NHERI TALLWOOD PROJECT
Updates 2020

NHERI TallWood Team

Discussion Topics

- Brief Overview / Recap on Project objective/vision
- What have been done?
  - Archetype development
  - Two-story test (shake table)
  - Assembly level test (biaxial cyclic)
- What is on-going?
  - Numerical modeling
  - Non-structural system inclusion
  - Resilience-based seismic design
- Updates on 10-story Shake Table Test
  - UCSD Table upgrade timeline
  - Design and Development
  - Construction planning
  - Steps forward with tentative schedule

Project Objective and Vision

- Mass Timber => A new way to build

Resilience
Do it RIGHT the first time

Wood is good in seismic

There is a market

- How about **develop and validate a design method for resilient tallwood buildings**?

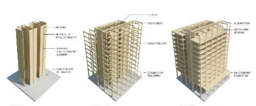
Get funding from NSF → R&D Design method, modeling approach, detailing, etc. → Design and build a 10-story full scale building → Test it to prove we can do it.

Collaborate with Industry (funding & talents)

GAME PLAN

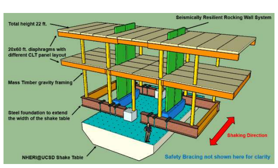
Project duration: 2016~2021

Nheritallwood.mines.edu

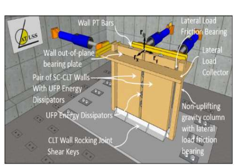


Define Tall Wood Archetypes

Investigative testing at system level



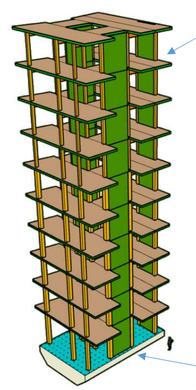
Two-story test at
NHERI@UCSD
2017 Summer

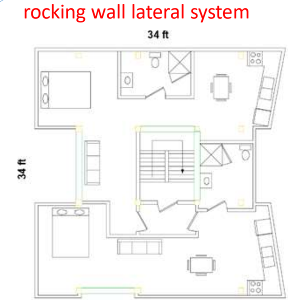


Bi-axial tests at
NHERI@Lehigh
Currently on-going

Full-scale 10-story validation Test (2021)

Mixed-Use building w/ CLT rocking wall lateral system





UCSD Shake Table

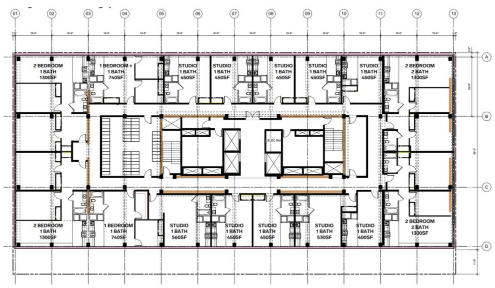
Seismic R & D
(2018~2019)

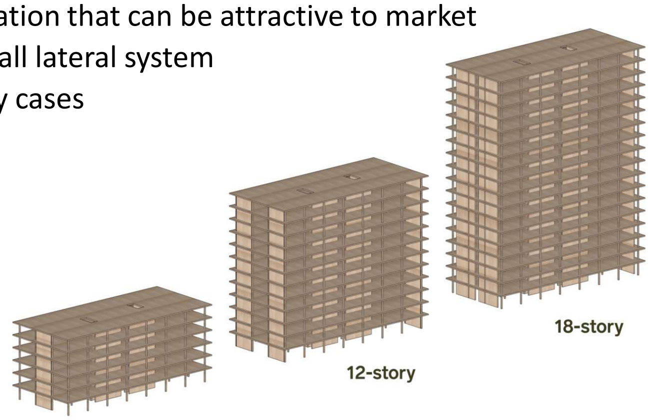
What’s Done? Archetypes

Thomas Robinson

Jonathan Heppner

- Lever Architecture led the development of Tall wood archetypes
  - Representing a general configuration that can be attractive to market
  - Floor plan suitable for rocking wall lateral system
  - Consider new IBC: 6, 12, 18 story cases





What’s Done? Two-story Test

- We completed a 2-story building test with PT CLT rocking walls in 2017.
- All results and publications now available on Project Website
- Main take-away:
  - The structural system can be damage free at all DBE and some MCE shakes
  - Numerical model works
  - Prototype connections and detailing work
  - Collaboration is key to get this done

Two-story building tested during Summer of 2017

What's Done? Assembly Test

- Building Assembly Testing Task
  - Assemble the proposed rocking wall - floor system and conduct loading tests to study the effects of biaxial loading on the structural and non-structural assembly

- Led by Lehigh Team

Co-PI: James Ricles
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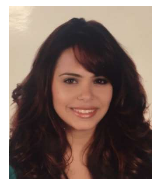
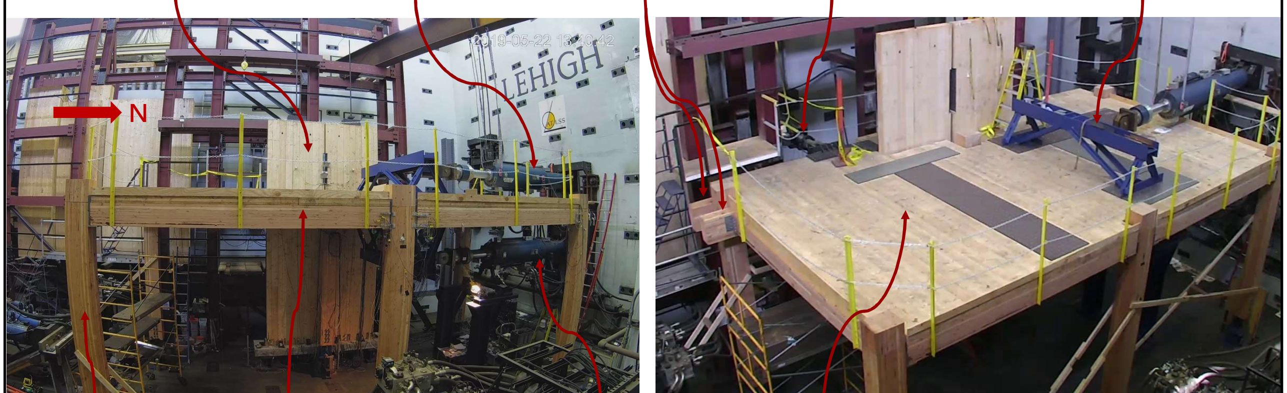
Co-PI: Richard Sause
rs0c@Lehigh.edu



Ph.D. student:
Alia Amer

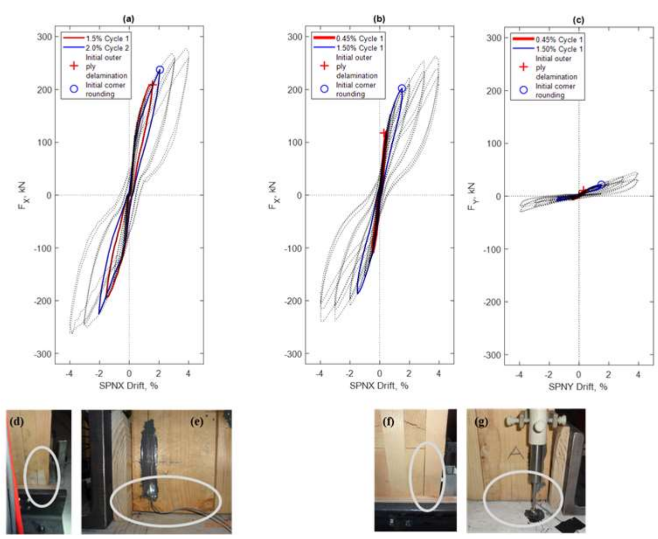
Lehigh Biaxial Test Sub-assembly



Testing Schedule 2020

Phase	Objective	Schedule
Phase II.1-S	• Investigation of the behavior of repaired SC-CLT wall (configuration [1]) under bidirectional loading (repaired foundation) • Investigation of the deformation behavior of the gravity connection under reduced-scale gravity load • Investigation of the deformation behavior of the gravity connection when the rotation of the steel seat is restrained	Last week of March
Phase II.2-S	Investigation of the behavior of repaired SC-CLT wall (configuration [2]) under bidirectional loading	Mid-April
Phase III	Investigation of the response of the SC-CLT wall (new wall) and a new connection (if needed) under predefined bidirectional earthquakes displacement time histories	November

Preliminary results (Sause et al. 2020)



Sause, R., Ricles, J., Amer, A., and Marullo, T. (2020). Multi-directional cyclic testing of cross-laminated timber rocking wall-floor diaphragm sub-assemblies. Procedings of the 17th World Conference on Earthquake Engineering, September 13-18, Sendai, Japan, 2020

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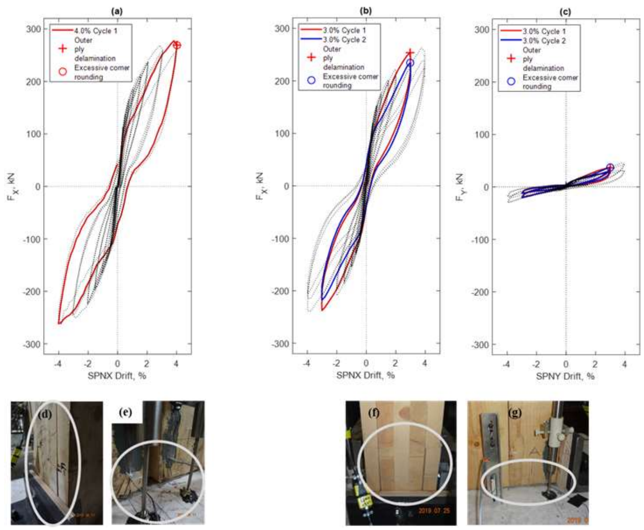

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What's On-going? Modeling Method

- Numerical modeling Task
  - Developing numerical models for tall wood building with post-tensioned rocking wall systems to be used for design and dynamic response prediction

- Led by University of Washington Team

Co-PI: Jeffrey Berman
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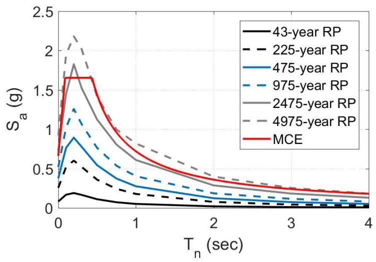
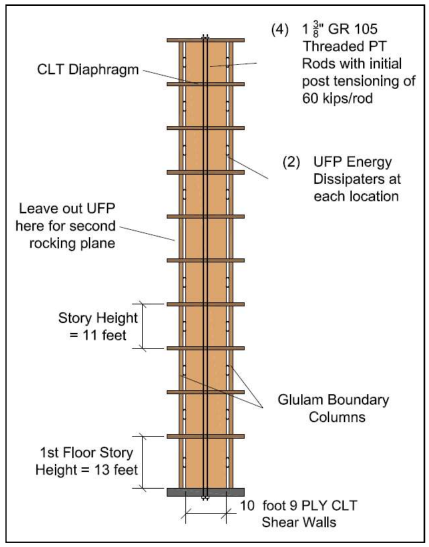
Ph.D. student:
Sarah Wichman

Lateral Design Parameters



- Location: Downtown Seattle, WA
- Site Class: C
- Risk Category II



Limit States:

- No crushing at 975 yr
- No PT yield at 975 yr
- No PT fracture at 4975 yr
- No UFP fracture at 4975 yr

Limit States

- 2% drift limit at 975 yr
- 3.5% drift limit at 4975 yr

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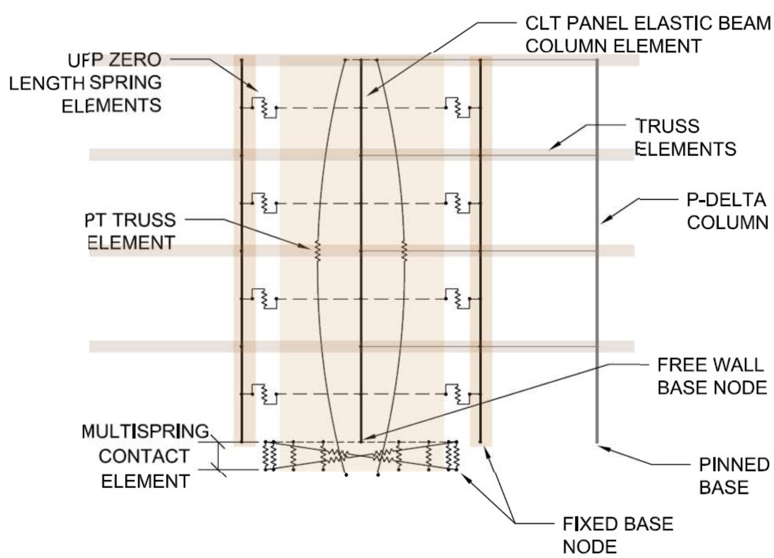
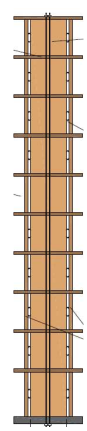
10 Story Modeling Approach





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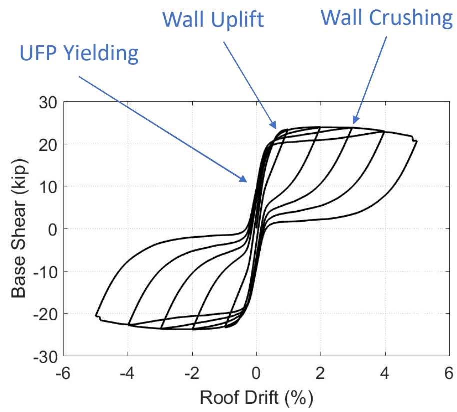
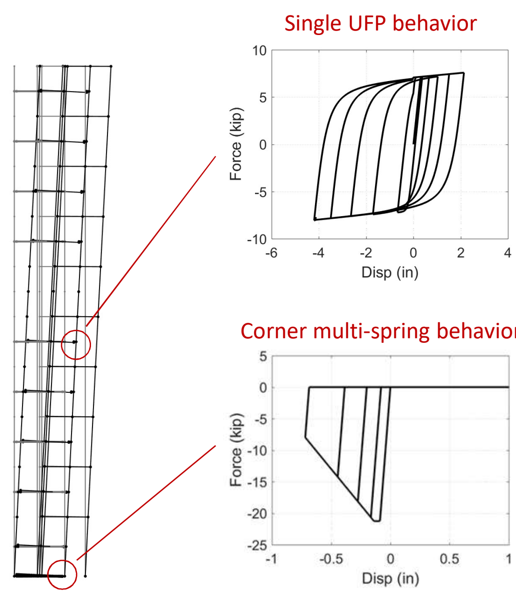
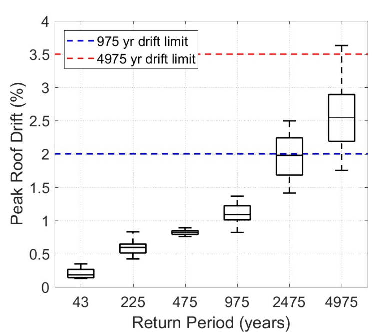
Preliminary 10 Story Model Results



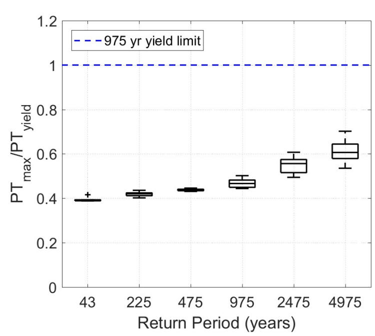


Preliminary 10 Story Model Results

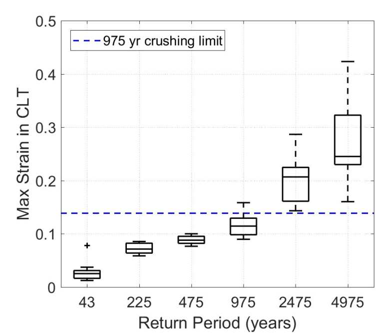
Drift:



PT Forces:



CLT Crushing Strain:



What's On-going? Non-structural sys

- Resilient non-structural system design Task
  - Develop improved non-structural system modeling and detailing techniques so they are compatible with resilient tall wood buildings.

- Led by University of Nevada at Reno team, in collaboration with UCSD

Co-PI: Keri Ryan
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Ph.D. student:
William Roser

Ph.D. student:
Hasani Hamed

Prof. Tara Hutchinson
Collaborating PI at UC San Diego

Nonstructural Components of Interest for the Test Program

- Interior Partition Walls
- Lightweight Building Skins/Facades with Glazing
- Stairs
- Suspended Ceilings
- Sprinkler Piping/Plumbing
- Mechanical/Electrical Equipment

Priority (the first four items)

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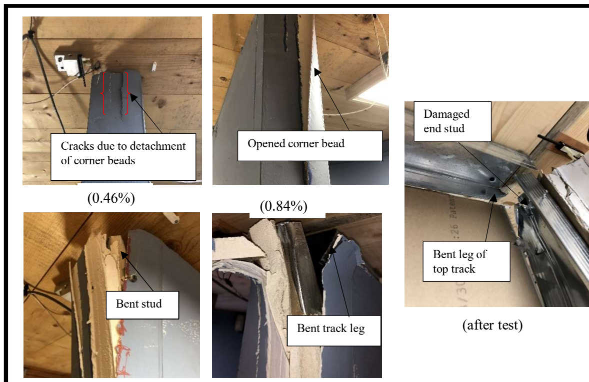
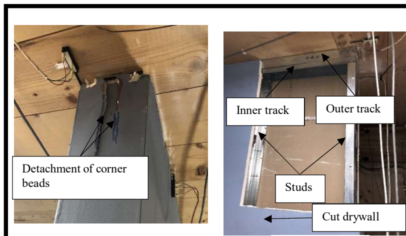
Brief Outcomes Report of Nonstructural Wall Tests at Lehigh
Slip Track vs. Telescoping Slip Detailing in a Straight Wall

Slip-track detailing



(0.46%) (0.84%) (2.56%) (3.2%) (after test)

Telescoping detailing

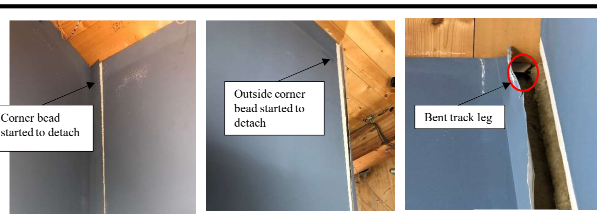


(5%) (After test)

- Conclusion: Telescoping eliminated typical damage at wall ends. Damage was limited to minor detachment of corner beads.

Brief Outcomes Report of Nonstructural Wall Tests at Lehigh
Corner Gap vs. Distributed Gap Detailing for Intersections in C-shaped Walls

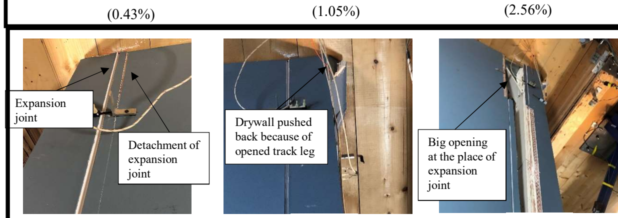
Corner gap



(0.43%) (1.05%) (2.56%)

Conclusions:
Significant damage delayed until about 2.5% drift

Distributed gap



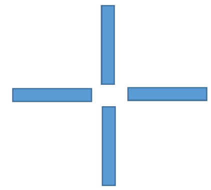
(0.84%) (1.05%) (2.56%)

The onset of damage was postponed to almost 1% drift.

However, the walls separated at the gaps into isolated segments that posed a collapse risk.

Where to go from here in 10-story tests?

- Further investigation of telescoping detail with corner gaps, through walls in both directions.
- Explore engineered products such as expansion joint covers that allow for larger gaps (Construction Specialties).
- Allow slip of the out-of-plane walls using a transversely slotted top track.



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Extension to Exterior Walls/Building Skins

- Many detailing issues for interior walls are relevant to exterior walls, but with the addition of windows/glazing.
- Racking tests validate the drift compatible performance of curtain walls, window walls, but extensive glass damage is typical, even in moderate shaking.

Systems of Interest	Class of Variation	Variations Considered
Storefront	Glazing method	Mechanically captured vs structurally glazed
Curtain wall w/ glazing	Glass aspect ratio	Varied from 1:2 to 2:1
Stick built curtain wall	Glass treatment	Heat strengthened vs. fully tempered
Unitized curtain wall	Glass type	Laminated and insulating glass units (IGU)
Light-framed with windows	Framing style	Balloon vs platform framed
Light gage steel stud framing	Finish material	Metal panel, wood shingle, and stucco
Wood stud framing	Window type	Fixed or operable, variable size
	Window framing	Metal or wood framed
	Glass variations	Same variables as for curtain walls may be applied

Partnership with Construction Specialties to Explore Stair Detailing

- CS DriftReady™ Stairs detailed with slip joint to accommodate interstory movement
- Details to be explored
  - Incorporation into scissor stairs with intermediate landing
  - Connection to the main structural system
  - Interaction with surrounding fire protection walls

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What's On-going? RBSD

- Resilience Based Seismic Design Task
  - Developing a quantitative approach to design tall wood buildings to hit a predefined resilience (i.e. down time) level after an earthquake.

- Led by Colorado State University Team

Co-PI: John van de Lindt
jwv@engr.colostate.edu

Ph.D. student: Jace Furley

Objectives

- NIST Hazard Levels – Linked With Proposed Performance
  - Routine: 50 to 100 year MRI, 64%-39% PO.
    - No Damage (Immediate Full-Recovery)
  - Design: 500 year MRI, 10% PO.
    - Immediate Functional Recovery (REDi Repair Class = 1 or lower)
  - Extreme: 2,500 year MRI, 2% PO.
    - Immediate Re-Occupancy (REDi Repair Class = 2 or lower)

Routine	***Earthquakes that are likely to occur routinely.*** Routine earthquakes are defined as having a 70% probability of occurring in 50 years. In general, earthquakes of this size will have magnitudes equal to 5.0 – 5.5, should not cause any noticeable damage, and should only serve as a reminder of the inevitable. San Francisco's Department of Building Inspection (DBI) uses this earthquake level in their Administrative Bulletin AB 083 [San Francisco Building Code 2014] for purposes of defining the *service level* performance of tall buildings.
Expected	***An earthquake that can reasonably be expected to occur once during the useful life of a structure or system.*** It is defined as having a 10% probability of occurrence in 50 years. San Francisco's Community Action Plan for Seismic Safety (CAPSS) [ATC 2010] assumed that a magnitude 7.2 earthquake located on the peninsula segment of the San Andreas Fault would produce this level of shaking in most of the city.
Extreme (Maximum Considered Earthquake)	***The extreme earthquake that can reasonably be expected to occur on a nearby fault.*** It is defined as having a 2% probability of occurrence in 50 years. The CAPSS defined magnitude 7.9 earthquake located on the peninsula segment of the San Andreas Fault would produce this level of shaking in most of the city.

Table 1: SPUR Guidelines for SF

Objectives (cont.)

- Proposed Design Performance Objectives
  - Routine: 50% NE Probability
    - Structural:
      - ISD < 1.6% (UFP Yielding)
    - Non-Structural:
      - Floor Acceleration < 0.72 g (HVAC Chiller)
      - ISD < 0.4% (Interior Partition Walls)
  - Design: 50% NE Probability
    - Structural:
      - ISD < 1.6% (UFP Yielding)
    - Non-Structural:
      - Floor Acceleration < 0.72 g (HVAC Chiller)
      - ISD < 1.9% (Interior Partition Walls)
  - Extreme: ISD < 1.6% 50% NE
    - Structural:
      - ISD < 1.6% (UFP Yielding)
    - Non-Structural:
      - Floor Acceleration < 1.5 g (HVAC Ducts)
      - ISD < 1.9% (Interior Partition Walls)

Repair Class	Repair Description
3	Heavily damaged *structural* or *non-structural* components which pose a risk to 'life-safety' and must be repaired to achieve **Re-occupancy**. Consequently, these components must also be repaired to achieve Functional Recovery and Full Recovery, since by definition they follow Re-occupancy.
2	Damaged *non-structural* components which do not pose a 'life-safety' risk or otherwise hinder Re-occupancy but must be repaired to achieve **Functional Recovery**. Consequently, the component must all be repaired to achieve Full Recovery, since by definition it follows Functional Recovery.
1	Minimal or minor cosmetic damage to *structural* or *non-structural* components which do not hinder Re-occupancy or Functional Recovery but must be repaired to achieve **Full Recovery**.

Table 2: REDi Repair Classes

Objectives (cont.)

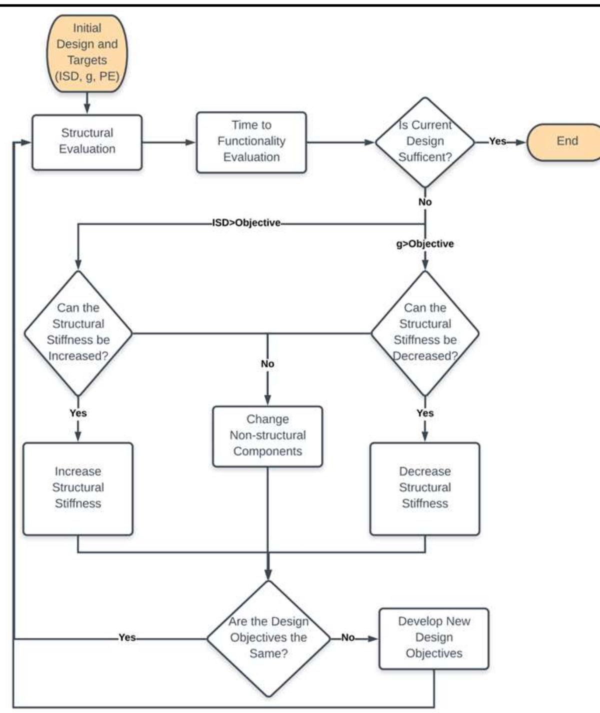
- Proposed Time to Functionality Objectives
  - Routine: 0 weeks to Full Recovery
  - Design: 0 weeks to Functional Recovery (Repair Class 1 or lower)
    - 6 weeks to Full Recovery
  - Extreme: 0 weeks to Re-Occupancy (Repair Class 2 or lower)
    - 12 weeks to Functional Recovery
    - 14 weeks to Full Recovery

Repair Class	Repair Description
3	Heavily damaged *structural* or *non-structural* components which pose a risk to 'life-safety' and must be repaired to achieve **Re-occupancy**. Consequently, these components must also be repaired to achieve Functional Recovery and Full Recovery, since by definition they follow Re-occupancy.
2	Damaged *non-structural* components which do not pose a 'life-safety' risk or otherwise hinder Re-occupancy but must be repaired to achieve **Functional Recovery**. Consequently, the component must all be repaired to achieve Full Recovery, since by definition it follows Functional Recovery.
1	Minimal or minor cosmetic damage to *structural* or *non-structural* components which do not hinder Re-occupancy or Functional Recovery but must be repaired to achieve **Full Recovery**.

Table 2: REDi Repair Classes

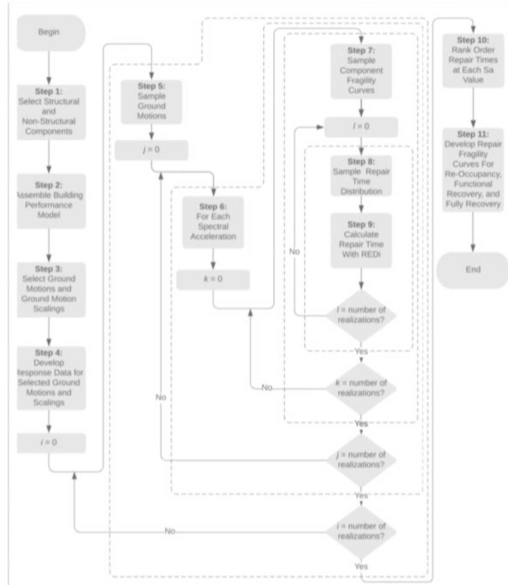
Methodology

- Optimizes Design (Needs Refinement)
  - Considers Structural and Non-Structural Modifications
  - Can Alter Design Objectives to Consider New Design



Time to Functionality (Repair Fragility Curves)

- Differences from REDi and PACT
  - Multi-Layered Monte Carlo Used Instead of 90% Repair Value.
  - REDi Repair Methodology is Incorporated into the Multi-Layered Monte Carlo Instead of Using Results from PACT.
  - Instead of Considering 1 Event (such as 2500 MRI), a Variety of Events are Considered
  - Effectively Incorporates REDi and PACT into a Stochastic Simulation



10-story test planning team… so far

Researchers

PI: Shiling Pei | PhD. Da Huang | PhD. Aleesha Busch | MS. Rachel Chaggaris

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

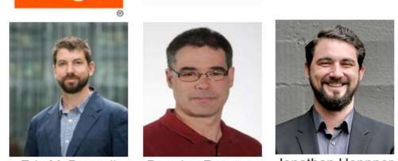
Andre Barbosa | Arijit Sinha | Co-PI: Dan Dolan

Oregon State University | TALLWOOD DESIGN INSTITUTE | WASHINGTON STATE UNIVERSITY

Industry Partners

Steve Pryor | Reid Zimmerman | Hans-Erik Blomgren | Kevin Smith

SIMPSON Strong-Tie | kpff | KATERRA | CS Construction Specialties



Eric McDonnell | Douglas Rammer | Jonathan Heppner

Holmes | Forest Service U.S. Department of Agriculture | LEVER ARCHITECTURE

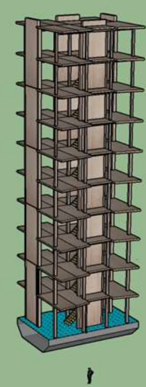
Structural Framing with 4 Mass Timber Rocking walls

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

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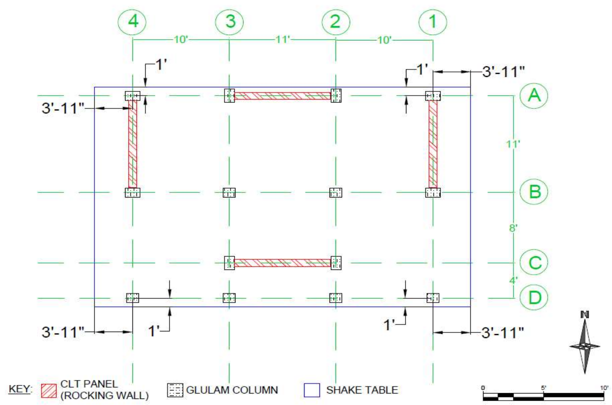
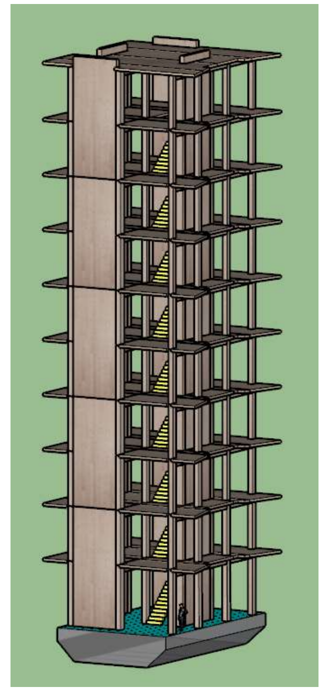
Updates on 10-story tallwood test

- UCSD Shake Table upgrade
  - The table will have 3D capacity for our test
  - It is ongoing, so far on schedule (complete by 2/2021)
  - One quick testbed structure test (1 month) will be conducted on the table before we get on (Good for us)
- Preliminary design of the building is complete
  - Gravity frame design done, connection details TBD
  - Lateral design done (CLT rocking wall), initial simulation done, RBSD to follow, MPP rocking wall design to follow
  - Waiting for Wood Innovation Grant results (05/2020) for inclusion of NLT/DLT floors

Floor Plan Basics

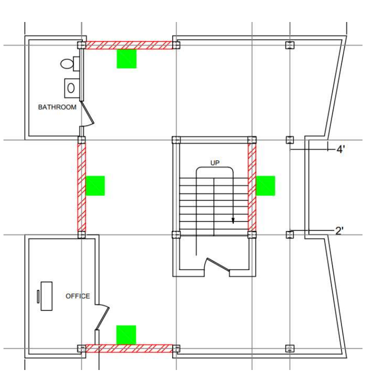
- UCSD Shake table 25 x 40 ft (7.6 x 12.2 m)
- Building column grid 22 x 31 ft (6.7 x 9.4 m), floor cantilever out



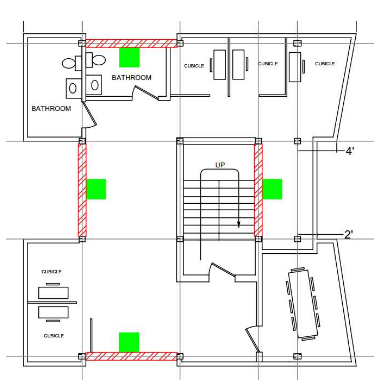


Architectural Design

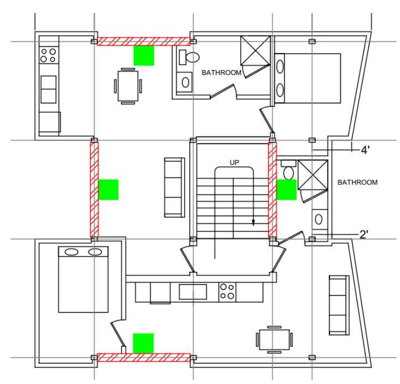
- Three different Floor usage types



Retail shop (1-2 story)

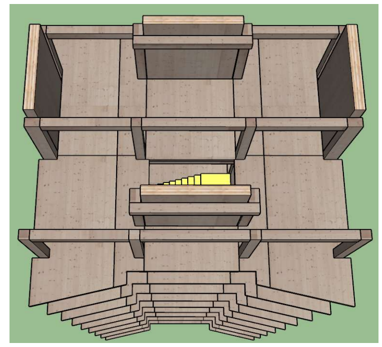


Office space (3-6 story)

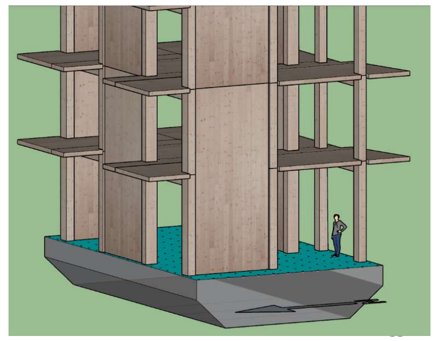


Residential (7-10 story)

Gravity Design Summary

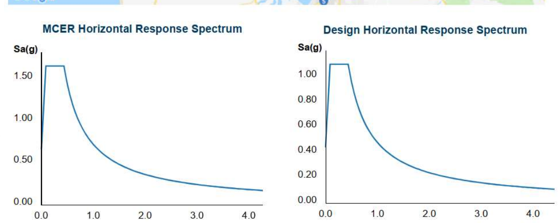


- Gravity Design following NDS
  - Total floor dead load = 70 lb/sq.ft. (3.35kN/m2)
  - Total floor live load = 65 lb/sq.ft. (3.1 kN/m2)
- Final size of the members
  - Columns (12.25 x 12 ~ 15 in) (31 x 30 ~ 38 cm)
  - Beams (12.25 x 13.5 in) (31 x 34 cm)
  - CLT floor (5-ply CLT, 6 in) (15 cm)
  - Rocking wall panel (9-ply CLT, 12 in) (30 cm)
  - All sizes considering 2-hr fire sacrificial layers (3.6 in) (9 cm)



Basic Lateral Design Parameters

- ASCE7-16 Uniformed hazard demands at Seattle WA. Site Class C, Risk Category II
- Seismic weight approximately 70 PSF.
  - The final building specimen will be loaded to this overall weight level using Steel Plates during seismic test.
  - Seismic mass placement in the building will be arranged to minimize eccentricity
- Four rocking walls, 2 in each direction, 2 CLT, 2 MPP.



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Tentative Schedule-10st Test

- 05/2020: Contractor selected and engage in design (Currently working with Swinerton and a few others to obtain quotes)
- 07/2020: Design and Detailing complete
- 09/2020: Final Construction package complete
- 10/2020: All material production orders in place
- 03/2021: First batch of construction material arrive @ UCSD
- 04/2021: UCSD shake table upgrade complete, ready for construction
- 05~08/2021: Construction + Instrumentation
- 09/2021~02/2022: Building Testing (may contain different phases)
- 03/2022: Disassemble of the building specimen

Consider joining the team if interested.

Project Information

www.nheritallwood.mines.edu

Information on this project and past results

- List of published papers
- Some presentations

10-story building:

- Revit model of the current gravity design
- A summary of 10-story building structural frame sizes and configurations
- Important updates

Contact me if there is any questions:
spei@mines.edu

Questions and Open Discussion

Seriously, Folks: Questions & Comments