

Structural reliability analysis of Cross Laminated Timber plates subjected to bending

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Abstract

Failure modes of Cross Laminated Timber (CLT) plates reach by an excess of tensile stress on finger joints, shear stress on transverse layer due to rolling shear effect, and also by natural vibration. The Probability of Failure (POF) of CLT plates can be estimated from the probability distribution of its rupture and stiffness, as well as their correlation coefficients. In this context, the aim of this paper is to estimate the load capacity of Cross Laminated Timber plates from a specific probability of failure and the experimental results of mechanical and physical properties. For this purpose, CLT plates were manufactured with wood species of *Pinus taeda* L., originally from Brazilian reforestation. Four-point bending tests were conducted to investigate the failure behavior of the CLT plates. Density and moisture content were obtained from small specimens extracted from CLT plates. Monte Carlo simulation was carried out to predict the probabilistic loads that produce the failure of CLT plates, considering the failure occasioned by natural vibration as well. Experimental and numerical results of the failure modes were compared and the maximum loads to an acceptable probability of failure of the several CLT lengths were estimated too.

Keywords: Timber Structures, Cross Laminated Timber, Bending, Structural Reliability, Monte Carlo Simulation.

1 Introduction

Cross Laminated Timber (CLT) panel is an engineered wood product consisting of several layers of kiln-dried lumber boards arranged in crossed orthogonal directions, bonded with structural adhesives, and pressed to form a solid, straight, rectangular panel. It is used primarily as a plate or wall structure (Fig. 1).

Failure prediction of CLT plates is necessary for structural design. The main modes of CLT failure in bending are reach by an excess of tensile stress on finger joints (Fig. 2), shear stress on transverse ply due to rolling shear effect (Fig. 3), excessive displacement (Fig. 4) and natural vibration (Fig. 5).

Monte Carlo method is often applied to estimate the performance and the probability of failure (POF) of structural components. Coefficient correlations and probability distributions of the variables are used in this method.

The goal of the study is to estimate the load capacity of Cross Laminated Timber plates from a specific probability of failure and experimental results of mechanical and also taking into account the wood physical properties.



Fig. 2: Rolling shear



Fig. 3: Finger joint



Fig. 1: Cross Laminated Timber

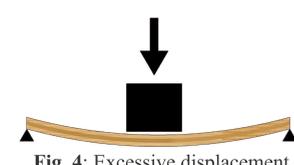


Fig. 4: Excessive displacement

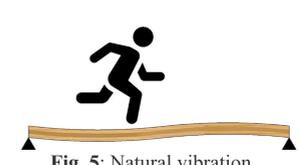


Fig. 5: Natural vibration

2 Materials & Methods

Twenty-one CLT plates manufactured with Brazilian *Pinus taeda* L. wood were tested experimentally (Fig. 6). From this, resistant moment, resistant shear, bending stiffness, and shear stiffness were obtained (Fig. 7). Moisture and specific gravity tests were carried out in forty-eight *Pinus taeda* L. specimens extracted from previously tested CLT plates (Fig. 8).

The density distribution (Fig. 9) and the correlation coefficient (Fig. 10) of these variables were measured and used to generate other random variables with the same characteristics by Cholesky decomposition (Fig. 11). This procedure was released to apply the Monte Carlo simulation to estimate probabilities of failure.

The load required producing a POF greater than or equal to 10^{-5} was recorded for each mode of failure in discrete lengths at 0.08m (Fig. 12).

3 Results and Discussion

The maximum load necessary to produce failure for a specific length was estimated from the probability of failure equals $POF = 10^{-5}$. Fig. 13 shows these results.

In general, the load limits were obtained by the limit displacement ($l/200$). Thereafter, the rupture by shear governed the limit loads until about 1.5 m. For greater lengths, the rupture by bending moment is responsible to limit the load. Meantime, the first natural frequency limited the CLT length in 5.58 m. The CLT length that produces a natural frequency $f_n = 8$ Hz varied from 5.50 until 6.85 m (Fig. 14).

Comparing the values obtained by structural reliability procedure to the serviceability limit state procedure carried out by Vilela (2020), it can be observed that maximum load stabilized by displacement in the first procedure is, in general, more conservative than the serviceability limit state method. These results can be associated by weighting coefficients applied to limit the serviceability limit state responsible for improving the limit loads in Service Limit State (SLS).

Natural vibration by limiting the serviceability limit state restricts the CLT length in 5.99 being this value is within the results obtained by the probabilistic method.

The bending and shear stiffnesses, and bending moment and shear resistance estimated by experimental procedures involve the global CLT behavior, which is composed by individual behavior and strength of each lamination (e.g., finger joints, rolling shear strength). The use of a full-size CLT bending test in several lengths is capable of representing the wood and laminations variables necessary to reliability structural analysis. Then, this procedure is an alternative to the semi probabilistic method (i.e., limits states) that uses characteristic values to estimate the wood and CLT properties.

4 Conclusions

Excessive displacement is the main mode of failure to analyze the CLT element in bending until 5.6 m length. After this length the natural vibration governs the failure mode with a $POF = 10^{-5}$. Predicted maximum load from probabilistic displacement proved to be more conservative than the Limit State method.

The variability of wood is considerably large and should not be overlooked in the structural design of the CLT. The use of Monte Carlo Simulation to predict the limit loads according to the main failure modes of the CLT shown to be an alternative technique capable of estimating such loads for different failure probabilities according to each design criteria.

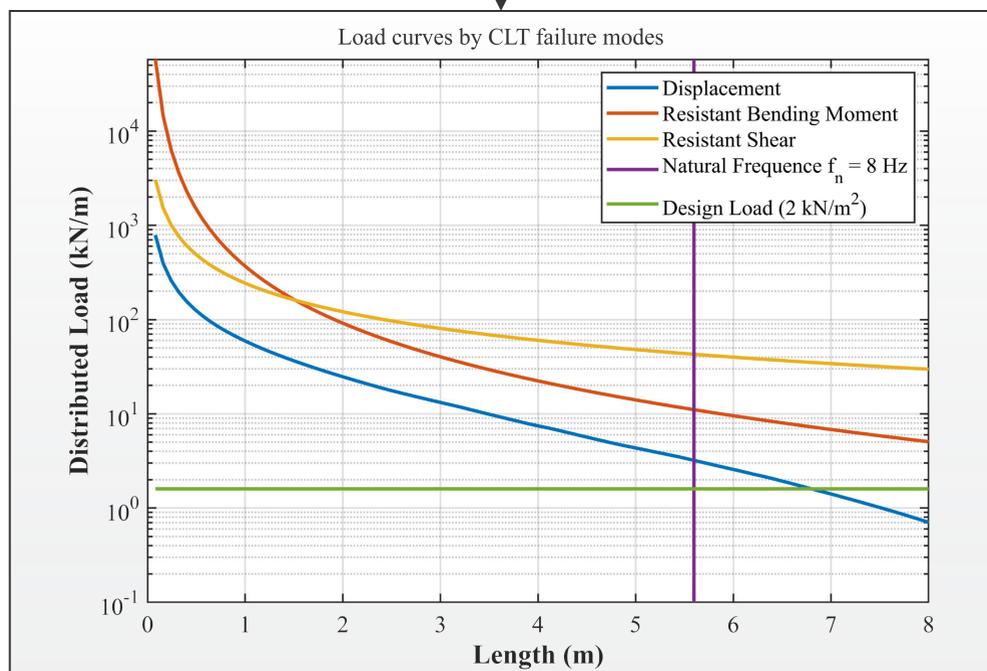
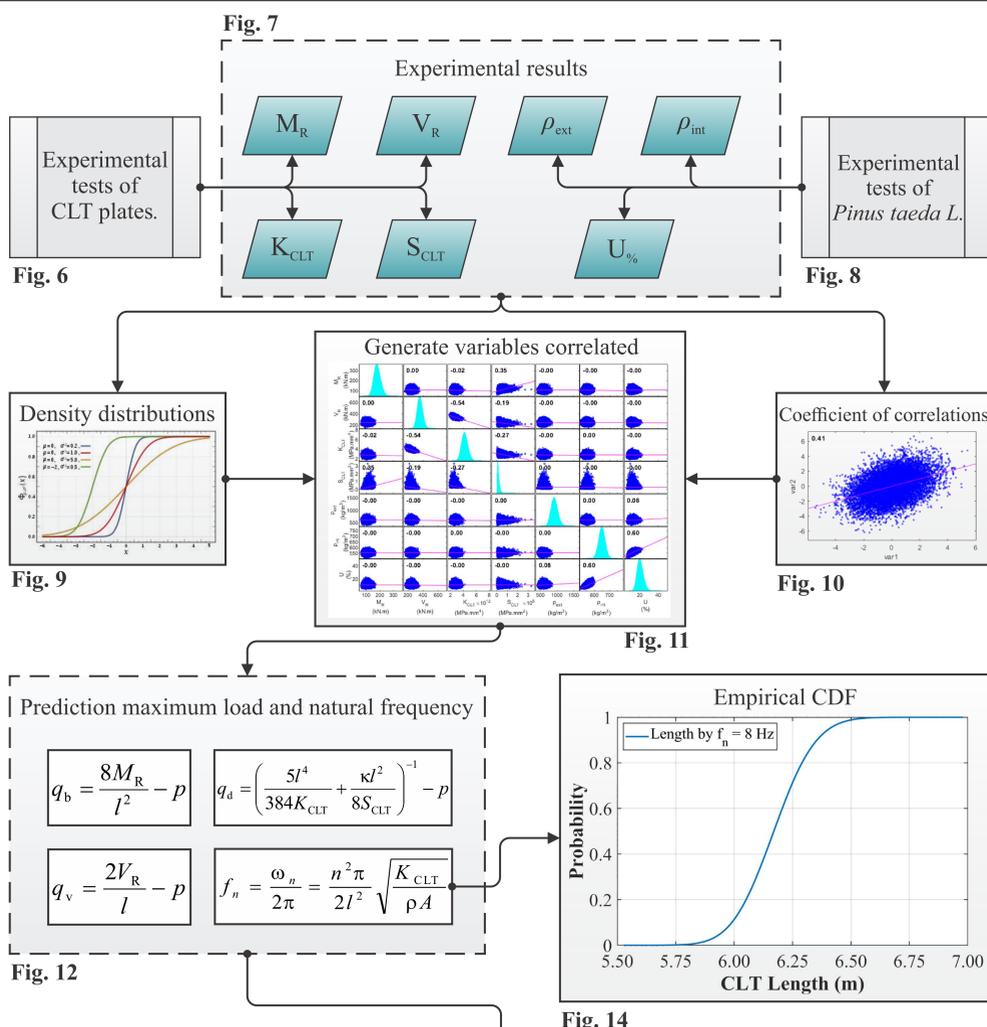


Fig. 13

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