NHERI TallWood Project

Developing and Validating Seismically Resilient Tall Wood Buildings

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Colorado School of Mines

SEAOSD Meeting
San Diego, CA

RESILIENCE

- Ability to quickly recover from disruption and resume function
- Minimize loss of use and recovery cost

We can do Better than THIS

EQ-Proof Wood Buildings

Evolution of CLT System (for earthquakes)

CLT Invented 1990's

Platform CLT System

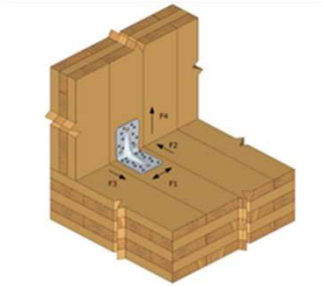
Research in Slovenia and Macedonia

Trento Province, Italy SOFIE project 2009

Canadian Research FPI

P695 Project at FPL/CSU

Japan Platform CLT tests

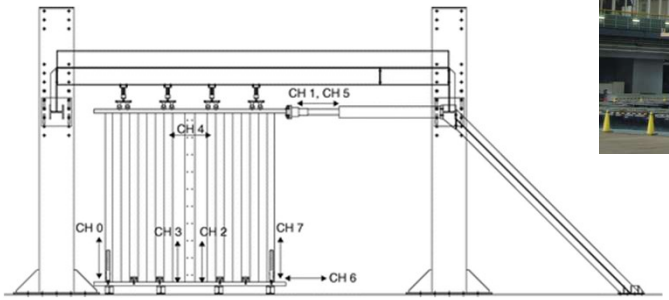


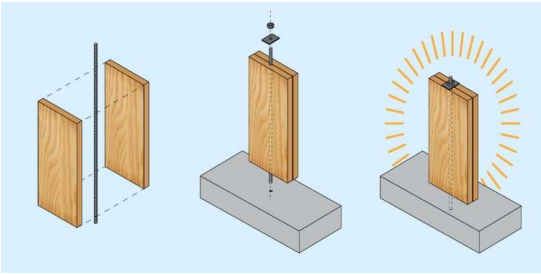
Timber Framing + CLT lateral System

NZ prestressed wood research

NEES-Planning 2013-15

NHERI Tall Wood 2016-20

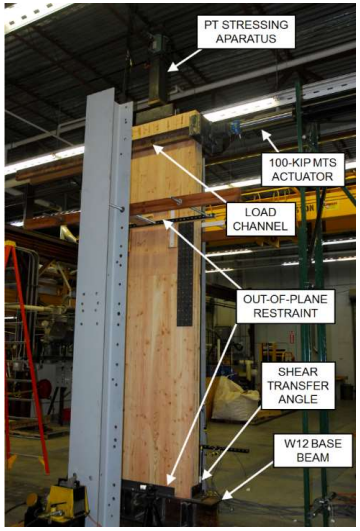




NHERI TallWood

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


Jeffrey Berman


Keri Ryan


James Ricles


Richard Sause


Dan Dolan


John van de Lindt

Senior Personnels


Thomas Robinson


Reid Zimmerman


Hans-Erik Blomgren


Andy Buchanan


Marjan Popovski


Douglas Rammer

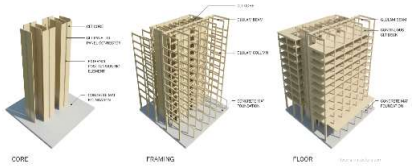

Eric McDonnell


Andre Barbosa

GAME PLAN

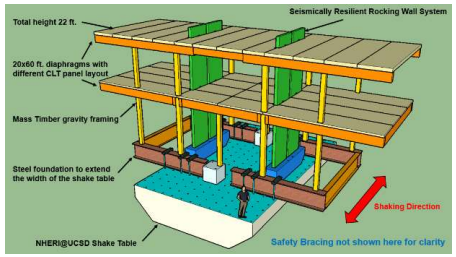
Project duration: 2016~2021

Nheritallwood.mines.edu

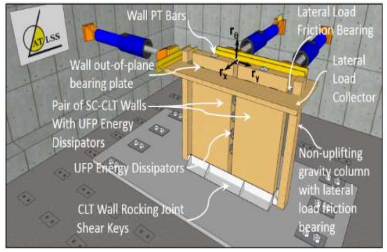


Define Tall Wood Archetypes

Investigative testing at system level

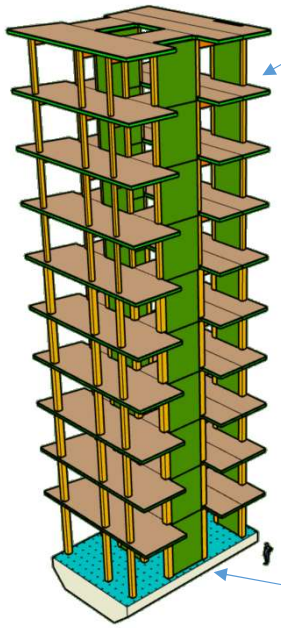


Two-story test at
NHERI@UCSD
2017 Summer

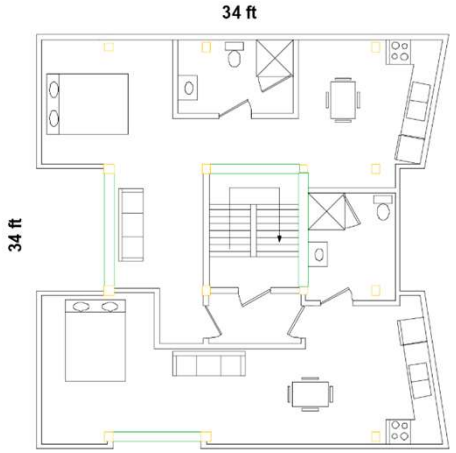


Assembly test at
NHERI@Lehigh
2019

Full-scale 10-story validation Test (2021)



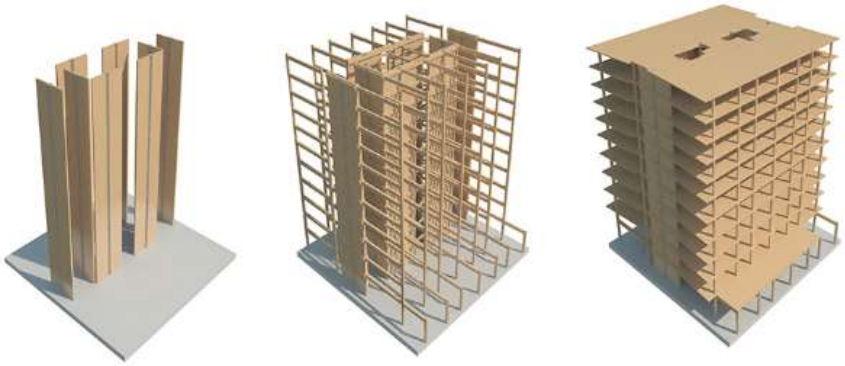
Mixed-Use building w/ CLT rocking wall lateral system



UCSD Shake Table

Seismic R & D
(2018~2020)

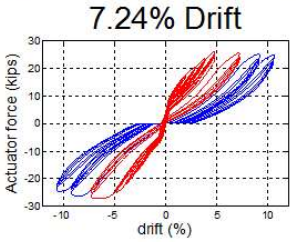
First Year into NHERI TallWood



Tall Wood Archetype Decided

Free time on UCSD Shake Table

Design experience from recent mass timber projects

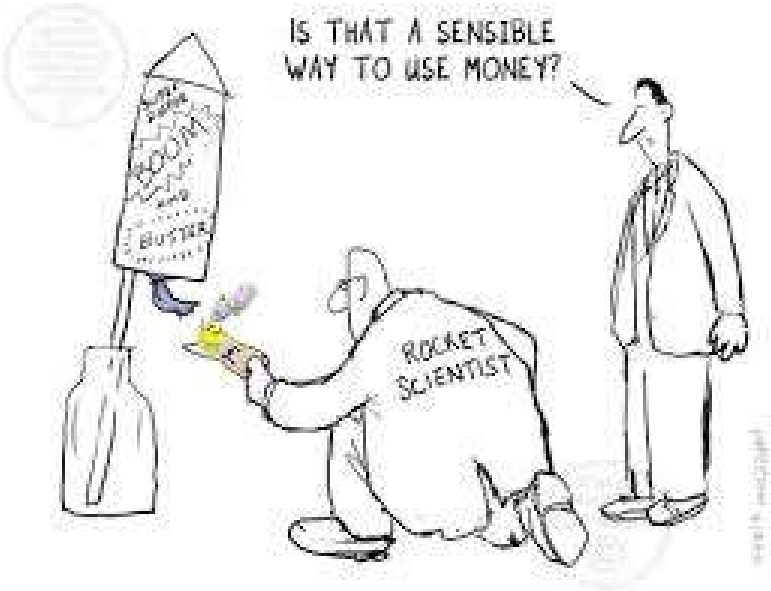


Knowledge on rocking wall component behavior

A Test is Possible in 2017

But additional funding needed.

- Industry: Katerra, Simpson Strong-Tie, SLB
- Collaborating institution: OSU, TDI
- Stake-holder: City of Springfield
- Partner: Forest Products Lab



Many people want to see this done.

A Three-Phase Test Program (Done Fast!)

Concept and Site Reservation
January ~ March

Structural Design
April

Fabrication and Construction
May ~ June

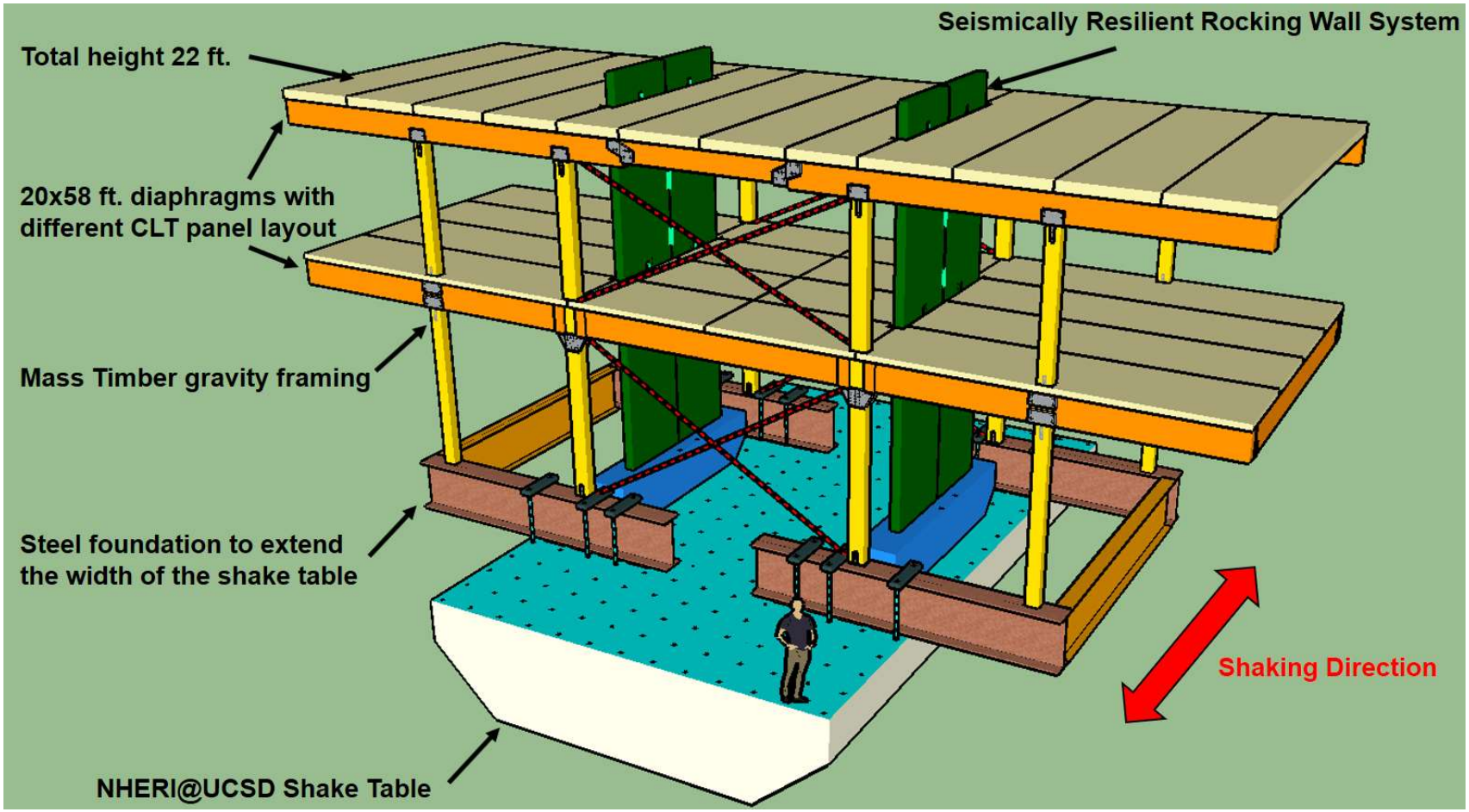
Phase 1
Post-tensioned Rocking Wall
July 1-15
14 tests

Phase 2
Non-post-tensioned Rocking Wall
July 16-28
13 tests

Phase 3
Traditional Platform CLT shear Wall
August
7 tests

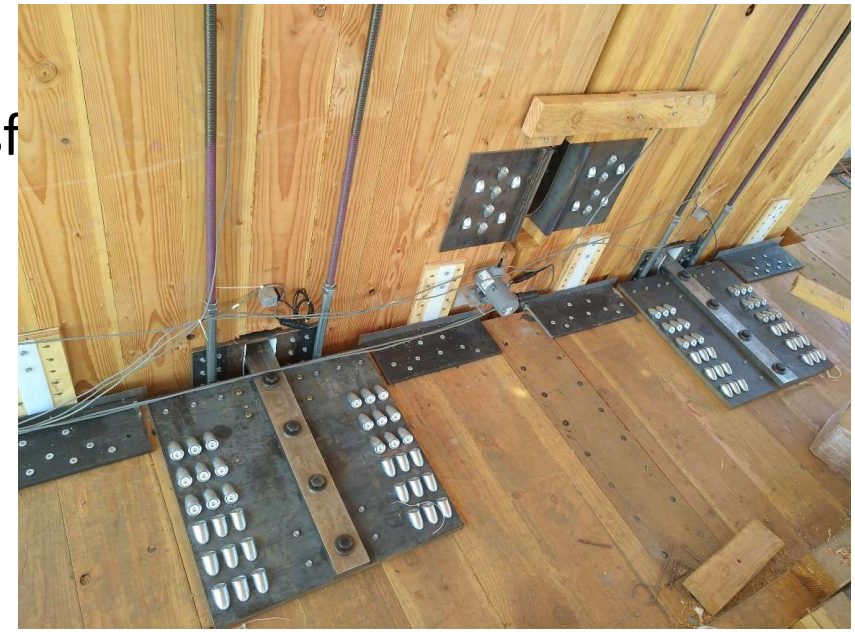
Disassembly and Removal
September

Overall Configuration Dictated by Research Objectives

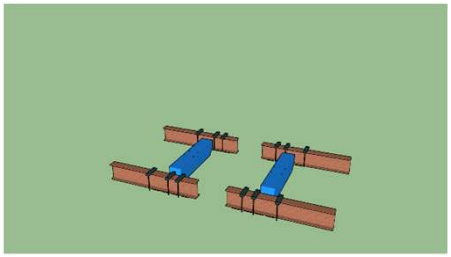


Design…

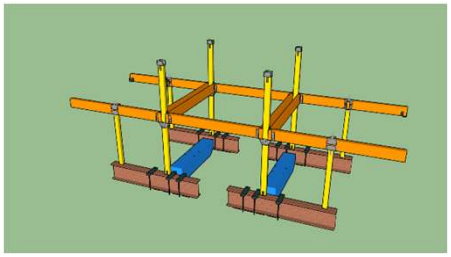
- Gravity design following NDS and CLT handbook
- Diaphragm design by OSU (two types)
- Frame joints detailed to allow rotation
- Lateral design based on San Francisco Hazard levels
- Shear transfer detail
- Roof 79 psf, floor 64 psf



Construction…



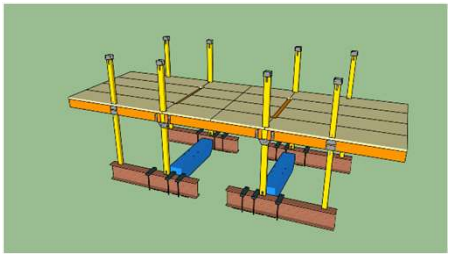
June 8



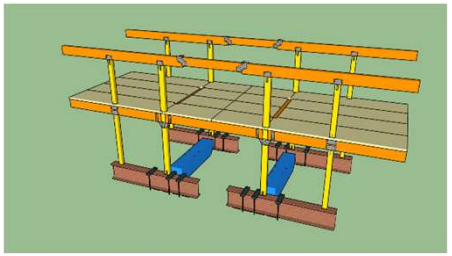
June 9

June 10-11 were weekend

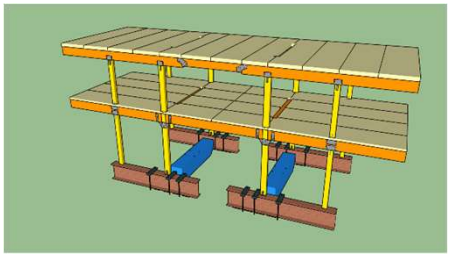
… enjoy while we could….



June 12



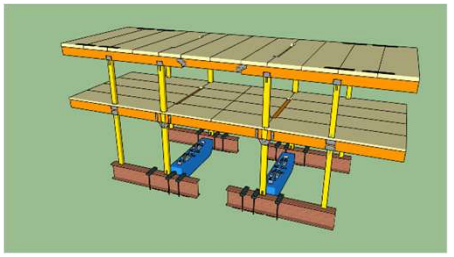
June 13



June 14

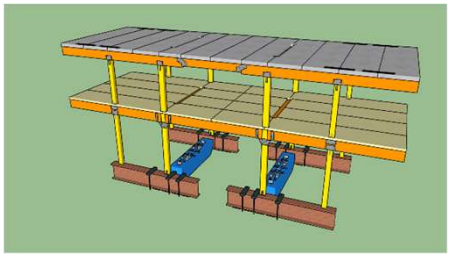
Gravity system done in **4 days**

Concrete roof prep



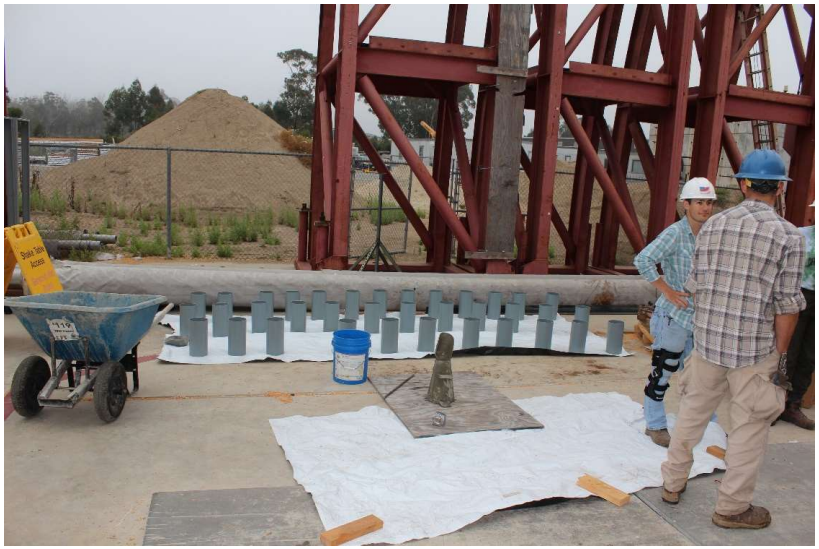
June 15-21

Rocking wall base detail

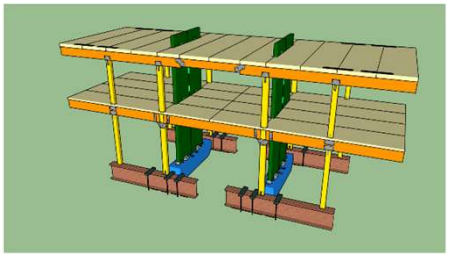


June 22

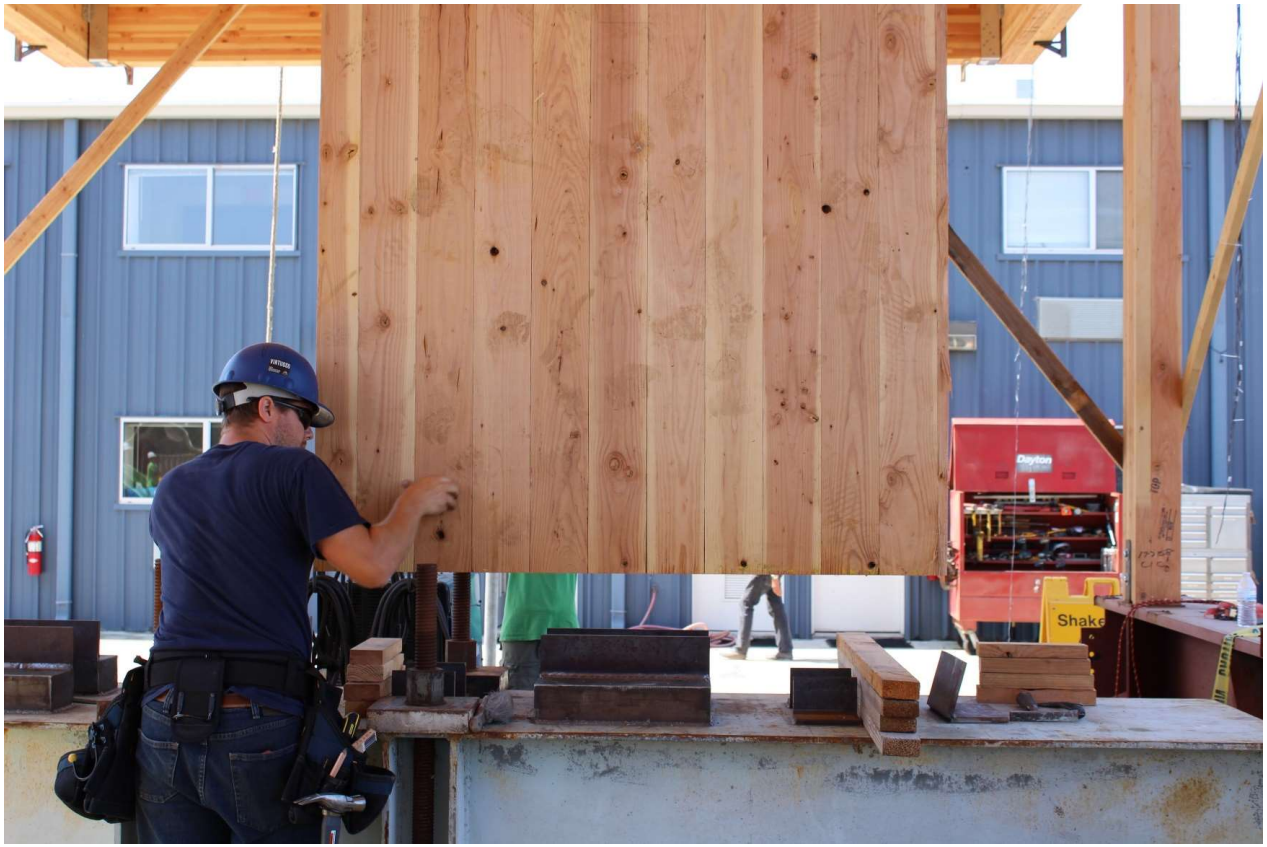
Pour Concrete, test strength….

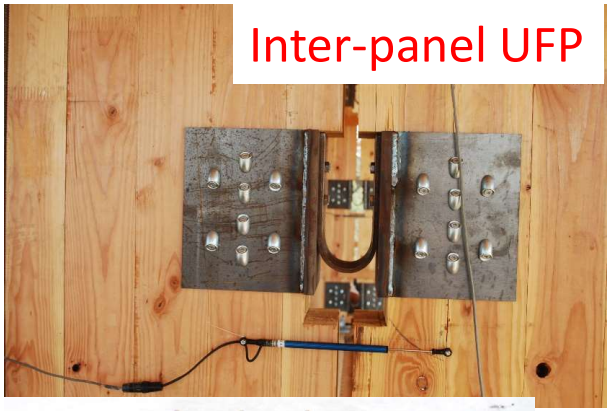


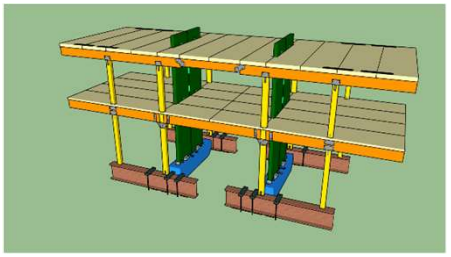
June 23



Inserting Rocking walls





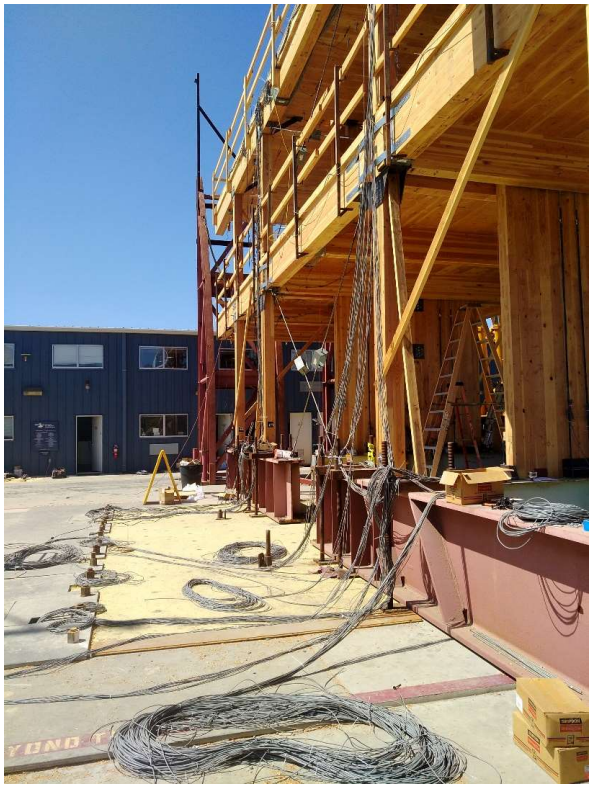


June 26

Post-
tension
By hand

Over 350 Channels of Instrumentation

(about an entire week to set-up…)



Structural Component and response of interest	Instrumentation used
Global overall building • Inter-story drift • Torsion • Acceleration	10 string potentiometers from diaphragm to fixed reference towers by the shake table 36 accelerometers on floor and roof diaphragms
Rocking wall • Post-tension force • Rocking uplifts • Panel deformation	16 load cells for post-tension rod forces 30 (20 at rocking base, 10 between walls) LVDT displacement sensors for wall uplift and panel relative slip 16 String potentiometers to measure panel shear deformation
Diaphragm • Panel deformation • Concrete-wood slip • Chord forces	50 Strain gages on tension straps 53 LVDT at panel splices and concrete/wood for slip 26 String potentiometers for out-of-plane diaphragm deformation
Gravity frame • Rotation at column joints	16 string pots attached at column face to measure uplift and join rotation
Shear key • Shear force transfer	24 Strain gages on the shear keys

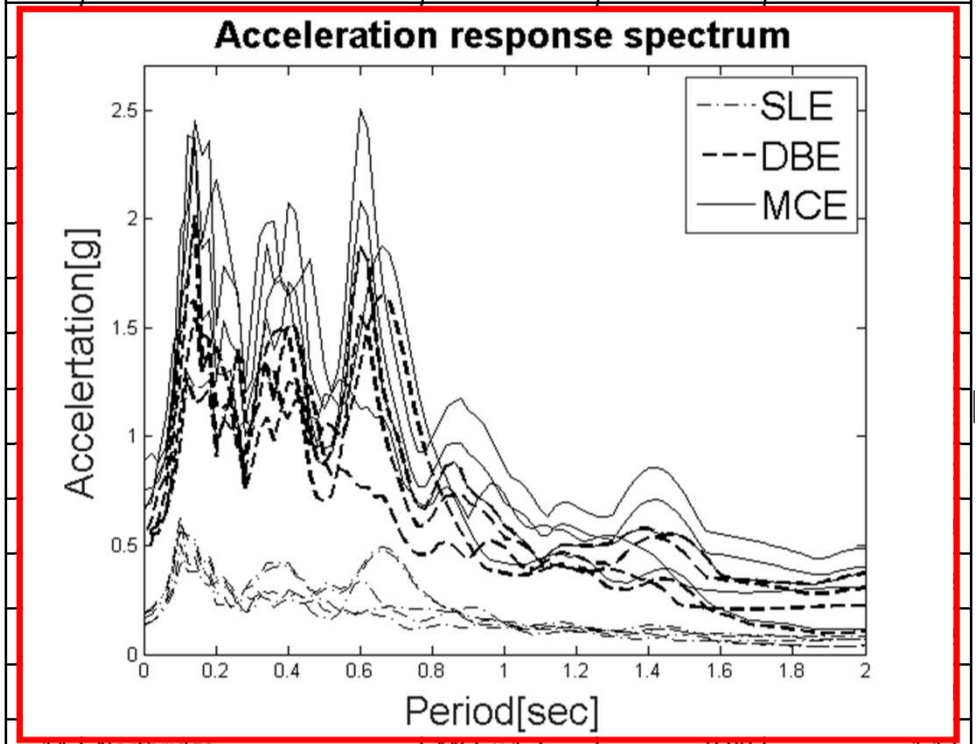
Building Ready for Test (near July 4th)

Phase 1 Test Program

- Why 14?
- Day 1: Feel it out (test 1~5)
  Baby steps
- Day 2: Public test 1 (test 6)
  NSF public test
- Day 3: Public test 2 (test 7~8)
  CA commissioner & congress woman
- Pushing the limit (test 9~14)
  Still Day 3, after the visitors left

A total of 14 earthquake tests conducted

ID	Ground Motion	Hazard level	PGA (g)	Sa @ 0.9 sec (g)
14	Northridge	MCE x 1.2	0.89	1.12



SLE: Service Level Earthquake (frequent)
DBE: Design Basis Earthquake (Design code)
MCE: Maximum Considered Earthquake (2500 yr return period)

Public Test Northridge x 2 (Test 6)

The MCE+ Shake (Test 14) 5% drift

Close up on Rocking Wall

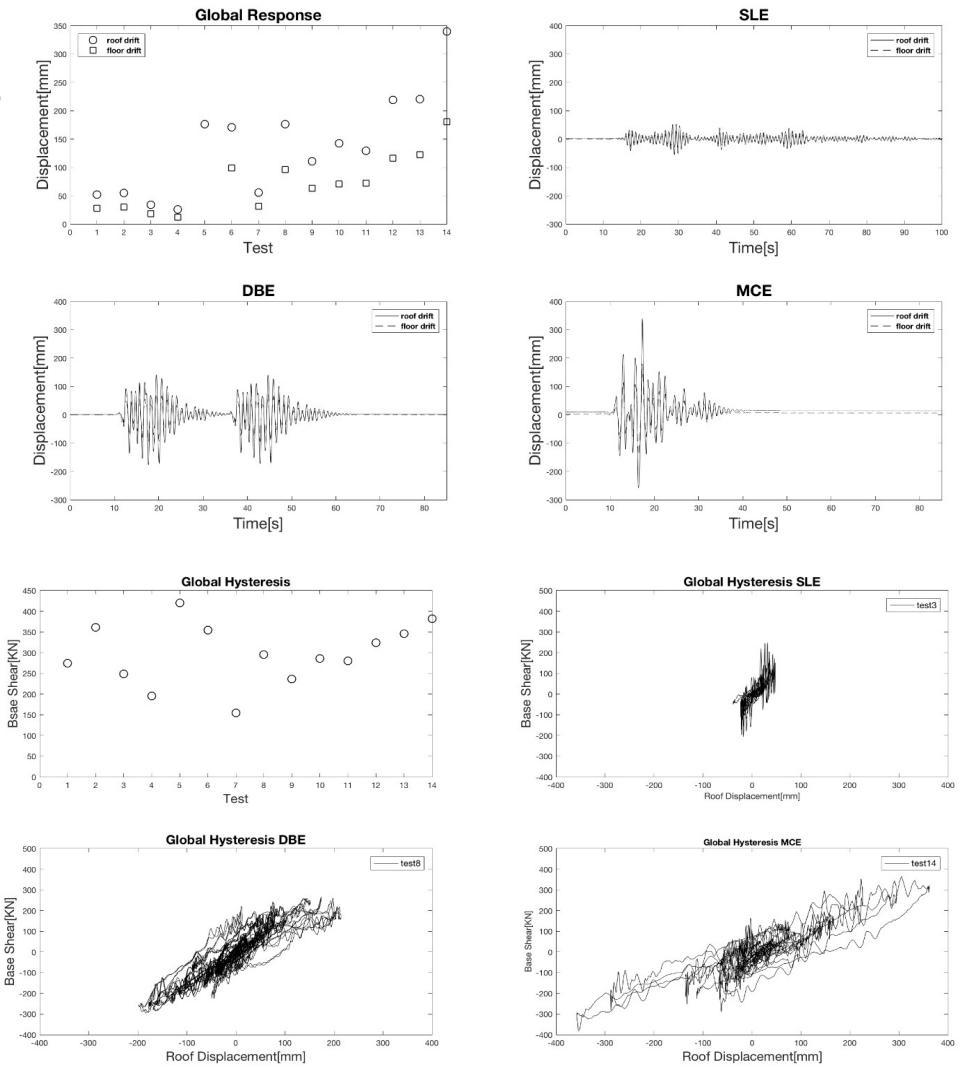
Second story wall & column

Details and gravity connections (Test 14 MCE+)

Building Performance

- White noise period 0.85 sec
- Maximum drift 5% (test 14)
- Maximum base shear 430 kN (96 kips) (Building total weight 171 kips)
- Diaphragm mostly linear rigid
- Some PT bars yielded in MCE events
- No damage to wood

Journal paper published in J. of Structural Eng.



Removal of the Rocking Wall

No Damage after 14 earthquakes

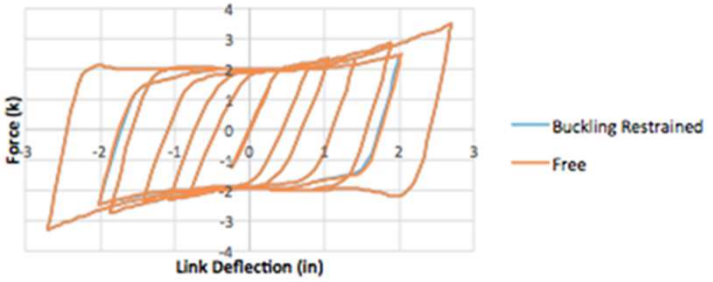
Slight compression deformation at the rocking wall corner

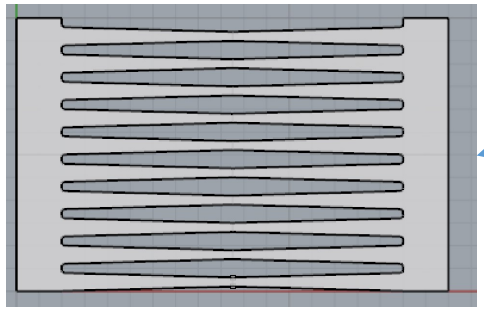
Chipping of wood at the rocking wall corner

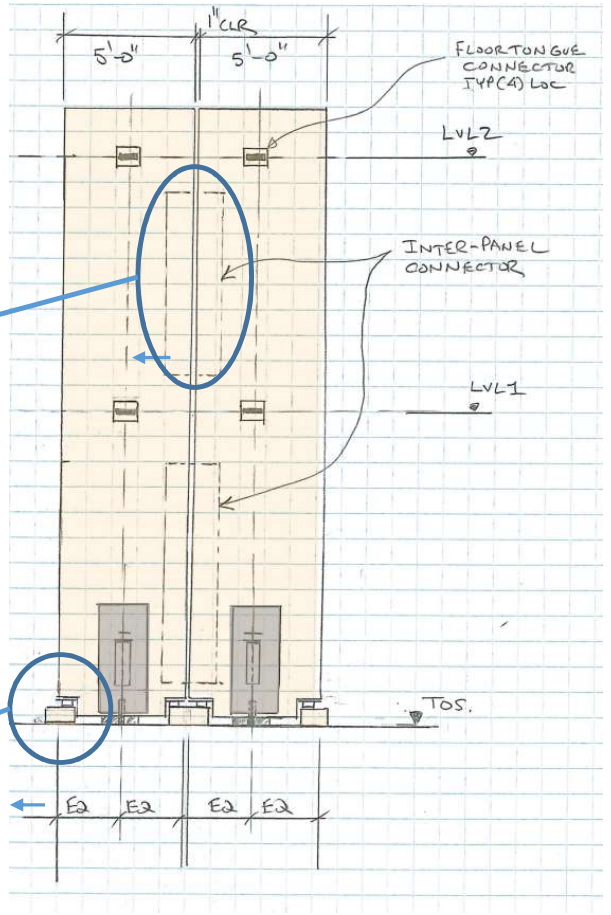
End of Phase I

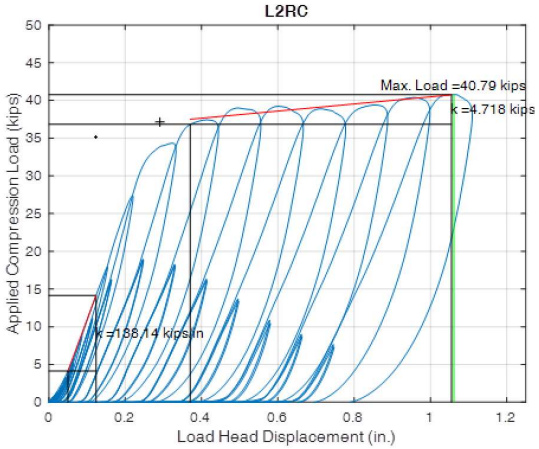
Phase 2: Katerra Wall (13 tests)

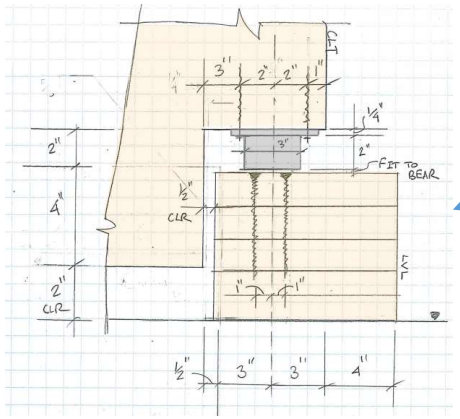
- A new Rocking wall design without post-tension





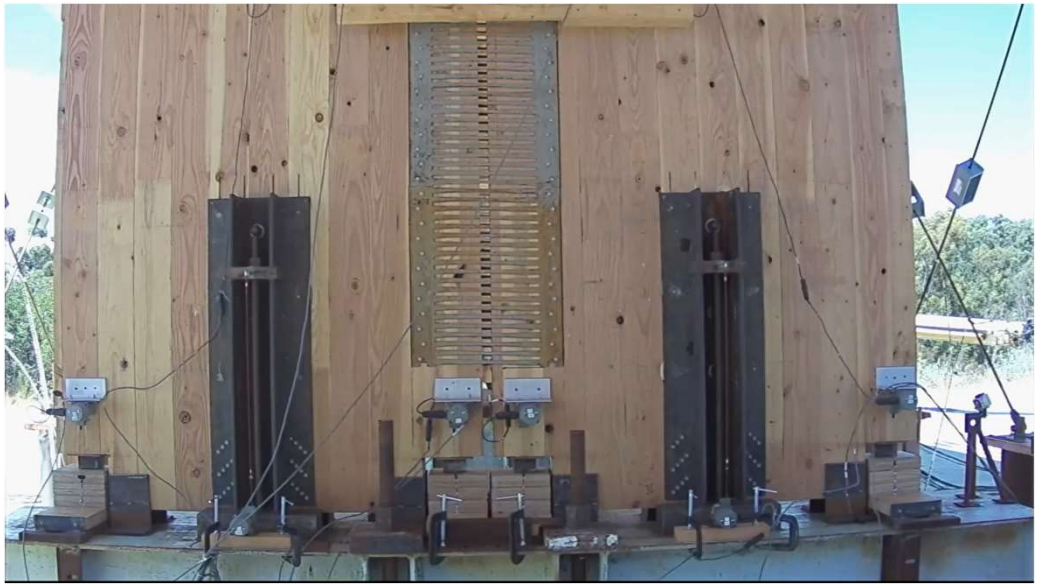






KATERRA
BREAK NEW GROUND

Response under MCE Northridge Shake

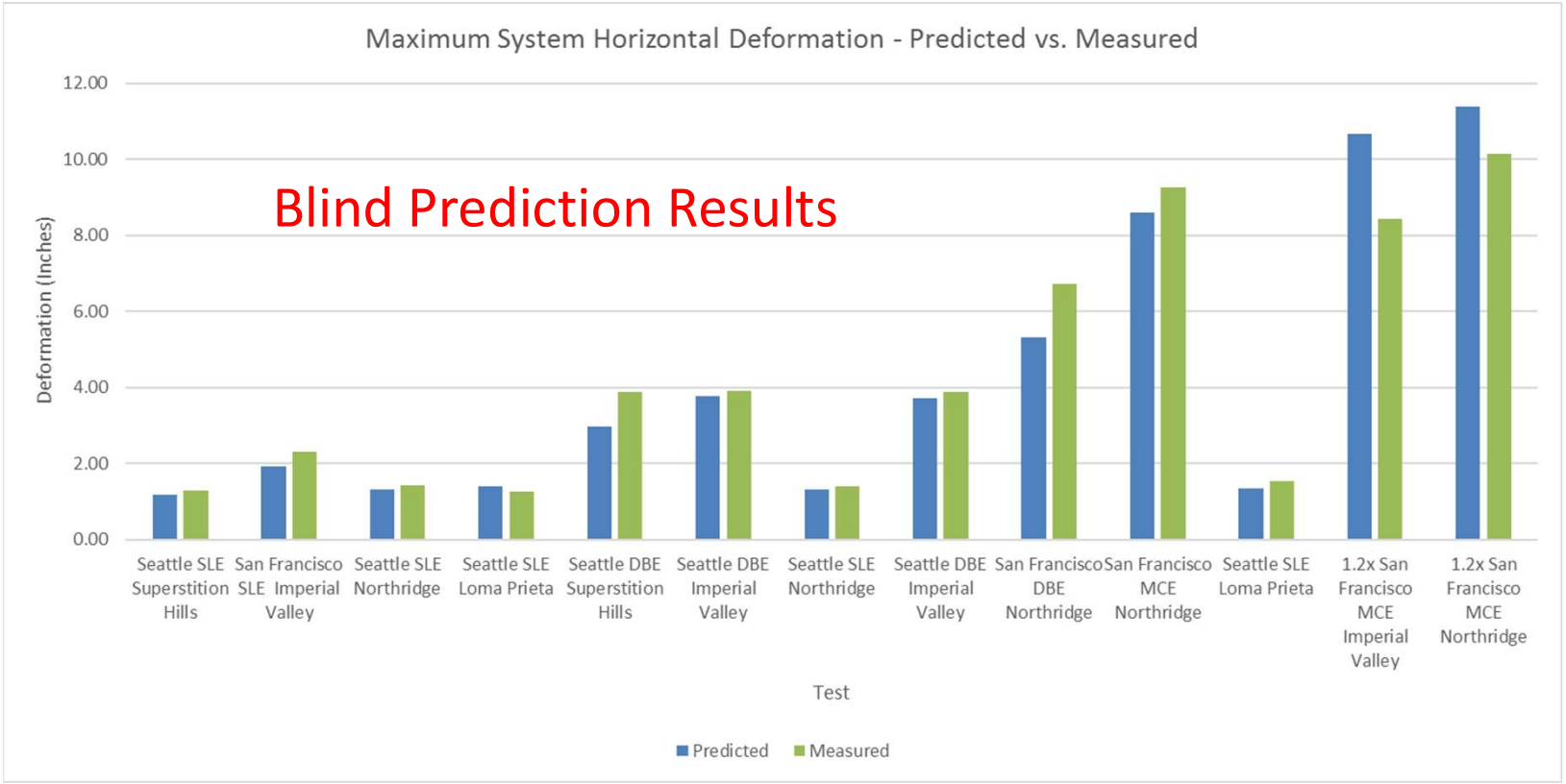


KATERRA
BREAK NEW GROUND

Repairable Damage @ Planned Locations

KATERRA
BREAK NEW GROUND

Our Numerical Model is Working!

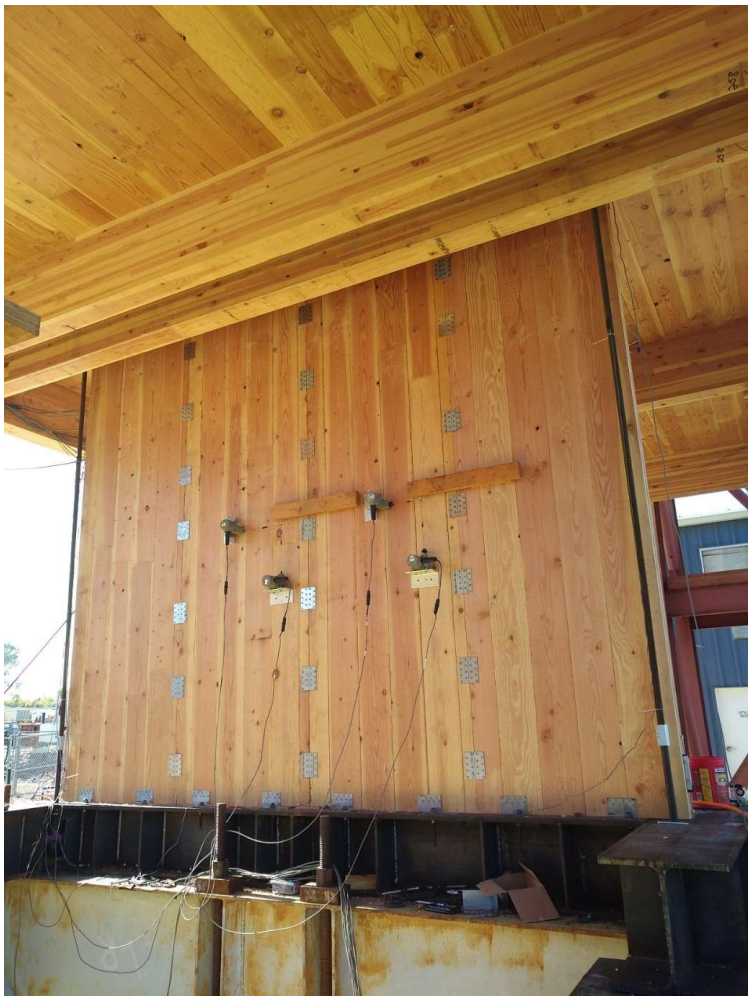


KATERRA
BREAK NEW GROUND

Remove rocking walls, end of Phase 2

Phase 3: Platform CLT shear walls

- Designed based on “fresh” seismic factors from P695 project
- Damage expected on shear walls during large seismic events
- 7 earthquake tests
- Collaborated with FPL on this



Phase 3 main findings

After Three Phases of Testing…

The gravity framing was essentially intact. “Sold” for demolishing.

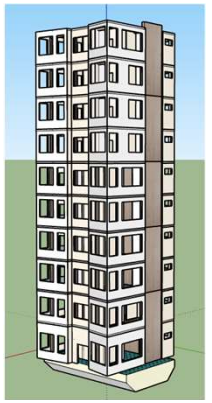
This is not the end…

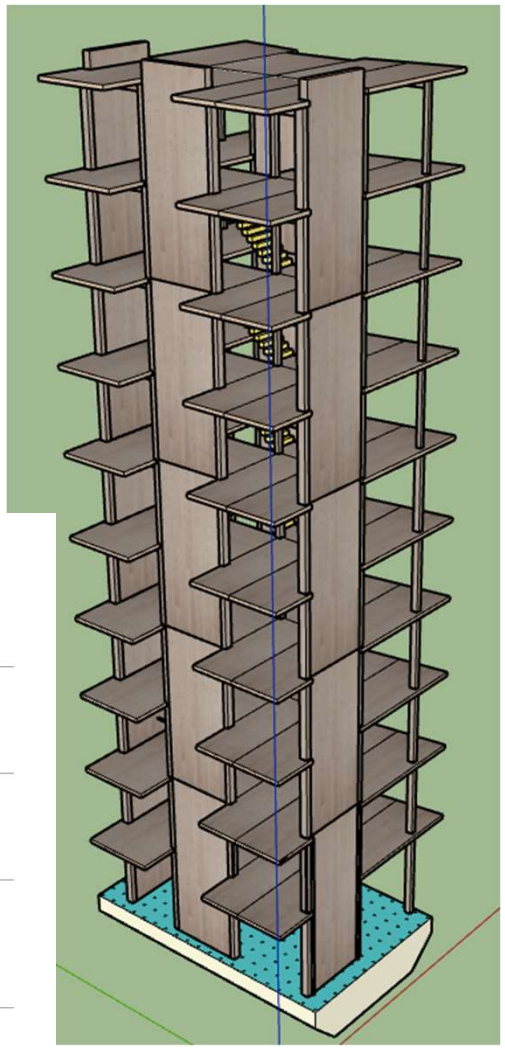
- Now we have solid proof that mass timber structural system in an open floor plan building can be designed to achieve resilience against earthquakes.

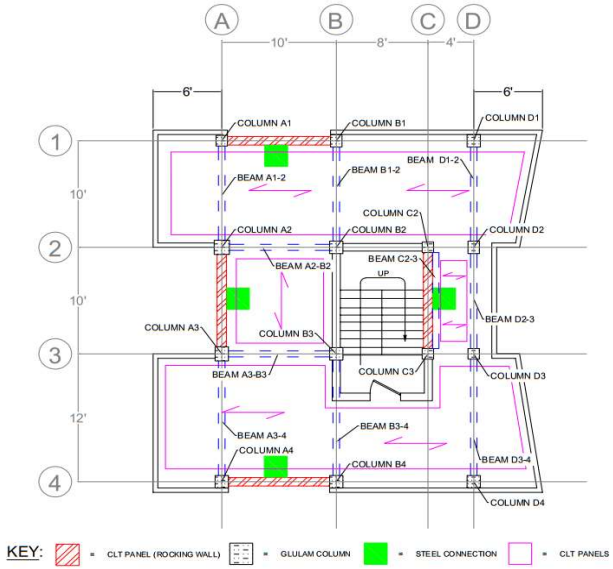
- With significant amount of data and experience obtained through investigative testing, the project team will continue working on design method development, non-structural system detailing, numerical modeling, and the 10-story building for the 2020 validation test.

How about build a 10-story wood building and shake it?

- First building ever designed to minimizing downtime.
- 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







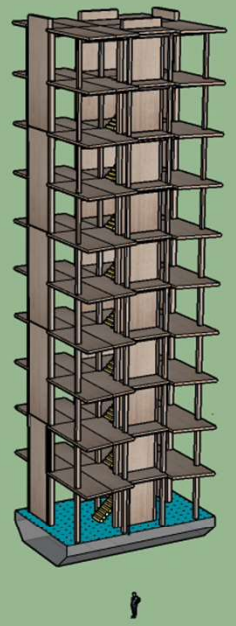
Structural Framing with 4 Mass Timber Rocking walls

Envelope + Non-structural systems

Story: 7-10
Residential floorplan

Story: 3-6
Office floorplan

Story: 1-2
Retail floorplan



NHERI

Full-Scale

Mass Timber

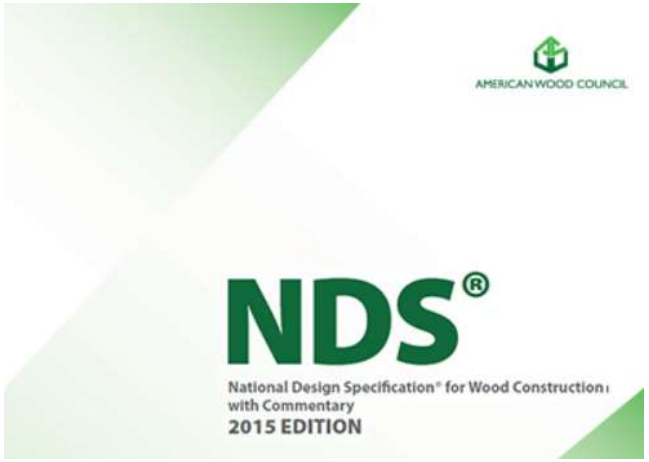
RESILIENT

The World's Tallest Building Ever Tested.

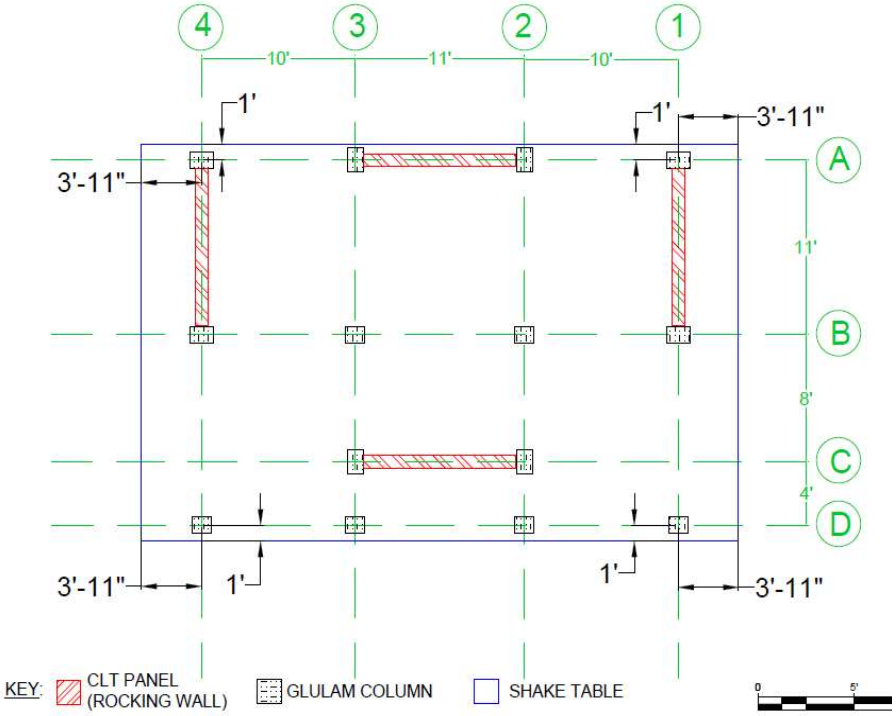
2021

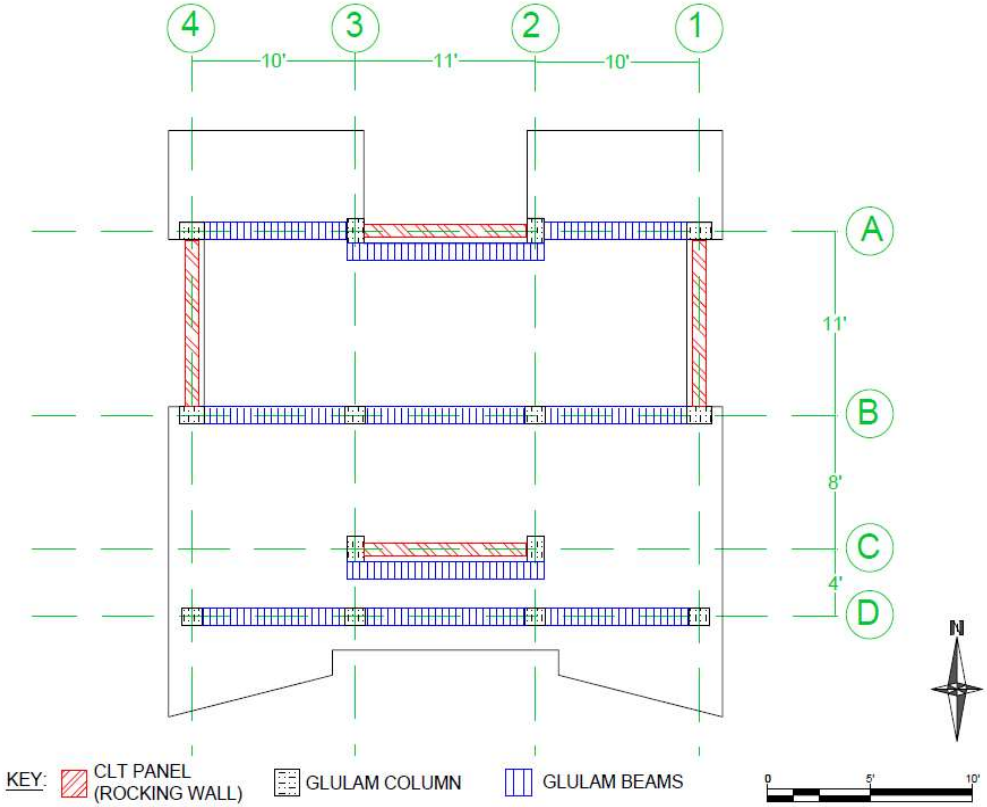
Design of the Ten-story Building

- Schematic Design
  - Floor plan and frame grids
  - Prelim gravity and lateral design
- Structural/Non-structural Design
  - Connections (gravity and lateral)
  - Simulation models
  - Non-structural system selection
  - Resilience based design
- Construction Design
  - Detailing and drafting
  - Logistics and construction



Floor Plans


4
3
2
1
10'
11'
10'
1'
1'
3'-11"
3'-11"
A
B
C
D
11'
8'
4'
3'-11"
1'
1'
3'-11"
KEY:
CLT PANEL (ROCKING WALL)
GLULAM COLUMN
SHAKE TABLE
0
5'


4
3
2
1
10'
11'
10'
A
B
C
D
11'
8'
4'
N
KEY:
CLT PANEL (ROCKING WALL)
GLULAM COLUMN
GLULAM BEAMS
0
5'
10'

Gravity Design

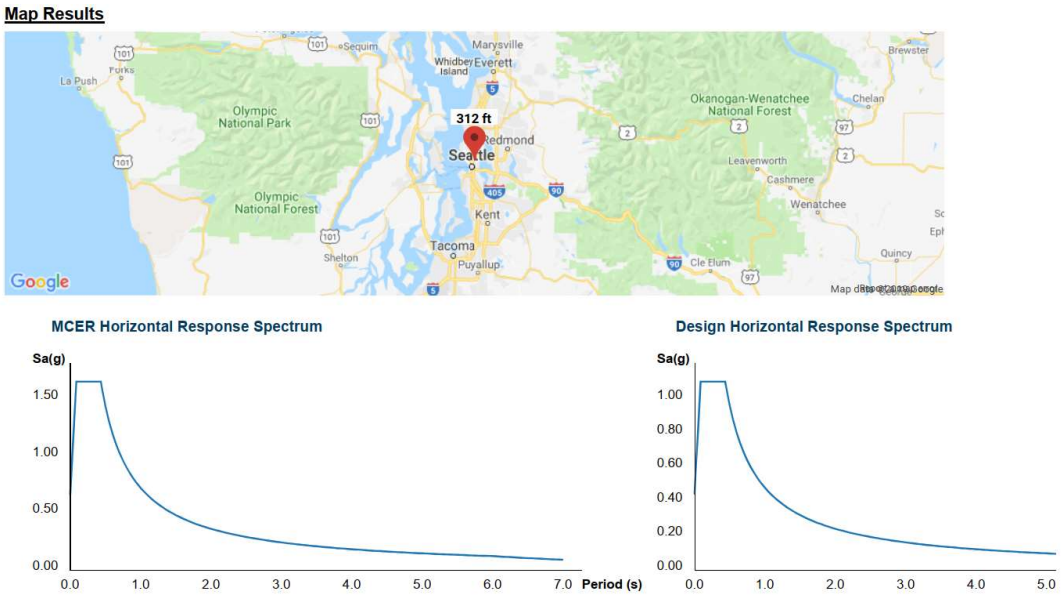
- Consider 2hr fire for exposed beam/column (@ 3.6 inch/hr char rate on all exposed surfaces)
- Dead load of 70 lb/sq.ft. for all floors and roof
- Live load of 65 lb/sq.ft. for all floors

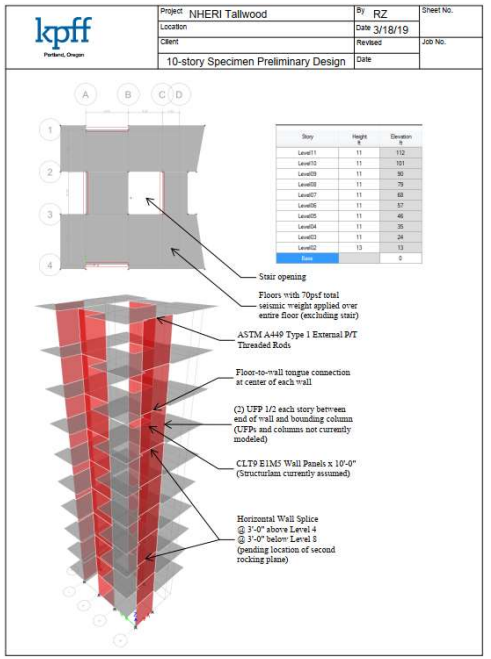
Table 1: Column and Beam Sizes Summary

Member	Size (in)	Control D/C ratio before fire	Control D/C ratio after fire
Columns (Floor 1-2)	12.25 x 15	0.576	1.041
Columns (Floor 3-6)	12.25 x 13.5	0.512	1.031
Columns (Floor 7-10)	12.25 x 12	0.288	0.677
Rocking wall bounding Columns (All Floor)	12.25 x 18	0.480	0.752
Beam (All)	12.25 x 13.5	0.459	0.732

Seismic Design

- In the end the building will go through RBSD via time history simulations
- Preliminary design was done using ASCE7 force-based method with R=6





Want to get involved?

- Project Timeline:
  - 2019: Resilience-based Seismic Design
  - 2020 Summer: Finalizing construction documents
  - 2020 Fall: Procurement and Production
  - 2021 Spring: Construction Starts
  - 2021 Summer: Shake it up!

- Contact us if you:
  - Would like to help “wood” grow in seismic regions
  - Have products that can be integrated into the design and testing
  - Want to put something in building while we shake it (no live animals please...)
  - Somehow want your organization’s banner on the building☺

LET’S BUILD TOGETHER!

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