Repair of Partially Embedded Metal Connector Plates

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Abstract

Partially embedded metal connector plates can occur in wood trusses when the plates are not properly pressed, when they ''walk out'' as the wood dries during service, or when there is a mismatch in member thickness. Current industry practice is to ignore the remaining strength of a partially embedded plate when making repairs. This assumption results in a large, overdesigned repair along with high material and labor costs. The project objective was to determine if a smaller clamped repair is sufficient to restore the strength of the partially embedded plate to the fully embedded connection strength. A total of 40 tension splice connections were fabricated from 2 by 6 members with 5 by 3 metal connector plates. The specimens included 10 fully embedded plates, 10 partially embedded plates, 10 partially embedded plates repaired with plywood gussets secured outside of the main 2 by 6 members (RC), and 10 partially embedded plates repaired with plywood gussets and light wood screws (RS). The average strength of the partially embedded RC specimens and partially embedded RS specimens were 87 and 108 percent of the fully embedded specimens' strength, respectively, whereas the unrepaired partially embedded plates achieved only 60 percent of the fully embedded specimens' strength. The results of the tests indicate that smaller screw-type gusset repairs are sufficient to return the strength of a tensile splice connection with a 1/16-inch partially embedded plate to its fully embedded plate capacity. Both the clamping action of the plywood gussets and the additional tensile capacity of the screwed plywood gussets were observed to contribute to the strength gains.

Partially embedded truss connector plates can occur when the plates are not properly pressed, when they ''walk out'' as the wood dries during service, or when there is a mismatch in member thickness. Testing (Klein and Kristie 1988) indicates that joints with partially embedded plates are much weaker than fully embedded plates. Losses of strength of up to 50 percent are found when gaps between the plate and wood of only 1/16 inch occur. Current repair methods include plywood or oriented strand board (OSB) gussets and dimensional lumber scabs attached with nails, proprietary high-strength screws, through-bolts, or lag screws. Another method for repair is adding or replacing connector plates, or fully embedding previously partially embedded connector plates using hydraulic C-clamps. Klein and Kristie (1988) recommend that the remaining capacity of the existing connector plate should generally be ignored because the stiffness of a plate-connected joint is considerably less than a joint connected with nails, screws, or bolts. When two overlapping connections with different stiffnesses are present at the same joint, the load would not be shared proportionally between the two connection systems; the stiffer connection will resist the majority of the load.

Work performed by Jacob Nielsen at Aalborg University (Nielsen 1999) shows that partial connector plate embedment is not usually uniform and that often greater partial embedment is found at the center of the connector plate, even when the plate appears to be fully embedded. Nielsen identified six primary modes of partial embedment: different timber thicknesses, unevenness at the timber surface (knots), unequal embedding pressure or a tilted plane, a low embedment pressure, spring back, and cushioning. The first

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Table 1.—Strength to partial embedment chart reported to Nielson (1999).

Gap (mm)	Gap (in.)	x/64 in.	Strength ratio[a]
0	0.00	0.0	1.00
1	0.04	2.5	0.82
2	0.08	5.0	0.56
3	0.12	7.6	0.30
4	0.16	10.1	0.06

[a] Ratio of strength of partially embedded plate to that of a fully embedded plate.

Table 2.—Allowable strengths of lumber and truss plate connection.

Component (failure mode)	Allowable load capacity (kips)
2 by 6 No. 2 Hemlock (tension)	9.00
Metal connector plate (tension)	4.48
Metal connector plate—full embedment (pullout)	3.94[a]
Metal connector plate—1/16-in. embedment gap (pullout)	1.97[a,b]

[a] Includes load duration factor of 1.6 for 10-minute laboratory test.

[b] 50% reduction in strength based on literature review.

four modes should be avoidable with proper pressing conditions, but spring back and cushioning are a function of moisture content, grain direction, and density of the lumber. Although the partial embedment in reality will not be uniform throughout the entire plate, Nielsen surveyed others and was informed that tests have yielded relationships for the loss of strength at different ''average'' embedment depths, as shown in Table 1 for strength ratios with partial embedment. Nielsen also found that the strength of a partially embedded plate depends on several factors, including density, moisture content, species of lumber, and direction of the annual rings. There also appears to be a good deal of randomness with respect to the occurrence of partial embedment.

The truss repair process relies heavily on the individual engineer's ability to apply theory, real-world judgment, engineering common sense, and knowledge of field conditions to develop practical, economical, and realistic repairs. Most engineers who design truss repairs have learned the skill from other engineers with past experience. Two common repair techniques utilize dimensional lumber scabs and gussets of plywood/OSB; plywood and OSB are generally interchangeable (Fox 2008). High-strength structural screws (United Steel Products, Simpson Strong-tie, Fasten-Master, etc.) may be used for their high steel quality and shear/yield strength.

Clinching nails can also be used to increase the shear capacity of a single nail. The repair process with clinched nails consists of placing a plywood gusset on each side of the deficient connection. Nails are then driven through the first gusset, the main member, and then the second gusset. The tips of the nails are finally clinched (bent over) such that they are secured on both sides of the connection and act in double shear. The clamp holding the gussets in place prior to securing the nails is removed (Fox 2008).

There is evidence that partial embedment of plates does not decrease the effectiveness of load transfer when gaps are less than 1/32 inch (Street 2010). Partial embedment with teeth embedment gaps greater than 1/16 inch are considered to be ineffective at transferring load, while teeth with embedment gaps between 1/32 and 1/16 inch are considered to be 60 percent effective.

The current National Design Standard for Metal Plate Connected Wood Truss Construction (ANSI/TPI 1; Truss Plate Institute Inc. 2008) outlines tooth effectiveness as a

Figure 1.—F4 test specimen after fabrication.

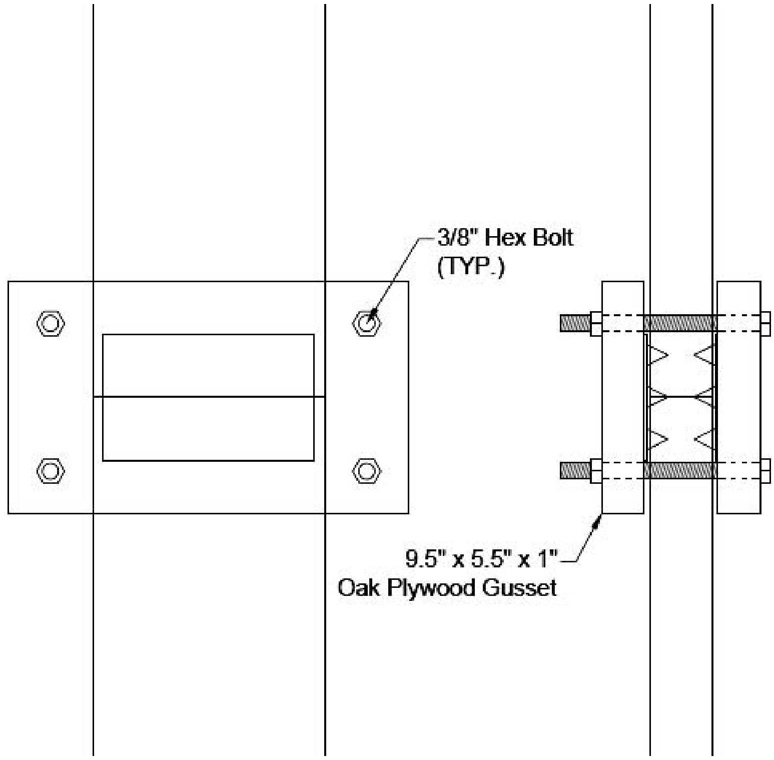

Figure 2.—Diagram of clamped repair (RC).

function of embedment depth. Design calculations are conservatively based on the assumption of a 1/32-inch gap as opposed to a truly fully embedded connector plate. Tooth effectiveness values are 119, 100, 60, 40, and 0 percent for tooth embedment gaps (G) of 0 inches, $0 < G < 1/32$ inch, 1/32 inch $< G <$ 1/16 inch, 1/16 inch $< G <$ 3/32 inch, and $G > 3/32$ inch, respectively, such that a 1/32- to 1/16-inch gap reflects a 50 percent reduction in fully embedded strength. The reduction values vary from the Truss Plate Institute of Canada (2015) standards (Street 2010) in that a reduction in strength is allowed for a partial embedment gap of 1/16 to 3/32 inch in TPI.

Current industry practice is to ignore the remaining strength of a partially embedded plate when making repairs. The assumption that the partially embedded plate does not contribute to the strength of the connection may result in a large, overdesigned repair with excess material and high labor costs owing to the cumbersome nature of working with large gussets and scabs in tight attic and floor spaces. This work examines that assumption. Large plywood gussets and either structural screws or bolts are used to form the new

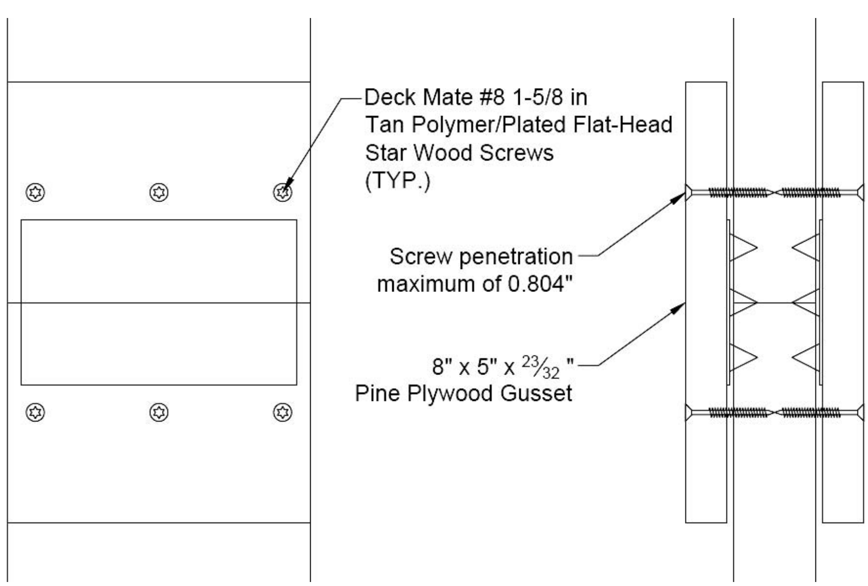

Figure 3.—Diagram of screwed repair (RS).

Figure 4.—Test specimen mounted in the testing machine.

connection at the joint. The objective of this work was to determine if a smaller gusset-style repair that clamps the plate and provides lateral resistance to prevent further pullout is sufficient to restore the connection strength to a fully embedded plate capacity.

Materials and Methods

Dimensional lumber tensile splice connections were tested to evaluate the strength of clamped repair techniques for partially embedded connector plates.

Specimens

Each specimen consisted of two No. 2 Hemlock 2 by 6s spliced together with 5 by 3-inch Alpine 20-gauge Wave Plates in the AA orientation. The allowable lateral resistance value of the plate is 164 lb/in^2 per plate, and the allowable tensile design value for the plate is 895 pounds per lineal inch per pair of plates, based on report ICC ESR-1118 of ICC Evaluation Services (2011). As lateral resistance (pullout) is dependent on contact area of the plate while resistance to tensile rupture is dependent only on width of the plate, the length of the plate along the length of the member was the controlling factor for failure mode. According to design procedures in ANSI/TPI 1-2007, a plate length less than 3.41 inches (1.705 in. on each side of the splice connection) is required to force a pullout failure mode rather than fracture on the net section. A plate size of 5 by 3 inches was selected to ensure the desired lateral withdrawal failure mode. Table 2 shows the results of design calculations for allowable and nominal load capacities of the connection elements.

Test matrix

The test matrix included 10 fully embedded control specimens (identified as F-x, where x identifies the specimen number from 1 to 10), 10 partially embedded control specimens (P-x), 10 partially embedded and repaired clamped specimens (RC-x), and 10 partially embedded specimens repaired with lightly screwed gusset plates (RS-x).

Fabrication procedure

Specimens were fabricated from the lumber by cutting the boards into 18-inch lengths. Each board was visually inspected before cutting, and knots and damaged sections were avoided, in accordance with TPI Section 5.2.4.3, which requires clear wood in the area of the plates.

Two wood pieces were attached with 5 by 3-inch Alpine 20-gauge Wave Plates with an AA orientation, as shown in Figure 1. All of the connector plates were pressed in a controlled laboratory setting using a hydraulic platen press. The fully embedded specimens were pressed to close to a 0-inch gap between the metal plate and the wood without overpressing. Fully embedded specimens were not pressed farther than half of the metal plate thickness into the wooden test specimens. All of the partially embedded specimens were pressed with 1/16-inch steel shims placed between the wood members and metal connector plates. The plates were pressed until contact with the steel shims was achieved.

Repair 1.—In order to isolate a clamping force resisting the lateral pullout forces, the first repair design involved no direct attachment to the wood members. Rather, plywood gussets sized 9½ by 5½ by 1 inch were applied to each face of the connection and centered over the partially embedded

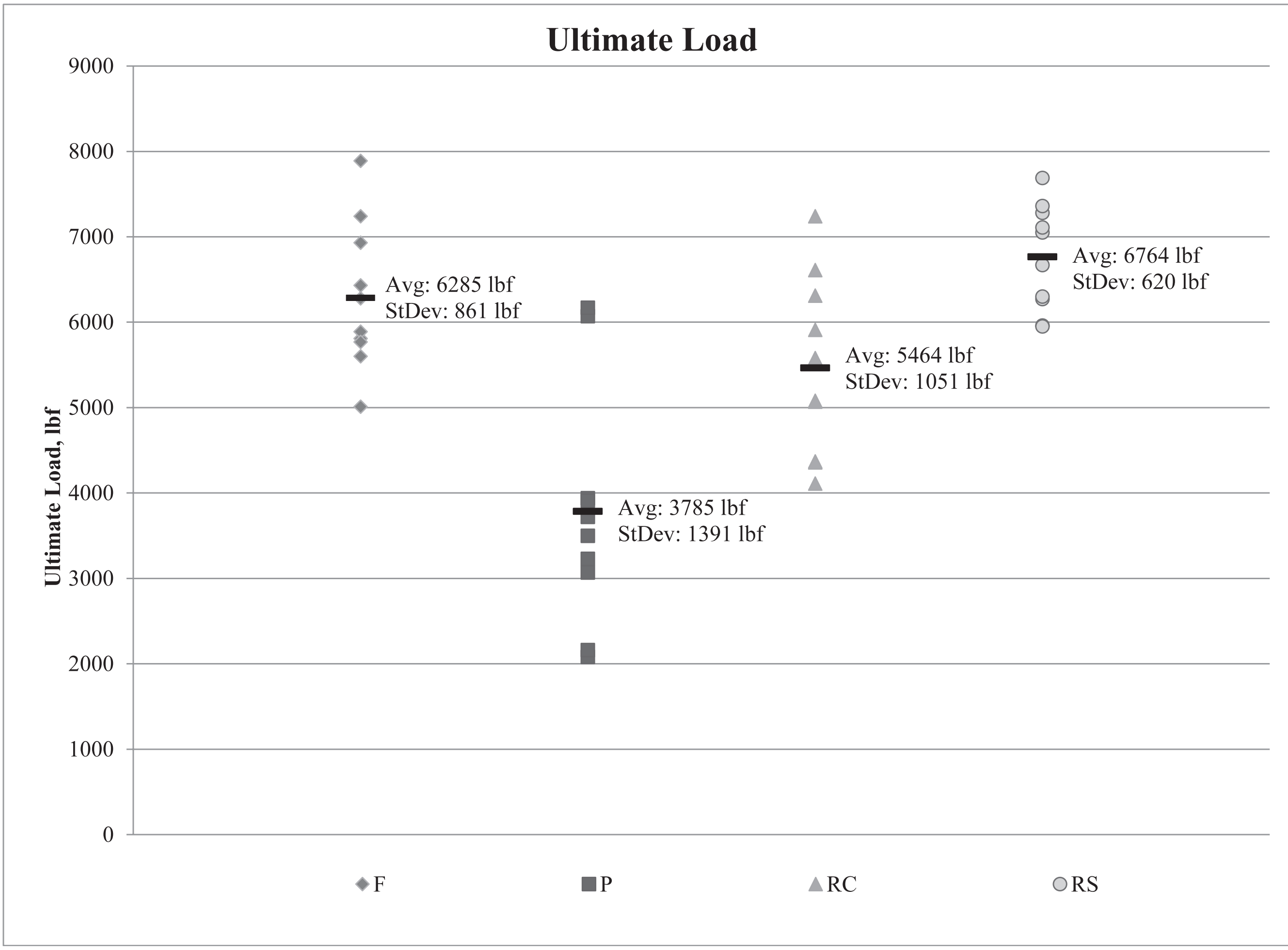

Figure 5.—Comparisons of ultimate load for each specimen group.

connector plates. The gussets were then attached to one another with 3/8-inch-diameter A307 bolts outside the zone of the main wood members, as shown in Figure 2. The repair does not impart any direct tensile strength to the connection but rather prevents the existing partially embedded plates from pulling out laterally.

Repair 2.—It is also important that a repair for these defective joints be practical and easy to install in the field. The first repair was developed to prove the concept of a clamping force providing significant lateral resistance to plate pullout; the second repair took a step toward practicality and attached two plywood gussets sized 8 by 5½ by 23/32 inch directly to the wooden members using standard wood screws in lieu of the nails, structural screws, and bolts currently recommended. The gussets were attached to the dimensional lumber with three Deck Mate #8 (1-5/8 in.) bulge head star wood screws on each side of the tensile splice for a total of 12 screws per specimen, as shown in Figure 3. When this repair is used to repair joints of existing installed trusses, dead loads and sustained live loads are already being resisted by the partially embedded plate. The screws should resist only live load and only in proportion to the stiffness of the light screw connection to the stiffness of the connector plate (Klein and Kristie 1988). The screws are primarily intended to anchor the side gusset plates to the existing connection to prevent further pullout of the metal plate.

Test procedure

Testing was performed in accordance with ANSI/TPI 1-2007 standards and occurred 14 days after specimen fabrication. Immediately prior to testing, the connector plate locations on the front and back sides of the specimen were measured with respect to the ends and sides of the adjoining wood members. Moisture content was also measured for each specimen and ranged from 12 to 17 percent, consistent with moisture contents at time of fabrication (10% to 18%). Embedment depth was measured at eight locations. The specimens were loaded in tension as shown in Figure 4, at a constant load rate of 25 lb/s until failure, defined as a loss of 90 percent of the peak load. During testing, the amount of slip at the splice connection was measured using dial gauges with 0.001-inch precision every 15 seconds. These data were plotted to produce load-versus-slip curves for each specimen.

Results

The primary data used to evaluate the performance of each specimen group consisted of the ultimate tensile load carried before failure. Comparisons were made between the ultimate loads achieved by the fully embedded, partially

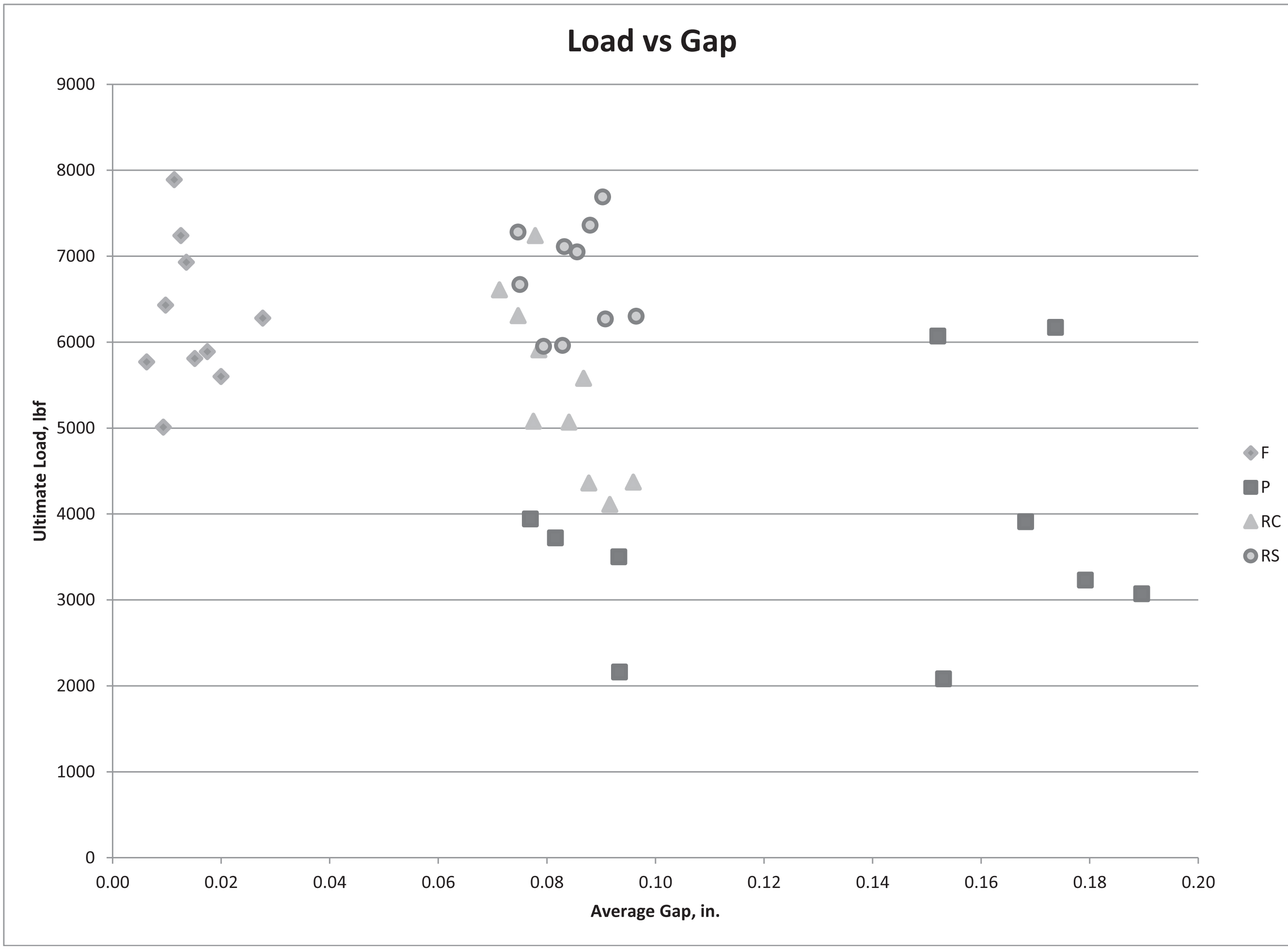

Figure 6.—Comparisons of ultimate load to average embedment gap.

embedded, RC, and RS specimens. Figure 5 details the ultimate tensile loads of all 40 specimens graphically and includes the average and standard deviation of the ultimate loads within each group.

Figure 6 shows the ultimate load-versus-gap data. Owing to some rebounding of the plates after pressing, the measured gap between the connector plate and wood member was typically 0.071 to 0.096 inch for the partially embedded plates, which is greater than the 1/16-inch shims used to cause partial embedment. However, six of the partially embedded nonrepaired specimens had partial embedment gaps of 0.152 to 0.190 inch. While the gaps were larger than anticipated, the ultimate loads of those specimens were, in fact, consistent with the other partially embedded control specimens.

The ultimate strength results show that the partially embedded unrepaired plates achieve only 60 percent of the fully embedded plate specimens' strength (40% reduction in strength). This value is consistent with previous studies. Klein and Kristie (1988) noted a 50 percent reduction at a 1/16-inch gap; Nielsen (1999) reported an 18 to 40 percent reduction at a 1/16-inch gap (Table 1). Street (2010) noted a 40 percent reduction (60% efficiency), and the current TPI document limits connector plate strengths with 1/16-inch embedment gaps to 50 percent of the fully embedded strength (60% of the 1/32-in. embedment strength).

Both RC and RS repairs clearly showed a significant return of strength to the connections with partially embedded plates. The RC repair yielded ultimate loads an average of 87 percent of the strength of the fully embedded specimens. The RS repair showed an increase in ultimate load capacity beyond that of the fully embedded specimens to 108 percent. In addition to the average ultimate load being greater with the RS repair, the standard deviation of the results was also smaller. This shows that the repair was more consistent in restoring the strength of the partially embedded connections within group RS. Statistical analysis using a Student's t distribution gives a 92 percent confidence that the mean strength of the RS specimens is greater than the fully embedded specimens and a 96 percent confidence that the mean of the fully embedded specimens is greater than the RC specimens.

It is worth noting that an alternate failure mode was exhibited in the repaired specimens versus the normal pullout failure of the fully and partially embedded specimens. The fully embedded and partially embedded (unrepaired) specimens failed as a result of lateral withdrawal of the connector plates (i.e., pullout), as seen in Figure 7. Because of the spatial constraints created by the repairs, these partially embedded plates experienced bending of the teeth, as shown in Figure 8, creating slip between the two wooden members. The ultimate failure mode was bending and subsequent pullout of the teeth on the plates in

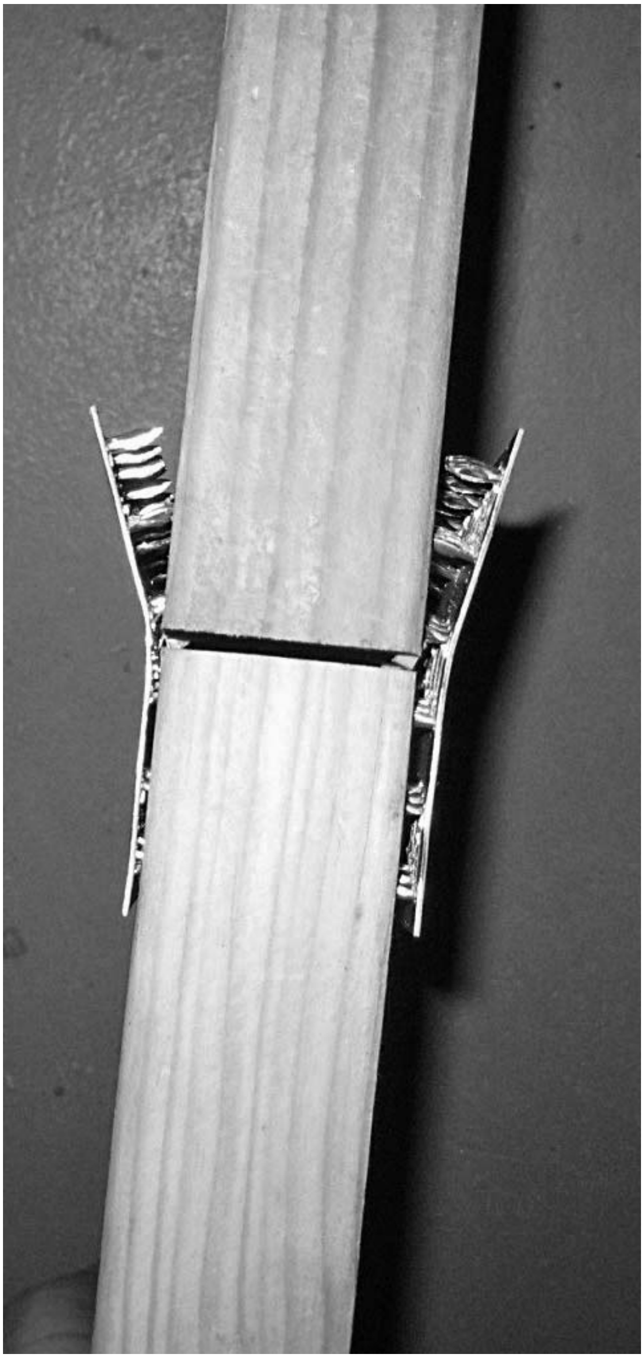

Figure 7.—Example of lateral withdrawal failure (pullout).

the direction of the axial load, not a lateral withdrawal or a fracture of the plate, which are the two current design limit states.

Based on calculation of the nominal strength of the plywood and wood screw connection using Load and Resistance Factor Design procedures, the tensile capacity of the six #8 screws in single shear is 857 pounds. If the 857-pound single shear strength of the screws is subtracted from the 6,764-pound average connection strength, the connector plate was capable of resisting a tensile load of 5,907 pounds, or 94 percent of the fully embedded specimen strength, showing promising results for use of the lightly screwed repair.

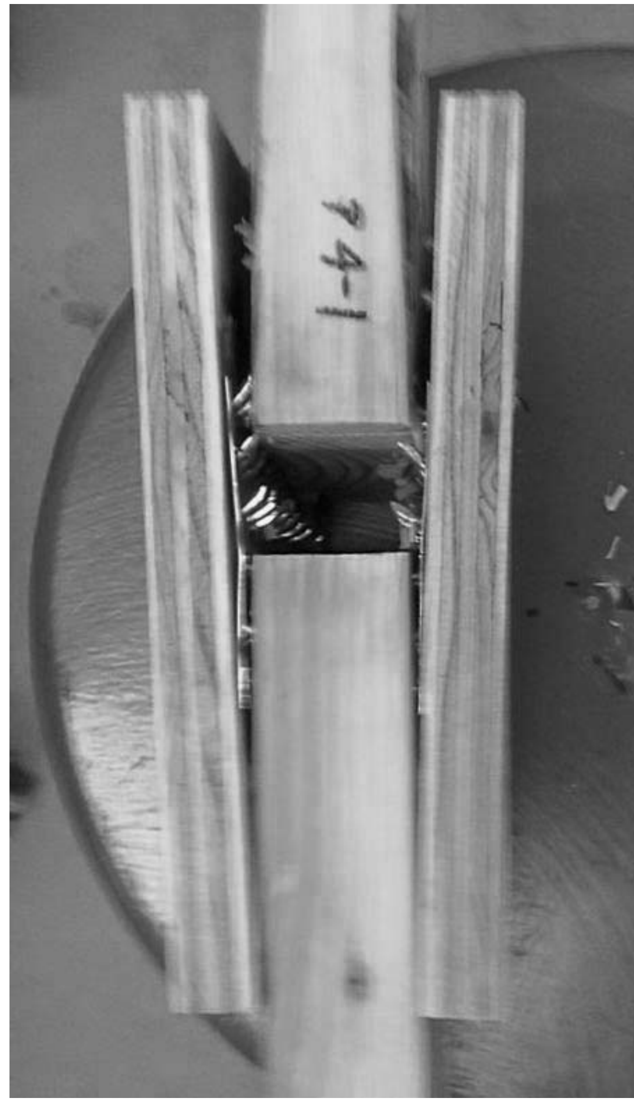

Figure 8.—Example of teeth bending and axial withdrawal failure with screwed repair.

Conclusions

The objective of this project was to determine if a cost-efficient and noninvasive passive clamp-style repair method is sufficient to repair partially embedded connector plates in wood trusses. After testing 10 fully embedded and 10 partially embedded specimens, it was observed that a partial embedment of 1/16 inch resulted in a 40 percent reduction in strength. The results from the two repair methods tested show that significant strength was returned to the partially embedded connections. The RC repair and RS repair returned 87 and 108 percent of the fully embedded strength to the 1/16-inch partial embedment connection, respectively. The results show that a localized repair that prevents further plate pullout by providing passive clamping to the existing connector plates is sufficient to return strength to the connection. However, without the use of supplemental fasteners such as screws, the full strength of a properly embedded plate may not be achievable. The results also show that an alternate failure mode, teeth bending, occurs when the plate is repaired in this manner.

Limitations of Research and Recommendations

The experiment consisted of testing only tensile splice connections with AA plate orientation and did not normalize for individual specimen–specific gravity, although all specimens were fabricated from the same wood lot. There are several other types of connections in a truss, including angled tensile and compressive loads, compression splices, and tensile splices. Future tests could be performed using angled joints or joints in compression instead of just tension joints. Plate orientation including the AE, EE, and EA orientations could also be studied.

Another limitation of this work and an area for future research is to vary the partial embedment of the plates. This experiment tested only one partial embedment depth. In addition, plates that were fully embedded could be tested to determine if the fully embedded plate strength can be increased using repairs as well. Because the failure mode of the partially embedded connection changes from a lateral withdraw to teeth bending and eventually an axial withdrawal, there may be a maximum partial embedment at which the repair would no longer be effective.

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