Condition of Chromated Copper Arsenate Treated Hem-fir Guardrail Posts after 20 Years in Service in Western Washington State

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Abstract

Wood guardrail posts are among the most common wood materials currently used in highway construction. Preservative treated hem-fir is an important species for guard-rain applications in the western United States. The service life of treated timber post guardrail systems has been estimated to be between 10-20 years. However, there is surprisingly little information on performance of timber guard rails. One aspect of the service life estimate is wood durability. This study assessed the flexural properties, level of decay, and residual preservative levels in chromated copper arsenate preservative treated hem-fir guardrail posts removed from a project near Bellingham, WA. Increment cores were removed from each post for assessing preservative treatment and fungal colonization. The posts were then tested for flexure properties in a three point bending test. Posts that met the AWPA Standards for preservative penetration trended to have lower levels of internal decay after 20 years in service and nearly all posts tested retained sufficient flexural properties to meet AASHTO Standards.

Key Words : Timber Guardrail, Decay, In-service performance, chromate copper arsenate, hem-fir

Introduction

Wood has been used in highway construction in the United States since the development of the first roads. Wood guardrail posts are among the most common wood materials currently used in highway construction. Guardrail systems are longitudinal barriers designed to redirect the energy of a collision and minimize the risk of occupant injury. These systems consist of rectangular timber posts and flexible steel (W-beam) guardrails. Three of the most commonly used guardrail systems in the US are the G4(1S), G4 (2W), and G4(RW). The standard G4(1S) uses a W150 x 14 (W 6x9) structural steel shape post embedded 1,118 mm (44 in) in soil. The G4 (2W) and G4 (RW) systems use 150 x 200 mm (6x8 in.) and 184 mm (7.25 in.) diameter wood posts with standard embedment depths of 1,118 mm (44 in.) and 965 mm (38 in.), respectively. Each of these systems has been tested as an individual component and in full-scale crash tests of W-beam guardrail systems and subsequently approved for use as energy dissipating devices along highways (Bligh et al. 1995).

Many guardrail systems utilize treated timber guardrail posts to protect motorists from roadside hazards. Preservative treated hem-fir, Douglas-fir, or southern pine have traditionally been used in these applications, but other species are used in some localities. The service life of treated timber post guardrail systems has been casually estimated to be between 10-20 years. However, there is surprisingly little information on performance of timber guard rails. One aspect of the service life estimate is durability concerns for wood.

Durability is influenced by a number of factors including the climate, soil conditions, impact damage, maintenance, drainage conditions, and sunlight exposure (Zabel and Morrell, 1992). The most important factors influencing guardrail post service life are the effectiveness of the preservative treatment and the environmental conditions at the ground line. Proper pressure-treatment creates a protective shell of treated material around an untreated core. This core remains protected as long as the external shell remains intact, but checking after treatment can expose untreated wood to possible fungal or insect attack. The risk of decay is typically highest in the zone just above groundline to approximately 450 mm below that line. Coincidentally, the groundline area is also critical for guardrail performance.

Routine inspection of guardrails is not required and is not typically performed unless there is an automobile accident. Therefore, replacement decisions are based upon past experience and can be somewhat arbitrary. Most times the condition of the guardrail system is not assessed until the roadway is scheduled for upgrade or reconstruction. Moreover, the amount of deterioration in wood guardrail posts cannot easily be determined by visual field inspection, so degraded posts may go unnoticed by maintenance personnel (Kennedy et al. 2006). Much of the literature on highway guardrail posts has focused on their dynamic performance under vehicle impact loadings. There is little research examining the condition of guardrails after they have been in service, nor are there data on the potential for reusing these systems.

Timber guardrail posts are widely used because they are inexpensive, easy to install and their capacity to absorb considerable load without failing makes them ideal for dissipating the energy associated with a vehicle impact. The use of wood in this application may also be viewed as positive because these materials are renewable, while many alternatives are produced using much higher energy inputs and non-renewable resources. At the same time, questions have arisen about the long term performance of wood guardrail posts and some government entities have moved to alternative non-renewable materials such as steel for this application. There is surprisingly little data on the long term performance of wood guardrails. In this study, we describe the results of field inspections and full scale bending tests of guardrail post material that had been in service for 20 years in Western Washington State. The specific objectives were:

1. Assess the residual flexural properties of guardrail posts after 20 years in service
2. Examine the levels of decay in the guardrail posts
3. Investigate the effects of decay on flexural properties of guardrail posts.

Materials and Methods

Guardrail posts were removed from a project near Bellingham, WA and transported to Sumner, WA. The posts averaged 125 mm by 175 mm by 1.8 m in length. Because the posts were in bundles, only the exterior pieces could be examined; however, the contractor noted that no special effort was made to sort posts prior to bundling. Each post was first sounded with a hammer to determine if large voids were present. The goal was to select equal numbers of posts without voids, with small voids less than 25 mm deep or with large voids 25 to 75 mm in size. This was difficult because there were a limited number of posts with voids. As a result, the population was skewed towards posts with voids, despite the fact that these levels were higher than found in the overall population. Once a post had been selected, increment cores were removed from the exposed face of each post approximately 300 mm from each end of the post as well as from the former groundline (Figure 1). Each core was then placed into a plastic drinking straw which was labeled on one end and then stapled shut. The holes produced by the increment borer were then probed with a shell depth indicator to detect the presence of any voids. The posts were classified on the basis of the presence or absence of a void and then, if a void was present, whether the void was greater or less than 25 mm in size. These preliminary assessments were used to categorize the posts for testing.

The posts were marked to indicate the respective defect level and tagged for removal from the bundles and subsequent shipping to Oregon State University for further evaluation. The goal was to sample as many posts as possible. As time became limiting, sounding was used to select additional posts that exhibited evidence of internal defects, but no attempt was made to internally inspect these on site. Instead, these posts were marked for shipping to OSU for later inspection.

The increment cores were also returned to OSU where they were removed from the straws for examination. The depth of preservative penetration was measured (nearest mm) and then the outer 15 mm of each core was removed. These segments were combined into groups of 20, which were ground to pass a 20 mesh screen. The resulting material was then analyzed for copper, chromium and arsenic by x-ray fluorescence spectroscopy (AWPA, 2004a). Retention was expressed on kg/m^3 basis using an assumed density value of 448 kg/m^3 for hem-fir as per American Wood Protection Association Standard A12 (AWPA, 2004b). The minimum depth of penetration required in AWPA Standard U1 is 10 mm on 16 of 20 cores removed from a given treatment charge, while the required retention for material for highway construction is 8.0 kg/m^3 (AWPA, 2008). It was not possible to sample in exactly the same manner as would be done for freshly treated material because we had no information on the charges from which a given post originated. Typically, cores are removed from 20 randomly selected pieces in a single charge. As a result, the retention data must be viewed as advisory only.

The remainder of each core was briefly flamed to eliminate fungal spores that might have fallen on the wood surface and then placed on the malt extract agar in a plastic petri dish. The plates were observed for 30 days and any fungi growing from the wood were examined for characteristics typical of the class Basidiomycetes, a group that contains many important wood decay fungi.

The posts that were shipped to Corvallis for further testing were very wet when they arrived and were stickered and placed in a dry kiln where they were slowly dried using a low temperature (<67 C) and a narrow depression. The goal was to reduce the moisture content without adversely affecting wood strength. At about the same time, an additional set of 29 hem-fir posts that had been freshly treated with CCA were obtained and dried in a similar fashion.   These posts were slightly larger (150 by 200 mm by 1.8 m long).

Guardrail Evaluation

There are number of ways to evaluate the properties of guardrails, including simple bending tests, pendulum tests, and simulated crash tests. Crash tests were not suitable for this assessment because they would require construction of assemblies that would need to incorporate posts with similar degrees of internal damage. This would have been difficult to determine “a priori” and the absence of this knowledge would have required much more extensive testing that might have caused damage to the posts. Pendulum tests can have wide variations which would also have been complicated by the presence of voids at various locations across the post cross section. As a result, we elected to use a more controlled fourth point loading test that allowed comparison of properties between new and used posts under similar test conditions.

The dried posts were subjected to flexural testing in an asymmetric three point loading. The posts were placed simply supported with a span of 1588 mm on a Universal Testing Machine where they were subjected to a load about the ground line (521 mm from nearest support) applied at a rate of 6 mm/minute until failure. Load and deflection data were continuously recorded 5 times per second until failure (Fig. 2) using a LVDT. The results were used to determine modulus of rupture (MOR) and modulus of elasticity (MOE) by principle of superposition. Moisture contents were then determined to ensure that the posts were at approximately 12 % moisture content at time of test.

Following testing, the used posts were cut in half at groundline and the exposed cut was used to determine actual presence of fungal decay. Each post cross section was photographed and digital images of these cross sections were used to delineate the percentage of each cross section with visible decay. These images were then analyzed to identify the zones in which higher percentage of decay were observed. Two zones were delineated; the Central zone, i.e., ¼ height below and above the geometrical center of the beam, and Edge zone which was ¼ from top and bottom. Percentage decay in each zone was visually separately estimated by two assessors and then tallied. The differences in % decay assessment between the two observations were within 5 % of each other. A total 69 posts with no defects (29 new, 40 used), 19 with a void 0 to 25 mm wide and 25 with a void that was 25 mm or greater were examined.

Statistical Analysis

The effects of preservative penetration depth on the presence of decay and whether bending strength was influenced by factors such as decay observed, void size, preservative penetration. The data were subjected to an analysis of variance (ANOVA) followed by a regression model. The variables for regression analysis were void size, density, and total decay. The multiple linear regression approach was applied:

$$MOR = \beta_0 + \beta_1 \times size + \beta_2 \times density + \beta_3 \times decay \tag{1}$$

Where, β_i were the regression coefficients associated with various terms, void size (in mm), density (kg/m^3), and total decay (%). Assumptions of ANOVA and regression such as normality and homogeneity of variance were evaluated using Shapiro-Wilk and Levene's tests, respectively, at α=0.05.

Results and Discussion

Extent of Penetration

Average depth of preservative penetration in the in -service posts ranged from 14.8 to 19.3 mm (Table 1). Penetration was generally above the minimum of 10 mm required in the AWPA Standards. However, penetration was below the minimum in a number of posts, especially those with some level of internal decay. Only 5 of 25 posts with no evidence of voids failed to meet the minimum penetration level, while 6 of 15 posts with a void less than 25 mm deep and 8 of 14 posts with voids that were larger than that failed to meet the penetration level (Fig. 3). Moreover, shallower average penetration depth was associated with a significant negative influence on the presence of decay (ρ= 0.03, ANOVA). These numbers must be viewed with caution since the initial selection process was designed to identify posts with defects in certain ranges. As a result, the relative percentages of defects present in the overall population are not representative. However, the results do illustrate the relationship between preservative penetration and decay and illustrate the importance of adhering to the AWPA Standard for this material.

Average preservative retention ranged from 5.99 to 9.03 kg/m^3 with a mean of 7.91 kg/m^3 (Standard deviation = 0.79 kg/m^3). The AWPA required retention for this material is 8.0 kg/m^3 (AWPA, 2008). These posts have been in service for some time and the samples likely came from different treatment charges. As a result, the samples may not be completely representative of the initial wood quality. Despite these limitations, the wood appears to generally meet the AWPA requirements and there was no evidence of surface decay that would suggest retentions below those required for protection against fungal attack.

More than half of the 258 cores that were cultured contained some type of fungus; however, the majority of isolates were non-decay fungi. While these fungi can utilize sugars and other non-structural compounds in the wood, they have little effect on wood properties (Table 1). Some non-decay fungi can even inhibit the activity of decay fungi, although no attempt was made to determine the roles of the various species isolated in our tests. Decay fungi, which can cause serious losses in structural properties of the wood, were much less prevalent in the posts. Only 2.7 % of cores from posts without voids contained decay fungi. These results suggest that these posts would be at relatively low risk of developing advanced decay in the next few years because the fungi necessary to cause this damage have not been able to penetrate through the preservative treated shell. Over 13 % of cores removed from posts with small voids contained decay fungi, while fungal isolations were lower in posts with larger voids (4.8 % of cores). This is consistent with the difficulty of isolating fungi from wood in the more advanced stages of decay. The results indicate that fungi are present in posts with visible decay; however, they are not present in overwhelming numbers. In studies of internal decay in utility poles, we have found up to 60 % of cores infested with decay fungi after 15-20 years (Helsing et al., 1984). The results in the current tests indicate that the future levels of risk of fungal attack are much lower in the posts.

Posts with shallow penetration were significantly correlated with the presence of internal decay. This is consistent with the function of the treatment as an envelope of protection. Thinner barriers are more likely to be compromised through the development of seasoning checks over time. The initial sampling pattern was designed to select posts with some level of decay and it sometimes proved difficult to find many posts with decay pockets in the desired size range. The results suggest that a properly treated post should be largely resistant to fungal attack and that most of the posts met these criteria. These data are consistent with long-term trials of posts at Oregon State University (Morrell et al., 1999).

Flexural Testing

The flexural data will be presented in several different ways. First, we compared MOR and MOE for new vs. used posts without regard to the presence of defects in the used materials. Next, we segregated the used posts into categories of no voids, voids less than 25 mm, and voids greater than 25 mm. We also plotted the relationship between MOR or MOE and actual void size as measured on the cross section cut through the groundline after testing.

Freshly treated guardrail posts had an average MOR of 32.17 MPa and an average MOE of 7.91 GPa (Table 2). These values are slightly lower than those reported for hem-fir in the USDA Wood Handbook (USDA, 2010). The differences reflect both the nature of the test and the small population size. The test method produced an asymmetric load on the post in order to force the failure through a zone about the intended groundline. This was necessary because the in-service posts were tested to bring the maximum loading to the area that had been subjected to the highest risk of decay (the groundline). Thus, the results for the new posts should only be used as a comparator for the materials removed from service. The posts had a normal distribution around 34.5 MPa. The overall distribution of MOR values was also normal for used posts, but it had shifted downward slightly as a result of the presence of voids in some posts. Scatter plots of these data indicated that many posts still retained excess capacity (Fig. 4). The mean value for guardrail posts after 20 years of service was 24.45 MPa and 7.35 GPa for MOR and MOE, respectively. While the MOR of the new and used guardrail posts were significantly different ($p<<0.01$, 2 sample t-test), no statistical difference ($p>0.05$, t-test) was observed in the MOE values. This was expected since MOE is the wood property that is least affected by exposure to property degrading mechanisms (MacLean 1953, Sinha et al. 2011). Further, there was a significant decrease in MOR values as void size increased ($p<0.05$, ANOVA) as observed in Fig. 4. Increased void sizes were associated with significantly lower MOE values ($p<0.05$).

AASHTO refers back to the NDS (AFPA 2012) for a minimum MOR value for guardrail posts. The minimum graded design value for Hem-Fir beams and stringers is 4.65 MPa (675 psi) for No.2 grade, while it is 9 MPa for select structural lumber (1300 psi). All of the new posts easily exceeded this range of values and also met the minimum values when we applied a safety factor of 2.2 to the minimum value (19.8 MPa, Select

Structural Hem-Fir). These results illustrate the high residual capacity present in guardrail material at the time of installation. Fig. 5 presents the frequency distribution for MOR values of used posts. The AASHTO recommended value of 8.2 MPa for Hem-Fir is also marked for comparison (AASHTO 2007). All but three (3) posts exceeded the maximum design value of 8.2 MPa (Fig. 4a). Grades No.1 and No.2 are widely used lumber grades and select structural grade is seldom used in practice for guardrail posts applications. Previous research (e.g., Atahan et al. 2002) reported an average MOR for wooden guardrail posts of 3 MPa, which was lower than the results observed in this study. The differences may be due to the different test methods in the current study compared with the static center-point bending used by Atahan et al. (2002).

Mean MOR values for guardrails in service for 20 years, but with no detectable voids were only slightly lower than those for new posts, while those for posts where small voids (<25 mm) were detected by probing retained 74.7 % of the original value (Table 3). Posts with voids that were greater than 25 mm in size had average MOR's that were 54.5 % of the original values. While these values suggest a sharp drop in properties, MOR's were still well above the minimum value (8.6 MPa). As with MOR, MOE values were similar for the new posts and those with no detectable voids, while there were slight decreases in MOE in posts with voids. The ability of the wood to absorb impacts without experiencing permanent deformation is an important attribute, especially in comparison to alternative materials. The flexural tests indicate that the presence of internal decay in the posts did not markedly affect flexural properties.

Flexural testing of new and used guardrail posts indicated that properties of used posts with no internal defects were similar to those for new posts when no defects were present and that both populations easily met the minimum AASHTO standards. As expected, posts with small internal defects (<25 mm in size) had slightly lower properties, but these levels were still acceptable. Posts with larger defects had more variable properties and a small percentage of these posts failed to meet the minimum AASHTO standard. Not all posts with defects had reduced properties and, in fact, one of those with the largest defect area also had the highest MOR (Fig. 4), illustrating the range in wood properties present in a population. It is also important to remember that posts with defects represented less than 52 % of a sample that was originally selected to include a high percentage of defects. The results indicate that a very high percentage of the posts removed from service were sound and retained properties that were well above those required to perform in the intended application

MOR data was regressed against void size, bulk density, and the extent of decay and the following relationship was observed:

$$MOR = 29.3590 - 0.0449 \times size + 6.3300 \times density - 0.1367 \times decay$$

The R^2 observed for this regression model was low ($R^2 = 0.3044$). Void size and extent of decay both were associated with significantly lower observed MOR values for guard rails (β_1 and β_3 – $p < 0.05$). Although the R^2 value observed in this study was low, they were comparable to other regression models proposed in the literature for MOR of wood (Winandy and Lebow 1996; Brancheriau and Bailleres 2003; Sinha et al. 2011). A similar but slightly higher correlation was observed between the extent of decay observed on cross section cut after testing and MOR (r^2= 0.35)(Fig. 6). The low correlation reflects the inherent high coefficient of variation for wood properties that poses a challenge for any regression models. Decay development is also variable and this variability further reduces the ability to relate wood properties with post condition. Examples of typical severity of decay are presented in Fig. 7. All the pieces were also visually graded for the extent of decay and classified into decay in the central zone, i.e., ¼ height below and above the geometrical center of the beam, and Edge zone is the ¼ from top and bottom. Decay in the central zone was associated with significantly lower MOR values ($p<0.05$), while decay in the edge zone did not influence the MOR values. This is counterintuitive, as decay in extreme fiber should lead to decreased MOR values. Contrastingly, the extent of decay in the central or edge zones, did not significantly affect MOE.

Conclusion

Posts that met the AWPA Standards for preservative penetration trended to have lower levels of internal decay after 20 years in service and nearly all posts tested retained sufficient flexural properties to meet ASHTO Standards. Flexural strength was influenced significantly by the presence of decay and void size. CCA treated hem-fir guardrail posts provided excellent performance in this application.

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Table 1. Average preservative penetration and percentage of hem-fir guardrail posts containing non-decay and decay fungi.

Depth of Void (mm)	Number of cores	Average penetration (mm)	% of posts from which fungi were isolated	
			non-decay	decay
0	75	19.2	54.7	2.7
0-25	45	14.7	64.4	13.3
25-75	42	15.7	71.4	4.8
Unknown	96	16.8	66.7	2.1

Table 2. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of CCA treated hem-fir guardrail posts either shortly after treatment (New) or after 20 years in service in Western Washington.

Condition	MOR (MPa)			MOE (GPa)		
	Range	Mean (SD)	COV	Range	Mean (SD)	COV
New	21.27-45.23	32.170 (5.03)	15.4	5.0 -11.87	7.91 (1.61)	20.35
Used	2.26 -49.36	24.44 (9.69)	39.6	1.09-17.70	7.35 (1.66)	22.6

Table 3. MOE and MOE of CCA treated hem-fir guardrail posts as determined by testing new posts or posts in service for 20 years and determined to have no defects, voids less than 25 mm in size or voids larger than 25 mm in size.

Condition	Number Tested	Mean MOE (GPa)	Mean MOR (MPa)
Used-no void	40	7.93	29.07
Used (<25 mm void)	19	7.01	24.02
Used (>25 mm void)	25	6.70	17.53
New	29	7.91	32.17

Figure 1. Example of a bundle of used guardrail posts after sampling. Arrows show locations where increment cores were removed

Figure 2. Examples of a guardrail post in test and a close-up showing a tension failure after testing.

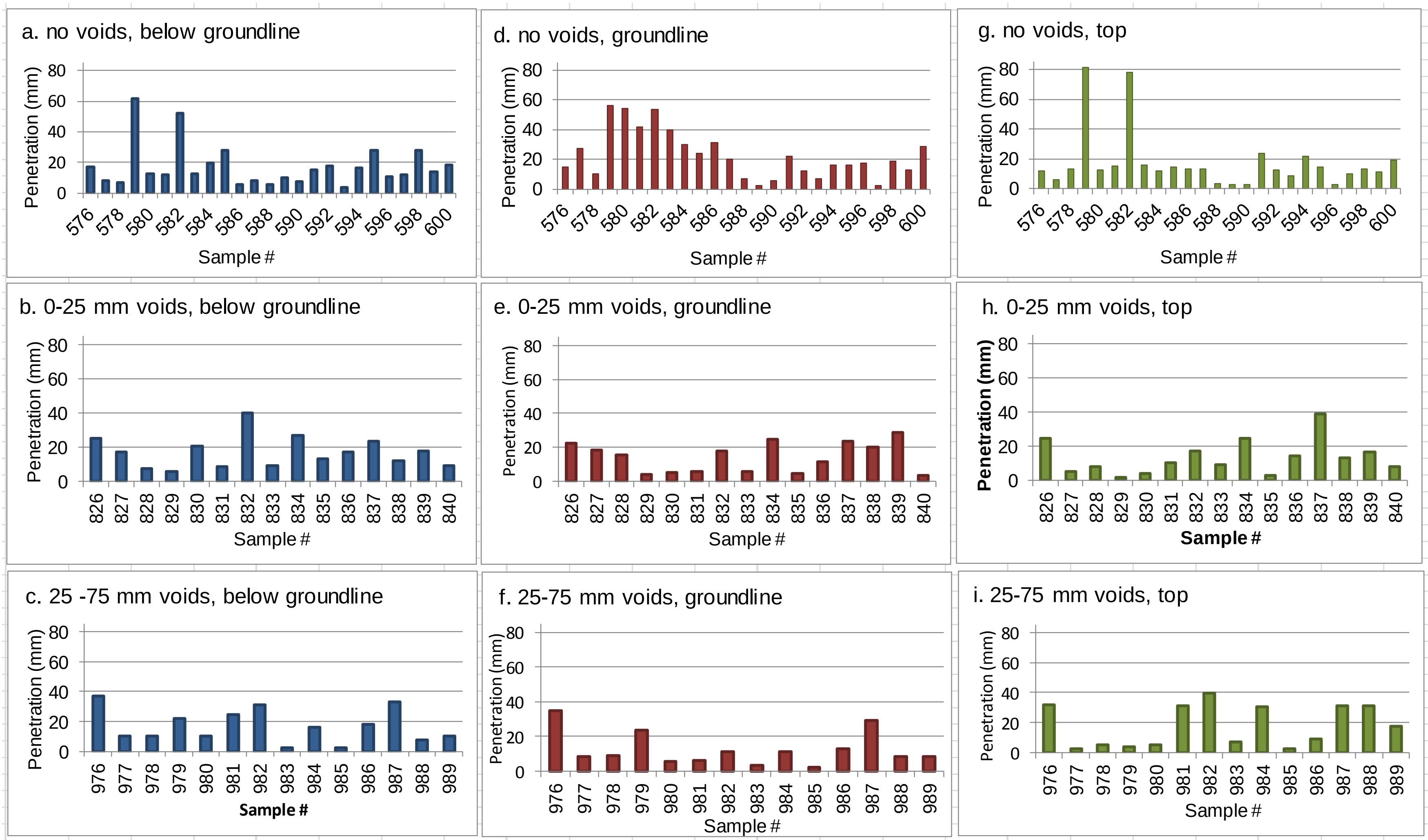
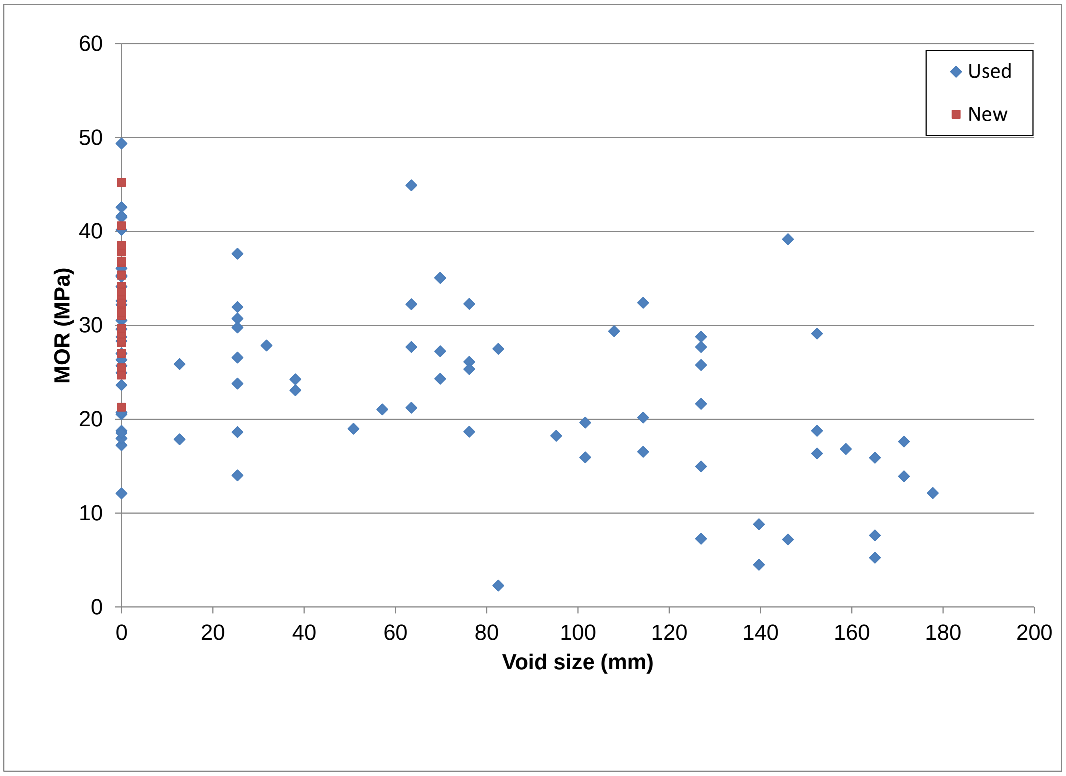


Figure 3. Preservative penetration in guardrail posts with no voids, voids of 0-25 mm, and voids of 25-75 mm at below ground line (a-c), at ground line (d-f) and top (g-i) portion of guardrail posts.



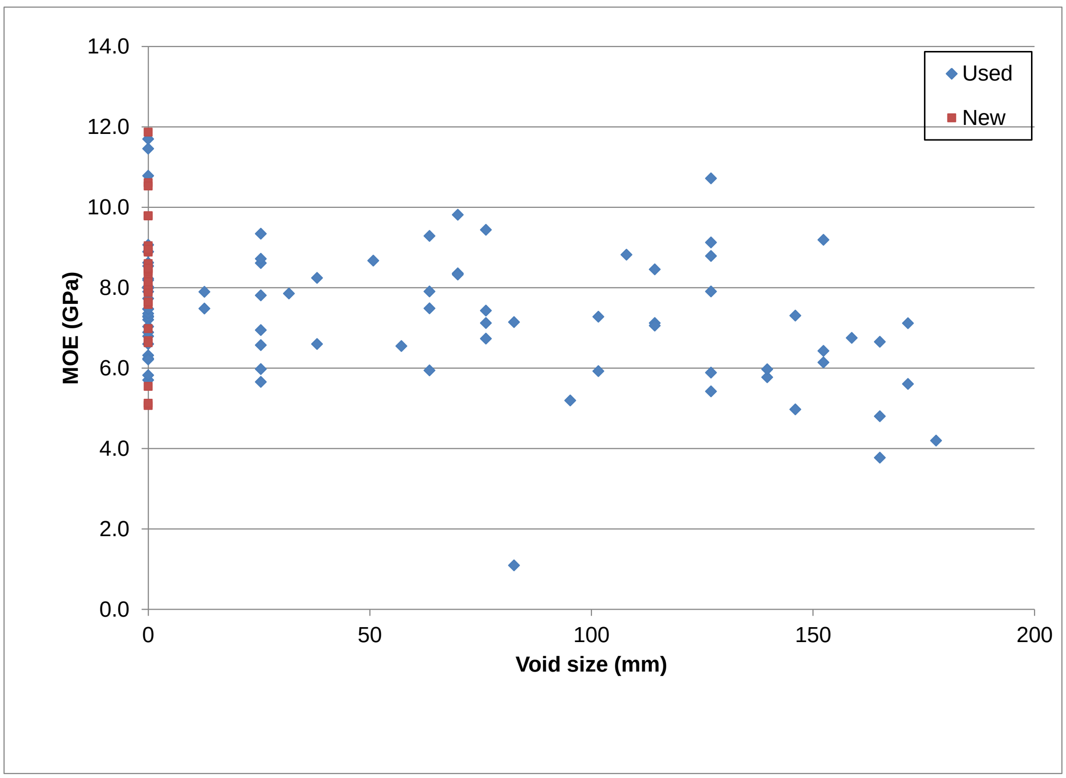


Figure 4. Scatter plots of (a) MOR and (b) MOE vs. void size in new and used CCA treated hem-fir guardrail posts.

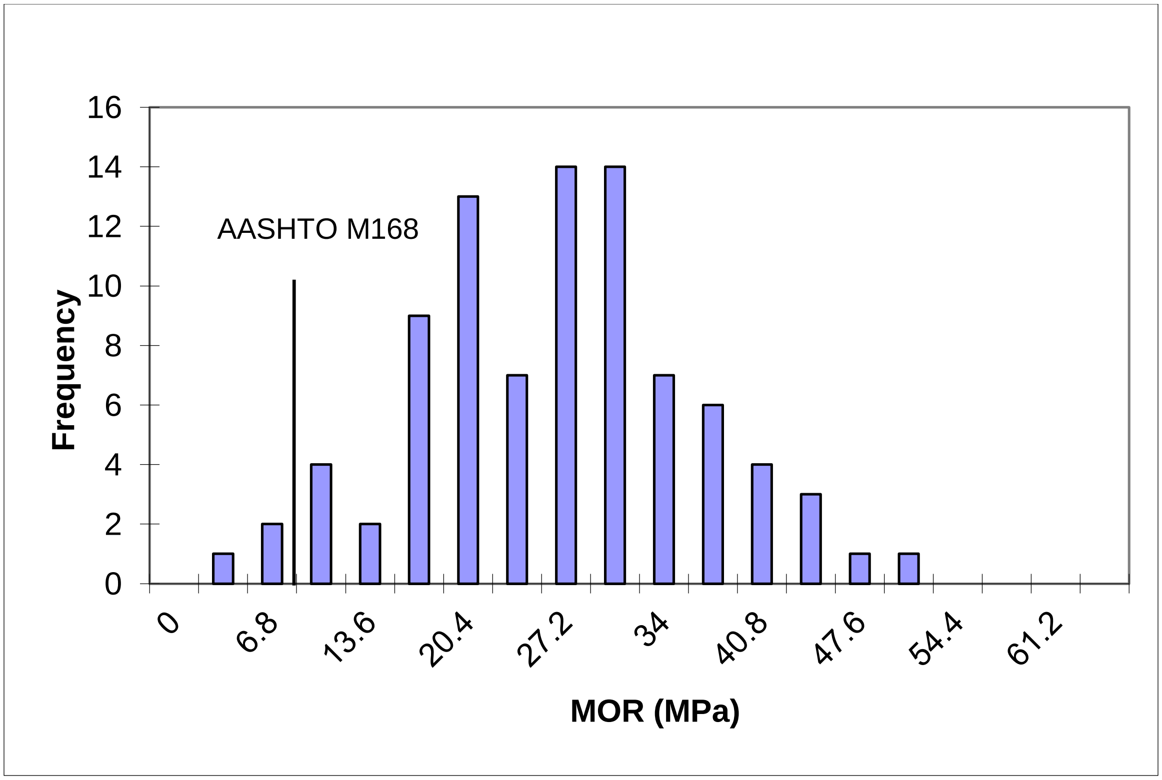


Figure 5. Distribution of Modulus of Rupture (MOR) values in a population of 84 posts that had been in service for 20 years that were tested to failure in fourth point loading. The line at 9 MPa denotes the AASHTO minimum strength criteria for the highest stress grade of Hem-Fir for guardrail posts.

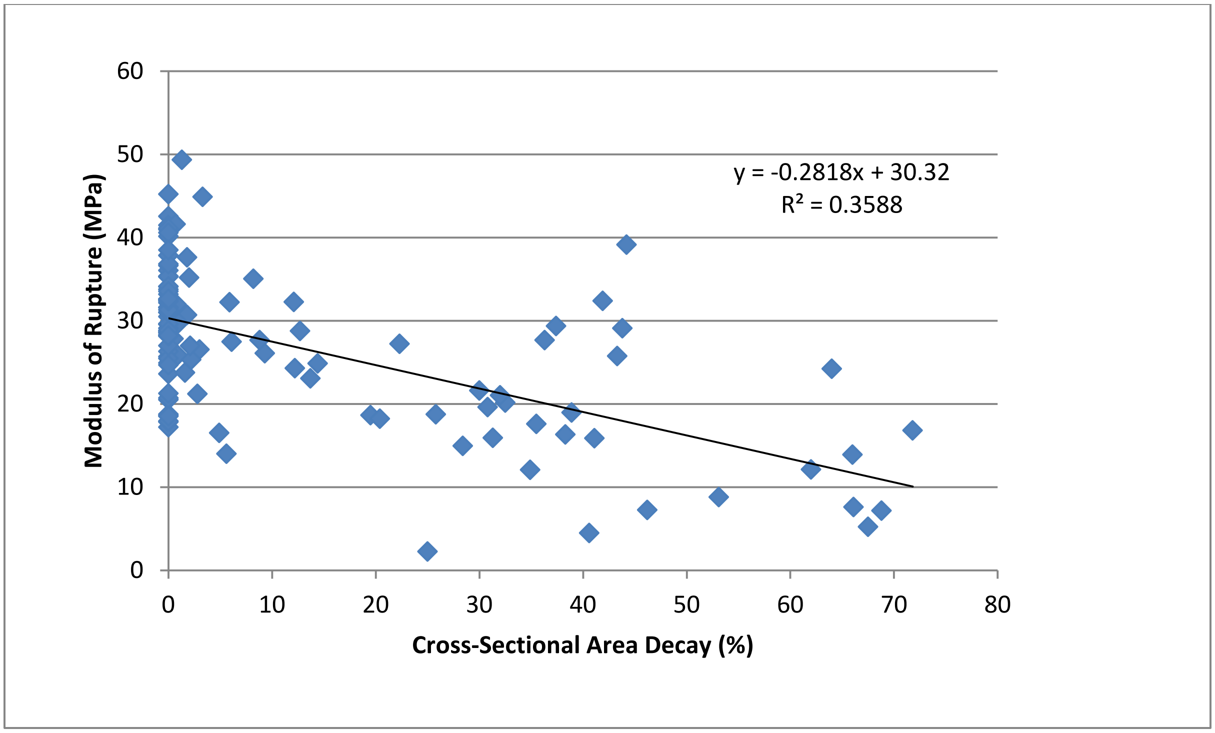


Figure 6. Relationship between MOR and percentage of cross section area decayed in hem-fir guardrail posts.

(a) no decay (b) small decay pocket (c) large decay pocket

Figure 7. Examples of cross sections cut through the failure zones on CCA treated guardrail posts with no decay, and small vs. large decay pockets