Summary

The practice of through-boring extends the service life of utility poles by protecting the pole from internal decay but little is known about its effects on bending strength and there is an insufficient knowledge base to develop standards for the practice. A through-boring pattern was developed based on treatment penetration and preliminary finite-element analysis (FEA). A suitable test method was developed that addressed the inadequacies present in current test methods. Poles were subsequently through-bored and tested to determine if the boring hole size affected pole bending strength when compared to that of a control group. Results showed that 12.7 mm holes in a staggered pattern with 127 mm longitudinal spacing, 38 mm radial spacing, and 50 mm edge distance provides excellent treatment potential without compromising bending strength.

1. Introduction

It is estimated that there are 160 to 180 million wood utility poles in service in the United States (Mankowski et al. 2002). Clearly, wood utility poles are an important asset to the companies that own them, and at the same time, represent a significant use of the forest resource. If properly maintained, poles are estimated to have a life span of 50 years or more (Mankowski et al. 2002). One prevalent problem in thin-sapwood species with nondurable heartwood is internal decay. This damage can be arrested in service, but it is more efficient to improve the quality of the original treatment than to mitigate in-service decay.

Improvements to preservative penetration can be accomplished through several different mechanical treatments that are applied to the pole prior to going into service. Incising, radial drilling and through-boring are the most common means of improving preservative penetration in utility poles (Morrell 1991). Of these, only through-boring affords 100 percent chemical coverage throughout the pole cross-section. The practice of through-boring is a well-established method for improving preservative treatment at the groundline to protect the pole against decay yet the effects on pole performance, if any, on the bending strength of the pole are poorly described.
The development of a standard pattern requires consideration of chemical transport in the wood structure as well as the mechanical effects of the pole performance. The transportation of the chemicals through the wood in the various directions was accomplished in prior work done by the Oregon State University Pole Cooperative (Morrell 1998). The second aspect, the mechanical effects, was the subject of our investigation and this was accomplished by developing a through-boring test pattern and subsequently testing through-bored poles. The proposed through-boring pattern was developed using numerical analysis tools (FEA) to examine and compare different test parameters. Secondly, a reliable full-scale test method was developed to more accurately assess the effects of the through-boring on the strength of the pole. Finally, an experiment was conducted with statistical analyses. The analysis and test development is the focus of this paper and will be discussed in detail. Complete details of the test experiment and its results can be found in Elkins (2005a and 2005b).

2. Preliminary Finite-Element Analyses

The objectives for the computer modeling were to examine stress concentrations created by different hole sizes, to examine the effect of various longitudinal and lateral hole spacings as well as edge distances on bending strength and hole interaction and to determine the effect of loading direction on bending stress with respect to the orientation of the through-bored holes.

A global elastic model of the tapered pole with through-bored holes was created. However, the stress analysis in the critical region was inadequate because the mesh was too coarse. As a result, a submodel was created so that sufficient mesh refinement would allow us to assess the stress concentration factors attendant to various combinations of hole size and hole spacing. The submodel was a 610 mm tapered pole section representative of the global pole at the groundline ($\Theta_{\text{top}} = 140$ mm, $\Theta_{\text{bottom}} = 146$ mm).

ANSYS® solid element 95 was used with nodal translations fixed at the groundline. The fixed boundary condition prevented the submodel from translating as a rigid body or rotating at the base. Linear elastic properties were used based on Douglas-fir so that the model was planar isotropic with $E_L = 11.9$ GPa and $E_{R/T} = 6.9$ MPa (USDA 1999). The model coordinate system was setup with the Z-direction as the longitudinal material orientation and the X and Y directions as the averaged radial and tangential orientations. The submodel was meshed automatically by ANSYS®. The principal interest was that the mesh refinement yield a compromise between stress output uncertainty and computational efficiency. A typical mesh for a submodel is shown in Figure 1.

Fig 1 Typical submodel meshing around a single through-boring hole.
2.1 Hole Size

The effect of hole size was investigated by developing models where hole size was varied in 6 mm increments, from 6 mm up to 31.7 mm, while keeping other model variables constant. The meshes around the varying holes were dissimilar due to the changing radii and a constant mesh was not able to be produced with the program manually. As a result, there were variations in the stress distribution for the hole size parameter due to mesh refinement. Finer meshes typically produced higher peak stress concentrations and the smallest hole size typically had the largest stress concentration factor, but beyond this, no other distinct generalizations could be made given the variability in the modeling. No hole size emerged as “optimal” in terms of having the lowest peak stresses as was predicted by the stress concentration formula developed by Pilkey (1997) for cylinders in pure bending.

2.2 Hole spacing

The effect of longitudinal and transverse hole spacing was assessed by using a submodel with two borings near the centerline. The spacing of the two holes was varied as a function of hole radii to determine the effect of spacing on peak stresses. Generally, the finite-element analysis output showed more closely spaced holes had lower peak stresses than did spacings at greater distances. Bending stresses for the 19-mm holes were fairly uniform at longitudinal spacings of three and six times the hole radii, but stresses increased approximately 8 percent for spacings of nine and twelve hole radii. The finite-element results confirmed previous reports that stress concentration factors decrease due to the presence of nearby holes; however, this effect is small. The difference due to longitudinal spacing was nominal when multiple hole submodels were run with varied spacings. Hole placement with respect to the edge had a larger influence on the maximum stress around the hole. Our results were similar to those by Falk et al. (2003) and Williams et al. (2000) showing that the location of holes in bending members was a critical issue.

Holes placed further out the pole diameter in regions with higher bending stresses were found by modeling to have greater stress concentrations. The increase in peak stresses was approximately linear as the hole was moved out the pole radius, away from the centroidal axis, until the edge distance was changed from 38 mm to 25.4 mm. When a hole was placed in this location, there was a sharp increase in the peak stresses, suggesting that a minimum edge distance should be maintained for through-boring. It is suggested that a 51 mm edge distance be maintained to account for deviations in the drilling process. Keeping holes out of the higher stressed regions of the pole will help reduce the risk of inducing substantial negative effects on pole strength.

2.3 Load Direction

Jessop et al. (1959) showed that members loaded in bending perpendicular to the hole axis, have lower peak stresses then poles loaded parallel to the hole axis. This effect was reassessed with FE analysis, comparing the stress output from two hole spacing patterns; 51x75-mm and 38x127-mm over a fixed length of 381 mm. Loading perpendicular to the holes produced significantly lower peak stresses in tension and compression for both spacing patterns. Peak tension stresses for the longitudinal and transverse directions were 36 and 26 percent higher, respectively, when loaded parallel to the holes.
2.4 Test Pattern

Chemical penetration research by the Utility Pole Research Cooperative (Morrell 1998) at Oregon State University has shown that creosote penetration averaged 216 mm longitudinally (± 96 mm) and 18 mm transversely (± 4 mm) around single holes drilled into Douglas-fir heartwood. These values suggest that a longitudinal and transverse spacing of 127 mm and 38 mm, respectively, repeated every 127 mm along the pole area to be bored, would provide the necessary coverage. These values, combined with the FE analysis, were used for the basis of the proposed test pattern.

After integration of test data and the literature, a basic through-boring pattern was defined by hole size, hole spacing (longitudinal and transverse), and edge distance. Spacings were based on edge-to-edge, not center-to-center distance. This resulted in an increased number of holes for the smaller spacings but preservative penetration coverage area stayed relatively constant. The basic through-boring pattern was a repeated staggered pattern with 127-mm longitudinal spacing, 38-mm transverse spacing, and 50-mm edge distance. The holes were drilled parallel to one another. This hole pattern was applied to the poles over a 1524 mm length, starting at 914 mm from the butt of the pole (-914 mm to +610 mm relative to the groundline on a 12,200 mm pole).

3. Test Method

3.1 Background on Test Method

Crews et al. (1998), Crews and Yates-Horrigan (2000), and Crews et al. (2004) evaluated typical bending moment distributions in wood utility poles and concluded that the existing test methods did not reasonably create bending stresses typical of those in-service. The maximum moment in a distribution size pole is estimated to occur at, or below, the groundline and is changing gradually in magnitude over this region. A graphical representation of this is shown in Figure 2 but it is only an estimate because the way in which an embedded pole interacts with the soil is complex, and many variables such as types of loading, depth of embedment, taper of pole, and soil type make it difficult to develop an exact stress profile.

![Fig 2 Estimated bending moment diagram for an embedded pole (Crews et al. (2004)).](image)

Both ASTM standard test methods detailed in ASTM D1036 (2005) produce the maximum moment at the groundline near the true maximum moment location of a distribution pole in service, but neither of these tests adequately represents the stresses away from the groundline. The cantilever test clamps the pole at the groundline, which essentially removes the pole below the groundline from the pole performance. This may be an accurate representation for poles embedded in concrete but it is not accurate for poles embedded in soil.
Another drawback of the cantilever method is that the fixity of the clamp crushes the wood fibers at the point of failure. Brown and Davidson (1961) described this as a “sharp fulcrum” effect. They also noted that failures from the cantilever machine test differed from those of the ground-embedded test poles. The assessment of testing methods by Crews et al. (2004) found that the clamped effect from the cantilever test might induce premature failures and impart forces that were not necessarily indicative of those seen in normal service. These factors make the cantilever test less than ideal with respect to repeatability and safety.

The 3-point bending test applies a single point load at the groundline to produce a sharp moment gradient on both sides of the loading point. This makes the moment at the failure section difficult to accurately predict. In addition, the full load force is imposed at a single point (or over a short bearing length) so that compression damage perpendicular to the grain is difficult to avoid. The method may overestimate pole strength because the volume of material subjected to the maximum moment is relatively small as compared to the 4-point load.

An accurate and representative test method is critical for determining pole bending strength because the value is premised on the stress calculated at the location of failure. The bending strength (MOR) is calculated from the moment at the failure point so the accurate identification of this location is important for accurate strength values but it is difficult to determine in most available testing methods because the failure can often be splintery, and extend over a large volume of the pole. The 3-point test method has the rapidly changing moment distributed across the critical through-bored region. Rapidly changing bending moments in this section introduce subjectivity and inaccuracy into the MOR values.

Crews et al. (1998) described a bending test derived from a 4-point bending test used in New Zealand by Walford (1994). Crews et al. (2004) showed that the bending moment did not change dramatically at the groundline, i.e., there was a nearly constant moment region at the groundline. The method generates a stress distribution similar to that seen in-service, and the International Organization for Standardization (ISO) is in the process of adopting it in their draft standard for wood pole testing (Crews et al. 2004).

The Australian 4-point method has a constant bending moment in the groundline area that reflects typical stresses at the groundline and makes the failure moment easy to calculate. Therefore, even if the exact location of the failure is not identified, the bending moment at failure can be reasonably estimated. The major drawback of the 4-point method is that to produce the constant moment region in the pole the shear force must be zero in this same area. An engineering analysis of a loaded pole shows some shear at the groundline. Furthermore, the moment and shear interaction may influence the failure that would not otherwise be seen in a pure moment failure.

### 3.2 Test Method

Building on the Australian test method, a new test methodology was developed to address the drawbacks of the current tests outlined above. First, the length of the test set-up was established. The top portion of the pole was not of concern for this purpose because the test was concerned with the through-bored region around the groundline so the pole was shortened to a convenient length for ease of testing. With those criteria, the length for the test span (L) was three times the embedment length (l) of the pole with a 305-mm overhang on each end. The embedment length for poles is typically 10
percent of the pole length plus 610 mm. In our example and subsequent demonstration of the method, we used a 40-ft (12,200-mm) long pole.

The poles were tested horizontally as simply supported beams with two point loads at the ends of the through-bored region. The reaction bearing points allowed the pole to rotate as well as move longitudinally. Wood saddles were used at the bearing points, as well as the points of loading, to minimize stress concentrations at these locations. The u-shaped saddles (279 mm long) were made from Douglas-fir so the point of contact between the two materials was of similar hardness.

The 2-point load was applied in the through-bored region to produce the desired bending moment. The loading span was made 305 mm shorter than the length of the through-bored zone, which is typically 1524 mm for Class 4 poles. The ratio between the two forces that would create a constant moment region was calculated to be 4.6:1, with the larger force applied closest to the butt end of the pole. Rounding up to the next whole number, 5:1, gave an easy ratio for design and introduced a small amount of shear at the groundline, slightly less than 1 percent of the total force.

A lever-arm approach was implemented in the load head design. In this case, the point load is set off center on the load head by the calculated distance to give the desired ratio of forces. Statics was used to calculate the required location for the point load to produce the 5:1 force ratio at the end of the 1220-mm lever arm. The point load was 203 mm from the end of the lever arm closest to the end where the larger load was needed, or 1016 mm from the opposite end.

Deflection was measured at the loading point above the groundline using a large displacement potentiometer. The potentiometer was mounted on the floor where it would not be damaged when the pole broke. Reaction settlement was measured at each end using linearly variable differential transformers (LVDTs). The end settlements were averaged and subtracted from the measured deflection. Force was measured by an electronic load cell mounted between the load head and the hydraulic actuator. Hydraulic control and data acquisition were managed using LabVIEW software. Force and displacement were recorded at a rate of 1 Hz. Complete testing apparatus set-up and details are found in Elkins (2005b).

4. Results and Discussion

The results of bending tests (Fig. 3) showed that the bending strength of the poles was not significantly affected (significance level = 0.05). The lines shown in Figure 3 show that as the hole size increased, the distributions tended to bunch and the mean decreases. The control poles had the greatest mean value, but that mean value also the largest standard deviation. We inferred from the data that the pole performance was modestly affected by the placement of holes in this pattern regardless of size. However, the holes do not negatively influence the bending strength until the holes reach a diameter that approximates 25 mm.

Failure modes were generally splintering bending tension failures. Although, it was not unusual to see compression wrinkles develop before the bending tension failure. We saw more compression controlled failures in the treatment group with 25 mm holes than in the other groups. Approximately four percent of the failures were sudden brash failures, where the pole simply snapped into two pieces.
5. Conclusions

Finite-element analyses showed typical boring patterns did not significantly impact peak stresses around holes and a test pattern was developed based on adequate chemical penetration. The alternative 4-point bending test set-up was used to test the pattern on full-size poles and it was deemed a more reliable test for assessing the impact of through-boring on the strength of the pole. Results showed that small to intermediate hole sizes did not significantly impact strength at moderate spacings and therefore, no design strength adjustment for through-boring should be necessary.

6. References


