SEISMIC DESIGN OF A MULTI-STORY CROSS LAMINATED TIMBER BUILDING BASED ON COMPONENT LEVEL TESTING

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ABSTRACT: Cross laminated timber (CLT) is a new type of timber structural system that has just been introduced in North America, but has been used successfully in Europe for over 20 years. There have not been any notable data sets developed on the performance of tall CLT buildings during major earthquakes and there are no seismic design criteria currently in place for CLT structures. Shake table testing of walls, assemblies and multi-storey CLT structures have been performed, but dedicated nonlinear numerical models have yet to be developed. In order to provide the necessary information to develop practical seismic design procedure for mid-rise CLT buildings, a group of CLT walls with different geometry and connector configurations were tested at FP Innovations, Canada to obtain the component level resistance data. Then, a simplified numerical model to predict the reverse cyclic behaviour of CLT wall components was developed and calibrated with the test results. Using the wall component capacity predicted by the model, a 10-story CLT building was designed using a performance-based seismic design procedure known as direct displacement design (DDD) to achieve predefined drift limits at various seismic hazard levels. This design procedure was adopted in a recent research effort to successfully design a 6-story light frame wood building tested at Japan’s E-Defense shake table. In this study, the 10-story CLT building was designed with 80% confidence to survive the hazard level of maximum credible earthquake for the City of Los Angeles, California with less than 4% inter-story drift. The DDD of the building was refined and verified with nonlinear time history simulation using a suite of bi-axial ground motions scaled to the predefined hazard levels. Based on the performance-based design results and laboratory testing of individual CLT shear walls, a response modification factor (R-factor) is proposed for structures with CLT wall components according to both the US and Canadian building codes, thus providing quantitative insight into CLT design using traditional force-based design procedures in North America.

KEYWORDS: Cross laminated timber; Multi-story building; performance-based seismic design; Response modification factor

1 INTRODUCTION

An innovative structural system called Cross Laminated Timber (CLT) has been introduced and adopted in Europe as an ideal material for mixed use and light-commercial multi-story buildings. This system has just begun to gain attention in North America, but suitable seismic design procedures for this new system have not yet been developed for high seismic hazard regions such as the west coast of the U.S. Results from quasi-static tests on CLT wall panels showed that the connection layout and design has a strong influence on the overall behaviour of the wall [1]. A shake table test of a traditional seven-story CLT building was conducted by Ceccotti at Japan’s E-Defense facility. A hand book published by FPInnovations in Canada summarizes recent development and practice in CLT design and construction [2].

An project focused on the development of a performance based seismic design methodology for mid-rise wood frame construction was carried out in the U.S. through a NSF funded research project NEESWood [4], in which a 6-story light frame wood building was designed using direct displacement design and nonlinear time history simulation. This building was built and tested at full scale to validate the design procedure. In this study, the component level testing data for CLT panelized walls was combined with the performance-based seismic design methodology developed in NEESWood to conduct the seismic design of a 10-story CLT building.
The suitable response modification factor for CLT wall components for use in traditional force-based design procedures was calibrated.

2 PANELIZED WALL MODELING

Based on cyclic wall testing results from an earlier study [3], a numerical model for CLT wall components was developed utilizing the kinematic relationship of CLT wall panels under lateral deformation. The model was calibrated with the test results and can predict cyclic response of any CLT panel wall given the connection details.

Figure 1: Direct Displacement Design (DDD) flowchart.

3 PERFORMANCE BASED SEISMIC DESIGN OF A TEN-STORY CLT BUILDING

Performance objectives used previously in the NEESWood project were adopted in this study because damage to both light frame wood and CLT systems are highly correlated to inter-story drifts. The controlling case for the design is such that the inter-story drift of any story does not exceed 4% during a Maximum Considered Earthquake (MCE) level event with 80% chance.

The floor plan of the Capstone building used in the NEESWood project was adopted in this study. The direct displacement design procedure was used to determine the required push-over backbone capacity of each story at predefined drift levels. The CLT wall configurations were then determined based on the numerical model developed for the assembly level wall component. Finally, the numerical model for the building system was constructed and subjected to a suite of earthquakes scaled to multiple hazard levels in order to verify the performance of the as-designed configuration.

4 CALIBRATION OF RESPONSE MODIFICATION FACTOR

After the design was verified by nonlinear time history analysis to meet the performance targets, a calibration procedure for traditional force-based seismic design procedure was carried out. The objective of the calibration was to find an appropriate response modification factor (referred to as the R factor) for CLT wall system so that the engineer can use traditional force-based design methods (such as equivalent lateral force procedure) to achieve the same level of performance as the design conducted using PBSD. The calibration was conducted by estimating the capacity of the as-designed building at each story and comparing it to the shear capacity demand calculated based on traditional procedures, which is a function of the R factor.

5 SUMMARY AND CONCLUSIONS

Based on component level testing and performance based design methodology developed in earlier studies, a 10-story CLT building was designed to withstand MCE level earthquake events in California, U.S.A. The suitable R factor for force-based design procedures in Canada and the U.S. was also identified in order to allow designing of CLT multi-story building with traditional seismic design methods.

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REFERENCES


