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INFLUENCE OF BOUNDARY CONDITIONS IN MODAL TESTING ON EVALUATED ELASTIC PROPERTIES OF TIMBER PANELS

Jan Niederwestberg[1], Jianhui Zhou[2], Ying Hei Chui[3]

ABSTRACT: Cross laminated timber (CLT) has the potential to play a major role in timber construction as floor and wall systems. In order to meet specific design needs and to make the use of CLT more effective, property evaluation of individual CLT panels is desirable. Static tests are time-consuming and therefore costly, and for massive products such as CLT practically impossible to implement. Modal testing offers a fast and more practical tool for the property evaluation of CLT and timber panels in general. This paper presents a comparison of different boundary conditions in modal testing in terms of accuracy, calculation effort and practicality. Single-layer timber panels as well as scaled CLT panels were fabricated. Three elastic properties of the panels were evaluated using modal testing methods with different boundary conditions (BCs). The results were compared with results from static test.

KEYWORDS: Cross laminated timber, Modal testing, Boundary conditions, Elastic properties

1 INTRODUCTION

Cross laminated timber (CLT) is an engineered wood product made from layers of timber pieces. Due to the layered glue-up with alternating grain directions of adjacent layers, CLT forms a stiff and strong orthotropic plate structure. The stiff structure shows high potential in shear wall and flooring applications, domains that are dominated by reinforced concrete in large structures. CLT has the potential to replace reinforced concrete in these applications up to a certain point. Unlike reinforced concrete elements, which are designed based on the structural needs, CLT elastic properties used for design purposes are based on the build-up of the panels and on assumed elastic constants of the component material. The elastic properties of individual CLT panels can be evaluated by static tests. From these static test methods only one elastic constant can be evaluated at a time, which makes static tests time-consuming and therefore costly. Static test methods also have an inherent risk of causing structural damage within the panel during testing. Moreover for massive panels, it is practically difficult to test the full-size panels from production lines, using static test methods. Modal testing methods show potential to be adopted for non-destructive evaluation of elastic properties of CLT. In modal testing, the structure is exposed to a controlled excitation and the natural frequencies are measured. The natural frequencies and their order within a response spectrum are influenced by the dimensions and the density of the structure as well as the boundary conditions (BCs) and the elastic properties of the structure. Therefore the elastic constants of a structure can be evaluated if its dimensions, density, the BCs and the response spectrum are known.

While modal testing appears to be a more efficient test method compared with static test, especially for massive panels, research is still required before the model test can be adopted widely. One technical challenge is the choice of boundary condition. As mentioned before, BCs affect the natural frequencies and the response spectrum of a structure. Also, some BCs offer close-form solutions for the property evaluation while others require the use of cumbersome iterative numerical procedures. Furthermore, different BCs show different levels of practicality. The

[1] Jan Niederwestberg, Faculty of Forestry and Environmental Management, University of New Brunswick, 28 Dineen Drive, Fredericton, NB, Canada. E3B 5A3, Email: j.nwb@unb.ca
[2] Jianhui Zhou, Faculty of Forestry and Environmental Management, University of New Brunswick, 28 Dineen Drive, Fredericton, NB, Canada, E3B 5A3. Email: jh.zhou@unb.ca
[3] Ying Hei Chui, Faculty of Forestry and Environmental Management, University of New Brunswick, 28 Dineen Drive, Fredericton, NB, Canada, E3B 5A3. Email: yhc@unb.ca

objective of this study is to compare modal testing methods with different BCs in terms of accuracy of evaluated elastic properties, calculation effort and practicality.

2 METHODOLOGY

2.1 SPECIMEN DESCRIPTION AND GENERAL PROCEDURE

Single-layer panels have been produced from conditioned (moisture content 13%) spruce laminates. The single-layer panel elastic constants, namely the modulus of elasticity parallel to the grain (E_{11}), the modulus of elasticity perpendicular to the grain (E_{22}) and the in-plane shear modulus (G_{12}), have been evaluated using different test methods. The single-layers were face-glued to form 3- and 5-layer CLT panels after the single-layer panel tests were completed. The elastic constants (E_{11}, E_{22} and G_{12}) of the CLT panels were evaluated using the same test methods as for the single-layer panels. The results of the different test methods were compared with each other.

2.2 MODAL TESTING METHOD

The elastic properties of the single-layer panels and the CLT panels were evaluated using modal testing methods with different BCs. In the method by Sobue and Katoh [1] the layer is simply supported on one edge while the other edges have free BCs (SFFF). The three elastic constants, E_{11}, E_{22} and G_{12}, were calculated based on three natural frequencies and simple equations. The method by Larsson [2] is based on free-free BCs (FFFF) and has no closed form solution. Here E_{11}, E_{22} and G_{12} were determined in an iterative process using finite element analysis. In the process, the three elastic constants were adjusted successively until experimental and analytical natural frequencies matched. Further modal test with BCs of two simply supported opposite edges and the other edges free (SFSF) were undertaken. Tests were performed for the two directions, span parallel- and perpendicular to the grain. Based on Leissa [3], natural frequencies were determined and the elastic constants E_{11} and E_{22} were evaluated. G_{12} cannot be determined with these BCs. In addition modal tests with BCs of all four edges simply supported (SSSS) were performed. For SSSS BCs a closed form solution exists. For these BCs the three elastic constants, E_{11}, E_{22} and G_{12}, can be calculated directly with three experimentally determined natural frequencies as stated in Leissa [3] and Hearmon [4].

2.3 STATIC TESTING METHODS

Static tests have been performed to evaluate the elastic constants (E_{11}, E_{22} and G_{12}) of the single-layer panels and the CLT panels. The elastic constants E_{11} and E_{22} were evaluated by single-span three-point bending tests based on ASTM test procedure [5]. The test procedure for the evaluation of the in-plane shear modulus G_{12} was based on ASTM test procedure [6]. The elastic properties evaluated in static tests were used as reference values in the comparison of those measured using modal test method under different BCs. As a control mechanism static tests were performed on the CLT panels with BCs SSSS. In an iterative process the elastic properties in a finite element model were adjusted successively until experimental and analytical deformation matched.

3 RESULTS AND CONCLUSION

At the time of the submission of this abstract, single-layer modal tests with BCs SFFF, FFFF, SFSF have been conducted and the elastic properties have been evaluated. Modal tests with BCs SSSS are in progress. E_{11} and E_{22} of the single-layer panels have been evaluated in static tests. It is expected that results from the modal and static test of the all single-layers and CLT panels will be included in the final paper.

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