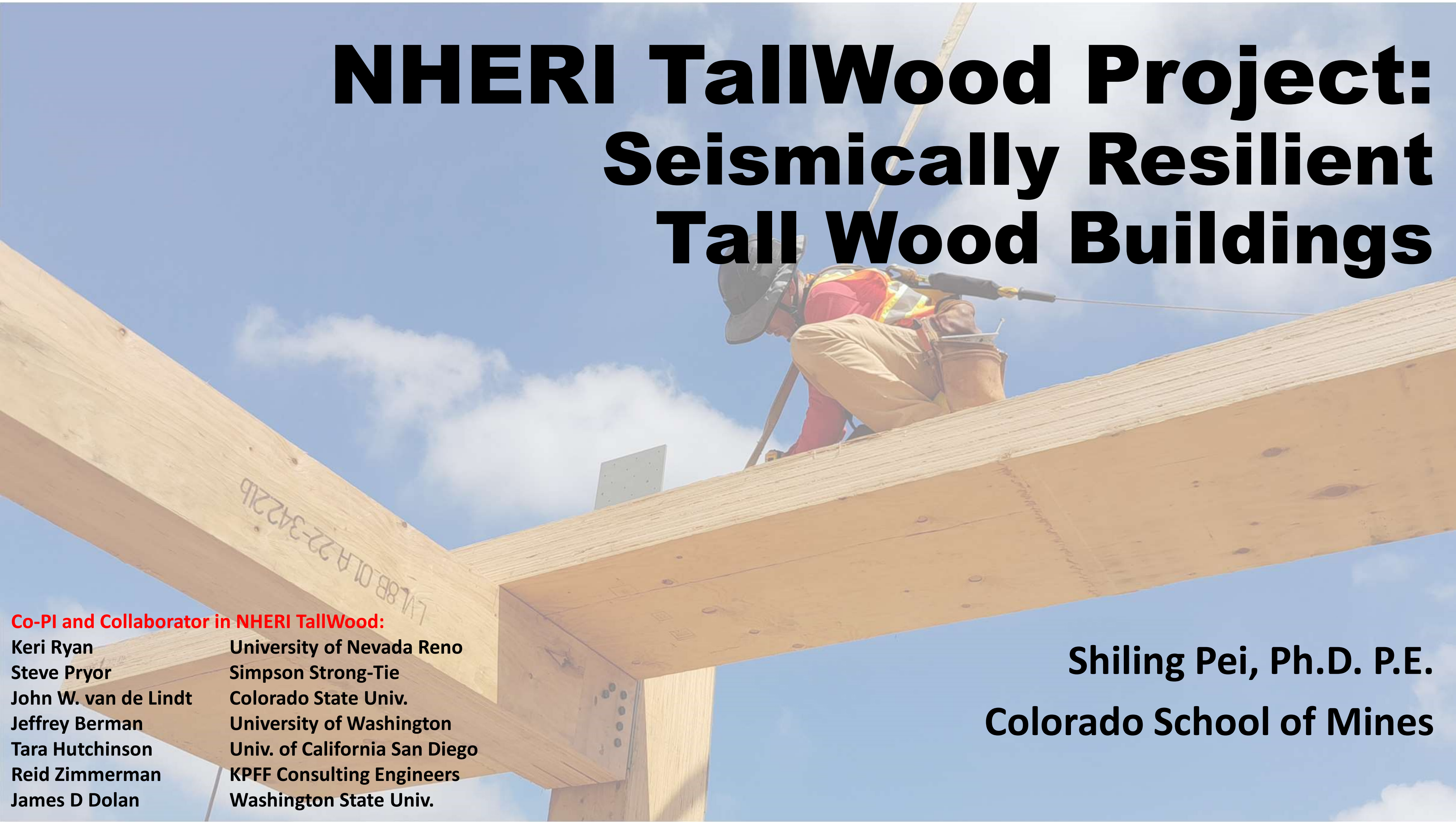


NHERI TallWood Project: Seismically Resilient Tall Wood Buildings

Shiling Pei, Ph.D. P.E.

Colorado School of Mines

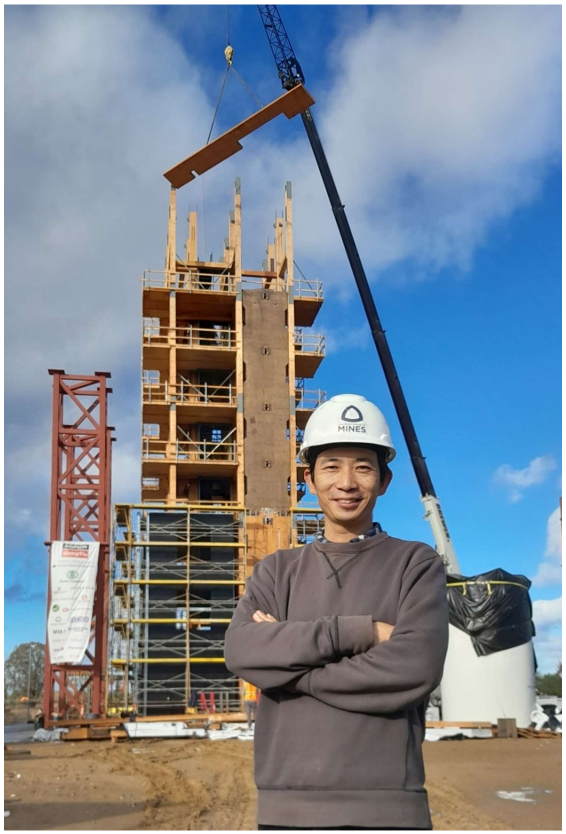
Co-PI and Collaborator in NHERI TallWood:

Keri Ryan	University of Nevada Reno
Steve Pryor	Simpson Strong-Tie
John W. van de Lindt	Colorado State Univ.
Jeffrey Berman	University of Washington
Tara Hutchinson	Univ. of California San Diego
Reid Zimmerman	KPFF Consulting Engineers
James D Dolan	Washington State Univ.

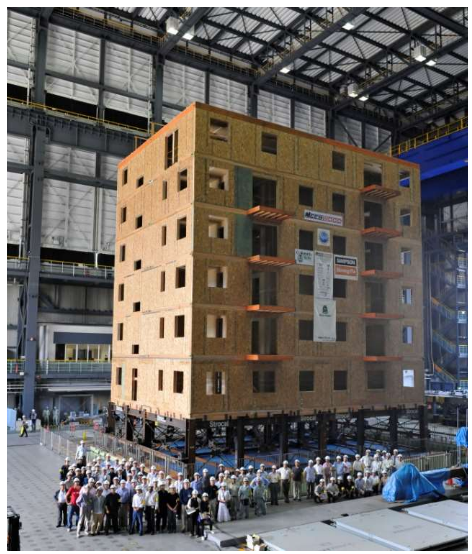
My Background

Shiling Pei, Ph.D, PE, F. SEI & ASCE
Associate Prof. Colorado School of Mines
Email: spei@mines.edu
Twitter: @slpei Website: http://nheritallwood.mines.edu/

- Conducting wood building research since 2004
- Start doing MT research in 2010
- A two-story test in 2017
- A 10-story test in 2023
- Working on P695 study on Mass Timber RW

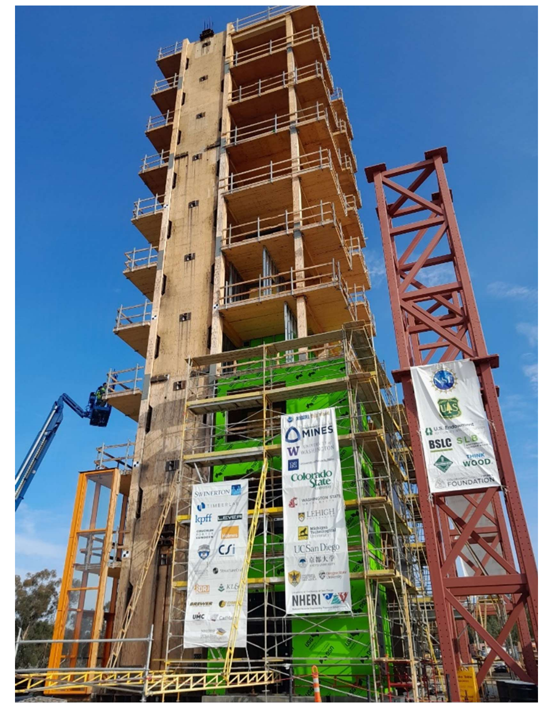


PhD 2007, Colorado State University
Advisor: John W van de Lindt



2009 NEESWood Project
(post-doc work)

2017 2-story test



2023 NHERI TallWood Project

(Lead PI on NHERI TallWood Project)

What is a Seismically Resilient Building?

2011 Christchurch Earthquake M6.2

Credit: Elle Hunt https://www.theguardian.com/

Credit: Elle Hunt https://www.theguardian.com/

Credit: Elle Hunt https://www.theguardian.com/

Credit: Elle Hunt https://www.theguardian.com/

This is what you get by following typical modern building codes (maybe except in Japan)

Total Buildings Demolished AFTER the earthquake

1200+

Total Casualty

185

Can Wood Building do better?

Total Buildings Demolished AFTER the earthquake

0

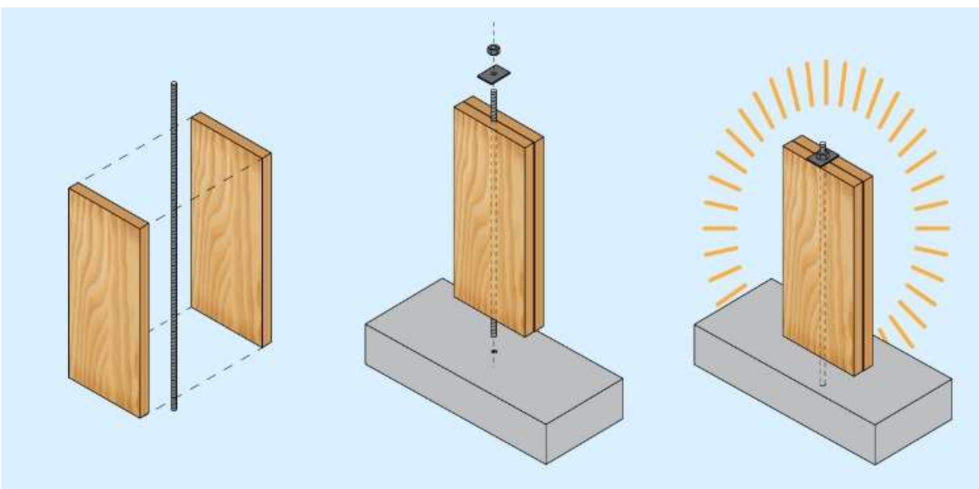
Total Casualty

0

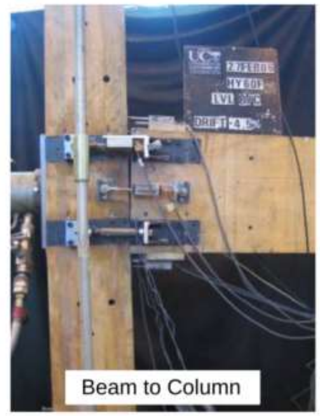
Could we do this?

In Theory This is Doable

WOOD
Push Puppet
on Steroid



Post-tensioned Mass Timber Rocking Wall

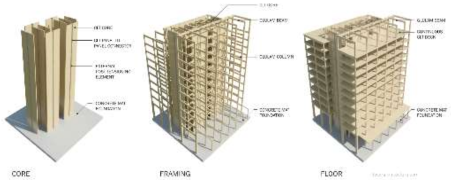


NHERI TallWood Project

Project duration: 2016~2023

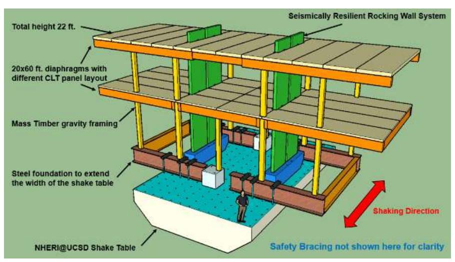
Developing Resilience-based Seismic Design Method for Tall Wood buildings

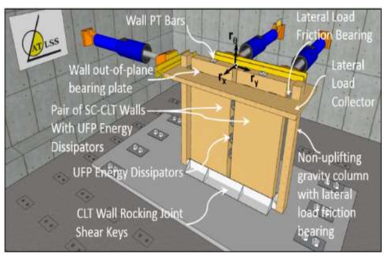
Concept: What can sell?



Define Tall Wood Archetypes

Small scale trials: Investigative testing

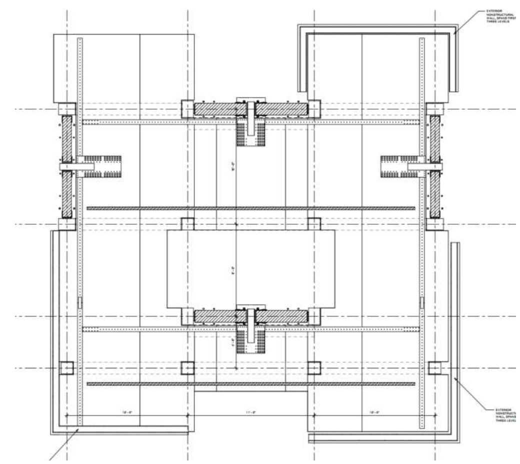




Two-story test at
NHERI@UCSD
2017 Summer

Assembly test at
NHERI@Lehigh
2019-2020

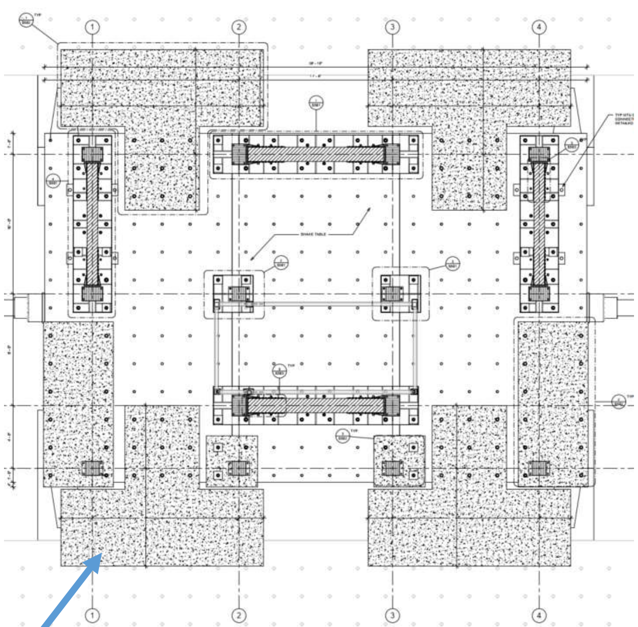
Validation: Full-scale 10-story Test (2023)



Seismic R & D
(2018~2022)

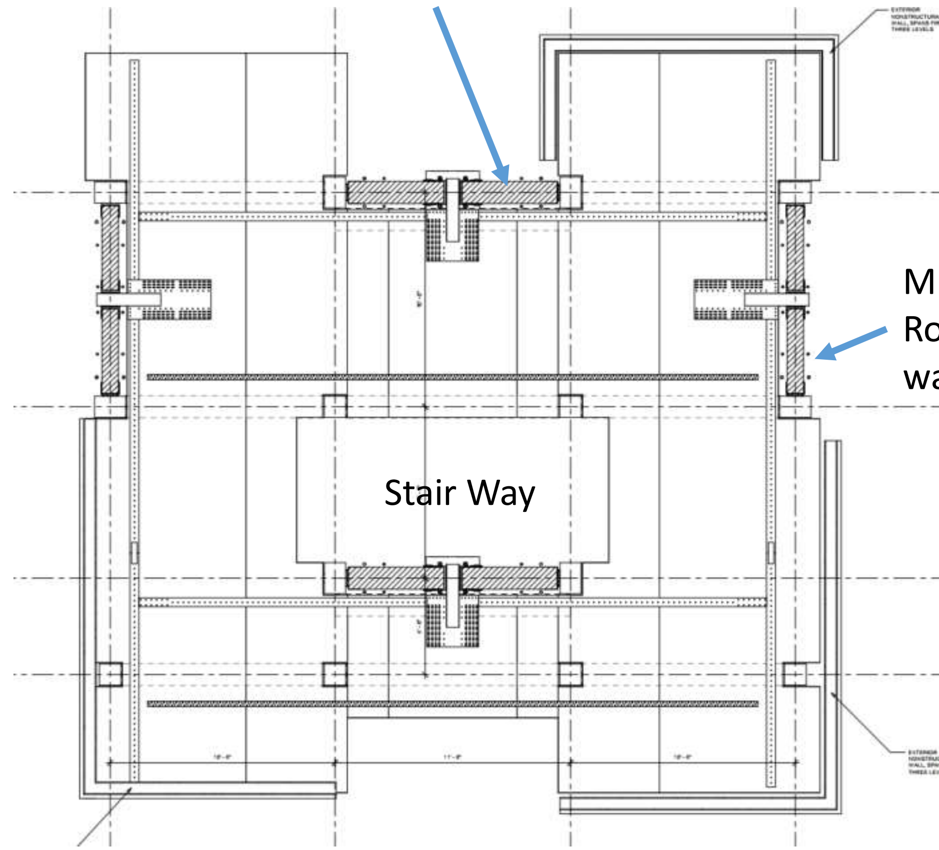
Building Design

Shake table size 40 x 25 ft (12.2 x 7.6 m)



Use concrete overhang foundation to expand Shake table base

CLT Rocking walls



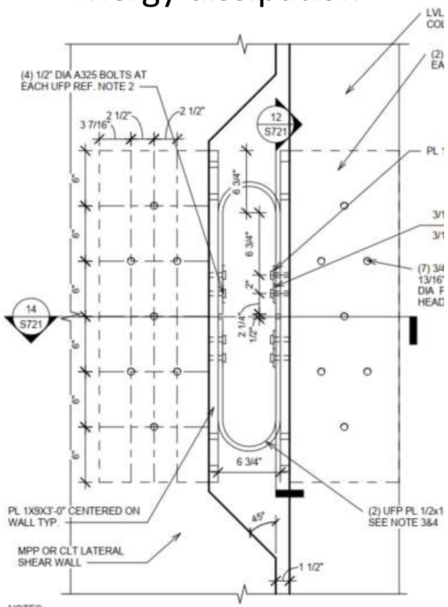
MPP Rocking walls

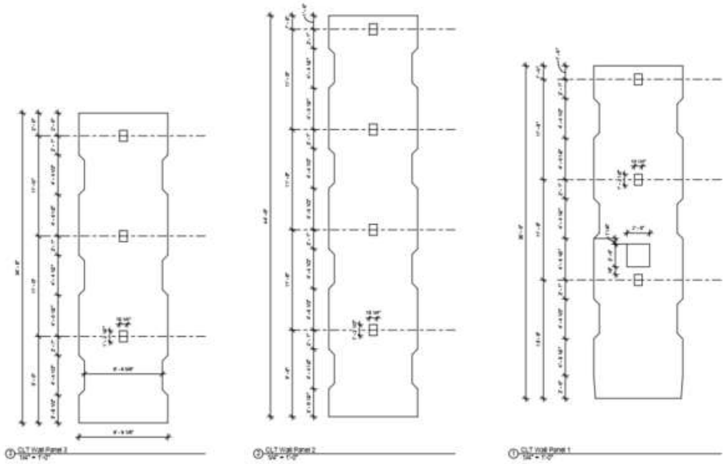
Stair Way

A floor plan of 35 x 32 ft (10.6 x 9.8 m)

Elevation & Rocking Wall

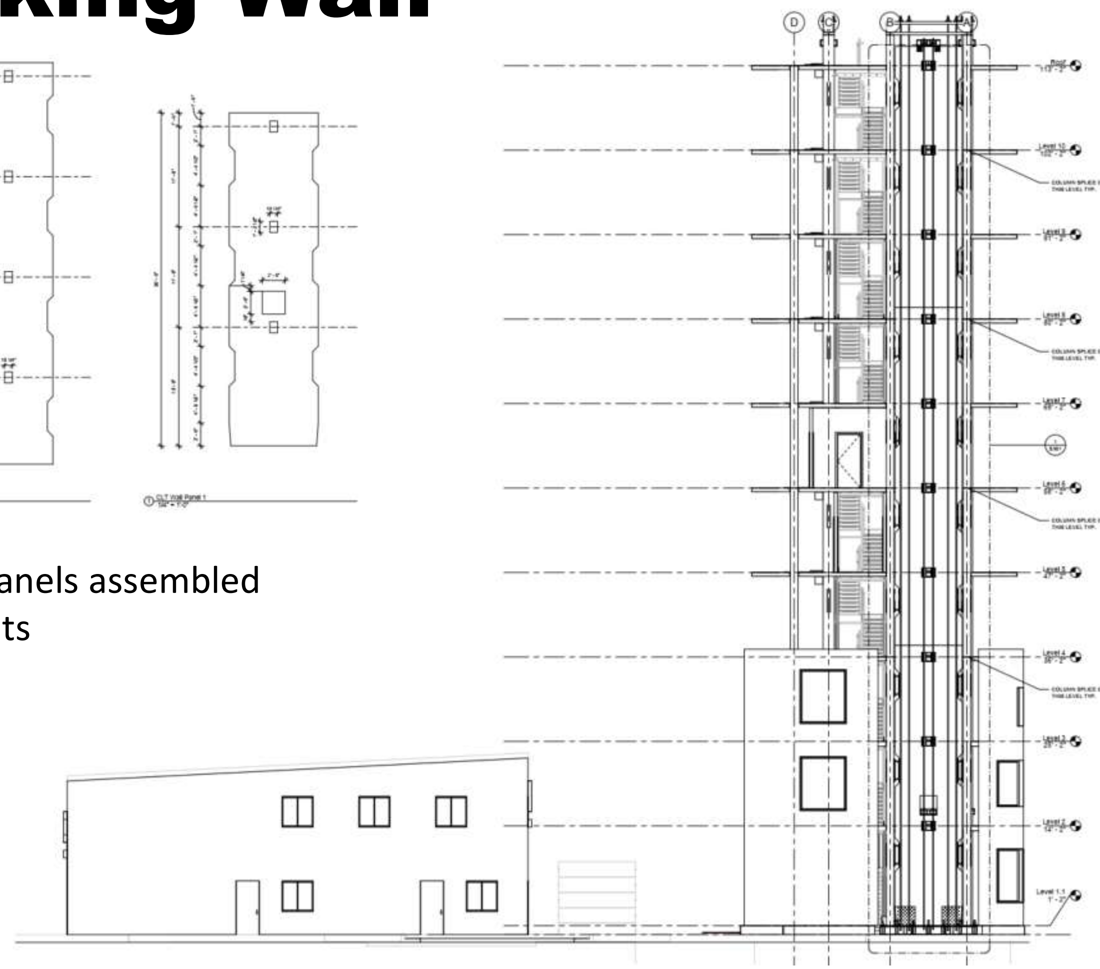
Using UFP (U-shaped flexural plate) for Energy dissipation



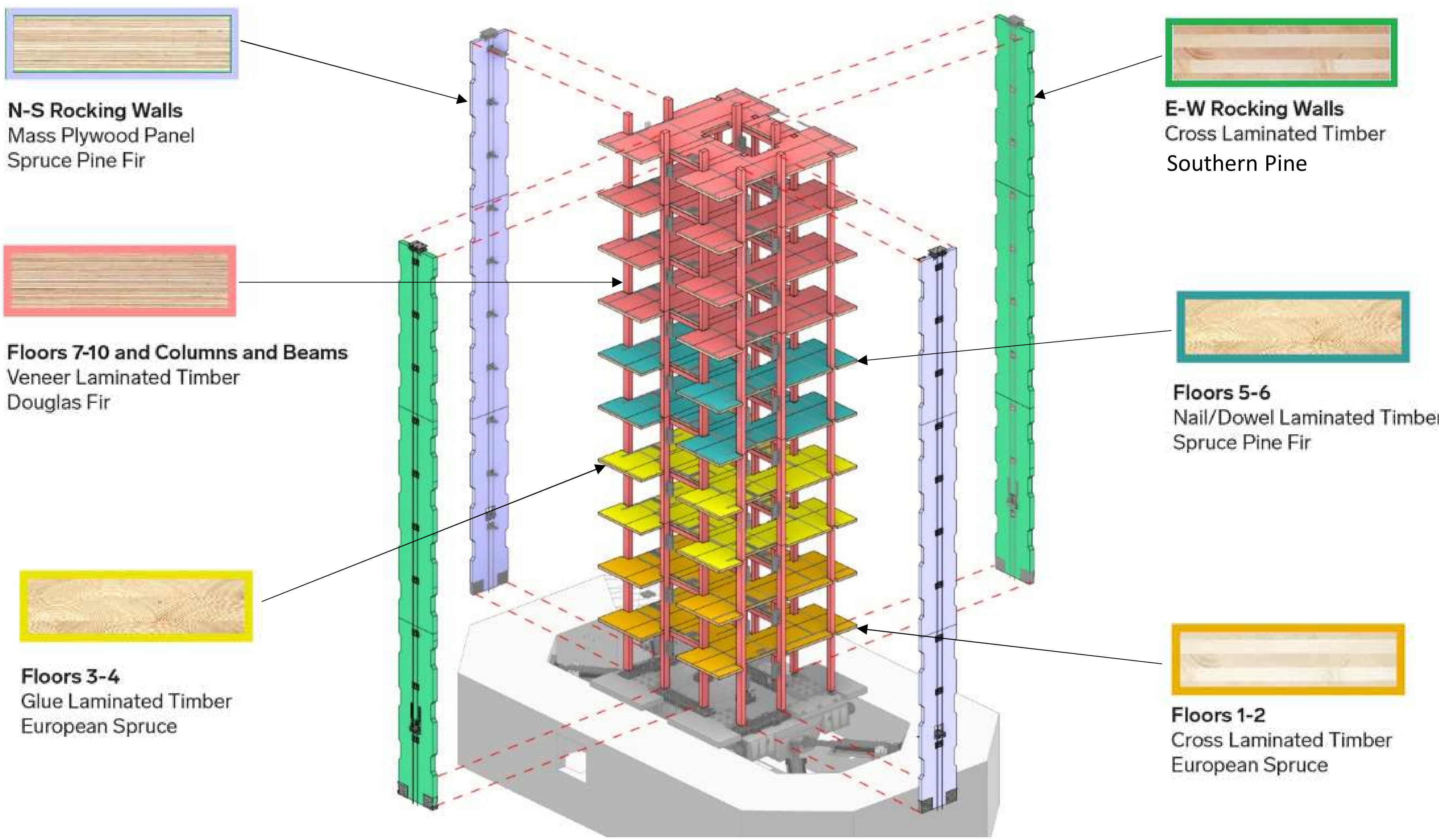


Rocking wall panels assembled with 3 segments

Total height 110 ft (~33m)



Busch, A., R. B. Zimmerman, S. Pei, E. McDonnell, P. Line, and D. Huang. "Prescriptive seismic design procedure for post-tensioned mass timber rocking walls." *Journal of Structural Engineering* 148, no. 3 (2022): 04021289.

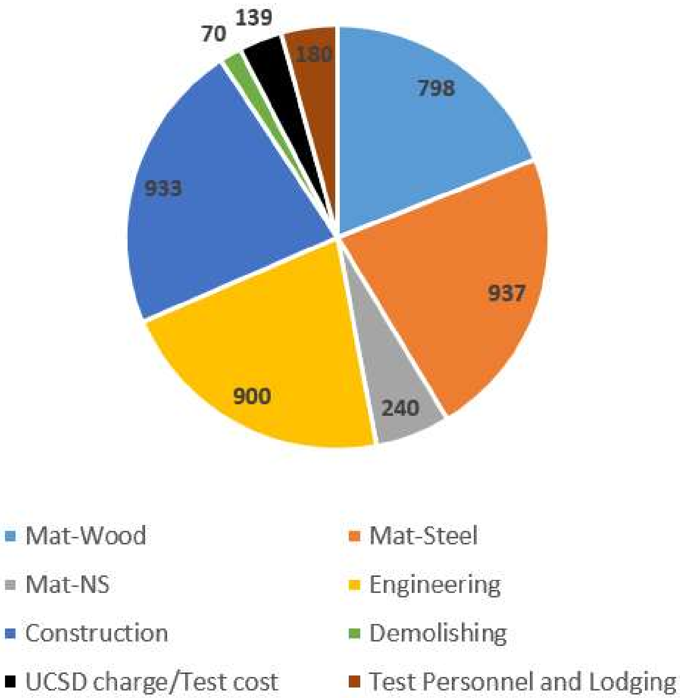


NHERI TallWood

http://nheritallwood.mines.edu/

Now you have a design: Fund-raise to build it

10-Story Tallwood Test Total Cost
$ 4.20 M



University

NHERI TallWood
Colorado School of Mines
University of Washington
University of Nevada, Reno
Colorado State University
Washington State University
Lehigh University
Michigan Technological University
UC San Diego
京都大学 Kyoto University
Università degli Studi dell'Aquila
Oregon State University
University of California at San Diego NHERI Natural Hazards Engineering Research Infrastructure

Industry partner

Simpson Strong-Tie
Happiness Grows from Trees
Sumitomo Forestry
Boise Cascade
SmartLam North America
Freres Engineered Wood
Mass Timber Services
Allegion
REX Lumber
Construction Specialties
Idaho Forest Group
CEMCO
SFIA
SABM
Aqurahome Group
innotech windows + doors
Winco
USG
Exponent
Hexion
Henkel

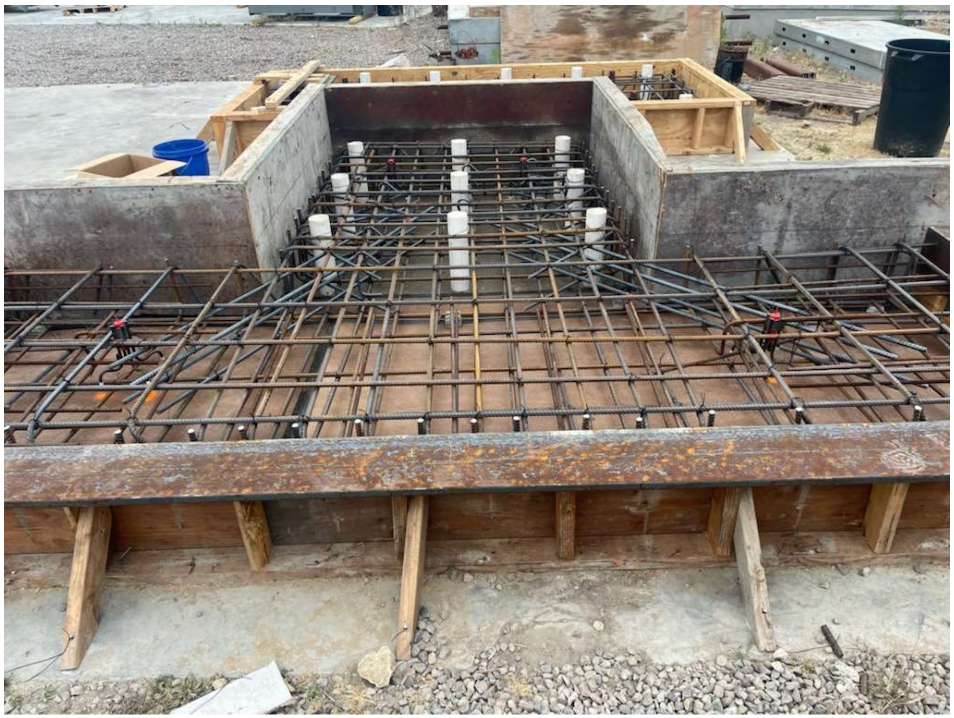
Construction/Design partner

Swinerton
Timberlab
kpff
Lever
Coughlin Porter Lundeen
Holmes
CSI
Magnusson Klemencic Associates
StructureCraft
DRJ
KL&A Engineers & Builders
Brewer
Ehmcke Sheet Metal Corp.
UMC
CadMakers
NHERI@UCSan Diego

Non-Prof Sponsor

NSF
Forest Service U.S. Department of Agriculture
U.S. Endowment for Forestry and Communities
BSLC
SLB Softwood Lumber Board
WoodWorks
Think Wood
Colorado School of Mines Foundation

Construction: First thing first, foundations

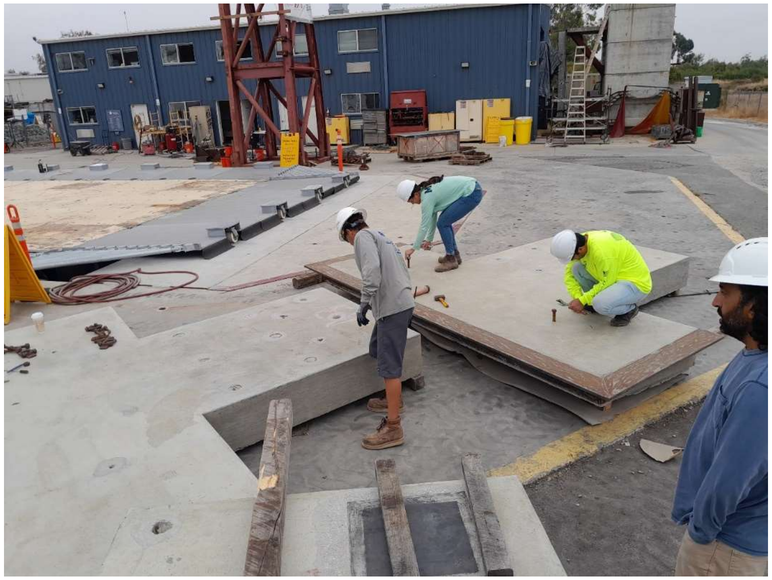


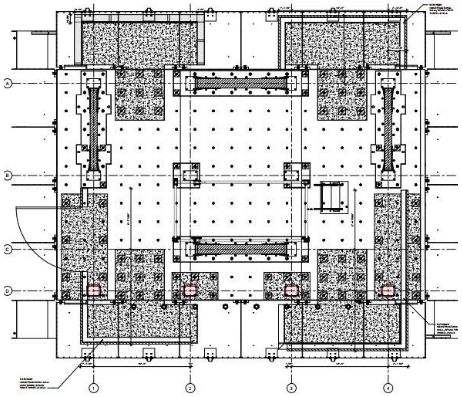
Foundation needed for expanding shake table

This was done by the end of May 2022

Early June

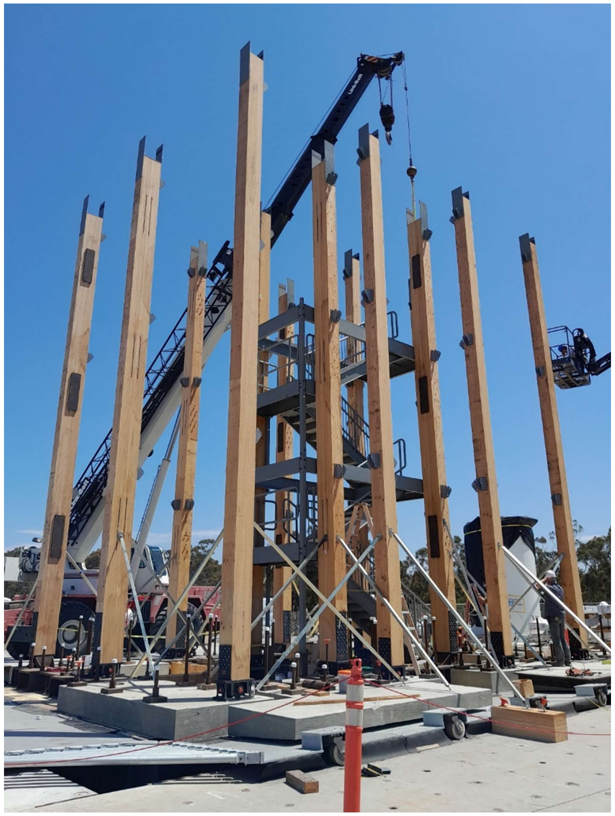
Placing and Post-tensioning of the foundation blocks and beams





July

Swinerton arrived on site after 7/4
Stair first, then Column of the first 3 floors
CLT floors.



Rocking Wall Panels

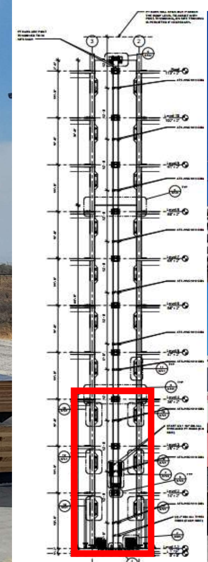
Each Rocking wall consists of 3 segments

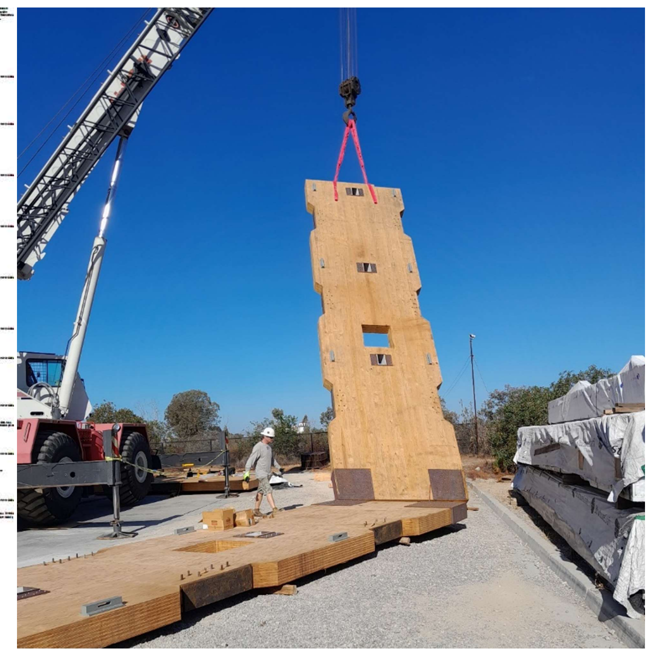
Manufacture

Fabricate and ship

Arrive on site

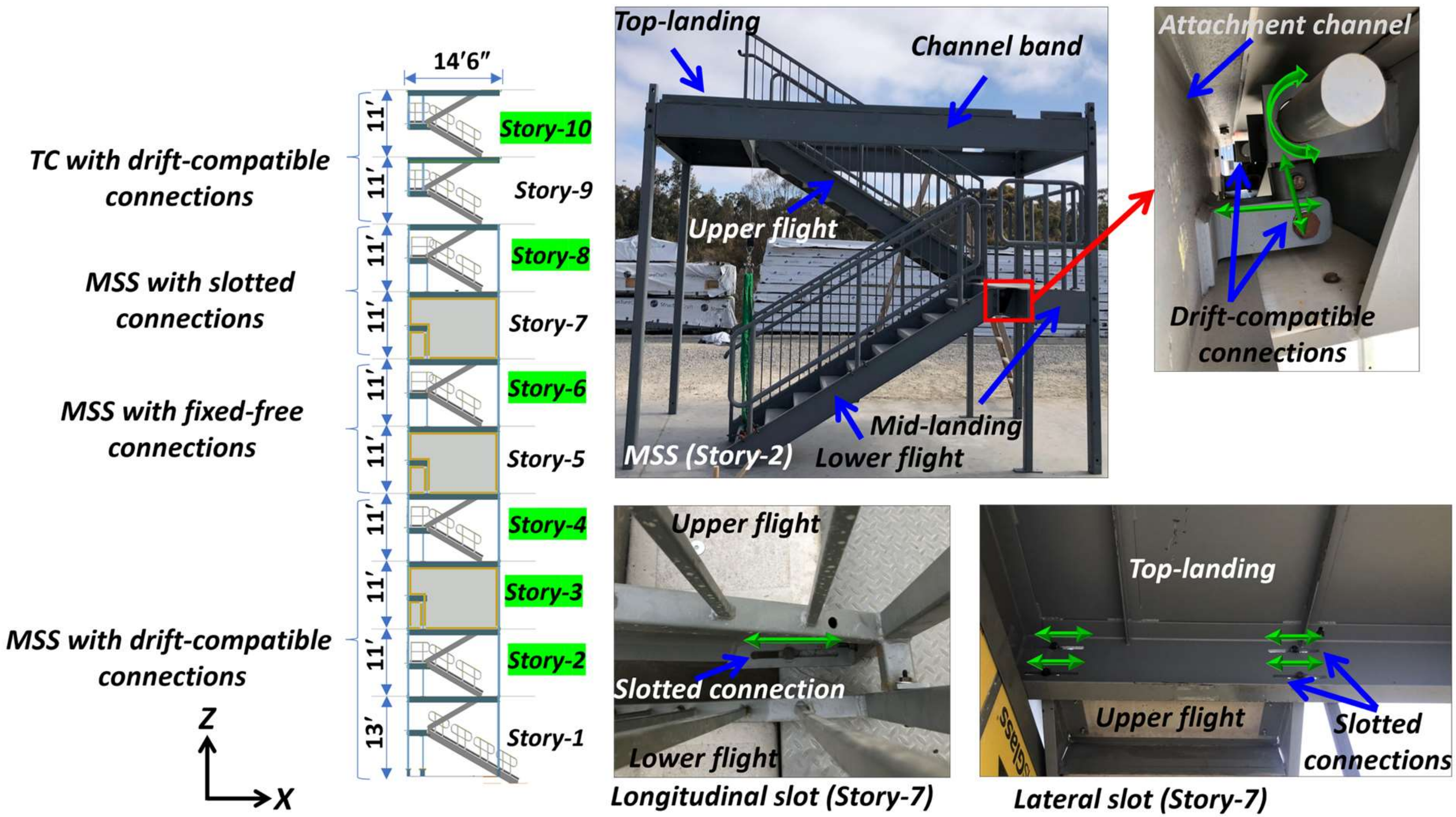
Hardware prep and install





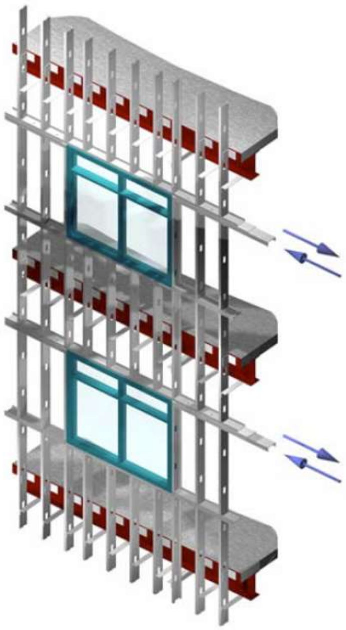

Strong-Tie
Happiness Grows from Trees
SUMITOMO FORESTRY
Boise Cascade
SMARTLAM
FRERES
MASS TIMBER SERVICES
ALLEGION
Construction Specialties
CEMCO
AQURAHOME GROUP
WINCO
Exponent
Henkel

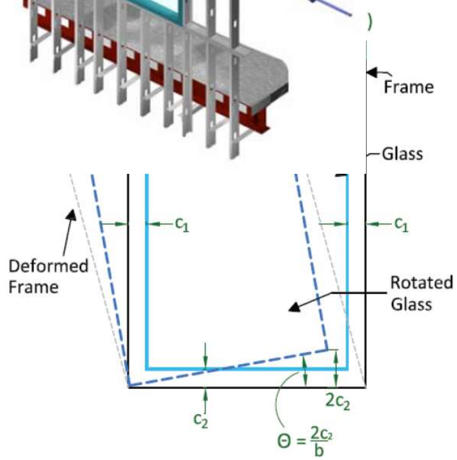
Features of Stair Testing



Credit: Prof. Tara Hutchinson, UCSD

Basic Exterior Wall Configurations



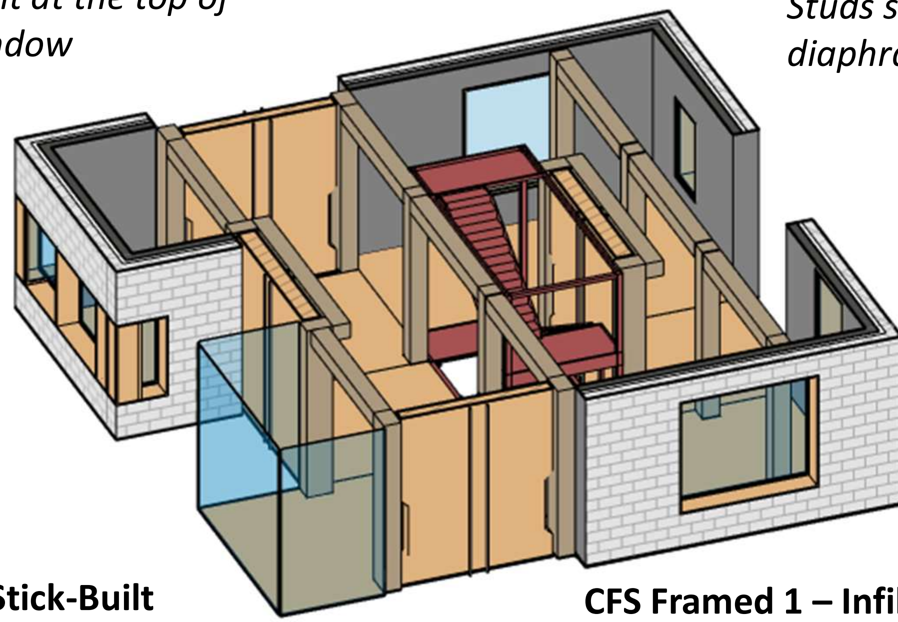


CFS Framed 3 – Spandrel Units with Ribbon Windows

Slip joint at the top of the window

CFS Framed 2 – Bypass Framed with Drift Clips

Studs slip relative to diaphragm



Stick-Built Glass Curtain Wall

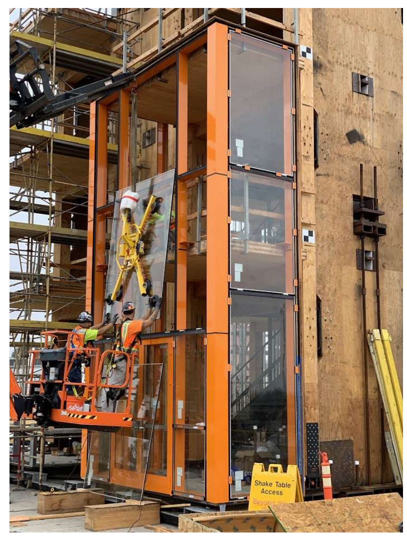
Glass rotates within the frame

CFS Framed 1 – Infill or Platform Framed

Slip joint at the top of the wall

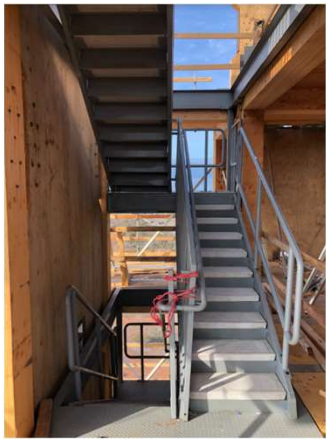
Credit: Prof. Keri Ryan, U Nevada Reno


JLG

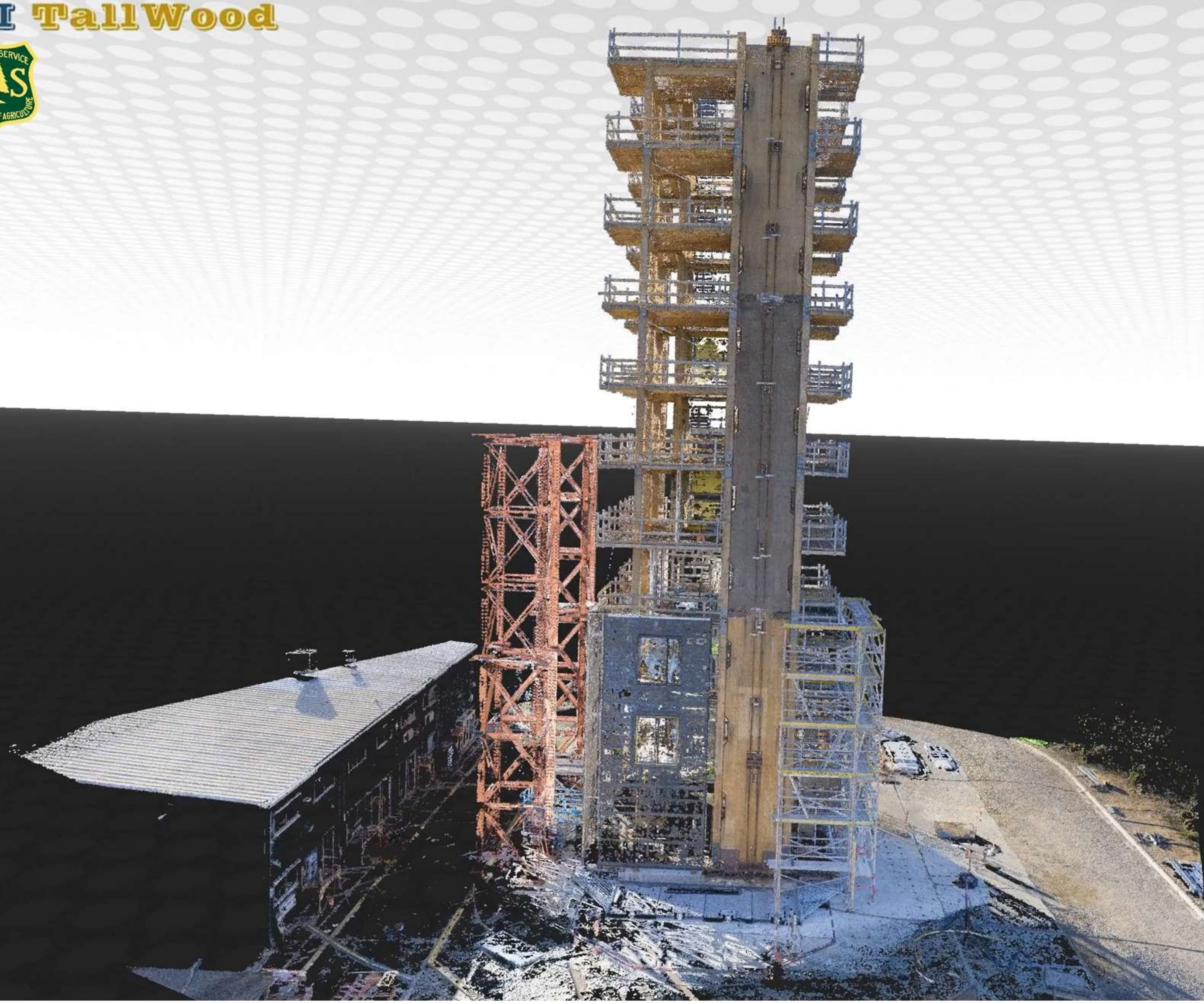

Shake Table
Access






NHERI TallWood

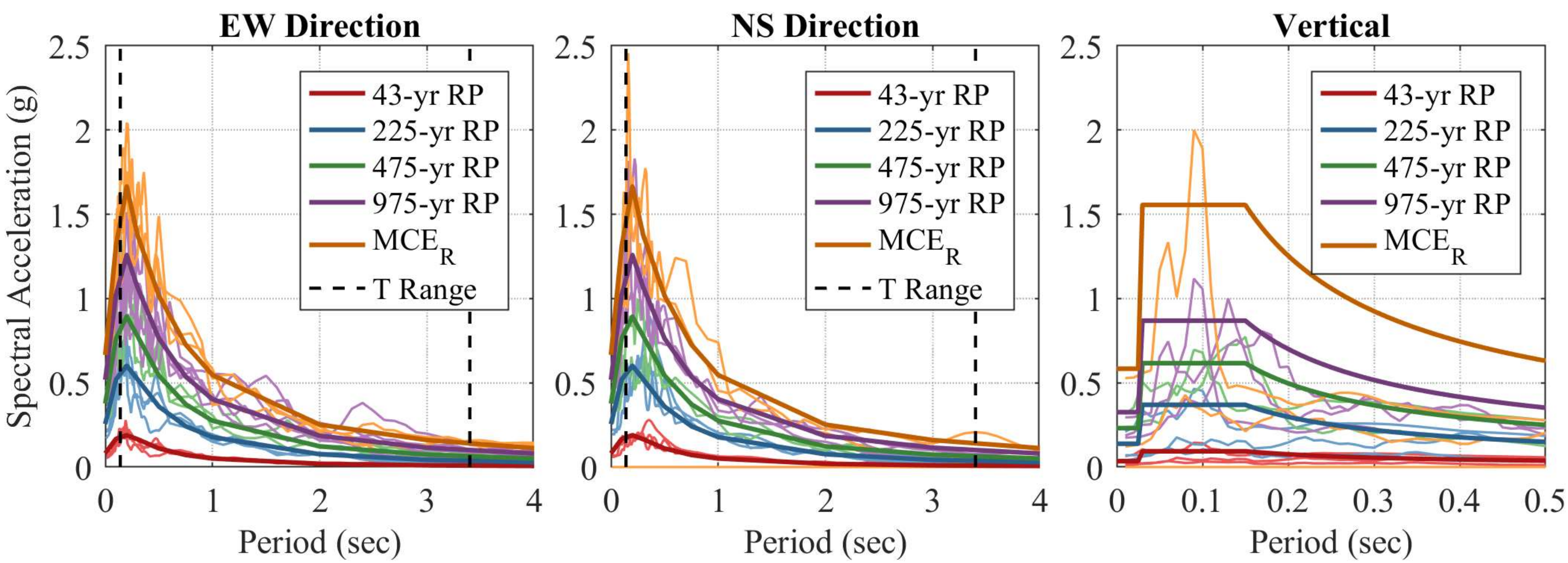


ALERTCalifornia

Are you going to collapse it?

Test Program

Wichman (2023). "Seismic Behavior of Tall Rocking Mass Timber Walls" Ph.D. thesis, University of Washington, Seattle, Washington.



Ground motion selected to represent different return periods at the design location (Seattle WA)
Motions also represent different seismic sources (crustal, subduction interface, subduction intraslab)
Motions include uniaxial, biaxial, and 3D

How many earthquakes should we run?

Total 88 Seismic Tests in Phase 1

Test Program (Cont.)

Hazard Level	Design Set #	Record ID	Earthquake Name	Source
43	3	4213	Niigata, Japan	Crustal
	6	CHBH041103111446	Tohoku	Interface
	7	HKD1310309260450	Tokachi	Interface
	10	subRSN2000890	Ferndale	Intraslab
	11	subRSN2000905	Ferndale	Intraslab
225	3	4213	Niigata, Japan	Crustal
	6	CHBH041103111446	Tohoku	Interface
	7	HKD1310309260450	Tokachi	Interface
	10	subRSN2000890	Ferndale	Intraslab
	11	subRSN2000905	Ferndale	Intraslab
475	2	2951	Chi-Chi	Crustal
	3	3471	Chi-Chi	Crustal
	4	4213	Niigata, Japan	Crustal
	6	CHBH041103111446	Tohoku	Interface
	10	subRSN2000890	Ferndale	Intraslab
	11	subRSN2000905	Ferndale	Intraslab
975	2	268	Victoria, Mexico	Crustal
	4	964	Northridge-01	Crustal
	5	CHBH041103111446	Tohoku	Interface
	6	HKD1270309260450	Tokachi	Interface
	11	subRSN2000890	Ferndale	Intraslab
MCE_R	3	4228	Niigata, Japan	Crustal
	5	761	Loma Prieta	Crustal
	7	CHBH041103111446	Tohoku	Interface
	8	HKD1270309260450	Tokachi	Interface
	11	subRSN2000890	Ferndale	Intraslab
Media	Media Day*	964	Northridge-01	Crustal

A suite of historical ground motions were selected and scaled to represent different hazard levels. These were also used in the RBSD of the building

An unique opportunity to apply the design suite for actual tests.

5/1/23
Small shake
225 Yr
DBE
Small & 225 Rerun
5/9/23
Media Day!
DBE Rerun
975 Yr
MCE
Re-runs
5/22/23

Phase 1 Completed

Test ID	Hazard Level	Direction	EQ Source	Record Number	Record ID	Earthquak	UCSD File	dt	Sig. Horiz.	Sig. Vert. Duration	Total Duration	Target Table Scale Horiz.	Target Table Scale Vert.	Target input pga (g) X Comp.	Target input pga (g) Y Comp.	Target input pga (g) Z Comp.
1	43	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0655	0.0000	0.0000
2	43	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0000	0.0684	0.0000
3	43	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0655	0.0684	0.0000
4	43	X	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0525	0.0000	0.0000
5	43	Y	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0000	0.0604	0.0000
6	43	XY	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0525	0.0604	0.0000
7	43	X	Crustal	3	4213	Niigata, J	225_4213	0.01	9.42	0.0	165.88	0.312	0.000	0.0689	0.0000	0.0000
8	43	Y	Crustal	3	4213	Niigata, J	225_4213	0.01	9.42	0.0	165.88	0.312	0.000	0.0000	0.0995	0.0000
9	43	XY	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	0.312	0.000	0.0689	0.0995	0.0000
10	43	XYZ	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	27.2	80.9	0.213	0.213	0.0655	0.0684	0.0638
11	225	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.0000	0.0000
12	225	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.0000	0.2195	0.0000
13	225	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.2195	0.0000
14	225	X	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.1686	0.0000	0.0000
15	225	Y	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.0000	0.1938	0.0000
16	225	XY	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.1686	0.1938	0.0000
17	225	X	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.2213	0.0000	0.0000
18	225	Y	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.0000	0.3197	0.0000
19	225	XY	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.2213	0.3197	0.0000
20	475	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.3150	0.0000	0.0000
21	475	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.0000	0.3290	0.0000
22	475	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.3150	0.3290	0.0000
23	475	X	Crustal	3	3471	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.4671	0.0000	0.0000
24	475	Y	Crustal	3	3472	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.0000	0.2614	0.0000
25	475	XY	Crustal	3	3473	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.4671	0.2614	0.0000
26	225	XYZ	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	34.2	165.9	1.000	1.000	0.2213	0.3197	0.0697
27	Media Day*	X	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.3488	0.0000	0.0000
28	Media Day*	Y	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.0000	0.2516	0.0000
29	Media Day*	XY	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.3488	0.2516	0.0000
30	225	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.2195	0.0000
31	Media Day*	XYZ	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	20.2	39.8	0.716	0.358	0.3488	0.2516	0.0615
32	Media Day*	XYZ	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	20.2	39.8	0.716	0.716	0.3488	0.2516	0.1230
33	Media Day*	XYZ	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	20.2	39.8	0.716	0.716	0.3488	0.2516	0.1230
34	475	XY	Crustal	3	3473	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.4671	0.2614	0.0000
35	43	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0655	0.0000	0.0000
36	43	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0000	0.0684	0.0000
37	43	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.213	0.000	0.0655	0.0684	0.0000
38	43	X	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0525	0.0000	0.0000
39	43	Y	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0000	0.0604	0.0000
40	43	XY	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	0.319	0.000	0.0525	0.0604	0.0000
41	43	X	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	0.312	0.000	0.0689	0.0000	0.0000
42	43	Y	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	0.312	0.000	0.0000	0.0995	0.0000
43	43	XY	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	0.312	0.000	0.0689	0.0995	0.0000
44	43	XYZ	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	27.2	80.9	0.213	0.213	0.0655	0.0684	0.0638
45	225	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.0000	0.0000
46	225	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.0000	0.2195	0.0000
47	225	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.2195	0.0000
48	225	X	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.1686	0.0000	0.0000
49	225	Y	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.0000	0.1938	0.0000
50	225	XY	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.1686	0.1938	0.0000
51	Media Day*	X	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.3488	0.0000	0.0000
52	Media Day*	Y	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.0000	0.2516	0.0000
53	Media Day*	XY	Crustal	Media Day	964	Northridg	975_964	0.01	23.0	0.0	39.8	0.716	0.000	0.3488	0.2516	0.0000
54	225	X	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.2213	0.0000	0.0000
55	225	Y	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.0000	0.3197	0.0000
56	225	XY	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	1.000	0.000	0.2213	0.3197	0.0000
57	225	XYZ	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	34.2	165.9	1.000	1.000	0.2213	0.3197	0.0697
58	475	X	Crustal	3	3471	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.4671	0.0000	0.0000
59	475	Y	Crustal	3	3472	Chi-Chi	475_3471	0.005	24.6	0.0	76.0	1.000	0.000	0.0000	0.2614	0.0000
60	475	X	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.3150	0.0000	0.0000
61	475	Y	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.0000	0.3290	0.0000
62	475	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	1.000	0.000	0.3150	0.3290	0.0000
63	475	XYZ	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	27.2	80.9	1.000	1.000	0.3150	0.3290	0.3065
64	475	X	Interface	6	CHBH041	Tohoku	MCE CHBH	0.01	65.1	0.0	300.0	0.529	0.000	0.2900	0.0000	0.0000
65	975	X	Crustal	4	964	Northridg	975_964	0.01	23.0	0.0	39.8	1.000	0.000	0.4869	0.0000	0.0000
66	975	Y	Crustal	4	964	Northridg	975_964	0.01	23.0	0.0	39.8	1.000	0.000	0.0000	0.3512	0.0000
67	975	XY	Crustal	4	964	Northridg	975_964	0.01	23.0	0.0	39.8	1.000	0.000	0.4869	0.3512	0.0000
68	475	XYZ	Crustal	3	3474	Chi-Chi	475_3471	0.005	24.6	18.0	76.0	1.000	0.500	0.4671	0.2614	0.1185
69	475	XYZ	Crustal	3	3474	Chi-Chi	475_3471	0.005	24.6	18.0	76.0	1.000	1.000	0.4671	0.2614	0.2370
70	975	X	Interface	5	CHBH041	Tohoku	MCE CHBH	0.01	65.1	0.0	300.0	0.738	0.000	0.4047	0.0000	0.0000
71	975	X	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	0.0	59.7	0.740	0.000	0.4575	0.0000	0.0000
72	975	Y	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	0.0	59.7	0.740	0.000	0.0000	0.4388	0.0000
73	975	XY	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	0.0	59.7	0.740	0.000	0.4575	0.4388	0.0000
74	975	XYZ	Crustal	4	964	Northridg	975_964	0.01	23.0	20.2	39.8	1.000	1.000	0.4869	0.3512	0.1717
75	975	XYZ	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	15.4	59.7	0.740	0.277	0.4575	0.4388	0.2926
76	MCE_R	XYZ	Crustal	5	761	Loma Prie	MCE_761	0.005	17.9	19.6	39.8	1.000	1.000	0.5558	0.7587	0.1175
77	MCER (TBD)	XYZ	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	15.4	59.7	1.000	0.496	0.6187	0.5934	0.5238
78	MCE_R	XYZ	Intraslab	11	subRSN20	Ferndale	MCE subR	0.005	20.3	15.4	59.7	1.000	0.496	0.6187	0.5934	0.5238
79	975	X	Interface	6	HKD12703	Tokachi	MCE_HKD	0.01	45.1	0.0	205.0	0.738	0.000	0.369	0	0
80	975	XYZ	Crustal	2	268	Victoria, I	975_268	0.01	11.1	12.6	15.7	1.000	1.000	0.345	0.505	0.188
81	MCE_R	X	Interface	7	CHBH041	Tohoku	MCE CHBH	0.01	65.1	0.0	300.0	1.000	0.000	0.5484	0.0000	0.0000
82	975	XYZ	Crustal	4	964	Northridg	975_964	0.01	23.0	20.2	39.8	1.000	1.000	0.4869	0.3512	0.1717
83	43	XYZ	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	27.2	80.9	0.213	0.213	0.0655	0.0684	0.0638
84	43	XY	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	0.0	165.9	0.312	0.000	0.0689	0.0995	0.0000
85	225	XY	Intraslab	11	subRSN20	Ferndale	475_subR	0.005	22.0	0.0	80.9	0.667	0.000	0.2102	0.2195	0.0000
86	225	XYZ	Crustal	3	4213	Niigata, J	225_4213	0.01	9.4	34.2	165.9	1.000	1.000	0.2213	0.3197	0.0697
87	225	XY	Interface	6	CHBH041	Tohoku	225_CHBH	0.01	68.3	0.0	300.0	1.000	0.000	0.1686	0.1938	0.0000
88	475	XYZ	Crustal	3	3474	Chi-Chi	475_3471	0.005	24.6	18.0	76.0	1.000	1.000	0.4671	0.2614	0.2370

MCE: Loma Prieta EQ (0.76 g)

Gravity Column

Corner of the West Rocking wall

NS performance: Effective low damage detail (MCE)

You can see the NS façade returned to original position after shake

We did not break a single window


L6-16N
L6-16E
L6-15E

Initial Observations

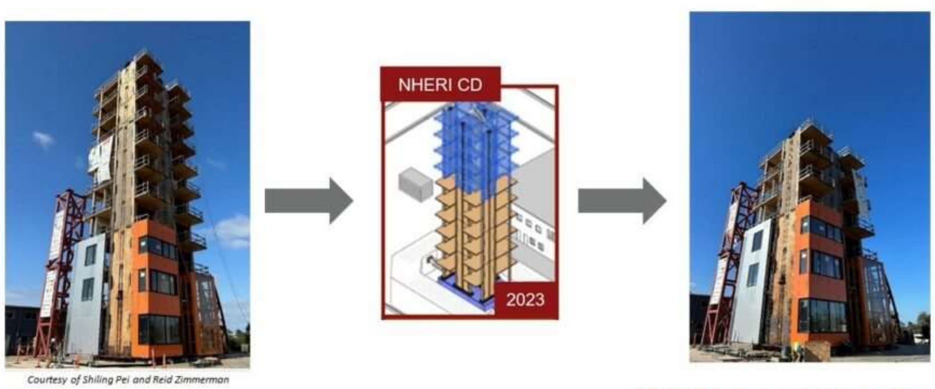
- Building periods are relatively long (about 1.8-2 sec)
- After all 88 earthquake loading, No structural damage, No residual drift.
- Further tests for a total of more than 200 earthquakes, rocking wall element and gravity framing essentially undamaged
- Large overall building deformation, rocking mechanism engaged at intensity levels above DBE, reached close to 3% max drift
- Low-damage NS system details are effective, did not break a single window.

First Paper to JSE:
"Shake Table Test of a Full-Scale Ten-Story Resilient Mass Timber Building"

More testing…

- Payload test by MTU (June 2023) +19 shakes
- Phase 2 Japanese test (August 2023) +51 shakes
- Deconstruction to 6-story

Prof. Andre Barbosa from OSU (3 phases of testing)
[Converging Design – Home – TallWood Design Institute (tallwoodinstitute.org)](tallwoodinstitute.org) + 66 shakes (first 2 config)
So far 88+19+51+66=224 earthquakes



NHERI TallWood
10-story Building Specimen

NHERI Converging Design
6-story Building Specimen

Codification underway…

Previous Wood Innovation Fund

Development of prescriptive design provisions and commentary for post-tensioned mass timber rocking wall lateral systems.
(2018-2023) Completed

CHARLES PANKOW FOUNDATION
Building Innovation through Research

COLORADO SCHOOL OF MINES

kpff

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

(Mandatory) Requirements for Post-Tensioned Mass Timber Rocking Walls

C.1 General

C.1.1 Scope
These provisions shall be used for the design and construction of all members and connections that are part of a post-tensioned mass timber rocking wall lateral force-resisting system (LFRS) including mass timber panels, mass timber bounding columns (where present), post-tensioning components, and energy dissipation components. The provisions provided herein shall be applied in combination with the requirements of this Standard, the NDS including Appendix E, ASCE 7-16, and the applicable building code.

C.1.2 Notation

$F_{pti,j}$ = initial force in post-tensioning components for wall segment j, lb.

$F_t(A_{parallel})'$ = adjusted tension design value for mass timber panel composed of cross-laminated timber, lb.

$M_{ed,rm,j}$ = moment capacity of the rocking mechanism contributed by all the energy dissipation components for wall segment j, lb-in.

$M_{n,rm,j}$ = nominal moment capacity of the rocking mechanism for wall segment j, lb-in.

$M^{*}_{n,rm,j}$ = nominal moment capacity of the rocking mechanism neglecting energy dissipation components for wall segment j, lb-in.

$M_{pr,rm,j}$ = probable moment capacity of the rocking mechanism for wall segment j, lb-in.

Busch et al. (2021) "Prescriptive Seismic Design Procedure for Post-Tensioned Mass Timber Rocking Walls", Journal of Structural Engineering.

Prescriptive Seismic Design Procedure for Post-Tensioned Mass Timber Rocking Walls

A. Busch, S.M.ASCE[1]; R. B. Zimmerman, M.ASCE[2]; S. Pei, M.ASCE[3]; E. McDonnel, M.ASCE[4]; P. Line, M.ASCE[5]; and D. Huang, S.M.ASCE[6]

Abstract: In this study, a prescriptive seismic design procedure for post-tensioned mass timber rocking wall lateral force–resisting systems is proposed. Unlike performance-based design approaches that employ nonlinear analysis, this procedure utilizes techniques and analysis procedures that are routinely applied in design industry practice as well as adhering to traditional approaches contained in current US standards. The design procedure targets providing a basis for prescriptive design of mass timber rocking wall lateral force–resisting systems and their future adoption into model codes. For illustration, the design approach is applied to an example building, with the building's performance validated through a nonlinear numerical model simulation. DOI: 10.1061/(ASCE)ST.1943-541X.0003240.

FEMA P695 Study on post-tensioned mass timber rocking wall lateral systems
(2024-2026) on going

ASCE7 update (2028)

Thank You

Earthquake-proof Tall Buildings

Yes.

Mass Timber + Rocking Wall

At least we know **for sure** this is one of the ways to do it.

And we are working to codify it in ASCE7 and SPDWS

Twitter: @slpei

NHERI TallWood

Colorado School of Mines
University of Washington
University of Nevada, Reno
Colorado State University
Washington State University
Lehigh University
Michigan Technological University
UC San Diego
京都大学 Kyoto University
Università degli Studi dell'Aquila
Oregon State University
University of California at San Diego NHERI Natural Hazards Engineering Research Infrastructure
ALERTCalifornia UC San Diego

Special Thanks to UCSD Drone Lab for great footage!

Simpson Strong-Tie
Happiness Grows from Trees SUMITOMO FORESTRY
Boise Cascade
SmartLam North America
Freres Engineered Wood
Mass Timber Services
Allegion Pioneering Safety
Rex Lumber
CS Construction Specialties
Idaho Forest Group
CEMCO
SFIA
AQ Group AQURA HOME
innotech windows + doors
WINCO Window
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Exponent
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BSLC
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WoodWorks
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Colorado School of Mines Foundation
Charles Pankow Foundation Building Innovation through Research

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