Integrated Remedial Protection of Wood in Bridges

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Abstract

While timber bridges can perform well under a variety of conditions, many bridges experience premature internal decay due to poor specification, inadequate preservative treatment or poor construction practices. Arresting deterioration in these bridges poses a major challenge since the wood under attack is normally deep beneath the surface treatments and is highly resistant to impregnation by most conventional liquids. In this report, we discuss the use of fumigants and water diffusible fungicides for arresting these attack and preventing renewed invasion. The benefits of the two chemistries are discussed in relation to the potential for attacks and speed of control required.

Keywords: fumigants, timber bridges, remedial preservation treatment

Introduction

Properly performed preservative treatment of wood produces an excellent barrier against attack by most agents of biological deterioration, however, this barrier is often disrupted during fabrication or as the wood seasons and checks. Nowhere is this problem more acute than in timber bridges. These structures are subjected to extensive design considerations, but often require extensive field fabrication during installation which exposes untreated wood to potential biological attack. In addition, many fasteners are driven through the treated zone into the untreated wood, again exposing the zone beyond the treated shell to entry by moisture and fungal spores. Finally, the larger timbers employed in bridges are generally not completely seasoned to their in-service moisture contents prior to treatment. These timbers can check extensively as they season in service, again exposing untreated wood to fungal and insect attack. The rate of decay in large timbers exposed above ground varies with species and the climate to which the bridge is exposed, but the ultimate result is the development of internal decay which reduces bridge service life (Scheffer, 1971).

These problems have led to a general perception that timber bridges have shorter service lives and require more maintenance than comparable bridges constructed with other materials (Smith et al., 1995; Smith and Bush, 1995).

A variety of methods have been developed to improve the depth of initial treatment to reduce the potential for internal decay (Graham, 1983). These practices include incising, through boring, radial drilling and kerfing, but not all of these activities are compatible with timber used in bridges. In addition, studies have shown that even wood treated using these methods experiences low levels of internal deterioration. As a result, there is a substantial need for field treatments which can be applied to timber in bridges to arrest deterioration and prevent renewed attack (ASHTO, 1983; Ritter, 1990).

Deterioration in large wood members has long posed a major challenge to those charged with prolonging the useful life of a bridge (Ritter and Morrell, 1990). Most oil-based treatments lack the ability to migrate through wood for substantial distances. As a result, they cannot reach the points where decay fungi are actively growing. For many years, the treatment options for deteriorating timbers were limited, but the development of fumigants for wood application in the late 1960's provided a new, highly effective retreatment option (Graham, 1973, 1979). Fumigants are capable of moving as gases through the heartwood of nearly all wood species (Ruddick, 1984; Morrell et al., 1992a).

First developed for use on utility poles, fumigants are applied as liquids to steep angled holes drilled into poles and volatilize to move as gases through the wood. Three chemicals were initially explored for this purpose. Chloropicrin (trichloronitromethane) is a tear gas which has strong lachrymatory properties, Vorlex (20% methylisothiocyanate in chlorinated C_3 hydrocarbons) is a potent nematocide, and metham sodium (32.7 % sodium n-methyl-dithiocarbamate) has a long history of use for treating agricultural fields. Field trials with these chemicals showed that fungi were virtually eliminated from wood poles within one year after treatment (Figure 1). While these results were similar to experiences in soil application, it was the surprising ability of these chemicals to remain in wood for long periods after treatment that made them especially attractive for remedial protection. Fumigants are typically not detectable within 14 days after soil fumigation, yet these same chemicals were detectable in wood at levels which remained inhibitory to fungi for up to 20 years after treatment. Chloropicrin remains detectable at high levels in a number of species for many years after treatment (Morrell and Scheffer, 1985; Schneider et al., 1995). As result of these tests, fumigant usage in wood has steadily risen as utilities seek to extend the useful life of their wood structures (Morrell, 1989). Of the original three fumigants employed for this purpose, chloropicrin and metham sodium continue to be used. Vorlex, which was nearly as effective as chloropicrin, was difficult to apply and was never widely used for this purpose. In addition, a third fumigant, solid methylisothiocyanate (MITC) encapsulated in aluminum for safer application is registered for wood use. While fumigants are widely used by electric utilities, their use in timber bridges is less uniform, despite their potential for substantially extending wood service life. In this report, we will review the properties of the currently registered fumigants, outline the methods for application to timbers, describe newer formulations which are under development and finally, discuss several alternative chemicals which are available for remedial treatment of timber bridges.

Fumigant Application

Fumigants are normally applied to the wood through steeply sloping holes drilled across the grain (Graham and Helsing, 1979). These holes are then plugged with tight fitting wooden dowels which reduce the risk that the vaporizing fumigant will be lost to the outside environment. The goal of the steep sloping hole is to maximize the amount of chemical which can be applied while minimizing the number of strength-reducing holes which must be drilled. In round timbers, the drilling pattern derives from the pattern of inspection holes used to detect internal decay (Graham and Helsing, 1979). In timbers, the chemicals are normally applied through perpendicular holes drilled into the upper face on either side of any checks which might be present. In other areas of a bridge, fumigant application can become more problematic since care must be taken to avoid connectors and since it is sometimes difficult to drill vertically into a timber. At least one fumigant is available in a solid encapsulated formulation which permits application to timbers through holes drilled at almost any angle.

Properties of Existing Fumigants

Chloropicrin and metham sodium are both liquid fumigants. Chloropicrin is highly volatile and its handling properties have generally limited its usage to areas away from inhabited buildings. Applicators must wear full face respirators during application of this chemical, creating considerable public image problems in some areas of the country. There have been a number of attempts to gel or otherwise encapsulate chloropicrin, but none have been commercially successful (Goodell, 1989). One formulation of chloropicrin is available in semi-permeable tubes which slow the release rate for a short period prior to application (Fahlstrom, 1982). These plastic tubes have a permeable membrane on the top which degrades over a several day period, releasing chemical into the

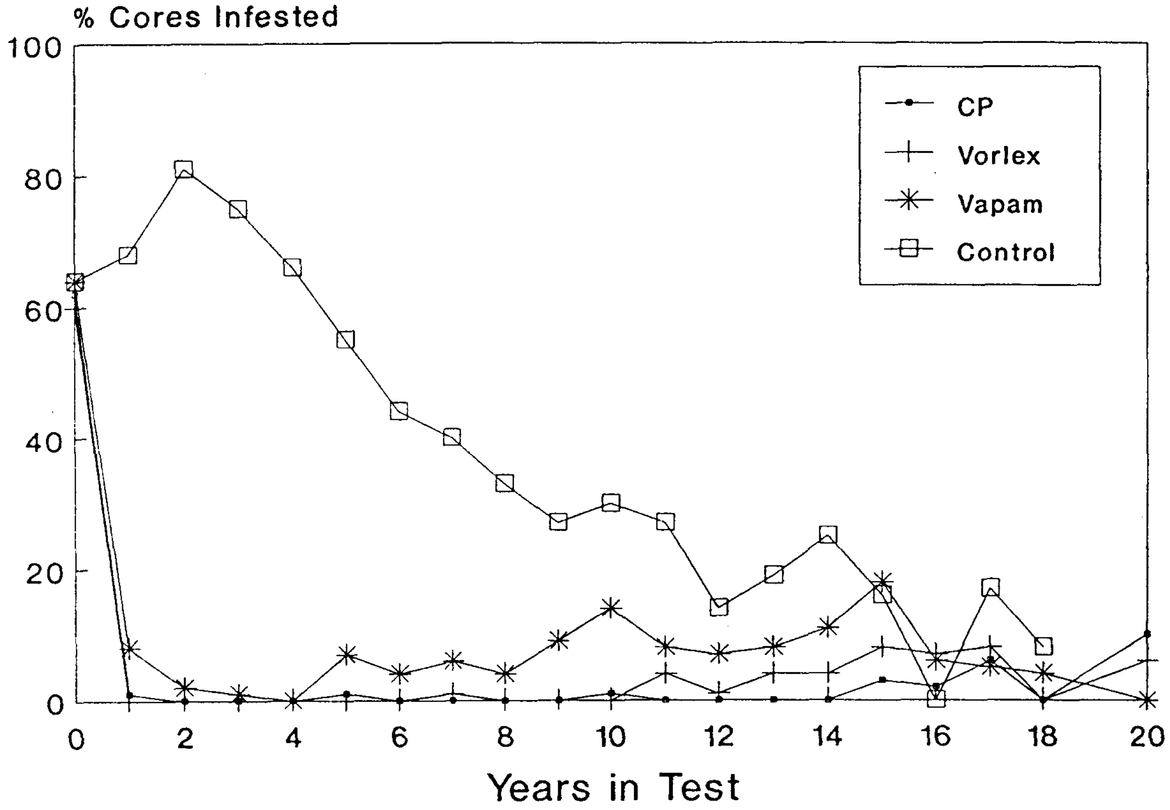


Figure l-Effect of fumigant application on survival of decay fungi in Douglas-fir poles.

wood. Tubes are normally filled at the beginning of a work day. This formulation has found its primary application for remedial treatment of bridges, where the large numbers of contiguous timbers being treated makes the process economical. The system also has some benefits because it permits application farther above the ground than would be possible with liquid chloropicrin. Liquid chloropicrin can leak from checks or other wood defects during application, posing a hazard to workers, while the tubes limit this risk. Despite its drawbacks, chloropicrin remains the most effective of the currently registered fumigants.

Metham sodium is the most widely used fumigant for remedial wood treatment. This compound is not, as applied, a very effective fungicide. Instead, metham sodium decomposes in the presence of organic compounds (such as wood) to produce a variety of fungitoxic compounds including MITC, which was the primary fungicide present in Vorlex (Morrell, 1994). Metham sodium smells like rotten eggs and is caustic, but it is the least toxic of the currently registered wood fumigants. It is has also proven to be the least effective of these chemicals (Figure 1). While chloropicrin has provided up to 20 years of protection, metham sodium eliminates decay fungi within one year, but provides only seven to 10 years of protection in Douglas-fir timbers (Helsing et al., 1984). Part of this differential performance reflects the lower amount of active ingredient applied. Chloropicrin is 96-97% pure, while metham sodium is a 32.7 % solution of the sodium salt. Thus, for a given amount of treatment hole, metham sodium provides much less protective chemical. In addition, studies suggest that the rate of decomposition of metham sodium to MITC is very poor and is sensitive to wood species, moisture content, and temperature (Morrell, 1994). As a result, only about 12% of the total liquid metham sodium applied actually becomes fungicidal. One final drawback of metham sodium is its high toxicity to aquatic life. As a result, metham sodium is not recommended for use in wood near standing water.

A field test of metham sodium in a Douglas-fir timber bridge located near Salem, Oregon shows that the MITC was present at fungitoxic levels at significant distances from the point of application 3 years after treatment (Table 1, 2). These results were similar to those found for Douglas-fir poles treated with equivalent dosages and suggest that fumigant treatment of bridge timbers should provide comparable protection against fungal invasion. Eventually, chemical loss might be expected to increase from bridge timbers; however, since these members have a higher surface to volume ratio. Fumigant is rapidly lost from the wood surface, so increasing the surface area should diminish the protective period provided by a given volatile chemical (Zahora and Morrell, 1989).

The risks of handling volatile, caustic liquids during remedial treatments encouraged the development of MITC as a wood fumigant. MITC is a solid at room temperature and sublimes directly to a gas, but it is also very caustic and must be encapsulated for safe handling (Zahora and Corden, 1986). Field tests in utility poles have shown that MITC is more effective than metham sodium but less effective than chloropicrin in terms of the length of the protective period (Figure 2)(Morrell et al., 1992c). In addition, MITC, as currently packaged, is more costly than either of the other materials, although the encapsulation does improve safety and permits application to wood well above the ground.

In addition to the registered formulations, efforts are underway to develop other, safer fumigants. The simplest strategy is to encapsulate an existing liquid fumigant to reduce the risk of spills and worker exposure. This strategy has recently been employed by encapsulating chloropicrin in various polymers to slow the release rate and reduce the risk of worker exposure during application. Preliminary field trials suggest that release may occur over a six to 10 year period (Love et al., 1996). When coupled with the tendency of wood to retain chloropicrin, this release rate creates the potential for longer protective periods than those afforded by current treatment technologies. Considerable effort remains to demonstrate the validity of these assumptions. This formulation is currently undergoing registration with the U.S. Environmental Protection Agency.

The other alternative to the currently registered fumigants is to identify solid chemicals which decompose to produce volatile fungicides in the presence of wood. There are a number of compounds which could potentially be used for this purpose, but the most likely candidate is Basamid (Forsyth and Morrell, 1995). Basamid is a crystalline material whose cyclic structure decomposes to produce MITC. Field trials have shown that this material decomposes too slowly to be of use as a remedial treatment (Highley and Eslyn, 1989), but the rate of decomposition can be accelerated by addition of buffers or metals. Field trials, again in utility poles, suggest that incorporating copper into Basamid prior to application produces decomposition at levels which would control fungi already present and limit the risk

Table 1- **Residual MITC content in Douglas-fir bridge stringers one or two years after metham sodium treatment as determined by gas chromatographic analysis of ethyl acetate extracts of wood samples.**

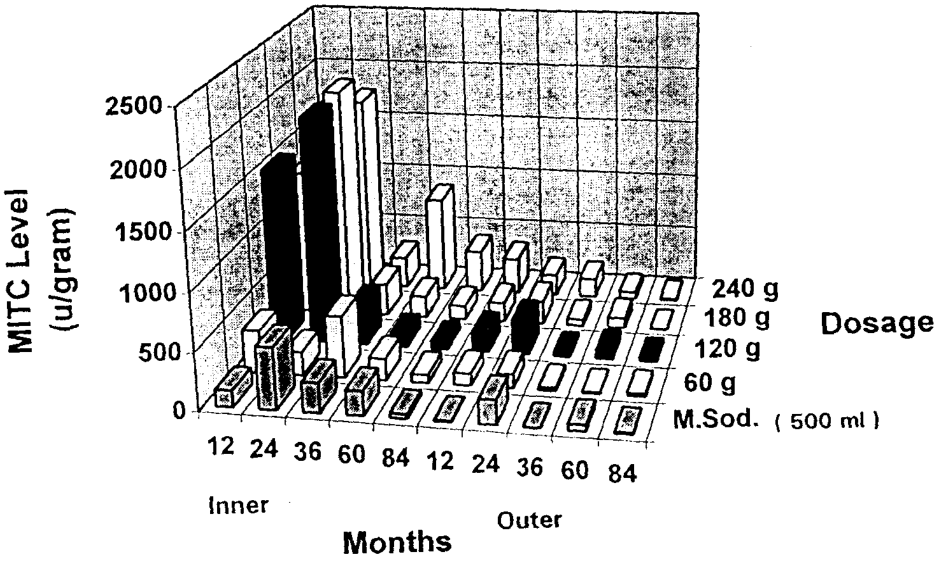
		µg MITC/OD g wood					
		Inner			Outer		
Structure #	Stringer Position	1 year	2 years	3 years	1 year	2 years	3 years
5	Top	4.3	52.3	9.7	0.00	27.6	3.3
	Bottom	59.7	34.7	31.1	24.5	112.4	84.1
10	Top	40.2	136.1	71.3	53.2	60.3	76.4
	Bottom	75.8	114.9	43.0	39.9	59.4	116.3
15	Top	27.3	66.1	46.4	37.4	59.5	145.4
	Bottom	16.0	99.7	17.8	24.3	112.9	43.4
20	Top	26.2	115.5	58.2	65.4	130.6	44.6
	Bottom	82.7	42.6	67.7	23.2	19.9	163.1
25	Top	26.5	80.2	40.7	13.1	44.4	52.5
	Bottom	33.4	83.3	86.0	65.5	95.4	32.1
30	Top	73.2	126.8	77.5	100.3	98.5	70.2
	Bottom	83.6	40.8	83.3	75.8	63.7	49.3
35	Top	44.1	74.1	108.7	60.6	120.8	56.5
	Bottom	14.0	75.1	19.2	9.2	42.4	8.8
40	Top		50.1			140.4	
	Bottom		92.1			56.7	
Average	Top	34.5	87.7	58.9	47.1	85.3	64.1
	Bottom	52.3	72.9	49.7	37.5	70.4	71.0

Table 2- **Levels of colonization by Douglas-fir timbers one to three years after application of metham sodium as measured by culturing increment cores.**

		Cores With Decay Fungi (%)[a]		
Structure #	**Stringer Position**	**1 year**	**2 years**	**3 years**
5	Top	0	0	0
	Bottom	0	0	0
10	Top	0	0	0
	Bottom	0	0	0
15	Top	17	0	0
	Bottom	0	0	0
20	Top	0	0	0
	Bottom	0	0	0
25	Top	17	0	0
	Bottom	0	0	0
30	Top	0	0	0
	Bottom	0	0	0
35	Top	17	0	0
	Bottom	0	0	0
Average	Top	7.3	0	0
	Bottom	0	0	0

[a] Values represent means of 6 cores/treatment

MITC-FUME Levels in Southern Pine 0.3 m Below Treatment



MITC-FUME Levels in Douglas-fir 0.3 m Below Treatment

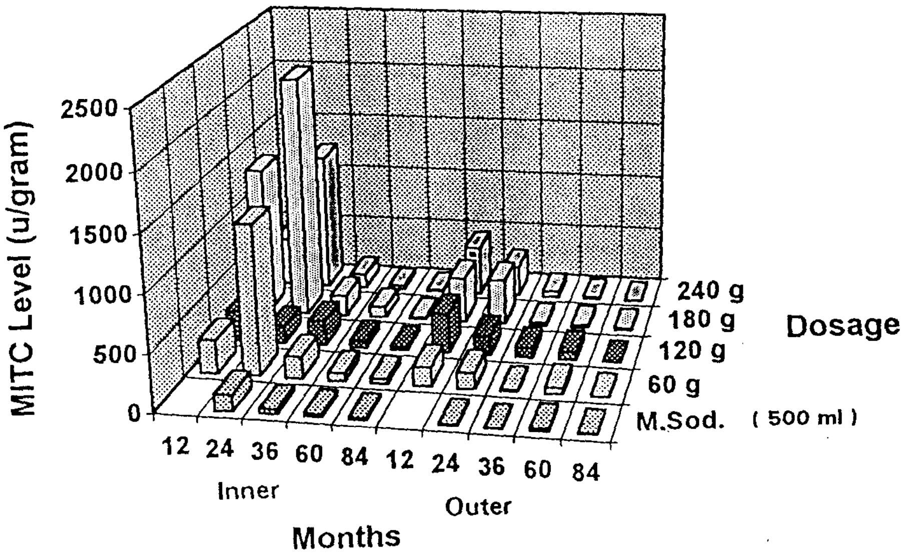


Figure 2-Residual levels of MITC in Douglas-fir and southern pine poles one to seven years after application of MITC-Fume.

of reinvasion (Forsyth and Morrell, 1993). One other advantage of this chemical is its existing registration for application to non-food crops, making it far easier to register for wood application.

Ultimately, strategies utilizing solid fumigants which can decompose slowly over a several year period can provide a safer method for preventing internal decay using volatile chemicals.

Alternative to Fumigants

While fumigants have proven to be highly effective, their handling properties have encouraged a search for less toxic decay control strategies. One alternative to fumigants are water diffusible fungicides including boron and fluoride. These compounds do not volatilize like fumigants, but they are able to diffuse from areas of high to low concentrations whenever free water is present in the wood. Both boron and fluoride have been used for many years for protecting a variety of products from decay, but their use for internal decay control in large timbers in North America is a relatively recent development (Becker, 1976). Boron is highly effective against most decay fungi and insects, although the levels required for control can vary quite widely. Typically, a target boron retention between 0.25 and 0.5% by weight is required for wood protection. Levels required for preventing wood attack where the Formosan termite is present are many times higher. Fluoride is generally only used for controlling decay fungi. In a number of studies, boron and fluoride have moved well through moist wood, but move very little when the moisture content falls below 30% (Smith and Williams, 1969). Proponents of these systems have pointed out that substantial fungal decay does not occur when the moisture content falls below 30%, therefore, it should not matter if the diffusible compound does not move in dry wood since no decay can occur under these conditions. However, this approach ignores the fact that wood moisture contents can vary widely along the length of large timbers. As a result, the boron or fluoride may be applied to a dry zone, where no movement will occur, while an adjacent wet area contained actively growing decay fungi. Judicious application can help overcome some of this limitation, but there remains the risk that the improperly placed chemical will not diffuse to the points where it is needed.

Two formulations of boron and fluoride are labeled for wood use in the U.S. Fused boron rods are produced by heating boron to high temperatures and pouring this molten material into molds. The boron cools and hardens into a glass-like rod which is applied to the same steep angled holes used for fumigant treatment. Boron diffuses from the rods in the presence of moisture (Morrell et al., 1990) and moves well through a variety of North American wood species (Morrell et al., 1992b). Sodium fluoride is available in rod form and has a long history of use in railroad ties, but has only recently been labeled for other wood uses. Field trials are currently underway to evaluate the performance of these materials in larger timbers. An additional formulation which is not currently labeled in the U.S. is composed of both fluoride and boron in a rod form (Preschem Ltd., Cheltenham, Australia). Field trials with this formulation suggest that the rate of chemical movement from the rods remains slower than that found with fumigants (Table 3).

Field trials of boron in fused boron rods have shown that boron diffusion away from the application point in Douglas-fir poles takes up to 3 years to achieve chemical levels which can provide effective fungal control (Table 4)(Morrell and Schneider, 1995). Since decay continues while this diffusion occurs, the user takes a risk that the timber will deteriorate to an unsafe condition before boron levels are sufficient to effect fungal control. Trials with southern pine poles have proven more successful, perhaps reflecting the more permeable nature of this wood species (Zahora et al., 1996). Trials with a fluoride/boron rod have shown that boron has moved more rapidly than the fluoride over a 2 year period. These results are interesting since a prior trial of groundline preservative pastes containing fluoride and boron showed the opposite effect in Douglas-fir posts (Morrell et al., 1994).

A final diffusible preservative system available for timber in bridges is a water soluble copper naphthenate/boron paste. Limited field trials with this formulation indicate that the boron moves well from the point of application, while the copper naphthenate moves to only a limited extent (Forsyth and Morrell, 1992). As a result, this treatment might be useful for treating the inner surface of large voids, where the copper naphthenate would coat the surface of the void, while the boron would diffuse further into the wood. This treatment, however, would be unlikely to completely eliminate established decay fungi.

Selecting Remedial Treatments

Bridge maintenance specialists have a variety of options for arresting internal decay in their bridges. Each chemical has certain pros and cons which may make it especially attractive for specific applications. For example, where decay is actively occurring in a bridge located away from inhabited structures, chloropicrin

Table 3- **Residual boron and fluoride at selected locations above or below the groundline in Douglas-fir poles one year after treatment with fluoride/boron rods.**

		Residual Chemical (%F or BAE) [b]											
		Distance from Treatment Zone											
Dosage (g)	**Application Pattern (Degrees)**[a]	**-300 mm**				**300 mm**				**600mm**			
		Outer		**Inner**		**Outer**		**Inner**		**Outer**		**Inner**	
		F	**BAE**	**F**	**BAR**	**F**	**BAE**	**F**	**BAE**	**F**	**BAE**	**F**	**BAE**
70.5	90	0.02	0.10	0.11	0.63	0.08	0.54	0.11	0.51	<0.01	0.03	0.01	0.02
	120	0.01	0.06	0.03	0.26	0.02	0.09	0.06	0.49	<0.01	0.04	<0.01	0.05
141.0	90	0.01	0.28	0.07	0.06	0.02	0.07	0.07	0.36	0.01	0.03	0.01	0.05
	120	0.04	0.09	0.12	0.67	0.03	0.10	0.04	0.20	0.01	0.04	0.01	0.05
0.00	-		0.01	-	0.08	-	0.04	-	0.01	-	0.01	-	0.01

[a] **Values represent composite analyses of 5 poles/treatment. BAE represents boric acid equivalent.**

[b] **Application patterns were holes at 90 or 120” intervals around the pole.**

Table 4 -- **Residual boric acid equivalent (BAE) at selected locations in Douglas-fir poles 1 or 3 years after treatment with borate rods with and without supplemental moisture.**

		Residual Boron Concentration (%BAE) by position[a]											
Borate Dosage (%)	**Water Added**	**Groundline**				**300 mm above Groundline**				**900 mm above Groundline**			
		Outer		**Inner**		**Outer**		**Inner**		**Outer**		**Inner**	
		Year 1	**Year 3**	**Year 1**	**Year 3**	**Year 1**	**Year 3**	**Year 1**	**Year 3**	**Year 1**	**Year 3**	**Year 1**	**Year 3**
120	-	0.02	0.17	0.02	0.34	ND[b]	0.20	ND	0.32	ND	0.02	ND	0.02
	+	0.02	0.49	0.02	0.72	ND	0.11	ND	0.16	ND	0.03	ND	0.04
240	-	0.02	0.45	0.02	0.75	ND	0.13	0.02	0.10	ND	0.05	ND	0.04
	+	0.01	0.38	0.02	0.54	ND	0.14	ND	0.22	ND	0.03	ND	0.04

[a] **Values represent composite analyses of 5 pole sections.**

[b] **ND signifies boron levels <0.0l % BAE.**

might represent the best option, while a similar bridge near houses might be better suited to treatment with metham sodium or MITC. In instances where there is no visible evidence of decay, the use of water-diffusible boron or fluoride may be appropriate since the risk of deterioration while the chemical diffuses through the wood is minimal.

Timber bridge inspectors contemplating the use of diffusible boron or fluoride must carefully weigh the benefits of safer chemical application against the need for rapid decay control. In instances where the timbers contain active decay fungi, fumigants may provide the fastest control, thereby preventing further deterioration of the bridge capacity. In some instances, inspection may show that a bridge has only minor decay problems. In these cases, the preventative application of diffusible chemicals may prevent the inception of decay. One advantage of boron or fluoride is the unrestricted classification of these compounds. Fumigants are generally restricted use pesticides and, even where they are not, considerable care must be taken during application. The diffusibles are more easily handled and may be more suitable in locations where extensive training of the inspection crew in chemical handling is not desirable or cost effective.

The long term protective effect of diffusibles remain under study, so users of these technologies would be strongly advised to consider some form of monitoring of the chemical levels in their structures to determine when retreatment is necessary.

Conclusions

The wide array of treatment options provide a variety of opportunities for prolonging the useful life of timber in bridges. Along with the obvious safety and economic benefits, these treatments also conserve our valuable forest resources.

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