DURATION-OF-LOAD EFFECT ON THE ROLLING SHEAR STRENGTH OF CROSS LAMINATED TIMBER: DURATION-OF-LOAD TESTS AND DAMAGE ACCUMULATION MODEL

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ABSTRACT: In this study, the duration-of-load (DOL) effect on the rolling shear strength of cross laminated timber (CLT) were evaluated. The study of the DOL effect on the strength properties of wood products is typically challenging; and, additional complexity exists with the DOL effect on the rolling shear strength of CLT, given the necessary consideration of crosswise layups of wood boards, existing gaps, non-uniform stress distributions in the cross layers, glue bonding between layers, and strength and stiffness variability of timber materials. In this study, short-term ramp loading tests and long-term trapezoidal fatigue loading tests (damage accumulation tests) were used to study the DOL behaviour of the rolling shear strength of CLT. A stress-based damage accumulation model was used to investigate the DOL effect on CLT rolling shear. The model was calibrated with the test data. The test results show that the model predictions agree well with the test data. This calibrated model can be used to quantify the rolling shear DOL effect of CLT under other loading conditions in future research.

KEYWORDS: Duration-of-load effect, damage accumulation model, trapezoidal fatigue loading, cross laminated timber, rolling shear, mountain pine beetle

1 INTRODUCTION

In this study, short-term ramp loading protocol and long-term trapezoidal fatigue loading protocol to accumulate damage have been considered in the research of the rolling shear DOL behaviour of CLT under uncontrolled laboratory climatic conditions, where temperature and relative humidity remained fairly constant. To limit the influence of environment variables on the damage accumulation, low cycle trapezoidal fatigue loading protocol was adopted. The applied cyclic load intensities for the trapezoidal fatigue load tests were based on the short-term ramp loading test data. Compared with the constant loading method, there is more damage accumulated in the same period of time in the trapezoidal fatigue loading test, so the total test time of the trapezoidal loading is reduced.

A stress based damage accumulation model was developed by Foschi and Yao to consider the DOL effect on the strength properties of dimension lumber. The Foschi and Yao model considers the damage accumulation rate as a function of stress history and the already accumulated damage state as follows:

\[
\frac{da(t)}{dt} = a_0 (\sigma(t) - \tau_0) + c (\sigma(t) - \tau_0)^n \alpha \quad \text{if} \quad \sigma(t) > \tau_0 \sigma_s, \\
\frac{da(t)}{dt} = 0 \quad \text{if} \quad \sigma(t) \leq \tau_0 \sigma_s
\]

where \( a \) is the damage state variable (\( a = 0 \) in an undamaged state and \( a = 1 \) in a failure state); \( t \) is the time history; \( \tau \) is the stress ratio, defined as the applied stress history \( \sigma(t) \) divided by the short-term strength \( \sigma_s \), i.e., \( \tau = \sigma(t) / \sigma_s \); \( \tau_0 \) is the stress threshold below which damage will not accumulate; and \( a_0, \alpha, b, c \) and \( n \) are random model parameters.

In this study, basic short-term rolling shear strength distribution can be first established by short-term ramp loading, and the time to failure data from the trapezoidal fatigue loading tests can be obtained to understand the development of deflection and damage accumulation process. By analysing the measured data from the trapezoidal fatigue loading tests, this stress based damage
accumulation model can be calibrated, with consideration of the DOL effect on rolling shear strength. Then, the calibrated model can be used to quantify the rolling shear DOL effect of CLT under other loading conditions.

2 RESULTS

2.1 TEST RESULTS

In the short-term ramp loading tests, rolling shear failure was the major failure mode. In the trapezoidal fatigue loading tests, the number of cycles to rolling shear failure $N_f$ was recorded when first rolling shear crack was observed. The shape of these rolling shear cracks in the cross layer was typically very similar to those in the short-term ramp loading tests.

2.2 MODEL CALIBRATION

The theory for the damage accumulation model is one of the key tools to investigate the DOL behaviour in wood-based products. The Foschi and Yao model was applied in the DOL investigation on the strength property of dimensional lumber. This model was adopted in the current DOL research of CLT rolling shear capacity.

These model calibration and verification results are shown in Figure 1, which includes the relationships between the stress ratio and the number of cycles to failure in a logarithm scale. Figure 2 shows the cumulative distributions of the experimental and the simulated $N_f$ values based on the model calibration and verification for the CLT group. The results show that the model predictions agree well with the test data.

3 CONCLUSIONS

Based on the ramp loading test data and the trapezoidal fatigue loading test data, the DOL effect on the rolling shear strength of MPB lumber based CLT was investigated. A stress-based damage accumulation theory was used to investigate the DOL effect of CLT rolling shear behaviour. This model included the evaluation of rolling shear capacity from ramp loading tests. This model was calibrated and verified with the trapezoidal fatigue loading test data. The results show that the model predictions fit well with the test measurements. This calibrated model is available to elucidate the DOL effect on the CLT rolling shear strength under various loading conditions.

ACKNOWLEDGEMENT

The authors would like to thank NSERC strategic network for engineered wood-based building systems for supporting this research.