Estimating the Impacts of Preservative Ports on Bridge Tie Strength

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Abstract

Scale models of wooden bridge timbers were broken in bending to assess the impact of holes drilled along their length to permit the addition of wood preservatives. The results indicate that the holes have minimal impact. However, the common practice of cutting ''daps'' on the underside of the beams to accommodate the supporting beams appears to have substantial strength-reducing effects. Railroads could consider using borate ports to improve the life of their bridge timbers and reducing the depth of, or eliminating, daps.

Many railway bridges in the United States have ''open decks'' (no ballast) with large bridge timbers that rest on the main bridge structure (Fig. 1). Unlike railroad ties that are supported by a ballast, the bridge timbers are structural members that carry load from the train cars to the main structural system. Replacement of bridge timbers is typically a slow, labor-intensive process that presents its own set of worker safety risks and creates a bottleneck in track maintenance.

Railway bridges and especially bridge ties in the United States are often made of wood. This wood must be preservative treated to protect against fungi and termites and thus ensure adequate service life. However, the large cross section of the bridge timbers (often 10 in^2 [25 cm^2]) presents challenges to achieve effective preservative penetration depths and retention levels. Traditional oil-borne, pressure-applied preservative processes often leave the interior of the beams, especially the heartwood, unprotected. One approach to improving bridge timber preservative treatment is ''dual treatment'': apply a water-soluble and diffusible borate-based treatment in combination with the traditional oil-borne preservatives (e.g., creosote, copper naphthenate).

Borates have been used successfully as wood preservatives and pest-control products for many decades (Lloyd 1997). Advantages of borates include broad-spectrum efficacy against all wood-destroying organisms, low cost, low mammalian toxicity, and a low environmental impact. Adding borates before creosote treatment has been shown to provide significant benefit to railway crossties (Amburgey et al. 2003) and utility poles (Dickinson et al. 1990).

Because of the low surface area–to–volume ratio and the large proportion of heartwood in large bridge timbers, pressure treatments with dissolved borate will be unlikely to result in sufficient treatment penetration and retentions. A high-concentration borate emulsion (dip treatment) is being used for railway crossties and provides sufficient retention levels; however, this technology works by allowing the borate to diffuse into the wood after the initial dip treatment (on the undried tie) for several months before overtreating with the second preservative (Kim et al. 2011). Bridge timbers can be different for every bridge in terms of dimensions and fabrication and so are typically ordered ''just in time'' per project. For this reason, they are usually dried rapidly using a Boulton cycle (Lloyd et al. 2014): boiling out the water by submerging the green timber in heated oil. Thus, producers do not have the many months of drying time to facilitate dip- or pressure-diffusion approaches.

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Figure 1.—Typical open-deck railroad bridge.

Another approach to providing sufficient borate to a bridge timber is to drill holes in the member before treatment and fill the holes with solid or powdered preservative. Fused borate rods have been used for many years as remedial treatments, for example for utility poles (Ruddick and Kundzewicz 1992, Peylo and Bechgaard 2001, Freitag et al. 2011). Diffusion of borate from rods is very slow in aboveground, drier environments, but recent research has shown that a high-concentration liquid borate placed in a hole and sealed in place with a plastic plug will disperse rapidly longitudinally during the Boultonizing process (Lloyd et al. 2014) and subsequently will diffuse widely through the cross section of bridge timbers. Sufficient borate retention to meet the relevant standard can be achieved easily by drilling multiple 2-in. (5-cm)-diameter holes to a depth just over half the thickness of the member. However, a concern with this concept is the possible reduction in structural properties caused by drilling the holes.

Morrell et al. (2014) studied the effect of 15.6- to 21.9-mm (0.6- to 0.9-in.)-diameter inspection holes on the flexural strength of approximately 250-mm (10-in.)-diameter utility poles. No significant negative effect on the flexural properties was found. Falk et al. (2003) studied the effect of 1-in. (25.4-mm) and 1.75-in. (44-mm) holes on 3.5 by 7.5-in. (89 by 184-mm) lumber. The holes were drilled in the wide face (side of the beam) at midpoint. Holes in the tension side and in the compression side resulted in a 15 to 20 percent reduction in bending strength, whereas a hole at the tension face resulted in about a 30 percent reduction in bending strength. These results are in reasonable agreement with the reduction in the section modulus of the lumber. The holes in these studies did not match the nature of the holes that are drilled for preservatives. These studies also did not address shear failure, which is often the controlling design parameter for bridge timbers (American Railway Engineering and Maintenance-of-Way Association [AREMA] 2015).

The objective of this study was to assess whether holes drilled in bridge timbers to provide reservoirs for borate preservatives would significantly impair the mechanical properties of the beams.

Structural Analysis

When designing wooden railway bridges, both bending and shear in the bridge timbers need to be considered. The bending strength of the timber is related to the wood properties and to the section modulus, a geometric property used in the flexural design (AREMA 2015). Holes in the side cause virtually no reduction in the section modulus (Fig. 2), and the bending stress is zero at the mid-height or neutral axis (for a symmetrical section) and greatest at the top and bottom. Typically, holes have less effect on the compressive strength of the beam, so—for bending—it would generally be better to drill the hole in the top of the beam (the compression face, instead of the bottom of the beam (the tension face).

Shear is constant between the support and the rail, and zero between the rails (Fig. 3; Hibbeler and Kiang 2015). Shear stress is highest at the mid-height of the beam, and varies quadratically, with a zero shear stress at the top and bottom of the beam. Theoretically, a hole in the top or bottom of the timber would reduce the shear strength by 20 percent, and a hole in the side of the beam would reduce the shear strength by 55 percent. However, this analysis implicitly assumes a continuous hole along the length of the beam, or a slot; the behavior with just the hole is quite complicated. Thus, a testing program was used to estimate the impact of holes on the strength of small models of bridge timbers.

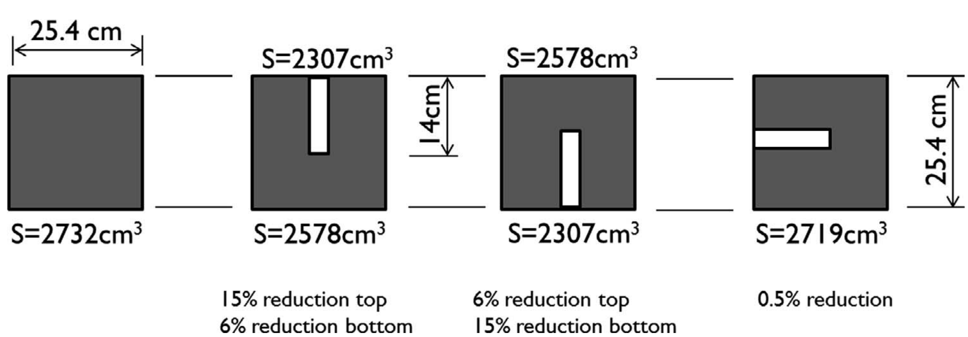

Figure 2.—Reduction in section modulus for various locations of holes.

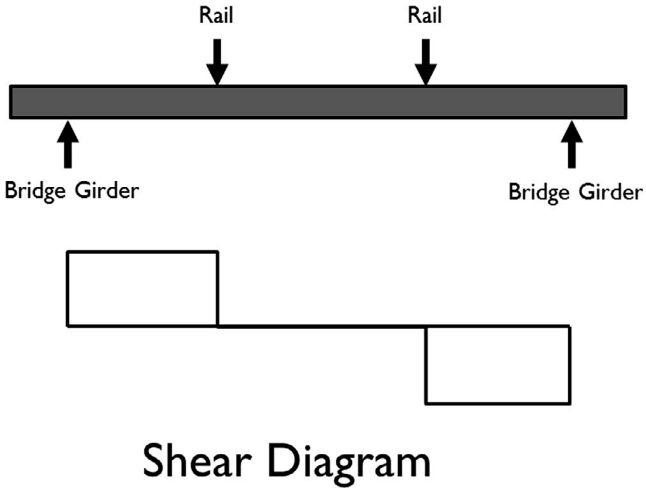

Figure 3.—Shear diagram of bridge timber.

Materials and Methods

Typical bridge timbers are large; however, full-scale testing is not necessary and may confound the effect of geometry with natural defects from the wood. Therefore 2 mm:2.54 cm (0.079 in.:1 in.) scale models were used. Small, clear, mostly straight-grained samples of southern yellow pine (*Pinus* spp.) and red oak (*Quercus* spp.) were sawn from kiln-dried lumber. Samples were 20 by 20 by 340 mm (0.87 by 0.87 by 13.39 in.) long to represent a 10-in^2, 14-ft-long bridge timber (note: the industry uses English units). A 14-ft (4.3-m)-long timber was chosen as the worst-case scenario among the options represented in Figure 4—it has the longest span between the supports, which results in the highest bending moment.

Holes (4 mm [0.16 in.] in diameter) were drilled in the beams to a depth of 12 mm (0.47 in.), as indicated by the black bars in Figure 5. Holes were drilled either on the top, side, or bottom of the beams. Control beams had no holes. ''Daps,'' which are cutouts on the bottom that accommodate the beams' supports in industrial practice, were cut using a dado blade on a table saw. Daps were to scale: 4 mm deep and 28 mm wide (0.16 by 1.10 in.). The side of the sample with the dap was considered to be the bottom. Daps were cut on all samples, unless otherwise noted (see below).

The lumber was stored until constant weight in a conditioning chamber set to 12 percent equilibrium moisture content conditions (23°C/65% relative humidity) before cutting. Prepared samples were stored in the same chamber until testing. Sample groups ($n = 30$) of each species and hole placement combination were tested in four-point bending, with the supports at the daps (span of 264 mm [10.4 in.]), and two load points spaced to the scale of track width (128 mm [5.04 in.]). Steel plates were placed at both the supports (28 mm [1.1 in.] long) and load points (36 mm [1.4 in.] long) to mimic the tie plates (at load points) and to distribute the load. The steel plates covered the width of the beams (20 mm [0.79 in.]). Beams were loaded to failure at 2.5 mm (0.1 in.) per minute. Only maximum load was recorded. All beams were loaded in the same configuration and tested in the same manner. Maximum load values were averaged for the sample groups. Differences among treatments was assessed using analysis of variance and sample groups were compared using t tests.

Results and Discussion

The oak beams were stronger than the pine, as expected for a denser wood species (Fig. 5; Forest Products Laboratory [FPL] 2010). The holes only slightly reduced the average maximum load supported by the beams, with the holes drilled on the top of the beam being the most damaging. The impact of the holes was similar for both species.

The beams tended to show shear-type failure originating at the daps (Fig. 6). The beams almost never failed in the extreme fibers at the center of the span, as might have been expected in a bending test. This suggests that the dap contributed to the failure mechanism. This may also explain why the holes in the top had more effect than that predicted; the dap effectively reduced the height of the beam near the ends and the top holes were reducing more of the effective cross section than the bottom holes.

Subsequent to this observation, a test was conducted with pine (only) beams of the same dimensions, with no holes

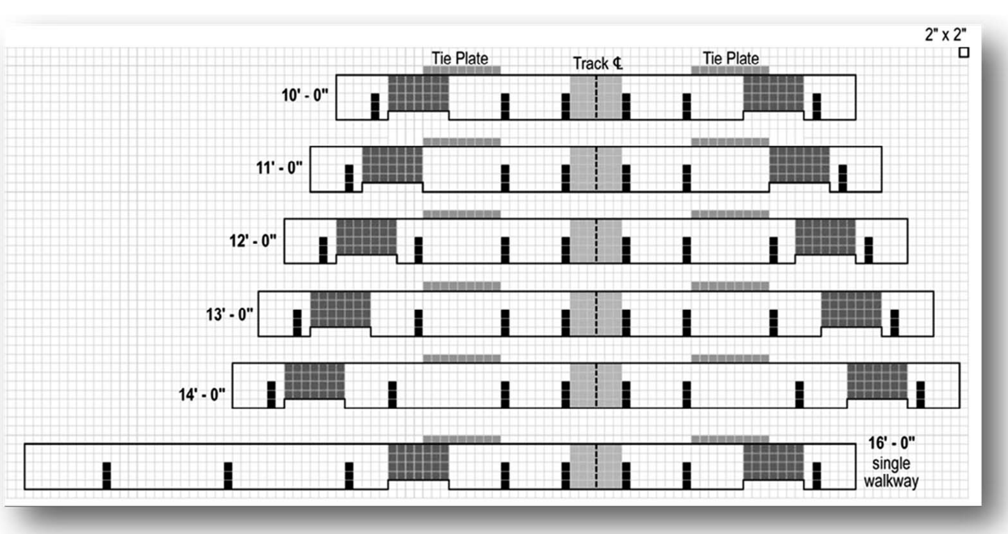

Figure 4.—Bridge timbers of various lengths, showing potential preservative port (hole) locations in black.

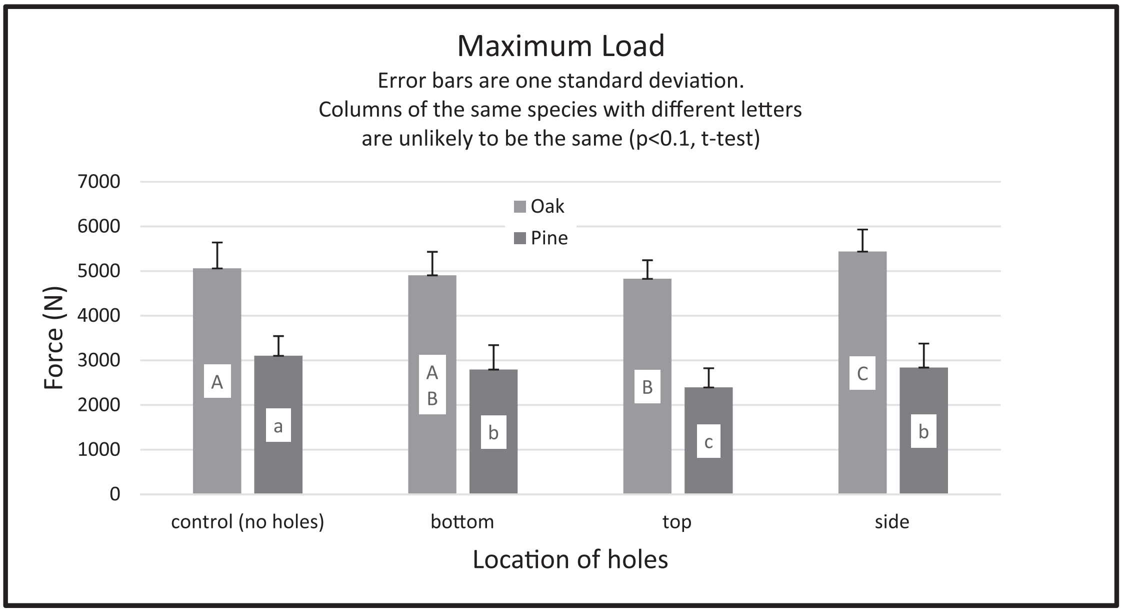

*Figure 5.—Average load to failure of scaled bridge timbers (*n = 30*).*

and with and without daps. An additional group of beams was sawn down to a uniform thickness along its length of 16 mm (0.63 in.)—i.e., the depth of the other beams at the dap area. Bending tests of these beams showed that the dap reduced the load-carrying capacity by almost as much as having the entire beam of reduced depth (Fig. 7).

The effect of the dap is similar to that of a notched beam. Notches at the end of a beam are known to greatly reduce the shear strength of the beam and the *Manual for Railway Engineering* (AREMA 2015) has a double penalty for the shear strength of notched beams. The shear strength is reduced because of the decrease in height of the beam at the end, and there is an extra empirical reduction factor of the ratio of the reduced height to the unreduced height. A 1-in. (2.5-cm) dap in a 10-in. (25-cm) timber would cause a 19 percent reduction in design shear strength; a 2-in. (5-cm) dap would cause a 36 percent reduction.

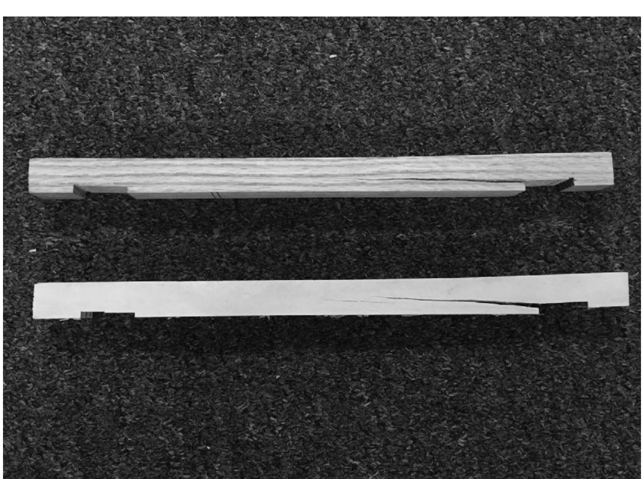

Figure 6.—Typical failure pattern in the scaled bridge beams. Red oak on top, pine below.

This testing purposefully omitted many variables that would be encountered in practice—greater species variation, moisture content variation, preservative treatment, and wood defects. Some wood characteristics such as slope in grain and intragrowth ring variability, which were not included here as test variables, may affect small beams disproportionately compared with actual bridge timbers. However, the results of this controlled, limited experiment suggest that the impacts of preservative ports on the structural properties of bridge timbers would be of little practical significance. Further testing with full-scale beams could be conducted to provide more accurate predictions of the impact of preservative ports on bridge tie strength. This study did not include an investigation into the effects of the preservative port holes on stiffness. This is because the design of railroad bridge timbers is concerned only with strength (AREMA 2015). The low span-to-depth ratios of the bridge timbers mean that deflections will be small. Other aspects, such as overall deflection of the bridge, uneven bearing of the timbers, and the deterioration of the wood will contribute much more to the deflection than the stiffness of the bridge timber itself. For other applications of timbers with preservative port holes, stiffness may be an important consideration.

The potential advantages of the supplemental preservative treatments enabled by the holes would likely far outweigh the reduction in structural properties caused by the holes. For the 14-ft (4.3-m) bridge timber, the holes result in estimated strength losses of generally $<$10 percent on average. By contrast, as little as 1 percent mass loss due to fungal decay can result in (highly unpredictable) reductions in mechanical properties of over 50 percent (Wilcox 1978).

Daps in the bridge timbers cause a greater reduction in structural properties than the preservative ports. Although the daps could be eliminated in some cases, the daps are often necessary when replacing bridge decks on old railroad bridges where the top of the beam elevation varies because of cover plates, gussets, and other causes.

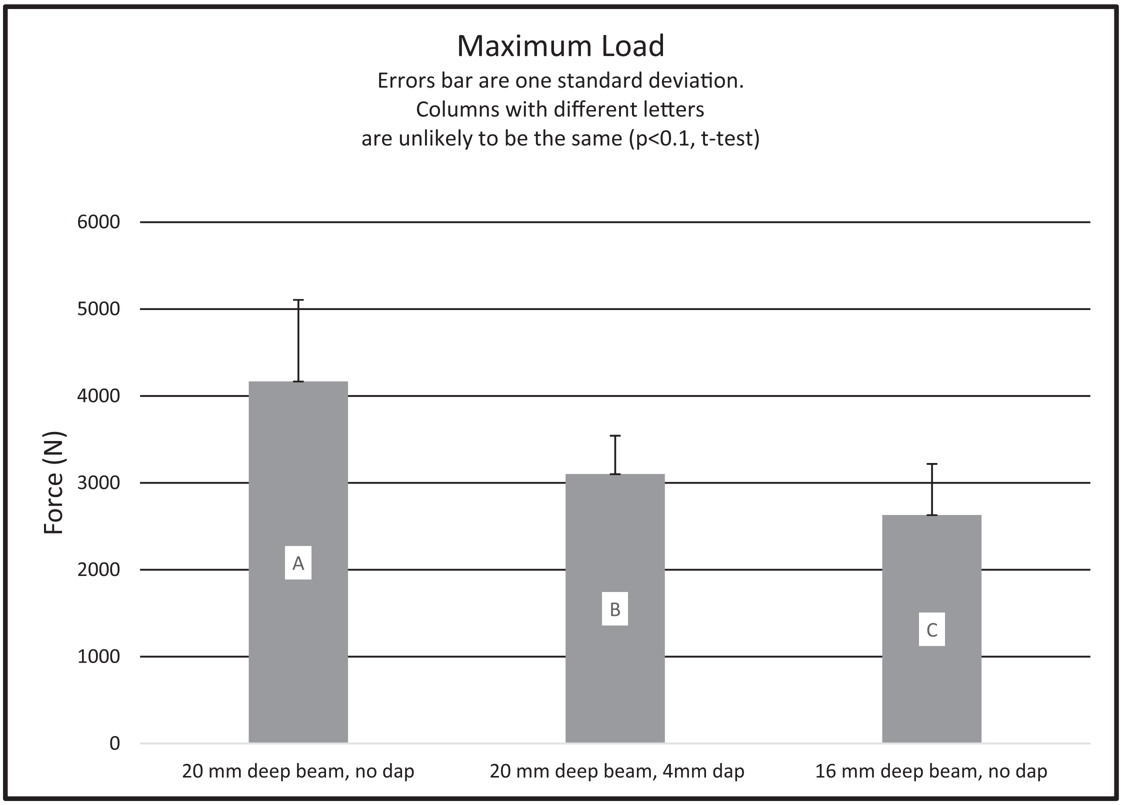

*Figure 7.—Effect of dap on pine scaled bridge timbers (*n = *30).*

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