Eleventh U.S. National Conference on Earthquake Engineering
Integrating Science, Engineering & Policy
June 25-29, 2018
Los Angeles, California

DYNAMIC TESTING OF MULTI-STORY ROCKING CROSS LAMINATED TIMBER WALLS

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ABSTRACT

With the recent development of engineered wood products such as cross laminated timber, tall timber buildings are becoming feasible and offer benefits such as faster construction and the use of sustainable building materials. It has also opened the door to creating seismic resilience systems that sustain minor damage during large earthquakes. With this in mind, the NHERI TallWood Project funded by the National Science Foundation, is developing a rocking cross laminated timber wall seismic force resisting system for tall timber buildings that enables seismic resilience by meeting rigorous performance requirements. Recently, the NHERI TallWood group tested a full-scale two-story mass timber building, with cross laminated timber post-tensioned rocking walls as the lateral system, on the world's largest outdoor shake table in San Diego, California at the NHERI @UCSD facility. Here, the design and dynamic testing of the rocking walls will be discussed. The results of this work will be used to create numerical models and to inform the design of the rocking walls for an upcoming ten-story test.

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Wichman S, Berman J, Pei S, van de Lindt J, Barbosa A, Dolan J.D., McDonnell E, Zimmerman R.B. Dynamic Testing of Multi-Story Rocking Cross Laminated Timber Walls. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

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Introduction

Using cross laminated timber (CLT) panels in a post-tensioned rocking wall system shows great potential for creating reliable, cost-effective, and rapidly constructible ductile seismic load resisting systems. Using post-tensioned rocking wall systems with replaceable ductile elements allows tall timber buildings to be easily repaired following even large earthquakes, improving the seismic resilience and sustainability of the building. Systems utilizing CLT post-tensioned rocking walls have been implemented (e.g. the Framework building in Portland, Oregon) using results of previous experimental programs [1] [2] but there is a need to develop design standards for conventional design and for performance and resilience-based design, so the full potential of these buildings can be utilized.

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The NHERI TallWood Project includes research on the behavior of rocking CLT wall systems in tall timber buildings, including the development of performance-based and resilience-based seismic design procedures. The project involves modelling and testing tasks, including the recent completion of a full-scale two-story shake table test, utilizing the rocking CLT walls. This paper focuses on the design and results of the rocking walls for two-story shake table tests. These methods will be used to verify the system's performance prior to designing a full-scale ten-story structure and returning to the NHERI@UCSD facility in 2020 for testing. The test structure for the two-story test can be seen in Figure 1.

Figure 1. The full-scale test structure at the NHERI@UCSD facility

Specimen Design

The gravity frame for the two-story test structure was designed in accordance to the U.S National Design Specification for Wood Construction and consisted of glulam columns and beams with modified slotted pin connections to accommodate the increased drifts from the rocking walls. The flexible CLT floor diaphragm measured 6.1 x 17.7 m (20 x 58 ft). The lateral system consisted of two post-tensioned CLT rocking wall which each had two CLT panels, coupled together with U-shaped flexural plate (UFP) energy dissipaters. The walls were connected to the diaphragm with a slotted shear key connection which allowed for rotational and vertical movement to decouple the diaphragm from the rocking walls.

The lateral system was designed to have no damage considering a frequent hazard (the 50% probability of exceedance in 50 years hazard level), limits damage to easily replaced energy dissipation elements in less frequent earthquakes (10% probability of exceedance in 50 years), and has more considerable damage that may require CLT repair in even less frequent hazard (such as 2% probability of exceedance in 50 years). To achieve these performance objectives, the proposed design procedure from an earlier study on CLT rocking walls [1] was used. The design for the walls can be seen in Figure 2, along with the outlined proposed performance based design procedure used.

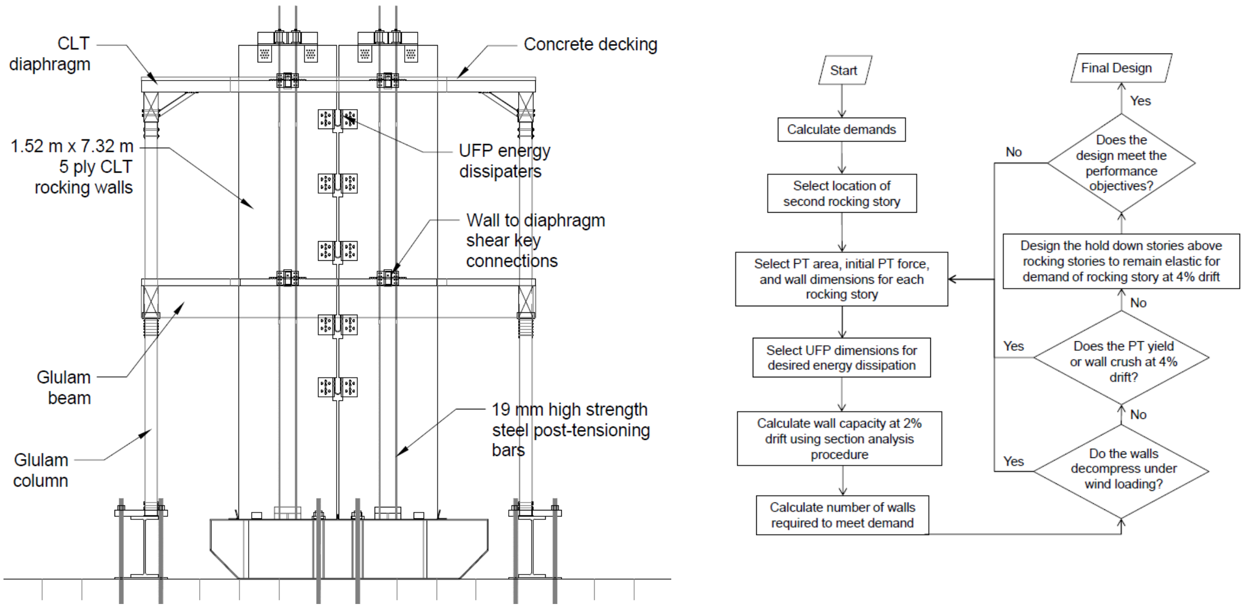

Figure 2. The design of the rocking walls and the performance based design procedure used to design the walls.

Rocking Wall Performance

The tests consisted of 14 ground motions selected to match the uniform hazard response spectra for the different seismic hazard levels at the estimated elastic period of the structure which was 0.9 secs. The performance of the walls, diaphragm, PT bars, and UFPs were measured using a combination of accelerometers, potentiometers, strain gauges, and load cells. A total of about 350 measurements were taken during each test, with about 200 of those measurements specifically measuring the motion of the walls. In addition to the sensors, visual damage inspections were conducted after each test which showed negligible damage at the end of the consecutive tests. Damage evaluation showed that the wall met the performance objectives for each hazard level. The 14 tests are summarized in Table 1 with the peak ground acceleration, the spectral accelerations at the buildings approximate period, and the drifts experience at the roof and floor levels during each test.

Test results have shown that the walls remained elastic during the 50% probability of exceedance in 50 year hazard level earthquakes, meaning significant wall rocking and yielding of the UFP energy dissipaters did not occur until the 10% probability of exceedance in 50 year hazard level earthquakes. In addition, the post-tensioning bars did not yield until the 14th test when the 2% probability of exceedance in 50 year scaling of the Northridge earthquake was increased by a factor of 1.2. These results indicate that the performance based design procedure is accurately predicting the performance of the walls and meeting the predetermined performance objectives.

Table 1. Ground motions used during the tests.

Test	Record Name and Station	Hazard Level	PGA (g)	Spectral Accel. 0.9 sec (g)	First Story Drift (%)	Roof Drift (%)
1	Loma Prieta, Capitola	50/50	0.16	0.15	0.83	0.80
2	Loma Prieta, Capitola	50/50	0.18	0.16	0.85	0.83
3	Northridge, Canoga Park	50/50	0.19	0.18	0.57	0.52
4	Superstition Hills, Poe Road	50/50	0.13	0.12	0.41	0.41
5	Northridge, Canoga Park	10/50	0.53	0.69	-	2.62
6	Northridge, Canoga Park	10/50	0.52	0.74	2.75	2.60
7	Imperial Valley, Delta	10/50	0.13	0.21	0.93	0.85
8	Northridge, Canoga Park	10/50	0.53	0.74	2.71	2.63
9	Loma Prieta, Capitola	10/50	0.52	0.49	1.81	1.68
10	Superstition Hills, Poe Road	10/50	0.44	0.42	2.09	2.13
11	Loma Prieta, Capitola	2/50	0.62	0.57	2.08	1.96
12	Northridge, Canoga Park	2/50	0.73	0.91	3.02	3.20
13	Superstition Hills, Poe Road	2/50	0.63	0.63	3.22	3.30
14	Northridge, Canoga Park	2/50 x 1.2	0.85	1.11	4.20	4.96

Conclusions

Results from the first large scale test of the NHERI TallWood Project show that post-tensioned CLT rocking walls can provide great seismic performance while remaining essentially damage-free. Current work on this project includes refining the OpenSEES model to more accurately represent the results of the test. In addition, the design procedures used to meet the performance objectives will be verified and modified if needed. Ongoing and future work for this project will be in preparation for the ten-story test structure.

Acknowledgments

This research project is supported by the National Science Foundation through a number of awards including: CMMI 1636164, CMMI 1634204, CMMI 1635363, CMMI 1635227, CMMI 1635156, CMMI 1634628. The use of NHERI experimental facility is supported by the National Science Foundation's Natural Hazards Engineering Research Infrastructure Program. The authors would also like the acknowledge support for the two-story shake table testing program from industry partners including: Katerra, Simpson Strong-Tie, Forest Products Laboratory, Softwood Lumber Board, DR Johnson Lumber, MyTiCon Timber Connectors, and the City of Springfield, Oregon. The opinions presented here are solely those of the authors. The authors would also like to acknowledge individual students worked on this project including Jace Furley, Leonardo Fgrodrigues, Brian Demeza, Gabriele Tamagnone, Daniel Griesenauer, Ethan Judy, Steven Kordziel, Aleesha Busch, Ali Hansan, Joycelyn Ng, Monica Y. Liu, and Ata Mohseni.

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