DESIGN EQUATIONS FOR EMBEDMENT STRENGTH OF WOOD FOR THREADED FASTENERS IN THE CANADIAN TIMBER DESIGN CODE

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1 INTRODUCTION

The Canadian standard for engineering design in wood (CSA O86) [1] uses the European yield model for calculations of lateral resistance of connections with dowel-type fasteners. This model takes into account the moment resistance of the fastener, the assembly’s geometry and the embedment strength of wood. The latter is considered a function of the relative density of wood and diameter of the fastener. The purpose of this study is to verify the significance of these variables as applied to the embedment strength for threaded dowel-type fasteners of diameters 6.4 mm and greater. The importance of this research is justified by the growing interest in the use of large-diameter threaded fasteners in heavy timber and hybrid structures of high load-bearing capacity.

2 BACKGROUND

The embedment strength, also known as the dowel bearing strength, was studied by several researchers in Europe and in the US in the 1980s for potential adoption of the European yield model for design of dowel-type fastenings. As a result, in Canada the embedment strength values have been based on the work of Smith et al. [2]. The European [3] values for fasteners installed into wood with pre-drilled holes are equivalent to Canadian for parallel to grain direction but different for fasteners of diameters greater than 6 mm loaded in transverse direction. The dowel bearing strength in the American timber design code (NDS) [4] are based on the work of Wilkinson [5] who proposed embedment equations independent of the fastener diameter in parallel to grain direction. Later, Chui et al. [6] reported new findings for threaded fasteners 6.4 mm in diameter and less, which are different from those currently adopted in the design codes.

3 METHODOLOGY

The test program conducted jointly by FPInnovations and Université Laval [7] included embedment tests on lag screws using glued-laminated timber manufactured in Quebec and British Columbia and made of Spruce-pine, Spruce-pine-fir and Douglas-fir. All specimens were conditioned to (65±5) % of relative humidity and (20±2) °C temperature prior to testing. Lag screws of six diameters (from 6.4 mm to 19.1 mm) were commodity off-shelf fasteners.

Figure 1. Embedment test set-up

Embedment tests were performed in accordance with ASTM D5764 [8] half-hole test method with the fasteners inserted perpendicular to the lamination face of the glulam blocks and loaded at an angle of 90°, 45° and 0° to grain direction. The specimen width and depth were 5 and 6 times the fastener diameter, respectively. The embedment length was 76 mm for lag screws of three smaller diameters (6.4, 7.9 and 9.5 mm) and twice as long for those of larger diameters (12.7, 15.9 and 19.1 mm). The tests were conducted separately on the smooth shank (unthreaded) portion and on the threaded portion of the lag screw. Specimens were prepared by drilling a hole in the center of a glulam block and then cutting it into two halves to obtain two specimens. For tests on the smooth shank portion, the hole diameter was equal to the nominal fastener diameter. For the threaded shank, the hole was

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70% of the nominal diameter, and the lag screw was carefully inserted in and out of the hole using a wrench before cutting the block in half.

The load was applied to the half-hole specimen using a fastener welded to a steel plate attached to the loading head of a hydraulic actuator (Figure 1). The specimen was loaded at a constant speed of 1.0 mm/min, and test was stopped when the load decreased to 80% of the peak load unless the displacement first reached the lesser of 7.0 mm or half the diameter of the fastener. The displacement was calculated as the average of measurements recorded using two laser sensors installed at the ends of the specimen. After the test, a wood sample was taken from each specimen to determine the relative density and moisture content in the vicinity of the loaded zone.

4 ANALYSIS OF RESULTS

The following parameters were determined after the tests using load-displacement curves (Figure 2):

- Initial stiffness (K);
- Maximum load and corresponding displacement;
- Yield load and corresponding displacement according to Yasumura and Kawai [9];
- 5% diameter offset load and corresponding displacement according to Wilkinson [5]; and
- Failure load and corresponding displacement.

The embedment strength was calculated using the maximum load or the load corresponding to the point of minimum slope of the curve before a 5-mm displacement, whichever occurs first, divided by the embedment length and the nominal diameter of the fastener. The test results were compared with those found in previously published literature and with the design equations found in the CSA O86 [1], Eurocode 5 [3] and NDS [4].

![Figure 2. Analysis of load-displacement curve](image)

The analysis of experimental data obtained to date on the fasteners in the tested range shows that the diameter has no significant influence on the embedment strength of wood at any angle to the grain. Also, the test data suggest that the difference between the embedment strength parallel and perpendicular to grain is less than is currently given in the CSA O86 [1]. Once the test program is completed and all data analysed, it is likely that new equations for the embedment strength for lag screws (and potentially for bolts and dowels), independent of the fastener diameter, will be proposed for potential inclusion into the Canadian timber design code.

5 CONCLUSION

Equations for embedment strength of wood for dowel-type fasteners currently used in CSA O86 standard are a function of wood relative density and fastener diameter, and, for lag screws, bolts and dowels, are strongly dependent on the angle between the load and the grain direction. Experimental data obtained recently for lag screws of diameters 6.4 mm and greater suggest that the equations can be revised and be independent of the fastener diameter. The new findings will be useful for design of timber connections with lag screws and other threaded fasteners. Also, the data will be useful for development of design equations for fastenings in cross-laminated timber (CLT), which is a subject of a parallel ongoing investigation.

6 REFERENCES