Use of Acoustic Assessment to Detect Decay and Assess Condition of Wooden Guardrail Posts

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Abstract

Wood guardrail posts are the most common wood materials currently used in highway construction. Maintenance crews and engineers are often faced with the challenge of rapidly assessing the extent of decay or damage in individual posts. Many conventional intrusive techniques are unsuitable for inspecting guardrail posts because they are too time-consuming. Acoustic detection could be an ideal inspection method because of its rapid assessment. The potential for using acoustic inspection for wooden guardrail posts was assessed on treated hem-fir guardrail posts removed from western Washington State. The posts were tested nondestructively using an impulse hammer, and then increment cores were removed from each post for assessing preservative treatment and fungal colonization. The posts were then tested to failure in bending to determine flexural properties. All but one of the posts met the minimum threshold for strength according to the American Association of State Highway and Transportation Officials. There was a weak correlation between acoustically predicted modulus of elasticity (MOE) and actual MOE. Correlations between acoustically predicted MOE and modulus of rupture were slightly better but still weak and lower than would be acceptable for this method to be used in the field. The results indicate that acoustic methods might be useful for detecting the presence of advanced decay but failed to provide definitive estimates of post properties.

Wood is an effective, economical material for supporting guardrail assemblies and is widely used in this application across North America. A recent examination of guardrail posts removed after 20 years in service in western Washington revealed that virtually all of the posts tested retained sufficient capacity to meet the current standards of the American Association of State Highway Transportation Officials (AASHTO 2011), although many had small internal decay pockets (Love et al. 2014). The posts sampled in this study were selected for the presence of decay, and therefore contained much higher levels of decay than would be present in a randomly selected population. The presence of internal decay, although limited, raised questions about how to detect this damage and assess its effect on guardrail system properties.

There are a variety of methods for detecting internal decay in large timbers, including physically drilling, X-rays, and acoustic devices (Morrell 2012). Many of these techniques would not be suitable for inspecting guardrail posts because they are too time-consuming to be used on a system with so many individual test pieces. Drilling into the posts at ground line, for example, would be reasonably effective for detecting internal decay but would be too time-consuming because of the large number of posts in a given assembly. X-rays might also be useful, but the technology brings with it implicit risk associated with potential exposure to ionizing radiation. One potential alternative method for assessing post condition would be to use acoustic devices.

Acoustic devices have been successfully used for a variety of wood applications (Ross and Pellerin 1994, Beall 2002, Ross et al. 2005, Titta 2006, McGovern et al. 2010, Senalik et al. 2013) on the underlying principle that sound waves moving through wood are affected by a variety of factors, including density and the presence of defects. The time required for a sound wave to propagate through a cross

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section or along the length of a beam can be used to predict flexural properties. A number of devices have been developed that claim to be capable of predicting residual properties of poles, timbers, lumber, and veneers. These property predictions are usually based on comparisons of acoustic properties with full-scale destructive tests of a known population of similar material. Results in the field are then compared with this population. Acoustic detection could be ideal for use on guardrails because it is rapid and relatively easily adapted to some sort of mobile, automated platform that could be used to assess post condition. The potential for using acoustic inspection to assess guardrail posts was assessed on a population of posts removed from service in western Washington.

Materials and Methods

Eighty chromated copper arsenate–treated hem-fir posts 178 mm by 229 mm by 1.22 m (7 by 9 by 4 ft long) that had been removed from service in western Washington were examined. No attempt was made to sort the materials for the presence of decay or other defects prior to testing, so this sample should be representative of the general guardrail population. The posts had been removed from service as part of regular highway repaving or upgrade projects and were sold for reuse in secondary projects. Previous tests have shown that most posts retain a large percentage of their original capacity (Love et al. 2014).

On arrival, the dimensions of each post were measured, and then a resistance-type moisture meter was used to determine initial moisture content. All the posts were dry (<20% moisture content). A piezoelectric accelerometer was then attached to the post either at the base, at 300 mm from the base, or at the original ground line (Fig. 1). An impulse hammer was then used to deliver a sound pulse through the wood directly across from the accelerometer to create different pathways for sound transmission (Fig. 1). The signal was collected, and the data were used to calculate modulus of elasticity (E) using the following relationship:

$$E = (V)^2(d)$$

where

V = velocity (km/s) and

d = density (kg/m^3).

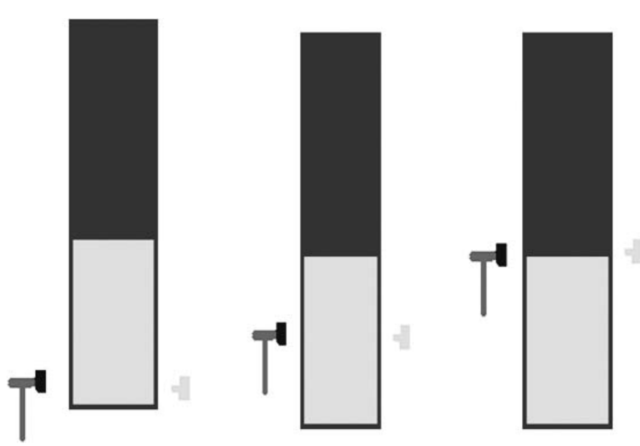


Figure 1.—Locations of piezoelectric accelerometers and an impulse hammer used to evaluate time of flight as an inspection tool for assessing guardrail posts.

The posts were then subjected to flexural testing in an asymmetric three-point loading. The posts were placed simply supported with a span of 1,588 mm on a Universal Testing Machine where they were subjected to a load at about the ground line (521 mm from nearest support) applied at a rate of 6 mm/min until failure. Load and deflection data were continuously recorded five times per second until failure using a load cell and a linear variable differential transformer. The results were used to determine modulus of rupture (MOR) and modulus of elasticity (MOE) by the principle of superposition. Moisture contents were then determined to ensure that the posts were at approximately 12 percent moisture content at the time of testing.

Following testing, 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 ground line. The depth of preservative penetration was visually measured (nearest millimeter) on each core, 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 (American Wood Protection Association [AWPA] 2004a). Retention was expressed on a kilogram per cubic meter basis using an assumed density value of 448 kg/m^3 for hem-fir as per AWPA Standard A12 (AWPA 2004b). The minimum depth of preservative penetration required for guardrail posts in AWPA Standard U1 (AWPA 2014) is 10 mm on 16 of 20 cores removed from a given treatment charge, while the required chromated copper arsenic retention for material for highway construction is 8.0 kg/m^3 (AWPA 2014). 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 posts were cut in half at ground line, and the exposed cut was used to determine the 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. The degree of visible decay was estimated as occupying 1 to 25, 25 to 50, or >50 percent of the area in either the outer 25 mm or the inner core inside the 25-mm outer shell. While there was little evidence of decay in the outer 25 mm, this zone is especially critical for flexural properties.

The predicted E values were plotted against actual MOE or MOR by the location of the acoustic test site on a post, and then preservative penetration and the presence of internal defects were plotted against MOE or MOR.

Results and Discussion

The average depth of preservative penetration in all posts combined was 22.2 mm (SD = 8.7 mm). Penetration was generally above the 10-mm requirement stipulated in the AWPA standards. The depth of preservative treatment should play a major role in limiting the development of internal decay with deeper penetration reducing the risk of decay. To investigate this relationship, preservative penetration was segregated into three categories: posts with no voids, posts with voids between 2 and 4 cm, and posts with voids larger than 4 cm at the ground line. Only nine posts had preservative penetration measuring less than the AWPA-specified minimum (10 mm). Two posts with <10 mm of penetration had no voids at ground line, two had 2- to 4-cm-diameter voids, and five had voids larger than 4 cm at the ground line (Fig. 2). These results indicate that the sample largely met the current AWPA standard.

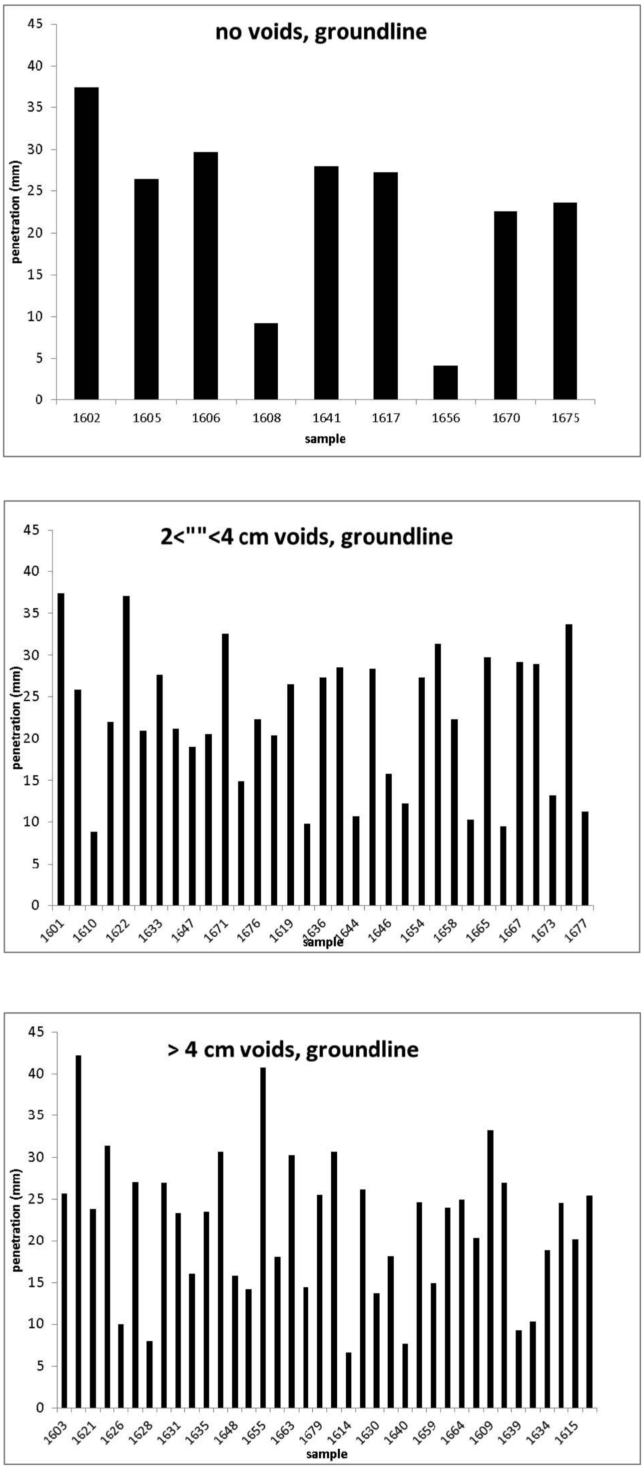


Figure 2.—Preservative penetration depth in posts with no internal voids (top), with voids 20 to 40 mm in diameter (middle), and with voids greater than 40 mm in diameter (bottom).

A majority of the posts (seven of nine) that did not meet the AWPA standard contained voids at the ground line. These posts represented less than 10 percent of the total sampled population. Moreover, no correlation ($P = 0.56$, analysis of variance) was found between the level of cross-sectional decay observed and the depth of preservative penetration (Fig. 3). These results differed from previous observations reported by Love et al. (2014), who showed that shallower penetration was associated with a significant increase in the presence of decay. However, the population sampled by Love et al. (2014) was skewed toward decayed posts. No attempt was made in the current study to sort the materials for the presence of decay or other defects. As a result, the population in this report is likely to be representative of the overall population.

Modulus of rupture

AASHTO M168 (AASHTO 2007) provides a design value of 8.2 MPa for guardrail posts, which is similar to the national design specification value for hem-fir after accounting for all the factors (American Forest and Paper Association 2015). Mean MOR for guardrail posts with no observable decay in cross-sectional area was 23.3 MPa (SD = 8.3 MPa). All but one of the guardrail posts met the minimum 8.2-MPa threshold (Fig. 4). All the posts tested were in-service posts, and they exceeded the minimum threshold by a significant margin.

MOR for the posts was categorized into six groups (<10, 10–15, 15–20, 20–25, 25–30, and >30 MPa; Fig. 4). Only 1 post had an MOR below 10 MPa, while 17 posts had MORs between 10 and 15 MPa. The remaining posts had MORs greater than 15 MPa, indicating that almost all posts retained sufficient capacity to remain in service. These results are consistent with previous reports and indicate that wooden guardrails are often removed prematurely (Love et al. 2014). There was a general inverse relationship between the presence of decay pockets in posts and MOR, although the correlations were generally low ($r^2 = 0.43$; Fig. 4). Segregating data into posts with internal versus external decay produced no noticeable improvement in correlation (Fig. 5). Internal decay should have less influence on MOR because most of the bending strength will be closer to the wood surface, and removing internally decayed samples from the population did not have any effect on the relationship between decay and MOR. The decay assessment was made only at the ground line of each post, and it is possible that decay above or below this region influenced the results. Longitudinal dissection of posts might have improved the ability to relate decay to MOR; however, this was not feasible in the current experiment.

Acoustic detection of condition

Bending modulus as predicted by acoustic assessment just below the ground line tended to be more closely correlated with the values calculated using static bending tests (Fig. 6). This would be consistent with the application of the test load at this location, but it also reflects the tendency for decay to occur more frequently at ground line, where conditions are more suitable for microbial growth. The correlation between actual and predicted values was expected to be poor in all cases because static MOE is less affected by wood degradation (Yang et al. 2002, Sinha et al. 2011), while dynamic MOE is dependent on the presence and size of

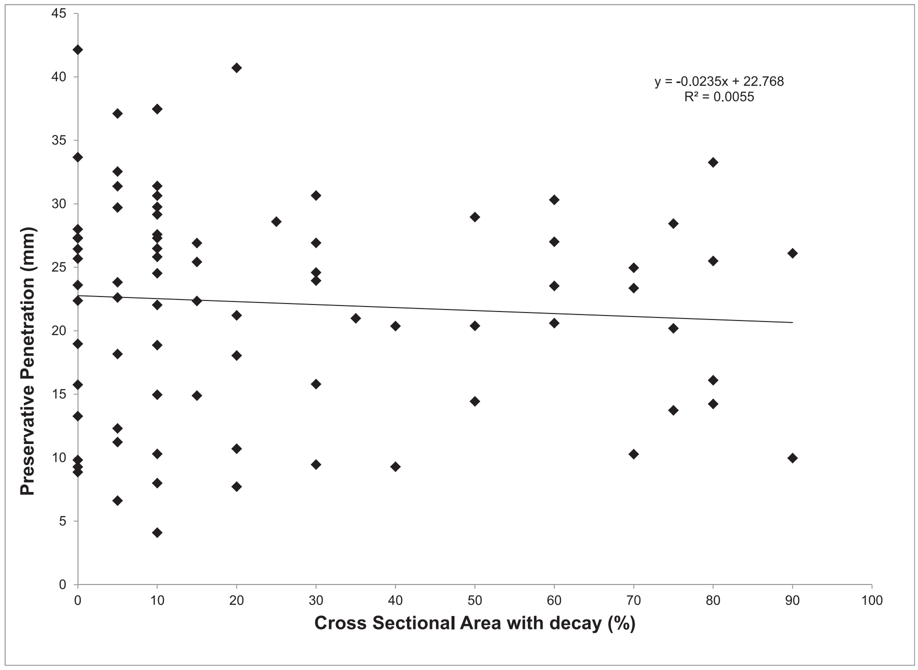


Figure 3.—Relationship between initial preservative penetration and the presence of internal decay in chromated copper arsenic–treated hem-fir guardrail posts.

voids. Because these voids are strength-limiting defects, predicted MOE should be more comparable to actual MOR.

Actual MOR was more closely related to predicted MOE at the ground line than to static MOE, but the correlation was still relatively poor (Fig. 7). The r^2 value of 0.45 was consistent with previous reports that have found r^2 values between 0.40 and 0.52 (Machek et al. 2001, Yang et al. 2002, Kretschmann 2010). Acoustic assessments at the other two locations farther from the point where the posts were subjected to bending produced even poorer predictions. These results would be consistent with time-of-flight measurement systems. Because voids extend the time of a flight of a sound wave, they are most effective when the wave must move across the cross section and are increasingly less effective the farther the measurement is away from the actual location of the decay. Because the bending tests were performed at ground line, time-of-flight measurements further below the ground line will tend to fail

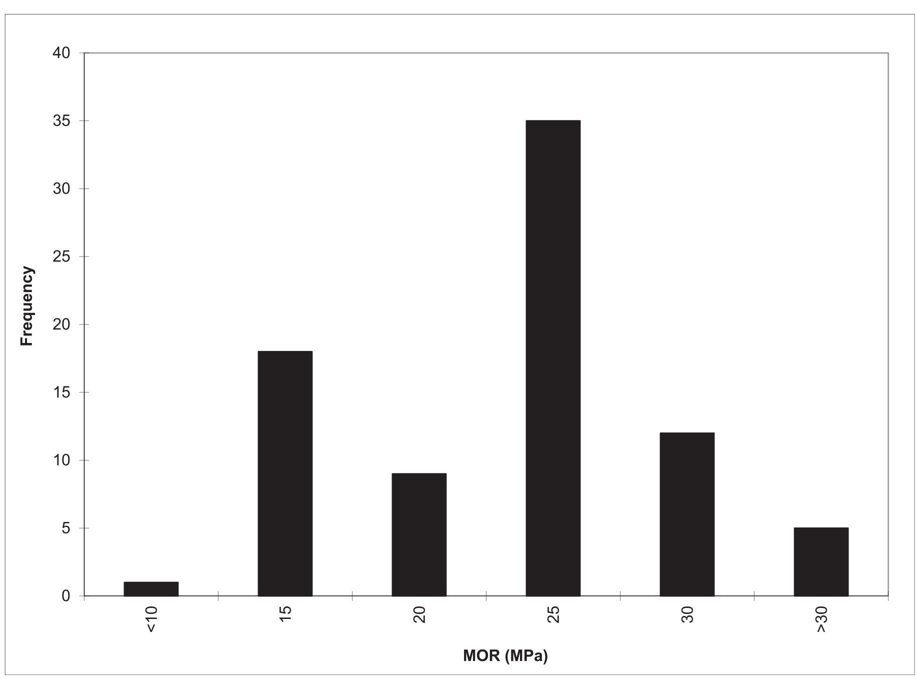


Figure 4.—Modulus of rupture (MOR) frequencies for chromated copper arsenic–treated hem-fir posts removed from service in western Washington.

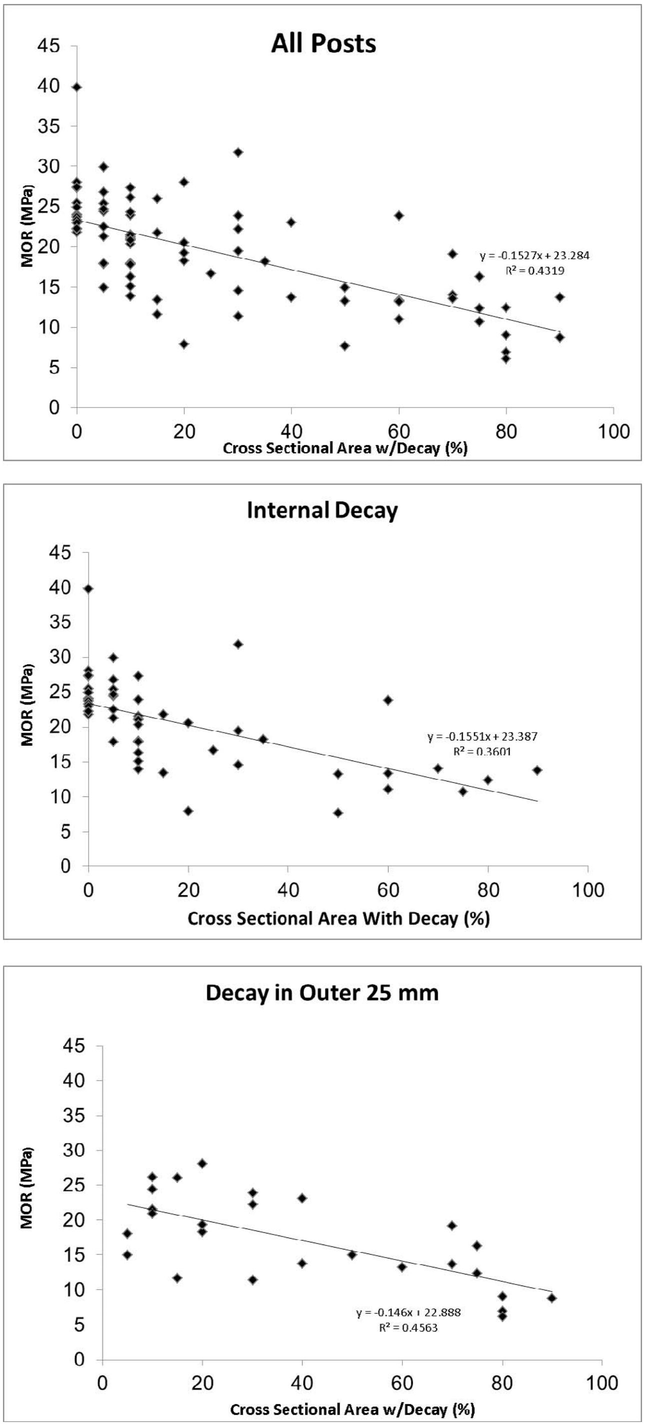


Figure 5.—Relationship between the loss in cross-sectional area associated with fungal decay and modulus of rupture (MOR) for chromated copper arsenic–treated hem-fir posts plotted as all posts combined (top), posts with internal decay (middle), and posts with decay in the outer 25 mm of the cross section (bottom).

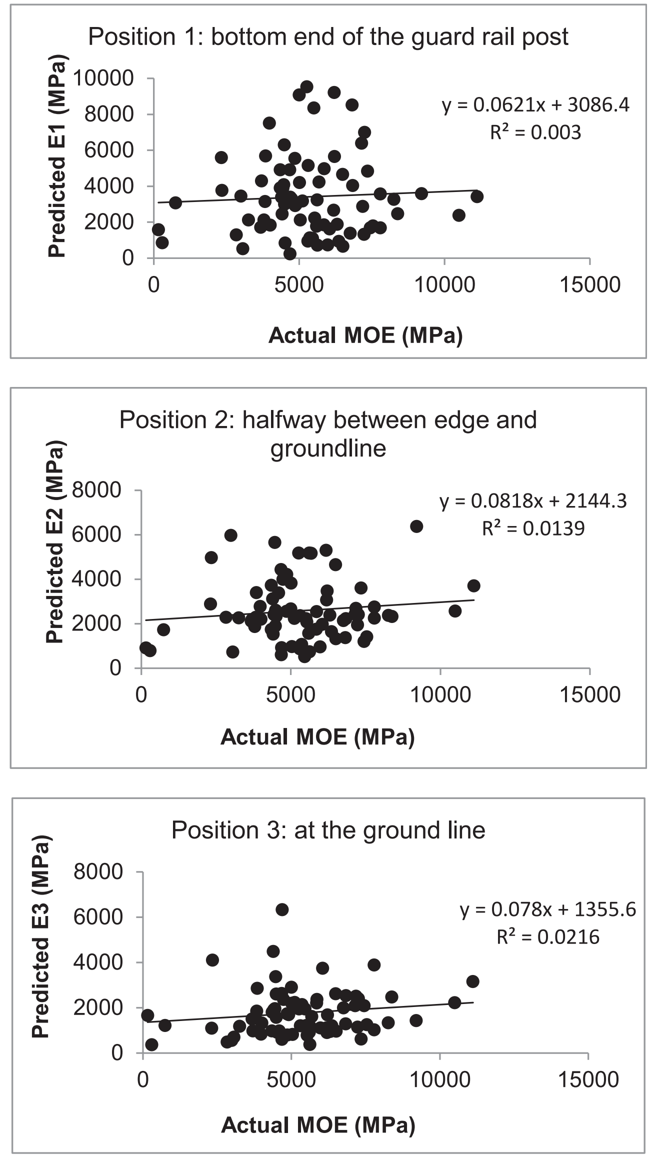
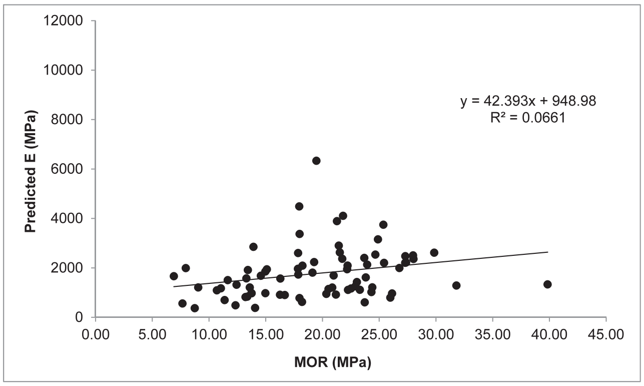


Figure 6.—Relationship between modulus of elasticity determined by flexural testing and E *predicted from acoustic testing at the bottom (top), 1 foot from the bottom (middle), and at ground line (bottom) of chromated copper arsenic–treated hem-fir guardrail posts.*

to detect damage in that zone. While neither of the belowground locations would be practical for acoustic testing in terms of field assessment, they illustrate the variability in prediction based on sampling location.

Field inspection of guardrail posts would have to be relatively rapid given the large number of posts in a given length of guardrail. However, the process could also be relatively crude because the posts tend to share load and the presence of a limited number of weaker posts should not markedly reduce the capacity of the system. Furthermore, there appears to be considerable overcapacity in a wood-based system because of normal wood variability and the need to design systems for the weakest members. This overcapacity would allow for a less robust prediction system for the reason that the risk of incorrectly retaining a weaker member would be lower both because of the load sharing and because the system itself tends to be far stronger than the intended design. These parameters might allow for a system with a lower probability of accurately detecting decay as long as it was capable of detecting the extremely weak members so that they could be replaced or at least more closely monitored over time.



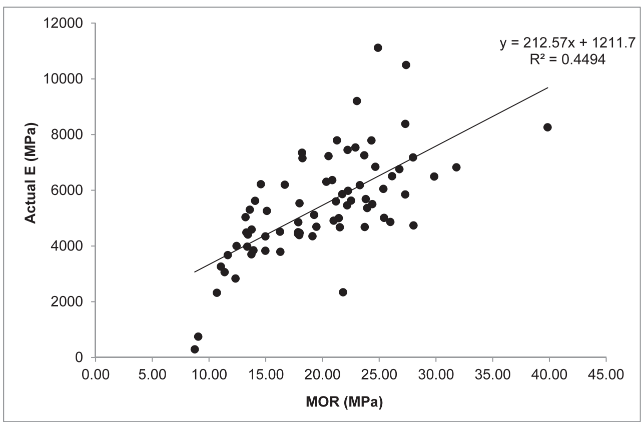


Figure 7.—Relationship between modulus of rupture (MOR) and actual (top) or predicted (bottom) modulus of elasticity of chromated copper arsenic–treated hem-fir guardrail posts.

Conclusions

All the posts tested, except one, met the AASHTO minimum strength threshold. Most of the posts met the AWPA standards for preservative penetration but also contained minimal decay. Nine posts did not meet the AWPA criteria, and seven of these had voids at the ground line. There was a weak correlation between acoustically predicted MOE and actual MOE. Correlations between acoustically predicted MOE and MOR were slightly better but still weak and lower than the acceptable range for this method to be used in the field. The results indicate that acoustic methods might be useful for detecting the presence of advanced decay but were not suitable for definitive measurement of guardrail properties. These results illustrate the challenges associated with using acoustics to assess guardrail condition in the field.

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Literature Cited

American Association of State Highway and Transportation Officials (AASHTO). 2007. Standard specification for wood products. M168. AASHTO, Washington, D.C.

American Association of State Highway and Transportation Officials (AASHTO). 2011. Roadside design guide. AASHTO, Washington, D.C.

American Forest and Paper Association. 2015. National design specification for wood construction. American Forest and Paper Association, Washington, D.C.

American Wood Protection Association (AWPA). 2004a. Standard method for analysis of treated wood and treating solutions by x-ray fluorescence spectroscopy. Standard A9. AWPA, Birmingham, Alabama. pp. 282–286.

American Wood Protection Association (AWPA). 2004b. Wood densities for preservative retention calculations. Standard A12. AWPA, Birmingham, Alabama. pp. 291–292.

American Wood Protection Association (AWPA). 2014. Use category system: User specification for treated wood. Standard U1. AWPA, Birmingham, Alabama. 66 pp.

Beall, F. C. 2002. Overview of the use of ultrasonic techniques in research on wood properties. *Wood Sci. Technol*. 36:197–212.

Kretschmann, D. E. 2010. Mechanical properties of wood, chap. 5. *In:* US Department of Agriculture Wood Handbook: Wood as an Engineering Material. General Technical Report FPL-GTR-190. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Love, C., M. Clauson, A. Sinha, and J. J. Morrell. 2014. Condition of chromated copper arsenate treated hem-fir guardrail post after 20 years in service in western Washington State. *J. Mater. Civil Eng*. 26(1):160–166.

Machek, L., H. Militz, and R. Sierra-Alvarez. 2001. The use of an acoustic technique to assess wood decay in laboratory soil-bed tests. *Wood Sci. Technol*. 34:467–472.

McGovern, M., A. Senalik, G. Chen, F. C. Beall, and H. Reis. 2010. Detection and assessment of wood decay using x-ray computer tomography. Paper 7647-152. SPIE Smart Structures Conference, March 7–11, 2010, San Diego, California.

Morrell, J. J. 2012. Wood pole maintenance manual. Research Contribution 51. Forest Research Laboratory, Oregon State University, Corvallis.

Ross, R. J. and R. F. Pellerin. 1994. Nondestructive testing for assessing wood members in structures: A review. General Technical Report FPL-GTR-70 (Rev.). USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 40 pp.

Ross, R. J., X. Wang, and B. K. Brashaw. 2005. Detecting decay in wood components, chap. 5. *In:* Inspection and Monitoring Techniques for Bridges. G. Fu (Ed.). CRC Press, Boca Raton, Florida.

Senalik, A., M. McGovern, F. C. Beall, and H. Reis. 2013. Detection and assessment of decay in wooden utility poles using an acoustic approach. *Int. J. Environ. Prot*. 3(8):13–28.

Sinha, A., R. Gupta, and J. A. Nairn. 2011. Thermal degradation of the bending properties of structural wood and wood-based composites. *Holzforschung* 65:221–229.

Titta, M. 2006. Non-destructive methods for characterization of wood material. PhD dissertation. University of Kuopio, Kuopio, Finland.

Yang, X. Y., Y. Ishimaru, I. Iida, and H. Urakami. 2002. Application of modal analysis by transfer function to nondestructive testing of wood I: Determination of localized defects in wood by the shape of the flexural vibration wave. *J. Wood Sci*. 48(4):283–288.