Strength Loss in Southern Pine Poles Damaged by Woodpeckers

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Abstract

Woodpecker damage caused extensive reductions in strength of 50-foot, class-2 utility poles, the amount depending on the cross-sectional area of wood removed and its distance from the apex. Two methods for estimating when damaged poles should be replaced proved to be conservative when applied to results of field tests. Such conservative predictions of failing loads could be used for systematic replacement of damaged poles. Each utility company would have to balance the cost of timely replacement (with resultant loss of some serviceable pole life) against the cost of pole failure and replacement after failure.

WOODPECKERS OFTEN MAKE EXTENSIVE EXCAVATIONS in utility poles (Rumsey 1970). Poles so damaged are subject to breakage from lateral loads imposed by windstorms; compressive strength is also affected and may be critical in regions where lines frequently ice over; but it is likely that most failures ultimately occur in bending. This paper assesses strength losses from woodpecker attack on southern pine poles and presents two methods for predicting when damage is sufficient to require replacement of the poles.

Methods

Eighteen class-2, 50-foot creosoted southern pine poles set 7 feet in the ground were broken in place in central Louisiana during June 1971[1]. The poles had been in the field for 4 years. With the exception of two used as controls, they contained one or more completed nest cavities or holes with entrance openings at least 3 inches in diameter. Twelve of the poles had been steam-conditioned, and the other six had been kiln-dried. All had been treated with preservative to 10 pounds per cubic foot.

A cable was attached 2 feet from the apex (ASTM Designation D 1036-56) to apply load with a winch truck. Direction of pull produced tension on the face that contained the entrance hole to the nest cavity. A special collar at the groundline prevented the poles from moving. The rate of loading was 7.5 feet per minute. The angle of the cable from horizontal averaged 19°27'.

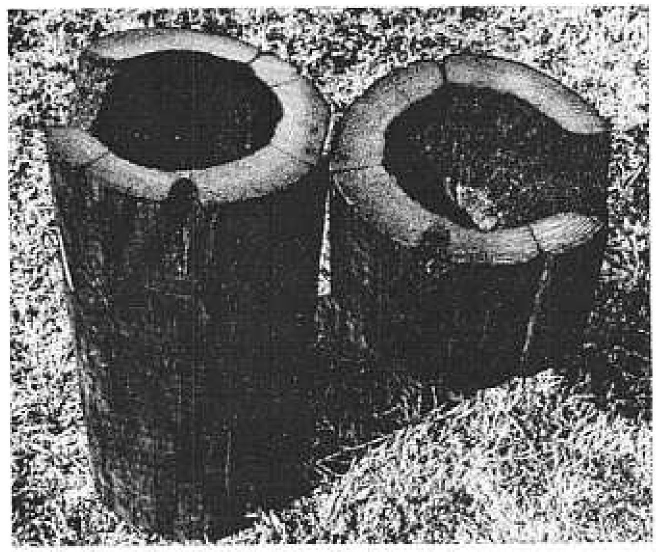

Figure 1. — Cross-sectional view of typical damage.

Trigonometric functions were used to convert observed load to equivalent lateral load. It is recognized that a combined loading situation existed, but the compressive stress was generally less than 100 psi and therefore was not included in the calculations.

Circumferential measurements were made at the top, point of loading, groundline, and point of failure. Distances from apex to groundline, to point of damage, and to point of failure were recorded. Woodpecker cavities were relatively uniform in shape (Fig. 1), but the cross-sectional area of wood removed ranged from 11.6 to 72.2 percent.

Strength of Control Poles

Two poles had no woodpecker damage, and four failed below the damaged portion. These six were therefore used as controls. Their maximum fiber stress in bending (modulus of rupture) averaged 7,091 psi. The range was 6,286-8,017 psi, and the standard deviation (s)

[1]All labor and materials used in breaking the poles were furnished by Central Louisiana Electric Company, Pineville, La.

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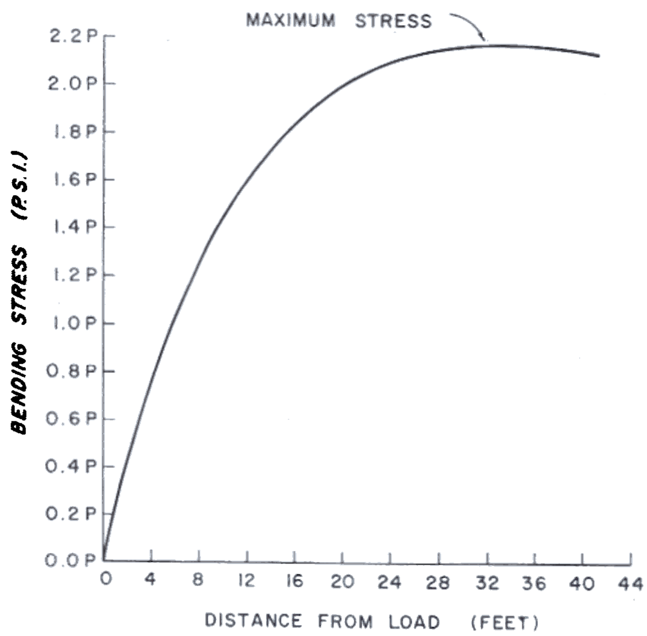

Figure 2. — Point of maximum stress in undamaged class-2, 50-foot pole with a lateral load (P in pounds) applied 2 feet from the apex. Poles assumed to have minimum dimensions and uniform taper.

was 686 psi. The 95-percent exclusion limit was calculated by use of the tabulated K for one-sided statistical tolerance limits (see Table A-7 in Natrella 1963). By this procedure the appropriate K (for $n=6$) is 3.707, and the 95-percent exclusion limit is 7,091 minus Ks. Thus, the probability is 95 percent that at least 95 percent of the stress values in the distribution from which the sample was drawn exceeded 4,548 psi.

Wood, et al., (1960) found that 55-foot untreated southern pine poles broke at 9.0 feet above groundline, while the majority of smaller poles broke at 1 to 3 feet above ground. They concluded that the difference between the large and small poles was due to the maximum stress (in a cantilever with the shape of a frustum) occurring where the diameter is 1.5 times that at point of loading. Since the taper is greater in longer poles, the point of maximum stress is higher from the groundline than for the shorter poles. Figure 2 indicates that the maximum stress in undamaged 50-foot poles of class 2 occurs at a point 33 feet from the load when the load is applied 2 feet below the apex. In the six poles used as controls, average distance from load point to failure was 33.2 feet.

Estimated Lateral Load Capacity

Information on the 12 poles that broke at a cavity is summarized in Table 1. Location and size of the cavities varied widely, and the samples were too few to permit conventional analyses. Instead, an attempt was made to derive models to indicate when damaged poles should be replaced, and the field data served as a check on the prediction methods.

In cross section nest cavities resemble the schematic in Figure 3. Estimating lateral load capacity of damaged poles requires the composite moment of inertia of the section, location of the centroid, location of the damage, and the fiber stress in bending at that location. Several assumptions were made:

1) The poles are fixed in the ground so that they act as a cantilever with a tapered section.
2) Wood in the cross section is homogeneous.
3) Lateral load is applied at a point 2 feet below the apex of the pole.
4) In cross section the woodpecker nest cavity can be estimated with a circle (area B in Fig. 3) and a rectangle (area C in Fig. 3).

Table 1. — DAMAGE ANALYSIS, ACTUAL FIBER STRESS, AND COMPARISON OF ACTUAL TO ESTIMATED LOADS AT FAILURE IN DAMAGED POLES.

Pole No.	Distance from load to failure (ft.)	Reduction of section modulus (%)	Proportion of wood removed (%) Actual	Proportion of wood removed (%) Estimate	Actual stress (psi)	Actual load (lb.)	Estimated load[1] P_{TC} (lb.)	Estimated load[1] P_{SG} (lb.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)		
4121	1.8	62.8	72.2	66.4	1,934	2,465		
7122	3.2	56.6	62.7	60.4	3,639	4,403		
2122	7.7	55.1	52.0	49.4	5,043	4,257		
7222	13.3	43.7	41.8	38.9	6,520	3,089		
4221	15.3	48.6	44.3	36.2	5,326	2,467		
7221	16.0	46.3	45.6	42.2	6,231	2,467		
2222	16.8	45.3	52.9	42.8	10,430	4,184		
6222	16.8	45.2	54.2	48.0	9,417	3,784		
1221	17.5	38.5	32.0	31.2	4,798	2,152		
2221	21.5	33.0	30.5	29.9	7,627	4,077		
6121	25.0	41.5	25.5	26.0	5,518	2,161		
5112	34.0	31.5	11.6	11.2	9,722	4,208		

[1] P_{TC} represents load estimated by the model to cause failure, as calculated with stress (σ_{TC}) adjusted as in a tapered cantilever pole; P_{SG} represents load calculated with stress (σ_{SG}) adjusted for variation in specific gravity and arbitrary correction for knots and stress concentrations.

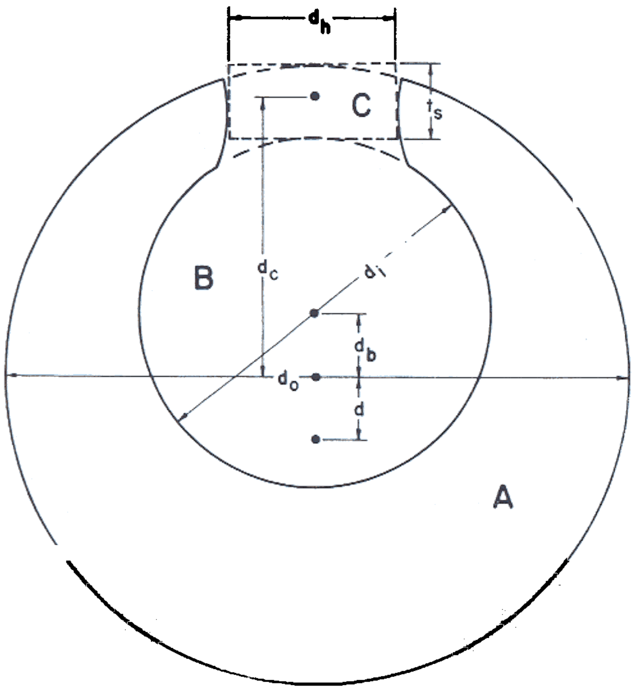

Figure 3. — Model for reduction of moment of inertia. A is cross-sectional area before damage, B is area of cavity, C is area of entrance hole.

5) The woodpecker damage is in the most damaging position on the pole when the load is applied so that the entrance to the nest cavity is on the tension or compression face.
6) Tensile strength of wood is equal to compressive strength.

Standard stress analysis from flexure theory has been employed (Popov 1968). A woodpecker cavity shifts the centroidal axis away from the center and reduces the pole's moment of inertia and section modulus, thereby lessening the strength in bending. The following paragraphs summarize the analysis leading to the values required for estimating the lateral load-carrying capacities of damaged poles.

Shift of Centroid

Suppose that a class-2 pole 50 feet long contains a woodpecker hole 23.5 feet from the apex and that the following measurements are recorded at the point of damage (see Fig. 3 for clarification):

d_o=outside diameter of pole = 12.8 inches

d_i=inside diameter of cavity = 6.6 inches

d_h=horizontal width of entrance = 3.25 inches

t_s=average thickness of shell on each side of entrance hole = 1.8 inches

Distance from centroids of areas B and C to centroid of A are, respectively, d_b and d_c. Products of (d_b) (B) and (d_c) (C) are summed and divided by area of remaining undamaged wood (A minus $(B + C)$). For the hypothetical pole the results are:

$$(d_b)\ (B)=(1.3)\ (-34.19)=-44.45$$
$$(d_c)\ (C)=(5.5)\ (-5.85)\ =-32.18$$
$$\overline{-76.63}$$

$$d=\frac{-76.63}{88.57}=-0.86$$

Thus, the centroid of the remaining wood has shifted 0.86 inch away from the center of the pole, i.e., away from the entrance hole.

To test whether d_i, d_h, and t_s approximate the cross-sectional areas of wood actually removed, areas at the points of breakage were measured in detail. The two sets of values corresponded closely (Table 1, cols. 4 and 5), with the approximations tending to understate the percentage of cross section destroyed. Maximum difference noted in the 12 sets of measurements was between an estimate of 42.8 percent and an actual value of 52.9.

Moment of Inertia and Section Modulus

By the parallel-axis theorem (Popov 1968):

$I_o=\overline{I}_o+Ad^2$=Moment of inertia of original section A about new centroidal axis.

$\overline{I}_o$=Moment of inertia of original section about its own centroidal axis.

d=Distance from the new centroidal axis to centroid of A.

$$\overline{I}_o=\frac{\pi(d_o)^4}{64}=\frac{\pi}{64}(12.8)^4=1{,}316.94\ \text{in.}^4$$

$$Ad^2=(128.61)\ (-.86)^2=\ 95.12\ \text{in.}^4$$

$$I_o\qquad =1{,}412.06\ \text{in.}^4$$

similarly:

$I_B=I$ of area B about new centroidal axis, or 252.61 in.^{4}

and $I_C=I$ of area C about new centroidal axis, or 238.21 in.^{4}

and $I_{composite}=I_o-I_B-I_C=921.24$ in.^{4}

By these calculations, the section modulus (i.e., moment of inertia divided by distance from centroid to extreme fiber) of the pole at the location of woodpecker damage is reduced 38 percent, from 205.8 in.^{3} to 126.9 in.^{3}, with proportionate loss in strength.

Fiber Stress in Bending for Damaged Poles

Woodpecker damage is not restricted to a small zone; it may occur at almost any height. Moreover, the wood in a pole rarely is homogeneous from base to top. Rather, specific gravity decreases with height, and extreme fiber stress in bending is correspondingly less. Likewise, the frequency of knots increases and thereby the probability that zones of exposed grain deviations will appear in the upper half of machine-peeled poles.

With these variations in mind, two methods are proposed to correlate the maximum fiber stress in bending with height in the pole; this maximum stress can then be used in computing the capacity of damaged poles to carry lateral loads.

The first method assumes that maximum fiber stress in bending of a pole is related to height in the pole in the same pattern that maximum fiber stress is related to height in the tree. The following equation was therefore used:

$$\sigma_{TC} = \frac{122.292(P)\ (X)}{d^3}$$

where

σ_{TC}=predicted stress at failure in tapered cantilever pole at given distance from the apex (psi).

P=load at apex to produce a stress of 4,548 psi at point of maximum stress located 35 feet from apex (lb.).

X=distance from apex (ft.).

d=diameter of pole at the desired distance from apex (in.).

Solving for $X=2$ gave a stress of 874 psi, and it was assumed that the upper 2 feet of the pole had a constant stress value of this amount.

A second method made allowance for variation in specific gravity with height. The 95-percent exclusion limit was adjusted from 4,548 psi at the base to 2,650 psi at the load point. This adjustment corresponds to a linear reduction of extreme fiber stress with decreasing specific gravity. Test data (Taras 1965; Koch 1972, p. 256) indicate that specific gravity may decrease from 0.60 to 0.35 over a similar distance in the outer growth increments of a standing southern pine tree. A further arbitrary reduction equal to 50 percent at the top was made to adjust for knots and stress concentrations. Thus, the final adjustment was made linearly from 4,548 psi at the base to 1,325 at the load point. Extreme fiber stress at any given distance from the load point was calculated as:

$$\sigma_{SG} = 1{,}325 + 78.61\ (X)$$

where

σ_{SG}=predicted extreme fiber stress adjusted for specific gravity, knots, and stress concentrations (psi).

X=distance from load point located 2 feet from apex (ft.).

Estimated Lateral Load-Carrying Capacity

Given the composite moment of inertia of the section at the location of damage, the location of the centroid, and a value for fiber stress as calculated by the two preceding methods, the load at failure can be estimated from the classic flexure formula for a beam under load:

$$P_{TC} = \frac{\sigma_{TC} I}{12Lc} \quad \text{or} \quad P_{SG} = \frac{\sigma_{SG} I}{12Lc}$$

where:

P_{TC} or P_{SG}=estimated load at point 2 feet from apex to cause failure (lb.).

σ_{TC} or σ_{SG}=fiber stress in bending (psi).

I=moment of inertia after damage (in.^{4}).

L=distance from load point to damage (ft.).

c=distance from centroidal axis to extreme fibers (in.).

Accuracy of Stress Estimates

Table 1 (cols. 7, 8, and 9) compares actual loads at failure with values predicted by the two methods. Both methods are conservative, but variability of wood with

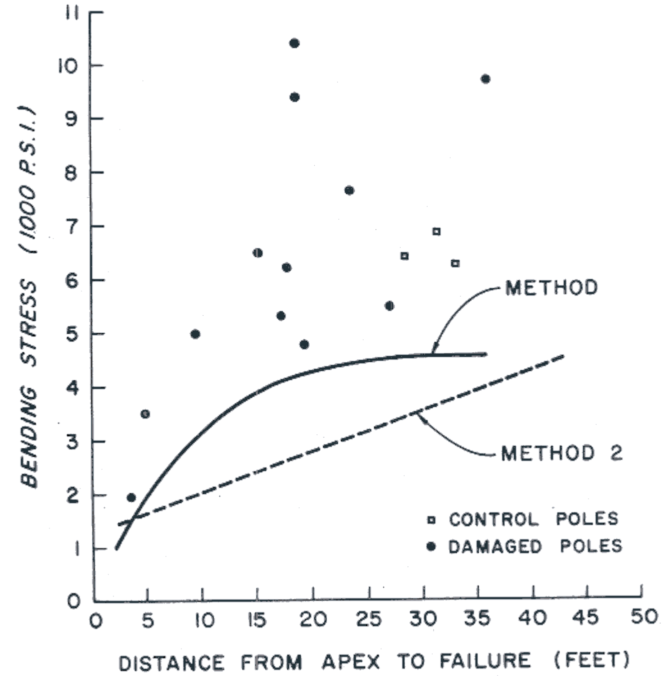

Figure 4. — Modulus of rupture of eighteen class-2, 50-foot poles, and plots of fiber stress computed by two methods designed so that the actual strengths will exceed the predicted stress values.

height in tree and effects of stress concentrations around knots and cavities make a margin of safety necessary.

The straight-line method provided a looser fit than did the method that allowed for stress distribution in a cantilever beam (Fig. 4). It will be recalled that both models were based on computation of 95-percent exclusion limits but that neither had additional factors of safety. All poles failed, however, at loads higher than those indicated by either method.

Such predictions of failing loads may be useful for systematic replacement of damaged poles. In deciding on the degree of conservatism desirable, utility companies would have to balance the cost of timely replacement (with resultant loss of some pole life) against the cost of failure and replacement in service.

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