TENSILE STRENGTH OF SPECIAL DOUGLAS-FIR AND HEM-FIR 2-INCH DIMENSION LUMBER

James W. Johnson
Associate Professor Forest Products
School of Forestry, Oregon State University, Corvallis, OR 97331

and

Robert H. Kunesh
Wood Technologist
Trus-Joist Corporation, Boise, ID 83702

(Received 12 August 1974)

ABSTRACT

Nominal 2- by 4-, 6-, 8-, and 10-inch Douglas-fir and hem-fir dimension lumber was tested in tension parallel-to-grain. Five hundred ninety-three pieces of hem-fir and 563 of Douglas-fir were included in various categories of none, single small and large center and edge knots, and multiple knots. Tension stress, specific gravity, and modulus of elasticity in flatwise bending decreased as width of lumber increased. Tensile strength decreased with increased knot size. Pieces of lumber with single center knots occupying 21% of the width were similar in tensile strength to pieces of lumber with single edge knots occupying 14%. Pieces containing several small knots, well scattered, were as strong in tension as those with single small knots. Tensile strengths of Douglas-fir and hem-fir were not significantly different. In estimating lower exclusion values, adjustments should be made for skewed distributions. One method is suggested.

Additional keywords: *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Abies spp.*, edge knots, center knots, single knots, multiple knots, specific gravity, modulus of elasticity, skewed distributions, strength tests, lumber strength.

INTRODUCTION

The objective of this study was to determine the tensile strength parallel-to-grain of high-grade Douglas-fir and hem-fir dimension lumber. We believe that where tensile strength becomes a critical factor in specialized uses, these uses will demand the higher grades of material, or possibly a newly established special grade. Our primary effort was directed toward providing information to those concerned with establishing lumber grades and to those using Douglas-fir and hem-fir dimension lumber in tension.

This work was the major part of a series of tension tests started several years ago at Oregon State University's Forest Research Laboratory. Results have been published (Kunesh 1966; Kunesh and Johnson 1972; Kunesh and Johnson 1974). The work reported herein was more extensive than our previous studies and was intended to supplement studies made by others, referred to by Kunesh and Johnson (1972), who have done work with Douglas-fir and other species, not including hem-fir.

The species combination, hem-fir, includes western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), California red fir (*Abies magnifica* A. Murr.), grand fir (*Abies grandis* [Dougl.] Lindl.), noble fir (*Abies procera* Rehd.), Pacific silver fir (*Abies amabilis* [Dougl.] Forbes), and white fir (*Abies concolor* [Gord. & Glend.] Lindl.). Identification by piece was not made, but a sampling indicated that probably 85% or more of the hem-fir specimens were western hemlock. Probably, most of the *Abies* was *grandis* and little *magnifica* or *concolor* was included.

PROCEDURE

Five hundred ninety-three pieces of hem-fir and 563 of Douglas-fir were se-

TABLE 1. *Summary of tension parallel-to-grain tests made on Douglas-fir and hem-fir dimension lumber showing numbers of pieces tested that contained different types and sizes of single knots, plus clear pieces, plus some pieces of lumber with a combination of knots*

Type of knot	Douglas-fir Size of knot[1] In.	Douglas-fir Percent knot[2] %	Douglas-fir Number of pieces	Hem-fir Size of knot[1] In.	Hem-fir Percent knot[2] %	Hem-fir Number of pieces
Nominal 2 by 4 inch (1.5 by 3.5 actual)						
None (clear)	---	--	22	---	--	22
Edge (small)	1/2	14.3	22	1/2	14.3	22
Edge (large)	1	28.6	22	7/8	25.0	22
Center (small)	3/4	21.4	22	3/4	21.4	22
Center (large)	1 1/4	35.7	16	1 1/8	32.1	22
Combination A[3]	1/2 E & 3/4 C	--	22	1/2 E & 3/4 C	--	22
Combination B	same[4]	--	22	same[4]	--	22
Nominal 2 by 6 inch (1.5 by 5.5 actual)						
None (clear	---	--	22	---	--	22
Edge (small)	3/4	13.6	22	3/4	13.6	22
Edge (large)	1 1/2	27.3	22	1 1/4	22.7	22
Center (small)	1 1/8	20.5	22	1 1/8	20.5	22
Center (large)	1 7/8	34.1	5	1 5/8	29.5	17
Combination A[3]	3/4 E & 1 1/8 C	--	22	3/4 E & 1 1/8 C	--	22
Combination B	same[4]	--	22	same[4]	--	22
Nominal 2 by 8 inch (1.5 by 7.25 actual)						
None (clear)	---	--	22	---	--	22
Edge (small)	1	13.8	22	1	13.8	22
Edge (large)	2	27.6	22	1 5/8	22.4	22
Center (small)	1 1/2	20.7	22	1 1/2	20.7	22
Center (large)	2 1/2	34.5	9	2 1/8	29.3	19
Combination A[3]	1 E & 1 1/2 C	--	22	1 E & 1 1/2 C	--	22
Combination B	same[4]	--	22	same[4]	--	22
Nominal 2 by 10 inch (1.5 by 9.25 actual)						
None (clear)	---	--	22	---	--	22
Edge (small)	1 1/4	13.5	22	1 1/4	13.5	22
Edge (large)	2 1/2	27.0	22	2 1/8	23.0	22
Center (small)	1 7/8	20.3	22	1 7/8	20.3	·22
Center (large)	3 1/8	33.8	5	2 3/4	29.7	7
Combination A[3]	1 1/4 E & 1 7/8 C	--	22	1 1/4 E & 1 7/8 C	--	22
Combination B	same[4]	--	22	same[4]	--	22

[1]Width of knot measured on wide face between lines parallel to edge of piece.
[2]These are approximate. Size of knot in column 2 divided by the actual widths corresponding to the respective nominal sizes.
[3]More than one knot in a piece, but limited to the same size as the smallest edge (E) or center (C) knot. Knots well scattered (2-foot minimum spacing, except when small knots in a 1-foot section were accumulated).
[4]Same as Combination-A, but these were pieces that were just on the borderline of being in the Combination-A category.

lected from five mills in western Oregon. Test material was nominal 2- by 4-, 6-, 8-, and 10-inch dimension lumber. Seven categories (samples) were established within each width of lumber and in each species that depended on ratio of knots to lumber width, on location of knots in the lumber, and on combinations of knots. These categories did not correspond to standard grades. We selected pieces with single knots to isolate knots as a variable. Pieces with combinations of knots were selected for comparison because most pieces that are manufactured contain multiple knots.

In this report, small edge knots refer to knots that occupied about 14% of the

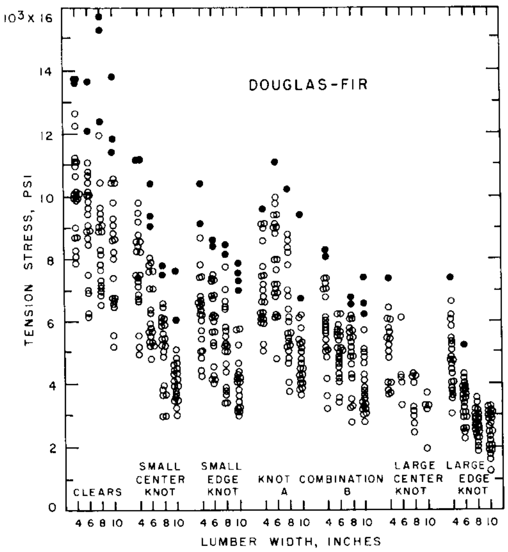

FIG. 1. Distributions of tension stress obtained from tests of nominal 2- by 4-, 6-, 8-, and 10-inch Douglas-fir dimension lumber at 9% moisture content. See Table 1 for sizes of knots in the different samples within each size of lumber. Solid circles were the values excluded so that remaining values were the adjusted distributions.

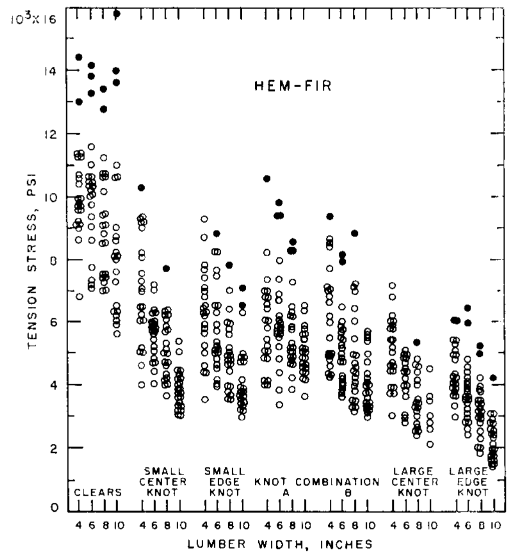

FIG. 2. Distributions of tension stress obtained from tests of nominal 2- by 4-, 6-, 8-, and 10-inch hem-fir dimension lumber at 10% moisture content. See Table 1 for sizes of knots in the different samples within each size of lumber. Solid circles were the values excluded so that remaining values were the adjusted distributions.

width of the piece of lumber and small center knots occupied about 21%. For Douglas-fir, large edge and center knots occupied 28 and 35% of widths, respectively; and in hem-fir the percentages occupied were about 23 for large edge and 30 for large center knots. Exact sizes of knots and percentages are given in Table 1, along with the number of pieces tested in each category.

The seven categories were: (one) clear lumber; (two) a single small edge knot; (three) a single large edge knot; (four) a single small center knot; (five) a single large center knot; (six) pieces of lumber that contained more than one knot (Combination A); and (seven) pieces quite similar to those of Combination A, but of borderline quality based on visual characteristics (Combination B). All test specimens were chosen randomly from the mills, consistent with the restrictions placed on each category.

Restrictions and comments regarding the selection of specimens are as follows:

1. General slope of grain not to exceed 1 in 16 was required for all specimens.
2. Exceptionally light-weight pieces, amounting to about 1% of pieces otherwise suitable, were not included. Lightest Douglas-fir piece had a specific gravity of 0.38 (oven-dry weight and volume); lightest hem-fir was 0.32.
3. Pieces with excessive grain distortion around a knot or excessive local grain (large knot missing, but grain deviation still present) were not included.
4. Knot size was an average width of knot measured on the 2 wide faces between lines parallel to edges of the piece, with a tolerance of plus or minus ⅛ inch for sizes up to 2 inches and ¼ inch for sizes 2 inches and greater. Few spike-type knots were included.
5. Edge knots generally were whole knots (not parts of big knots), and at least ¾ of the knot was within the outside quarter-width of the piece. In most pieces, the knots touched the edge.

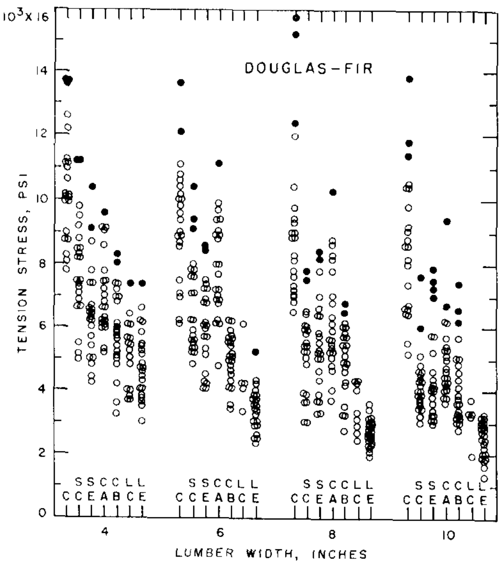

FIG. 3. Distributions of tension stress obtained from tests of nominal 2- by 4-, 6-, 8-, and 10-inch Douglas-fir dimension lumber at 9% moisture content. Code for samples: C for clears, SC for small center, SE for small edge, CA and CB for knot combinations A and B, LC for large center, and LE for large edge knots. See Table 1 for sizes of knots in the different samples within each size of lumber. Solid circles were the values excluded so that remaining values were the adjusted distributions.

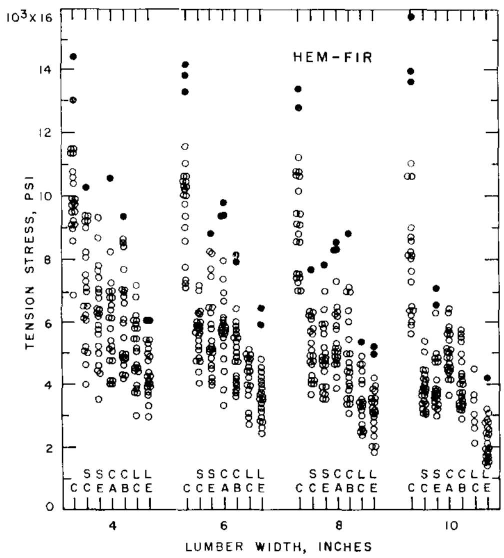

FIG. 4. Distributions of tension stress obtained from tests of nominal 2- by 4-, 6-, 8-, and 10-inch hem-fir dimension lumber at 10% moisture content. Code for samples: C for clears, SC for small center, SE for small edge, CA and CB for knot combinations A and B, LC for large center, and LE for large edge knots. See Table 1 for sizes of knots in the different samples within each size of lumber. Solid circles were the values excluded so that remaining values were the adjusted distributions.

6. Center knots had at least ¾ of the knot within the central half-width of the piece.
7. Combination A were pieces containing more than one knot, with the edge and center knots being limited to the same sizes used in the small edge and small center knot categories. Generally, one or more maximum-size knots were present. Knots were well scattered with a minimum spacing of 2 ft except that smaller knots in a 1-ft length could be added together (accumulated) if the sum were not greater than the limiting size for the category. Few specimens had the accumulative-type knots.
8. Combination B were pieces that, in the judgment of the selector, were questionable of inclusion (borderline) in Combination A category. Combination B was included to gain some indication of tension values to expect if restrictions of Combination A were relaxed slightly, such as allowing a little more grain distortion by a knot or the knot size to increase by as much as 1/16 inch.

Selection of the lumber took considerable time because of restrictions imposed. From four categories—clears, smallest edge knot, smallest center knot, and Combination A—we expected to obtain good tension values, but at the expense of careful selection. The larger single-knot sizes were considered as the maximum size knots worth testing. In other words, we thought that specimens with knots of larger size would give tension values too low for use. Our goal was to obtain at least 20 pieces in each category, if possible. Finding dimension lumber with the single large center knot was very difficult, however, and was abandoned before reaching 20. Other-

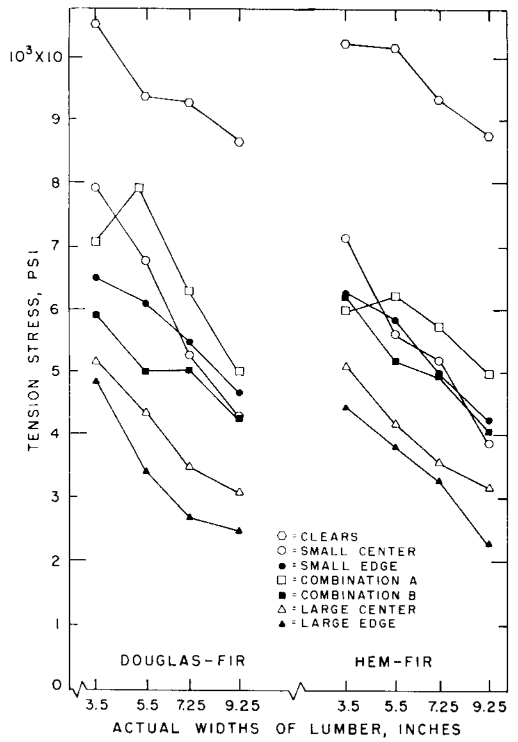

FIG. 5. Average values of tension stress for the various categories of knots for Douglas-fir and hem-fir 2-inch dimension lumber of nominal 4-, 6-, 8-, and 10-inch widths. Douglas-fir was at 9 and hem-fir at 10% moisture content when tested. Plotted points are an average of 22 specimens except for the large center knot samples, which had fewer specimens (see Table 1).

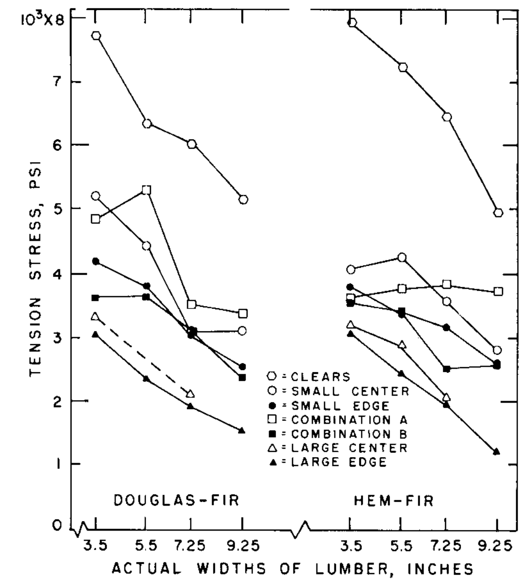

FIG. 6. Tension stress values at the lower 5% exclusion limit for the various categories of knots for Douglas-fir and hem-fir 2-inch dimension lumber of nominal 4-, 6-, 8-, and 10-inch widths. Douglas-fir was at 9 and hem-fir at 10% moisture content when tested. Plotted points were calculated from the adjusted distributions in which some of the greater test values were not included. See Figures 1–4 for values left out.

wise, each of the categories had 22 pieces, which were selected during all seasons of the year.

Before testing in tension, each 17-ft piece of lumber was measured for stiffness in flatwise bending (MOE), using a deadweight load midlength of a 14-ft span. In the single-knot specimens, the knot was located within the midlength 10 ft; so the knot could have been from zero to 5 ft away from the center-point load. Also, for the single-knot categories we recorded the small and large size of the knot and distance from the edge of the knot to edge of the piece. We did not measure MOE in tension.

Tension tests conformed with provisions of designation D 198-67 of American Society for Testing and Materials and were made on a specially designed tensile tester of 200,000 pounds capacity, described earlier (Kunesh and Johnson 1974). Tensile stresses and MOE in bending were computed by standard formulas using actual dimensions of the specimens, and specific gravity was based on the oven-dry weight and volume of cross-section discs cut from one end of each piece.

RESULTS AND DISCUSSION

Results are presented in several tables and graphs in an attempt to condense the large amount of data and the many calculations that were made. Statistical analyses and procedures were used extensively. Average moisture content of the specimens was 9 and 10% respectively, for the Douglas-fir and hem-fir, which were reached by long-term storage under ambient conditions.

TABLE 2. *Summary of average[1] and standard deviation values (below) for tension parallel-to-grain and related properties of Douglas-fir dimension lumber at 9% moisture content when tested*

Nominal width of lumber, inches	Clears	Single small center knot (21%)	Single small edge knot (14%)	Combination of small edge and center knots; well-scattered A	B	Single large center knot (35%)	Single large edge knot (28%)
Tension stress, psi							
4	10,550	7,930	6,530	7,080	5,930	5,170[1]	4,850
	1,779	1,686	1,536	1,333	1,361	1,101	1,103
6	9,370	6,790	6,100	7,920	5,010	4,360[1]	3,420
	1,865	1,564	1,364	1,561	788	1,036	691
8	9,280	5,280	5,490	6,320	5,030	3,480[1]	2,670
	2,542	1,319	1,501	1,718	1,105	735	434
10	8,660	4,300	4,680	5,030	4,270	3,070[1]	2,480
	2,196	1,007	1,566	1,304	1,307	663	547
Moduli of elasticity in flatwise bending, 1000 psi[2]							
4	2,538[b]	2,619[b]	2,607[b]	2,994[a]	2,583[b]	2,360[1]	2,531[b]
	262	384	434	402	359	238	396
6	2,408[b]	2,451[b]	2,578[b]	2,900[a]	2,581[b]	2,203[1]	2,264[c]
	395	372	259	148	315	351	217
8	2,509[b]	2,454[b]	2,457[b]	2,534[b]	2,542[b]	2,086[1]	2,188[c]
	431	260	354	309	370	322	349
10	2,650[b]	2,079[c]	2,451[b]	2,285[c]	2,163[c]	1,968[1]	2,156[c]
	443	342	393	363	343	473	322
Specific gravity, oven-dry weight and volume[2]							
4	0.56[a]	0.55[b]	0.55[b]	0.57[a]	0.51[c]	0.53[1]	0.54[b]
	0.06	0.05	0.07	0.06	0.05	0.05	0.07
6	0.54[b]	0.53[b]	0.54[b]	0.56[a]	0.52[b]	0.50[1]	0.50[c]
	0.05	0.06	0.04	0.05	0.07	0.07	0.04
8	0.54[b]	0.52[b]	0.53[b]	0.55[b]	0.52[b]	0.50[1]	0.52[b]
	0.07	0.04	0.05	0.07	0.06	0.03	0.06
10	0.58[a]	0.48[c]	0.52[b]	0.49[c]	0.48[c]	0.51[1]	0.52[b]
	0.07	0.05	0.05	0.06	0.04	0.07	0.05

[1]Average of 22 pieces in all samples except in large center knots; 16 pieces for 4-, 5 for 6-, 9 for 8-, and 5 for 10-inch samples.
[2]The superscripts a, b, c indicate, in a general way (some overlapping between samples), the values that were significantly different or not by analyses of variance at the 5 percent level of significance; those with the same superscript were not significantly different. Values with superscript 1 were not in analyses. See Tables 4 and 5 for analyses of tension values.

Correlations of various properties

We were not expecting high correlations, because the project was not really designed for correlations but was planned to obtain values from samples in which all specimens of each sample contained knots of essentially the same size and kind (center, edge, or a combination of the two). However, we attempted to correlate measurements of each of the single knots, MOE, and specific gravity with tensile stress.

Single and multiple correlations were tried for all data from the 2- by 4-inch size and for both species. Correlation coefficients (r) were poor, generally (most were below 0.50). Multiple correlations to predict tension stresses were no better than single correlations. Plotted data from larger pieces (6-, 8-, and 10-inch widths) gave no better indications of good relationships, so these data were not tried for possible correlations.

TABLE 3. *Summary of average[1] and standard deviation values (below) for tension parallel-to-grain and related properties of hem-fir dimension lumber at 10% moisture content when tested*

Nominal width of lumber; inches	Clears	Single small center knot (21%)	Single small edge knot (14%)	Combination of small edge and center knots; well-scattered A	B	Single large center knot (30%)	Single large edge knot (23%)
Tension stress, psi							
4	10,230	7.140	6,270	5,990	6,240	5,090	4,460
	1,574	1,801	1,441	1,584	1,598	1,088	846
6	10,170	5,630	5,850	6,240	5,190	4,180[1]	3,810
	1,931	791	1,471	1,716	1,228	737	1,000
8	9,340	5,210	5,000	5,760	4,940	3,570[1]	3,280
	1,834	1,024	1,147	1,343	1,541	904	864
10	8,760	3,870	4,260	5,000	4.060	3,180[1]	2,280
	2,803	607	1,139	730	867	785	705
Moduli of elasticity in flatwise bending, 1000 psi[2]							
4	2,197[b]	2,157[b]	2,253[a]	2,271[a]	2,408[a]	2,225[b]	2,103[b]
	309	210	344	317	322	359	256
6	2,271[a]	2,013[c]	2,147[b]	2,189[b]	2,101[b]	1,967[1]	2,094[c]
	255	231	207	264	246	261	324
8	2,237[b]	1,988[c]	2,109[b]	2,208[b]	2,123[b]	1,880[1]	2,005[c]
	275	296	238	259	251	219	213
10	2,260[a]	1,896[c]	2,054[c]	1,945[c]	1,977[c]	1,888[1]	1,691[d]
	330	275	298	247	174	215	213
Specific gravity, oven-dry weight and volume[2]							
4	0.47[a]	0.47[a]	0.48[a]	0.46[b]	0.49[a]	0.48[a]	0.46[b]
	0.04	0.04	0.05	0.05	0.05	0.04	0.04
6	0.48[a]	0.46[b]	0.47[a]	0.46[b]	0.45[b]	0.46[1]	0.46[b]
	0.04	0.04	0.03	0.04	0.05	0.04	0.04
8	0.47[a]	0.44[b]	0.46[b]	0.47[a]	0.46[b]	0.45[1]	0.46[b]
	0.05	0.05	0.03	0.05	0.03	0.04	0.03
10	0.49[a]	0.45[b]	0.46[b]	0.45[b]	0.45[b]	0.45[1]	0.42[c]
	0.05	0.03	0.05	0.04	0.03	0.03	0.04

[1]Average of 22 pieces in all samples except some in large center knots; 17 pieces for 6-, 19 for 8-, and 7 for 10-inch samples.

[2]The superscripts a, b, c, d indicate, in a general way (some overlapping between groups), the values that were significantly different or not by analyses of variance at the 5 percent level of significance; those with the same superscript were not significantly different. Values with superscript 1 were not in analyses. See Tables 4 and 5 for analyses of tension values.

For one 2- by 4-inch sample (small edge knot, hem-fir), a correlation coefficient of 0.82 was obtained between MOE and tension stress; but for most samples in both species, correlation coefficients for MOE and tension were less than 0.50. Best, and most consistent correlations (r), were between specific gravity and MOE. Most were above 0.50, but few were above 0.70.

Examination of all samples in both species showed that in most samples the lowest value for tension stress generally was associated with one of the three lowest values for MOE or specific gravity (or both); but further association of lower tension values with low MOE or specific gravity was not consistent. Likewise, the greatest values in tension usually were correlated with higher MOE or specific gravity values. But generally, MOE (in flatwise bending) and specific gravity were of limited value in estimating tension stress within these samples that had pieces of lumber so much alike visually.

TABLE 4. *Summary of analyses of variance[1] for average[2] values of tension parallel-to-grain for dry[3] Douglas-fir and hem-fir dimension lumber*

Nominal width of lumber; inches	Clears	Single small center knot (21%)	Single small edge knot (14%)	Combination of small edge and center knots; well-scattered A	B	Single large center knot (%)[4]	Single large edge knot (%)[4]
			Douglas-Fir				
4	10,550	7,930	6,530	7,080	5,930	5,170[2]	4,850
6	9,370	6,790	6,100	7,920	5,010	*4,360*[2]	3,420
8	9,280	5,280	5,490	6,320	5,030	*3,480*[2]	2,670
10	8,660	4,300	4,680	5,030	4,270	*3,070*[2]	2,480
			Hem-Fir				
4	10,230	7,140	6,270	5,990	6,240	5,090	4,460
6	10,170	5,630	5,850	6,240	5,190	4,180[2]	3,810
8	9,340	5,210	5,000	5,760	4,940	3,570[2]	3,280
10	8,760	3,870	4,260	5,000	4,060	*3,180*[2]	2,280

[1]The short lines off the longer vertical and horizontal lines indicate values not significantly different at the 5 percent level of significance. Values in italics were not included in analyses.
[2]Average of 22 pieces in all samples except for large center knots: 16 pieces for 4-, 5 for 6-, 9 for 8-, and 5 for 10-inch samples of Douglas-fir; 17 pieces for 6-, 19 for 8-, and 7 for 10-inch samples of hem-fir.
[3]Douglas-fir at 9 percent moisture content, hem-fir at 10 percent.
[4]Douglas-fir, large center knot 35 percent and large edge knot 28 percent; hem-fir, large center knot 30 percent and large edge knot 23 percent.

Moduli of elasticity and specific gravity

Average and standard deviation values for tension stress, MOE, and specific gravity are given in Tables 2 and 3. Also included for MOE and specific gravity are summaries from analyses of variance at the 5% level of significance. Analyses for tension stress are given later in more detail.

For both MOE and specific gravity, the classifications of average values by significant and nonsignificant differences (as indicated by superscripts a, b, c, d) were not distinct. Values with the same superscript (Table 2 and 3) were not significantly different, but there was some overlapping. For example, in some instances, the lower values in the group with the superscript b could have been classed with the higher values in the group identified by the superscript c, and so on.

Average MOE and specific gravity tended to decrease with an increase in width of lumber for most of the different knot types and sizes and for both species; but the decrease because of width of lumber was not always significant. Two samples of lumber (Douglas-fir, 2- by 4- and 2- by 6-inch, Combination A knots) had high specific gravity, noticeably high values for MOE, and correspondingly high values for tension stress. Probably, these two samples had slightly higher values than would be expected should another random sampling be made.

TABLE 5. *Comparison of average[1] values for tension parallel-to-grain (psi) of dry[2] Douglas-fir and hem-fir dimension lumber*

Species[3]	Nominal width of lumber, inches	Clears	Single small center knot (21%)	Single small edge knot (14%)	Combination of small edge and center knots; well-scattered A	B	Single large center knot (%)[4]	Single large edge knot (%)[4]
DF	4	10,550	7,930	6,530	7,080	5,930	5,170[1]	4,850
HF	4	10,230	7,140	6,270	5,990[5]	6,240	5,090	4,460
DF	6	9,370	6,790	6,100	7,920	5,010	*4,360*[1]	3,420
HF	6	10,170	5,630[5]	5,850	6,240[5]	5,190	4,180[1]	3,810
DF	8	9,280	5,280	5,490	6,320	5,030	*3,480*[1]	2,670
HF	8	9,340	5,210	5,000	5,760	4,940	3,570[1]	3,280[5]
DF	10	8,660	4,300	4,680	5,030	4,270	*3,070*[1]	2,480
HF	10	8,760	3,870	4,260	5,000	4,060	*3,180*[1]	2,280

[1]Average of 22 pieces in all samples except for large center knots: 16 pieces for 4-, 5 for 6-, 9 for 8-, and 5 for 10-inch samples of Douglas-fir; 17 pieces for 6-, 19 for 8-, and 7 for 10-inch samples of hem-fir. Values in italics were not included in statistical analyses.
[2]Douglas-fir at 9 percent moisture content; hem-fir at 10 percent.
[3]DF means Douglas fir; HF means hem-fir.
[4]Douglas-fir, large center knot 35 percent and large edge knot 28 percent; hem-fir, large center knot 30 percent and large edge knot 23 percent.
[5]Significant difference between these two values at the 5 percent level of significance.

Comparisons among average values for tension stress

Comparison of tension stress among widths of dimension lumber. The tendency for tension values to decrease as lumber width increased, for clear material and for each size and type of knot, is shown in Figs. 1, 2, and 5. Pieces within each of the seven categories of a species had the same percentage knot (size of knot divided by actual width of lumber, Table 1). Most distributions had a wide range of values (standard deviation values are given in Tables 2 and 3) and were skewed positively; however, this is quite common for distributions of values for properties of wood. Within each species, clear material had the largest standard deviation. Some effects of skewness will be discussed later.

Significant differences among tension stress values because of width of lumber were found within the clears and every category of knots for each species (Table 4), except for the large-center-knot category of Douglas-fir, which did not contain enough values for analysis. In all categories, there was a significant difference between the 4- and 10-inch widths. Among tension stresses of 4-, 6-, and 8-inch widths, differences ranged within the various knot categories from significant differences in all three widths to no significant difference among the three widths. Values connected by ticks off vertical lines in Table 4 were not significantly different.

Comparison of tension stress among knot types and sizes. Distributions of tension values, arranged according to various knot sizes and types within the different lumber widths, are given in Figs. 3 and 4, along with distributions for clear wood. Results of the analyses of variance are shown in Table 4; values connected by ticks off horizontal lines were not significantly different. Some grouping of values by significant differences were definite; some were not. But even where separations were not distinct, some guidelines can be given.

Average tension stress values for clear wood were significantly higher than all other categories, as expected. Values from the large edge knot and large center knot categories were similar to each other and were significantly lower than values from all other knot sizes.

Within most widths of lumber, the tension stress values for the single small cen-

TABLE 6. *Minimum values, in pounds per square inch (psi), obtained from the various sample distributions of tests of Douglas-fir and hem-fir 2-inch dimension lumber in tension parallel-to-grain*

Values[1] from samples	Douglas-fir nominal width, inches				Hem-fir nominal width, inches			
	4	6	8	10	4	6	8	10
			Clears					
Lowest	7,880	6,100	6,540	5,190	6,890	7,130	6,960	5,650
Next lowest	8,100	6,240	6,880	5,560	8,670	7,290	7,020	5,900
5%, standard	7,490	6,160	4,910	4,880	7,520	6,850	6,180	3,940
5%, adjusted	7,730	6,340	6,030	5,170	7,930	7,250	6,470	4,970
			Single Small Center Knot					
Lowest	4,920	4,770	2,960	3,030	3,950	4,020	3,670	3,120
Next lowest	5,130	5,210	2,980	3,260	4,640	4,450	3,970	3,140
5%, standard	5,030	4,100	3,010	2,570	4,040	4,270	3,450	2,830
5%, adjusted	5,210	4,440	3,100	3,110	4,070	4,270	3,580	2,830
			Single Small Edge Knot					
Lowest	4,250	4,090	3,350	2,960	3,560	3,930	3,530	2,930
Next lowest	4,430	4,150	3,350	3,100	4,330	4,040	3,570	3,270
5%, standard	3,890	3,750	2,910	1,990	3,790	3,320	3,030	2,300
5%, adjusted	4,200	3,830	3,050	2,550	3,790	3,400	3,180	2,600
			Combination Knots A					
Lowest	5,160	4,770	3,700	3,600	4,010	3,340	3,850	3,670
Next lowest	5,250	6,100	4,080	3,770	4,020	3,830	4,230	4,110
5%, standard	4,790	5,230	3,360	2,790	3,260	3,290	3,450	3,740
5%, adjusted	4,840	5,310	3,530	3,380	3,630	3,770	3,840	3,740
			Combination Knots B					
Lowest	3,200	3,400	2,750	2,760	4,230	3,670	3,100	2,910
Next lowest	3,620	3,530	3,270	3,010	4,320	3,700	3,320	3,170
5%, standard	3,590	3,650	3,130	2,020	3,490	3,080	2,290	2,570
5%, adjusted	3,630	3,650	3,100	2,370	3,550	3,410	2,520	2,570
			Single Large Center Knot					
Lowest	3,670	3,310	2,470	1,940	3,040	2,740	2,370	2,110
Next lowest	3,710	4,050	2,700	3,190	3,730	2,920	2,510	2,620
5%, standard	3,240	---	---	---	3,220	2,890	2,000	---
5%, adjusted	3,330	---	---	---	3,220	2,890	2,060	---
			Single Large Edge Knot					
Lowest	3,070	2,290	1,910	1,290	2,960	2,450	1,850	1,400
Next lowest	3,550	2,510	1,990	1,630	3,340	2,660	2,010	1,470
5%, standard	2,950	2,230	1,920	1,540	3,000	2,090	1,790	1,070
5%, adjusted	3,060	2,340	1,920	1,540	3,080	2,440	1,940	1,200

[1]Lowest and next lowest values obtained directly. "5% standard" are values at the lower 5 percent exclusion limit obtained by standard statistical methods using the table for t-distributions and the mean and standard deviation of all values (generally 22) in the sample. "5%, adjusted" are values at the lower 5 percent exclusion limit obtained by eliminating just the higher values in each distribution, then treating the remaining values in the standard way. In most distributions, two or less values were eliminated; in some, no values were eliminated.

ter and single small edge knots were not significantly different. Where there was a significant difference (4-inch width), average values from pieces with center knots were greater.

Logically, pieces of lumber containing several knots (even though well scattered) should not be stronger than pieces each with a single knot of similar size. Yet one sample with Combination A knots (Douglas-fir, 2 by 6) had an average value significantly higher than either the single small center or single small edge knot samples; but the MOE values for that Combination A sample were high also (Table 2).

We believe that tension stress values from three categories—single small center, single small edge, and Combination A knots—should be grouped together. Or stated another way, pieces of lumber with several small knots, well scattered, were

TABLE 7. *Statistics, pounds per square inch, and number of specimens for actual distributions followed by adjusted distributions (below) for the different width and knot classes of nominal 2-inch Douglas-fir dimension lumber at 9% moisture content tested in tension parallel-to-grain*

Statistic	Clears	Single small center knot[1]	Single small edge knot[1]	Combination of small edge and center knots; well-scattered A	Combination of small edge and center knots; well-scattered B	Single large center knot[1]	Single large edge knot[1]
			Nominal width, 4 inches				
Median	10,100	7,880	6,410	6,700	5,790	5,370	4,720
Mean	10,550	7,930	6,530	7,080	5,930	5,170	4,850
Std. dev.	1,779	1,686	1,536	1,333	1,361	1,101	1,103
5% excl.	7,490	5,030	3,890	4,790	3,590	3,240	2,950
Specimens	22	22	22	22	22	16	22
Median	10,040	7,490	6,280	6,610	5,720	5,280	4,710
Mean	10,060	7,600	6,200	6,960	5,710	5,020	4,730
Std. dev.	1,345	1,382	1,159	1,230	1,206	961	967
5% excl.	7,730	5,210	4,200	4,840	3,630	3,330	3,060
Specimens	19	20	20	21	20	15	21
			Nominal width, 6 inches				
Median	9,580	6,310	6,050	7,820	5,070	---	3,420
Mean	9,370	6,790	6,100	7,920	5,010	4,360	3,420
Std. dev.	1,865	1,564	1,364	1,561	788	1,036	691
5% excl.	6,160	4,100	3,750	5,230	3,650	---	2,230
Specimens	22	22	22	22	22	5	22
Median	9,280	5,940	6,010	7,700	---[2]	---[3]	3,410
Mean	9,020	6,330	5,860	7,770	---	---	3,330
Std. dev.	1,550	1,089	1,175	1,424	---	---	575
5% excl.	6,340	4,440	3,830	5,310	---	---	2,340
Specimens	20	19	20	21	---	---	21
			Nominal width, 8 inches				
Median	8,890	5,440	5,260	5,790	5,210	---	2,640
Mean	9,280	5,280	5,490	6,320	5,030	3,480	2,670
Std. dev.	2,542	1,319	1,501	1,718	1,105	735	434
5% excl.	4,910	3,010	2,910	3,360	3,130	---	1,920
Specimens	22	22	22	22	22	9	22
Median	8,320	5,350	5,220	5,650	5,030	---[3]	---[2]
Mean	8,460	5,040	5,210	6,130	4,870	---	---
Std. dev.	1,404	1,266	1,251	1,509	1,023	---	---
5% excl.	6,030	3,100	3,050	3,530	3,100	---	---
Specimens	19	20	20	21	20	---	---
			Nominal width, 10 inches				
Median	8,630	4,130	4,150	4,690	3,840	---	2,560
Mean	8,660	4,300	4,680	5,030	4,270	3,070	2,480
Std. dev.	2,196	1,007	1,566	1,304	1,307	663	547
5% excl.	4,880	2,570	1,990	2,790	2,020	---	1,540
Specimens	22	22	22	22	22	5	22
Median	8,260	4,040	4,110	4,560	3,660	---[3]	---[2]
Mean	8,070	4,050	4,060	4,730	3,870	---	---
Std. dev.	1,670	546	868	780	867	---	---
5% excl.	5,170	3,110	2,550	3,380	2,370	---	---
Specimens	19	20	18	20	19	---	---

[1]For sizes of knots see Table 1.
[2]No adjustment.
[3]Not enough specimens.

as strong in tension as pieces with single small knots, considering knots of equal size. Grouping these three categories together is important from two standpoints. One, pieces with multiple knots are more common than pieces with single knots; and two, edge knots are more restrictive to tensile strength than center knots.

TABLE 8. *Statistics, pounds per square inch, and number of specimens for actual distributions followed by adjusted distributions (below) for the different width and knot classes of nominal 2-inch hem-fir dimension lumber at 10% moisture content tested in tension parallel-to-grain*

Statistic	Clears	Single small center knot[1]	Single small edge knot[1]	Combination of small edge and center knots; well-scattered A	B	Single large center knot[1]	Single large edge knot[1]
			Nominal width, 4 inches				
Median	9,890	7,030	6,290	5,990	6,080	5,100	4,250
Mean	10,230	7,140	6,270	5,990	6,240	5,090	4,460
Std. dev.	1,574	1,801	1,441	1,584	1,598	1,088	846
5% excl.	7,520	4,040	3,790	3,260	3,490	3,220	3,000
Specimens	22	22	22	22	22	22	22
Median	9,800	6,980	---[2]	5,820	5,980	---[2]	4,180
Mean	9,890	6,990	---	5,770	6,090	---	4,310
Std. dev.	1,133	1,695	---	1,242	1,470	---	711
5% excl.	7,930	4,070	---	3,630	3,550	---	3,080
Specimens	20	21	---	21	21	---	20
			Nominal width, 6 inches				
Median	10,340	5,710	5,310	5,840	5,080	4,470	3,630
Mean	10,170	5,630	5,850	6,240	5,190	4,180	3,810
Std. dev.	1,931	791	1,471	1,716	1,228	737	1,000
5% excl.	6,850	4,270	3,320	3,290	3,080	2,890	2,090
Specimens	22	22	22	22	22	17	22
Median	10,100	---[2]	5,240	5,690	4,940	---[2]	3,570
Mean	9,600	---	5,710	5,710	4,910	---	3,570
Std. dev.	1,356	---	1,339	1,120	850	---	656
5% excl.	7,250	---	3,400	3,770	3,410	---	2,440
Specimens	19	---	21	19	20	---	20
			Nominal width, 8 inches				
Median	9,110	5,040	4,800	5,230	4,460	3,410	3,220
Mean	9,340	5,210	5,000	5,760	4,940	3,570	3,280
Std. dev.	1,834	1,024	1,147	1,343	1,541	904	864
5% excl.	6,180	3,450	3,030	3,450	2,290	2,000	1,790
Specimens	22	22	22	22	22	19	22
Median	8,980	4,940	4,790	5,110	4,410	3,360	3,160
Mean	8,960	5,090	4,860	5,340	4,760	3,480	3,100
Std. dev.	1,438	877	974	868	1,300	818	670
5% excl.	6,470	3,580	3,180	3,840	2,520	2,060	1,940
Specimens	20	21	21	19	21	18	20
			Nominal width, 10 inches				
Median	8,140	3,810	3,730	4,940	3,860	---	2,210
Mean	8,760	3,870	4,260	5,000	4,060	3,180	2,280
Std. dev.	2,803	607	1,139	730	867	785	705
5% excl.	3,940	2,830	2,300	3,740	2,570	---	1,070
Specimens	22	22	22	22	22	7	22
Median	8,080	---[2]	3,720	---[2]	---[2]	---[3]	2,110
Mean	7,860	---	4,010	---	---	---	2,180
Std. dev.	1,667	---	816	---	---	---	568
5% excl.	4,970	---	2,600	---	---	---	1,200
Specimens	19	---	20	---	---	---	21

[1]For sizes of knots see Table 1.
[2]No adjustment.
[3]Not enough specimens.

Ranking of tension stress values from Combination B pieces is questionable. From the analyses, Combination B values could be grouped with the single small center and single small edge knot; yet for most widths of lumber, there was a significant difference between average tension values of the Combination A and B pieces. At least, the study indicated that a slight relaxation of the rules for selecting the

Combination A specimens resulted in significantly lower tension values.

Comparison of tension stress between species. Average values for the two species are plotted in Fig. 5 by lumber width and by size and type of knot. Summaries of analyses of variance comparing the two species are given in Table 5. Simply stated, there was no (or little) significant difference between average tension stress values of the two species. We were surprised that average values were so close in so many of the pairs.

Five categories—clears, small single center, small single edge, Combination A and B knots—were directly comparable, because the same knot sizes and rules for selection of pieces applied to each species. Of twenty pairs of samples compared (4 widths × 5 categories), three were significantly different. Two of the three pairs (Combination A, 2 by 4 and 2 by 6) contained pieces of Douglas-fir that had such high MOE values (Table 2).

Tension stress values from the large center and edge knot categories were not directly comparable between the two species because knots in Douglas-fir were a little larger than corresponding knots in hem-fir (footnote, Table 5 or Table 1). Considering differences between average values and in sizes of knots for the two species, however, we believe there would have been little significant difference, if any, had the larger knots been of equal size in the two species.

Although a different mixture of hem-fir (less western hemlock and more true fir) could produce lower values, we believe the values for MOE and tension might compare to values of these hem-fir samples, provided the specific gravities were comparable. We threw out exceptionally lightweight pieces (about 1% of each species) during selection. Following the same rules, a sampling of more true firs could result in more pieces thrown out, but tension values not significantly different from values of these hem-fir samples. More testing would be needed to show the importance of specific gravity (or MOE) to the tensile strength of a mixture of western hemlock and true firs.

Tension stress values at lower 5% exclusion limits

Sometimes, too low values can be obtained when estimating exclusion limits from distributions that are skewed positively, as were many of the distributions in this study (Figs. 1–4). The extremely high values are a penalty (which should not be) as they cause a large standard deviation, which consequently extends the exclusion limit too far below the average value (mean) if the skewed distribution is considered a *t*-distribution (approaching normal) and standard procedures are used.

Estimating exclusion limits from distributions that are not normal has been considered by many. Two recent papers[1] (Warren 1974) discuss several distributions such as the log-normal, Pearson I, Weibull, gamma, and nonparametric. While it is beyond the scope of this paper to discuss such a complex subject, we present a simplified method, which was used with the distributions of this study in arriving at exclusion values to compare with values found by considering the distributions as being normal.

After considering several possibilities with a statistician, we adjusted the distributions until each was more nearly like a normal distribution by eliminating the extreme higher values until the mean and median values were nearly equal (see Figs. 1–4). Remaining values were treated as a *t*-distribution with fewer observations than before, and a new mean, standard deviation, and exclusion limit were calculated. This "adjusted-distribution" method was easy to use and seems more realistic for distributions of this study and probably would be more realistic for many other distributions of strength properties of wood. By adjusting in this manner, all lower values remain in the distribution.

[1] Habermann, H. Simulation studies of nonparametric tolerance intervals. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin (unpublished report).

Several low values, from most distributions in this study, are listed in Table 6, namely, the two lowest values, and 5% exclusion values using both standard procedure and adjusted-distribution method. Additional statistics for the actual and adjusted distributions are given in Tables 7 and 8. Values at the 5% exclusion limit obtained from adjusted distributions are plotted in Fig. 6. In most adjusted distributions, two or one of the higher values were eliminated; in some, none was left out.

For most categories, 5% exclusion values for tension stress by the adjusted method were a little higher (in some samples, considerably higher) than the same exclusion values obtained by the standard method. Differences in these two values are the penalties imposed on low values by extremely high ones (skewness). In most categories, there was little difference between Douglas-fir and hem-fir low values, especially with values from the adjusted distribution (Fig. 6).

CONCLUSIONS

Tension stress, specific gravity, and MOE in flatwise bending decreased with an increase in width of dimension lumber, for clear material and pieces with knots.

The lowest value for tension stress was associated with one of the three lowest values for MOE or specific gravity or both.

Tension strength decreased as knot size increased, for both edge and center knots.

Pieces of lumber with single center knots occupying 21% of the width were similar in tensile strength to pieces with single edge knots occupying 14%.

Pieces of lumber containing several small center and edge knots, well scattered (minimum spacing of 2 feet), were as strong in tensile strength as pieces with small single knots.

When rules for selecting pieces with multiple knots were relaxed slightly, tension strength decreased.

Tensile strengths of Douglas-fir and hem-fir were not significantly different.

In estimating lower exclusion values, adjustments should be made for skewed distributions. One method is suggested.

REFERENCES

KUNESH, R. H. 1966. Grips for tension tests of structural-size lumber. For. Prod. J. 16(6): 60.

———, AND J. W. JOHNSON. 1972. Effect of single knots on tensile strength of 2- by 8-inch Douglas-fir dimension lumber. For. Prod. J. 22(1):32.

——— AND ———. 1974. Effect of size on tensile strength of clear Douglas-fir and hem-fir dimension lumber. For. Prod. J. 24(8):32.

WARREN, W. G. 1974. Comparison of exclusion values for lumber strength. Wood Fiber 6(3):237–241.