STRENGTH AND RELATED PROPERTIES OF WESTERN RED CEDAR POLES

by

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Sommaire en français

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SUMMARY

One hundred and eighty-two western red cedar poles collected from coastal and interior regions of British Columbia were conditioned and tested to destruction. The test results provide a reasonable estimate of strength and quality of current production. In addition to the major strength tests, several associated factors were investigated and are discussed.

Statistical analyses show no significant differences in strength between coast-grown poles and poles from the interior or between hand-peeled poles and those which were machine-shaved. Unseasoned poles were not significantly different from air-seasoned poles which were butt-soaked prior to testing and poles grown at an elevation of 4,000 feet were similar in strength to others from the 2,500-foot level. The so-called "target pattern" which is prevalent in some areas has no effect upon strength but may have an adverse effect upon the durability of untreated poles.

Maximum crushing stress as determined from tests of small, clear specimens cut from the poles was found to provide the best correlation with bending strength of the poles. The average modulus of rupture of the 182 poles tested was 5,258 p.s.i. with a standard deviation of 889 p.s.i. An appendix showing the results of other earlier tests is also included in this report.

SOMMAIRE

Cent quatre-vingt-deux poteaux de thuja géant, provenant des forêts des régions côtières et de l'intérieur de la Colombie-Britannique, ont été conditionnés, puis soumis à des épreuves de résistance à l'effort de rupture. Les épreuves ont permis d'estimer avec une précision raisonnable la solidité et la qualité des poteaux de production courante. En plus des principales épreuves de résistance, les essais ont aussi permis d'étudier plusieurs autres facteurs qui influent sur la qualité des poteaux.

L'analyse statistique des résultats a révélé qu'il n'existe pas de différences significatives entre les poteaux provenant des régions côtières et ceux qui proviennent de l'intérieur, pas plus qu'entre les poteaux écorcés à la main et les poteaux écorcés à la machine. Les poteaux verts avaient à peu près les mêmes caractéristiques que les poteaux séchés à l'air dont le pied avait préalablement été trempé; les poteaux provenant d'arbres croissant à 4,000 pieds d'altitude étaient aussi solides que ceux qui provenaient d'arbres croissant à 2,500 pieds d'altitude. La coloration dite «en forme de cible», qu'on trouve fréquemment chez les arbres de certaines régions, ne semble pas nuire à la solidité des poteaux, mais il se peut très bien qu'elle nuise à la durabilité des poteaux non traités.

Le coefficient de résistance à l'effort d'écrasement calculé d'après des épreuves ayant porté sur des éprouvettes sans défauts prélevés des poteaux, se rapproche sensiblement du coefficient de résistance à l'effort de flexion des poteaux proprement dits. Le module de rupture moyen des 182 poteaux mis à l'épreuve s'établit à 5,258 livres au pouce carré, l'écart type étant de 889 livres au pouce carré. Le présent rapport renferme en appendice les résultats d'épreuves du même genre auxquelles on avait procédé auparavant.

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INTRODUCTION

Because of its many desirable characteristics, western red cedar (*Thuja plicata* Donn) has long been recognized as a valuable pole species for the support of power and communication lines. Perhaps the most favourable characteristic of this species is its inherently decay-resistant heartwood. Other natural characteristics of good quality cedar poles are straightness, pronounced taper, light weight and moderate strength. A decidedly large butt-section contributes to a low centre of gravity; thus, the bulk of the wood substance is in proximity to the groundline where strength is desirable.

In Canada, the growth of western red cedar is confined to British Columbia (1), the range approximating that of western hemlock. It generally occurs in mixed stands ranging as far north as Alaska on the Pacific Coast, and eastward in the humid valleys of the interior. Its principal associates are Sitka spruce and yellow cedar in the north and Douglas fir and western hemlock in the south.

In recent years, a large proportion of the annual cut has been exported for use in the U.S.A. Since Canadian data were rather limited and based upon tests conducted prior to 1925, the need for further research to supplement the extensive pole-testing program sponsored by the American Society for Testing and Materials (A.S.T.M.) during the period from 1954 to 1960 was apparent. Therefore, sampling was extended to include western red cedar poles from those coastal and interior areas where large quantities of the species now originate. This report presents the test results and discusses a number of variables relating to strength which have not heretofore been assessed in detail. The results of the early tests, published in 1925, have also been incorporated as additional information in an appendix to this report.

PURPOSE OF TESTS

The primary objectives of the test series were as follows:

(1) To provide additional data concerning the strength and related properties of western red cedar poles upon which to base design stresses for efficient utilization.

(2) To compare the strength of unseasoned poles to poles in the air-seasoned, butt-soaked condition.

(3) To evaluate the relative effects upon strength of hand-peeling versus machine-shaving of poles.

(4) To determine if a significant strength difference exists between poles grown at 2,500 feet elevation and poles grown at 4,000 feet elevation.

(5) To determine if a significant difference in strength exists between interior-grown poles and coast-grown poles.

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(6) To determine if there is a significant correlation between the strength of poles and the strength of small, clear specimens cut from butt-sections of the poles.

TEST MATERIAL

Particulars of the pole samples are shown in Table 1.

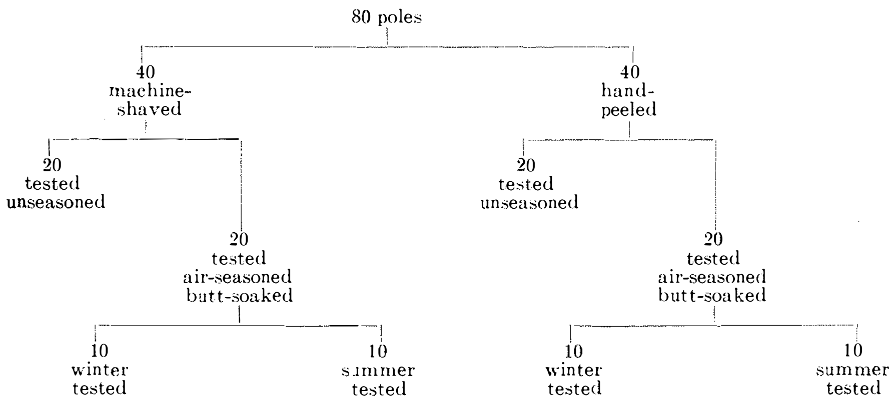
TABLE 1. ORIGIN, SIZE AND CONDITION OF SAMPLES OF 30-FOOT WESTERN RED CEDAR POLES

Shipment No.	Number of Poles	Place of Origin (British Columbia)	Condition
153	51	Lumby	Machine-shaved
154	17	Harrison	" "
154	17	Bella Coola	" "
154	4	Surrey	" "
154	4	Squamish	" "
154	4	Langley	" "
154	5	Sooke	" "
157	40	Lumby	Hand-peeled
157	40	Lumby	Machine-shaved

All poles were received at the Laboratory in the fresh-cut, unseasoned condition. Poles of shipments number 153 and 154 were randomly selected and were representative of interior-grown and coast-grown stock respectively. These poles were selected for tests in which the moisture content throughout their full-length was to be maintained at (or above) the fibre saturation point. Therefore, they were placed in storage in a tank of water until time of test.

The selection of the 80 interior-grown poles of shipment number 157 was based on uniformity in size and density rather than on a purely random basis. Upon receipt at the Laboratory, this shipment was subdivided and individual poles were tested in the condition indicated on the following chart:

Breakdown Chart of Shipment Number 157



Poles of the sub-groups within a given shaving treatment were selected on the basis of absolute specific gravity (weight oven-dry: volume oven-dry) as determined from discs cut from the extreme butt. The object of this procedure was to furnish sub-groups of poles of approximately equal density.

It may be noted that preservative-treated poles were excluded from the investigation. The effect of preservative treatment upon the strength of poles is well documented in other experimental work and its inclusion could possibly obscure the investigation of other variables.

TEST METHODS—POLES

Two types of test methods are in general use; the cantilever method and the machine method. In the former, the pole is usually held horizontally from butt to ground-line in a rigid concrete crib and the tip of the pole is pulled laterally to failure. In the machine method, the pole is tested as a simply supported beam with the load applied at the ground-line to failure. Fortunately, the recent pole testing program of the American Society for Testing and Materials (2) showed that for 25- and 30-foot poles, both methods yielded substantially the same test data.

In this test series, all poles were tested in accordance with the American Society for Testing and Materials standards, Specification D1036-58(3) as outlined under Machine Method, Figure 3b. Load was applied at the ground-line at a constant rate of cross-head speed to ultimate failure. Hydraulic load cells mounted on roller supports and equipped with rocker cradles were used to

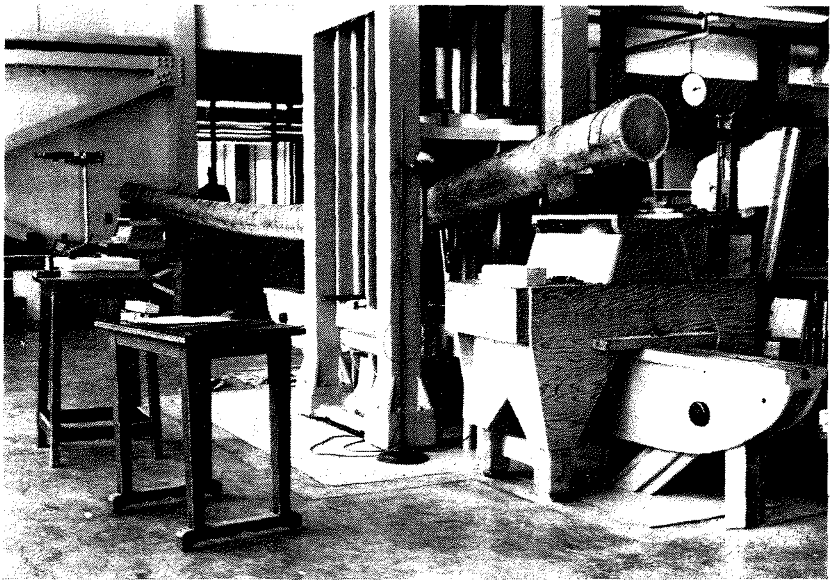


PLATE 1—Pole under test approaching maximum load.

measure reaction forces over a 27-foot span. Deflection readings at the ground-line were recorded to the nearest 0.01 inch for each 500 pound increment of butt reaction. Change of moment-arm due to displacement of the load cells on their rollers as the load was applied was also recorded. Plate 1 shows the test set-up with a 30-foot pole approaching failure. Plate 2 illustrates the method used to record displacement of the load cells with application of load.

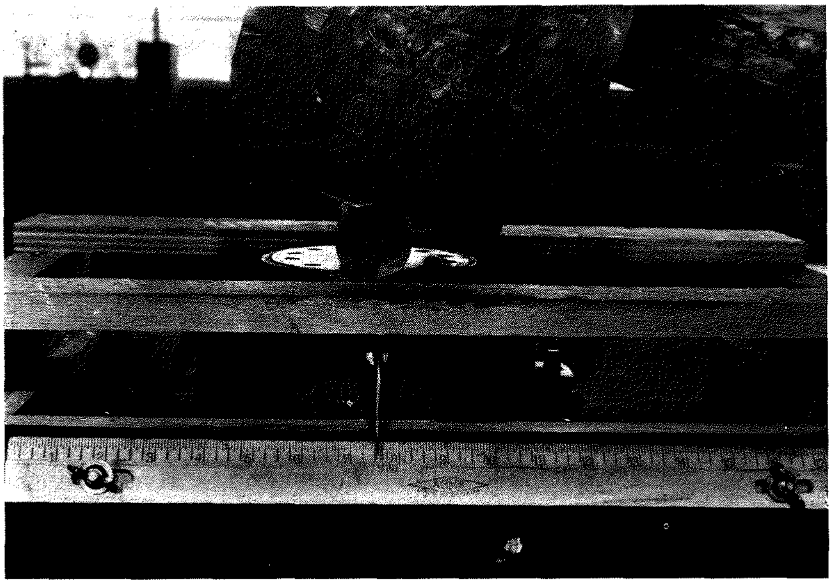


PLATE 2—Load cell and cradle at butt support.

Prior to test, all poles were positioned with any sweep in the vertical plane. The age, weight, class and length of the pole were then recorded. Circumferences at two-foot intervals from butt to tip and at butt-support and ground-line were also determined. The location and size of knots and other strength reducing characteristics were plotted graphically relative to a line drawn longitudinally along the upper pole-face.

Subsequent to each test, discs were cut at appropriate positions to determine moisture content, sapwood thickness, rate of growth, and specific gravity.

TEST METHODS—SMALL, CLEAR SPECIMENS

For comparative tests of clear material, 1-inch by 1-inch by 40-inch sticks were selected from the butt sections of poles subsequent to test. Tests in static bending and compression parallel to the grain on clear, straight-grained specimens from these sticks were conducted in accordance with A.S.T.M. Specification D143–52 (secondary method) (4).

COMPARISON OF POLE TEST METHODS

The results of tests conducted in 1925 at this Laboratory on 25-foot western red cedar poles (5) have been incorporated as additional information in Appendix 6. These early tests followed closely the machine test-method outlined in A.S.T.M. Specification D1036–58, Figure 3a, in which the top bearing point of the pole rested on a cradle mounted on an extension of the weighing platen of the testing machine. Using this method, the superimposed load applied at the ground-line was read directly from the testing machine. Reaction forces were then obtained by calculation rather than by direct measurement as in later tests.

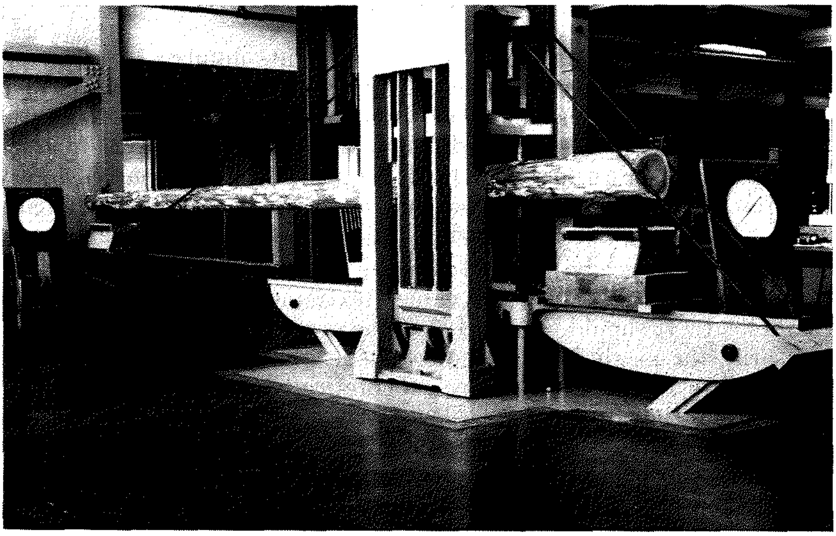


PLATE 3—Test set-up for comparison of early and recent test methods.

To confirm that the results derived by the two machine-methods of test were not materially different, a 25-foot pole was loaded as shown in Plate 3. The load-cell at the butt support was in direct contact with the platen of the testing machine and the cell at the tip support was in direct contact with the extension of the platen. Simultaneous readings of load were taken from the load-cells and the testing machine together with the longitudinal displacements of load-cells and centre of gravity of the pole. Several trial runs were made at loads below the proportional limit of the pole. Finally, the pole was tested to complete failure.

The results showed that the two dissimilar machine-methods yield essentially the same data, provided that couples acting about the load-cells are kept to a minimum and that longitudinal motion of the pole (change of moment-arm and span) with load is accurately recorded. The application of non-axial or eccentric loads to a cell results in load readings lower than actual values. Accordingly, bearing surfaces of cradles were well lubricated and load-cell supports were designed to permit a high degree of longitudinal freedom. The smallest graduation of the load-cell gauges was 50 pounds. With care, loads could be estimated to the nearest 10 pounds. For a 30-foot pole, a personal error of 10 pounds in reading the tip reaction would result in an error of approximately 225 foot-pounds in the calculation of bending moment at the ground-line, whereas a similar error at the butt reaction would influence the calculation by only 45 foot-pounds. For this reason, fibre stresses were based on load-cell readings at the butt support, which, of course, eliminated the need to record longitudinal displacement of the tip support and of the centre of gravity of the pole during loading.

DISCUSSION OF TEST RESULTS

The results of individual pole tests of shipments number 153, 154 and 157 are tabulated in Appendices 1, 2, 3 and 4. Appendix 5 presents a summary of the data derived from tests of small, clear specimens cut from the butt-sections of these poles. The test results obtained from early (1925) tests of 25-foot western red cedar poles are shown in Appendix 6. As mentioned previously, these latter data are presented solely as additional information and were not included in the assessment of strength and other variables discussed later in the report.

Analyses of strength within and between the shipments of poles were based on ground-line modulus of rupture values (extreme fibre stress at ground-line at ultimate load). It should be noted that the ground-line modulus of rupture is not necessarily the maximum stress developed, because of the decrease in diameter from butt to tip. It can be shown theoretically that the point of maximum stress for a uniformly tapered cantilever of round cross-section, subjected to bending stresses only, occurs at a section where the diameter is 1.5 times the diameter at the tip reaction. If the tapers are slight, such a diameter will occur below the ground-line, in which case the theoretical point of maximum stress and maximum moment coincide at the ground-line.

Examination of the tapers of the interior-grown poles (shipments number 153 and 157) and coast-grown poles (shipment number 154) showed that approximately 8 per cent and 6 per cent respectively, had tapers sufficiently great to raise the point of maximum stress above the ground-line. The lowering influence on the average modulus of rupture, calculated at the ground-line, due to the more pronounced taper of these few poles, however, could not have been great. The ratio of ground-line diameter to tip reaction diameter of the most severely tapered pole was only slightly greater than 1.6.

COMPARISON OF STRENGTH BETWEEN POLES GROWN AT ALTITUDES OF 2,500 AND 4,000 FEET

Twenty-four of the poles of shipment number 153 were grown at the 2,500-foot elevation; the remaining 27 poles at the 4,000-foot elevation. An analysis of variance (6) of moduli of rupture of these two groups showed that the variances of the samples were approximately equal and that statistically, there was no significant difference in strength between the samples grown at these two altitudes. Table 2 presents the results of the analysis.

TABLE 2. ANALYSIS OF VARIANCE OF MODULI OF RUPTURE OF POLES GROWN AT ALTITUDES OF 2,500 AND 4,000 FEET

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Total	50	17,951,720		
Samples	1	302,239	302,239	N.S.*
Residual	49	17,649,481	360,193	

*Indicates lack of significance at 0.05 probability level.

COMPARISON OF STRENGTH BETWEEN COAST-GROWN AND INTERIOR-GROWN POLES

Moduli of rupture values obtained from shipments number 153 and 154 were used in the comparison. They were representative of interior-grown and coast-grown material respectively. The results of an analysis of variance are shown in Table 3. The "F" value obtained, being fractional, indicated that there was no significant difference in strength between these two groups of poles.

TABLE 3. ANALYSIS OF VARIANCE OF MODULI OF RUPTURE OF INTERIOR-GROWN VERSUS COAST-GROWN POLES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Total	181	143,086,119		
Samples	1	58,178	58,178	N.S.*
Residual	180	143,027,941	794,600	

*Indicates lack of significance at the 0.05 probability level.

EFFECT OF SHAVING METHODS AND SEASONING PROCEDURE ON STRENGTH

The strength values derived from shipment number 157 comprising 40 machine-shaved and 40 hand-peeled poles were used to make the following comparisons relating to strength: machine-shaved versus hand-peeled poles, unseasoned versus air-seasoned, butt-soaked poles and winter-tested versus summer-tested poles. These poles were obtained from the same general area and subsequent segregation into sub-groups was based on absolute specific gravity determinations of discs cut from the extreme butt to provide comparable samples of approximately equal density. Table 4 shows the breakdown of the shipment into its sub-groups, the average modulus of rupture, specific gravity, and the variability in terms of the standard deviation and coefficient of variation of each sub-group.

TABLE 4. PARTICULARS OF SUB-GROUPS OF INTERIOR-GROWN WESTERN RED CEDAR POLES, SHIPMENT NUMBER 157

Condition at Test	Number of Poles	Average Specific Gravity[1]	Modulus of Rupture		
			Average p.s.i.	Standard Deviation p.s.i.	Coeff. of Variation per cent
Machine-shaved					
Unseasoned	20	0.322	5,801	749	12.9
Air-seasoned, butt-soaked, winter-tested	10	0.329	5,560	1,036	18.7
Air-seasoned, butt-soaked, summer-tested	10	0.330	5,317	724	13.6
Hand-peeled					
Unseasoned	20	0.328	6,087	757	12.4
Air-seasoned, butt-soaked, winter-tested	10	0.323	5,706	1,099	19.3
Air-seasoned, butt-soaked, summer-tested	10	0.327	5,267	635	12.1

[1]Volume at test: weight oven-dry.

To test the hypothesis that the average moduli of rupture did not differ significantly between sub-groups, an analysis of variance on the appropriate test data was carried out, the results of which are shown in Table 5.

The F-values obtained indicate that no significant differences exist between the average strengths of the machine-shaved and hand-peeled poles; between the unseasoned and the air-seasoned, butt-soaked poles and between the winter-tested and summer-tested sub-groups of the shipment. Although the means of

TABLE 5. ANALYSIS OF VARIANCE OF MODULI OF RUPTURE OF 80 WESTERN RED CEDAR POLES, SHIPMENT NUMBER 157

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Machine-shaved vs. Hand-peeled	1	561,125	561,125	*
Between Treatments	4	6,178,108	1,544,527	*
Error	74	50,445,374	681,694	
Total	79	57,184,607		

*Indicates lack of significance at 0.05 probability level.

the sub-groups vary considerably between themselves, these differences were not detected by the analysis of variance because of the high pole-to-pole strength variation within treatments.

It may be noted that the variability in strength of the winter-tested poles is somewhat greater than the variability of the other sub-groups. F-tests on the variances of the winter-tested versus the summer-tested strength data indicate, however, no significant difference between the samples.

COMPARISON OF FIBRE STRESS OF POLES AND SMALL, CLEAR SPECIMENS CUT THEREFROM

Since the small test specimens were cut from the butt-sections in proximity to the ground-line, specific gravity difference between butt-section and ground-line was considered negligible and strength values were compared directly without adjustment by a specific gravity-strength relationship. Furthermore, strength values were compared without adjustment in regard to shape of cross-section, depth, and strength reducing characteristics. Two correlations were tested; bending strength of poles with bending strength of small, clear specimens and bending strength of poles with maximum compressive strength parallel to the grain of small, clear specimens. Each pole value was paired with a corresponding average obtained from two small test specimens located at the outermost distance from the pith. This procedure was carried out for the test data derived from shipments number 153, 154 and 157, a total of 182 poles.

Employing the modulus of rupture (X_1) and the maximum compressive stress (X_2) values of small specimens as independent variables in a multiple regression analysis, these two variables accounted for 59.4 per cent of the variation in the dependent variable (Y), the modulus of rupture of poles. The analysis also showed that 51.9 per cent of this variation was related to the maximum compressive stress (X_2) of the small specimens and only 7.5 per cent to their modulus of rupture (X_1). A variance-ratio test (F = 1.34; d.f. 1:179) indicated

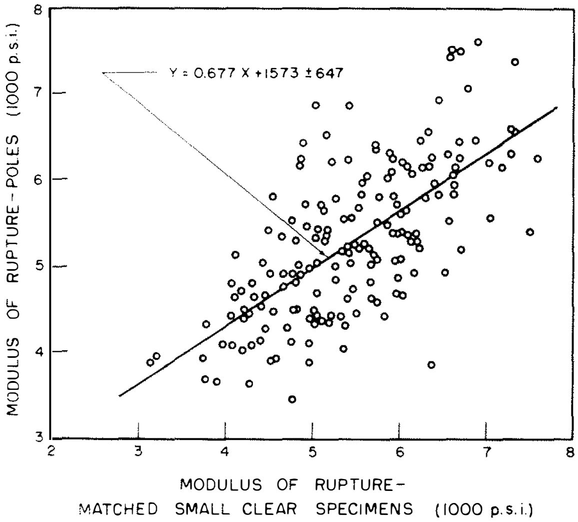


FIGURE 1—Relation of bending strength of poles to bending strength of small, clear specimens cut from their butt-sections.

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that the modulus of rupture of small specimens did not contribute significantly to the amount of variation removed by the multiple regression equation ($Y = 0.109X_1 + 1.128X_2 + 1528$). A regression line of best fit was thus calculated using the maximum compressive stress values alone as the independent variable. A correlation coefficient for the regression was found to be 0.768 which is almost as high as that determined by the multiple regression ($R = 0.771$). A similar regression of bending strength of poles on the bending strength of small specimens produced a correlation coefficient of 0.688 indicating a relationship of lower degree between moduli of rupture of poles and moduli of rupture of small test specimens. In both cases, however, the regressions were highly significant ($F = 259.6$ and 162.0; d.f. 1:180 respectively for the variables; maximum compressive stress and modulus of rupture of small specimens). The relationships are shown in Figures 1 and 2.

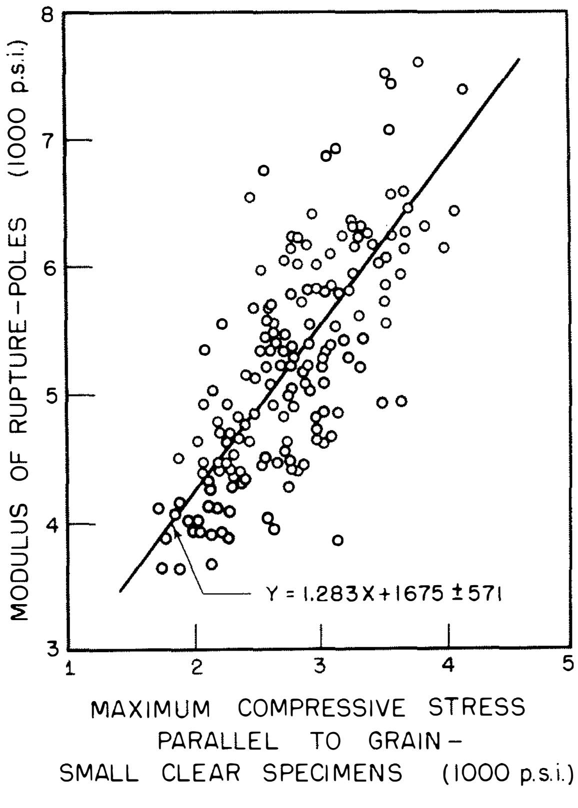

FIGURE 2—Relation of bending strength of poles to maximum compressive stress of matched small, clear specimens cut from their butt-sections.

POLE STRENGTH—SPECIFIC GRAVITY RELATIONSHIP

Specific gravity, being an index of wood substance, is also a valuable index of strength. Figure 3 shows the frequency distribution of specific gravity derived from 51 coast-grown and 131 interior-grown western red cedar poles. These two groups were combined in the distribution since the difference between their average specific gravities (0.322 for coast-grown and 0.313 for interior-grown poles) was found to be statistically insignificant.

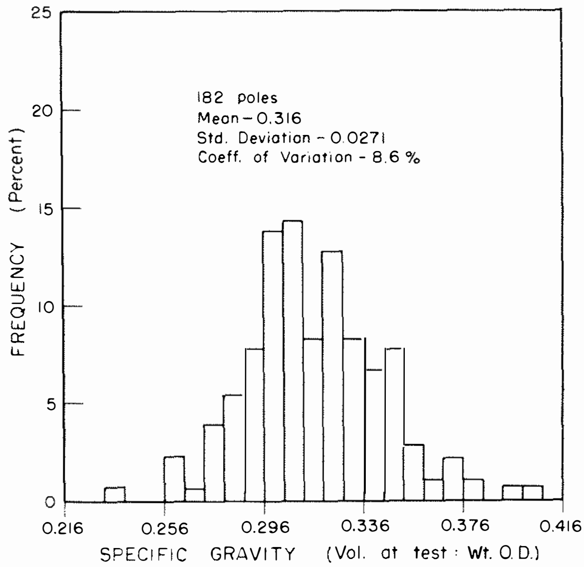

FIGURE 3—Frequency distribution of specific gravity in 182 western red cedar poles.

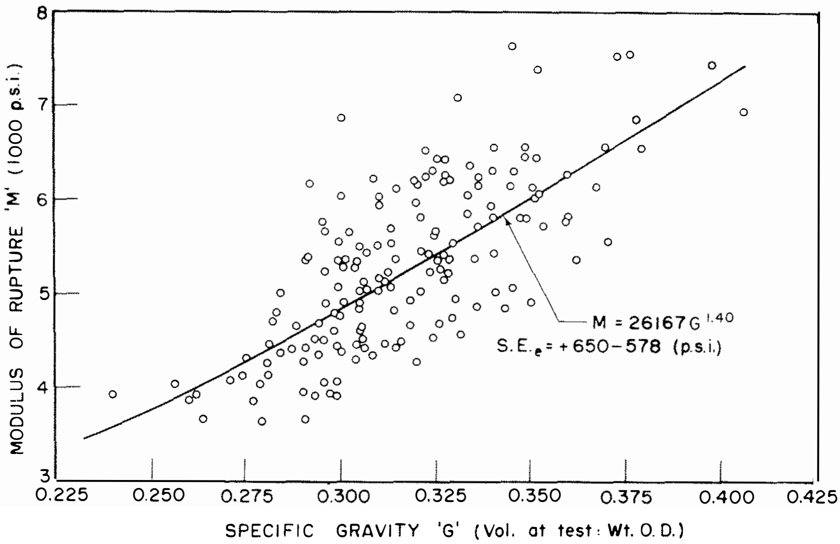

FIGURE 4—Relation of bending strength to specific gravity of untreated western red cedar poles.

The relationship of bending strength to specific gravity is presented graphically in Figure 4. This relationship was derived by assuming the trend of the plot to be best expressed mathematically by an equation of the form:

$$M = a\,G^{n}$$

where:

M = modulus of rupture (p.s.i.)
a = a constant
G = specific gravity (based on volume at test and the oven-dry weight)
n = a constant

The solution of the constants 'a' and 'n' by the method of least squares obtains the relationship: $M = 26167\,G^{1.40}$ with a standard error of the estimate of plus 650 p.s.i. or minus 578 p.s.i.

STRENGTH VARIATION

In the assignment of safe design stresses for poles, consideration must also be given to the inherent variability of the species. Table 6 presents the variation about the average modulus of rupture of the respective shipments in terms of the standard deviation and coefficient of variation. Values for all shipments combined have also been tabulated since, statistically, no significant differences were found between the shipment averages.

TABLE 6. SHIPMENT AVERAGE MODULUS OF RUPTURE, STANDARD DEVIATION AND COEFFICIENT OF VARIATION

Shipment No.	Number of Poles	Average M. of R. p.s.i.	Standard Deviation p.s.i.	Coefficient of Variation per cent
153	51	4,587	599	13.1
154	51	5,229	763	14.6
157	80	5,703	851	14.9
Combined	182	5,258	889	16.9

STIFFNESS PROPERTIES

The modulus of elasticity, which is a measure of stiffness, was calculated for each pole using the formula recommended for the machine-method of test by A.S.T.M.

A variance analysis of the values derived from the poles of shipment number 157 indicated no significant difference between the average moduli of elasticity of seasoned, butt-soaked poles and that of unseasoned poles. A significantly higher difference at the 0.05 probability level was noted for the hand-peeled group relative to the machine-shaved group. From a practical standpoint, however, the difference is probably of no great consequence.

A comparison of the moduli of elasticity of poles of shipment number 154 to those of small, clear specimens cut from their butt-sections showed generally lower values for small test specimens. These latter values were calculated by the usual deflection formula for a freely supported, simple beam with a concentrated load at centre-span. This formula ignores the effect of shearing force on deflection, thus the values as calculated are lower than the modulus of elasticity obtained for pure bending. On the other hand, values as calculated for poles are relatively close to the modulus of elasticity of pure bending because of the much greater span to depth ratio which, in turn, decreases the effect of shear deformation on deflection. Assuming that pole deflections were not affected by shear, the theoretical difference between the moduli of elasticity of poles and small specimens should be approximately 10 per cent. This compares favourably with the shipment average of 1,123,000 p.s.i. for poles and 1,026,000 p.s.i. for small specimens.

A regression analysis of the elastic moduli of poles on those of small specimens (as derived from shipment number 154) produced, for the best fitting straight line relationship, a slope of 0.338 and a correlation coefficient of 0.52. Although the relationship was statistically significant, a higher degree of correlation with a slope closer to 1.000 was expected.

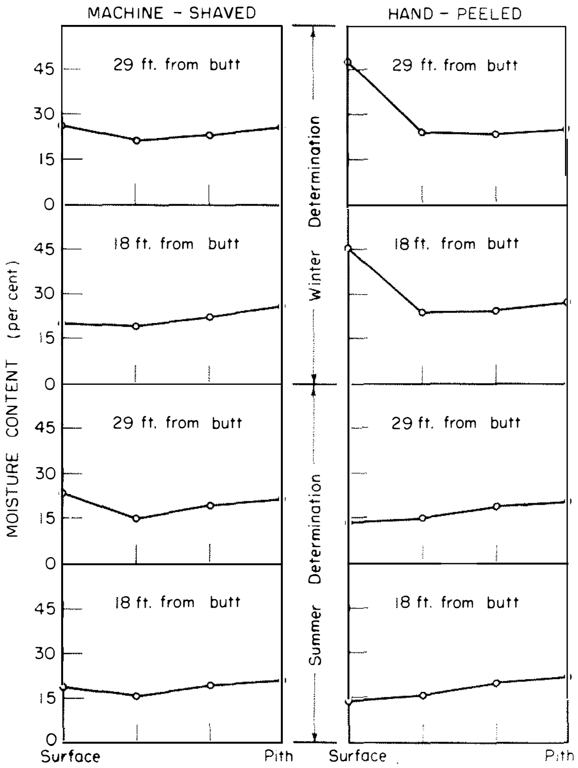

FIGURE 5—Moisture content gradients from pith to surface at indicated distance from extreme butt. Plotted points are averages of 10 determinations.

MOISTURE CONTENT

All test poles were received at the Laboratory in the fresh-cut, unseasoned condition. Poles which were selected for tests in the unseasoned condition throughout were placed in under-water storage until time of test. The average moisture content of these poles near the ground-line was 71.0 per cent; the minimum value being 36.6 per cent. These values are well above the accepted fibre saturation value for the species (approximately 25 per cent for western red cedar) above which moisture change has little effect upon strength.

The average moisture content at the ground-line of poles which had been exposed for one year to natural air-seasoning processes and subsequently butt-soaked was also well above the fibre saturation point (58.4 per cent). Figure 5 shows the moisture content gradients (from pith to surface) of these poles as determined at 18 feet and 29 feet from the butt. The plotted points are average values of 10 determinations. Examination of the gradients shows a marked difference between the average moisture content of the sapwood of the machine-shaved and hand-peeled groups. After a particularly wet season, the sapwood moisture content of winter-tested hand-peeled poles was raised to approximately 45 per cent whereas that of the machine-shaved poles was raised to only 25 per cent. After a moderately dry season, the sapwood moisture content of summer-tested hand-peeled poles was reduced to about 14 per cent as compared to 22 per cent for the machine-shaved group. It would appear from these results that the hygroscopicity of the exposed surface of the machine-shaved poles has been somewhat retarded by the machining process.

It may be noted that, for a given season, the moisture content of the heartwood compares closely regardless of the method of peeling. Furthermore, for a given method of peeling and season, there is little difference in the gradients at the two heights in the poles. It is doubtful that the average heartwood moisture content of either group of poles descended below 20 per cent from the time of cutting.

PLATE 4—Cross-sections of western red cedar poles showing normal brown coloured heartwood (left) and "target pattern" heartwood (right).

TARGET PATTERN

"Target pattern" refers to a colour variation found in the heartwood of some species and is particularly noticeable in some stands of western red cedar (see Plate 4). The cross-section of the heartwood is seen as alternate concentric layers of light and dark coloured wood. These layers or bands often vary appreciably in width and they are not necessarily contained within a given group of annual growth rings. Sometimes they appear only as arcs of circles, the light and dark colour of the wood varying in intensity. The bands occur also at any age within the tree.

Although coast-grown stands of cedar exhibit this colour variation to some extent, it appears to be most prevalent in interior-grown stands. The interior-grown poles of shipment number 153 (51 poles) showed a predominance of "target pattern" in the heartwood cross-sections.

The light-coloured zones, being very similar in appearance to normal sapwood, are sometimes referred to as included sapwood. A careful estimate of this so-called included sapwood was made on a percentage area basis of the total heartwood of the 51 poles of shipment number 153. Sapwood inclusion in the heartwood varied from zero to approximately 20 per cent.

Regression analyses comparing the moduli of rupture and specific gravity data with per cent sapwood inclusion indicate that "target pattern" produced no apparent effect on the strength or the specific gravity of these poles. The calculated correlation coefficients were close to zero which indicates no functional relationship.

Included sapwood, however, is known to have a lower resistance to decay than normal brown coloured heartwood; the decay resistance being similar to

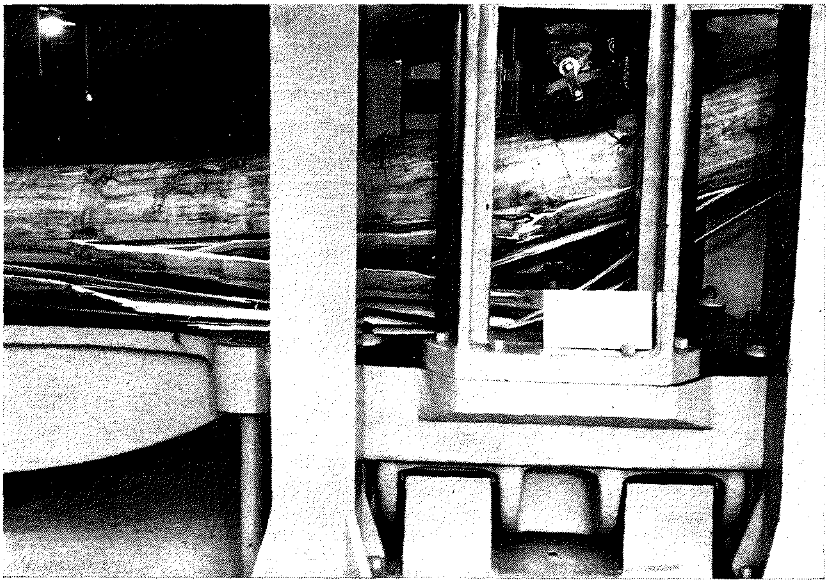

PLATE 5—Typical compression and tension failure.

that of normal cedar sapwood (7, 8). Pole users have reported decay in untreated western red cedar poles progressing longitudinally along the white rings within the heartwood.

FAILURE CHARACTERISTICS

In general, pole failures occurred between 0 and 3 feet from the ground-line (load-point) towards the pole tip. The initial indication of excessive stress was a wrinkling of the extreme fibres near the ground-line on the concave face of the pole. These compression wrinkles became more pronounced and more numerous towards the tip as loading progressed. They frequently developed through a knot or at an irregularity of the pole surface. Final failure was usually a sudden, abrupt fracture in tension on the convex face of the pole. In many of the tension failures long, cup-shaped splinters indicated a weak bond between the early-wood and latewood junction of the growth rings. Plate 5 illustrates the compression wrinkles and splinters of a typical fracture. Plate 6 shows the characteristic cup-shaped splinters of a tension failure.

Approximately 20 per cent of the poles failed in a short-fibred, brash fracture. Three poles broke completely in two or more pieces and eight poles failed in longitudinal shear (see Plates 7, 8 and 9). Poles which failed in shear had a higher than average modulus of rupture.

PLATE 6—Typical cup-shaped splintering tension failure.

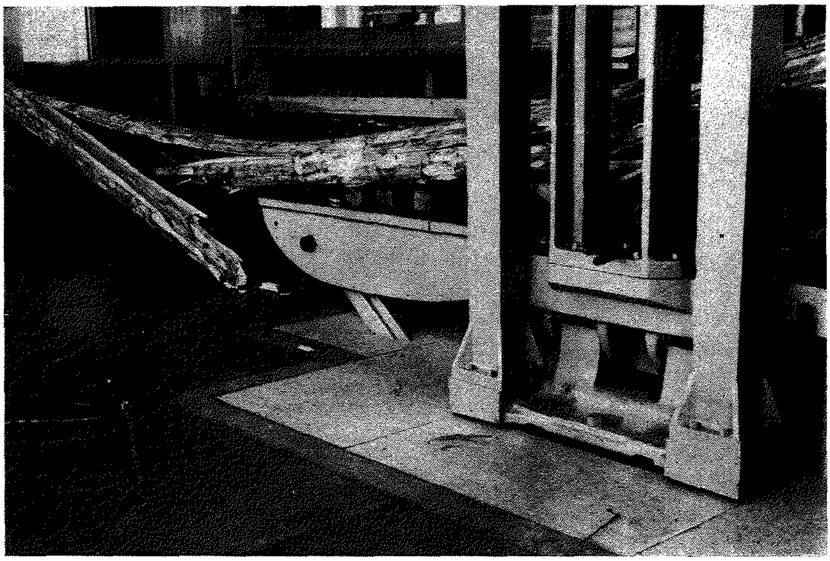

PLATE 7—Short-fibred, brash tension failure.

PLATE 8—Cross-grained tension failure.

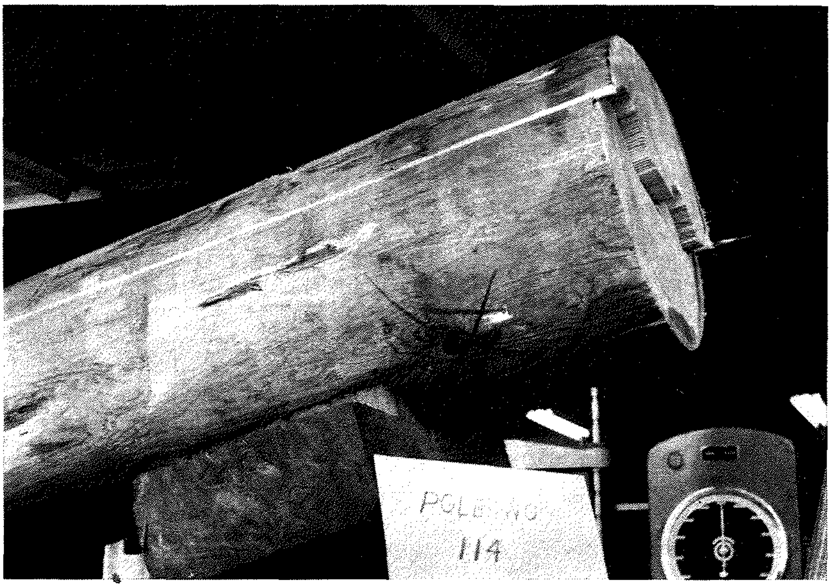

PLATE 9—Longitudinal shear failure.

PRINCIPAL FINDINGS

The principal findings of the test series on 30-foot western red cedar poles are as follows:

1. There is no significant difference in strength between:
    - (i) Poles grown at altitudes of 2,500 feet and poles grown at 4,000 feet.
    - (ii) Coast-grown poles and interior-grown poles.
    - (iii) Machine-shaved poles and hand-peeled poles.
    - (iv) Unseasoned poles and air-seasoned, butt-soaked poles.
2. There is a high degree of correlation between the strength of poles and the maximum compressive stress parallel to the grain of small, clear specimens cut from their butt-sections.
3. The strength of a pole is related to its specific gravity.
4. The average modulus of rupture of all poles tested was 5,258 p.s.i.
5. There is no significant difference between the moduli of elasticity of unseasoned poles and seasoned, butt-soaked poles.
6. The modulus of elasticity of poles was approximately 10 per cent higher than the bending modulus of elasticity of small, clear specimens.
7. "Target pattern" had no apparent effect on the strength of poles. Untreated poles containing "target pattern" heartwood, however, are known to have a lower resistance to decay than normal brown coloured heartwood.

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APPENDIX 1

STRENGTH AND RELATED PROPERTIES OF WESTERN RED CEDAR 30-FOOT POLES SHIPMENT 153[1]

Pole No.	Class	Circumference		Taper 1-inch in designated number of feet	Age	Summer-wood[2]	Average Sapwood Thickness[3]	Average Moisture Content[3]		Specific Gravity[4]	Weight per Cubic Foot	Stress at Propor-tional Limit	Modulus of Rupture	Modulus of Elasticity	Maximum Longi-tudinal Shear Developed	Pole No.
		6 feet from butt	Top					Entire Cross-section	Heart-wood							
		inches	*inches*		*years*	*per cent*	*inches*	*per cent*	*per cent*		*pounds*	*p.s.i.*	*p.s.i.*	*1000 p.s.i.*	*p.s.i.*	
1	4	35.2	23.3	6.59	50	10	0.68	105.6	40.8	0.260	36.5	2,270	3,896	956	122.1	1
2	4	35.6	22.7	5.79	48	9	0.83	93.7	41.2	0.238	39.8	2,466	3,924	920	118.3	2
3	5	32.3	21.9	7.91	44	10	0.67	93.3	42.2	0.275	40.0	2,521	4,318	1,105	123.2	3
4	5	31.5	24.1	11.36	62	17	0.81	83.8	34.8	0.313	40.3	3,549	5,227	1,265	150.4	4
5	4	33.0	24.1	8.65	61	20	0.68	98.6	37.3	0.302	37.7	3,725	5,684	1,228	162.0	5
6	4	33.7	26.7	12.10	63	15	0.47	85.1	50.4	0.296	35.5	3,373	5,679	1,064	173.3	6
7	4	35.0	22.1	6.04	47	12	0.63	98.8	52.0	0.281	38.5	1,989	4,139	879	124.8	7
8	5	32.6	22.8	7.92	55	11	0.66	93.7	40.5	0.296	39.6	2,686	5,241	940	148.1	8
9	4	34.0	23.5	7.48	54	14	0.57	78.7	49.6	0.304	36.7	1,738	4,307	893	126.0	9
10	4	33.1	26.3	11.76	59	17	0.62	53.7	35.3	0.307	32.1	2,835	5,449	1,144	164.6	10
11	4	33.3	22.6	7.54	51	10	0.69	58.7	48.2	0.294	38.7	2,505	4,374	956	127.9	11
12	5	31.1	21.5	8.33	61	19	0.59	83.5	45.1	0.323	39.3	2,826	5,238	1,199	143.1	12
13	4	34.4	22.7	7.32	52	17	0.75	103.6	45.3	0.272	41.1	2,319	4,118	935	128.5	13
14	5	32.2	22.8	7.92	45	12	0.60	107.1	48.6	0.297	37.7	1,994	3,948	804	110.4	14
15	5	30.8	21.8	9.23	56	10	0.78	111.1	48.0	0.274	40.5	2,373	4,153	800	114.4	15
16	5	30.7	21.0	8.55	49	11	0.79	111.2	49.1	0.290	41.5	2,362	4,297	977	118.9	16
17	5	32.7	25.8	11.07	65	23	0.61	91.4	38.7	0.319	37.5	3,442	5,990	1,186	174.2	17
18	3	35.9	25.1	7.73	53	14	0.63	90.8	54.0	0.293	39.7	2,570	3,902	980	126.8	18
19	4	35.0	27.6	9.93	53	14	0.56	96.3	43.9	0.306	33.4	2,397	4,530	901	135.9	19
20	5	31.9	20.3	6.88	55	18	0.64	94.3	46.8	0.305	39.4	2,358	4,646	939	128.4	20
21	4	34.7	26.0	9.17	57	13	0.67	103.6	48.1	0.256	37.0	2,049	4,028	872	123.8	21
22	4	33.5	25.7	9.23	54	11	0.52	72.3	50.9	0.296	33.5	2,302	4,909	881	139.2	22
23	5	30.9	22.5	9.90	53	16	0.38	79.3	42.5	0.304	37.1	2,012	4,485	908	126.2	23
24	5	31.5	20.8	8.04	50	14	0.81	120.2	48.5	0.271	42.4	1,623	4,076	837	118.4	24

25	4	33.3	23.2	8.17	50	12	0.70	122.2	67.3	0.281	44.2	2,552	4,483	937	132.0	25
26	5	32.0	21.9	7.73	45	13	0.61	103.8	44.8	0.263	35.9	2,074	3,653	826	101.4	26
27	4	35.1	23.8	6.99	46	17	0.68	90.7	40.6	0.314	39.5	2,183	4,404	838	133.6	27
28	5	32.1	23.6	9.71	56	14	0.68	105.7	47.6	0.294	40.4	1,790	4,700	971	137.2	28
29	6	29.6	21.3	9.35	58	15	0.46	87.7	40.4	0.309	38.2	3,308	5,533	1,206	144.1	29
30	4	33.6	27.6	13.89	57	13	0.58	87.8	35.4	0.299	34.0	2,502	5,092	1,099	157.1	30
31	5	30.6	21.8	9.35	48	19	0.66	91.6	40.2	0.284	37.6	1,787	4,385	904	118.5	31
32	4	33.5	22.7	7.43	46	11	0.59	93.1	56.2	0.308	37.2	2,285	4,350	976	126.1	32
33	5	30.9	21.1	8.00	45	12	0.78	96.4	46.4	0.262	37.3	1,739	3,924	823	104.9	33
34	5	32.0	24.8	11.63	49	14	0.57	74.9	44.4	0.295	36.0	2,084	4,467	955	130.4	34
35	4	33.0	23.6	9.15	49	13	0.53	66.3	51.0	0.277	33.5	2,126	3,883	808	117.7	35
36	5	31.9	25.3	12.60	56	14	0.59	88.1	50.0	0.291	36.4	2,636	5,397	1,124	159.6	36
37	4	35.3	28.8	10.71	58	12	0.40	53.2	42.4	0.311	34.9	2,703	5,101	1,096	157.3	37
38	3	36.3	28.0	10.34	56	15	0.42	66.4	40.9	0.304	34.4	2,878	4,849	1,060	163.0	38
39	5	31.4	23.5	10.14	59	15	0.70	100.0	47.9	0.328	42.4	2,747	5,216	988	145.4	39
40	4	33.2	23.0	7.79	51	12	0.81	102.3	50.0	0.299	40.2	1,888	4,087	907	116.6	40
41	5	32.8	22.4	7.19	53	11	0.83	110.9	50.4	0.279	38.7	1,623	3,654	767	103.3	41
42	4	34.3	26.1	10.49	63	11	0.71	101.2	48.5	0.290	37.4	1,909	3,965	898	126.3	42
43	5	32.6	22.4	8.33	49	13	0.73	98.4	41.5	0.298	41.3	1,739	4,651	995	133.5	43
44	4	33.9	25.7	11.36	59	13	0.81	105.4	55.9	0.299	43.6	2,657	4,776	1,100	155.4	44
45	5	31.0	24.3	12.05	65	10	0.65	92.9	45.1	0.306	39.6	2,857	5,476	1,075	148.8	45
46	4	33.6	22.1	6.58	61	12	0.60	103.4	49.7	0.296	39.5	1,324	4,504	901	126.8	46
47	5	30.8	21.1	8.50	53	16	0.62	105.5	47.0	0.287	39.2	1,756	4,421	878	118.8	47
48	5	32.3	25.3	11.07	50	11	0.55	96.2	46.3	0.298	36.2	2,259	4,800	1,101	138.8	48
49	5	31.8	24.8	10.68	58	18	0.63	111.6	46.4	0.282	37.5	2,164	4,715	1,086	129.4	49
50	3	35.8	29.9	13.27	65	14	0.68	94.5	40.5	0.328	39.7	3,118	5,235	1,147	174.5	50
51	3	36.2	23.8	6.51	51	16	0.41	84.8	50.0	0.291	36.4	2,156	3,670	957	115.1	51
Average		33.0	23.8	9.13	54	14	0.64	93.0	46.1	0.293	38.2	2,375	4,587	980	134.2	
Maximum		36.3	29.9	13.89	65	23	0.83	122.2	67.3	0.328	44.2	3,725	5,990	1,265	174.5	
Minimum		29.6	20.3	5.79	44	9	0.38	53.2	34.8	0.238	32.1	1,324	3,653	767	101.4	

[1] Poles of this shipment were interior-grown, machine-shaved and were tested unseasoned. [2] As determined from discs cut at extreme butt. [3] As determined from discs cut near ground-line. [4] Based on volume at test; weight oven-dry.

APPENDIX 2

STRENGTH AND RELATED PROPERTIES OF WESTERN RED CEDAR 30-FOOT POLES SHIPMENT 154[1]

Pole No.	Class	Circumference: 6 feet from butt	Circumference: Top	Taper 1-inch in designated number of feet	Age	Summerwood[2]	Average Sapwood Thickness[3]	Average Moisture Content[3]: Entire Cross-section	Average Moisture Content[3]: Heartwood	Specific Gravity[4]	Weight per Cubic Foot	Stress at Proportional Limit	Modulus of Rupture	Modulus of Elasticity	Maximum Longitudinal Shear Developed	Pole No.
		inches	*inches*		*years*	*per cent*	*inches*	*per cent*	*per cent*		*pounds*	*p.s.i.*	*p.s.i.*	*1000 p.s.i.*	*p.s.i.*	
101	4	34.9	28.8	13.27	94	18	0.64	43.9	32.5	0.313	29.4	2,391	5,720	1,188	181.6	101
102	6	30.7	25.6	16.57	79	20	0.70	30.4	30.4	0.321	26.9	3,235	5,033	1,084	143.2	102
103	5	30.9	23.8	10.49	76	18	0.33	63.4	37.6	0.324	34.2	3,440	5,678	1,372	156.6	103
104	6	31.1	27.7	23.08	92	20	0.40	39.8	29.8	0.321	29.2	2,820	5,468	1,100	157.5	104
105	4	33.9	23.2	6.98	51	12	0.65	91.5	41.5	0.305	36.9	2,195	4,905	1,076	140.2	105
106	5	31.2	23.5	9.32	67	18	0.63	36.4	34.4	0.301	27.4	2,251	4,914	1,068	128.5	106
107	5	34.2	29.3	20.13	93	18	0.32	60.6	31.0	0.310	31.6	2,800	5,954	1,104	192.8	107
108	4	33.2	23.0	7.25	89	17	0.37	51.6	29.7	0.336	33.8	2,561	5,716	1,087	160.9	108
109	6	31.0	25.2	13.45	65	16	0.60	47.4	34.3	0.298	28.7	2,877	4,620	1,213	127.3	109
110	5	32.7	26.0	10.83	60	21	0.59	65.6	30.2	0.333	34.2	3,470	6,049	1,287	170.0	110
111	5	32.6	25.0	11.49	81	21	0.18	38.9	33.8	0.333	29.9	2,998	5,864	1,175	176.6	111
112	4	32.9	25.5	9.15	67	13	0.24	57.1	41.0	0.301	27.0	2,347	5,383	1,114	150.7	112
113	4	35.5	28.9	13.64	87	22	0.46	60.7	31.8	0.336	35.2	3,479	6,253	1,433	211.3	113
114	6	30.2	23.7	11.19	123	20	0.35	38.7	34.8	0.345	31.1	4,077	6,312	1,040	163.3	114
115	5	32.8	25.6	10.49	143	24	0.53	32.8	30.8	0.367	32.2	3,200	6,154	1,118	173.6	115
116	4	34.8	28.2	10.27	105	17	0.74	76.0	31.7	0.350	37.2	2,624	6,158	1,013	181.9	116
117	5	32.8	26.8	12.24	68	12	1.01	53.0	35.1	0.293	29.6	2,584	4,507	838	132.4	117
201	4	35.9	25.2	7.54	69	23	0.48	26.9	24.5	0.327	28.3	3,265	5,436	1,137	178.4	201
202	3	31.7	27.3	18.50	77	32	0.63	27.4	25.7	0.325	25.6	2,975	6,471	1,348	187.7	202
203	6	29.8	25.1	14.29	82	22	0.60	24.1	23.5	0.324	24.9	3,574	6,312	1,177	165.1	203
204	4	35.7	28.8	10.10	84	30	0.34	28.8	26.3	0.359	29.0	3,170	6,284	1,325	202.3	204
205	5	31.5	25.4	13.50	89	23	0.34	27.5	28.1	0.320	29.2	3,499	6,180	1,225	177.2	205
206	4	34.3	27.9	11.90	96	32	0.42	24.4	27.0	0.348	28.1	4,028	6,573	1,373	200.3	206
207	5	33.5	26.3	10.45	74	34	0.50	37.4	28.3	0.303	26.0	2,937	5,229	1,100	156.9	207

208	5	33.5	27.4	12.71	78	34	0.40	54.7	33.5	0.326	31.0	2,502	4,690	1,037	141.8	208
209	5	31.9	24.4	9.35	71	23	0.81	49.5	29.4	0.312	29.7	2,470	4,464	1,041	130.0	209
210	5	32.7	26.1	11.24	76	26	0.46	53.6	32.4	0.336	31.5	2,665	4,866	1,049	137.7	210
211	6	30.7	23.0	9.90	60	31	0.78	73.5	30.9	0.300	30.2	2,082	4,390	1,004	117.7	211
212	5	30.7	20.3	7.25	50	27	0.66	43.3	28.7	0.341	34.2	2,370	5,038	1,058	127.5	212
213	4	35.2	27.6	9.74	83	32	0.48	41.9	30.1	0.359	31.9	2,913	5,815	1,330	182.3	213
214	6	29.7	21.4	8.88	41	27	0.72	55.1	32.8	0.327	31.2	2,302	5,131	1,079	130.0	214
215	4	36.2	29.1	10.34	81	29	0.53	50.4	30.6	0.281	24.5	2,695	4,272	851	137.4	215
216	4	34.2	28.5	11.63	69	29	0.68	53.1	33.8	0.311	29.9	2,788	5,167	1,221	152.5	216
217	4	35.6	28.7	10.99	79	26	0.58	45.0	29.3	0.291	25.6	2,286	4,423	995	140.5	217
301	4	35.6	22.9	5.35	43	14	0.76	40.1	34.7	0.279	23.5	2,859	4,031	897	139.6	301
302	4	34.0	25.2	9.15	203	21	0.00	47.2	47.7	0.345	30.3	4,000	5,091	1,107	152.1	302
303	5	28.9	20.5	7.09	39	17	0.78	67.6	71.3	0.350	27.5	2,826	4,928	1,052	111.6	303
304	5	31.2	20.3	6.41	37	15	0.91	57.4	61.7	0.314	30.0	3,342	4,821	1,264	119.7	304
305	5	30.7	22.5	9.15	33	15	0.61	67.6	43.4	0.328	30.9	3,877	5,216	1,376	135.6	305
306	5	33.4	24.6	8.49	186	23	0.00	35.4	32.7	0.318	28.0	4,040	4,662	903	137.9	306
307	7	27.9	19.2	7.31	49	20	0.68	69.4	48.4	0.324	31.4	3,581	4,505	1,047	100.4	307
308	6	28.7	20.5	8.49	49	13	0.78	44.3	37.0	0.306	27.9	2,152	4,458	898	105.1	308
309	4	34.8	24.9	7.31	48	14	0.97	41.8	34.9	0.283	27.2	3,077	4,811	1,206	140.6	309
310	4	34.0	26.4	9.06	203	24	0.32	48.5	44.0	0.328	30.8	4,282	6,226	1,206	179.8	310
311	5	31.6	23.8	8.98	168	18	0.29	43.1	36.5	0.344	30.0	2,984	3,870	847	104.1	311
312	5	29.7	21.4	8.20	40	12	0.93	70.9	61.7	0.274	28.9	2,617	4,116	1,020	104.0	312
401	3	37.8	25.5	6.16	67	11	0.65	88.0	55.7	0.298	37.6	2,547	3,909	989	125.9	401
402	4	33.3	21.3	6.37	72	11	0.64	83.1	57.4	0.332	41.0	2,555	4,050	1,049	114.5	402
403	5	32.2	25.6	13.86	71	14	0.47	48.2	32.5	0.347	32.0	3,343	5,823	1,181	171.7	403
404	5	32.5	25.4	10.47	71	11	0.69	70.3	43.0	0.340	37.6	3,675	5,857	1,285	168.0	404
405	4	34.0	24.7	7.85	80	13	0.69	76.9	47.5	0.343	36.8	3,440	4,874	1,279	142.7	405
Average		32.7	25.0	10.55	82	21	0.56	51.1	36.4	0.322	30.5	3,001	5,229	1,123	150.3	
Maximum		37.8	29.3	23.08	203	34	1.01	91.5	71.3	0.367	41.0	4,282	6,573	1,433	211.3	
Minimum		27.9	19.2	5.35	33	11	0.00	24.1	23.5	0.274	23.5	2,082	3,870	838	100.4	

[1] Poles of this shipment were coast-grown, machine-shaved and were tested unseasoned. [2] As determined from discs cut at extreme butt. [3] As determined from discs cut near ground-line. [4] Based on volume at test; weight oven-dry.

APPENDIX 3

STRENGTH AND RELATED PROPERTIES OF WESTERN RED CEDAR 30-FOOT POLES MACHINE-SHAVED SHIPMENT 157[1]

Pole No.	Class	Circumference: 6 feet from butt	Circumference: Top	Taper 1-inch in designated number of feet	Age	Summer-wood[2]	Average Sapwood Thickness[3]	Average Moisture Content[3]: Entire Cross-section	Average Moisture Content[3]: Heart-wood	Specific Gravity[4]	Weight per Cubic Foot	Stress at Propor-tional Limit	Modulus of Rupture	Modulus of Elasticity	Maximum Longi-tudinal Shear Developed	Pole No.
		inches	*inches*		*years*	*per cent*	*inches*	*per cent*	*per cent*		*pounds*	*p.s.i.*	*p.s.i.*	*1000 p.s.i.*	*p.s.i.*	
Unseasoned																
1	3	36.3	30.6	10.59	196	20	0.53	60.0	34.5	0.282	31.3	2,309	4,642	861	136.5	1
3	4	34.6	28.1	10.13	135	22	0.46	72.3	35.6	0.322	36.7	3,305	6,546	1,028	182.3	3
5	4	35.1	26.3	9.52	159	16	0.56	67.5	31.1	0.314	35.4	3,186	5,397	1,109	164.4	5
9	4	35.4	28.3	11.22	215	28	0.57	61.9	33.5	0.336	35.7	2,958	6,177	1,041	181.4	9
10	4	34.5	26.9	6.98	224	32	0.30	43.9	31.5	0.348	28.1	2,895	5,801	908	145.2	10
11	4	35.3	28.0	10.36	138	22	0.50	60.5	32.7	0.348	35.9	3,716	6,472	1,241	192.5	11
14	3	36.1	28.3	9.82	180	19	0.63	66.5	33.0	0.310	35.3	3,242	5,037	978	152.8	14
16	4	35.4	24.8	8.20	213	26	0.63	72.2	29.5	0.313	35.9	2,644	5,090	1,059	163.7	16
18	4	35.4	28.1	11.09	240	21	0.40	62.2	34.3	0.314	32.4	3,340	6,109	965	188.1	18
19	4	34.1	26.2	9.33	122	16	0.44	55.9	36.5	0.322	31.3	3,478	6,263	1,046	183.9	19
22	4	33.8	24.7	8.27	137	21	0.58	84.3	40.5	0.305	36.6	3,268	5,035	1,056	141.2	22
23	4	33.8	26.2	11.22	110	18	0.61	70.4	31.9	0.305	38.0	2,924	5,536	1,031	158.2	23
24	3	37.3	23.2	5.71	158	14	0.66	76.9	33.3	0.282	35.2	2,826	4,325	911	135.5	24
25	3	36.2	26.7	8.57	141	27	0.36	55.5	39.9	0.359	36.3	3,822	5,798	1,042	182.9	25
26	4	35.2	29.3	12.40	149	24	0.67	57.4	30.8	0.372	40.1	4,739	7,516	1,425	227.0	26
29	4	34.8	26.6	9.92	226	24	0.21	36.6	30.6	0.333	29.8	3,718	6,375	1,046	193.1	29
32	4	35.0	22.5	6.93	151	18	0.48	62.2	28.8	0.300	36.6	3,054	6,038	1,020	190.4	32
33	3	35.7	24.9	7.79	239	25	0.62	79.0	30.1	0.340	39.0	3,133	5,842	1,108	173.3	33
34	3	37.0	29.8	8.42	121	28	0.59	77.9	33.0	0.327	33.8	3,580	6,437	1,101	185.8	34
37	3	35.9	29.3	12.08	130	21	0.34	60.6	34.5	0.299	32.5	3,165	5,575	1,064	177.3	37
Average		35.3	26.9	9.43	169	22	0.51	64.2	33.3	0.322	34.8	3,265	5,801	1,052	172.8	
Maximum		37.3	30.6	12.40	240	32	0.67	84.3	40.5	0.372	40.1	4,739	7,516	1,425	227.0	
Minimum		33.8	22.5	5.71	110	14	0.21	36.6	28.8	0.282	28.1	2,309	4,325	861	135.5	

Air-Seasoned, Butt-Soaked, Winter-Tested																
4	4	33.8	28.7	16.50	135	23	0.52	46.0	28.8	0.351	31.2	4,241	6,460	1,269	195.8	4
6	4	35.1	26.4	9.24	181	29	0.62	74.2	25.5	0.299	28.3	3,204	6,883	1,024	209.9	6
7	4	34.2	28.8	12.60	145	21	0.56	46.7	25.6	0.377	28.8	4,333	6,876	1,259	199.4	7
12	4	34.8	25.8	9.06	208	25	0.18	26.8	27.0	0.320	28.0	3,260	4,281	859	133.0	12
13	4	34.1	27.4	13.09	200	33	0.38	29.8	29.1	0.352	29.7	4,135	6,082	1,201	185.7	13
15	4	35.2	26.6	8.12	234	25	0.46	63.4	30.5	0.306	26.7	2,767	5,132	919	139.4	15
17	3	36.2	23.0	5.82	155	15	0.41	33.6	28.1	0.296	27.4	2,858	4,064	994	124.6	17
21	4	35.0	27.2	7.54	160	17	0.33	48.4	28.8	0.340	25.9	2,997	5,437	981	140.4	21
27	4	34.3	24.4	6.59	210	20	0.35	24.9	20.8	0.332	27.2	2,923	4,577	913	117.2	27
28	3	37.4	27.0	6.28	227	25	0.50	43.2	30.7	0.321	26.3	2,771	5,808	1,236	167.1	28
Average		35.0	26.5	9.48	186	23	0.43	43.7	28.1	0.329	28.0	3,349	5,560	1,066	161.3	
Maximum		37.4	28.8	16.50	234	33	0.62	74.2	30.7	0.377	31.2	4,333	6,883	1,269	209.9	
Minimum		33.8	23.0	5.82	135	15	0.18	24.9	25.5	0.296	25.9	2,767	4,064	859	117.2	
Air-Seasoned, Butt-Soaked, Summer-Tested																
2	4	33.8	28.2	12.91	199	19	0.50	64.6	30.2	0.328	28.5	2,869	5,395	1,055	160.4	2
8	4	34.2	28.8	18.12	144	23	0.55	25.9	28.3	0.344	29.2	3,691	6,161	1,298	191.3	8
20	4	34.2	25.5	9.24	173	17	0.37	29.3	25.6	0.314	27.2	3,013	4,436	984	131.9	20
30	4	34.2	24.8	8.27	102	22	0.77	44.0	28.8	0.353	29.9	2,762	5,740	1,234	170.1	30
31	4	34.1	24.5	8.20	159	18	0.39	68.4	33.0	0.326	27.5	3,228	5,293	1,140	153.8	31
35	3	36.2	27.5	9.72	223	20	0.45	83.3	28.6	0.298	26.9	2,503	4,620	907	149.7	35
36	4	34.8	24.8	8.73	229	16	0.44	27.9	27.5	0.299	26.5	3,497	4,420	973	137.1	36
38	4	34.5	29.2	12.08	110	18	0.59	55.8	27.9	0.340	26.2	3,392	6,562	1,253	185.5	38
39	4	35.1	28.3	11.22	111	25	0.58	71.3	27.9	0.330	28.1	3,737	4,956	1,067	155.5	39
40	4	34.3	27.2	11.09	246	29	0.39	32.5	28.2	0.370	30.5	3,945	5,586	1,268	170.1	40
Average		34.5	26.9	10.96	170	21	0.50	50.3	28.6	0.330	28.1	3,264	5,317	1,118	160.5	
Maximum		36.2	29.2	18.12	246	29	0.77	83.3	33.0	0.370	30.5	3,945	6,562	1,298	191.3	
Minimum		33.8	24.5	8.20	102	16	0.37	25.9	25.6	0.298	26.2	2,503	4,420	907	131.9	

[1] Poles of this shipment were interior-grown. [2] As determined from discs cut at extreme butt. [3] As determined from discs cut near ground-line. [4] Based on volume at test; weight oven-dry.

APPENDIX 4

STRENGTH AND RELATED PROPERTIES OF WESTERN RED CEDAR 30-FOOT POLES HAND-PEELED SHIPMENT 157[1]

Pole No.	Class	Circumference		Taper 1-inch in designated number of feet	Age	Summerwood[2]	Average Sapwood Thickness[3]	Average Moisture Content[3]		Specific Gravity[4]	Weight per Cubic Foot	Stress at Proportional Limit	Modulus of Rupture	Modulus of Elasticity	Maximum Longitudinal Shear Developed	Pole No.
		6 feet from butt	Top					Entire Cross-section	Heartwood							
		inches	*inches*		*years*	*per cent*	*inches*	*per cent*	*per cent*		*pounds*	*p.s.i.*	*p.s.i.*	*1000 p.s.i.*	*p.s.i.*	
Unseasoned																
3	4	35.1	25.3	8.89	139	16	0.69	80.1	38.2	0.324	40.6	3,300	5,607	1,093	182.5	3
5	4	35.1	28.2	11.93	165	33	0.57	61.3	33.8	0.405	37.4	3,812	6,946	1,226	218.9	5
7	4	34.5	30.9	19.20	110	24	0.60	77.9	35.6	0.330	36.3	4,442	7,088	1,312	222.1	7
8	4	34.7	26.2	5.97	78	27	0.87	87.0	31.7	0.335	33.0	3,111	5,396	1,108	144.5	8
10	4	33.7	25.0	9.52	142	14	1.00	61.5	37.2	0.378	40.2	4,703	6,569	1,176	193.1	10
13	4	35.4	30.3	9.72	115	19	0.79	100.0	35.9	0.295	33.0	3,627	5,794	980	164.1	13
14	4	34.2	26.8	6.98	80	27	0.75	58.6	31.4	0.327	28.1	3,820	6,233	1,133	171.1	14
17	4	35.0	26.1	5.93	137	23	0.58	66.5	37.1	0.326	30.7	2,732	5,325	883	138.0	17
18	4	33.2	28.6	12.57	125	20	1.00	71.9	42.1	0.375	38.6	4,715	7,545	1,304	208.7	18
19	5	32.8	24.7	8.98	105	16	0.73	67.8	33.3	0.304	34.5	2,910	5,356	941	148.8	19
22	4	33.5	24.6	8.65	68	26	0.75	79.1	35.8	0.284	36.5	2,966	5,008	1,094	146.1	22
24	4	34.5	25.8	9.52	85	17	0.86	97.0	34.4	0.319	40.5	2,690	6,228	1,118	193.4	24
27	4	34.2	26.7	9.72	77	23	0.78	59.6	29.9	0.308	30.6	3,414	6,227	1,151	188.9	27
28	3	36.2	31.3	13.46	160	31	0.64	62.7	34.1	0.344	34.1	4,082	7,613	1,264	233.9	28
29	4	33.0	25.9	8.81	75	34	0.81	80.1	35.3	0.346	36.9	3,588	6,275	1,201	165.2	29
30	4	33.6	25.4	8.89	64	22	1.08	81.8	51.3	0.329	40.2	3,867	5,562	1,121	157.4	30
33	3	33.5	24.5	8.42	147	25	0.62	71.0	30.1	0.310	33.9	2,797	6,037	909	173.6	33
34	4	34.0	26.6	9.72	106	23	0.66	93.5	35.5	0.299	35.7	2,720	5,346	1,006	157.6	34
37	4	35.2	26.3	9.24	85	25	0.72	41.3	29.0	0.292	29.5	2,775	6,182	1,054	191.7	37
40	4	33.7	24.2	8.98	78	18	0.78	55.1	29.3	0.323	32.5	3,003	5,411	1,103	159.6	40
Average		34.3	26.7	9.76	107	23	0.76	72.7	35.1	0.328	35.1	3,454	6,087	1,109	178.0	
Maximum		36.2	31.3	19.20	165	34	1.08	100.0	51.3	0.405	40.6	4,715	7,613	1,312	233.9	
Minimum		32.8	24.2	5.93	64	14	0.57	41.3	29.0	0.284	28.1	2,690	5,008	883	138.0	

Air-Seasoned, Butt-Soaked, Winter-Tested																
1	4	34.6	28.5	9.33	117	28	0.72	47.8	27.6	0.397	31.5	3,725	7,467	1,581	204.5	1
2	3	35.5	25.4	6.41	86	21	0.69	42.4	26.7	0.288	25.1	3,077	4,680	1,016	133.0	2
4	4	33.8	25.9	9.42	78	21	0.79	65.6	26.4	0.327	30.0	4,036	6,241	1,247	182.2	4
6	4	33.4	26.2	11.09	176	18	0.72	53.4	29.9	0.291	29.9	2,775	5,350	889	157.1	6
9	4	33.9	24.0	5.64	63	20	0.91	109.3	33.3	0.306	26.9	2,560	4,637	1,005	121.4	9
11	4	33.5	26.3	6.73	75	19	0.75	48.2	29.2	0.316	26.1	2,479	4,486	1,156	115.0	11
16	4	33.9	27.9	12.91	110	20	0.70	46.7	36.3	0.351	32.1	4,440	7,398	1,367	223.7	16
20	4	34.0	26.5	9.52	82	21	0.84	74.9	30.3	0.310	30.3	2,594	5,180	1,126	150.0	20
21	4	34.2	26.5	8.73	69	15	0.94	56.2	28.3	0.301	30.1	3,006	5,300	1,188	158.9	21
23	4	33.1	25.5	9.42	120	20	0.49	46.6	33.2	0.339	29.9	4,258	6,320	1,177	179.9	23
Average		34.0	26.3	8.92	98	20	0.76	59.1	30.1	0.323	29.2	3,295	5,706	1,175	162.6	
Maximum		35.5	28.5	12.91	176	28	0.94	109.3	36.3	0.397	32.1	4,440	7,467	1,581	223.7	
Minimum		33.1	24.0	5.64	63	15	0.49	42.4	26.4	0.288	25.1	2,479	4,486	889	115.0	
Air-Seasoned, Butt-Soaked, Summer-Tested																
12	4	34.1	24.7	8.98	166	19	0.71	79.5	46.5	0.318	29.4	3,047	4,942	1,114	153.1	12
15	3	35.7	30.4	13.86	86	25	0.76	78.3	36.8	0.369	31.8	3,332	6,596	1,528	215.3	15
25	3	36.1	23.1	6.64	116	18	0.85	69.9	29.7	0.329	31.8	2,634	4,737	1,128	150.4	25
26	4	34.3	27.0	10.13	73	17	0.87	100.4	42.0	0.304	29.8	2,970	4,445	1,173	134.7	26
31	4	35.4	26.0	8.34	73	21	0.84	86.5	29.6	0.305	29.0	2,497	4,827	1,066	150.1	31
32	4	33.5	27.1	8.65	98	18	0.88	87.1	33.6	0.307	24.5	2,924	5,052	1,138	136.4	32
35	4	35.4	29.0	8.49	92	25	0.71	89.3	31.5	0.313	26.4	2,881	5,547	1,300	161.7	35
36	4	33.8	27.4	7.48	93	21	0.78	91.4	36.3	0.362	25.6	2,814	5,376	1,159	136.1	36
38	4	35.2	28.9	7.48	101	22	0.72	71.2	28.8	0.327	24.7	3,475	5,204	1,233	142.0	38
39	4	33.5	27.3	7.14	83	24	0.76	52.2	28.1	0.339	21.7	3,536	5,947	1,151	150.8	39
Average		34.7	27.1	8.72	98	21	0.79	80.6	34.3	0.327	27.5	3,011	5,267	1,199	153.1	
Maximum		36.1	30.4	13.86	166	25	0.88	100.4	46.5	0.369	31.8	3,536	6,596	1,528	215.3	
Minimum		33.5	23.1	6.64	73	17	0.71	52.2	28.1	0.304	21.7	2,497	4,445	1,066	134.7	

[1] Poles of this shipment were interior-grown. [2] As determined from discs cut at extreme butt. [3] As determined from discs cut near ground-line. [4] Based on volume at test; weight oven-dry.

APPENDIX 5

SUMMARY OF TEST RESULTS OF SMALL CLEAR SPECIMENS CUT FROM WESTERN RED CEDAR POLES

	STATIC BENDING						COMPRESSION PARALLEL TO GRAIN			
	No. of Tests	Moisture Content	Specific Gravity Vol. at test Wt. O.D.	Stress at Proportional Limit	Modulus of Rupture	Modulus of Elasticity	No. of Tests	Moisture Content	Specific Gravity Vol. at test Wt. O.D.	Maximum Crushing Stress
		per cent		*p.s.i.*	*p.s.i.*	*1000 p.s.i.*		*per cent*		*p.s.i.*
Shipment 153										
Average	194	64.8	0.300	3,101	5,099	950	234	58.3	0.300	2,421
Maximum		231.5	0.375	4,714	6,762	1,286		231.5	0.433	3,333
Minimum		26.8	0.237	1,575	3,150	580		24.4	0.239	1,680
Shipment 154										
Average	178	41.7	0.322	3,529	5,621	1,027	235	43.0	0.319	2,859
Maximum		180.3	0.416	5,880	8,018	1,444		179.0	0.411	4,310
Minimum		19.1	0.217	1,260	3,381	369		21.1	0.249	1,676
Shipment 157 Machine-Shaved Unseasoned										
Average	40	71.7	0.325	3,621	5,567	1,015	40	80.1	0.322	2,884
Maximum		184.1	0.432	4,620	6,720	1,312		177.3	0.372	3,935
Minimum		24.4	0.245	2,520	3,717	696		29.2	0.250	1,765
Air-Seasoned Butt-Soaked Winter-Tested										
Average	17	46.7	0.343	3,299	5,044	853	20	54.0	0.339	2,916
Maximum		132.1	0.439	4,620	7,602	1,125		136.7	0.449	4,485
Minimum		21.8	0.290	2,520	3,780	534		24.1	0.288	2,160
Air-Seasoned Butt-Soaked Summer-Tested										
Average	17	55.8	0.337	3,886	6,148	1,092	16	56.0	0.332	3,157
Maximum		165.3	0.467	5,040	7,318	1,345		207.5	0.373	3,699
Minimum		25.2	0.232	3,360	5,103	794		23.1	0.289	2,545

Shipment 157 Hand-Peeled Unseasoned										
Average	39	93.1	0.335	3,890	5,834	1,080	39	101.2	0.328	3,094
Maximum		211.2	0.427	5,040	8,022	1,544		235.0	0.406	4,000
Minimum		32.6	0.295	2,520	4,536	739		31.4	0.286	2,415
Air-Seasoned Butt-Soaked Winter-Tested										
Average	16	78.9	0.336	3,315	5,332	931	20	83.9	0.333	2,974
Maximum		185.1	0.414	4,667	7,665	1,314		173.1	0.400	4,170
Minimum		24.1	0.254	2,100	4,053	641		23.5	0.278	2,355
Air-Seasoned Butt-Soaked Summer-Tested										
Average	17	105.5	0.330	4,045	6,181	1,121	15	116.8	0.328	3,090
Maximum		207.1	0.377	5,040	7,467	1,419		238.0	0.386	4,101
Minimum		23.6	0.241	3,360	5,260	950		24.0	0.277	2,112

APPENDIX 6

RESULTS[1] OF EARLY (1925) TESTS OF 25-FOOT WESTERN RED CEDAR POLES[2]

Pole No.	Rings Per Inch	Summer-Wood	Sapwood	Moisture Top Section	Diameter At Load Point	Weight	Maximum Load	Top Reaction Adjusted To 7-Inch Top Diameter	Modulus of Rupture
		per cent	*per cent*	*per cent*	*inches*	*pounds*	*pounds*	*pounds*	*p.s.i.*
KA[3]— 1	20	30	19.4	21.7	10.3	340	17,410	2,176	6,502
2	28	28	17.0	22.8	9.2	269	11,950	2,078	6,290
3	32	17	13.6	21.6	9.4	278	13,900	2,003	6,839
4	16	39	26.6	20.9	9.2	285	12,870	1,665	6,776
5	18	27	16.6	18.7	10.0	292	14,950	1,916	6,116
6	11	27	18.5	16.5	9.8	295	15,560	2,336	6,757
7	15	31	16.2	25.4	9.2	293	14,750	2,118	7,747
8	12	15	19.9	17.6	10.1	302	16,760	2,609	6,650
9	14	23	23.4	21.2	9.4	276	16,040	2,638	7,882
10	22	31	13.1	20.5	9.8	287	14,990	2,788	6,486
11	11	25	14.7	16.8	10.3	334	19,480	2,684	7,283
12	15	27	20.4	20.7	10.3	342	20,070	2,939	7,492
13	19	29	22.8	16.8	9.2	280	14,500	2,306	7,611
14	23	38	17.9	18.4	10.2	350	21,800	2,622	8,367
15	34	35	23.6	20.8	10.2	336	17,440	2,177	6,721
Average	19	28	18.9	20.0	9.8	304	16,165	2,337	7,035
Maximum	34	39	26.6	25.4	10.3	350	21,800	2,939	8,367
Minimum	11	15	13.1	16.5	9.2	269	11,950	1,665	6,116
VA[4]— 1	11	26	23.2	21.2	8.8	250	9,950	1,571	5,950
3	17	33	36.3	20.1	8.6	241	10,040	1,903	6,498
4	11	25	20.0	22.9	9.2	268	11,780	1,644	6,230
5	10	30	22.0	19.3	9.6	283	12,470	2,264	5,772
6	8	26	28.7	16.9	8.7	255	9,870	1,717	6,147
7	17	35	26.6	17.6	8.9	274	11,850	2,218	6,847
8	20	32	28.1	19.8	8.0	195	7,600	1,723	6,089
10	11	35	31.8	20.4	8.1	212	7,660	1,734	5,920
11	10	30	29.5	20.4	9.9	252	11,690	2,447	4,917
13	9	33	24.1	18.6	9.8	278	16,020	2,641	6,944
14	11	10	28.8	16.1	8.3	201	7,900	1,660	5,667
15	9	21	28.8	20.5	8.1	221	7,710	1,520	5,967
Average	12	28	27.3	19.5	8.8	244	10,378	1,920	6,079
Maximum	20	35	36.3	22.9	9.9	283	16,020	2,641	6,944
Minimum	8	10	20.0	16.1	8.0	195	7,600	1,520	4,917
HA[4]— 1	—	—	—	17.7	11.1	432	25,830	2,412	7,697
2	25	26	18.2	20.9	10.3	342	19,230	2,478	7,167
3	19	24	20.7	22.2	10.3	327	16,050	2,359	6,013
4	38	27	17.5	20.9	9.7	325	17,470	2,451	7,823
5	20	—	11.1	21.6	10.2	357	19,290	1,701	7,445
6	26	35	11.5	23.3	10.8	364	21,950	2,293	7,079
7	16	29	19.2	18.8	11.0	375	17,350	2,571	5,318
8	24	29	15.5	25.3	10.0	368	18,860	2,745	7,690
9	24	33	17.7	21.9	11.0	380	20,310	2,157	6,239
Average	24	29	16.4	21.4	10.5	363	19,593	2,352	6,941
Maximum	38	35	20.7	25.3	11.1	432	25,830	2,745	7,823
Minimum	16	24	11.1	17.7	9.7	325	16,050	1,701	5,318

[1] As reproduced from Forest Service—Circular No. 21, Dept. of the Interior, Canada. [2] All poles were hand-peeled, seasoned and butt-soaked prior to test. These poles were tested over a 23-foot span. [3] Interior-grown group. [4] Coast-grown group.