PROCEEDINGS

7th Pacific Rim
Bio Based Composites Symposium

Nanjing, China
October 31th – November 2nd
2004

Volume2

Organized By
College of Wood Science and Technology and the Wood-based Panel Research
Institute, Nanjing Forestry University, Nanjing, 210037, China

Sponsored By
National Natural Science Foundation of China
Research Centre of Fast-growing Trees and Agro-fiber Material Engineering, Jiangsu,
China

Published By
Science & Technique Literature Press

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New method

Poster Session

Nondestructive Evaluation of Young's Moduli of Full-Size Wood Laminated Composite Poles

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ABSTRACT

An exploratory study was conducted to evaluate the Young's moduli of wood laminated composite poles (LCP) by using a free transverse vibration method. Full-size LCP, 6.1 m long and 10.2 cm in diameter, were lab-fabricated with 9 and/or 12 southern yellow pine [SYP] strips of thickness, 1.9 cm, 2.9 cm and 3.8 cm. The frequency of free transverse vibration in an LCP was measured via strain gages mounted on the pole surface through a StrainSmart system. Dynamic Young's moduli evaluated by the free transverse vibration method were compared to these calculated from the measured strains and both agreed very well. The free transverse vibration method can be an alternative to the static bending method which is commonly used in the evaluation of bending performance of solid wood beams and wood composite poles. The effect of strip-thickness on the Young's Moluli of LCP was observed. However, a significant effect of strip-number on the Young's Moduli of LCP fabricated with 2.9-cm and 3.8-cm strips was not observed.

Keywords: Laminated composite poles (LCP), non-destructive evaluation (NDE),free transverse vibration, Young's modulus, wood utility poles

INTRODUCTION

Solid wood poles are widely used in the power transmission, distribution, and telecommunication industries to carry cable lines in long distance. These wood utility poles are made of high quality tree-length logs, which are becoming expensive due to the ever increasing demand for utility poles in recent years. In the last three decades, several endeavors have been made to make full use of our renewable natural resources (e.g. Marzouk et al. 1978, Tang and Adams 1973) or to find substitutes for the solid wood poles (e.g. Adams et al. 1981, Erickson 1994 and 1995). More recently, wood laminated composite poles [LCP], which composed of trapezoid solid wood strips and bound with synthetic resins, were developed (Piao 2003 [Ph.D. dissertation]). As compared with composite wood utility poles [COMPOLE] (Adams et al. 1981) and hollow veneered poles [HVP] (Erickson 1994), LCP are more cost-effective, easier to fabricate in the size and shape to meet the structural performance requirements of wood utility poles, and treat with preservatives for durability. Experimental and theoretical studies on the structural behavior of LCP indicated that its mechanical properties and stiffness performance are comparable to those of solid wood composite poles (Piao et al. 2004a and 2004b).

Vibration methods have been extensively used for the evaluation of elastic properties of solid wood (e.g. Fukada 1950, Hearmon 1951, Kitazawa 1952, Kollman and Kerch 1960, Matsumoto 1958, Tang and Hsu 1972) and wood composites (e.g. Schultz and Tsai 1968, Pu and Tang 1997, Tang and Lee 1999). As an alternative to the static methods, vibration methods approximate the Young's modulus of wood members via measuring their resonant frequencies nondestructively while samples must be destructed in most static bending tests. The formula for the vibration test can be expressed as:

$$E = \frac{p f_n^2 L^4}{a_n^2 I} \qquad (1)$$

where p is the mass per unit length (g/cm), f_n designates the resonant frequency for nth mode of vibration (Hz), l is the length of the beam (cm), I is the moment of inertia of the beam (cm^4), and a_n represents the eigenvalues of the frequency equation governing the flexural vibrations. This formula is based on the Bernoulli-Euler beam theory, which does not include the effects of the shear deformation and rotatory inertia. When these two terms are included in the formula, the discrepancies between vibration and defection methods are reduced (Tang and Hsu 1972).

The objective of this current study is to use the free vibration method to measure the dynamic moduli of full-size LCP. Static bending tests of the LCP specimens were also conducted for comparison. The static Young's moduli of each LCP specimen were calculated from the strains yielded by the bending deflection when a small load was applied at the free end of LCP. Shear effects were not included in the calculation due to the fact that a large ratio of length/diameter of the full-size LCP was imposed on the design.

MATERIALS AND METHODS

The procedures used to make small-size LCP (Piao et al. 2004a) were used to fabricate full-size LCP in this study and they are briefly described herewith. Structural grade dimension SYP (*Pinus* spp.) lumber with sizes of 5.08 cm (2 in.) thick x 15.36 cm (6 in.) wide x 6.1 m (20 ft) long and 5.08 cm (2 in.) thick x 20.32 cm (8 in.) wide x 6.1 m (20 ft) long was obtained from a local construction materials store. The randomly selected lumber had small knots (diameter < 1 cm). The lumber was reduced to the target thickness with a planer. The size-reduced members were then cut into strips of specific target dimension by using a table saw with the saw blade adjusted to the designated angles for cutting the target trapezoid strips needed for the LCP fabrication.

Each trapezoid-shape strip was inspected for quality and those with knots were removed. The weight and the width of the large side of each strip were measured, and then all strips were stacked in a room under ambient condition for two weeks before pole fabrication. The adhesive used was the resorcinol-phenol formaldehyde (RPF) resin and commercially obtained. Viscosity and specific gravity of RPF were 800 cps and 1.177, respectively.

Strips assigned to a pole fabrication were randomly selected from the stacked members. Fifteen percent of setting agents was added to the adhesive and mixed with a blender. The adhesive was uniformly hand-spread onto the two trapezoid sides of each strip in an amount of 310 g/m^2. Consequently, some of the excessive glue was squeezed out during the LCP fabrication when pressure was applied to each strip for binding.

The consolidation of glued strips was performed in specially designed 6.5-m long steel molds and each contained one top half and one bottom half. Glue-spread strips were formed into a pole shape with a 10-cm inside diameter, tightened temporarily with plastic tapes and then put into the bottom half of the steel mold. Thin teflon sheets were placed in between strip-formed poles and each half of the steel mold to avoid the binding of pole surface to the inner face of the steel mold due to the squeezed out glue from the strips during fabrication. An impact wrench with 48.4 kg-m of torque was used to tighten the screws on both halves of the steel mold. Formed poles were pressed in the steel molds for 36 hours at the room temperature. They were then weighed, light sanded and stored in the same environment for 4 weeks before mechanical testing.

As above-described, basically there were two variables, strip-thickness and strip- number, incorporated in this LCP study. Therefore, the shell thickness of LCP was governed by the strip thickness which varies from 1.9 cm (0.75 in), 2.9 cm (1.125 in), to 3.8 cm (1.5 in). This variable was used to evaluate the effects of shell thickness on the stiffness/strength and integration of LCP. The LCP specimens fabricated for this study were composed of either 9 or 12 trapezoid-shape strips and this variable was also used to evaluate the shape effects on the mechanical properties of LCP. Two full-size LCP specimens were fabricated for each combination of these two variables, except for the groups with 12 trapezoid-shape, 2.9-cm thick strips, in which three specimens were made. All members had the same target length of 6.1m (20 ft.), except for three specimens, which had target length of 5.5 m (18 ft.). These three 5.5-m long LCP included one member each which had 9 trapezoid-shape strips [i.e. 9-side LCP] with a thickness of 1.9-cm and 2.9-cm, whereas the 3rd member had 12 trapezoid-shape strips [i.e. 12-side LCP] with a thickness of 1.9-cm.

LCP specimens were nondestructively dynamically tested by using a RIVEHLE machine in a cantilever bending mode (Figure 1). The length of the clamped end in each LCP specimen was 61 cm. Two M-M strain gages were bonded on the top and bottom surfaces 5-cm (2 in.) away from the clamp section (Figure 2). The strain gages were connected to a Vishay Model 6010 StrainSmart System, including a Strain Gage Input Card and a Model 6100 Scanner, which was interfaced with a micro-computer. A high tensile strength nylon rope was used to apply a load of 180 N (40.5 lbs) vertically at the free end of each LCP specimen. The nylon rope was then cut by using a scissors to let the LCP member vibrate freely in a bending mode (Figure 3). Then, the vibration frequencies of each specimen were recorded by a StrainSmart software. It follows that the Dynamic Young's modulus of each LCP along the length direction was calculated by using Equation 1. After the dynamic test, a 220 N (49.5 lbs) load was applied to the free end of each LCP specimen by using the RIVEHLE machine for obtaining the values of strains due to the bending deflections. The experimental Young's modulus for each LCP specimen was calculated based on the collected data of strains.

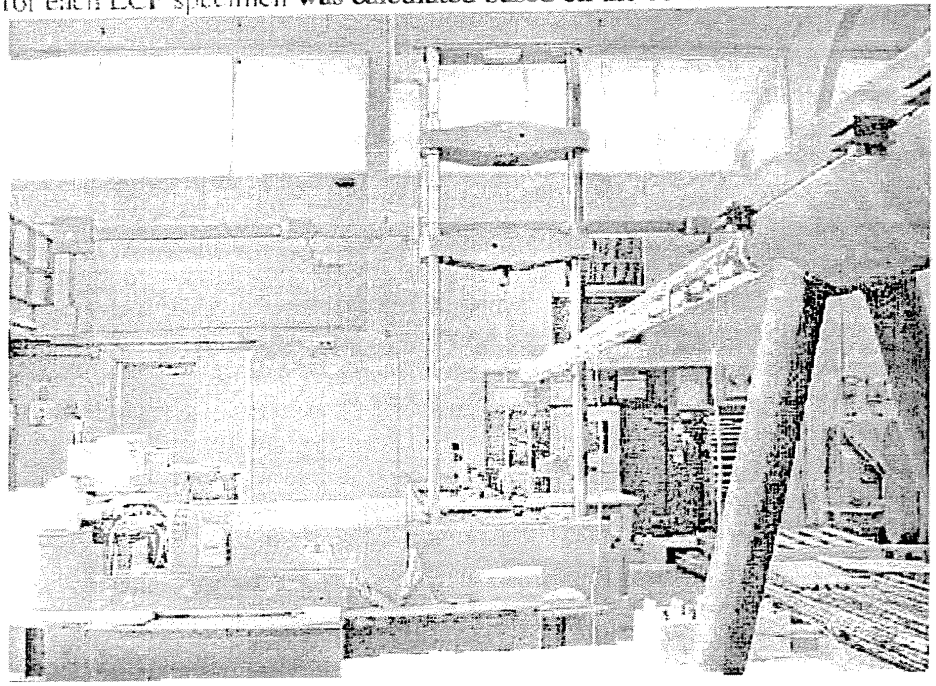

Figure 1. LCP specimens were non-destructively tested by using a RIVEHLE machine.

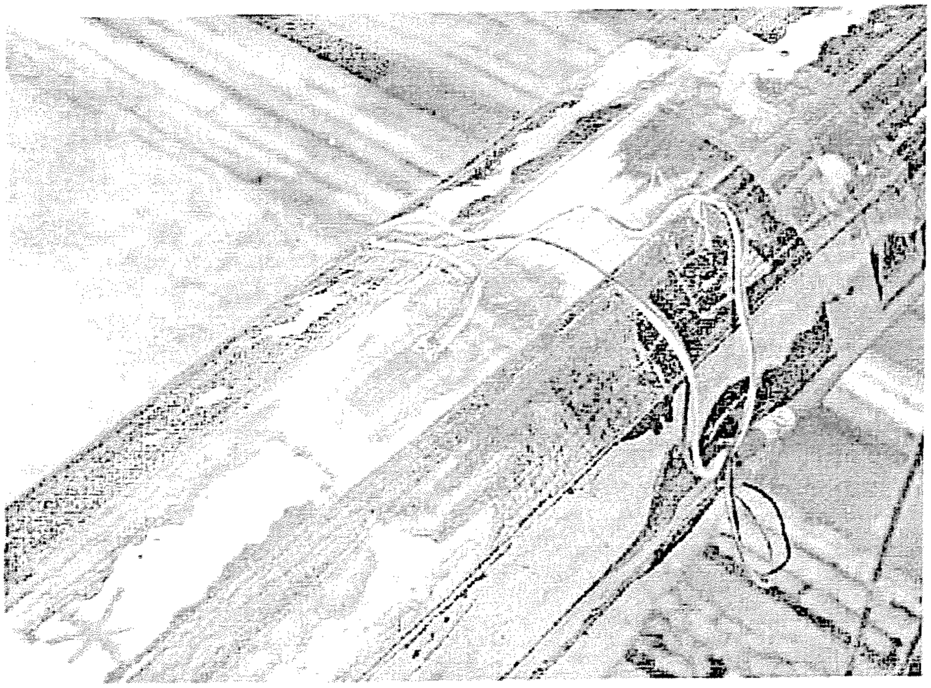

Figure 2. Strain gages were used to measure the strain and vibration frequencies of LCP.

Figure 3. Rope cutting for generating a free vibration of LCP in a dynamic bending test.

RESULTS AND DISCUSSION

For the LCP specimens tested in this study, the bending vibration frequencies ranged from 3.05 to 3.66 Hz. The differences in frequencies may be attributed to the differences in length and shapes of the cross section of the LCP. Figure 4 shows a typical vibration curve which was recorded from the dynamic bending test.

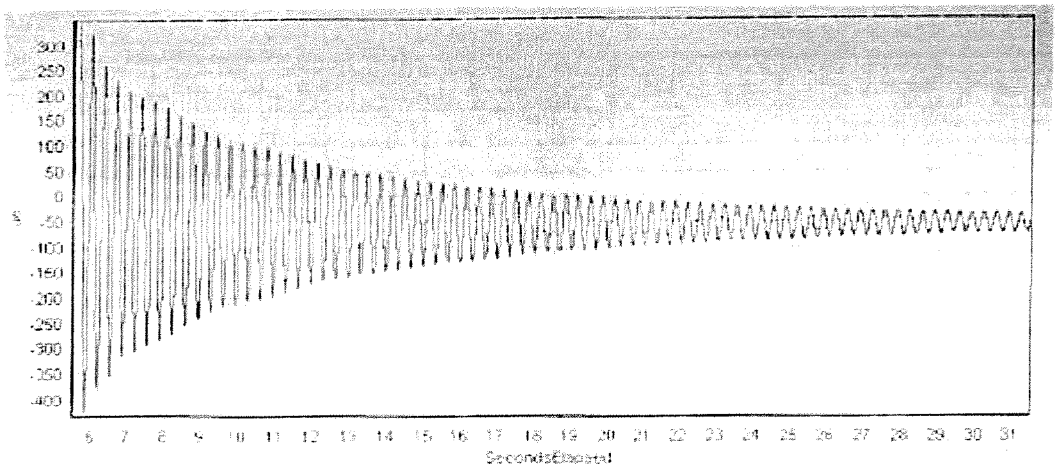

Figure 4. A typical vibration curve of a LCP tested under dynamic bending.

The results of static moduli and dynamic moduli of the 9-side and 12-side LCP specimens tested at 11 % moisture content are shown in Figures 5 and 6. As shown in these two figures, increase of Young's moduli was observed in both 9-side and 12-side LCP groups when its shell thickness was increased from 1.9-cm to 2.9-cm but such an effect was leveled off when the shell thickness was further increased from 2.9-cm to 3.8-cm. However, a significant effect of the strip-number on the Young's Moduli in both groups with 2.9-cm and 3.8-cm thick strips was not observed.

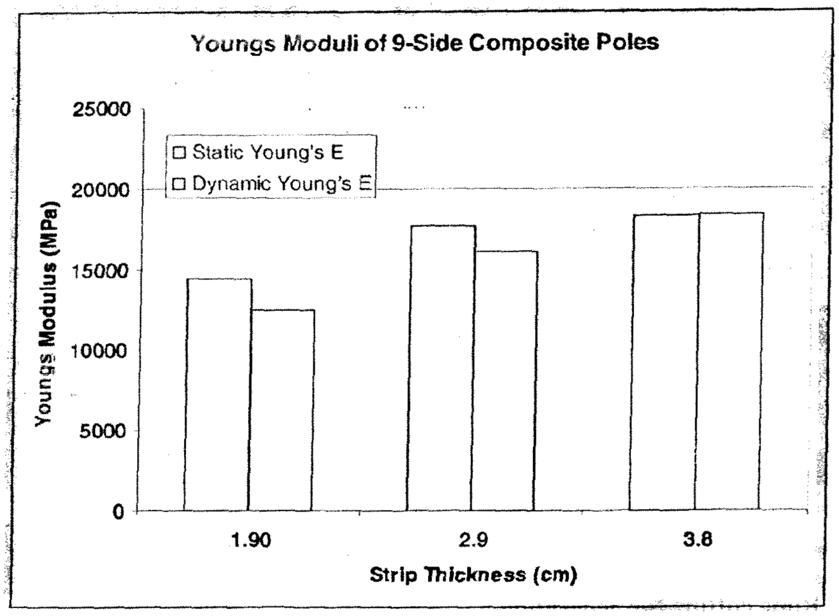

Figure 5. Comparisons between dynamic Young's moduli predicted by the free transverse vibration method and the static Young's moduli calculated from the measurement of strains in LCP members containing 9 trapezoid-shape strips.

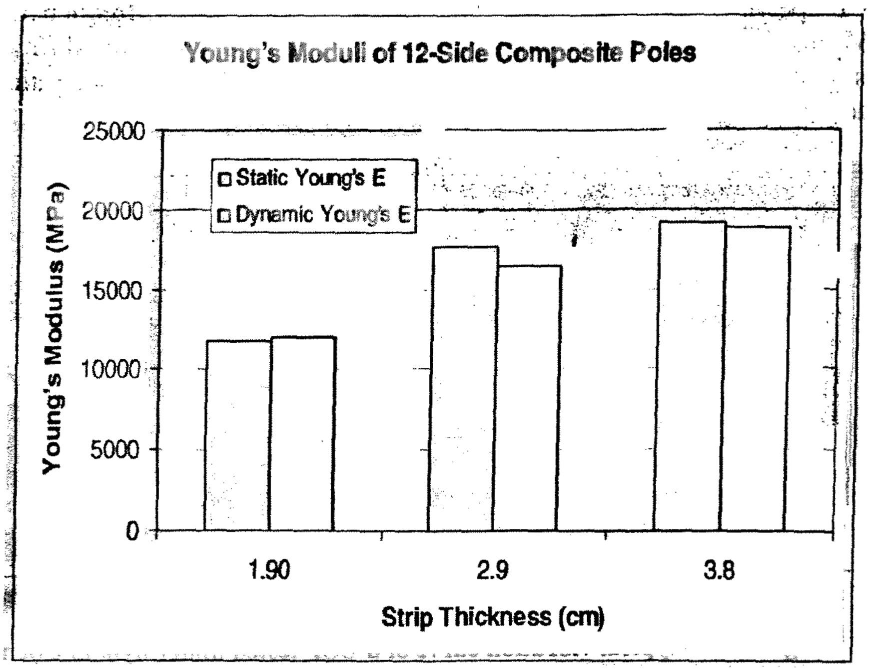

Figure 6. Comparisons between dynamic Young's moduli predicted by the free transverse vibration method and the static Young's moduli calculated from the measurement of strains of LCP members containing 12 trapezoid-shape strips.

In general, the dynamic moduli of the tested LCP specimens agreed well with those calculated from the strain measurement in the static test. Table 1 illustrates the differences between these two Young's moduli collected from different testing methods. The percentage differences, based on the value obtained from the static test, are respectively, +13.7%, +9.3%, and -0.6% for the 9-side LCP groups with the shell thickness of 1.9-cm, 2.9-cm and 3.8-cm while values of -2.1%, +6.8%, and +1.7% were observed, respectively, in the 12-side members. However, statistical analysis on the collected data was not performed due to the fact that only a limited number of samples was tested in this study.

Table 1. Percentage differences between the Young's Moduli predicted by free transverse method and those calculated based on the measurement of strains in a static test of LCP

Shell thickness (cm)	1.9	2.9	3.8
9-side	13.7	9.3	-0.6
12-side	-2.1	6.8	1.7

It should be noted here that in most previous studies on the elastic properties of small-size clear wood specimens, dynamic moduli were found to be slightly higher than those determined from the static tests (e.g. Tang and Hsu 1972). However, in the test of big members like the full-size poles in this study, many parameters which are known to have some influences on the determination of their elastic properties can not be accurately measured. One of these parameters was the accurate measurement of the vertical distance between strain gages, mounted on the surfaces of LCP shell, and the central line of the LCP specimen, especially in the 9-side members. Magnitude and distribution of moisture content in the shell wall of the tested LCP members is another parameter, which may have some effects on the determination of the Young's modulus, and such an effect may be very small in the test of small clear wood specimens (e.g. Kitazawa 1952, Matsumoto 1958, Tang and Hsu 1972). The average value of moisture content of the LCP tested in this study was about 11 percent. Furthermore, the neglect of shear effects in the Equation 1 may have some influences on the difference that observed between these two Young's Moduli (Tang and Hsu 1972). In addition, the strains generated by the bending deflection of LCP due to its body weight, before the load was applied to its free end, must be accurately measured. After taking these parameters into account, the accuracy of the dynamic method for the determination of Young's Modulus of large-size wood composite members would be improved. Thus, the free transverse vibration method can be an effective and efficient alternative to the static method in the test of elastic properties of large-size wood composite members.

CONCLUSIONS AND REMARKS

The results obtained from this study showed that the nondestructive test using the free transverse vibration is an effective and efficient alternative to the static testing method that is commonly used in the mechanical tests for the evaluation of elastic properties of large-size wood poles and beams. The elastic-property-effecting parameters, as above-mentioned, will be considered and weighted in the future tests of taper members of LCP. Furthermore, for the collection of more reliable data on the dynamic performance of field-installed solid wood or composite wood utility poles under weathering conditions, such as the windstorm and/or ice storms, tests of forced transverse vibration and torsional vibration, individually or combined, are highly recommended.

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