FINITE ELEMENT ANALYSES OF WOOD LAMINATED COMPOSITE POLES[1]

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ABSTRACT

Finite element analyses using ANSYS were conducted on orthotropic, polygonal, wood laminated composite poles subjected to a body force and a concentrated load at the free end. Deflections and stress distributions of small-scale and full-size composite poles were analyzed and compared to the results obtained in an experimental study. The predicted deflection for both small-scale and full-size composite poles agreed well with the experimental measurement. Maximum stress of a cantilever pole was in parabolic areas of the top and bottom skins near the ground line. The finite element model underestimated the deflection of full-size composite poles over a variable length from the ground line of the poles, depending on the loading levels. At a higher loading level, the finite element model might overestimate the deflection close to the free end of the full-size composite poles.

Keywords: Composite poles, deflection, finite element analysis, stress, utility poles.

INTRODUCTION

Wood composite poles are new engineered products with polygonal shapes and bonded with synthetic resins. These poles have multiple advantages over solid wood poles and are a promising solid pole substitute in power transmission, telecommunication, and cable TV services. The use of wood composite poles may reduce material and processing costs and conserve pole-size timber. Analyzing composite poles by finite element method (FEM) can provide an important

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way to fully assess the properties of these products.

The objective of this study was to conduct FEM of wood laminated composite poles with ANSYS. ANSYS is a large-scale, general-purpose finite element computer program. First released in 1971, ANSYS has been a leading FEM program for over 20 years (Moaveni 1999). It can be used for the solution of several classes of engineering analyses. In this analysis, deflection, stress, and strain for different configurations of poles subjected to concentrated and body force [i.e. weight of pole/unit length] were obtained using ANSYS. The FEM results were compared with those from an experimental study.

FEM procedures

There are two phases in FEM analysis using ANSYS, i.e., processing and solution phases. In the processing phase, the problem to be analyzed is defined. ANSYS delineates the geometry of the domain by a number of keypoints, which specify various principal coordinates to define the body. Since the composite pole is hollow, the cross-section solid can be viewed as being formed by two polygons for each configuration of the poles. The keypoints or vertex coordinates of the two polygons were first calculated and drawn in the Cartesian coordinate system. Lines were then drawn among the keypoints and cross-section was formed. Finally, the pole bodies were formed by extruding the cross-sections of different polygons and different thickness levels. The pole bodies were placed in the horizontal direction and analyzed in a cantilever mode.

To analyze the deflection of the poles, the material properties and element type were defined. The longitudinal [L] Young's modulus values of the poles were the experimental values obtained in another study (Piao et al. 2005). Other property values, including elastic constants in radial [R] and tangential [T] directions and the Poisson's ratios of the strips, were approximated by the same property values of the wood and listed in Table 1.

The last step for the processing phase is to mesh the body defined. Meshing the body is an important step and determines accuracy of the analysis, computation time, and convergence of the solution. For this study, since strip thickness was normally less than 2.54 cm (1 in.) for small-scale poles and more than 2.54 cm for full-size poles, the element size was set as 1.27 cm (0.5 in.) for small-scale poles and 2.54 cm (1 in.) for full-size poles. According to the specification, ANSYS meshed small-scale shells of the 2.54-cm-thick-strip poles into three layers, and two layers for the 2.0-cm-thick-strip poles, and one for other two thickness levels. The strip width of the 12-strip poles was about 2.0 cm (0.8 in.) and ANSYS meshed it into two parts. The width of each 9- and 6-strip was meshed into three elements. Each element in the domain was a hexahedron with element edges less than 2.54 cm (1 in.). The number of elements for each configuration and length level is presented in Table 2. Figure 1 shows the discretization of a 9-strip pole with a strip thickness of 2.54 cm.

In the solution phase, ANSYS conducts the analysis and gives the results. Constraints were applied to obtain a singular solution. The degrees of freedom of the fixed end were set to zero. Body force of the pole was calculated and uniformly applied along each member. A concentrated load was applied at the free end. For comparative purposes, the loads were the same

TABLE 1. *Selected elastic properties of clear southern yellow pine wood.*[1]

Stiffness properties (Mpa)					Poisson's ratios		
E_R	E_T	G_{LR}	G_{LT}	G_{RT}	ν_{LR}	ν_{LT}	ν_{RT}
1026	670	828	765	91	0.37	0.42	0.47

[1] Bodig and Jayne (1982).

TABLE 2. *Number of elements in each configuration of laminated composite poles.*

Strip thickness (cm)	107-cm pole			549-cm pole	
	6-strip	9-strip	12-strip	9-strip	12-strip
1.0	504	756	504	—	—
1.5	504	756	504	7004	8832
2.0	504	756	504	9888	14214
2.5	1008	1512	1008	10404	15862

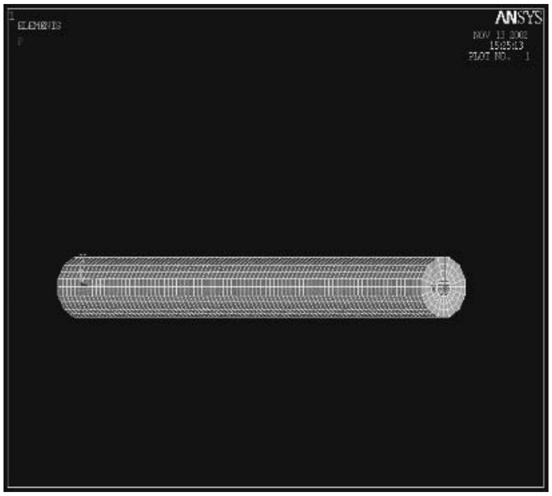

FIG. 1. Discretization and application of loads in the finite element analysis of a small-scale wood composite pole.

as in the experimental study. Glueline effects were neglected in this study.

EXPERIMENTAL STUDY

To validate the applicability of the FEM results, an experimental investigation was conducted on small-scale and full-size wood composite poles. Additional experimental details can be found in Piao et al. (2004). The length of the small-scale poles was 1.22 m (4 ft.), and the diameter was 7.6 cm (3 in.). The length and diameter of the full-size poles was 6.1 m (20 ft.) and 10.2 cm (4 in.), respectively. The species used was southern yellow pine (*Pinus* sp.). Strip thickness and number of strips were the two experimental variables for both sizes of the poles. For the small-scale composite poles, strip thickness levels were 1.0 cm (0.4 in.), 1.5 cm (0.6 in.), 2.0 cm (0.8 in.), and 2.5 cm (1.0 in.), each of which had 6, 9, and 12 strips. For the full-size poles, the strip thickness levels were 1.9 cm (0.75 in.), 2.9 cm (1.125 in.), and 3.8 cm (1.5 in.) and numbers of strip were 9 and 12. Thirty-six small-scale and twelve full-size composite poles were made. There were three replications for small-scale poles and two for full-size poles for each combination of strip thickness and strip number. Lumber was first planed to specific thickness and then cut to target size strips using a table saw. Resorcinol-phenol-formaldehyde resin was used to bond the strips and poles were fabricated in steel molds. The glue was uniformly hand-spread onto the two lateral-surfaces at 310 g/m^2 (63.3lbs/1,000 ft^2). Poles were pressed in molds for 36 h in an air-conditioning room. Figure 2 shows that a full-size composite pole was pressed in a steel mold.

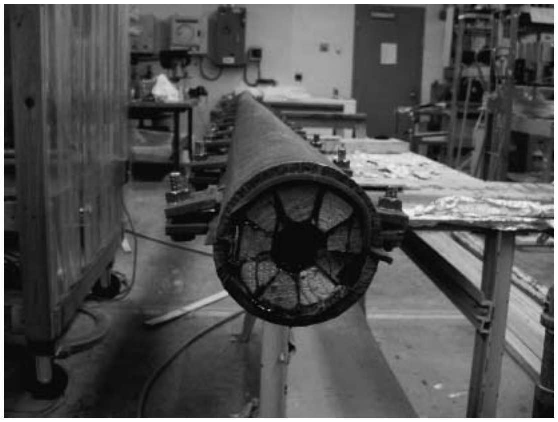

FIG. 2. A full-size wood composite pole as pressed in a steel mold.

A cantilever test was performed for all the composite poles using a RIEHLE machine. Before the test, the control system of the RIEHLE was replaced by a digital controller and connected to a computer. The clamped length for

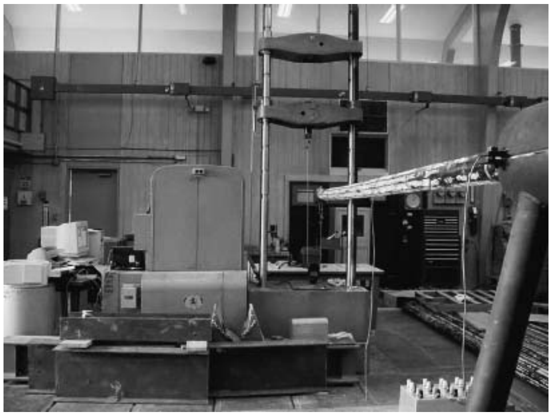

FIG. 3. A full-size composite pole as tested in a RIEHLE machine.

the small-scale and full-size poles was 15 cm (6 in.) and 91 cm (3 ft.), respectively. Therefore, the length-to-diameter ratios (L/d) were 14 and 51 for small-scale and full-size poles, respectively. A load of 222 N (50 lbs) was applied at the free end of each small-scale pole in the test and the deflection obtained after the bending test was used to verify the FEM results. In the bending test of each full-size pole, pins with 0.5-mm diameter were nailed along one side of the pole. The distance between two pins was 305 mm (1 ft.). A thin string was used to line up the pins. The displacement of the pole at each pin location was determined via measuring the vertical distance between the pin and the string. Each full-size pole was tested twice to obtain the deflection curves at two different loads (134 N and 267 N). The displacement at each pin location in each test was measured. Figure 3 shows a full-size composite pole tested in a RIEHLE machine.

RESULTS AND DISCUSSION

Results from FEM

Some of the ANSYS results are shown in Figs. 4 to 7. Figure 4 shows that a composite pole with 12 sides and 2.5-cm strip thickness was discretized into tetrahedron elements. ANSYS discretized the thickness of the pole shell into three layers of elements. The node and element numbering systems of a 9-side and 2.5-cm strip thickness composite pole are shown in this figure.

Figure 5 shows the stress distribution of a

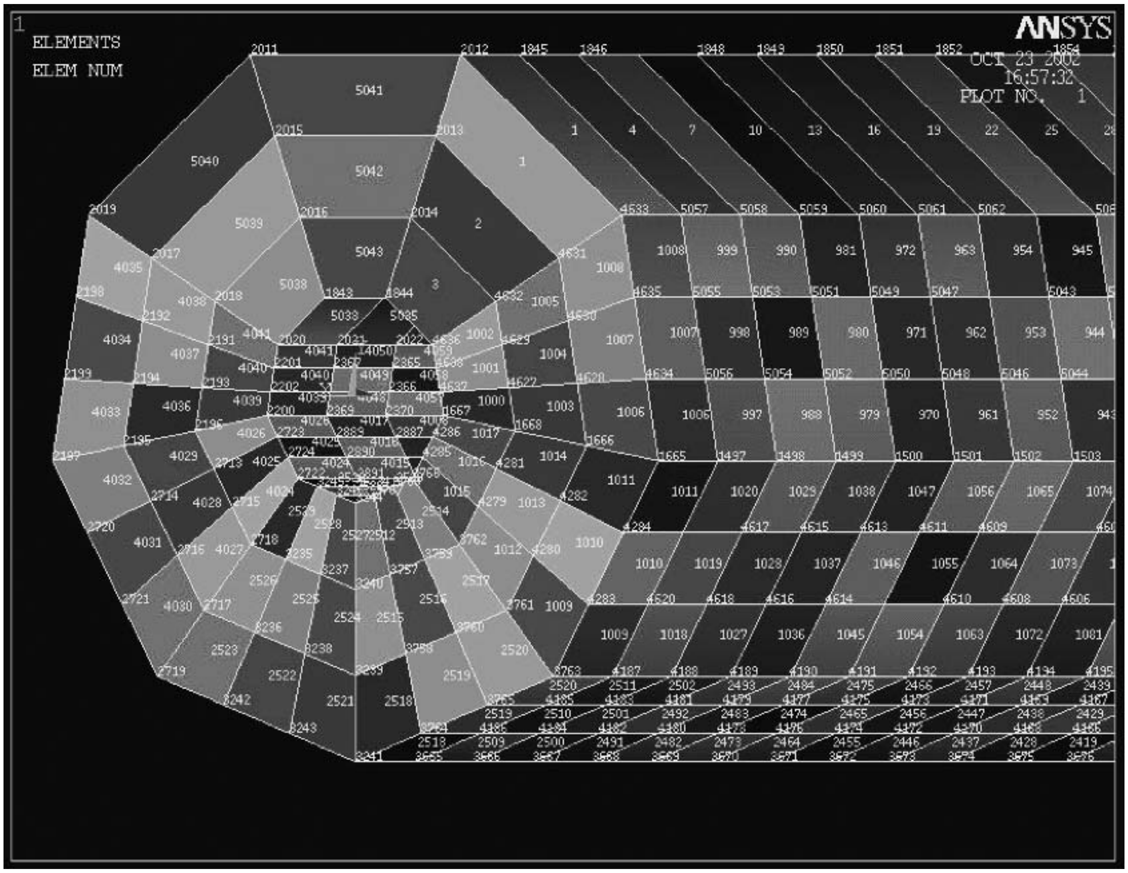

FIG. 4. Node and element numbers of a small-scale wood laminated composite pole.

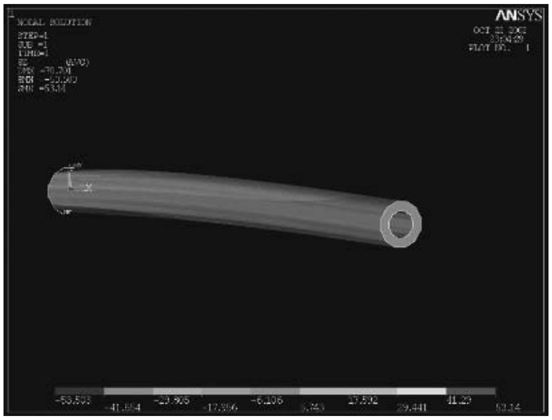

FIG. 5. Stress distribution of a small-scale wood laminated composite pole in the finite element analysis.

9-side composite pole with a strip thickness of 1.5 cm. The maximum bending stress of the pole occurred in the parabolic areas on top and bottom skins near the fixed end where all degrees of freedom were zero. On the top skin, the stress was in tension, whereas the compressive stress was on the bottom. The maximum deflection, as well as the distributions of compressive and tensile stresses, is shown in this figure. Similar stress distribution patterns to the one shown in the figure were found in the analyses of other small-scale and full-size composite poles.

Typical deflection curves based on strip thickness for small-scale and full-size composite poles are plotted in Figs. 6 and 7, respectively. The load was 134 N for the full-size pole shown in Fig. 7. The deflection values in both figures were obtained by tracing the node numbers in the ANSYS results for each pole. In both cases, the thinner shell poles deflected more, as expected. The deflection curve of 2.9-cm-thick full-size pole was close to that of 3.8-cm-thick pole.

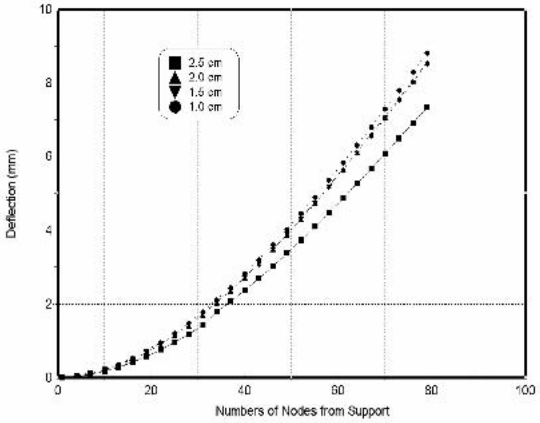

FIG. 6. Effect of strip thickness on the deflection of 12-sided small-scale composite poles.

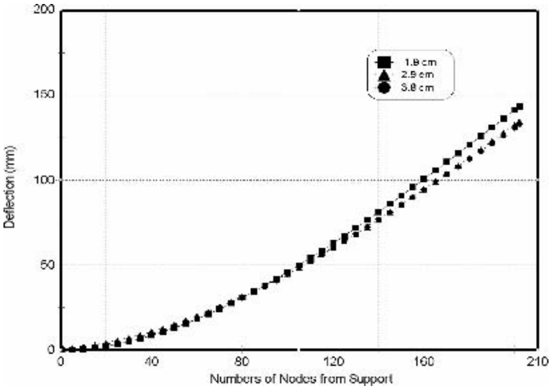

FIG. 7. Effect of strip thickness on the deflection of 12-strip full-size composite poles.

Comparison with experimental results

Deflections of both full-size and small-scale members predicted by the finite element analysis

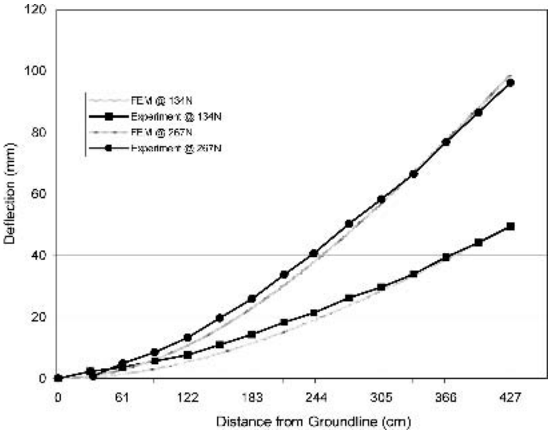

FIG. 8. Comparisons between the deflections predicted by a finite element model and measured in an experimental study at two loading levels.

TABLE 3. *Comparison between the deflection values obtained experimentally and the values predicted by the finite element method of the full-size composite poles subjected to the same load for both test methods (133 N (30 lbs)).*

	Strip thickness (cm)	1.91	1.91	2.86	2.86	3.81	3.81
9-Strip Poles	Experiment (mm)	130.2	88.9	91.4	79.5	91.9	93.4
	FEM Test (mm)	123.1	88.3	82.7	79.4	98.4	92.3
12-Strip Poles	Experiment (mm)	100.3	86.4	78.0	81.5	77.2	68.7
	FEM Test (mm)	91.3	88.0	84.3	85.6	78.9	68.3

were compared with those measured from the experimental study. The experimental data of the small-scale composite poles were obtained from the load-deflection graphs in the experimental test in the previous study (Piao et al. 2004). Figure 8 and Table 3 give the results obtained from the two tests. Most experimental values were higher than the finite element ones for the small-scale and full-size composite poles, showing that the FEM model was conservative in predicting the deflection properties. The difference between the experimental and FEM values of both small-scale and full-size poles varied from 2 to 10%. Except for some samples in the 1.0- and 1.5-cm thickness levels, experimental values of the small-scale poles agreed well with those of finite element analyses.

A detailed deflection comparison along the pole between the FEM and experimental results may present more useful information regarding the FEM model. Figure 8 compares the deflection predicted by the FEM method to that of the experiment for the 12-side and 2.5-cm-thick pole at two loading levels. The FEM model underestimated the deflection of the pole at the 134 N loading level, especially for the deflection from groundline to the midpoint of the pole length. However, the FEM model agreed well with the experimental results at the free end of the pole. Similar results were found when the load was 267 N. The FEM model underestimated the deflection of the pole from the groundline to about three fourths of the pole length and overestimated the deflection in the rest of the pole length.

Figure 9 shows the comparison between the experimental results and FEM results at the free ends for the thirty-six small-scale poles. It can be seen that the FEM values were closer to the experimental values at the free ends for the 2.0-cm and 2.5-cm strip thickness levels. It also shows that deflection decreased with an increase of strip thickness. The deflection of full-size composite poles obtained from the finite element analysis at the free ends also correlated well with the experimental data (Table 3).

The poor correlation between the experimental values and those of the FEM model for poles with a strip thickness of 1.0 and 1.5 cm may be attributed to plastic deformation of the poles. Table 4 gives the comparisons in two thickness levels when the load was set to 89 N (20 lbs). The accuracy was improved when a lower load was applied.

CONCLUSIONS

Finite element analysis was conducted on small-scale and full-size composite poles using ANSYS and the results were compared with those obtained from experimental data. The correlation between the experiment and finite element analysis was found to be good, indicating that ANSYS models may be used to assess the

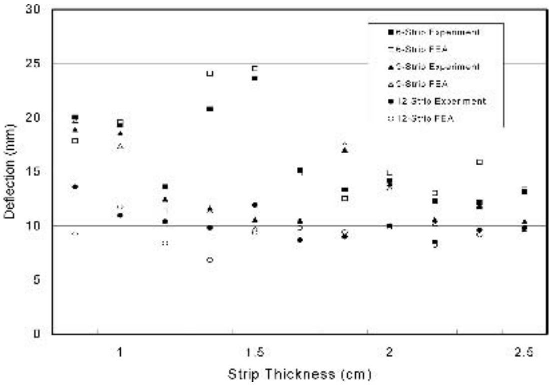

FIG. 9. A comparison between the deflections obtained from an experiment and predicted by a finite element model of small-scale composite poles.

TABLE 4. *Comparison between the deflection values obtained in the experiment and values predicted from finite element analyses of small-scale poles (1.0-cm and 1.5-cm thickness) subjected to an 89 N (20 lbs) load.*

	Strip thickness (cm)	1.0			1.5		
	Samples	1	2	3	1	2	3
6-Strip Poles	Experiment (mm)	6.93	7.88	8.32	4.92	9.83	10.20
	FEM (mm)	6.41	7.15	7.84	4.54	9.63	9.70
9-Strip Poles	Experiment (mm)	7.56	8.51	7.56	5.07	5.06	4.35
	FEM (mm)	7.30	7.89	6.94	4.96	4.56	3.90
12-Strip Poles	Experiment (mm)	5.35	5.37	5.39	4.10	3.52	4.76
	FEM (mm)	5.25	5.20	4.92	4.16	3.69	4.80

bending properties of wood laminated composite poles. The experimental deflection values of the poles tested in this study were 2 to 10% higher than the finite element ones predicted by ANSYS. The FEM model underestimated the deflection of the full-size poles from the groundline to a variable length of the pole, depending on the loading levels. At a higher load level, the FEM model might overestimate the deflection of the pole near the free end. Maximum bending stress of composite poles in the cantilever test was in parabolic areas on the top and bottom skins near the ground line at the fixed end. These areas need to be reinforced to improve the strength performance of laminated composite poles subjected to bending.

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