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Effect of Length on Tensile Strength in Structural Lumber

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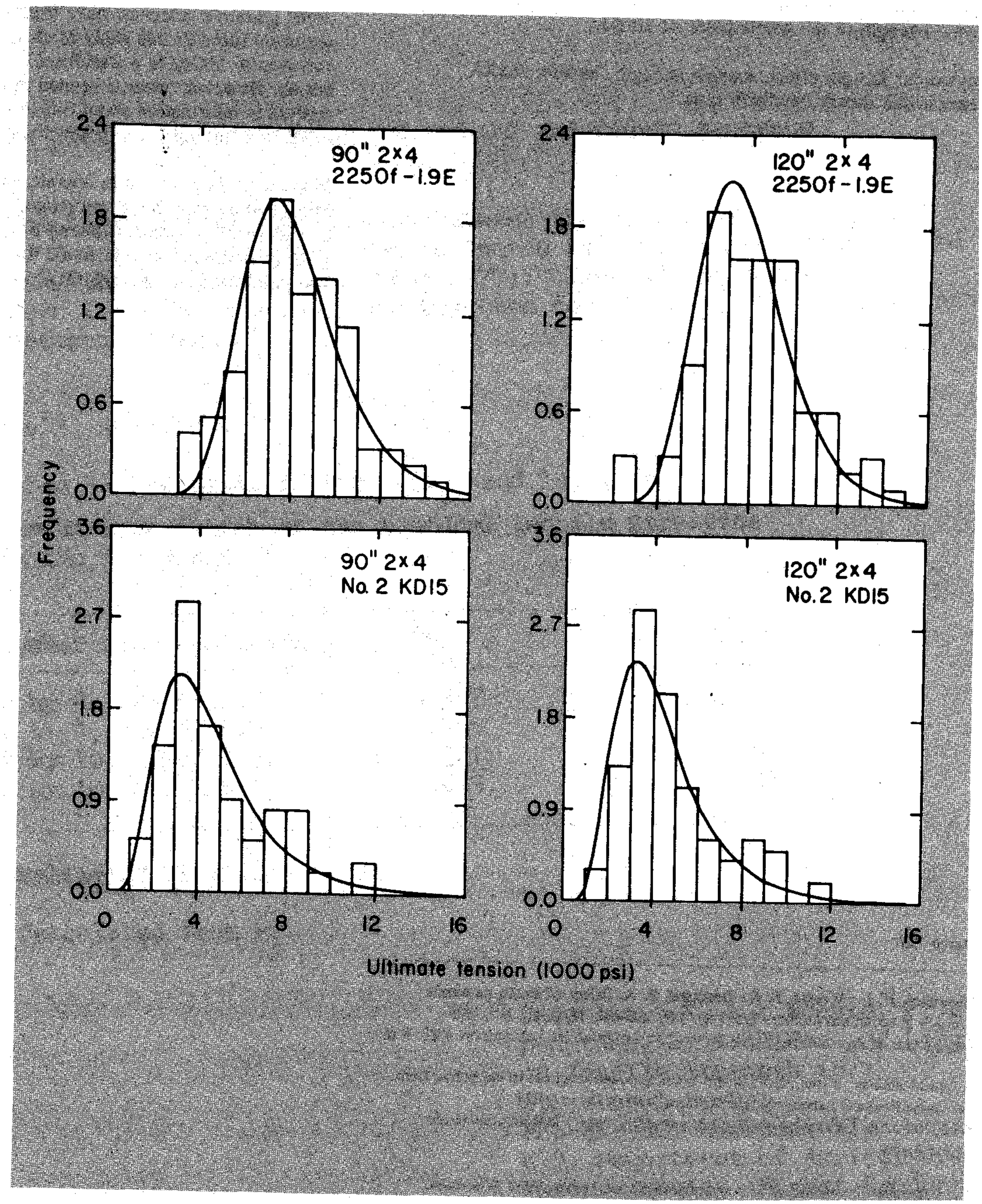

Abstract

For two grades and two sizes of Southern Pine lumber tested in tension parallel-to-grain, 30-inch test specimens had significantly higher tensile strength than 90- and 120-inch test specimens.

The model developed from these data generates tensile strength values of lumber taking the length effect into consideration. The model utilizes a second-order Markov generation of segment modulus-of-elasticity values followed by a first-order Markov generation of segment tensile-strength values along 30-inch segments of a piece of lumber. The tensile strength of the whole is then determined using the weakest link concept: The smallest of the tensile strength values for a segment is selected as the tensile strength of the whole piece of lumber.

Keywords: Length effect, tension strength, tension model, weakest-link theory, southern pine.

Research Significance

This report is the first published attempt to link the lengthwise stochastic variation of modulus of elasticity (MOE) in a single board to the board's tensile strength. The modeling method is applicable to research on truss design, glulam applications, and lumber grading, after acquisition of the additional information or refinement of the present model needed for these applications.

Because longer lengths of lumber have lower tensile strength, truss researchers will want improvements in structural and load models so as to be able to develop adjustments for length of truss span.

Some glulam researchers have used information about 30-inch segments (used in this study to characterize the lengthwise variation in MOE) in a transformed section analysis of glulam beams. However, what is needed in using the finite-element method is information about 6-inch segments. This report can serve as a starting point in developing a 6-inch model.

Modem grading machines operate on the principle that low-point MOE and average MOE are related to strength. With the development of a model linking 6-inch MOE and tensile strength, grading strategies may be found that are more refined than low-point MOE or average MOE.

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Page 5, first column, 4th paragraph, the third and fourth sentence should be

"The lag-3 serial correlation between the residuals of the first and fourth segments was then estimated and this correlation tested using the t distribution (Haan 1977). The null hypothesis (that there is no correlation) was rejected for three of the four 30-inch treatment groups."

Page 5, Table 3, should be

Table +-Estimates of lag-3 (r_3) and lag-1 (r_1) serial correlation of the residual tensile strengths in the log space

Lumber size and grade	[1] r_3	[2] r_1
2 by 4, 2250f-1.9E	0.397	0.735
2 by 4, No. 2 KD15	.560	.824
2 by 10, 2250f-1.9E	.321	.685
2 by 10, No. 2 KD15	.029	.306

[1] Estimated from test data.

[2] Calculated from r_3.

Showalter, K. L.; Woeste, F. E.; Bendtsen, B. A, Effect of-Length on Tensile Strength in Structural Lumber. FPL-RP-482. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1987. 9 p.

Effect of Length on Tensile Strength in Structural Lumber

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Introduction

This study was conducted to determine if there is a length effect on tensile strength parallel-to-grain in structural lumber and, if so, to develop a mathematical model for this length effect.

Background

By current design practice (National Forest Products Association 1986), design values are published for wood members subject to tension parallel-to-grain without regard to the length of the member in tension. Failure experience, however, indicates that long-span trusses have a higher incidence of failure than short-span trusses. Decreasing tensile strength with increasing length in the lower truss chord may be one of the factors involved.

The relationship between the size and strength of a wood member has been the subject of research for many years. It is apparent that as the size of a wood member increases its strength decreases. Assuming that wood is a material in which failure occurs by fracture at the weakest point, the size effect can be explained by the statistical theory of material strength or "weakest link theory" (Weibull 1939). This theory has been used in many applications to explain the effect of size on, strength of lumber (Barrett 1974, Bohannan 1966, Buchanan 1983, Liu 1980, Liu 1981).

Researchers have studied the effect on strength of volume (Barrett 1974, Liu 1980) and of aspect area (Bohannan 1966, Buchanan 1983, Liu 1981) but little has been done to model the effect of length as an independent factor. In the present study, an empirical evaluation of the effect of length on tensile strength provides the basis for a model that can be used for safety adjustments in long-span truss design and other applications where the effect of length on tensile strength is relevant.

General Method

Three lengths of lumber were tested in axial tension and the effect of length on tensile strength was observed in two grades and two sizes of Southern Pine lumber.

When observation showed a lower tensile strength parallel-to-grain in the longer test specimens, a model was developed to generate tensile strength values according to the length of the specimens.

The model developed determines the tensile strength of a piece of lumber by generating tensile strength values for segments of the piece and then applying a weakest link theory to the whole. For example, four tensile strength values are generated by the length effect model for the four 30-inch segments of a 120-inch piece of lumber and the lowest of these values is selected by the model as the -tensile strength of the whole piece. This paper includes details of the development and validation of the model.

Measurement of Modulus of Elasticity

One thousand pieces of 16-foot nominal 2-inch dimension Southern Pine lumber of two sizes and two grades were obtained on the open market. Consideration of the length effect in this range of sizes and grades should broaden the applicability of results. The size, grade, and the number of pieces of each group were as follows:

Number	Size	Grade
244	2 by 4	No. 2 KD15
250	2 by 4	2250f - 1.9E
256	2 by 10	No. 2 KD15
250	2 by 10	2250f - 1.9E

The No. 2 KD15 is a visually-rated stress grade denoted by VG, and the 2250f - 1.9E is machine-stress-rated (MSR).

The lumber was conditioned to equilibrium moisture content (EMC) in a room controlled at 75 °F and 68 percent relative humidity (RH) ($\cong$ 12 pct EMC). A capacitance moisture meter was used to monitor the progress of conditioning.

A full-span modulus of elasticity (MOE) was determined on all pieces by the vibration method. The pieces were ranked by MOE for each type (VG and MSR), and size (2 by 4 and 2 by 10) of lumber. The five pieces having the lowest MOE values were randomly assigned to the 30-, 90- and 120-inch test groups: one to the 30-inch group and two each to the 90- and 120-inch group because each 16-foot piece was long enough to yield two specimens for the 30-inch test. The five pieces with the lowest remaining MOE values were then randomly assigned to the test groups, and so on, until the three test groups were established with approximately 100 specimens per test length. Assigning the lumber according to rank by MOE makes the distribution of strength in the three test groups as similar as possible.

On each specimen designated for the 30-inch tension test, a flatwise static MOE was determined on four 30-inch-long segments. Figure 1 shows the location of each 30-inch segment and the loading configurations for testing segments 1 and 2 (or, when the piece was turned end to end, for testing segments 4 and 3). The MOE measurements on all four segments were used in research (Kline 1985) but only those on the first and fourth segments were used for this study.

A preload and a final load (dead loads) were applied to both the third points of a 90-inch span (fig. 1). The loads were 25 and 100 pounds for the 2 by 4's and 75 and 275 pounds for the 2 by 10's. On several specimens with low stiffness, the system "bottomed out" and the preloads and final loads had to be reduced accordingly. During tests of the various segments, an upward force was applied by a dead weight through a rope and pully system on the opposite end at the center of the overhang to counter the weight of the overhang and eliminate significant reverse bending moments.

Deflections were measured between the load points with a linear variable differential transformer (LVDT) mounted on a yoke and suspended from the specimen at the load points. This test arrangement permitted calculation of a shear-free MOE. Width and thickness were measured to the nearest 0.01 inch at the center of each 30-inch segment used to calculate MOE for individual segments. Three repetitions were performed an each segment and the MOE values reported are the averages of the measurements.

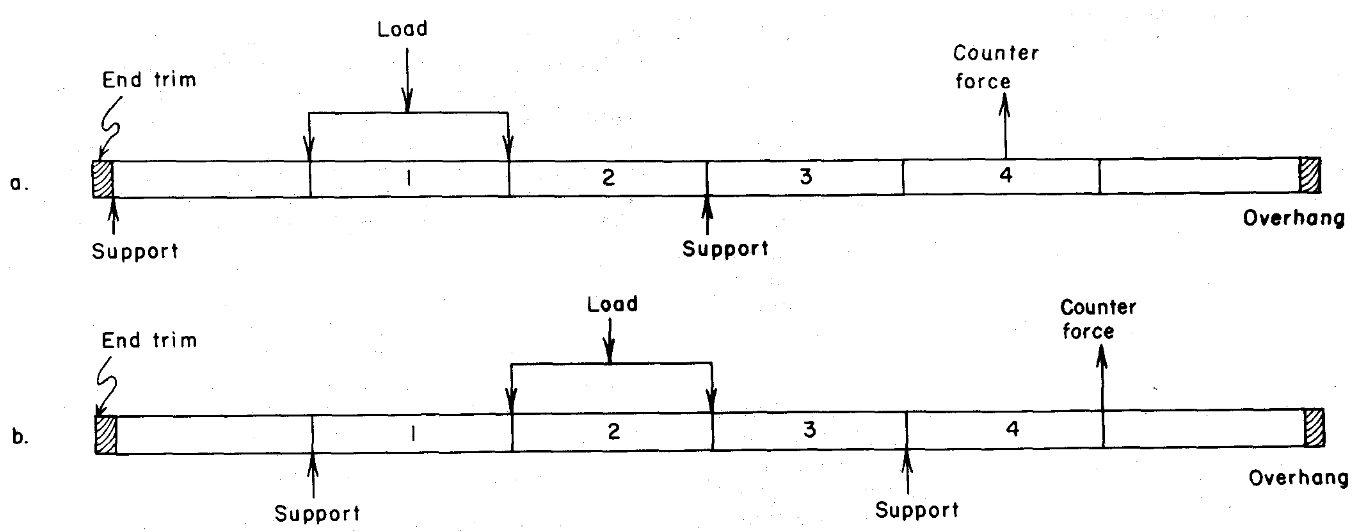

Figure 1—Location of four 30-inch segments for MOE measurements and the loading configuration (a) for Segment 1 (or 4) and (b) Segment 2 (or 3). (To test segments 3 and 4 the specimen was turned end for end in the equipment.) (ML86 5326)

Table 1—Mean tensile strength, coefficient of variation (COV), and sample size (N) of the lumber specimens tested

Lumber size and grade	30 inch			90 inch			120 inch		
	Mean	COV	N[1]	Mean	COV	N	Mean	COV	N
	Lb/b^2			*Lb/in^2*			*Lb/in^2*		
2 by 4, 2250f - 1.9E	9,436	0.305	100	8,107	0.286	98	8,100	0.289	100
2 by 4, No. 2 KD15	5,749	.472	98	4,868	.484	98	4,815	.468	98
2 by 10, 2250f - 1.9E	9,270	.251	100	8,139	.252	98	7,976	.262	99
2 by 10, No. 2 KD15	5,191	.583	104	4,046	.637	104	3,690	.662	101

[1]N observations were obtained from N/2 boards by cutting the boards to yield two specimens for the 30-inch test case.

Testing Tensile Strength

The pieces designated for the 30-inch lengths were cut in two pieces between segments 2 and 3 in preparation for tension testing, and then trimmed on the opposite end to a 90-inch length. The specimens designated for the 90-inch and 120-inch tests were trimmed equally on both ends to total lengths of 150 and 180 inches, respectively. Thus, the total lengths of 90, 150, and 180 inches allowed for a 30-inch grip length on both ends of the specimens and 30, 90, and 120 inches between grips. Width and thickness were measured to the nearest 0.01 inch at the center of the test zone. Specimens were centered between grips and loaded to failure in the U. S. Forest Products Laboratory tension machine at a rate of 260 pounds per second.

The measured axial tensile force was used to calculate the tensile strength parallel-to-grain for each specimen. Table 1 shows the mean tensile strength and coefficient of variation (COV) for each type of lumber. In every case, the mean tensile strength was considerably less in the 120-inch than in the 30-inch specimen. Figure 2 shows the relationship between length and strength for each group of lumber.

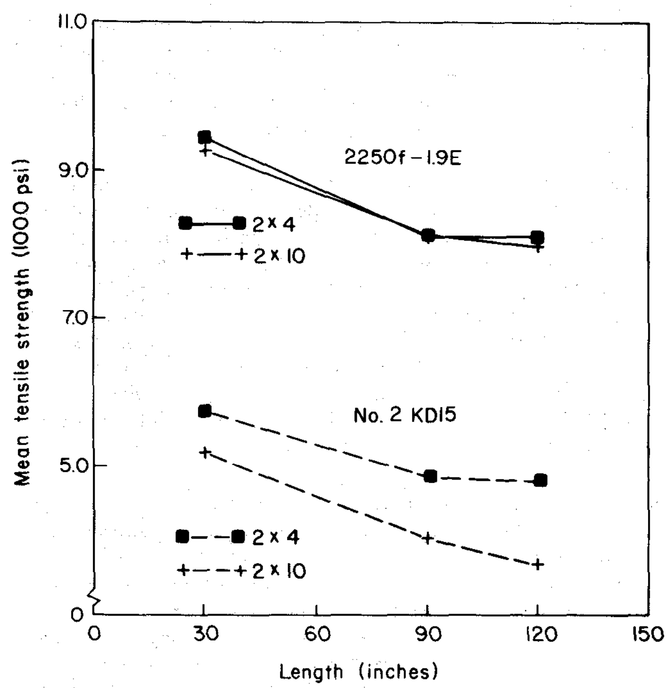

Figure 2—Mean tensile strength of Southern Pine specimens with test spans of 30, 90, and 120 inches. (ML86 5327)

The Mathematical Model

Development

Demonstration of the reality of a length effect on tensile strength of lumber specimens justified the development of a model to predict tensile strength, given that length is a factor of tensile strength. The model was based on the theory that a piece of lumber loaded in tension fails at the weakest point. That is, the ultimate tensile strength of a 90-inch (or a 120-in) specimen of lumber can be defined as the tensile strength in the weakest of the three (or four) 30-inch segments forming the specimen.

Assuming the weakest-link theory, the general approach was to generate tensile strength values for 30-inch segments of lumber specimens. For example, for a 120-inch piece of lumber, the model generated four tensile strength values and selected the lowest of the four as the tensile strength of the whole piece. The longer the specimen, the more numerous the 30-inch segments and the greater the probability of generating a low tensile strength value. In this way, the model generated tensile strength values according to the length of the specimens.

At first, it was assumed that the 30-inch segments in a lumber specimen were uncorrelated. A model was developed to generate a probability distribution of tensile strength for a lumber specimen of n 30-inch segments using the statistical theory of extreme values (Ang and Tang 1984). Actual test data from the 30-inch treatment groups from the four grade and size types were used for this purpose. The first model, however, failed to predict the actual tensile behavior of the 90-inch and 120-inch treatment groups and the approach assuming uncorrelated segments was abandoned. A more detailed description of the model is given by Showalter (1985).

The significant correlation observed between the tensile strengths of the first and fourth 30-inch segments in each of the four grade and size groups made it reasonable to assume lag-l serial correlation (i.e. that the tensile strength parallel-to-grain of one segment was correlated with that of the previous segment). A length-effect model was, therefore, developed taking into account the serial correlation of tensile strength between segments. The method used was to insert segment MOE values in an appropriate weighted least squares regression model to obtain an adjusted tensile strength parallel-to-grain for each of the 30-inch segments of the lumber specimen before selecting the least of the segment tensile strengths as the tensile strength of the whole.

It is well known that tensile strength parallel-to-grain is positively correlated with MOE in lumber. In the development of a length-effect model for tension, therefore, it was fortunate that an MOE variability model existed (Kline et al. 1986) that generates serially correlated MOE values along 30-inch segments of a piece of lumber. Following Kline et al., a second-order Markov process was used to model the lengthwise variability of MOE along a piece of lumber, given the type of lumber, number of segments, and a random observation from a distribution of piece-average MOE values.

Tensile strength values parallel-to-grain for the 30-inch segments of a lumber specimen were then generated using a weighted least squares regression model developed by Woeste et al. (1979). The regression model is given by

$$Y = \beta_1 X + \beta_0 + \varepsilon \qquad (1)$$

where

Y = tensile strength parallel-to-grain in pounds per square inch (lb/in^2)
X = the independent variable, MOE,
ε is assumed to be normally distributed with zero mean and residual variance kX.

Estimates by b_1, b_0, and k, of the parameters β_1, β_0 and k were calculated for each grade and size group using the MOE and tensile strength data from the 30-inch treatment groups. Scattergrams of observed MOE against tensile strength with overlays of the regression lines gave evidence that the residuals were nonnormal. The residuals appeared to be truncated in the lower tail and also skewed in the plus direction.

When data exhibit this type of lack of fit, a logarithmic transformation of the dependent variable (tensile strength) is likely greatly to improve the fit (Woeste et al. 1979). With this transformation, the regression model is

$$\ln(Y) = \beta_1 X + \beta_0 + \varepsilon \qquad (2)$$

Table 2 shows the estimates b_0, b_1 and k for each grade and size. With this model, the residuals showed no obvious lack of tit.

Thus, values of tensile strength for each of the 30-inch segments of a lumber specimen were generated. Assuming a theory analogous to Weibulls's "weakest link theory" (1939), the lowest of the values for a 30-inch segment defines the tensile strength of the lumber specimen.

Length-effect models of tensile strength were developed for 2 by 4 and 2 by 10, VG and MSR, 90-inch and 120-inch pieces of lumber using the procedure that assumes the segment values are correlated. Although the length effect models again failed to predict the actual tensile behavior of the 90-inch and 120-inch specimens, correlated-segment models appeared to predict the behavior better than independent-segment models (Showalter 1985). These findings suggested that perhaps the correlated segment model might be modified to predict the behavior of the tensile strength parallel-to-grain in a lumber specimen successfully.

Table 2—Estimates of parameters β_0, β_1, and k in the regression model (Eq. 2) for 30-inch treatment groups

Lumber size and grade	β_0	$\beta 1$	k
2 by 4, 2250f - 1.9E	8.14	0.381E-6	0.258E-7
2 by 4, No. 2 KD15	7.27	.744E-6	.629E-7
2 by 10, 2250f - 1.9E	8.48	.259E-6	.334E-7
2 by 10, No. 2 KD15	7.16	.717E-6	.930E-7

Refinement

In the previous correlated segment model, the only correlation taken into account when generating the tensile strength values was the serial correlation of MOE. However, tensile strength residuals of neighboring segments also may be correlated, as appears from extensive research on the correlations of bending and tension, and bending and compressive strength in the same piece of lumber (Evans et al. 1984, Green et al. 1984).

One way of modeling this residual correlation is to assume the residuals in the log space follow a first-order Markov normal process. Because-the relationship between MOE and tensile strength is modeled using the logarithmic. transformation of the tensile strength, the residuals also are taken in the log space. A first-order Markov model generates a series of values from a normal distribution while preserving the first-order, or lag-1, serial correlation. It also generates serial correlations of any tag K by the theoretical model

$$\rho_k = \rho_1^k \tag{3}$$

when the estimated lag-l serial correlation r_l is inserted in place of ρ_1 (Haan 1977).

It is physically impossible to measure the first-order serial correlation, but the lag-3 serial correlation can be estimated from data for the 30-inch treatment groups. Then by using the inverse of equation (3), the lag-1 serial correlation can be estimated for input into the Markov model.

The MOE and tensile strength data were collected from the first and fourth 30-inch segments for the groups of lumber. The residual for each segment was obtained, using equation (2) in the following form

$$\varepsilon = \ln(Y) - b_0 - b_i X \tag{4}$$

where
Y = measured tensile strength parallel-to-grain (lb/in^2)
X = measured MOE in (lb/in^2)
ε = calculated residual for each segment

and the estimates b_0, b_1, and k are given in the model development. The lag-3 serial correlation between the residuals of the first and fourth segments was then estimated and the logarithm of this correlation tested using the t distribution (Haan 1977). The null hypothesis (that there is no correlation) was rejected for all four 30-inch treatment groups. The implication was that, in the log space, residuals of tensile strength for the first and fourth segment are positively correlated.

The lag-l serial correlation r_l was calculated using the inverse of equation (3), $\rho_1 = \rho_k^{1/k}$. Table 3 lists r_l and the estimated lag-3 serial correlation, r_3, for each grade and size group.

Table 3—Estimates of lag-3 (r_3) and lag-1 (r_1) serial correlation

Lumber size and grade	[1] r_3	[2] r_1
2 by 4, 2250f - 1.9E	0.444	0.763
2 by 4, No. 2 KD15	.831	.940
2 by 10, 2250F - 1.9E	.402	.738
2 by 10, No. 2 KD15	.589	.838

[1]Estimated from test data.

[2]Calculated from r_3.

Assuming that residuals were normally distributed with mean zero and residual variance k times MOE (k*(MOE)), the next step was to generalize the first-order Markov model to account for the variation of the residual variance between segments. If the mean or variance is nonstationary or varies between segments, the first-order Markov model becomes

$$x_{i+1} = \mu_{x,i+1} + (\rho_1 \sigma_{x,i+1}/\sigma_{x,i})(x_i - \mu_{x,i}) + t_{i+1}\sigma_{x,i+1}(1 - \rho_1^2)^{\frac{1}{2}} \tag{5}$$

where
x_i = the value of x at segment i
$\mu_{x,i}$ = the mean of x at segment i
$\sigma_{x,i}$ = the standard deviation of x at segment i
ρ_1 = the first-order serial correlation
t_{i+1} = standard normal deviate, N(0,l)

This model assumes x_i to be from a normal distribution with mean $\mu_{x,i}$, variance $\sigma_{x,i}^2$, denoted by $N(\mu_{x,i}, \sigma_{x,i}^2)$, and first-order serial correlation ρ_1 (Haan 1977). It is also assumed that t_{i+1} is independent of x_i. Equation (5) is simplified by

$$x_{i+1} = r_1(k^*(MOE)_{i+1})^{\frac{1}{2}}/(k^*(MOE)_i)^{\frac{1}{2}} x_i + t_{i+1}(k^*(MOE)_{i+1})^{\frac{1}{2}}(1 - r_1^2)^{\frac{1}{2}} \tag{6}$$

where
μ_x is zero and σ_x^2 = k*(MOE).

Thus, the model incorporates the two processes occuring within each piece of lumber: variation of MOE and variation of residual tensile strength in log space with a variance k*(MOE). The 30-inch segment MOE variability within each piece of lumber has been shown to be modeled by a second-order Markov process (Kline et al. 1986). The 30-inch segment tensile strength residual within each piece was modeled by a first-order Markov process. This nonstationary model was developed to generate residuals in the log space along a piece of lumber, a different residual being generated every 30 inches, and all the residuals depending on the generated MOE values through their variance k*(MOE).

To start the generation process, Haan (1977) has suggested selecting the first value of x_i, x_1, at random from the-distribution $N(\mu_x, \sigma_x^2)$. and then discarding a number of the first generated values to eliminate the effect of x_1 on the generated sequence. For this study, the first residual, x_i in equation (6), was arbitrarily set equal to zero, and 10 values were generated and discarded. The corresponding 10 MOE values generated from the MOE variability model (MOE_1 through MOE_{10}) were also discarded. The eleventh generated residual, x_{11}, and the eleventh generated MOE value, MOE_{11}, were assigned to the first 30-inch segment, the twelvth values were assigned to the second segment, and so on until a residual and an MOE value had been generated for each 30-inch segment of me whole length. The segment residuals and MOE values were then used as input in the weighted least squares regression model (eq. (2)) to generate tensile strength values for each segment of the lumber specimen.

Verification

The refined length-effect models of tensile strength were used to generate tensile strength values for evaluation against test data from the 90-inch and 120-inch treatment groups. Two thousand piece-average MOE values were generated as input in the MOE variability model for each of the four types and two lengths of lumber. The segment MOE values and the segment residuals were then used as input in the weighted least squares regression to obtain the tensile strength parallel-to-grain for each 30-inch segment. The tensile strength values of the generated 90-inch and 120-inch lengths were then determined using a weakest link theory.

The probability distribution functions for each of the eight tensile strength models were determined in order to compare them with the test data. The lognormal distribution was overlaid on the histogram of generated tensile strength values from each model. Visual inspection indicated that the lognormal distribution fitted the generated tensile strength values for each of the eight cases under study.

The model-generated probability curves for the length effect on tensile strength were superimposed onto histograms of the actual test data. Figure 3 shows each model-generated probability curve overlaid on the test data for 90-inch and 120-inch specimens of each lumber grade and size. Visual appraisal indicated that the models adequately described the data. A Kolmogorov-Smirnov test was made of the goodness of fit of the model-generated probability curves on the eight sets of test data and the fit was rejected at the 5 percent significance level only in the case of the 2 by 10 MSR 120-inch lumber.

A goodness-of-fit test at the 5 percent significance level will on the average, reject a true hypothesis 5 times in 100 tests or about once in 20 tests. In this study, one out of eight cases was rejected (2 by 10 MSR 120-in). It is possible that the Kolmogorov-Smimov goodness-of-fit test in this case rejected a true hypothesis.

The fifth percentile values of tensile strength derived from the model and the data are shown in table 4 and figure 4. Values from the data were calculated assuming a lognormal distribution which provides a better fit than the 3-parameter Weibull. The values generated by the model appear to agree well with the data, especially if one considers the difficulty of predicting a tail value, such as the fifth percentile, of an unknown distribution. These values were generated from the length-effect model for lengths of 90, 120, and 300 inches, the 300-inch length being generated to show predictions for the limiting case where the number of segments is large.

Both model-generated and actual tensile strength values exhibit a nonlinear decrease in tensile strength with increasing length. This is to be expected on the asymptotic theory of statistical extremes. According to this theory (Ang and Tang 1984), the spread of the distribution of the smallest value in a sample of size n decreases as n increases and, as n approaches infinity, may converge to a particular functional form. Relating the theory to length effects in lumber, as the number of 30-inch segments in a lumber specimen increases, the probability of generating a smaller strength value increases more slowly, and the smallest strength value generated asymptotically approaches a minimal value.

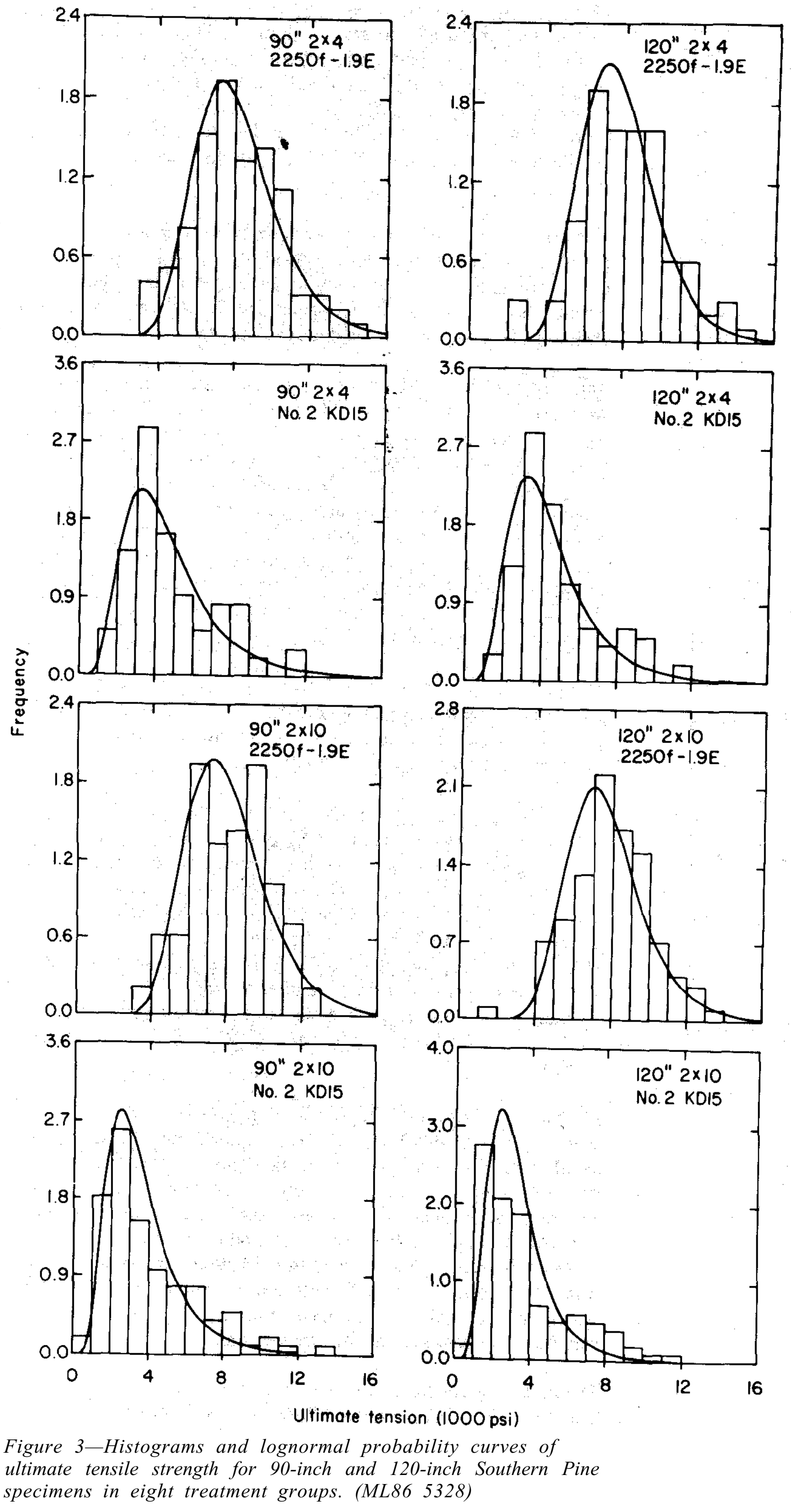

Figure 3—Histograms and lognormal probability curves of ultimate tensile strength for 90-inch and 120-inch Southern Pine specimens in eight treatment groups. (ML86 5328)

Table 4—Fifth percentile values of tensile strength

Lumber size, grade, and length	Actual[1]	Model
	-------- *Lb/in*^{2} --------	
2 by 4, 2250f - 1.9E, 300 in	—	4,547
120 in	4,533	4,982
90 in	4,749	5,102
2 by 4, No. 2 KD15, 300 in	—	1,685
120 in	2,103	1,866
90 in	1,995	1,855
2 by 10, 2250f - 1.9E, 300 in	—	4,476
120 in	4,733	4,002
90 in	5,039	5,031
2 by 10, No. 2 KD15, 300 in	—	1,230
120 in	1,025	1,421
90 in	1,230	1,456

[1]Assuming log-normal distribution.

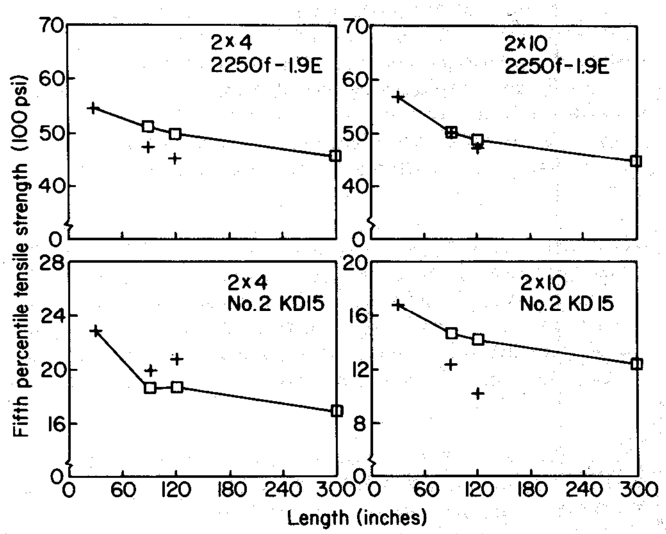

Figure 4—Fifth percentile tensile strength values of Southern Pine generated by model (•) and derived from test data (+). (ML86 5329)

Summary

This study was designed first to investigate the effect of length on tensile strength parallel-to-grain in lumber. This was done by testing diverse sizes and grades of Southern Pine lumber having test span lengths of 30, 90, and 120 inches. The measured tensile strengths were significantly lower in the longer specimens, average values being 70 to 86 percent less for 120-inch lengths and 78 to 88 percent less for 90-inch lengths than for 30-inch lengths.

The effect of length on tensile strength having been demonstrated, the objective became the development of a model to generate tensile strength values according to the length of the pieces of lumber. Samples of about 100 specimens in each test group were chosen to be adequate for model- development.

Tensile strength and MOE data from the 30-inch treatment groups- were used to develop length-effect models of tensile strength for the four grade and size groups. A MOE variability model (Kline et al. 1986) was used to generate 30-inch segment MOE values for a piece of lumber. The segment MOE values were used as input in a weighted least squares regression model in which the residuals were assumed to follow a first-order Markov process. The weighted least squares regression model generated 30-inch segment tensile strength values. Using the weakest link concept, the lowest of the segment tensile strength values was selected as the tensile strength of the whole.

The probability of generating lower tensile strength values increases as the number of segments, or the length of the lumber, increases. Thus, the length-effect model predicts a lower tensile strength for a longer piece of lumber.

The MOE variability model (Kline et al. 1986), which was necessary to model segment MOE, is a second-order Markov process. Segment tensile strength was found to follow a parallel first-order Markov process. The two Markov processes were linked by a weighted least squares regression model involving segment tensile strength as the dependent variable and segment MOE as the independent variable. This study showed that the tensile strength distribution of lumber 90 and 120 inches long can be adequately modeled from a statistically-based knowledge of the MOE and tensile strength characteristics of 30-inch lumber segments.

A model assuming that lengthwise segments of a lumber specimen are uncorrelated was found inadequate to describe the tensile behavior of a lumber specimen and was rejected. The first model developed to account for serial correlation in MOE was also rejected because of its inability adequately to describe the test data. In this correlated segment model, the only correlation between 30-inch segments used in predicting tension was derived from the correlation of MOE between the segments. Satisfactory results were obtained from a refined model, using the serial correlation in segment tensile strength parallel-to-grain.

The **data** base for the study was limited in scope and size. Larger samples, and a wider variety of commercial grades and species of lumber should be studied to verify that the Markov processes make a good model for the length effect on tensile strength and to improve the accuracy of estimates of the model parameters.

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