TAPER OF WOOD POLES

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Abstract

Round wood pole use has changed without accompanying advancement in engineering design data. Previous pole design was based on the assumption that maximum stress occurred at the groundline but, with the larger poles that are now being used, maximum stress may occur along the pole length. For accurate engineering analysis the shape or taper of a pole must be known.

Both curvilinear and straight-line functions were fit to data from 617 southern pine poles and from 225 Douglas-fir and 57 western redcedar trees. The best estimate of geometry or shape of the outer surface of the poles was a straight line. The southern pine data along with data from 1,069 Douglas-fir poles and 1,719 western redcedar poles were further analyzed for the mean and upper and lower 95 percent tolerance intervals of the taper of the pole surfaces. There was a statistical difference in the tapers between length-class combinations in a given species, but in the final analysis all data for a species were considered as a population.

Guidelines are given for updating engineering design criteria for round wood poles.

TAPER OF WOOD POLES[1]

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Introduction

Extensive data on the strength and related properties of wood poles were obtained from the ASTM Wood Pole Research Program.[3] These data along with limited information from other sources formed the basis for pole stresses as given in the ANSI Standard 05.1.[4] This standard is based on the assumption that maximum stress occurs at the groundline location in poles loaded as a simple cantilever. Factors considered in the development of the ANSI stresses are discussed in Forest Service Research Paper FPL 39.[5]

Most of the ASTM data were on poles 25 and 30 feet in length. Only a limited number of 55-foot-long poles were evaluated. However, since the ASTM pole strength data were developed, pole use has changed. The trend is to use larger poles and fewer of them. Multiple-pole tower structures are also being used.

In a pole the theoretical maximum stress, due to a transverse load applied near its top, is located where the pole circumference is 1-1/2 times the pole circumference where the load is applied. For the shorter poles this theoretical critical location usually does not exist. Thus the maximum stress is almost always at the groundline. However, for long poles the theoretical maximum stress location is usually some distance above the groundline, depending on the pole taper. Also for multiple-pole braced structures, the maximum stress is usually at a brace location which is somewhere near the midheight of the pole.

Many pole producers and users have questioned the use of the ANSI-published stresses for large poles in which the theoretical maximum stress under load is at some distance above the groundline. The reason for concern is a suspected decrease in strength from butt to tip of a round timber. As a result, a task force in the Subcommittee on Fiber Stresses of the ANSI Committee 05 was to determine if the strength of a round pole varies along the pole length. However, before a variable strength can be considered by design engineers, the shape or taper of a pole must be known. The assignment of the ANSI-05 task force was thus extended to investigate the shape of 55-foot and longer Douglas-fir, western redcedar, and southern pine poles.

Only the results of the investigation of the shape and taper of the round timbers are presented in this report.

Origin of Pole Circumference Data

The pole dimension measurements were made by the pole producers in their respective pole yards. The number of poles that were surveyed in each length and class is shown in tables 1, 2, and 3. The data were taken at 29

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[1] Poles that meet requirements of American National Standard ANSI 05.1.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Wood. Lyman W., Erickson, E.C.O., and Dohr. A. W. Strength and Related Properties of Wood Poles. American Society for Testing and Materials Rep. STP 295. Sept. 1960.

[4] American National Standards Institute. American National Standard Specifications and Dimensions for Wood Poles. ANSI 05.1-1972.

[5] Wood. L. W., and Markwardt, L. J. Derivation of Fiber Stresses From Strength Values of Wood Poles. U.S Forest Serv. Res. Pap. FPL 39. Forest Prod. Lab., Madison. Wis. 1965.

Table 1.–*Number of southern pine poles in each length and class*

Height	Class 1	2	3	4	5	6
Ft						
50	0	0	0	1	0	0
55	38	70	52	34	7	1
60	26	74	68	21	0	0
65	16	33	35	13	0	0
70	9	22	21	11	0	0
75	5	12	11	1	0	0
80	6	8	10	3	0	0
85	1	2	3	0	0	0
90	1	0	1	0	0	0
95	0	0	0	0	0	0
100	1	0	0	0	0	0

Table 2.–*Number of Douglas-fir poles in each length and class*

Height	Class 1	2	3	H1	H2	H3
Ft						
55	26	18	23	0	0	0
60	40	25	28	0	0	0
65	38	78	25	0	0	0
70	35	68	22	5	0	0
75	31	41	17	1	0	0
80	68	32	18	7	5	6
85	39	37	30	5	8	0
90	26	24	0	0	2	1
95	30	15	0	5	4	3
100	29	16	0	6	5	1
105	19	10	0	4	1	0
110	26	10	0	0	0	0
115	19	6	0	4	3	0
120	9	5	0	5	0	0
125	2	3	0	0	0	0

southern pine pole yards, at five Douglas-fir yards, and at eight western redcedar yards.

The Laboratory was not involved in sampling methods for the collection of the pole data. The data were assembled by the chairman of the Subcommittee on Fiber Stresses of ANSI Committee 05. The general request was that pole producers furnish dimension data for all length-class combinations of poles that were

Table 3.–*Number of western redcedar poles in each length and class*

Height	Class 1	2	3	H1	H2	H3	H4
Ft							
45	5	5	16	0	0	0	0
50	0	0	33	0	0	0	0
55	55	58	75	0	0	0	0
60	45	67	53	0	0	0	0
65	86	106	33	0	5	5	0
70	49	87	36	1	5	1	0
75	66	61	30	5	5	5	0
80	103	87	31	5	5	5	0
85	83	67	21	4	5	5	0
90	54	45	5	3	2	7	1
95	52	25	3	5	4	3	0
100	39	14	2	4	4	0	0
105	7	2	1	3	3	3	0
110	5	1	0	0	2	0	0
115	0	0	0	0	0	1	0

longer than 50 feet. Thus it is assumed that the ratio of the number of specimens in each length-class combination is somewhat representative of the types of poles that were processed through pole yards during 1971. Also, the poles were to be graded by the then-current ANSI 05.1 Standard,[4] which covers sizes, material requirements, description of pole classes, etc.

The circumferences of southern pine poles were measured at the butt, tip, and at each 10 feet from the butt. The circumferences of Douglas-fir and western redcedar poles were measured at 6 feet from the butt and at the tip.

Analysis of Data

The first question considered was whether or not the geometry or shape of outer surfaces of the poles could be described by a straight line of the form:

$$y = a + bx \tag{1}$$

In southern pine poles at least five circumferences were measured on each pole. The butt circumferences of southern pine poles were not used in the analysis because of the possible influence of a butt swell that is sometimes associated with this species.

Straight lines were fitted to each of the 617 pine poles by the method of least squares. The range of the multiple correlation coefficient(R^2)

was 0.73 to 0.99. Over 98 percent of the poles had fitted straight lines with an R^2 greater than 0.90. Figure 1 gives typical examples of radius-height relationships of class 2, 55-foot pine poles with the fitted straight line.

Several other functions. such as:

$$Y = ae^{bx^2}$$

$$Y = a(\text{CSCH } x) \qquad (3)$$

were also tried but none gave as good a fit as the straight lines. Figure 2 gives typical examples of three class 2, 55-foot pine poles with each of the functions (1), (2), and (3) fitted.

Unfortunately the pole data for Douglas-fir and western redcedar that were furnished by pole producers included only circumferences measured at 6 feet from the butt and at the tip.

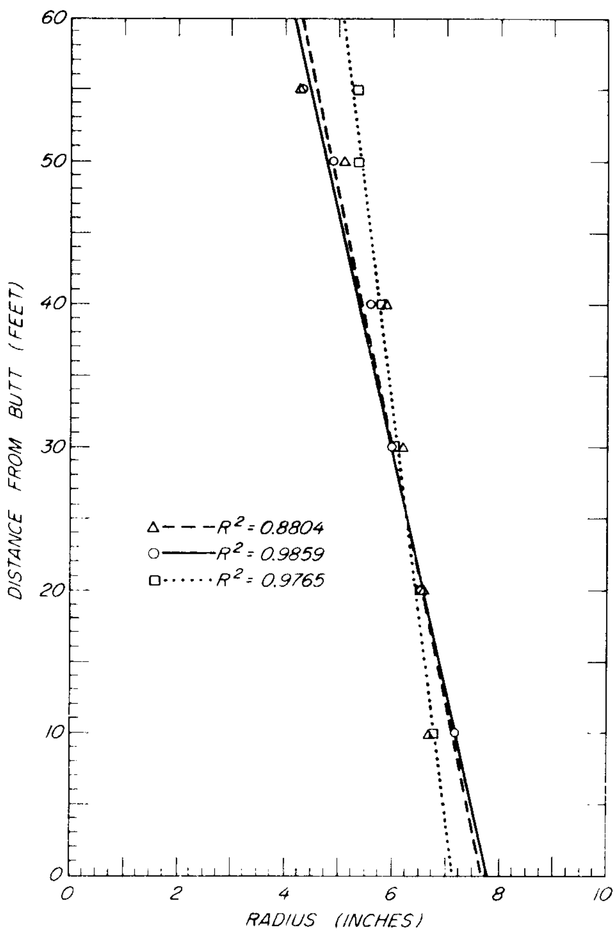

Figure 1 .–Radius-height relationship of three typical class 2-55 southern pine poles. The dotted line is at least squares fit of the measured data.

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Thus it was impossible to determine, for these species, if a straight line was an adequate fit. However, data from the Western Wood Density Survey[6,7] included circumference measurements at different locations along the length of selected trees. These data were analyzed to determine if the assumption of a straight line description was tenable.

Data for both Douglas-fir and western redcedar trees in the above-mentioned survey were considered if they included four or more circumference measurements and if the minimum circumference was at least 31 inches (minimum diameter of 10 in.). Straight lines were fitted to each of 225 Douglas-fir trees and 97 percent had an R^2 greater than 0.90. Ninety-six percent of the 57 western redcedar trees had an R^2 greater than 0.90.

On the basis of the above we decided that a straight line would be an adequate description of the geometry or shape of the outer surfaces of southern pine, Douglas-fir, and western redcedar poles.

Our next question was to decide whether or not the populations within each species, of which each length-class combination was a sample, had the same mean taper value. An analysis of variance approach indicated that there was sufficient reason to reject the assumption that the variances were the same. Thus, although one taper value for each of the three species of poles was desired, the single number representing each of the three species should be viewed in light of this information.

One objective was to categorize each species of poles with a near-minimum and a near-maximum taper value. We were interested in obtaining lower and upper 95 percent tolerance intervals for the population of taper and at a 95 percent degree of confidence. That is to say, we sought a number-in the lower 95 percent tolerance interval-such that we were 95 percent confident that 95 percent of all possible taper would lie above this number.

Two approaches were evident. One was to assume normality and the second was to use a nonparametric or order statistic approach. In our computation, we decided to eliminate from the sample all length class combinations which contained less than five members. This

[6]U.S. Forest Service. Western Wood Density Survey – Rep. No. 1 US. Forest Serv. Res. Pap. FPL 27. Forest Prod. Lab., Madison, Wis. 1965.

[7]Maeglin, Robert R. and Wahlgren, Harold E. Western Wood Density Survey-Rep. No. 2. USDA Forest Serv. Res. Pap. FPL 183. Forest Prod. Lab., Madison, Wis. 1972.

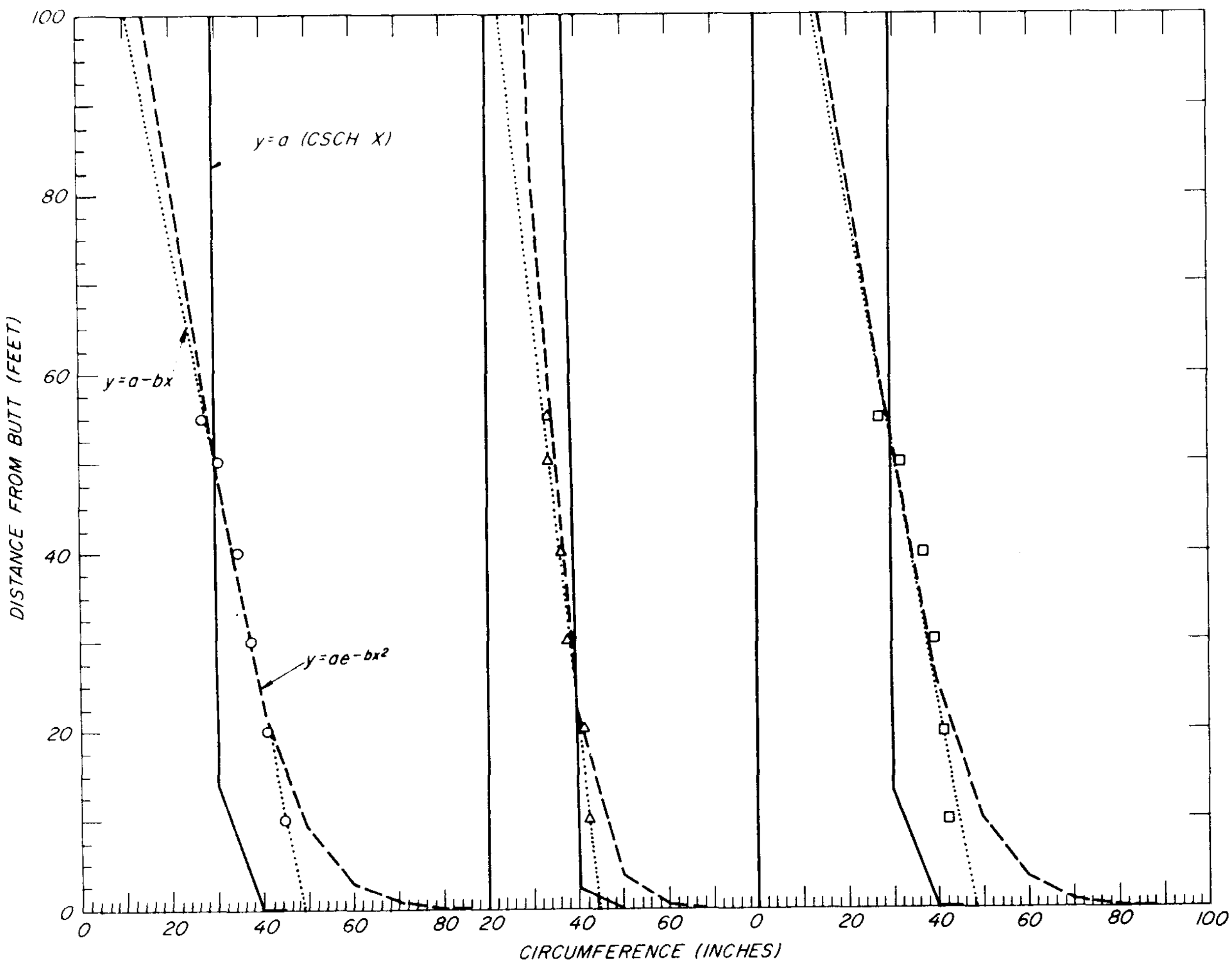

Figure 2.–Circumference-height relationship of three typical class 2-55 southern pine poles.

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Table 4.–*Summary taper data for all poles*[1]

Value	Southern pine	Douglas-fir	Western redcedar
Number in species	617	1,069	1,719
Largest taper	38.05	46.34	29.10
Median taper	18.33	19.47	13.44
Mean taper	18.91	20.36	13.89
Smallest taper	11.50	10.44	6.84

[1]Taper values are equal to $\frac{\Delta \text{ Height (in feet)}}{\Delta \text{ Radius (in inches)}}$

resulted in excluding 15 southern pine poles, 29 Douglas-fir poles, and 48 western redcedar poles. For all poles of each species the largest, median, mean, and smallest taper are shown in table 4. For the selected sample (all poles with five or more in a group) table 5 gives all the above information as well as the standard deviation and the end points for the upper and lower 95 percent tolerance intervals derived from both the normality and the order statistics approach. An examination of table 5 shows the close agreement between the two approaches with respect to the tolerance intervals.

Table 5.–*Summary of taper data. Length-class combinations with less than five samples are not included*[1]

Value	Southern pine	Douglas-fir	Western redcedar
Number in species	602	1,040	1,671
Largest taper	33.25	46.34	29.10
Median taper	18.33	19.50	13.44
Mean taper	18.85	20.41	13.91
Smallest taper	11.50	10.44	6.84
Standard deviation	3.65	4.72	3.021
End point of lower tolerance interval from normality theory	25.24	28.57	19.12
End point of upper tolerance interval from normality theory	12.46	12.25	8.69
Number of order statistic	22	41	69
End point of lower tolerance interval from nonparametric theory	26.67	30.08	20.16
Number of order statistic	581	1,000	1,603
End point of upper tolerance interval from nonparametric theory	13.36	13.73	9.51

'Taper values are $\frac{\Delta \text{ Height (in feet)}}{\Delta \text{ Radius (in inches)}}$

The mean and standard deviation of taper of each length-class combination with five or more members are given in tables 6, 7, and 8.

The tapers in the tables are

$$\frac{\Delta H \text{ (in feet)}}{\Delta R \text{ (in inches)}}$$

Now if AH is set equal to 1, then,

$$\Delta R = \frac{1}{\text{taper}} \qquad (4)$$

is the change in radius per foot of height for the pole with that taper. To obtain the change in circumference per foot of height, multiply the **AR** in equation (4) by 2π. The rate of circumference per foot of height is given in table 9 and shown graphically in figure 3.[8]

DISCUSSION OF RESULTS

One hypothesis at the start of the analysis was that the taper of all poles for a given species might be a constant. That is, the upper and lower exclusion limits and the mean might be the same for all classes and lengths within a species. A further analysis of how poles are placed in classes by the ANSI 05.1 standard[4] shows that this hypothesis should not be valid.

Poles are graded into classes by circumferences at the tip and 6 feet from the butt. The minimum tip circumference is a constant value for each pole class and for poles of all lengths within a class. The minimum 6-feet-from-butt circumference is calculated for poles of different lengths. Procedures for this calculation are given in the ANSI 05.1 standard.

The relationship between pole height and 6-feet-from butt circumference is

$$\gamma = kc^3$$

where γ is length, c is circumference, and k is a constant which depends on pole class and fiber stresses for species. This curvilinear relationship is shown in figure 4A.

[8] Since the poles were considered to be symmetrical, the sign of the slope is immaterial except that small negative values become large positive values, etc.

Table 6.–*The mean* and *standard deviation of taper values for each class-length combination of southern pine poles*[1]

Height	Value	Class 1	2	3	4	5
Ft						
55	Means	16.90	17.24	19.61	21.38	21.21
	S.d.	2.338	3.850	3.763	4.039	4.494
60	Means	16.08	18.90	20.00	20.48	0
	S.d.	1.912	3.603	3.318	4.601	0
65	Means	16.69	18.57	18.92	19.74	0
	S.d.	2.997	3.790	3.540	3.616	0
70	Means	18.25	19.67	19.86	21.38	o
	S.d.	2.268	3.494	1.876	2.822	0
75	Means	16.70	18.35	17.30	0	0
	S.d.	3.406	2.161	2.001	0	0
80	Means	17.29	19.00	19.82	0	0
	S.d.	3.145	2.446	3.372	0	0

[1]Taper values are $\frac{\Delta \text{ Height (in feet)}}{\Delta \text{ Radius (in inches)}}$

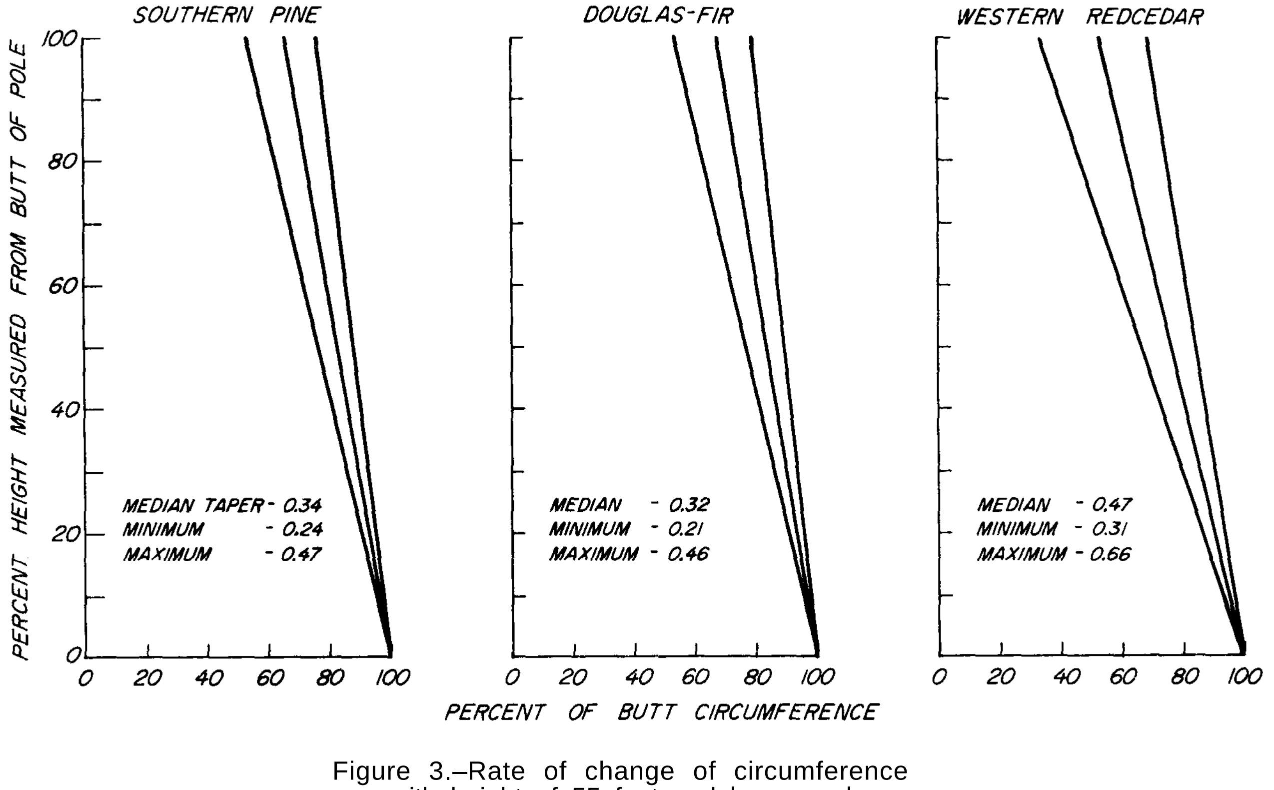

Figure 3.–Rate of change of circumference with height of 55 feet and longer poles.
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Table 7.–*The mean and standard deviation of taper values for each class-length combination of Douglas-fir poles*[1]

Height	Value	Class 1	2	3	H1	H2	H3
Ft							
55	Means	21.25	20.77	18.95	0	0	0
	S.d.	6.230	5.337	6.233	0	0	0
60	Means	18.76	20.55	21.30	0	0	0
	S.d.	4.809	5.534	5.562	0	0	0
65	Means	18.28	24.10	20.15	0	0	0
	S.d.	3.810	6.755	4.449	0	0	0
70	Means	19.38	19.17	19.39	18.33	0	0
	S.d.	4.694	4.363	3.964	2.343	0	0
75	Means	19.44	21.37	19.38	0	0	0
	S.d.	4.648	4.626	2.976	0	0	0
80	Means	19.68	20.48	21.61	17.13	14.85	16.14
	S.d.	4.493	2.721	3.315	5.971	.507	3.905
85	Means	18.97	23.31	21.91	21.97	18.19	0
	S.d.	3.874	5.107	3.953	2.611	3.700	0
90	Means	22.22	21.29	0	0	0	0
	S.d.	3.885	4.326	0	0	0	0
95	Means	21.49	22.15	0	16.56	0	0
	S.d.	4.203	2.162	0	.615	0	0
100	Means	19.26	21.51	0	19.96	17.95	0
	S.d.	2.503	3.355	0	6.509	2.238	0
105	Means	20.29	20.72	0	0	0	0
	S.d.	2.573	2.996	0	0	0	0
110	Means	19.76	20.07	0	0	0	0
	S.d.	2.877	2.327	0	0	0	0
115	Means	19.85	19.48	0	0	0	0
	S.d.	2.509	3.373	0	0	0	0
120	Means	19.52	18.25	0	19.15	0	0
	S.d.	2.761	2.020	0	2.160	0	0

[1]Taper values are $\frac{\Delta \text{ Height (in feet)}}{\Delta \text{ Radius (in inches)}}$

Table 8.–*The mean and standard deviation of taper values for each class-length combination of western redcedar poles*[1]

Ft	Value	Class 1	2	3	H1	H2	H3
45	Means	10.13	10.19	15.97	0	0	0
	S.d.	3.137	1.421	4.981	0	0	0
50	Means	0	0	17.76	0	0	0
	S.d.	0	0	4.129	0	0	0
55	Means	12.24	13.86	14.02	0	0	0
	S.d.	2.658	3.484	2.931	0	0	0
60	Means	12.80	13.22	15.55	0	0	0
	S.d.	2.326	2.537	3.635	0	0	0
65	Means	13.37	13.08	13.51	0	13.48	13.14
	S.d.	3.054	2.240	2.815	0	2.807	2.740
70	Means	13.22	13.56	15.73	0	13.67	0
	S.d.	2.403	2.481	3.066	0	1.209	0
75	Means	13.46	14.38	15.43	13.60	11.31	12.13
	S.d.	2.489	2.664	3.065	1.680	1.411	2.337
80	Means	12.76	14.24	15.53	12.79	12.41	12.30
	S.d.	2.126	2.710	2.907	.478	.370	1.030
85	Means	13.16	14.70	15.89	0	11.56	14.15
	S.d.	2.859	3.505	3.303	0	.612	2.508
90	Means	14.61	14.55	16.95	0	0	13.17
	S.d.	3.111	2.686	3.098	0	0	1.989
95	Means	15.07	13.11	0	11.37	0	0
	S.d.	3.259	2.199	0	.814	0	0
100	Means	13.84	15.16	0	0	0	0
	S.d.	2.582	2.854	0	0	0	0
105	Means	14.55	0	0	0	0	0
	S.d.	1.739	0	0	0	0	0
110	Means	16.65	0	0	0	0	0
	S.d.	4.250	0	0	0	0	0

[1]Taper values are $\frac{\Delta \text{ Height (in feet)}}{\Delta \text{ Radius (in inches)}}$

Table 9.–*Rate of change of circumference per foot of height*

Value	Southern pine	Douglas-fir	Western redcedar
Median	0.34	0.32	0.47
Near minimum 5 percent[1] exclusion limit	.24	.21	.31
Near maximum 5 percent[1] exclusion limit	.47	.46	.66
Taper value from ANSI 05.1	.25	.21	.38

[1]Obtained from the end points (derived from nonparametric theory) of the tolerance intervals given in table 5.

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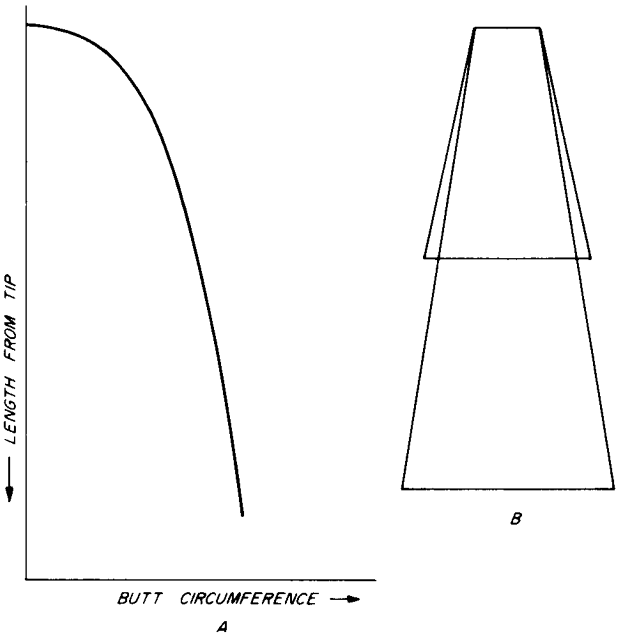

Figure 4.–A. The general relationship between length and butt circumferences of round timbers that are classed by the ANSI 05.1 standard. B. Profile of two poles of different lengths and with minimum tip and butt circumferences.
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The minimum tip circumference as given in the ANSI 05.1 standard is a constant for each pole class, regardless of pole length. Thus as shown in figure 4B the taper of a shorter pole with minimum butt and tip circumferences will be different than that of a longer pole with minimum dimensions. From this it would seem unlikely that the mean taper of poles in all length-class combinations would be a constant.

One objective of the study was to determine what taper should be used by design engineers. The analysis did not result in this taper value. However, a further analysis of minimum dimension values that are given in the ANSI standard did suggest a possible answer to such a taper value. As shown in figure 5, the minimum cross section at any location along the pole length should be defined by a straight-line taper between the minimum tip and minimum butt dimensions.

A pole is placed in a class by both a minimum butt and tip dimension or by a minimum of either butt or tip dimension. If a pole is in a class because of a minimum tip dimension, then the taper could be larger than that given by the straight-line taper between minimum dimensions as shown by dotted lines in figure 5A. Conversely, a pole that is in a class because of minimum butt circumference will have less taper (fig. 5B). However, regardless of which dimension controlled the pole class, the actual cross-sectional size at any location along the pole length should be larger than that defined by the the taper from minimum dimension. Thus a taper calculated from minimum dimensions of each pole class and length should be a conservative value for design.

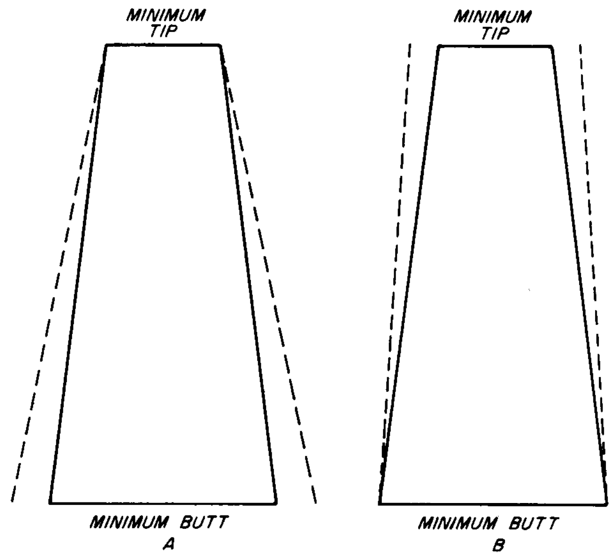

Figure 5.–Schematic profile of possible shapes of round poles that are graded by minimum tip or minimum butt dimensions. The solid lines indicate a pole with minimum dimensions. The dotted lines show possible tapers of poles in which the pole class is controlled by either minimum tip (A) or minimum butt (B).
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