REPAIR OF WHITE OAK GLUED-LAMINATED BEAMS

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Abstract

Connections between steel side plates and white oak glued-laminated beams subjected to tension perpendicular-to-grain stresses were tested to failure. The beams were then repaired with five different configurations using two sizes of lag screws, with and without steel reinforcing plates. The repaired beams were re-tested to failure. Results indicate that in all cases the repaired beams had greater ultimate loads than did the original beams. Results also indicate that lag screws without the reinforcing plate are sufficient for repair.

Introduction

This paper is a report on tests conducted on bolted joints that connected steel side plates to white oak glued-laminated beams and were subjected to tension perpendicular-to-grain forces. The joints are representative of a proprietary connection that had experienced service failure. Objectives were to first determine the failure modes and maximum loads and secondly to determine a repair procedure. Five repair configurations were tested because little information exists on repairing glued-laminated members with tension perpendicular-to-grain failures.

Experimental Procedure

Eight 254- by 406-mm (10- by 16-in.) glued-laminated (22 laminations) white oak beams, 1.98 m (6.5 ft) long, were tested in bending with a center-point load on a 1.67-m (5.5-ft) span. This is a modification of the standard test procedure described in ASTM D-1761 (ASTM 1988) to determine the strength of a connection loaded perpendicular-to-grain. ASTM D-1761 is essentially a midpoint loaded short deep beam with the load applied through a single bolt. We modified this standard procedure to have the load applied through steel side plates with five 25-mm- (1-in.-) diameter bolts. ASTM D-1761 defines the beam span to be a minimum of three

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times the beam depth. We modified the span dimension such that we would have three times the beam depth dimension outside of the five-bolt connection area.

The tests were conducted in a non-controlled temperature and humidity environment. The moisture content of the beams prior to testing was 7% to 9%, found by a moisture probe meter. Load was applied at a rate of 2.3 mm (0.09 in.) per minute, resulting in failure being achieved in about 5 minutes.

The test setup is shown in Figure 1. Relative deformation between the steel side plates and the glued-laminated beam was measured at the bottom row of bolts. Two plots of load versus deflection were recorded for each test. One plot corresponded to relative deformation at the threaded end of the bolt; the other corresponded to the shank end. This was done because there was 13 mm (1/2 in.) of thread bearing on the wood beam. All tests were continued until failure, which is defined as the maximum load the beam could resist.

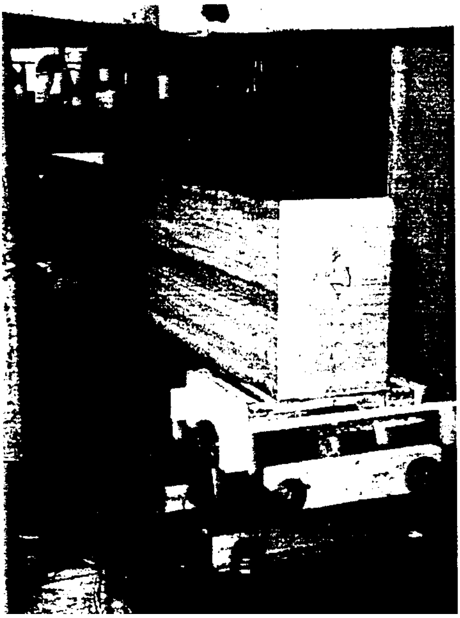

Figure 1. Test setup.

The eight beams were then repaired and re-tested using the same procedure as for the original tests. Figures 2-6 show schematically the five repair methods. The repair configurations are based on equating the strength of the lag screw (assumed yield stress of 248,200 kPa (36,000 lb/in^2)) to the wood strength of ultimate tension perpendicular-to-grain stress (5,500 kPa, 800 lb/in^2) times a contributary area of a 254-mm (10-in.) beam width by the lag screw spacing. This results in two 25-mm- (1 -in.-) diameter lag screws at about 102-mm (4-in.) spacing. The extent of spacing the lag screws is an unknown, dependent on the length of the tension perpendicular-to-grain fracture propagation, so a trial and error approach was used.

Repair method 1 consisted of sixteen 25-mm- (1-in.-) diameter by 305-mm- (12-in.-) long lag screws, with two steel reinforcing plates 241 by 6 by 406 mm (9-1/2 by 1/4 by 4 in.). Lead holes were 19 mm (3/4 in.) for the threaded portion and 25 mm (1 in.) for the shank portion of the lag screw. Each plate supported eight lag screws.

Repair method 2 used the same lag screws and lead holes as did method 1. However, the steel reinforcing consisted of eight plates 241 by 6 by 102 mm (9-1/2 by 1/4 by 4 in.). Each plate supported two lag screws. This configuration was chosen to enable a repair in a confined space using a number of smaller plates rather than one larger plate.

Repair method 3 used 13-mm- (1/2-in.-) diameter lag screws but otherwise had the same configuration as did method 1. Even though recommended-sized lead holes were used during fabrication, 3 of the 16 lag screws in one specimen sheared off. This configuration was chosen to find what beam capacity could be achieved with smaller lag screws.

Repair method 4 consisted of eight 25-mm- (1-in.-) diameter by 305-mm- (12- in.-) long lag screws with two steel reinforcing plates 241 by 6 by 203 mm (9-1/2 by 1/4 by 8 in.). This configuration was part of the trial and error process related to the extent of the fracture. It consisted of half the number of lag screws compared with method 1.

Repair method 5 had the same lag screw configuration as did method 1 but eliminated the steel reinforcing plate. This configuration was chosen to see if there would be any bearing failures under the head of the lag screw.

Results and Discussion

For the original and repaired beams, the ultimate center-point loads are given in Table 1. The failures for the original beams were tension perpendicular-to-grain fractures, which initiated at a line of bolts and propagated laterally. The crack propagation stopped prior to reaching the ends of the beams. The crack theoretically should initiate at the line of bolts nearest the loaded edge of the beam. This occurred in some beams while fabrication effects resulted in crack initiation at the other line of bolts in other specimens. We do not believe the initiation location related to the two lines of bolts to be significant. The bolt threads bearing partially on the wood. (considered bad practice) had negligible effect on the strength of the joint. We determined this by comparing deformations on both ends of the bolt.

The failure of the original beams was tension perpendicular-to-grain stress. which is found by dividing the ultimate center-point load by some effective area. If the effective area is assumed to be the 254-mm (10-in.) width of the beam times the 279-mm (11-in.) length of the side plates, the resulting tension perpendicular-to-grain stress will approximate the published value of 5,500 kPa (800 lb/in^2) (Forest Products Laboratory 1987). The failure of the repaired beams was tension yielding of the lag screws used in the repair.

The ultimate center-point load for all the repair methods was greater for the repaired beams than for the original joint tests (Table 1). Results indicate no advantage to (1) increasing the number of lag screws from 8 to 16 or (2) using steel reinforcing plates regardless of their size. It appears that increasing the diameter of the lag screw from 13 mm (1/2 in.) to 25 mm (1 in.) is not advantageous. Recall that three of the smaller lag screws sheared off during installation. It was difficult to screw the smaller lags using recommended-sized lead holes into the beams, thus we do not recommend the 13-mm (1/2-in.) diameter. Perhaps a compromise recommendation is to use a 19-mm- (3/4in.-) diameter lag screw, but this is not verified by this study.

Table 1. Ultimate center point load for original and repaired beams.

Beam number	Original beam ultimate load (kN)	(lb)	Repair method	Repaired beam ultimate load (kN)	(lb)
1	445	100,000	1	627	141,000
2	445	100,000	1	534	120,000
3	386	86,800	2	574	129,000
4	405	91,000	2	623	140,000
5	404	90,800	3	498	112,000
6	331	74,400	3	489	110,000
7	354	79,500	4	514	115,600
8	354	79.500	5	498	112.000

The relative deformation between the steel side plates and the glued-laminated beams was approximately 3 mm (0.1 in.) for all beams and for both the thread and shank ends. The effect of the 13-mm (1/2-in.) thread length bearing on the wood was negligible.

Concluding Remarks

This study presents the failure modes and ultimate center-point loads for joints consisting of steel side plates bolted to white oak glued-laminated beams. All failures observed in the original beams were caused by tension perpendicular-to-grain stresses. Cracks initiated at one line of bolts and propagated along the grain. Our ultimate loads divided by an assumed effective area compare reasonably well with the published tension perpendicular-to-grain strength for white oak.

The original beams were repaired by various combinations of lag screws and reinforcing plates. All repair methods resulted in ultimate center-point loads that exceeded the original beam strength Results indicate that four 25-mm- (1-in.-) diameter lag screws on each side of the joint without a steel reinforcing plate is sufficient for repair.

References

ASTM. 1988. Test Methods for Mechanical Fasteners in Wood. ASTM D-1761. American Society for Testing and Materials, Philadelphia, PA.

Forest Products Laboratory. 1987, Wood Handbook: Wood as an Engineering Material. Ag. Handb. 72. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, rev.

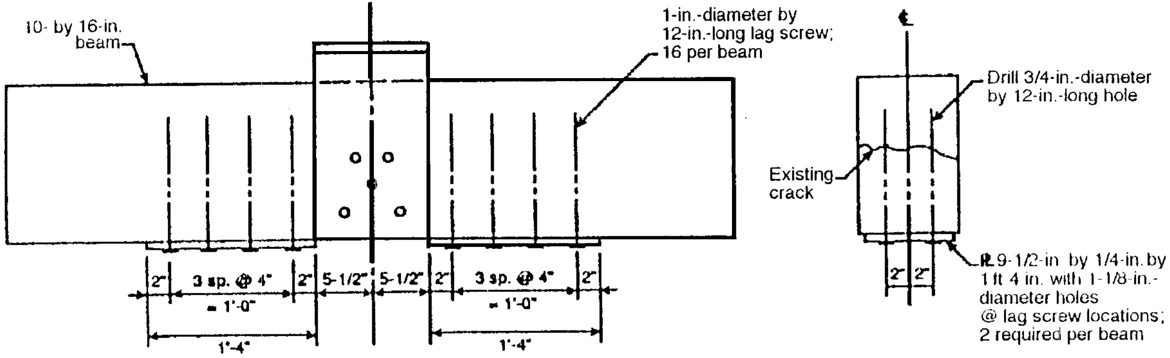

Figure 2. Repair Method 1: Continuous steel plates and 16 1-in.-diameter lag screws (1 in. = 25.4 mm).

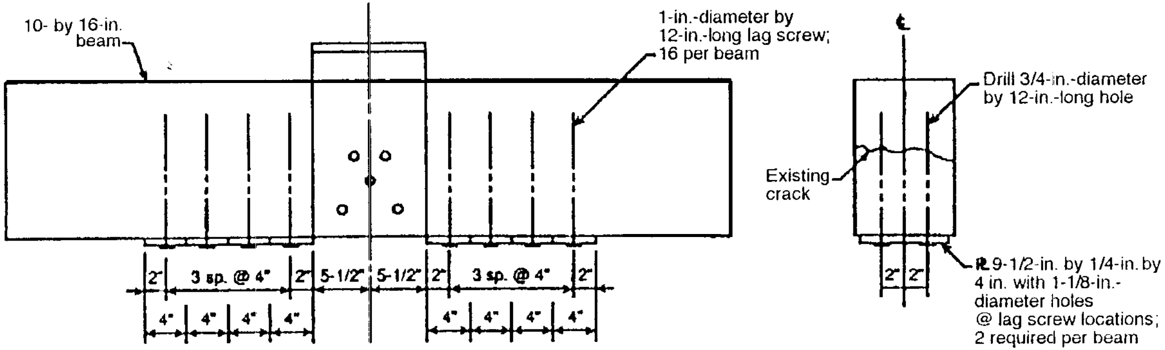

Figure 3. Repair Method 2: Separate steel plates and 16 1-in.-diameter lag screws (1 in. = 25.4 mm).

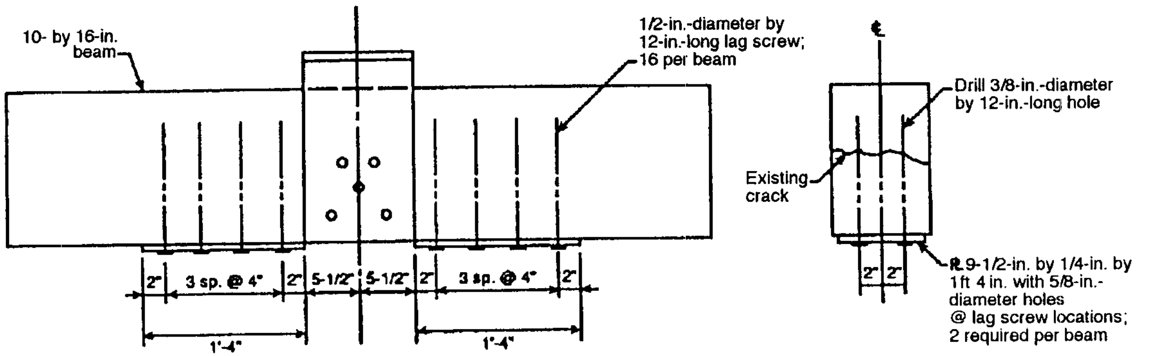

Figure 4. Repair Method 3: Continuous steel plates and 16 1/2-in.-diameter lag screws (1 in. = 25.4 mm).

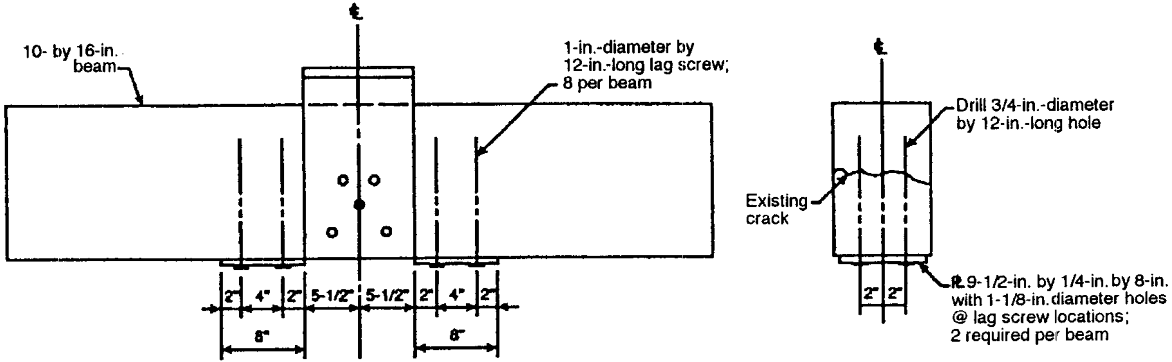

Figure 5. Repair Method 4: Continuous steel plates and 8 1-in.-diameter lag screws (1 in. = 25.4 mm).

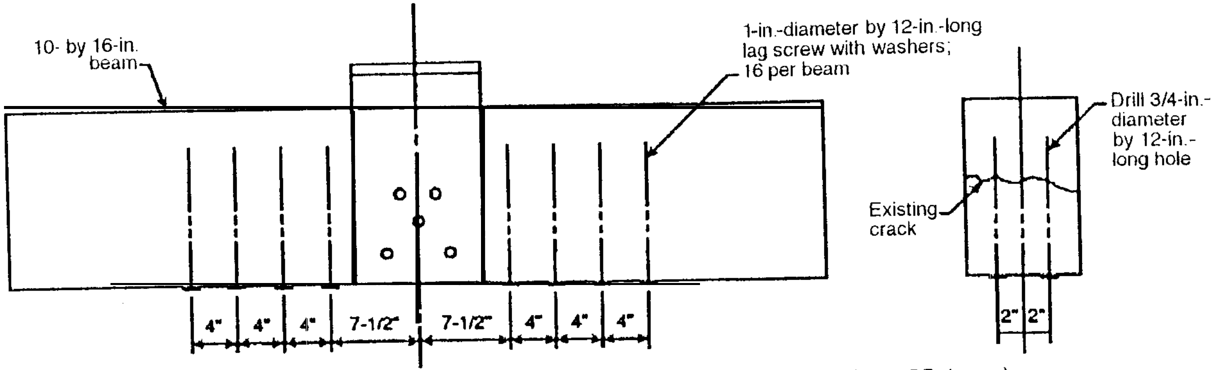

Figure 6. Repair Method 5: No steel plate and 16 1-in.-diameter lag screws (1 in. = 25.4 mm).

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