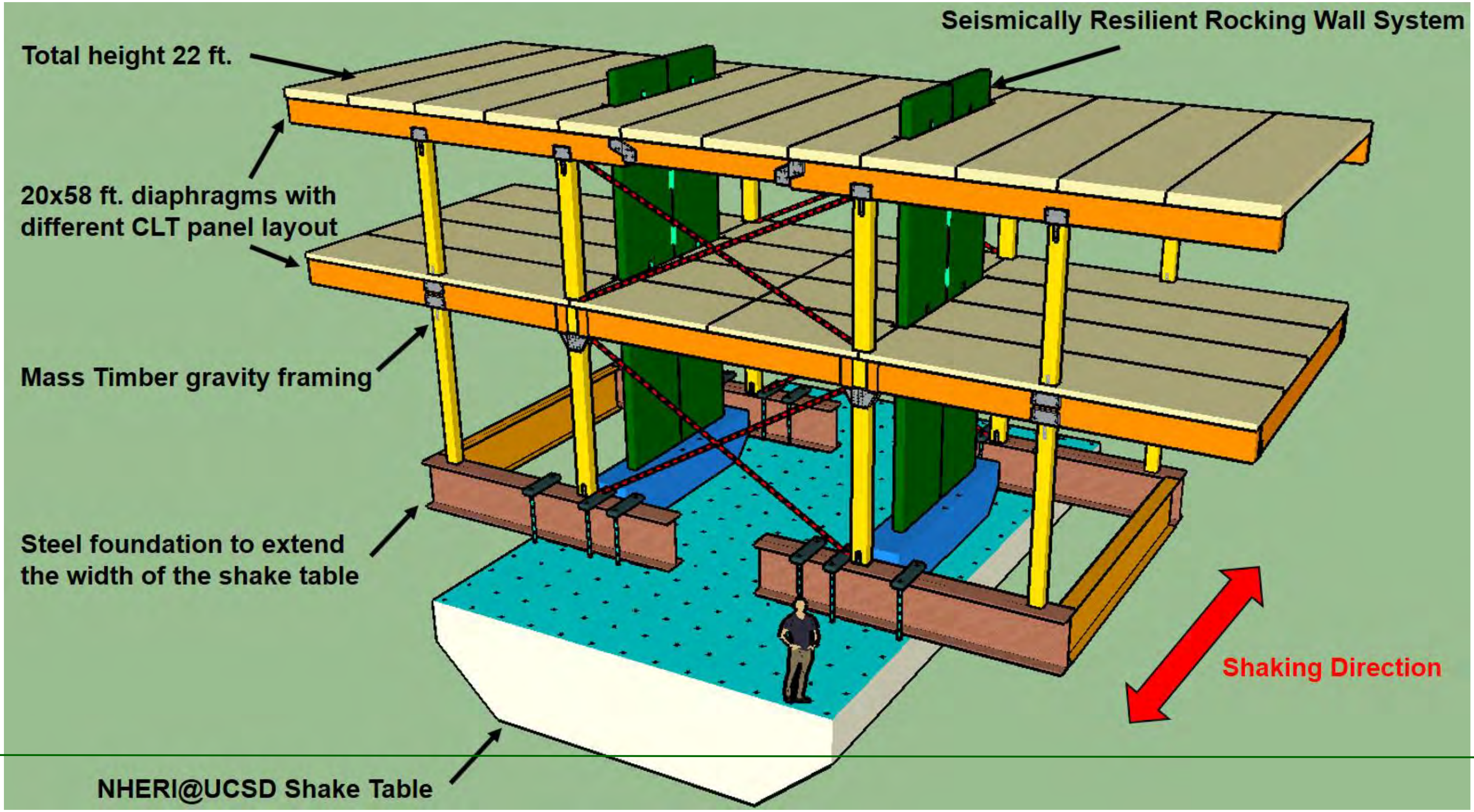


UCSD Shake Table

Seismic R & D

(2018~2021)

A Test to Validate Structural System Resilience



Public Test Northridge x 2 (Test 6)

Pei, S. J.W. van de Lindt, A. Barbosa, J. Berman, E. McDonnell, J.D. Dolan, H-E. Blomgren, R. Zimmerman, D. Huang, and S. Wichman. (2019). "Experimental seismic response of a resilient two-story mass timber building with post-tensioned rocking walls.", *ASCE Journal of Structural Engineering*, 145 (11) https://doi.org/10.1061/(ASCE)ST.1943-541X.0002382

The MCE+ Shake (Test 14) 5% drift

Close up on Rocking

Second story wall & column

Damage?

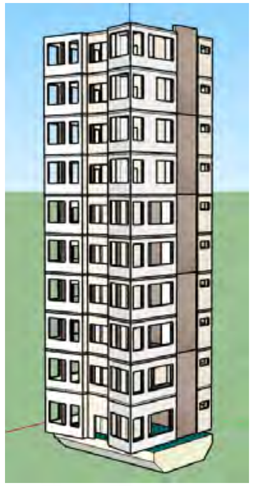
Only Cosmetic Damage after 14 earthquakes

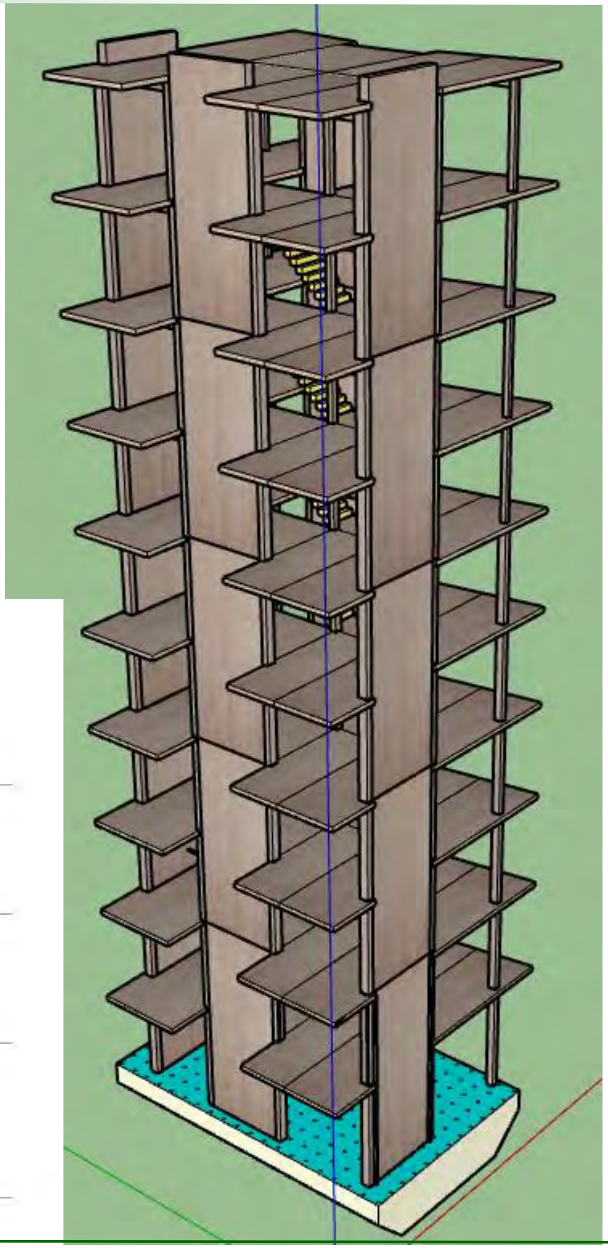
Slight compression deformation at the rocking wall corner

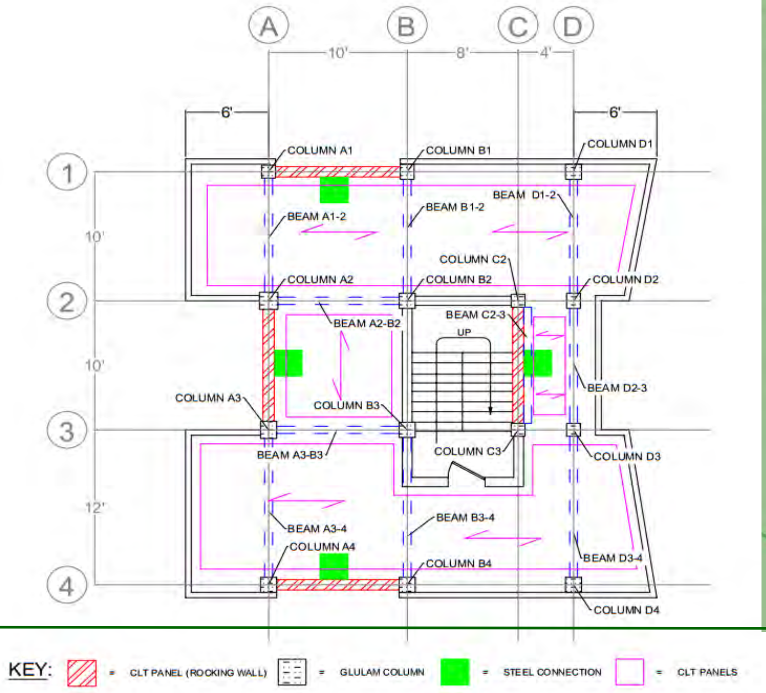
Chipping of wood at the rocking wall corner

Next Step: A 10-story wood building test

- First building ever designed to minimizing down-time.
- Full-scale 112 ft tall mass timber building
- Three different applications (Commercial, Office, Residential)
- 3D seismic testing (UCSD shake table is being upgraded to 3D!)
- Non-structural elements and finishing materials
- Showcase various Mass Timber & Engineered Wood Products







Opportunities and Challenges

- Early experiences in 2009 - Japan during NEESWood (2005-2009)
  - Industry always at the table – start early
  - Project teams for NSF proposals
  - Give them lead time to handle their IP/prelim patent issues
  - Treat it like a cooperative agreement

- Experiences at UCSD in 2013 during NEES-Soft (2010-2014)
  - Whole building testing is expensive – partner
  - Budget is often gone by the last year of an NSF
  - Breakdown
    - 20% NSF from the original proposal and maybe even a supplement
    - 30% NHERI@UCSD included as shake table use time
    - 50% to find
    - So, for a $2M test you need to find ….

Opportunities and Challenges

- Experiences at UCSD in 2017 during Tallwood (2016-2021) (PI: S. Pei, CSM)
  - Test of opportunity
  - Simpson Strong-Tie
  - Katerra
  - City of Springfield, OR
  - Tallwood Design Institute (TDI)
  - Others

Four Interrelated Grand Challenges as I see them…

- **Enabling collectivism in building design**
  - Just as a building is designed with components; a building should be designed with a community/city's resilience in mind
- **New codes and standards that are equitable and effective for recovery following extreme events**
- **Developing advanced technologies that are affordable for widespread use**
- **Enabling incorporation and incentivization of technologies and concepts in U.S. standards**

NEES-Soft Acknowledgements

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Thank you!

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