Bending strength of Chilean radiata pine poles

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Abstract

Because radiata pine has thrived in south-central Chile since it was introduced there more than a century ago, pine plantation productivity there has grown tremendously. Plantation owners are seeking new markets for this material. One potential market is utility poles. The American National Standards Institute 05.1 standard (ANSI 05.1) provides a means for radiata pine to be recognized as a viable pole species. Before radiata pine can be accepted into ANSI 05.1, test data must be provided to support the ANSI-designated fiber stress. This study presents an evaluation of radiata pine poles grown in southern Chile following the guidelines established by the ANSI O5.1 standard for approval of foreign species. The test sample includes 45 poles that were 12 m (40 ft.) long. Tests were conducted following procedures given in the ASTM D 1036 standard for evaluating bending strength of poles. Specific gravity values were above the average published for radiata pine despite a relatively fast growth rate. The mean strength determined as the maximum groundline stress was 52 MPa (7,554 psi), qualifying radiata pine for consideration as a utility pole that has strength equal to that of red pine, jack pine, and lodgepole pine.

Radiata pine or insignis pine (*pinus radiata* D.Don), native to the coast of California, was introduced to Chile more than a century ago and adapted extremely well to the country's climatic conditions. So much so that its average growth rate is far higher than the average annual growth rate for conifers in Canada, the former Soviet Union, Sweden, or even its native country, the United States.

Radiata pine grows in a wide variety of environments. It can survive in poor soil with relatively little rainfall. In Chile, it has mostly been planted on land considered unsuitable for agriculture, where few native plants can exist. Despite these poor conditions, it has demonstrated good growth capabilities throughout most of the southern half of the country.

The optimum growth areas for Chilean radiata pine are in the coastal mountains between Constitucion and Valdivia, in the country's south-central zone **(Fig. 1),** where temperatures seldom drop below −5°C and annual rainfall averages between 1 and 2 m. In that area, this species achieves an annual average growth rate exceeding 20 m^3 (883 $ft.^3$) per hectare.

Efforts to promote radiata pine plantations as a source of fiber began in Chile around the turn of the 20th century. Approximately 1.5 million hectares of radiata pine have been planted in Chile since then. To date, there is no evidence that the soil has been acidified or that contiguous terrain has been degraded. This conifer, which can grow to 40 m (13 1 ft.) high, gains an average of 1.5 to 2.5 cm (0.6 to 1.2 in.) in girth each year.

These trees were initially used for the production of pulpwood, so the genetic selection crop rotation policies centered around fast growth and harvesting at the point where the rate of increase in volume began to decline. Increases in pine plantation productivity have outpaced the growth in demand for pulpwood, causing the plantation owners to seek new markets for this material. One potential market for radiata pine is utility poles.

To improve market potential for Chilean radiata pine poles, the Chilean National Pole Association (CNPA) of pole producers is seeking recognition of radiata pine as a viable pole species by the American National Standards Institute (ANSI) 05.1 standard (ANSI 1992). Although only 6 percent of Chile's radiata pine production is currently harvested

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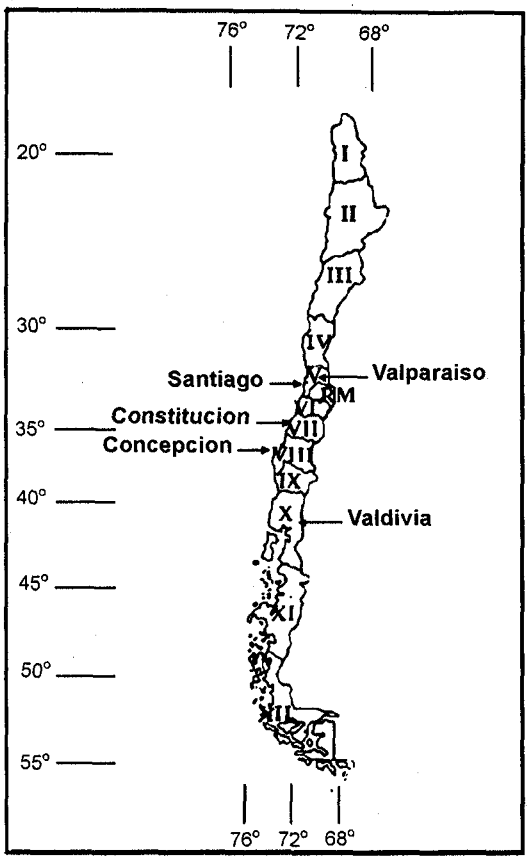

Figure 1.—Map of Chile.

for utility poles, there is a growing demand for electric and phone utility structures in many developing countries. These countries realize the value of referencing established standard specifications as a basis for ordering wood utility poles, and many of them request poles that meet the ANSI 05.1 standard. It is the oldest and most widely recognized wood utility pole standard available.

In addition to serving as a minimum quality specification for utility poles, ANSI 05.1 serves as the basis for deriving design strength of wood utility poles. A guideline for acceptance of foreign species in the ANSI 05.1 standard, recently adopted by the Accredited Standards Committee 05 (ASC O5) requires that full-scale pole tests be conducted following the American Society for Testing and Materials (ASTM) D 1036 standard or an equivalent procedure. Acceptance also requires that the applicant provide a test database sufficient to establish the 5 percent exclusion bending strength with 75 percent confidence and no more than a 10 percent standard error as described in ASTM D 2915 (ASTM 1998c).

Objectives and scope

The purpose of this paper is to present test data along with a derivation of pole nominal resistance in a form compatible with guidelines established by ASC 05 for acceptance of foreign species in the ANSI 05.1 standard. The data presented include test results from 45 radiata pine poles 12 m (40 ft. long).

Methods

The CNPA sponsored the testing of full-scale radiata pine poles as a means of establishing the database required by ASC 05 for derivation of a nominal strength. The tests were conducted at a test facility built and maintained by Forestal Copihue,[1] one of the larger producers of radiata pine and a pioneer in radiata pine pole production.

Poles

Poles tested for this study were obtained from pine plantations in regions VII (Maule) and VIII (Bio-Bio) of Chile (Fig. 1). The range from which the test poles were obtained represents 60 percent of the full range of pine plantations in Chile, covering latitude from 33 to 38 degrees south.

The test sample includes two individual pole groups. One set of poles harvested and tested in December 1999 included 30 poles, and the second group included 15 poles tested in January. The poles had moisture contents above 30 percent within 25.4 mm (1 in.) of the surface.

All poles exhibited similar growth characteristics. The poles within each group were of similar genetic background, which was improved to provide uniformity in form and wood quality. The poles were all close to the same age, generally 20 to 25 years. Trees were planted in these plantations at a density of 1,000 trees/hectare. They are thinned to 550 trees/hectare by age 8. After 20 years, the trees had an average diameter at breast height (DBH) of 330.2 mm (13 in.). They all exhibited rapid growth in the early stages of development. This growth slowed to the ANSI prescribed minimum rate (5 rings/25.4 mm [5 rings/in.]) with 40 to 60 percent latewood in the outer 50 mm (2 in.) of the cross section. Groundline circumferences for both pole groups averaged 858 mm (33.8 in.).

The poles were free of large knots and had little taper. Knots were generally less than or equal to 25 mm (1 in.) in diameter, appearing in whirls of six or fewer. The distance between knot whirls for the trees averaged about 1 m (3.3 ft.) but few knots were visible in the lower half of the poles. The pole taper, determined as the difference between the butt and tip diameters divided by the pole length, was generally small. December poles had a slightly greater taper than those tested in January (2.8% vs. 1.9%).

Test procedure

All poles were tested in the green condition following the cantilever bending test procedures described in the ASTM D 1036 standard (ASTM 1998b). The poles were transported to the test site within 2 weeks of harvesting and peeled just prior to testing. A concrete crib was used to confine the bottom portion of the pole, below the point identified as groundline (ANSI 05.1).

[1] Forestal Copihue is located outside the town of Constitucion, roughly 100 miles south of Santiago. In addition to pulp and poles, Copihue also produces lumber, millwork, and furniture parts from radiata pine.

Figure 2.—Cable loadplaced 0.6 m from the tip is bending the pole as a cantilever beam.

Loads were applied 0.6 m from the pole tip. A cable hand winch, attached in series with an analog dynamomete? and a log loader (large vehicle used as a reaction mass) was used to control the load. The log loader was located roughly 50 m (1 64 ft.) from the load point, keeping the angle of load close to perpendicular to the pole axis as the load point deflected longitudinally.

The load rate determined to give a maximum fiber strain rate (Z) of 0.001/min., as required by the standard, resulted in the rate of deflection (N) given by Equation [1]:

$$N = 2\pi Z L^2 / 3C_t \qquad [1]$$

where:

N = rate of deflection (in./min. [mm/min.])

Z = rate of fiber strain (in./in.*min. [mm/mm*min.]) = 0.0010 (the value specified in Test Methods D 198 [ASTM 1998a])

L = lever arm (in. [mm])

C_1 = circumference at point of load application (in. [mm])

[2] The dynamometer was calibrated by Dillon (a division of Weigh-Tronix Inc., Fairmont, Minnesota) within 1 month prior to tests. It had a capacity of 40,000 N (8,820 lb.) with accuracy of ±0.500 percent of capacity.

The loading devices used suggest a limited control on strain rate, but failure generally occurred in 5 to 15 minutes from the beginning of loading. The load was applied in increments of roughly 500 N (1 12.4 lb.) as indicated on the analog dynamometer. At each load increment, deflections were read manually. This process imposed control on the strain rate. Timed readings monitored for the January test series indicated a tendency to increase the rate of deflection as load increased.

Measurements included both the horizontal and longitudinal displacement of the load point relative to the groundline. These readings were taken in compliance with section 17.1 of the ASTM D 1036 standard. No measurements were made of groundline displacement, thus making estimates of bending deflection slightly conservative because the groundline was assumed to have zero displacement and all displacement was attributed to bending. Figure 2 shows the test setup and a pole being bent as a cantilever.

Specific gravity was evaluated on the basis of samples taken from 32 radiata pine poles of a genetic-silvicultural history that was the same or similar to that of the test poles. Specific gravity samples taken from the test poles did not adequately represent the test sample. Too few were taken, and some of them contained knots. A plug cutter was therefore used to give a uniform 12.5-mm- (OS-in.-) diameter cylindrical plug that was 2.5 cm to 3 cm (1 in. to 1.2 in.) long. These were taken close to the groundline from the outer 3 cm (1.2 in.) of the pole cross section. Specific gravity values were determined as the dry weight of the plug divided by its green volume.

Analysis methods

A nominal bending resistance, intended to be used in the assessment of design load capacity, was derived as a lower tolerance bound stress determined at groundline. This groundline stress, referred to as the MORGL, was determined for each pole. This is the magnitude of groundline stress at the time of maximum bending load. For new species being included in the ANSI 05.1 standard, the tolerance value on MORGL is derived to give a 75 percent confidence on the 5 percent exclusion value. The ANSI standard requires that this value be derived on the basis of a test sample that will support a maximum standard error of 10 percent as defined by the ASTM D 29 15 standard section 3.4.3.2 (ASTM 1998c).

Tolerance values were estimated using a standard confidence tolerance table and the following equation:

$$\text{MORGL5\%} = \overline{\text{MORGL}} - K \times \sigma \qquad [2]$$

where:

$\overline{\text{MORGL}}$ = the mean value of MORGL

σ = the standard deviation of MORGL

K = the number of standard normal deviations from the mean to the (75%, 5%) tolerance value; K = 1.991 when N = 15; K= 1.869 when N = 30; and K = 1.822 when N = 45.

The standard error (SE) was estimated using the following equation:

$$SE = S\sqrt{\frac{1}{n} + \frac{K^2}{2(n-1)}} \qquad [3]$$

where:

S = standard deviation of specimen values

n = sample size

K = confidence level factor

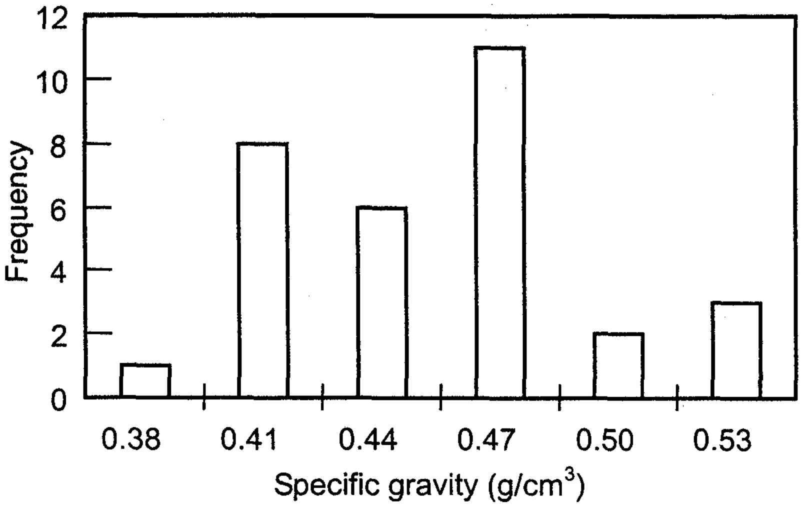

Figure 3. — Specific gravity of radiata pine poles.

In addition to the analysis of bending strength, this paper also offers some assessment of bending modulus of elasticity (MOE) for the test poles. The MOE values were derived assuming a linear taper and measured deflection under cantilever loading. The equation used for MOE in this case is:

$$\text{MOE} = P \times L^3 / (3 \times \delta \times I) \quad \textbf{[4]}$$

where:

P = applied load at tip end

L = length from groundline to tip support of wire

δ = tip deflection in the direction of the cantilever load

I = the effective moment of inertia for the tapered section $= \pi \times r_{gl}^3 \times r_t/4$; r_{gl} = radius of pole at groundline; r_t = radius of pole at point where load is applied.

Results

Material characteristics

Specific gravity values ranged from 0.38 to 0.53 **(Fig. 3).** Although measured values were not linked to individual test poles, the sample was considered to be representative of the test poles because it was obtained from trees of similar genetic-silvicultural history. **Figure 3** shows a slightly right-skewed distribution of specific gravity values with a median value of 0.44.

Pole taper averaged 2.5 percent. The poles tested in December had an average taper of 2.8 percent, whereas those tested in January averaged 1.9 percent. **Figure 4** shows that the poles with greater taper have a smaller tip circumference.

Pole failures

The majority of pole failures involved knots. All pole failures that occurred more than 1 m above the groundline involved knots or knot whirls. This may explain the trend for a decreasing stress at groundline as well as at the failure location with an increase in the distance between the failure location and the groundline **(Fig. 5).**

Analysis of results

The tolerance values for the poles tested are given in **Table 1.** These values are in agreement with those reported by Walford (1994). The lower exclusion value for bending strength of poles tested in this study was 39 MPa (5,592 psi). This supports the inclusion of radiata pine in the ANSI 05.1 group comprising red pine, jack pine, and lodgepole pine. The fiber stress values at the lower 5 percent exclusion for these species ranges from *36* to 50 MPa (5,200 to 7,200 psi) (Wolfe et at. 2001). The ANSI designated fiber stress for this group is 45 MPa *(6,600* psi).

Standard error of the estimate of the lower tolerance limit was 4.7 percent based on guidelines given in ASTM D 2915 (1998c). The MOE for the radiata pine poles estimated on the basis of the linear portion of the load displacement curve averaged 10.5 GPa (1.52×10^6 psi).

Conclusions

The 14 percent coefficient of variation on modulus of rupture determined for the poles tested in this study is low compared with that determined for the majority of pole test studies conducted on U.S. domestic species (Wolfe 2000). This may not be significant, however, because this sample represents a very narrow range of the genetic spectrum of poles being grown and harvested in Chile. Further study is required to verify this low variability.

Specific gravities for these Chilean radiata pine poles averaged 0.44. This value is slightly higher than published values for radiata pine (0.4) (Alden 1997).

Average stress at groundline for poles tested for this study was 52 MPa (7,554 psi), and the bending strength at the lower 5 percent exclusion with 75 percent confidence and with standard error

Table 1.—Tolerance values for radiata pine bending strength (ASTM 1998c)[a].

				Stress at GL				Stress at FL			
Sample	*n*	K	Taper	Mean	COV	TOL	SE	Mean	COV	TOL	SE
			(%)	(MPa) (psi)	(%)	(MPa) (psi)	(%)	(MPa) (psi)	(%)	(MPa) (psi)	(%)
December	30	1.869	2.8	50 (7,282)	16	35 (5,124)	6.9	52 (7,529)	19	35 (5,081)	7.9
January	15	1.99 1	1.9	56 (8,099)	8	47 (6,823)	4.3	52 (7,605)	13	39 (5,668)	7.8
Total	45	1.822	2.5	52 (7,554)	14	39 (5,592)	4.7	52 (7,554)	16	37 (5,373)	5.5

[a]*n* = number of poles tested; *K* = taken from tolerance table in ASTM D 29 15; GL = groundline; FL = failure location; COV = coefficient of variation; TOL = tolerance value (75%, 5%); SE = standard error.

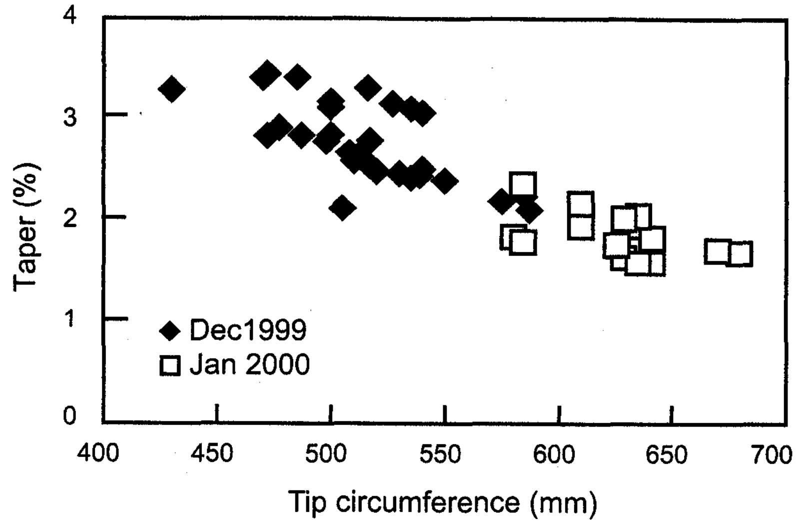

Figure 4. — Taper compared with tip circumference.

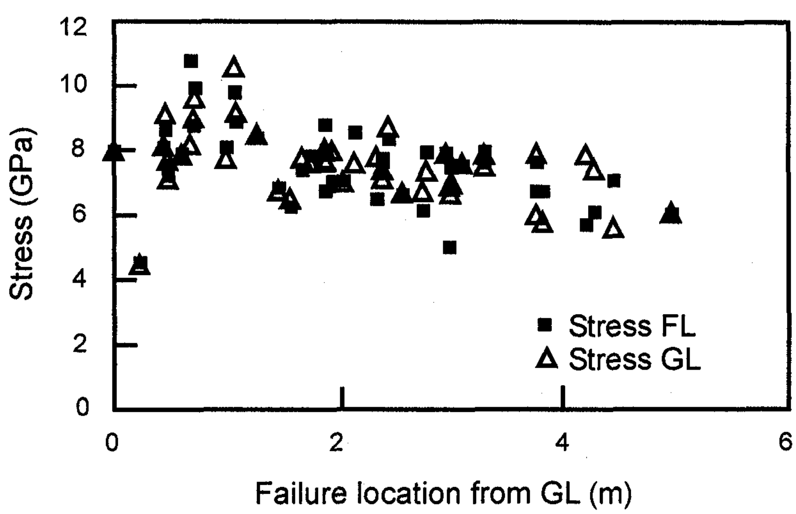

Figure 5.—Stress compared with failure location (FL) from groundline (GL).

of 4.7 percent was 39 MPa (5,592 psi). This is slightly higher than the 5th percentile strengths for red pine, jack pine, and lodgepole pine poles grown in the United States. Chilean radiata pine therefore qualifies to be included with this species group in the ANSI 05.1 standard specification for wood poles.

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