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Distribution of Borates Around Point Source Injections in Wood Members Exposed Outside

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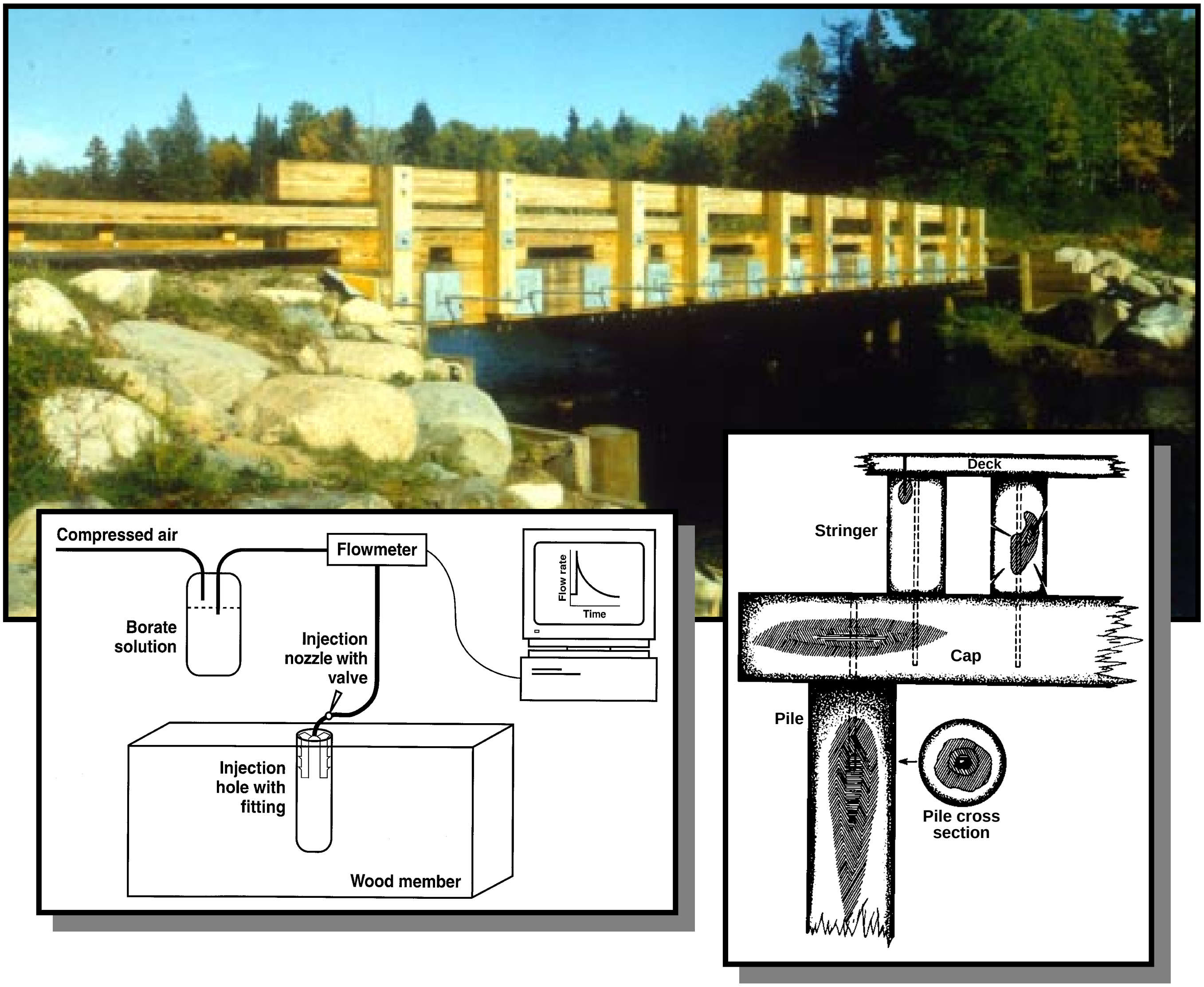

Abstract

In bridge timbers, wood decay is usually found where water has accessed the end-grain surfaces. In preservative-treated members, end-grain surfaces are most likely to be those resulting from on-site framing cuts or borings. Because these at-risk surfaces are easy to see, it seems feasible to establish a program where diffusible preservatives are repetitively inserted into those critical areas spatially distributed in a grid and on a schedule that will ensure protection, thereby extending the life of the entire structure. The objective of this study was to determine the vertical and lateral distribution and the post-treatment behavior of injected and inserted borate preservatives in wood exposed to natural wetting in field exposure. During this 1- and 2-year exposure, rain wetting elevated the moisture content of the wood enough to support growth of decay fungi in wood not protected by borates. Point source treatments consisted of either borate solutions or fused borate rods that were injected or inserted, respectively, into predrilled holes. The longitudinal movement of borates applied as either glycol or aqueous solutions was generally greater than that occurring with treatment of borate rods only. Lateral distribution of borates was similar among treatments. In Southern Pine, differences in both vertical and longitudinal movement of borate from the insertion holes were associated with the type of closure used. Results indicate that borates can be included in a maintenance program consisting of time-sequenced treatment of critical regions of wood bridges that are at risk for internal decay. Grids for placement of point sources of diffusible borates in engineered wood structures could be developed on a wood-species-specific basis. Such treatments would complement the exterior shell of protection provided by the original pressure treatment and enhance long-term durability.

Keywords: borates, preservative, diffusible preservative, post treatment, remedial treatment

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Distribution of Borates Around Point Source Injections in Wood Members Exposed Outside

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Introduction

In bridge timbers, critical wetting that leads to wood decay is, in the majority of cases, found at end-grain surfaces (Eslyn and Clark 1979). In preservative-treated members, end-grain surfaces are likely to be those resulting from on-site framing cuts or borings. Wood at joints is also vulnerable because water may be held or trapped in the joint interface or continuously supplied by capillary movement to the end grain of associated fastener holes as it is absorbed into the wood.

The locations where structural members in wood bridges are at risk for decay are known. Therefore, it seems technically feasible to establish a maintenance program where diffusible preservatives are repetitively inserted into those critical areas in a distribution grid and on a schedule that will ensure protection, thereby extending the service life of the entire structure. The insertion of solid, fused borate rods into affected members is a method that could be used for this purpose (Dietz and Schmidt 1988a, Dirol 1988, McCarthy and others. 1993, Ruddick and Kundzewicz 1992). Dickinson (1990) regards the development of fused borate rods for in situ treatments as a major advance in the use of borates. However, Dickinson (1990) and Schmidt (1990) emphasize the need to understand the moisture characteristics of wood in service, which are critical to the development of effective treating practices with diffusible preservatives. Difficulties in protecting millwork (joinery) and decking above ground are summarized by Schmidt (1990), who emphasizes the need for more field trials in the United States to show the specific benefits of using fused borate rods.

Borate solutions can also be injected into wood members. A conceptual advantage of injected borate solutions compared with insertion of fused borate rods is that immediate distribution of boron throughout a critical area can be accomplished at the time of treatment. Edlund and others (1983) observed faster diffusion of boron from a borate and glycol solution than that from fused borate rods in window joinery. Our observations (De Groot and Felton 1998) of generally limited movement of injected solutions in dry wood within weeks after injection led us to question whether benefits from borate injections were substantially greater than benefits derived from solid rods. The limited lateral movement of borates from the longitudinal flow of injected chemical could limit the immediate effectiveness of these treatments. Ultimate protection of the treated member would, as with solid fused borate rods, depend upon diffusion of the borates throughout the wood.

Diffusion of borates from point source applications usually is greater along the wood grain than across the grain. Longitudinal diffusion of borates to distances greater than 120 mm from the injection point (depot) occurred in sapwood portions of pine (*Pinus sylvestris*) joinery treated with fused borate rods and with borate and glycol solutions (Edlund and others 1983). There was faster diffusion of borates in the fiber direction than across the grain. It was recommended that, in practice, a spatial (longitudinal) distance of 20 cm between depots not be exceeded. In laboratory studies, borates diffused through glue lines and, after time in the field, diffused into the heartwood. Longitudinal diffusion of borates adequate to protect eucalyptus (*Eucalyptus obliqua)* in an accelerated field simulator was only 20 to 50 mm from the fused rods (Greaves and others 1982). Only minimal lateral diffusion of borate into Douglas-fir heartwood resulted from application of sodium borate solutions to one face of Douglas-fir heartwood (Grace and Yamamoto 1994).

Highley and Ferge (1995) monitored the movement of borate from fused boron rods that were placed in holes drilled into the upper surface of 15.2- by 15.2-cm timbers that were exposed for 2 years under field conditions near Madison, Wisconsin. Both transverse and longitudinal movements of boron from rods were greatest in Southern Pine, which was mostly sapwood and had the highest moisture content, and were least in Douglas-fir in which the moisture content in the field did not exceed 21%. On the basis of those observations, Highley and Ferge suggested that the spacing of borate rods shown in Table 1 was adequate for protection.

Table 1—Spacing of borate rods for adequate protection

	Borate rod spacing (mm)	
Species	Across the grain	Along the grain
Southern Pine	51	305
Red oak	25	152
White oak	25	76
Douglas-fir	Recommendations could not be developed	Recommendations could not be developed

In field settings, insertion of borates into bridge members and other engineered structures may have to be from the underside or the lateral surface of members. Little attention has been given to vertical redistribution of borates, but Dietz and Schmidt (1988b) did observe in deck members that the plume of diffused borate was longer on the bottom than on the topside of treated members.

In this study, we conducted experiments to determine the post-treatment behavior and the vertical and lateral distribution of injected and inserted borate preservatives in wood exposed to natural wetting in field exposure. Species of wood used in this study are either currently being used or being considered for use in transportation structures within the United States.

Materials and Methods

This investigation was conducted with wood members that were not treated with preservatives or were experimentally treated with creosote in a treatment cycle that was intended to give only an inadequate treatment. The distribution of preservative about the injection point (depot) was observed in wood members that were exposed for either 1 or 2 years in the field. Usually, 16 to 20 replicate units of each wood species were used, but as a result of constraints in availability of some materials, sometimes fewer replicates were used (Table 2). Only an overview of the sample preparation is given here. Specific details of sample preparation and treatment procedures were described by De Groot and Felton (1998).

In this study, we used solid members of eastern cottonwood (*Populus deltoides* Bartr. Ex Marsh.) and Southern Pine (probably longleaf pine, *Pinus palustris* Mill.) and laminated beams of red maple (*Acer rubrum* L.) or Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Southern Pine and cottonwood members (Table 2) typified the cross-sectional dimensions of individual members of a stress-laminated bridge deck. The laminated beams of red maple and Douglas-fir, although narrower than would probably be used in a bridge, were composed of 5-cm-thick laminates, which are typical of that type of construction.

All untreated members were from the same sources as the members used to monitor preservative distribution soon after treatment (De Groot and Felton 1998). To the extent possible, members in this study were end-matched with members used in the prior study. All materials were cut into lengths of 30 cm prior to borate treatments. Lateral surfaces of laminated beams (Douglas-fir and red maple) were coated with a commercial water repellent prior to cutting into 30-cm lengths.

Members to be treated with creosote were cut into 60-cm lengths and treated with creosote meeting AWPA standard P1/P13 (AWPA 1998a). The treating schedule was intended to produce only a shell treatment, but the laminates of red maple and Southern Pine and some Douglas-fir laminates received almost thorough penetration. Following treatment, the members were longitudinally bisected into two 30-cm lengths.

All borate treatments (Table 3) were inserted at midlength into 9.5-mm-diameter holes that were drilled through the narrow face of each 30-cm-long unit. Holes were positioned equidistant from both sides of the units. With the laminated units, the insertion hole penetrated through several laminates.

Solid borate rods were inserted into the holes, and then the holes were sealed with either a hardwood plug or an injection fitting. Solutions were injected through a nozzle pressed against commercially available fittings that were driven into the 9.5-mm-diameter holes in the wood units. When both a rod and solution were used, the rod was inserted, the hole sealed with a fitting, and the solution injected to refusal.

All treatments were completed at the USDA Forest Service, Forest Products Laboratory (FPL), in Madison, Wisconsin. Within 1 month of treatment, all units were shipped to the Harrison Experimental Forest in southern Mississippi and exposed above ground in January 1996. Ten replicates were juxtaposed with the longitudinal axis of each replicate in an east–west direction (Fig. 1). Insertion holes were positioned to the bottom of the replicate (toward the ground). Replicates were supported by a concrete base, approximately 0.3 m above ground. Replicates of each treatment were held tightly together with metal banding. Units were removed from the field in January of either 1997 or 1998. After exposure, units were shipped back to FPL where they were dried to a constant weight in a heated room (estimated 6% relative humidity).

Lateral and vertical movement of borate from the injection hole was determined visually on the cross-sectional surface of a cut made through the insertion port. Longitudinal movement was visually determined on surfaces of cross sections that were cut sequentially at distances of 2.5 cm from the injection point (Fig. 2). Solutions of turmeric followed by a hydrogen chloride–salicylic acid solution were

Table 2—Mean indices of diffusion for borates from insertion point after 1 or 2 years of field exposure[a]

Type of borate treatment	Number of replicates per treatment	Size of member, width, depth (cm)	Maximum longitudinal diffusion (parallel to grain) (cm)	Maximum diffusion above depot (insertion hole) (cm)	At point of insertion, depth below surface not protected by diffusion (cm)	Maximum width of diffusion plume (cm)
1-year exposure						
Cottonwood without creosote treatment						
None	20	5, 14				
Borate/glycol	20	5, 14	11.88 (0.523)	1.41 (0.661)	0.49 (0.919)	4.29 (1.16)
Borate/H_2O	20	5, 14	11.16 (1.37)	1.99 (0.77)	0.325 (0.55)	4.40 (0.91)
Fused borate rod (wood plug)	17	5, 14	5.22 (1.88)	0.50 (1.75)	0.312 (0.86)	4.36 (1.28)
Borate/glycol/rod	16	5, 14	10.31 (1.80)	2.88 (0.73)	0.235 (0.52)	4.90 (0.34)
Creosote-treated cottonwood						
None	14	5, 14				
Borate/glycol	16	5, 14	9.9 (2.22)	1.45 (0.50)	1.08 (0.61)	3.19 (0.30)
Fused borate rod (wood plug)	16	5, 14	9.45 (3.00)	0.84 (0.52)	0.83 (0.85)	3.23 (0.41)
Southern Pine without creosote treatment						
None	15	4, 18				
Borate/glycol	16	4, 18	4.95 (2.16)	2.28 (0.47)	0.34 (0.52)	3.58 (0.10)
Borate/H_2O	16	4, 18	3.75 (2.68)	1.42 (1.40)	0.14 (0.38)	3.38 (0.38)
Fused borate rod (wood plug)	16	4, 18	3.30 (1.87)	1.94 (0.58)	0.03 (0.12)	3.56 (0.20)
Fused borate rod (wood plug)	16	4, 18	6.45 (3.26)	1.28 (1.14)	0.09 (0.26)	3.43 (0.27)
Borate/glycol/rod	16	4, 18	5.40 (2.88)	2.41 (0.45)	0.0 (0.00)	3.55 (0.20)
2-year exposure						
Red maple without creosote treatment						
None	16	7, 18				
Borate/glycol	16	7, 18	7.50 (1.16)	0.84 (0.72)	0.06 (0.24)	3.94 (0.58)
Fused borate rod (wood plug)	16	7, 18	4.50 (2.38)	0.76 (1.63)	0.0 (0.0)	3.89 (0.42)
Borate/H_2O	15	7, 18	9.28 (0.82)	1.25 (0.43)	0.15 (0.38)	3.37 (0.43)
Creosote-treated red maple						
None	18	7, 18				
Borate/glycol	20	7, 18	6.84 (2.77)	2.04 (3.46)	1.15 (0.90)	2.18 (0.72)
Borate/H_2O	20	7, 18	9.96 (2.77)	1.75 (2.67)	0.57 (0.73)	1.45 (0.44)
Douglas-fir without creosote treatment						
None	16	7, 15				
Borate/glycol	16	7, 15	5.40 (4.11)	1.35 (0.33)	0.00 (0.00)	3.47 (0.41)
Fused borate rod (wood plug)	16	7, 15	0.00 (0.00)	1.73 (0.45)	0.86 (0.71)	3.66 (0.29)
Creosote-treated Douglas-fir						
None	14	7, 15				
Borate/glycol	15	7, 15	4.32 (2.00)	0.91 (0.36)	0.00 (0.00)	3.75 (1.22)

[a] Borate–H_2O = 15% $Na_2B_8O_{13} \cdot 4\,H_2O$ (saturated); borate–glycol = 15% $Na_2B_8O_{13} \cdot 4\,H_2O$; 26% ethylene glycol, borate rod = fused disodium octaborate (borate [B_2O_3] equivalent of 82.0%). Each rod contains 2.14 g $Na_2B_8O_{13}$. Data are means; standard deviations are in parentheses.

Table 3—Specifications of preservative treatments

Solution	Composition	Specific gravity at 20°C
Borate–H_2O	15% $Na_2B_8O_{13} \cdot 4\,H_2O$ (saturated)	1.00
Borate–glycol	15% $Na_2B_8O_{13} \cdot 4\,H_2O$, 26% in ethylene glycol (saturated)	1.16
Fused borate rods	2.5 cm long by 0.8 cm diameter, 2.14 g 15% $Na_2B_8O_{13} \cdot 4\,H_2O$ each	—

used to indicate the presence of boron at a threshold of ≥0.25 BAE (AWPA 1998b). With this methodology, the distance that the borate diffused and the maximum width of diffusion at the insertion point were recorded above the insertion hole. The distance was recorded from the surface, at the point of insertion, to the depth below the surface that was not protected by borate. The maximum longitudinal distance that borate diffused was also recorded. Means and standard deviations of these measurements are reported in Table 2.

Figure 1—Units of treatment held together with metal banding and exposed in southern Mississippi in east–west direction longitudinally. Insertion holes were on the side toward the ground.

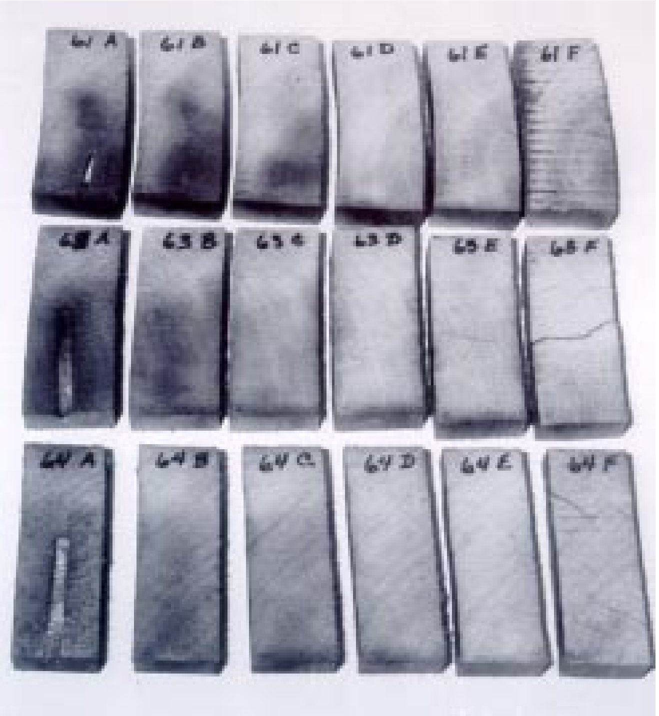

Figure 2—Sequential cross sections of cottonwood members treated with fused borate rods and exposed in the field for 1 year. Injection ports are shown in samples marked A on the left.

Results and Discussion

Comparisons among treatments were limited to within comparable woods for the same exposures. Visual measurements of curcumin on sawn surfaces are not precise, but they did demonstrate differences among treatments in patterns of distribution. Not one of the distribution patterns that we observed was influenced by pre-existing decay (Edlund 1982), because all wood materials were sound at the time of treatment. In untreated wood, advanced decay was observed at time of removal from the field in the portions unprotected by borates. In members exposed for 2 years, the boundary between positive curcumin reaction and visible decay was quite distinct. Therefore, the observed patterns were accepted as having practical value in defining a treatment grid for long-term maintenance of wood bridges and similar structures. No decay was visible in wood members treated with creosote.

The longitudinal (with the wood grain) movement of borates applied as either glycol or aqueous solution was generally greater than that occurring with treatment using borate rods only. An exception occurred in the Southern Pine that was exposed for 1 year. Maximum longitudinal penetration occurred in Southern Pine members in which the insertion holes were sealed with a solid wood plug after a fused borate rod was inserted. Edlund and others (1983) observed a more rapid diffusion of borate from a borate–glycol solution than from fused borate rods in window joinery. However, that difference was reduced over time. In this study, the difference in longitudinal diffusion had practical significance.

Vertical movement was characterized by a large relative variation about the respective mean of each treatment. With aqueous and glycol solutions, vertical movement of borate above the insertion ports in cottonwood and red maple was greater than that observed with solid rods. In Southern Pine, the vertical distribution of borates from treatment solutions was comparable with that from the solid rods in holes sealed with an injection fitting. Vertical distribution of borate from solid rods in holes sealed with a wood plug was less than other treatments in Southern Pine. Direct comparisons of solid rods and solutions in both vertical and longitudinal movement from the insertion depot, therefore, may be valid only if the same closures were used with all treatments. In Southern Pine, remnants of the solid fused rods were still in the insertion holes (depots) even after 2 years of exposure. In depots that had been sealed with a wood plug, fused rods were positioned near the base (plugged end) of the hole. The rods appeared to be resting on top of the wood plugs. In depots that had been sealed with a commercial injection fitting, the fused borate rods were at the upper end of the hole. During field exposure, the injection fittings moved into the insertion holes but the wood plugs remained at the surface. The effect of this was that the injection fittings forced the solid borate rod towards the top end of the insertion holes. The various positions of the solid rods within the Southern Pine members probably contributed to the differences in both vertical and longitudinal movement of borate that are associated with the type of closure that was used. In Douglas-fir that was not treated with creosote, vertical diffusion was somewhat greater with the borate rods than with the borate–glycol solutions.

With all treatments, the amount of wood near the opening of the entry port not yielding a positive response to curcumin (due to presence of enclosure in entry port) was usually less than 1 cm. The largest width not showing presence of borate occurred with the creosote-treated red maple. Lateral distribution of borates, as measured by maximum width of diffusion plume, was similar among treatments.

Diffusion of borate from injection ports also occurred in creosote-treated wood. When comparisons could be made, the amount of borate movement in creosote-treated wood was slightly less than that which occurred in untreated wood. Evidence of borate movement in creosote-treated wood indicates that these treatments would be functional in large creosote-treated timbers. Borate movement also suggests that insertion of borate solutions or rods into increment borer holes and then plugging the holes with a wood plug could be an acceptable means of protecting those holes after removing an increment boring.

Conclusions

Borates can be included in a maintenance program that consists of time-sequenced treatment of critical regions of wood bridges that are at risk for internal decay. Grids for placement of point sources of diffusible borates in wood members in bridges or in other aboveground engineered wood structures could be developed on a wood species-specific basis. Such treatments would complement the exterior shell of protection provided by the original pressure treatment and would enhance long-term durability.

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