AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

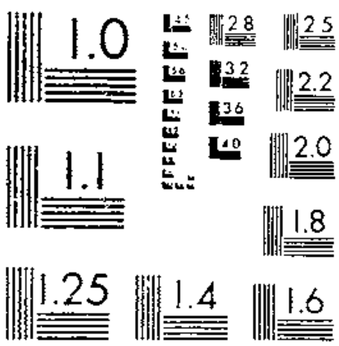
Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

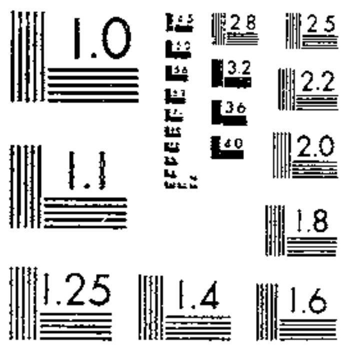
*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

TB 167 (1930) USDA TECHNICAL BULLETINS UPDATA
TESTS OF LARGE TIMBER COLUMNS AND PRESENTATION OF THE FOREST PRODUCTS...
NEWLIN, J.A.; GAHAGAN, J.M. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 167 February, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TESTS OF LARGE TIMBER COLUMNS AND PRESENTATION OF THE FOREST PRODUCTS LABORATORY COLUMN FORMULA

By J. A. NEWLIN,[1] *Principal Engineer in Charge*, and J. M. GAHAGAN, *Assistant Engineer, Section of Timber Mechanics, Forest Products Laboratory,*[2] *Branch of Research, Forest Service*

CONTENTS

SUMMARY

Producers and users of timber in the United States are concerned with the most efficient utilization of the available supply. This requires proper selection of the material for structural purposes and proper design of the structure. The value of timber is determined by its usefulness which, in turn, depends on its properties and on the completeness of its utilization. In the structural field, timbers are valued for stiffness, ability to sustain compressive stresses, appearance, capacity to take preservatives, seasoning characteristics, and a number of other properties or combinations of properties.

The results of the tests on large structural timbers presented in this bulletin together with other test data show that knots do not seriously affect the stiffness of timbers, columns, or joists. For structural members in which stiffness rather than strength is the controlling factor, such as posts in small dwellings, it is entirely safe to use

[1] The tests reported in this bulletin were made possible through the cooperation of the National Lumber Manufacturers' Association, which provided the timbers necessary for this study and to whose staff a mark of appreciation is due. Acknowledgment is particularly made to the following for their valuable assistance in the selection of the timbers: J. E. Jones, chief inspector of the Southern Yellow Pine Association; C. J. Hogue and L. P. Keith of the West Coast Forest Products Bureau; and C. W. Zimmerman, formerly of the Forest Service. The authors are especially indebted to H. S. Grenoble, formerly of the Forest Products Laboratory, for his part in conducting the tests and analyzing the test data reported in this bulletin.

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

79175°—30——1

knotty material. This information, if properly made use of, will increase the outlet for low-grade stock, which the lumberman always finds difficult to move, thereby increasing the returns from the forest.

Furthermore, a simple formula for computing accurately the strength of wooden columns commonly used in buildings, bridges, and other structures has been worked out by the Forest Products Laboratory and its application demonstrated in tests on 12 by 12 inch by 24-foot timbers provided by the National Lumber Manufacturers' Association. The employment in design by engineers and architects of this formula will eliminate the use of needlessly high factors of safety in column design with the accompanying use of timbers larger than necessary. The natural result of this more economical use of structural timber will be reflected in lowering the costs of wooden construction to the builder and consumer, in opening markets for low-grade material, and in lessening the waste of our forests.

In order that the type of column to which the formula applies may be understood, it should be stated that for building purposes three types of column are recognized—long columns, which depend for their strength on stiffness; short columns, which depend for their strength upon crushing strength in direction of length; and intermediate columns, which depend on a combination of stiffness and crushing strength. The Forest Products Laboratory formula applies to intermediate columns, which are the ones used most frequently in structural work.

The formula does not require any further knowledge of mathematics than is necessary to solve the straight-line formulas now used by many engineers. In addition, the formula will enable the selection of columns that will maintain the correct load rather than columns whose strength is in excess of the loads for which they are intended. This very fact should bring about a greater confidence in wood as a safe building material.

An interesting feature, which has been quite generally recognized by the Forest Products Laboratory for many years and which is borne out by the column study, is the effect of knots on strength. In a short column this effect is approximately the same as removing a similar amount of clear material from the cross section, and the combined effect of all the knots in any 6 inches of length is approximately the same as if they occurred at the same height and in the same plane. In a long column, where stiffness is the controlling factor, knots have little effect on strength.

INTRODUCTION

The study of columns has in the past been confined chiefly to materials other than wood. In the tests on wooden columns, which have been made by different investigators, relatively small specimens were used and no common testing procedure was followed. Furthermore, in most of these tests no attempt was made to determine the influence of the quality of the clear wood and of the grade of the material upon the strength, the purpose of such tests being merely to arrive at simple empirical formulas for use in design. As a result, the available information on wooden columns has been so meager and so apparently contradictory that many architects and engineers have been led to doubt the practicability of formulas that represent the strength of such members with a reasonable degree of accuracy and have continued to use a high factor of safety in column design. With the increasing cost of building material, however, there has come a demand for a better understanding of the mechanical properties of wooden columns and for formulas and safe working stresses that point definitely to a more economical use of structural timbers. In consequence, the National Lumber Manufacturers' Association has cooperated with the Forest Products Laboratory in the present study of the influence of defects on column strength and in the development of column formulas.

This study is concerned primarily with structural columns, and especially with the effect of knots on the strength of such columns. The tests were planned to afford the additional information requisite to a practical study of column formulas in current use and to gain information that would serve as a basis for determining safe working stresses for structural columns. Accordingly, the tests were conducted upon southern yellow pine and Douglas fir, the two species most commonly used for structural timbers. In addition the results of previous tests upon other species have been included in the discussion.

The test apparatus provided for pin-ended bearings [3] for the intermediate length and long columns, since the influence of knots and of quality of clear wood upon the strength of a column can be determined most readily under these conditions rather than under square-ended bearings.[4] It is anticipated that the investigation of columns will ultimately include a more general inquiry regarding the influence of end conditions.

MATERIAL

In order to obtain comprehensive results for a species, it was necessary to obtain test material that was representative of the particular species studied. The test material, which consisted of one hundred and sixty 12 by 12 inch by 24-foot timbers, therefore varied from clear and dense to very knotty and light and covered the entire range in density and knots of southern yellow pine and Douglas fir timbers cut for commercial uses. The timbers of each species were selected jointly on the ground by representatives of the National Lumber Manufacturers' Association and of the Forest Service from logs cut during the winter and from others cut during the summer, the time of selection being such that the test material was delivered to the Forest Products Laboratory at intervals of approximately six months in four groups of 40 timbers each. Furthermore, the timbers in each group were selected in so far as was practicable in pairs matched with regard to defects and quality of the clear wood. When received at the laboratory, one timber of each pair was tested in the green condition and the other was air-seasoned under shelter for two years and then tested.

The southern yellow pine consisted of longleaf (*Pinus palustris*) and of other southern yellow pine species which are designated here "southern yellow pine not longleaf." The whole of this material was representative in quality of the range of pine cut in the longleaf pine belt. The Douglas fir material was representative in quality

[3] With pin-ended bearings, the end connections are free to move in one plane.
[4] With square-ended bearings the column abuts against two rigid plates.

of the range of timbers cut from the small "yellow fir," large "yellow fir," and "red fir," all of which are included in the Pacific coast type of Douglas fir (*Pseudotsuga taxifolia*).

Because of the size of the Douglas fir trees, timbers of the desired range in grade and density were easily obtained. In the southern yellow pine timbers, however, because of the small size of the trees, it was necessary to take a greater number of butt cuts. Consequently, a less even distribution in grade and density was obtained in the southern yellow pine.

METHODS OF TEST

A preliminary stiffness test of each timber was made by applying a relatively light load in bending over a 200-inch span. The long column (24 feet) was then tested as a whole after which an intermediate column (8 to 13 feet), a short column (2 feet), and a section for small, clear test specimens were cut from the apparently uninjured portions. (Pl. 1.) The long and the intermediate columns were tested under pin-ended bearings (pls. 2 and 3) and the 2-foot columns under square-ended bearings. (Pl. 4.) The test procedure conformed as far as practicable to the standard methods (*1*)[5] for conducting static tests of timber. All tests on large columns were conducted in the Forest Products Laboratory 1,000,000-pound testing machine which was especially designed for tests on large timber columns. Detailed test procedure is given in the Appendix.

RESULTS AND DISCUSSION

LONG-COLUMN TESTS

The data from individual tests of long columns of both southern yellow pine and Douglas fir, are shown in Tables 1 to 4. Tables 1 and 2 are for green material and Tables 3 and 4 for air-dry.

[5] Reference is made by italic numbers in parentheses to Literature Cited, p. 43.

TABLE 1.—*Tests of long columns of southern yellow pine in a green condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet		Grade [2]	General description of columns tested
	Depth	adth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
[3] 1	11.80	11.99	23	11½	50.5	0.483	1,294	2,450	253.0	231.7	223.4	1,620	C	Many large knots (3½ inches) on four faces of upper three-fourths of length.
[3] 2	11.88	11.50	23	11⅛	28.9	.522	1,780	3,300	341.8	299.6	294.3	2,130	S	Practically clear.
3	11.95	11.77	23	10¾	31.3	.499	1,500	2,898	301.0	273.7	257.8	1,870	C	A few large knots (4 inches) in upper three-fourths of length.
[3] 4	11.81	11.91	24	⅛	46.1	.468	1,338	2,525	260.0	246.3	239.7	1,736	Cull.	Many large knots in clusters (2 to 4 inches) near middle of length.
5	11.82	11.82	23	11¼	28.3	.564	1,491	2,800	290.0	260.6	253.2	1,835	C	Many large knots (2 to 5 inches) throughout entire length.
6	12.00	11.97	24	¾	34.3	.524	1,608	3,200	328.0	310.4	287.6	2,083	S	Several knot clusters (¾ to 2 inches) near middle of length.
7	11.88	11.71	24	1/16	27.1	.636	1,841	3,475	358.0	362.0	351.3	2,545	S	A few knots on one face.
8	11.88	11.98	23	11½	35.3	.473	1,318	2,550	263.6	267.3	252.8	1,830	C	A few large knots on two faces in lower one-half of length.
9	11.94	11.84	23	10⅞	30.9	.579	1,936	3,750	389.0	[4] 412.0	386.6	2,800	S	Practically clear.
10	11.69	11.72	23	11⅞	30.6	.595	2,188	3,938	406.0	362.7	369.0	2,680	S	Clear.
21	11.89	11.96	23	11	26.5	.523	1,557	3,010	312.0	326.7	307.6	2,230	C	Many knots (1½ to 4 inches) on two faces.
22	11.88	11.78	24	⅜	30.2	.513	1,644	3,120	320.4	301.4	291.8	2,110	S	A few knots (1¾ inches) on one face.
23	11.91	11.79	23	11⅝	26.1	.522	1,687	3,230	333.5	289.6	276.5	2,000	S	Many large knots (1½ to 2¼ inches) in lower three-fourths of length.
24	11.90	11.93	24	¾	37.1	.457	1,293	2,500	256.0	255.6	243.8	1,765	S	A few knots (1 to 2 inches) on two faces in upper one-half of length.
25	11.93	11.90	24	2¼	39.6	.531	1,718	3,340	338.4	312.1	299.2	2,170	S	Clear.
26	11.87	11.84	24	¾	25.5	.624	1,758	3,350	343.0	338.7	328.0	2,375	S	Do.
27	11.95	11.72	24	3	52.8	.425	1,079	2,075	209.3	201.5	196.4	1,424	Cull.	Many large knots (1½ to 6 inches).
[3] 28	11.84	11.80	24	8¾	42.0	.510	1,494	2,812	273.2	260.8	269.2	1,950	S	Practically clear.
29	11.91	12.00	24	7½	33.8	.428	1,282	2,500	244.8	229.8	227.6	1,650	Cull.	Many large knots (1½ to 4 inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.04PL^3}{48DI}$

[2] American Society for Testing Materials standard grades: S=select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards, Vol. 27, p. 581.)

[3] Southern yellow pine, not longleaf.

[4] Actual test load reduced to 106 per cent of expected Euler load.

TABLE 1.—*Tests of long columns of southern yellow pine in a green condition*—Continued

Column No.	Dimensions: Depth	Dimensions: Breadth	Dimensions: Length (Ft.)	Dimensions: Length (In.)	Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: Adjusted test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: $\frac{P}{A}$	Grade	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
[3] 30	11.97	11.85	24	5	29.7	.558	1,527	2,985	297.0	301.5	292.8	2,120	S	Practically clear.
41	11.82	11.91	24	5	34.2	.457	1,401	2,650	263.8	[4] 279.5	280.8	2,035	C	Many large knots (2½ inches) in upper one-half of length.
42	11.81	11.84	24	⅜	35.7	.480	1,225	2,300	236.0	[4] 250.0	245.2	1,780	C	Many large knots (2 to 3 inches).
43	11.78	11.86	23	11⅞	36.9	.553	1,992	3,710	382.2	380.0	373.2	2,705	S	Many knots (1½ inches).
44	11.85	11.85	24	4⅝	32.4	.534	1,762	3,340	333.3	[4] 353.0	352.1	2,550	S	Several small knots (1 inch) in central one-half.
45	11.84	11.88	23	10	33.8	.489	1,266	2,400	250.5	247.2	235.6	1,706	S	A few large knots (2 to 3 inches):
46	11.87	11.89	24	⅞	36.4	.532	1,945	3,720	380.7	349.6	337.2	2,442	S	A few small knots (1 inch).
47	11.81	11.75	24	6	30.2	.634	1,818	3,385	334.7	[4] 354.6	364.0	2,640	S	Clear except for pitch streaks.
[3] 48	11.89	11.89	24	4	28.2	.602	1,264	2,427	243.2	233.9	229.0	1,660	C	Many knots (1 to 4 inches).
49	11.82	11.80	24	8	33.7	.488	1,527	2,860	279.0	256.6	265.5	1,925	S	Clear.
50	11.80	11.95	24	5⅜	37.4	.582	2,070	3,910	388.0	354.9	357.7	2,590	S	Do.
61	11.96	11.92	24	1	28.7	.536	943	1,850	189.2	187.9	177.0	1,283	C	Knots (⅞ to 4 inches) on all faces.
62	11.84	11.86	24	⅝	30.7	.600	2,112	4,000	410.0	418.4	406.8	2,950	S	Clear.
63	11.78	11.87	24	¼	32.3	.529	1,163	2,170	223.0	[4] 236.3	232.5	1,685	C	Many knots (1 to 5½ inches) on all faces.
64	11.82	11.90	24	⅞	37.6	.508	1,678	3,170	324.2	314.7	307.2	2,225	S	A few knots (1½ to 2½ inches).
65	11.96	11.70	23	11¾	34.4	.565	1,482	2,850	294.0	273.3	260.0	1,885	S	Several knots (¾ to 1½ inches) in central one-half.
66	11.89	11.85	24	⅜	36.2	.504	1,526	2,920	301.2	[4] 319.2	306.6	2,220	S	One medium-sized knot in central one-third.
67	11.86	12.01	24	1	32.7	.471	1,414	2,725	278.8	265.5	254.5	1,845	S	Several knots (1 to 2¾ inches) on three faces.
68	11.90	11.98	23	11	35.3	.538	1,778	3,450	357.8	[4] 379.0	355.3	2,575	S	Clear.
69	11.98	12.02	24	⅜	34.7	.534	1,538	3,175	326.0	323.7	299.8	2,170	S	Two knots (1½ inches) near middle of timber.
70	11.82	11.91	24	¾	29.3	.605	1,876	3,550	363.6	370.1	361.0	2,630	S	Clear.

[3] Southern yellow pine, not longleaf.

[4] Actual test load reduced to 106 per cent of expected Euler load.

TABLE 2.—*Tests of long columns of Douglas fir in a green condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity[1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet		Grade[2]	General description of columns tested
	Depth	Breadth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
1	11.91	11.98	24	1/16	31.6	0.441	2,131	4,150	427.0	406.3	383.0	2,770	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
3	11.93	11.90	24	0	29.1	.412	1,712	3,325	342.3	323.2	305.0	2,210	S	Do.
4	11.96	11.89	23	11¾	32.2	.419	1,584	3,100	320.0	312.4	292.4	2,115	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 2¼ inches) on three faces.
5	11.87	11.90	24	0	31.1	.439	1,854	3,550	365.6	296.6	284.3	2,060	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
6	11.84	11.90	24	⅛	32.0	.438	1,765	3,350	344.8	362.2	350.2	2,540	S	Boxed heart, small yellow fir type, top cut, many knots (⅜ to 2 inches) on all faces.
12	11.85	11.92	23	11¾	32.0	.447	1,519	2,900	299.0	295.6	283.8	2,057	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 2 inches) on all faces.
13	11.78	11.84	23	11⅞	33.9	.496	1,772	3,300	340.0	355.9	350.0	2,538	S	Side cut, large old-growth fir type, top portion of first 40-foot log, clear.
15	11.89	11.66	24	½	34.4	.402	1,851	3,488	357.8	309.2	302.0	2,190	S	Side cut, large old-growth fir type, top portion of first 40-foot log, a few small knots.
17	11.84	11.84	24	3/16	35.0	.440	1,508	2,850	293.0	281.6	273.3	1,980	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 4¼ inches).
19	11.78	11.89	23	11¾	34.1	.425	1,859	3,475	358.4	335.2	328.2	2,380	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 1 inch).
21	11.79	11.93	23	11⅞	37.9	.399	1,583	2,975	306.7	240.1	242.7	1,760	C	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 3 inches).
23	11.89	11.76	24	⅜	30.5	.483	1,249	2,375	244.0	258.2	249.8	1,800	C	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 5 inches).
25	11.66	11.96	24	⅛	36.7	.439	1,625	2,962	305.0	301.0	303.8	2,200	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 3½ inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.04PL^3}{48DI}$

[2] American Society for Testing Materials standard grades: S=Select grade; C=common grade. (See Amer. Soc. Testing Materials Standards, Vol. 27, p. 581.)

TABLE 2.—*Tests of long columns of Douglas fir in a green condition*—Continued

Column No.	Dimensions: Depth	Dimensions: Breadth	Dimensions: Length		Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: Adjusted test load	Values adjusted…: P/A	Grade	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
27														Side cut, large old-growth fir type, top portion of first 40-foot log (compression failure in timber prior to test).
29	11.84	11.90	24	0	31.5	.411	1,724	3,275	337.2	326.8	315.3	2,285	S	Side cut, large yellow fir type, top portion of first 40-foot log, clear.
31	11.88	11.92	23	11 7/16	31.4	.435	1,691	3,250	336.0	318.8	303.0	2,195	S	Side cut, large yellow fir type, butt cut, clear.
33	11.64	11.88	24	1/16	28.1	.437	1,887	3,400	350.0	315.9	321.8	2,330	S	Boxed heart, red fir type, one end split, many knots (½ to 2 inches) on all faces.
35	11.84	11.82	24	5/8	30.0	.471	1,976	3,725	382.0	357.7	349.0	2,530	S	Do.
37	11.90	11.92	24	5/16	34.5	.481	945	1,825	187.5	[3] 198.7	189.0	1,370	Cull.	Side cut, large yellow fir type, top portion of first 40-foot log, many knots (½ to 5½ inches) on all faces.
39	11.93	11.77	23	11 3/4	30.9	.413	1,119	2,150	221.7	207.6	197.8	1,430	Cull.	Side cut, large yellow fir type, top portion of first 40-foot log, many knots (1 to 4¾ inches) on all faces.
41	11.74	11.70	24	1/4	44.2	.418	1,908	3,475	357.0	372.1	375.2	2,720	S	Boxed heart, small yellow fir type, butt cut, clear.
42	11.74	11.70	23	11 7/8	31.5	.471	2,157	3,925	404.5	399.5	402.0	2,930	S	Boxed heart, small yellow fir type, top cut, many small knots (½ to 1 inch) on all faces.
43	11.75	11.73	23	11 7/8	30.0	.469	1,804	3,300	340.0	344.7	344.7	2,498	S	Boxed heart, small yellow fir type, butt cut, a few small knots (¼ to ½ inch) on three faces.
44	11.57	11.65	23	11 15/16	30.6	.456	1,770	3,070	316.1	[3] 335.0	353.5	2,560	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 1½ inches) on all faces.
45	11.56	11.62	24	0	31.3	.446	1,552	2,850	293.6	[3] 311.0	330.3	2,392	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1 inch) on three faces.
46	11.52	11.54	24	0	31.0	.442	1,651	2,800	288.2	304.4	329.0	2,385	S	Boxed heart, small yellow fir type, butt cut, many knots (½ to 1½ inches) on three faces.
47	11.71	11.62	24	0	30.8	.390	1,402	2,520	259.5	272.2	278.0	2,015	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 2 inches) on all faces.
48	11.72	11.60	23	11 7/8	31.0	.405	1,587	2,850	293.7	311.7	317.8	2,300	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 1½ inches) on two faces.

49	11.59	11.66	24	1/8	33.4	.371	1,524	2,660	273.7	253.4	266.8	1,930	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (3/4 to 2 1/2 inches) on all faces.
50	11.61	11.54	24	3/8	37.0	.448	1,438	2,500	256.8	220.6	233.4	1,690	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (3/4 to 4 inches) on all faces.
51	11.69	11.72	24	0	33.9	.397	1,192	2,145	221.0	219.3	223.2	1,617	Cull.	Side cut, large old-growth fir type, top portion of first 40-foot log, a few large knots on each of the four faces.
52	11.63	11.57	23	11 7/8	33.6	.428	1,286	2,250	231.8	228.4	239.2	1,735	C	Side cut, large old-growth fir type, top portion of first 40-foot log, a few large knots on three faces.
53	11.54	11.55	24	0	35.0	.462	1,730	2,950	304.0	285.3	306.6	2,220	S	Side cut, large old-growth fir type, butt cut, clear.
54	11.60	11.68	24	1/4	36.0	.484	1,741	3,050	313.4	316.0	331.0	2,400	S	Do.
55	11.54	11.59	24	1/8	43.8	.407	1,443	2,470	254.0	252.5	270.5	1,960	S	Side cut, large yellow fir type, butt cut, clear, cross grained.
56	11.56	11.53	24	0	31.4	.490	1,915	3,280	337.8	348.0	372.5	2,700	S	Side cut, large yellow fir type, upper cut, clear.
57	11.69	11.70	23	11 7/8	30.6	.389	1,363	2,450	252.4	246.4	251.2	1,820	C	Side cut, large yellow fir type, butt cut, many knots (3/4 to 4 inches) on all faces.
58	11.52	11.50	23	10 3/4	30.4	.427	1,099	1,860	193.2	198.6	213.6	1,548	Cull.	Boxed heart, large yellow fir type, top cut, many knots (3/4 to 5 inches) on all faces.
59	11.64	11.68	24	1/8	28.5	.478	2,400	4,250	437.0	426.4	442.3	3,210	S	Boxed heart, small red fir type, butt cut, clear.
60	11.58	11.67	24	1/8	27.6	.459	1,951	3,400	350.0	[3] 371.0	390.8	2,830	S	Boxed heart, small red fir type, top portion of first 48-foot log, many knots (3/4 to 1 1/2 inches).

[3] Actual test load reduced to 106 per cent of expected Euler load.

79175°—30——2

TABLE 3.—*Tests of long columns of southern yellow pine in an air-dry condition*

Column No.	Dimensions: Depth	Dimensions: Breadth	Dimensions: Length		Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11½ by 11½ inches by 24 feet: Adjusted test load	Values adjusted: $\frac{P}{A}$	Grade [2]	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
11	11.50	11.53	23	11⅞	17.0	0.512	1,616	2,725	281.0	262.6	262.5	1,985	S	A few knots (¾ to 1½ inches) on all faces.
12	11.56	11.60	23	11½	17.5	.588	1,930	3,325	343.5	319.5	311.0	2,350	S	Several knots (1 to 3 inches).
[3] 13	11.47	11.45	23	11¼	18.2	.621	2,031	3,375	349.2	332.6	335.0	2,530	S	Clear, considerable compression wood, badly twisted.
[3] 14	11.30	11.28	24	0	16.1	.464	1,438	2,250	231.7	227.7	244.8	1,850	C	Many knots up to 3 inches in size.
[3] 15	11.56	11.59	23	11¾	18.1	.566	1,845	3,175	327.3	305.5	298.6	2,250	S	A few small knots.
16	11.32	11.69	23	11¼	18.6	.630	1,828	2,980	308.3	282.7	290.0	2,180	S	Many small knots.
[3] 17	11.59	11.53	23	10⅞	17.8	.508	1,892	3,262	338.5	324.9	313.8	2,370	S	One large knot at middle of timber.
18	11.68	11.63	23	11⅜	17.5	.456	932	1,662	171.8	161.1	151.5	1,145	Cull.	Many knots (1 to 6 inches).
[3] 19	11.30	11.43	24	0	18.0	.548	1,949	3,090	318.0	287.8	305.0	2,305	S	Clear.
[3] 20	11.52	11.53	23	11 9/16	16.5	.448	1,268	2,150	222.0	197.2	195.0	1,475	C	Many knots (1 to 3 inches).
31	11.66	11.66	24	0	17.7	.502	1,637	2,910	299.6	265.9	251.3	1,900	S	A few knots (¾ to 3 inches).
32	11.65	11.46	24	⅛	19.8	.609	1,851	3,225	331.8	337.4	326.3	2,468	S	A few small knots (¾ to 1 inch).
33	11.53	11.49	23	11¾	18.6	.516	1,742	2,950	304.2	289.6	287.2	2,170	S	Many knots (1 to 3 inches), cut from crooked log.
34	11.50	11.63	23	11½	18.1	.528	1,837	3,125	323.0	313.9	309.3	2,340	S	Clear.
[3] 35	11.58	11.36	24	⅛	16.0	.476	1,708	2,900	298.2	282.2	280.0	2,118	S	Practically clear.
36	11.40	11.44	24	⅜	18.1	.502	1,731	2,820	289.5	252.6	261.4	1,976	C	Many knots (1½ to 4 inches).
[3] 37	11.48	11.54	24	⅛	18.1	.584	2,055	3,450	355.0	334.0	334.5	2,530	S	A few knots (¾ to 2 inches).
38	11.57	11.52	24	0	20.0	.618	1,574	2,700	278.0	277.9	272.4	2,060	C	A few knots (1½ to 4 inches).
39	11.54	11.66	24	0	17.5	.562	1,698	2,925	301.0	297.7	291.0	2,200	S	Many knots (1 to 2½ inches).
[3] 40	11.62	11.49	24	0	18.5	.584	2,050	3,550	365.4	338.5	328.5	2,480	S	Several small knots (½ to 1 inch).
51	11.71	11.71	24	0	20.0	.535	1,631	2,950	303.8	306.1	284.7	2,150	S	A few large knots (1½ to 3 inches).
52	11.45	11.56	23	11¾	19.1	.512	1,380	2,305	237.8	223.0	221.5	1,697	S	Many large knots (1½ to 3 inches).
53	11.61	11.56	23	11¾	19.1	.536	1,868	3,250	335.2	302.6	292.0	2,208	S	Practically clear, some shake.
54	11.47	11.57	23	11¾	19.0	.554	1,995	3,352	345.8	322.1	322.5	2,440	S	Clear.
55	11.62	11.58	23	11⅞	19.7	.538	1,669	2,918	300.7	271.0	260.5	1,970	Cull.	Two large knots (3 to 5 inches).
56	11.56	11.40	23	11¾	19.6	.570	2,230	3,775	388.5	375.1	372.5	2,815	S	Clear.
57	11.64	11.50	23	11¾	19.7	.483	1,344	2,342	241.6	233.1	224.7	1,697	S	Several knots (¾ to 1½ inches).
58	11.68	11.64	23	11⅝	21.6	.543	1,600	2,855	294.8	285.7	269.0	2,035	S	Several knots (2 to 2¼ inches).
59	11.66	11.52	23	11⅝	19.0	.578	1,727	3,031	313.0	298.5	285.0	2,155	S	A few small knots (¾ inch).
60	11.56	11.65	23	11⅞	20.0	.577	1,926	3,335	343.8	321.3	312.0	2,360	S	Clear.
71	11.66	11.42	23	11¾	19.2	.535	1,847	3,214	331.4	327.5	316.0	2,388	S	Several knots (¾ to 2½ inches).
72	11.58	11.55	23	11¾	--------	.552	2,002	3,456	356.3	349.2	340.0	2,570	S	Clear.

73	11.59	11.63	24	⅜	18.4	.577	1,464	2,548	262.0	240.8	233.2	1,764	S	Many knots (¾ to 2½ inches).
74	11.69	11.56	23	11½	19.3	.556	1,887	3,350	346.3	346.6	327.2	2,474	S	Several knots (1¼ to 2 inches).
75	11.67	11.48	23	11⅞	19.1	.582	2,103	3,690	380.3	352.7	338.0	2,555	S	A few small knots (1 inch).
76	11.68	11.58	23	11⅞	18.7	.530	1,491	2,648	273.0	256.0	242.3	1,833	S	Many knots (¾ to 2 inches).
77	11.32	11.53	23	11¾	19.5	.543	1,758	2,828	291.3	258.0	269.3	2,038	S	Many knots (1 to 3 inches).
78	11.62	11.68	23	11¾	20.0	.582	2,190	4,650	398.5	402.5	383.0	2,895	S	A few knots (1¼ inches).
79	11.58	11.59	23	11¾	--------	.589	1,945	3,369	347.4	314.0	304.7	2,300	S	Practically clear.
80	11.58	11.72	23	11¾	17.4	.557	1,963	3,435	354.0	343.9	330.0	2,494	S	Several knots (1½ inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span making it read $E=\frac{1.04PL^3}{48DI}$

[2] American Society for Testing Materials standard grades: S=Select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards Vol. 27, p. 581.)

[3] Southern yellow pine other than longleaf.

TABLE 4.—*Tests of long columns of Douglas fir in an air-dry condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11½ by 11½ inches by 24 feet		Grade [2]	General description of columns tested
	Depth	Breadth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
2	11.49	11.54	24	0	18.1	0.452	2,063	3,475	358.0	345.9	345.5	2,610	S	Boxed heart, small yellow fir type, top cut, many knots (¾ inch) on one face.
7	11.50	11.38	24	0	18.3	.356	2,363	3,938	405.5	369.8	373.8	2,830	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
8	11.67	11.46	23	11¾	18.5	.377	1,462	2,562	264.2	255.0	244.8	1,850	S	Boxed heart, small yellow fir type, top cut, many knots (½ to 1¼ inches) on all faces.
9	11.48	11.54	24	0	17.5	.406	1,825	3,062	315.4	299.2	300.0	2,270	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 3 inches) on two faces.
10	11.57	11.56	23	11¾	17.7	.410	1,758	3,025	312.0	288.6	281.6	2,130	S	Boxed heart, small yellow fir type, top cut, many knots (1 to 3 inches) on two faces.
11	11.59	11.56	23	11¹⁵⁄₁₆	18.9	.445	1,787	3,094	319.0	300.4	292.0	2,210	S	Boxed heart, small yellow fir type, butt cut, many knots (1 to 2½ inches) on three faces.
14	11.54	11.52	23	11¾	19.7	.492	1,870	3,181	328.0	313.8	310.0	2,340	S	Side cut, large old-growth fir type, top portion of first 40-foot log, clear.
16	11.44	11.62	24	¹⁄₁₆	18.4	.436	1,891	3,162	325.5	310.0	312.1	2,360	S	Do.
18	11.50	11.56	23	11⅛	19.7	.443	1,819	3,075	317.0	299.0	297.2	2,250	S	Side cut, large old-growth fir type, many small knots, one knot 1½ inches in size, near top end.
20	11.59	11.58	24	0	17.1	.492	2,050	3,556	366.1	356.0	345.3	2,610	S	Side cut, large old-growth fir type, a few knots (1 to 1½ inches) near top end.
22	11.50	11.62	24	¼	19.0	.421	1,589	2,700	277.5	259.7	257.8	1,950	S	Side cut, large old-growth fir type, a few knots (1 to 2 inches) near top end.
24	11.60	11.58	23	11¹³⁄₁₆	18.9	.479	1,748	3,038	313.3	275.0	265.8	2,010	S	Side cut, large old-growth fir type, a few knots (1 to 3 inches) on two faces near top end.
26	11.58	11.61	23	11⅜	18.2	.418	1,490	2,586	267.5	250.6	242.2	1,830	S	Boxed heart, large old-growth fir type, many knots (1 to 3 inches) near top end.
28	11.66	11.58	23	11⅞	18.1	.432	1,412	2,492	257.0	231.8	220.6	1,670	C	Side cut, large old-growth fir type, many knots (1 to 4 inches) near top end.
30	11.83	11.68	23	11⅝	18.1	.407	1,502	2,794	288.7	273.6	246.6	1,865	S	Side cut, large yellow fir type, top portion of first 48-foot log, clear.
32	11.59	11.35	23	11¹¹⁄₁₆	19.0	.447	1,650	2,805	289.6	282.3	278.8	2,110	S	Side cut, large yellow fir type, butt cut, clear.
34	11.53	11.63	24	0	18.5	.419	1,995	3,419	352.0	319.6	313.0	2,370	S	Boxed heart, medium sized red fir type, a few small knots.
36	11.42	11.50	23	4	18.5	.431	1,856	3,060	333.8	312.8	302.0	2,280	S	Boxed heart, medium-sized red fir type, many small knots.
38	11.54	11.52	24	11¾	19.0	.460	1,115	1,900	181.0	183.5	196.4	1,485	Cull.	Side cut, large yellow fir type, top portion of first 48-foot log, many knots (½ to 6 inches) on all faces.

40	11.53	11.52	24	1/8	18.9	.442	1,575	2,674	275.2	256.4	254.4	1,925	Cull.	Side cut, large yellow fir type, top portion of first 48-foot log, many knots (1/2 to 5 inches) on all faces.
61	11.50	11.57	23	11 7/8	17.0	.492	2,282	3,862	398.0	357.1	354.6	2,682	S	Boxed heart, small yellow fir type, butt cut, many small knots (1/2 to 3/4 inch) on three faces.
62	11.60	11.50	23	11 13/16	18.0	.456	2,082	3,594	370.8	361.7	352.0	2,685	S	Boxed heart, small yellow fir type, top cut, many small knots (1/2 to 3/4 inch) on three faces.
63	11.54	11.52	23	11 11/16	17.5	.471	1,932	3,288	339.0	308.8	304.2	2,302	S	Boxed heart, small yellow fir type, butt cut, many knots (3/4 to 1 1/4 inches) on two faces.
64	11.46	11.42	24	0	18.0	.500	2,344	3,875	399.0	391.2	398.5	3,015	S	Boxed heart, small yellow fir type, top cut, many small knots (1/2 to 1 inch) on three faces.
65	11.51	11.52	23	11 13/16	17.6	.471	2,060	3,480	359.0	357.8	355.2	2,690	S	Boxed heart, small yellow fir type, butt cut, many knots (3/4 to 2 inches) on one face.
66	11.51	11.55	24	0	17.5	.483	2,229	3,775	389.0	380.9	378.0	2,860	S	Boxed heart, small yellow fir type, butt cut, many knots (1/2 to 1 1/2 inches) on two faces.
67	11.52	11.42	23	11 13/16	17.7	.469	2,161	3,625	373.7	369.2	369.4	2,792	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/2 inches) on three faces.
68	11.58	11.44	24	3/16	18.0	.426	1,765	3,014	309.8	292.7	288.8	2,180	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/4 inches) on all faces.
69	11.46	11.44	23	11 13/16	18.0	.434	1,840	3,050	314.6	292.2	296.6	2,240	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/2 inches) on all faces.
70	11.71	11.58	24	3/32	17.9	.434	1,573	2,814	280.6	262.8	247.3	1,870	S	Side cut, large old-growth fir type, top portion of first 40-foot log, a few knots (1 to 2 inches) on all faces.
71	11.78	11.59	23	11 7/8	18.7	.487	1,232	2,244	231.4	205.2	189.2	1,432	Cull.	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (7/8 to 3 inches) on all faces.
72	11.65	11.55	23	11	17.7	.452	1,630	2,862	296.9	270.0	257.0	1,945	C	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots.
73	11.54	11.46	24	0	16.8	.364	1,437	2,435	250.8	239.0	237.3	1,795	S	Side cut, large old-growth fir type, butt cut, clear.
74	11.60	11.50	23	11 5/8	19.2	.508	2,183	3,800	392.8	385.1	371.0	2,810	S	Do.
75	11.50	11.61	23	11 13/16	18.4	.420	1,538	2,615	269.8	257.4	354.8	1,928	S	Side cut, large yellow fir type, butt cut, clear.
76	11.52	11.49	23	11 7/8	18.4	.508	2,131	3,600	371.0	362.7	360.4	2,730	S	Side cut, large yellow fir type, top cut, clear.
77	11.61	11.48	23	11 9/16	17.0	.404	1,612	2,788	288.0	275.5	267.3	2,025	C	Side cut, large yellow fir type, butt cut, many large knots.
78	11.56	11.57	23	10	17.2	.439	1,190	2,048	214.0	190.6	183.8	1,390	Cull.	Side cut, large yellow fir type, top cut, many large knots.
79	11.43	11.55	23	11 13/16	18.4	.525	2,408	3,994	412.0	389.1	394.0	2,980	S	Boxed heart, small red fir type, top cut, many knots (3/8 to 1 1/4 inches).
80	11.57	11.39	24	1/2	18.5	.498	2,173	3,688	378.4	364.7	362.8	2,740	S	Boxed heart, small red fir type, butt cut, many knots (1/4 to 1 1/2 inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.04PL^3}{48DI}$.

[2] American Society for Testing Materials standard grades: S=Select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards Vol. 27, p. 581.)

The timbers were surfaced on a jointer and therefore varied slightly in size. For this reason the strength values were adjusted to arbitrary standard specimen dimensions of 11¾ by 11¾ inches by 24 feet for the green timbers, and 11½ by 11½ inches by 24 feet for the air-seasoned timbers. These values are given in the tables under the heading "Values adjusted."

The tables of results for the green timbers show that the columns sometimes sustained loads greater than their calculated Euler loads. Such columns (if the stiffness calculated from the bending tests is considered as the true stiffness of the timber) are in unstable equilibrium and the excess loads have no significance. Because of the relatively low load to which they were subjected in the bending test, there is a discrepancy between the true stiffness of the columns and that calculated from the bending tests. The green columns were not considered in unstable equilibrium unless the test load exceeded the expected load by more than 6 per cent in which event the test load was reduced to 106 per cent of the expected load. It may be seen in Table 5 that such reductions lowered the average of the calculated loads to about 98 per cent of the average Euler loads. To avoid unstable equilibrium in testing the air-dry 24-foot columns, they were set with an eccentricity of 0.07 inch; this eccentricity would cause a slight reduction in load which as a rule can not be evaluated absolutely. The test results given in Table 5 indicate that the reduction in load of the air-seasoned columns because of eccentric loading is between 2 and 3 per cent. The values for the air-seasoned timbers in which the test load exceeded the Euler load were considered correct because the slight eccentricity used in loading these columns prevented a condition of unstable equilibrium.

TABLE 5.—*Relation of test load to Euler load for 24-foot columns*

Species of wood	Seasoning condition	Average adjusted Euler load	Average adjusted test load [1]	Ratio of test load to Euler load
		Pounds	*Pounds*	*Per cent*
Southern yellow pine	Green	298,200	291,240	97.8
Do	Air-dry	305,700	299,500	97.9
Douglas fir	Green	311,500	305,025	97.9
Do	Air-dry	314,600	303,500	96.4
Average	Green			97.85
Do	Air-dry			97.15

[1] Test values were adjusted for variation of columns in cross section and in length. Cross section for green columns was adjusted to 11¾ by 11¾ inches and that of the air-dry to 11½ by 11½ inches—adjusted length was 24 feet for both. The values for air-dry material were further adjusted to a basis of 18 per cent moisture content.

The maximum and minimum strength values for southern yellow pine columns were obtained with longleaf pine. The difference between the strength of the longleaf pine and the southern pine not longleaf was so slight that the omission of the southern yellow pine not longleaf from the averages would have raised the green values by less than 3 per cent and would have lowered the air-seasoned values by less than 1 per cent. In summarizing the results of these tests therefore the pine columns are considered collectively and are called by the general name southern yellow pine.

The maximum, minimum, and average values for the long columns of both Douglas fir and southern yellow pine, for the two conditions of seasoning and for both winter and summer cutting, are given in Table 6. The figures show an advantage in strength for winter-cut material. This advantage may in part be attributed to the fact that these timbers were tested in colder weather, which would cause them to support somewhat greater loads than in warm weather, but after due consideration of the effects of temperature and any slight difference in moisture content and specific gravity of the timbers the advantage shown for the winter-cut timbers is still greater than that normally attributed to accident.

TABLE 6.—*Summary of strength values for Douglas fir and southern yellow pine 24-foot columns*

Species of wood	Season when cut	Season when tested	Condition when tested	Adjusted column strength values [1]		
				Maximum	Minimum	Average
				Pounds	*Pounds*	*Pounds*
Southern yellow pine	Summer	Summer	Green	368,000	190,400	282,430
Do	Winter	Winter	do	406,800	177,000	300,050
Do		Summer and winter.	do			291,240
Do	Summer	Summer	Air-dry	355,000	149,000	281,500
Do	Winter	Winter	do	425,000	236,500	317,500
Do		Summer and winter.	do			299,500
Douglas fir	Summer	Summer	Green	383,000	189,000	296,021
Do	Winter	Winter	do	442,300	213,600	313,580
Do		Summer and winter.	do			305,025
Do	Summer	Summer	Air-dry	381,000	200,000	292,000
Do	Winter	Winter	do	401,000	176,000	309,500
Do		Summer and winter.	do			303,500

[1] Test values were adjusted for variation of columns in cross section and in length. Cross section for green columns was adjusted to 11¾ by 11¾ inches and that of the air-dry 11½ by 11½ inches—adjusted length 24 feet for both. The values for air-dry material were further adjusted to a basis of 18 per cent moisture content.

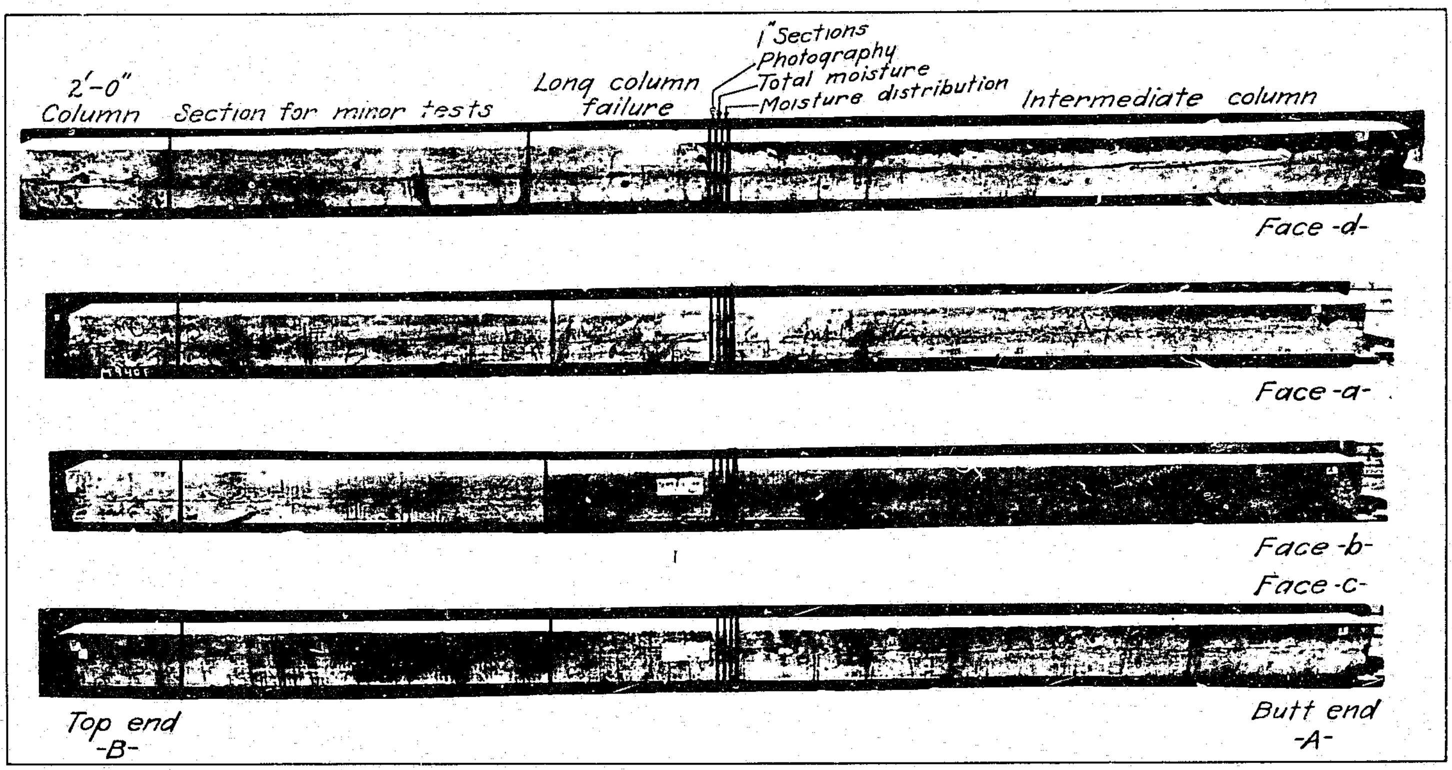
The tests show further that the maximum load which a long column will support is dependent upon its stiffness. The one-fourth inch reduction in cross-sectional dimensions of the air-seasoned timbers below that of the green timbers (about one-eighth of which results from shrinkage in seasoning from the green condition and the other one-eighth from surfacing) reduced the stiffness of the columns by an amount practically equal to the normal increase in stiffness of the wood caused by seasoning. Consequently the green and air-dry columns carried practically the same loads.

The Douglas fir long columns averaged 3 to 4 per cent higher in stiffness than the southern yellow pine and therefore withstood correspondingly higher loads. This small difference in stiffness, however, is not sufficient to justify the conclusion that Douglas fir is better as a long column than southern pine, regardless of the care exercised in selection, since the normal variation in strength of wood is such that a difference greater than the above would be expected between two such groups of timbers of the same species, either all Douglas fir or all southern pine or any other wood used for structural purposes.

The specific-gravity values of the material tested as compared to those of thousands of specimens of both species used in other tests at the Forest Products Laboratory show that in the selection of the long columns the range in density for each species was well covered.

INTERMEDIATE AND 2-FOOT COLUMN TESTS

Table 7 contains the data for the intermediate length and the 2-foot columns tested in the green and air-seasoned condition, together with the maximum compressive stress values from tests of standard 2 by 2 inch clear specimens. The table shows that the strength of the intermediate columns differed but little from that of the 2-foot columns, although some of the intermediate columns were 13 feet long. The results show that even with pin-ended bearings, which would be expected to always give lower results than square-ended bearings, and with good bearing surfaces, the length of these columns up to 11 times their least dimension had little effect on the strength.



M1213F

The relative positions of intermediate and 2-foot columns, and the sections from which minor test specimens were cut

A long column mounted upon the special roller bearings preparatory to test in the Forest Products Laboratory 1,000,000-pound timber-testing machine

TABLE 7.—*Tests of nominal 12 by 12 inch columns of intermediate and 2-foot lengths and of clear minor specimens 2 by 2 by 8 inches* [1]

SOUTHERN YELLOW PINE

Green											Air-dry									
Column No.	Intermediate				Two-foot columns			Minor specimens			Column No.	Intermediate				Two-foot columns			Minor specimens	
	Grade [2]	Moisture	Length	$\frac{P}{A}$	Grade [2]	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$			Grade [2]	Moisture	Length	$\frac{P}{A}$	Grade [2]	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$
		Per cent	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*				*Per cent*	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
1	S	50.3	11.96	2,820	S	57.0	3,000	47.0	2,970		11	S	17.4	7.67	4,760	S	16.5	5,430	15.9	4,913
2	S	27.8	10.77	4,100	----	----	----	25.6	4,410		12	S	18.3	7.46	5,810	S	18.0	5,330	16.8	5,520
3	C	30.8	13.00	3,425	----	----	----	28.7	4,233		13	S	18.6	9.00	5,170	S	16.4	5,620	17.1	6,155
4	C	44.8	12.00	2,960	C	39.2	2,910	45.3	3,152		14	S	15.8	9.00	4,015	S	14.3	4,010	15.1	4,710
5	C	29.8	11.50	3,600	C	23.7	4,240	26.7	4,050		15	S	16.8	8.79	5,040	S	16.0	5,565	16.1	5,245
6	S	32.8	10.06	3,790	S	31.3	3,890	29.7	3,998		16	S	17.8	9.29	4,690	S	19.3	5,300	17.3	5,135
7	S	27.3	12.00	4,930	S	26.5	4,580	26.5	4,663		17	S	18.2	8.50	4,735	S	16.6	4,850	17.4	5,640
8	S	37.5	9.50	3,510	S	34.3	3,380	30.6	3,120		18	S	16.8	9.15	3,560	C	16.4	3,060	15.2	3,850
9	S	30.6	13.00	5,010	S	31.2	5,360	34.6	4,910		19	S	17.5	9.00	4,650	S	19.0	4,910	17.6	5,695
10	S	27.9	11.33	4,890	S	30.2	4,840	33.2	4,478		20	C	17.0	10.21	3,130	S	14.2	4,560	16.4	4,680
21	C	31.5	10.33	3,530	S	26.8	4,000	24.9	4,177		31	S	18.3	10.58	4,600	----	16.2	----	15.3	5,603
22	S	29.1	10.00	4,345	S	27.1	4,800	26.0	4,178		32	S	20.5	8.90	5,340	S	16.9	6,025	19.2	5,953
23	S	28.2	9.65	4,450	S	26.1	4,460	26.5	4,022		33	S	18.5	7.00	5,100	S	18.4	5,540	16.8	5,858
24	S	36.4	10.68	3,240	S	36.1	3,590	29.6	3,261		34	S	18.6	10.00	5,100	S	16.0	5.550	17.3	5,943
25	S	41.3	10.08	3,480	S	36.6	3,990	36.2	4,262		35	S	16.6	6.92	4.700	S	16.4	4,920	16.8	5,695
26	S	28.8	11.15	4,550	S	26.5	4,470	26.5	4,702		36	S	18.5	11.00	4,280	S	17.0	4,540	15.4	5,092
27	C	40.5	10.82	2,930	C	59.0	3,540	49.7	2,981		37	S	18.1	9.00	5,350	S	17.2	5,960	15.8	6,932
28	S	47.0	11.46	3,870	S	50.6	3,430	31.0	3,165		38	S	19.6	12.00	5,100	S	17.2	5,620	16.4	5,787
29	C	37.9	10.33	3,090	C	34.4	3,330	28.7	3,409		39	S	18.5	12.00	4,870	S	16.5	5,260	16.0	5,865
30	S	26.6	9.83	3,770	S	27.0	4,500	28.7	3,780		40	S	18.1	9.50	6,040	S	18.4	6,340	16.2	7,290
41	S	34.5	9.74	3,070	S	28.5	4,150	26.1	3,780		51	S	20.2	9.00	5,220	S	17.3	4,440	15.6	5,455
42	S	31.3	7.68	3,560	S	32.4	3,620	47.8	3,210		52	S	18.7	10.83	4,210	S	17.5	4,050	15.5	5,362
43	S	36.3	9.58	4,300	S	35.0	----	36.3	4,370		53	S	19.0	9.50	5,450	S	17.8	5,200	16.0	5,969
44	S	29.9	10.42	4,390	S	30.4	4,710	35.2	4,520		54	S	19.0	9.29	6,045	S	17.6	5,330	14.5	6,322
45	S	33.4	9.04	3,510	S	34.0	3,340	29.9	3,870		55	S	19.5	11.75	4,900	C	18.4	4,530	14.2	5,853
46	S	35.6	10.73	4,120	S	33.5	4,450	32.4	4,450		56	S	19.0	12.00	5,600	S	18.2	5,880	15.5	6,983
47	S	31.5	9.68	4,640	S	30.0	4,900	29.3	4,900		57	S	19.6	10.27	3,250	S	19.2	3,800	13.0	5,685
48	C	26.7	9.65	3,290	C	27.6	3,840	27.8	4,380		58	S	21.4	8.67	5,060	S	18.6	4,330	15.7	5,815
49	S	31.4	9.97	----	S	30.4	3,740	30.9	3,550		59	S	19.5	7.75	5,250	S	19.9	6,000	14.7	6,715
50	S	39.4	9.37	4,550	S	30.7	5,420	40.2	4,500		60	S	15.0	10.10	5,315	S	19.1	5,580	14.6	6,530
61	C	29.4	9.54	3,030	S	29.5	3,460	27.4	2,290		71	S	18.6	7.67	4,260	S	18.3	5,440	14.5	6,425

[1] The omissions in the table indicate a lack of test material resulting from the type of failures in the 24-foot columns.
[2] S=Select grade; C=Common grade.

TABLE 7.—*Tests of nominal 12 by 12 inch columns of intermediate and 2-foot lengths and of clear minor specimens 2 by 2 by 8 inches*—Continued

SOUTHERN YELLOW PINE—Continued

Green											Air-dry									
Column No.	Intermediate				Two-foot columns			Minor specimens			Column No.	Intermediate				Two-foot columns			Minor specimens	
	Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$			Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$
		Per cent	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*				*Per cent*	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
62	S	30.2	9.92	5,340	S	29.9	5,170	29.7	4,890		72	S	18.6	10.90	5,475	S	18.4	6,100	16.6	6,942
63	C	31.6	9.05	3,160	S	30.6	3,220	33.9	2,790		73	S	18.9	9.42	4,140	S	19.0	3,900	17.7	4,778
64	S	38.0	10.98	3,810	S	39.0	4,070	35.5	3,780		74	S	18.6	9.29	5,950	S	19.1	5,820	14.8	6,755
65	S	34.1	9.79	3,810	S	46.5	4,280	54.2	3,190		75	S	18.8	8.94	5,900	S	16.6	5,950	14.5	7,315
66	S	34.7	11.03	3,720	S	37.0	4,090	33.7	3,750		76	S	19.0	9.54	4,640	S	17.2	5,025	13.2	5,792
67	S	32.9	9.27	3,160	S	34.1	3,200	34.3	3,460		77	S	20.0	7.60	4,770	S	16.6	4,710	14.3	6,075
68	S	32.9	10.25		S	34.0	4,110	33.0	4,230		78	S	19.1	8.19	5,880	S	16.7	6,160	15.4	7,273
69	S	33.6	9.78	3,875			4,010	34.8	3,570		79	S	19.8	9.56	5,650	S	16.1	5,270	14.2	6,147
70	S	28.0	10.12	5,650	S	28.6	5,290	30.7	5,020		80	S	19.6	11.92	5,610	S	14.3	5,555	15.0	6,088

DOUGLAS FIR

Column No.	Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$	Column No.	Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$
1	S	31.5	10.28	3,739	S	30.9	4,122	27.6	4,070	2	S	17.8	8.54	4,510	S	17.3	5,260	12.9	6,480
3	S	32.0	9.32	3,082	S	31.5	3,163	28.6	3,600	7					S	18.4	5,390	13.5	7,237
4	S	28.7	9.32	3,213	S	28.9	3,275	27.8	3,300	8	S	17.9	7.82	4,055	S	17.9	4,355	13.8	5,197
5	S	31.2			S	31.8	3,185	28.4	3,410	9	S	17.6	7.04	4,040	S	16.3	4,300	11.6	5,990
6	S	29.6			S	30.3	3,022	28.5	3,550	10					S	17.1	4,390	12.6	6,037
12	S		8.36	3,183	S	31.0	3,160	27.5	3,440	11					S	18.3	4,390	13.4	6,307
13	S	34.1	7.81	3,970	S	32.0	3,980	30.1	4,340	14	S	19.5	9.32	5,340	S	19.4	5,462	14.9	6,028
15	S	33.3	8.13	3,310	S	33.8	3,150	31.0	3,100	16	S	18.7	8.73	5,020	S	18.5	5,050	14.5	5,907
17					S	34.4	3,660	31.7	3,470	18	S	18.5	9.59	4,285	S	17.7	4,731	15.5	5,462
19	S	33.5	8.49	3,252	S	33.4	3,382	30.6	3,570	20	S	18.0	7.54	5,540	S	18.3	5,970	16.5	6,327
21								33.7	3,050	22					S	18.0	4,061	14.2	5,637
23	C	32.0	9.42	3,011	C	31.4	3,435	27.4	3,570	24	S	18.0	6.65	4,085	S	17.8	4,270	14.6	4,822
25	S	32.6	8.97	3,640	S	33.4	3,720	33.0	3,680	26					S	18.0	3,888	12.6	5,902
27										28					S	18.1	4,140	10.8	5,819
29	S	32.2	9.19	3,655				29.7	3,540	30					S	18.0	4,420	14.5	4,950
31	S	30.0	10.68	3,825	S	31.4	3,830	29.7	3,880	32	S	19.1	9.37	5,400	S	17.1	5,180	14.0	5,991
33	S	29.4	7.66	3,162	S	28.0	3,745	24.9	4,060	34					S	17.8	5,010	11.6	7,073

35	S	30.5	9.52	3,990	S	29.6	3,990	28.0	4,210	36					S	18.1	4,405	11.6	6,355
37	S	32.5			C			30.7	3,420	38	Cull.	18.5	8.57	3,189	C	18.2	3,710	15.0	5,014
39	Cull.	29.9	6.71	2,220	S	31.4	2,315	28.1	2,900	40					Cull.	18.7	3,445	13.3	5,688
41	S	30.7	9.78	3,910	S	30.6	4,350	29.6	3,858	61	S				S	17.4	5,110	15.7	7,035
42	S	30.4	10.08	4,030	S	30.3	4,280	31.1	4,310	62	S	19.2	12.08	5,260	S	18.1	5,510	14.1	6,312
43	S	28.8	9.82	3,770	S	29.6	4,230	29.2	4,340	63	S				S	18.2	4,400	14.5	5,993
44	S	29.9	11.92	3,500	S	30.2	3,820	28.9	3,890	64	S				S	17.7	5,700	15.7	6,627
45	S	30.9	10.15	3,460	S	30.8	3,820	28.6	4,140	65	S	19.3	11.53	4,890	S	16.5	5,430	13.9	6,315
46	S	30.3	9.17	3,630	S	30.1	4,070	28.0	3,940	66	S	18.5	7.17	5,010	S	18.4	5,840	14.6	6,782
47	S	30.2	8.08	3,235	S	29.9	3,400	26.2	3,430	67	S	19.3	5.87	4,830	S	17.2	5,480	13.3	6,903
48	S	29.9	11.52	3,510	S	30.7	3,450	26.2	3,530	68	S				S	19.0	3,990	14.2	5,988
49	S				S	32.5	2,730	27.7	2,950	69	S				S	17.8	4,840	12.0	6,735
50	S	36.5	10.50	2,610	S	36.3	3,300	32.7	3,430	70	S	19.0	8.9	3,510	S	17.9	4,070	16.1	4,935
51	S	33.2	8.98	2,215	S	35.1	3,110	30.4	2,830	71								13.9	5,462
52	C	32.1	13.65	2,490	S	32.2	3,150	30.2	3,170	72	S	18.5	9.38	3,750	S	18.0	5,220	15.4	5,460
53	S	34.4	10.63	3,550	S	35.3	3,380	34.3	3,540	73	S	17.0	9.93	4,130	S	17.7	4,430	14.3	4,642
54	S	36.0	10.00	3,920	S	35.6	3,670	32.5	3,550	74	S	19.8	12.02	5,480	S	18.2	5,710	16.7	6,115
55	S				S	41.7	3,040	36.9	3,020	75	S	18.9	9.70	4,160	S	19.0	4,200	15.9	4,738
56	S	30.8	12.09	4,365	S	31.0	4,220	28.6	4,350	76	S	19.6	10.33	5,920	S	17.7	5,950	15.4	6,287
57	S	31.5	7.09	2,210	Cull.			27.3	3,280	77					S	18.0	4,320	14.6	5,115
58	C	20.5	11.15	2,550	S	29.5	2,850	24.7	3,360	78	C	18.7	7.77	3,200	S	18.8	4,080	13.7	4,662
59	S	28.8	8.71	4,650	S	28.6	4,330	25.8	4,070	79	S	19.4	6.82	1,980	S	17.2	6,260	16.8	6,950
60	S	27.9	8.15	3,945	S	28.0	4,060	25.9	4,900	80	S				S	18.6	5,210	15.1	6,715

The table also shows somewhat higher ultimate compressive values for the southern yellow pine, both green and air-seasoned, than for the Douglas fir. In southern yellow pine timbers of smaller sizes than 12 by 12 inch cross section, however, a larger percentage of upper cuts would usually be included; such inclusion would lower the average density of the group and consequently the average compressive strength.

KNOTS

A study of the progress of failures in the long columns having knots showed that knots intensify local stresses within a timber and that the fibers adjacent to the knots are the first to be stressed beyond the elastic limit. The long-column tests also show that the effect that knots have on column strength is dependent not only upon their size and location but also upon the length of the timber. If the length is such that the fibers adjacent to the knots are not stressed to the elastic limit before the Euler load is reached, then this type of defect has practically no influence on column strength. The fact that the 24-foot columns of the select grades (Tables 1 to 4) took their full Euler loads indicates the correctness of this assumption. It may also be seen in these tables that the influence of knots on the strength of the long columns as a whole is relatively small and approximately the same for both Douglas fir and southern yellow pine. In fact the test loads for the very knottiest timbers (see values for culls in Tables 3 and 4) are as a rule less than 10 per cent below their calculated Euler loads.

For the short and intermediate columns there were fewer knotty specimens from which to judge the influence of knots on the strength, since these specimens were taken from the long column at some distance from the failure, which usually occurred in the knottiest portion. Only 22 of all the specimens selected were knotty enough to be classed as common grade, and only 3 as cull. Furthermore, on account of the inherent variability in the strength of clear wood and the lack of a proper distribution of the minor specimens throughout the entire timber the results obtained from the tests of minor specimens do not represent exactly the true strength of the clear wood of the timbers. The ratios of expected load to column test load are therefore very erratic. In making deductions as to the effect of knots on the strength of short and intermediate columns, the results of structural timber tests previously made have been used since the present actual column test values check these results. The reduction in column strength of 2-foot and intermediate sections, because of the presence of knots, was found to be approximately proportional to knot size. In other words, the proportional reduction in column strength by a single knot equals the ratio of the projected area [9] of the knot to the cross-sectional area of the column. When the piece contains a number of knots, occurring either singly or in whorls, the effect of all knots within any 6 inches of length is approximately equivalent to the removal of their total projected area from the cross section. Applying this reasoning to the 22 common grade intermediate columns tested, the calculated average loss would be 20 per cent while the actual test results show a reduction in strength of a little

[9] Projected area of a knot in boxed-heart timbers was taken as two-thirds its diameter measured on the surface and multiplied by the length. In side-cut specimens the projected area was calculated as the average diameter of knot times its length on the face measured.

over 16 per cent. In the case of the three culls, the calculated loss is about 27 per cent and the actual loss approximately 29 per cent. This proportionally greater decrease in strength with increase in size of knot in the cull specimens, is in accordance with previous information secured from tests which show that large knots have a somewhat greater weakening effect in proportion to their projected cross-sectional area than smaller ones.

CROSS GRAIN; SPIRAL GRAIN; CHECKS

It was not deemed necessary to make tests to determine the effect of cross grain or spiral grain on the strength of wooden columns, since sufficient tests (*7*) had already been made at the Forest Products Laboratory to show the effect that such defects have on the strength properties of wood. Deductions from previous tests show that in clear wood the stiffness and compressive strength are little affected with slopes of grain less than 1 to 12½. The compressive strength of material free from checks is somewhat less affected than the stiffness.

Tests of structural timbers show that spiral and cross grain further affect the strength because of the normal checking which accompanies seasoning and which invariably follows the grain. While the compressive strength is lowered because of such checking, the stiffness is not materially altered. More severe limitations than are necessary to insure proper strength are usually placed on spiral grain, on account of the twisting which accompanies moisture changes in a timber with such grain.

COLUMN FORMULAS

Prior to the present study a column formula for timber had been derived by the Forest Products Laboratory for use with clear material. The study of wooden columns in structural sizes has shown that this formula applies not only to clear material but also to ordinary structural material when the proper values for modulus of elasticity and crushing strength for the particular species, grade, and condition are inserted (*8*). The conceptions involved in the formula and its application to structural columns are considered in the following discussion.

Certain physical laws are common to all columns. Within the elastic limit of the material, the best interpretation of the law governing the strength of long columns of uniform cross section is that represented by Euler's formula:

$$\frac{P}{A}=u\frac{\pi^2 E}{\left(\frac{L}{r}\right)^2}$$

where P = maximum load on the column (pounds).

A = cross-sectional area of the column (square inches).

E = modulus of elasticity of the material (pounds per square inch).

L = length in inches.

r = radius of gyration of section (inches).

$\frac{L}{r}$ = slenderness ratio of the column.

u = factor depending on end conditions (for pin-ended conditions $u=1$).

From the elastic limit to the point of maximum stress, the curve which represents the load a column will take for different slenderness ratios varies in form with the characteristics of the material (6). In wooden columns the curve is smooth as would be anticipated from the nature of any stress-strain curve of a short block of wood in compression. In such a short wooden column the stress-strain curve is a straight line up to the elastic limit. At the elastic limit it breaks away very gradually from the straight line and retains its smooth form out to the point of maximum compressive stress. Any curve which represents the strength values of the column between the elastic limit and point of maximum compressive stress must therefore be a smooth curve tangent to the Euler curve at a $\frac{P}{A}$ equal to the elastic limit stress. A curve of the parabolic type with its vertex, zero $\frac{L}{r}$, at the point of maximum stress, and tangent to the Euler curve at the elastic limit, fulfills these conditions. The general form of this parabola is:

$$\frac{P}{A}=S\left\{1-\left(\frac{S-S'}{S}\right)\left(\frac{\frac{L}{r}}{\frac{L'}{r'}}\right)^{\left(\frac{2S'}{S-S'}\right)}\right\}$$

where S = maximum crushing strength (pounds per square inch).
S' = fiber stress at elastic limit (pounds per square inch).
$\frac{L'}{r'}$ = slenderness ratio of the column when $\frac{P}{A}=S'$ (this may be calculated by substituting the elastic limit stress of the material for $\frac{P}{A}$ in Euler's formula).

For columns of rectangular section this formula may be written:

$$\frac{P}{A}=S\left\{1-\left(\frac{S-S'}{S}\right)\left(\frac{\frac{L}{d}}{\frac{L'}{d'}}\right)^{\left(\frac{2S'}{S-S'}\right)}\right\}$$

where d = least dimension of the section (inches) = $\sqrt{12}\,r$.
$\frac{L}{d}$ = ratio of length to least dimension of a column of rectangular section (also spoken of as slenderness ratio).
$\frac{L'}{d'}$ = slenderness ratio when $\frac{P}{A}$ is equal to S'. In other words it is the $\frac{L}{d}$ ratio at the point of tangency between the parabola and the Euler curve.

If the elastic limit of the column is four-fifths of the maximum crushing strength and if $\frac{L'}{d'}$ is replaced by K_1 this parabolic equation becomes:

$$\frac{P}{A}=S\left\{1-\frac{1}{5}\left(\frac{L}{K_1d}\right)^8\right\}$$

When S' is two-thirds of the maximum crushing strength of the material and $\frac{L'}{d'}$ is replaced by K the equation takes the form known as the Forest Products Laboratory fourth-power parabolic equation:

$$\frac{P}{A}=S\left\{1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right\}$$

K and K_1 are values which depend upon the modulus of elasticity, E, of the species and the fiber stress at the elastic limit. Values for K and K_1 may be found by substituting the assumed value for fiber stress at elastic limit for the species, grade, and condition of use in the Euler formula, the r in the formula being replaced by $\frac{d}{\sqrt{12}}$.

This fourth-power equation requires no greater mathematical skill in its application than the straight-line formulas in common use. Both types require only the solution of relatively simple quadratic equations. It is more convenient, however, to take the required values directly from a table than to solve for them each time they are needed. Table 8 has been prepared for this purpose by substituting the Forest Products Laboratory's recommended safe working stresses in the fourth power and Euler formulas. Values for K and for modulus of elasticity have also been included in the table.

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards* [1]

SAFE WORKING STRESSES FOR COLUMNS USED IN A MORE OR LESS CONTINUOUSLY WET OR DAMP LOCATION [2]

Species	Modulus of elasticity [3]	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Ash, commercial white	1,500,000	Select	26.2	900	886	876	859	834	798	751	688	609	524	457	336	257	203	164
	1,500,000	Common	29.3	720	714	708	698	686	668	644	612	571	520					
Aspen and largetooth aspen	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	356	352	348	342	333	322	308	290	269				
Basswood	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	350	352	348	342	333	322	308	290	269				
Beech	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Birch, yellow and sweet	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Cedar, Alaska	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Cedar, western red	1,000,000	Select	25.1	650	639	629	614	593	564	523	471	405	350	304	224	171	135	110
	1,000,000	Common	28.1	520	514	510	502	491	476	455	428	394	350					
Cedar, northern and southern white	800,000	Select	27.1	450	444	439	432	420	405	384	356	321	280	244	179	137	108	88
	800,000	Common	30.2	360	357	354	351	345	337	326	312	294	271	243				
Cedar, Port Orford	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	487	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Chestnut	1,000,000	Select	26.2	600	591	583	572	556	532	500	459	405	350	304	224	171	135	110
	1,000,000	Common	29.2	480	476	472	466	457	445	429	408	381	346					
Cottonwood, eastern and black	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	356	352	348	342	333	322	308	290	269				
Cypress, southern	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476	419					
Douglas fir (western Washington and Oregon)	1,600,000	Select	26.9	907	895	885	869	847	815	772	716	644	559	487	358	274	216	175
	1,600,000	Common	31.1	680	675	670	664	655	641	624	600	569	531	484				
Douglas fir (dense)	1,600,000	Select	25.8	992	976	963	943	913	872	816	742	649	559	487	358	274	216	175
	1,600,000	Common	28.8	793	785	778	768	753	732	703	666	618	557					
Douglas fir (Rocky Mountain type)	1,200,000	Select	26.5	700	690	682	669	651	625	591	545	487	419	365	268	206	162	132
	1,200,000	Common	29.7	560	555	551	544	535	521	504	480	450	413					
Elm, rock	1,300,000	Select	24.4	900	882	868	844	811	765	702	618	527	454	396	291	223	176	142
	1,300,000	Common	27.2	720	710	704	691	674	650	617	574	520						
Elm, slippery and American	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Fir, commercial white	1,100,000	Select	27.4	600	593	587	577	563	544	518	484	440	385	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	397	369	334				

Gum, red, black, and tupelo	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Hemlock, eastern	1,100,000	Select	27.4	600	593	587	577	563	544	518	484	440	385	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	397	369	334				
Hemlock, western	1,400,000	Select	26.8	800	790	780	766	746	718	679	629	564	490	426	313	240	189	153
	1,400,000	Common	30.0	640	634	630	623	612	598	578	552	520	478	427				
Larch, western	1,300,000	Select	25.8	800	788	777	761	737	706	660	602	527	454	396	291	223	176	142
	1,300,000	Common	28.8	640	634	628	620	608	591	568	538	500	452					
Maple, sugar and black	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Maple, red and silver	1,100,000	Select	27.5	600	593	587	577	563	544	518	484	440	384	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	398	369	334				
Oak, commercial red and white	1,500,000	Select	27.7	800	790	783	771	753	728	695	650	595	524	457	336	257	203	164
	1,500,000	Common	31.1	640	636	631	625	616	603	586	563	534	498	453				
Pine, southern yellow	1,600,000	Select	26.9	907	895	885	869	847	815	772	716	644	550	487	358	274	216	175
	1,600,000	Common	31.1	680	675	670	664	655	641	624	600	569	531	484				
Pine, southern yellow (dense)	1,600,000	Select	25.8	992	976	963	943	913	872	816	742	649	559	487	358	274	216	175
	1,600,000	Common	28.8	793	785	778	768	753	732	703	666	618	557					
Pine, northern white, western white, western yellow, and sugar.	1,000,000	Select	25.1	650	639	629	614	593	564	523	471	406	350	304	224	171	135	110
	1,000,000	Common	28.1	520	514	510	502	491	476	455	428	394	350	304				
Pine, Norway	1,200,000	Select	26.5	700	690	682	669	651	625	591	545	487	419	365	268	206	162	132
	1,200,000	Common	29.7	560	555	551	544	535	521	504	480	450	413					
Redwood	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	484	419	365	268	206	162	132
	1,200,000	Common	28.6	600	594	588	581	569	552	531	502	465	419	365				
Spruce, red, white, and Sitka	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Sycamore	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Tamarack	1,300,000	Select	25.8	800	788	777	761	737	706	660	602	527	454	396	291	223	176	142
	1,300,000	Common	28.8	640	634	628	620	608	591	568	538	500	452					

SAFE WORKING STRESSES FOR COLUMNS IN AN OCCASIONALLY WET AND QUICKLY DRY CONDITION

				Pounds per square inch														
Ash, commercial white	1,500,000	Select	24.8	1,000	982	967	943	908	860	795	709	608	524	457	336	257	203	164
	1,500,000	Common	27.8	800	790	783	771	753	728	695	650	595						
Aspen and largetooth aspen	900,000	Select	25.9	550	542	534	523	507	484	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Basswood	900,000	Select	25.9	550	542	534	523	507	484	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Beech	1,600,000	Select	24.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639	559					
Birch, yellow and sweet	1,600,000	Select	24.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639						

[1] Basic provisions for American lumber standards grades are published by the U. S. Department of Commerce in Simplified Practice Recommendation No. 16, Lumber, revised July 1, 1926; specifications for grades conforming to American lumber standards are published in the 1927 Standards of the American Society for Testing Materials, and in American Railway Engineering Association Bulletin, Vol. 27, No. 284, dated February, 1926.

[2] Species which are nonresistant to decay, used under these conditions without adequate preservative treatment, will lose strength and require frequent replacement.

[3] The modulus of elasticity values given are the averages for the species.

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards*—Continued

SAFE WORKING STRESSES FOR COLUMNS IN AN OCCASIONALLY WET AND QUICKLY DRY CONDITION—Continued

Species	Modulus of elasticity	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Cedar, Alaska	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Cedar, western red	1,000,000	Select	24.2	700	686	674	656	620	592	542	476	405	350	304	224	171	135	110
	1,000,000	Common	27.1	560	553	547	538	524	505	479	445	402						
Cedar, northern and southern white	800,000	Select	25.7	500	492	485	474	459	438	409	372	324	280	244	179	137	108	88
	800,000	Common	28.6	400	396	392	387	379	368	354	335	310	279					
Cedar, Port Orford	1,200,000	Select	24.6	825	808	795	774	744	702	645	572	487	419	365	268	206	162	132
	1,200,000	Common	27.4	660	652	645	634	618	597	567	529	479						
Chestnut	1,000,000	Select	24.3	700	686	674	656	629	592	542	476	405	350	304	224	171	135	110
	1,000,000	Common	27.0	560	553	547	538	524	505	479	445	402						
Cottonwood, eastern and black	900,000	Select	25.9	550	542	534	523	507	484	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Cypress, southern	1,200,000	Select	22.2	1,000	972	947	910	856	781	679	571	486	419	365	268	206	162	132
	1,200,000	Common	24.8	800	786	773	754	726	688	636	567							
Douglas fir (western Washington and Oregon)	1,600,000	Select	24.8	1,067	1,048	1,031	1,006	969	917	848	757	649	559	487	358	274	216	175
	1,600,000	Common	28.6	800	792	785	774	758	737	708	670	620	558					
Douglas fir (dense)	1,600,000	Select	23.7	1,167	1,142	1,120	1,087	1,038	971	860	761	649	559	487	358	274	216	175
	1,600,000	Common	26.6	933	920	909	892	867	833	787	726	647						
Douglas fir (Rocky Mountain type)	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Elm, rock	1,300,000	Select	22.0	1,100	1,068	1,041	999	937	851	737	618	527	454	396	291	223	176	142
	1,300,000	Common	24.6	880	863	849	828	798	752	694	617	527						
Elm, slippery and American	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Fir, commercial white	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430	384					
Gum, red, black, and tupelo	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Hemlock, eastern	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430	384					
Hemlock, western	1,400,000	Select	25.3	900	885	872	852	823	783	728	658	567	490	426	313	240	189	153
	1,400,000	Common	28.3	720	712	706	696	680	660	632	595	549	489					
Larch, western	1,300,000	Select	23.1	1,000	976	955	923	877	813	726	618	527	454	396	291	223	176	142
	1,300,000	Common	25.8	800	788	777	761	737	706	660	602							
Maple, sugar and black	1,600,000	Select	24.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639						

Maple, red and silver	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	384	335	246	188	149	121
	1,100,000	Common	28.4	560	551	549	542	530	515	493	465	430						
Oak, commercial red and white	1,500,000	Select	26.1	900	886	876	859	834	798	751	688	609	524	457	336	257	203	164
	1,500,000	Common	29.3	720	714	708	698	686	668	641	612	571	520					
Pine, southern yellow	1,600,000	Select	24.8	1,067	1,048	1,031	1,006	969	917	848	757	649	559	487	358	274	216	175
	1,600,000	Common	28.6	800	792	785	774	758	737	708	670	620	558					
Pine, southern yellow (dense)	1,600,000	Select	23.7	1,167	1,142	1,120	1,087	1,038	971	880	761	649	559	487	358	274	216	175
	1,600,000	Common	26.6	933	920	909	892	867	833	787	726	647						
Pine, northern white, western white, western yellow, and sugar	1,000,000	Select	23.4	750	733	718	695	663	617	555	476	406	350	304	224	171	135	110
	1,000,000	Common	26.2	600	591	583	572	556	532	500	459	405						
Pine, Norway	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Redwood	1,200,000	Select	23.4	900	879	861	834	796	741	666	571	486	419	365	268	206	162	132
	1,200,000	Common	26.1	720	709	700	686	667	639	600	551							
Spruce, red, white, and Sitka	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465	419					
Sycamore	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Tamarack	1,300,000	Select	24.3	900	882	868	844	811	765	702	619	527	454	396	291	223	176	142
	1,300,000	Common	27.2	720	711	703	691	674	650	617	575	520						

SAFE WORKING STRESSES FOR COLUMNS USED IN DRY INSIDE LOCATIONS

				Pounds per square inch														
Ash, commercial white	1,500,000	Select	23.7	1,100	1,076	1,055	1,023	978	913	827	714	608	524	457	336	257	203	164
	1,500,000	Common	26.5	880	868	857	840	818	784	740	682	607						
Aspen and largetooth aspen	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	544	532	515	492	460	418							
Basswood	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	544	532	515	492	460	418							
Beech	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	761	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Birch, yellow and sweet	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	761	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Cedar, Alaska	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Cedar, western red	1,000,000	Select	24.2	700	686	674	656	629	592	542	476	405	350	304	224	171	135	110
	1,000,000	Common	27.1	560	553	547	538	524	505	479	445	402						
Cedar, northern and southern white	800,000	Select	24.5	550	540	530	516	496	468	430	381	324	280	244	179	137	108	88
	800,000	Common	27.3	440	435	430	423	412	398	378	353	320						
Cedar, Port Orford	1,200,000	Select	23.4	900	879	861	834	796	741	666	571	487	419	365	268	206	162	132
	1,200,000	Common	26.2	720	709	700	686	667	639	600	551							
Chestnut	1,000,000	Select	22.7	800	779	762	734	694	638	564	476	405	350	304	224	171	135	110
	1,000,000	Common	25.3	640	629	620	606	586	557	519	468							
Cottonwood, eastern and black	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	544	532	515	492	460	418							
Cypress, southern	1,200,000	Select	21.2	1,100	1,063	1,030	981	909	810	679	571	486	419	365	268	206	162	132
	1,200,000	Common	23.7	880	861	843	818	781	729	658								

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards*—Continued

SAFE WORKING STRESSES FOR COLUMNS USED IN DRY INSIDE LOCATION—Continued

Species	Modulus of elasticity	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Douglas fir (western Washington and Oregon)	1,600,000	Select	23.7	1,173	1,147	1,125	1,092	1,042	974	882	761	649	559	487	358	274	216	175
	1,600,000	Common	27.3	880	869	860	846	825	796	757	706	640						
Douglas fir (dense)	1,600,000	Select	22.6	1,283	1,249	1,221	1,177	1,112	1,023	902	761	649	559	487	358	274	216	175
	1,600,000	Common	25.3	1,027	1,010	995	972	939	894	832	750							
Douglas fir (Rocky Mountain type)	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Elm, rock	1,300,000	Select	21.1	1,200	1,158	1,122	1,067	988	877	734	618	527	454	396	291	223	176	142
	1,300,000	Common	23.6	960	939	920	892	852	795	718								
Elm, slippery and American	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Fir, commercial white	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430	384					
Gum, red, black, and tupelo	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Hemlock, eastern	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	403	465	430	384					
Hemlock, western	1,400,000	Select	25.3	900	885	872	852	823	783	728	658	567	490	426	313	240	189	153
	1,400,000	Common	28.3	720	712	706	696	680	660	632	595	540	489					
Larch, western	1,300,000	Select	22.0	1,100	1,068	1,041	999	937	851	737	618	527	454	396	291	223	176	142
	1,300,000	Common	24.6	880	863	840	828	798	752	694	617							
Maple, sugar and black	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	701	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Maple, red and silver	1,100,000	Select	23.8	800	782	768	746	712	666	601	524	446	384	335	246	188	149	121
	1,100,000	Common	26.6	640	631	623	612	594	572	540	498							
Oak, commercial red and white	1,500,000	Select	24.8	1,000	982	967	943	908	860	795	709	608	524	457	336	257	203	164
	1,500,000	Common	27.8	800	790	783	771	753	728	695	650	595						
Pine, southern yellow	1,600,000	Select	23.7	1,173	1,147	1,125	1,092	1,042	974	882	761	649	559	487	358	274	216	175
	1,600,000	Common	27.3	880	869	860	846	825	796	757	706	640						
Pine, southern yellow (dense)	1,600,000	Select	22.6	1,283	1,249	1,221	1,177	1,112	1,023	902	761	649	559	487	358	274	216	175
	1,600,000	Common	25.3	1,027	1,019	995	972	939	894	832	750							
Pine, northern white, western white, western yellow, and sugar.	1,000,000	Select	23.4	750	733	718	695	663	617	555	476	406	350	304	224	171	135	110
	1,000,000	Common	26.2	600	591	583	572	556	532	500	459	405						
Pine, Norway	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Redwood	1,200,000	Select	22.2	1,000	972	947	910	856	781	679	571	486	419	365	268	206	162	132
	1,200,000	Common	24.8	800	786	773	754	726	688	636	567							

Spruce, red, white, and Sitka	1, 200, 000	Select	24. 8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1, 200, 000	Common	27. 8	640	632	627	617	602	582	556	522	476						
Sycamore	1, 200, 000	Select	24. 8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1, 200, 000	Common	27. 8	640	632	627	617	602	582	556	522	476						
Tamarack	1, 300, 000	Select	23. 1	1, 000	976	955	923	877	813	726	618	527	454	396	29[illegible]	223	176	142
	1, 300, 000	Common	25. 8	800	788	777	761	737	706	660	602							

EXPLANATION OF TABLE 8.—The values in the table were obtained by the use of the Forest Products Laboratory fourth-power parabolic formula and the Euler formula for long columns, pin-ended conditions.

The Forest Products Laboratory fourth-power parabolic formula

$$\frac{P}{A}=S\left\{1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right\}$$

The Euler formula

$$\frac{P}{A}=\frac{0.274E}{\left(\frac{L}{d}\right)^2}$$

Legend

P=maximum load on column in pounds.
A=cross-sectional area in square inches.
S=compression-parallel stress in pounds per square inch.
L=unsupported length in inches.
d=least dimension in inches.
E=modulus of elasticity in pounds per square inch.
K=constant for given species, grade, and condition of service.

The stresses have a factor of safety of 4 based on the average crushing stress for short columns and a factor of 3 based on the average modulus of elasticity of the species.

With any given species the modulus of elasticity is the same for the two grades and three conditions of use since the influence of moisture and defects on modulus of elasticity is relatively small. Therefore, as an Euler column, each species has for a given $\frac{L}{d}$ a single stress for both grades and the three conditions of service.

Round columns.—The values in the table may be applied to round columns by reducing the cross-sectional area of the column to an equivalent square timber, d, the side of the square being taken as seven-eighths of the diameter, measured one-third the length from the small end. The crushing stress at the small end must not exceed the allowable stress for a short column.

A composite curve of Euler's curve and the Forest Products Laboratory fourth-power parabolic curve is shown in Figure 1. The eighth-power parabolic curve is also given together with curves representing several other column formulas. Curves 2, 3, 4, and 7 are all tangent to the Euler curve and are simply variations of the general parabolic equation. The eighth-power curve assumes a fiber stress at elastic limit of 80 per cent of the maximum compression stress; the fourth power assumes an elastic limit stress two-thirds the maximum; J. B. Johnson's or the second-power parabola, a stress of one-half the maximum; and T. H. Johnson's straight line or first-power curve, an elastic limit stress of one-third the maximum.

RELATION OF THE PARABOLIC-EULER FORMULA TO TESTS OF COLUMNS HAVING DIFFERENT $\frac{L}{d}$ RATIOS

The conceptions back of the Forest Products Laboratory parabolic-Euler formula have been given. But how accurately does the formula represent the action of columns under test? Knowing the crushing strength, the fiber stress at elastic limit, and the stiffness of the material how closely can the strength of columns of the same material of any length be estimated? Is the formula amply conservative?

To answer these questions Figure 2 has been plotted.

In this figure an attempt is made to eliminate the variability of the material, which is taken care of by the grading rules and factor of safety, and to show only the relation of the strength of the column to its slenderness, or ratio of length to least dimension, which is conceived to be the function of a column formula. The data obtained from the tests of the columns of structural sizes, which have been described here, are too limited in ratios of length to least dimension to establish the relation of $\frac{L}{d}$ to strength of a column. Other tests made primarily on dry Sitka spruce and Douglas fir, in which the range and the data necessary to establish such a relationship were afforded, have therefore been used. The Euler formula requires that the modulus of elasticity or stiffness be known. This can be determined with a fair degree of accuracy for both clear and defective material. All but the lowest grade 12 by 12 inch by 24-foot columns previously described here come within the Euler class and even the timbers with the largest knots are so close to being Euler columns that they, and also the 2 by 2 by 48 inch clear pieces cut from them, are included in Figure 2. Four hundred and eighty tests are represented by the distribution area at an $\frac{L}{d}$ ratio of 24. All the other points represent single tests.

The parabolic portion of the curve assumes that the crushing strength of a short block is known and also the fiber stress at elastic limit, and the stiffness. It is possible by means of matched pieces to determine all these properties for the clear wood within any column and to predict by the formula what a column of any length should support, the difference between the test load and the estimated load being due to experimental errors and to the inaccuracy of the formula. The inaccuracy in predicting the crushing strength of short blocks

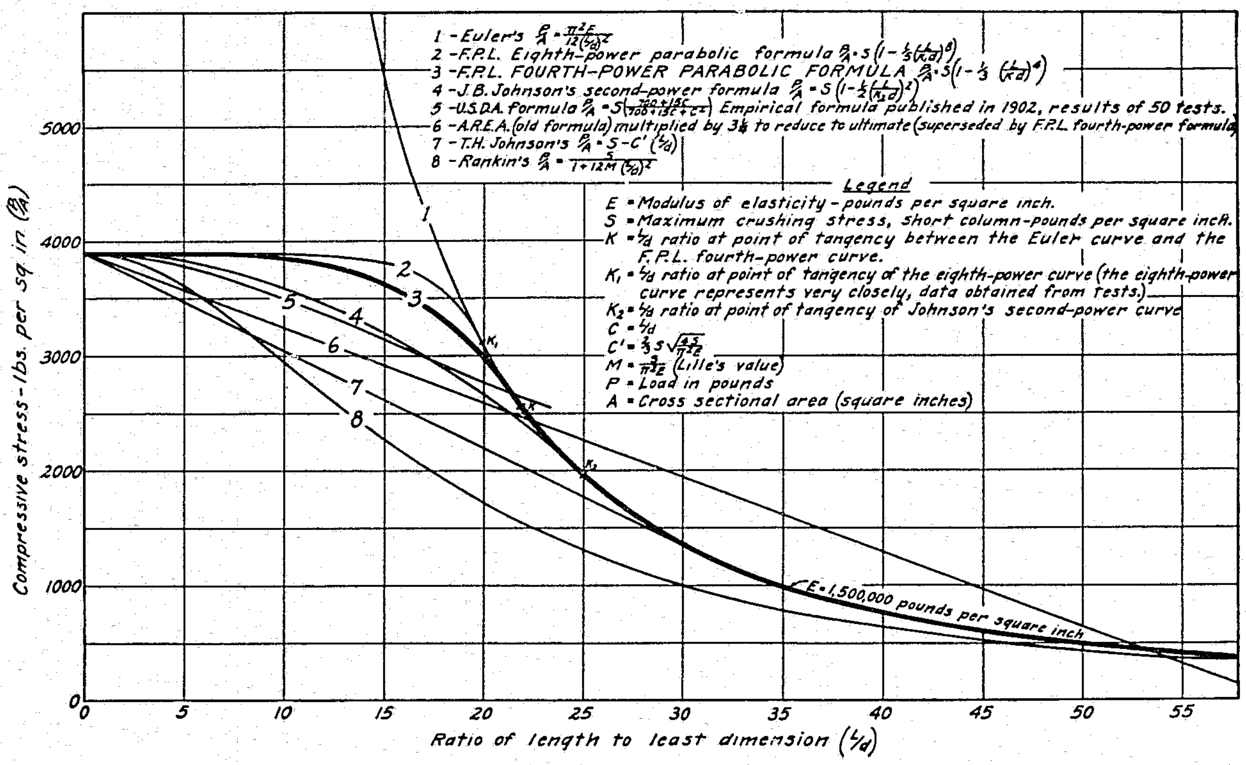


Figure 1.—Column formulas and the resultant curves

containing large knots is so great that no attempt was made to include the results of tests of commercial timbers in this portion of the curve.

The points on Figure 2 do not represent actual test values but were obtained indirectly by substituting in the general formula the constants obtained from matched sticks (except that for convenience the fiber stress at elastic limit was taken as 80 per cent of the ultimate whereas it as a rule is somewhat higher) and then by calculating the expected load for each column and the percentage that the actual test load differed from the calculated load. This percentage is represented in Figure 2 by the distance the test point representing a particular test is from the average eighth-power curve. Thus, the points represent experimental errors and formula inaccuracy but do not represent the variability of the material. The point at about $\frac{L}{d}=9$ was obtained from a test with a slightly eccentric load, which accounts for its being below the curve.

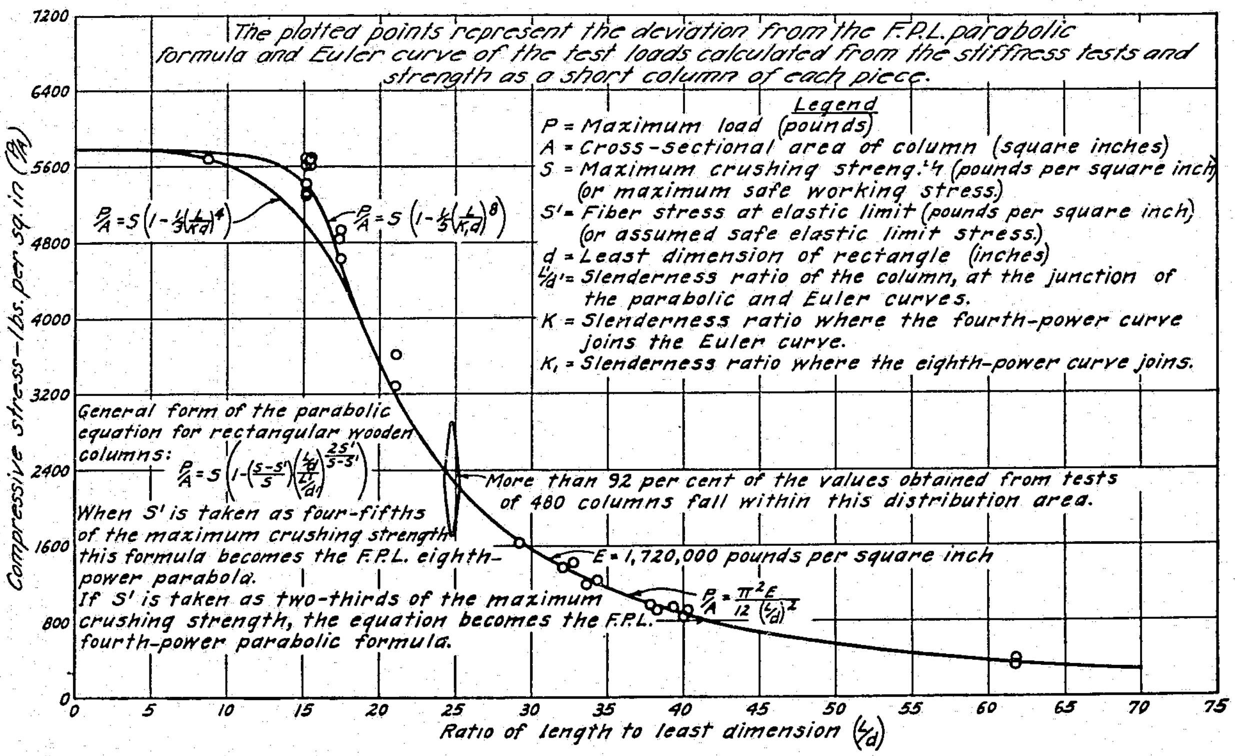
It was found that with an Euler column on a knife edge bearing the degree of conformity to the expected load is primarily a matter of the refinement used in determining the stiffness of the test specimen and care in making the column test.

The conformity of intermediate columns is very close when the maximum crushing strength, fiber stress at elastic limit, and stiffness for the individual pieces are all known and the general form of the equation is used. The points show that even the eighth-power equation is low for clear, dry spruce or Douglas fir. This conforms to laboratory test data, which shows that generally such material has a fiber stress at elastic limit more than 80 per cent of the ultimate. It is not practical to use different powers in the parabolic formula and the fourth-power parabola is recommended for use, since material of some species when green will have a fiber stress at elastic limit only two-thirds the ultimate for short columns; that is, under some conditions, the fourth-power parabola will be correct, and the eighth power unsafe.

Although the fourth-power formula may also be used to determine the safe stress for short columns, it is recommended that the crushing strength for short columns be used instead for all columns with a slenderness ratio of 11 or less, since the error would seldom be more than 1½ per cent of that obtained by the use of the formula.

RELATION OF THE FOREST PRODUCTS LABORATORY FOURTH-POWER PARABOLIC-EULER COLUMN FORMULA TO TESTS ON SOUTHERN YELLOW PINE AND DOUGLAS FIR STRUCTURAL TIMBERS

The relation of the Forest Products Laboratory fourth-power formula to the tests on southern yellow pine and Douglas fir structural timbers is shown in Figures 3 to 6, inclusive, which present data from tests on the nominal 12 by 12 inch columns of the various lengths investigated. The points on the figures represent individual tests. The large spread in these points is due to the fact that the test material ranged in grade from clear and dense to knotty and light. Furthermore, all the short and intermediate columns were cut from the long columns after test and some specimens may have been slightly injured and therefore may have given lower loads in test than would be expected.



$$\frac{P}{A}=S\left(1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right) \qquad \frac{P}{A}=S\left(1-\frac{1}{5}\left(\frac{L}{K_1d}\right)^8\right)$$

$$\frac{P}{A}=S\left(1-\left(\frac{S-S'}{S}\right)\left(\frac{L/d}{L/d'}\right)^{\frac{2S'}{S-S'}}\right) \qquad \frac{P}{A}=\frac{\pi^2E}{12\left(L/d\right)^2}$$

FIGURE 2.—Relation of the Forest Products Laboratory parabolic-Euler formulas to test data from columns of various $\frac{L}{d}$ ratios

Two ultimate stress curves which show the strength of columns for various $\frac{L}{d}$ ratios are plotted on each chart; one approximately through the average test values for the Select grade (*3*) of each of the three groups of columns, and the second through the minimum values of each group of columns irrespective of grade. It may be seen that the average test loads for the long columns fall slightly below the curves. This is due to the technic employed in the tests which is explained on page 14.

A comparison between the curves in Figures 3 and 4 and between those in Figures 5 and 6 shows a marked similarity in column strength between the two species. The curves also illustrate that the intermediate and 2-foot southern yellow pine columns in both the green and air-dry conditions sustained slightly greater ultimate compressive stresses than the Douglas fir columns of similar lengths and that the Douglas fir long columns had somewhat greater stiffness than the southern yellow pine long columns.

The lower curves in Figures 3 to 6 represent recommended safe working stresses for a dense select grade of southern yellow pine and Douglas fir columns.

END CONDITIONS, ECCENTRIC LOADING, AND CROOKED COLUMNS

In the present study the 24-foot columns were tested with pin-ended bearings as shown in Plate 2. Under these conditions the columns were carefully loaded in such a way that bending could take place freely in but one plane. Theoretically, a column of any length tested in this manner would carry less load than if the ends were carefully surfaced and the column tested with flat-ended bearings. The tests of the intermediate and short columns showed that up to a limit of 11 for $\frac{L}{d}$ any increase in strength caused by flat-end conditions is negligible. The reduction in strength of a wooden column resulting from imperfect end surfaces, crooks, eccentric loading, or any other condition that will result in combined bending and compression, is not so great as might be expected. Tests have shown that a timber, when subjected to combined bending and compression, develops a higher stress at both the elastic limit and maximum load than when subjected to compression only (*5*). This does not imply that crooks and eccentricity should be without restriction, but it should relieve anxiety as to the influence of imperfect end conditions and the influence of crooks such as those common in structural columns.

ROUND COLUMNS

It has been proven by tests (*4*) that round and square wooden members of the same cross-sectional area will carry the same loads in both bending and in compression, and have approximately the same stiffness. In the design of round columns the procedure is to design first for a square column and then to use a diameter of round column which will give the equivalent area of the square; namely, $\frac{2}{\sqrt{\pi}}$ times the side of the square. If the column is tapered, the diameter should be taken at one-third of the length from the small end. This will give a diameter of round column necessary to prevent failure from buckling. The stress at the small end of the column which will result from the assumed load should also be computed since it must not exceed the allowable stress for a short column.

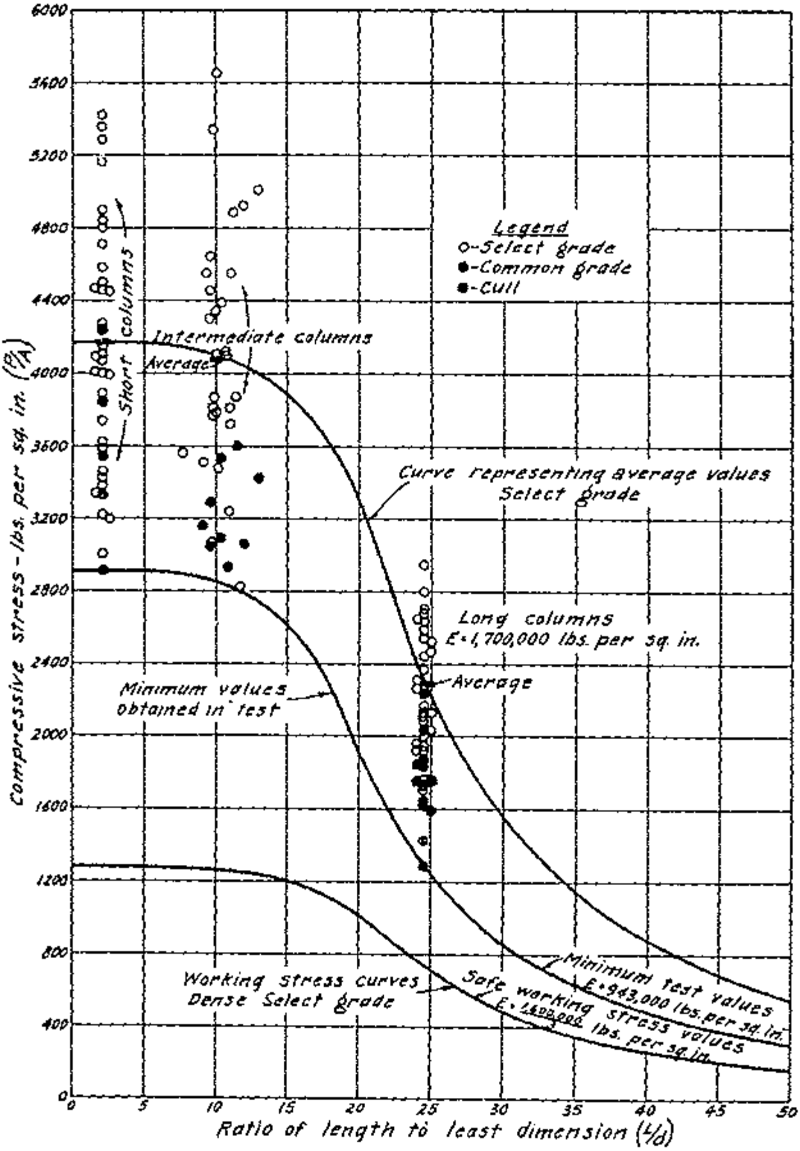


FIGURE 3.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of southern yellow pine in green condition

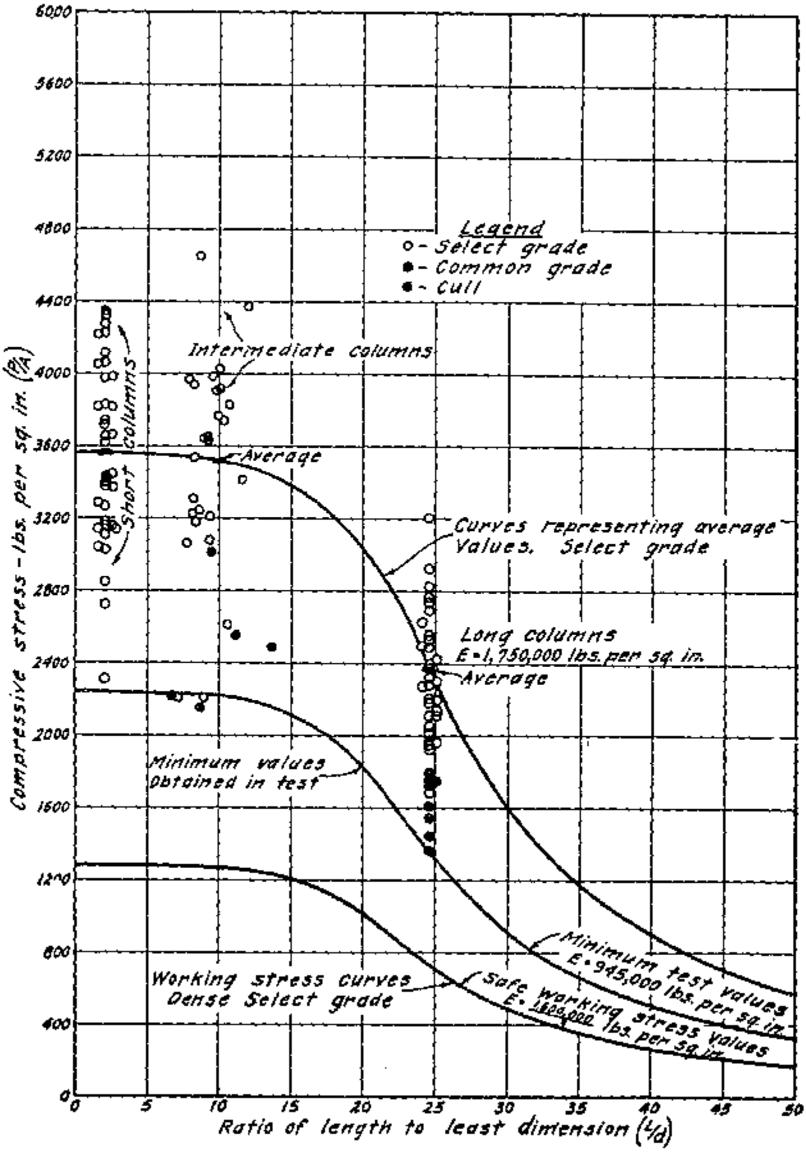


FIGURE 4.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of Douglas fir in green condition

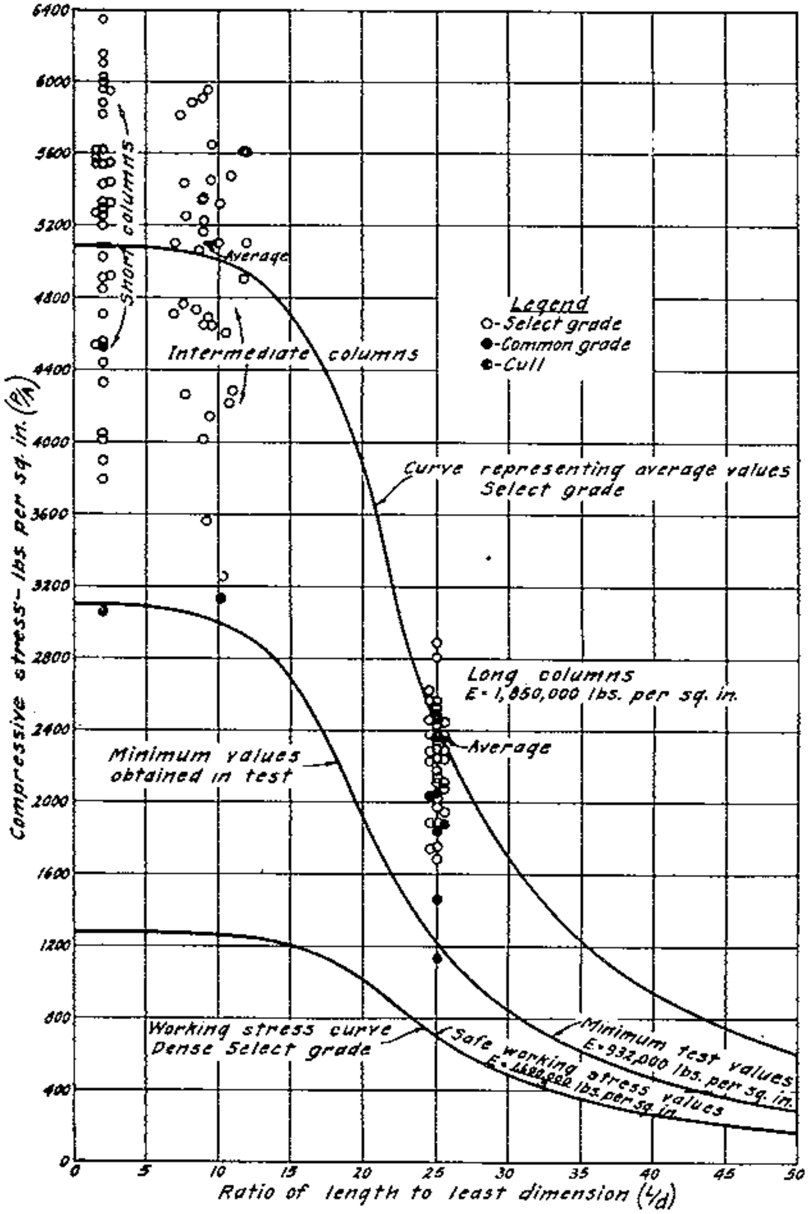


FIGURE 5.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of southern yellow pine in air-dry condition

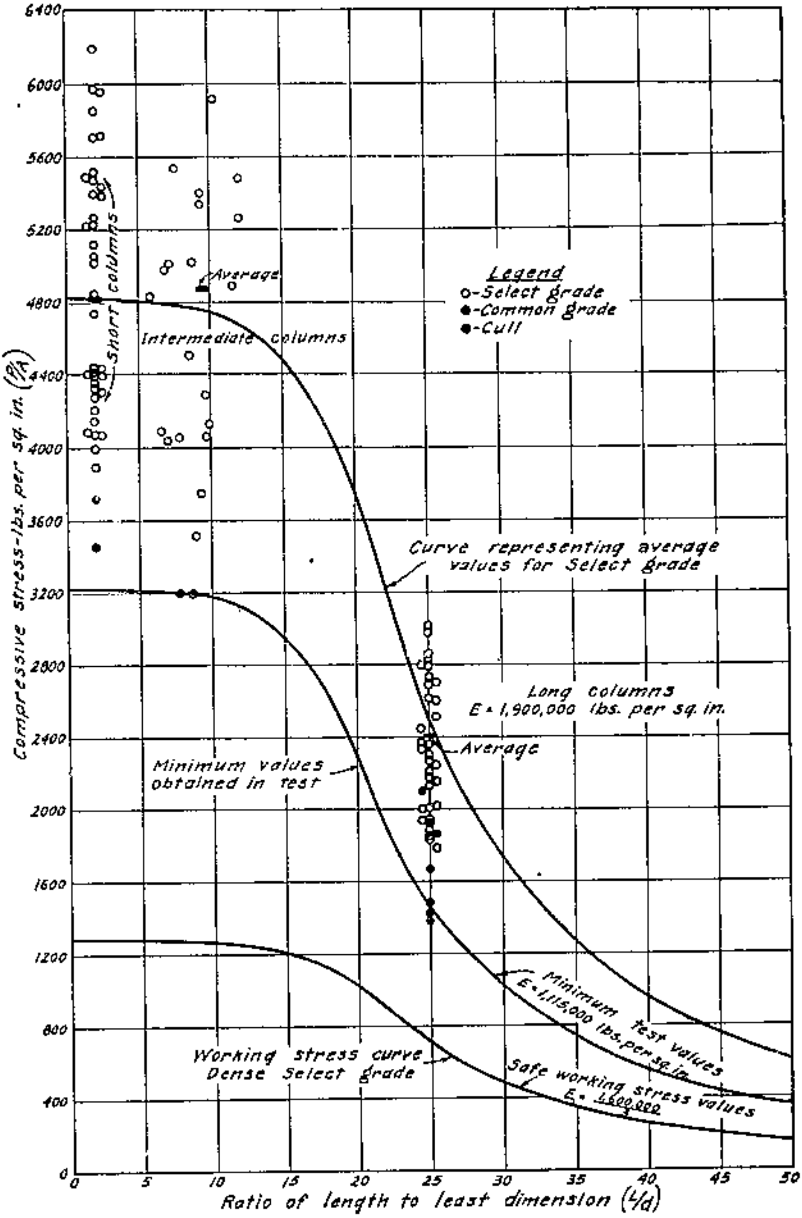


FIGURE 6.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of Douglas fir in air-dry condition

CONCLUSIONS

The tests on large timber columns confirm the Forest Products Laboratory column formula and in addition justify the following conclusions:

In long columns, where stiffness instead of crushing strength is the controlling factor, the loss in strength on account of knots is relatively small as compared to that for shorter specimens. The loss would be negligible in long columns of the common grade having a slenderness ratio of 30 or more to 1 and in high-grade columns with a slenderness ratio of approximately 20 to 1.

The effect of knots on the strength of short columns is proportional to the reduction in cross-sectional area that would result if all the knots in any 6 inches of the length were removed from the cross section.

A column with a slenderness ratio of 11 to 1 will sustain approximately the same load as a shorter column of the same cross-sectional area.

Long columns: Within the elastic limit of the material the best interpretation of the behavior of long columns is the Euler formula.

The decrease in cross section of an Euler column, on account of seasoning, largely offsets the increase in strength which accompanies the seasoning.

Intermediate columns: The most practical expression of the behavior of intermediate columns appears to be the Forest Products Laboratory fourth-power formula.

Southern yellow pine and Douglas fir columns of the type and grade tested are practically equal in strength.

APPENDIX

DETAIL TEST PROCEDURE

MAJOR TESTS

All long columns were surfaced on four sides, cut to nominal 24 feet, and the two ends planed perpendicular to one of the sides. The butt and top ends of each timber were marked A and B, respectively. The green material was surfaced to 11¾ by 11¾ inches in section and the air-seasoned to 11½ and 11½ inches. These dimensions are nominal, the actual sizes being somewhat less, particularly in the air-seasoned timbers, depending upon the amount surfaced off on account of twist. A vertical type testing machine capable of applying 1,000,000 pounds load was used for the tests.

STIFFNESS TEST

Each timber, prior to the long-column test, was tested in bending with center loading. The span was 200 inches (16 feet 8 inches), and the maximum load applied was 5,000 pounds. Two sets of data were taken with the top and butt ends of the timber, respectively, in the overhang. Deflections were read from scales attached to the two vertical faces of the timber. From these data the modulus of elasticity (E) of each timber was calculated; the load that the timber should carry as a pin-ended connected long column was then determined by means of Euler's formula. With a span of 200 inches, the static load for a deflection of 0.2 inch is approximately 1 per cent of the calculated Euler load.

The top face of the test specimen, as it was supported in the testing machine and as the operator faced the butt end of the timber, was marked *a*. The remaining three faces were marked *b*, *c*, and *d*, in clockwise rotation. The weight of the timber and the cross-sectional dimensions of the two ends and of the center were then recorded.

LONG-COLUMN TESTS

The long-column tests were made with pin-ended bearings. (Pl. 2.) The timber was placed butt end down upon a special roller bearing with the *a* and *c* faces of the timber turned so that they were either the compression or the tension faces. The method of centering of the column in the machine was by trial. The center of the column end was placed over the center of the bearing and an end load applied at the rate of 0.014 inch per minute. If a deflection of more than 0.01 inch occurred with a load of 100,000 pounds or less, the column was shifted slightly and the process repeated until zero deflection at the middle of the height was obtained with that load. Another load was then applied and deflections were read at the middle and quarter points of the column. Loads and deflections were recorded at every 10,000 pounds until near maximum. The maximum load and corresponding deflection were then recorded. After maximum load, the loads and deflections were read at irregular intervals until a deflection of 5 inches had been reached when the screws of the testing machine were stopped. The deflection of the column, however, continued to increase, and recording of the loads and of deflections was continued until the movement had virtually ceased. The column was then taken out of the machine and the size and location of each knot and the location and extent of failure were sketched. The section of the timber containing the failure was then marked off and the longer end section selected as the intermediate-length column. The short end was marked into a 2-foot section and a section for the minor tests. In some timbers, because of the character of the failure, the shorter sections were taken from other portions of the long column. The four faces of the column were then photographed. (See pl. 1 for method of marking.) In order to make the air-seasoned material deflect from the beginning of the test the columns were set 0.07 inch off center. This slight change in the method of procedure prevented the column from reaching a state of unstable equilibrium.

INTERMEDIATE COLUMN TESTS

The intermediate columns varied in length from 6 to 13 feet, approximately. The test was similar to that of the long column. (Pl. 3.) Care was taken to place the specimen with the faces in the same relative positions as in the long-column test. Deflections were read at the center of the column up to maximum load, in the same manner as with the long columns. Deflections were not read after maximum load had been reached.

TWO-FOOT COLUMN TESTS

These tests were performed with the column centered on a heavy stationary plate. The load was applied centrally at the rate of 0.032 inch per minute, and the amount of compression in the column was obtained by measuring the descent of the moving head by means of a deflectometer. (Pl. 4.)

MINOR TESTS

For each timber the following tests were made upon the clear straight-grained material cut from the section (pl. 1) reserved for minor tests:

- Two clear columns 2 by 2 by 48 inches, tested under flat-ended conditions; 2 of the same size, tested under pin-ended conditions.
- Two specific-gravity determinations.
- One radial-shrinkage determination.
- One tangential-shrinkage determination.
- Four static-bending tests.
- Two impact-bending tests.
- Six compression-parallel tests.
- Two compression-perpendicular tests.
- Two hardness measurements.
- Four shear tests (2 radial and 2 tangential).
- Four cleavage tests (2 radial and 2 tangential).
- Four tension tests (2 radial and 2 tangential).
- Four toughness tests.

The results of only a part of these minor tests were required in the present study of large columns, the remaining data being utilized in other investigations of Douglas fir and southern yellow pine.

All minor tests were conducted according to standard laboratory practice (*2*). The rate of application of the load for the 2 by 2 by 48 inch columns was 0.04 inch per minute.

MOISTURE CONTENT DETERMINATIONS

A 1-inch thick section was cut from each of the intermediate and the 2-foot columns after the completion of the test and a total moisture determination made. Two moisture sections were cut from the long column. (Pl. 1.) A

M355F

An intermediate column in the Forest Products Laboratory 1,000,000-pound timber-testing machine

A 2-foot column in place ready for testing in the Forest Products Laboratory 1,000,000-pound timber-testing machine

TABLE 9.—*Percentage moisture distribution in 12 by 12 by 1 inch sections cut from Douglas fir structural timbers*

Green										Air-dry									
Column No.	Sectional No.[1]—									Column No.	Sectional No.[1]—								
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
1	28.0	27.5	27.6	28.5	32.5	31.4	31.4	32.1	31.5	2	15.0	16.0	15.0	15.1	17.6	19.0	18.3	18.1	19.8
3	25.1	20.3	23.6	26.9	30.1	30.1	30.4	30.1	32.6	7	14.7	15.6	14.8	15.7	19.0	19.0	17.9	19.4	18.5
4	27.3	27.9	28.4	27.7	33.0	33.2	33.4	33.1	35.0	8	15.7	16.9	15.7	15.9	18.5	18.6	18.6	17.5	19.6
5	23.5	26.4	26.5	25.2	30.5	32.1	32.3	31.5	34.5	9	15.0	17.1	14.8	17.6	17.8	16.7	18.2	18.3	18.9
6	29.2	25.5	25.5	27.2	31.9	32.4	31.2	34.1	34.5	10	15.6	15.3	15.0	15.4	17.4	18.3	17.0	18.1	18.6
12	25.3	27.0	24.7	25.4	32.2	33.7	32.7	32.4	34.7	11	16.0	16.9	15.4	16.5	19.8	18.8	19.6	17.7	20.2
13	28.6	28.5	30.9	32.5	34.2	34.2	32.7	36.0	35.8	14	16.0	15.8	15.7	16.6	19.4	19.0	19.7	20.0	21.4
15	31.0	30.0	26.0	26.5	36.0	37.4	34.0	35.5	36.9	16	15.3	15.7	15.7	15.8	18.6	18.1	18.8	18.7	20.5
17	36.9	29.0	63.3	30.5	38.0	30.3	34.5	35.5	37.0	18	17.0	16.7	16.3	16.6	19.7	19.1	19.3	19.0	21.6
19	28.9	27.0	28.0	31.1	31.0	32.0	34.0	36.5	36.9	20	15.1	16.3	14.9	15.3	18.3	18.9	18.0	18.4	20.2
21	23.5	27.0	34.8	33.0	32.7	36.6	42.4	39.6	42.2	22	15.4	15.9	15.9	15.7	17.9	18.3	17.8	18.0	19.9
23	27.4	26.0	25.1	25.6	33.0	29.7	30.7	32.1	33.4	24	15.7	16.2	15.8	14.8	17.8	18.7	17.4	17.9	19.4
25	29.1	30.5	30.8	28.6	36.5	43.0	39.4	34.0	41.5	26	14.6	15.4	14.3	14.8	18.0	18.0	18.2	18.5	19.4
27	24.4	25.0	23.5	27.5	31.5	34.4	34.0	32.5	36.0	28	14.6	15.4	14.6	15.2	18.3	18.3	18.3	17.4	19.7
29	27.3	29.4	23.6	24.4	33.9	35.1	32.4	31.0	34.5	30	16.6	16.1	16.0	16.6	18.5	17.7	18.1	18.4	19.5
31	24.4	28.0	24.5	24.6	31.6	32.9	32.1	31.0	34.2	32	16.2	17.1	17.2	17.0	18.4	19.5	19.6	19.1	18.7
33	22.0	22.6	22.9	20.9	29.5	30.5	29.0	29.5	32.2	34	15.3	15.1	15.1	15.5	18.0	18.1	17.6	17.9	19.8
35	22.6	27.2	24.9	22.5	30.1	31.1	30.1	30.5	34.0	36	16.2	16.0	15.6	16.0	18.3	18.3	18.2	18.3	20.5
37	28.8	27.7	31.5	31.5	35.2	36.0	33.2	33.4	35.4	38	16.5	15.1	16.4	16.6	18.5	18.8	19.0	19.4	20.8
39	20.0	20.1	22.5	30.0	29.4	28.0	32.0	36.0	35.5	40	15.7	16.1	15.5	14.9	19.0	18.9	18.4	14.9	20.8
41	28.2	27.2	27.1	27.2	32.1	32.3	32.8	34.5	33.1	61	14.3	14.7	15.2	14.9	17.6	18.1	17.9	18.8	20.1
42	28.4	29.2	26.1	28.6	31.5	34.3	32.5	32.7	34.0	62	16.2	15.1	14.8	16.5	19.1	18.6	18.8	19.6	20.6
43	25.4	26.4	15.0	25.7	31.2	30.7	30.0	31.4	33.1	63	14.1	15.2	15.2	15.3	18.7	18.8	18.2	19.5	21.1
44	27.0	27.5	27.6	25.4	30.5	32.4	32.4	31.8	33.4	64	16.1	16.2	16.1	17.0	19.6	18.1	18.5	19.7	20.0
45	26.7	27.7	25.1	27.7	32.0	33.7	33.1	33.5	34.1	65	14.8	16.8	17.0	17.1	18.9	19.1	19.2	19.4	21.1
46	25.7	27.2	24.0	28.4	30.4	31.4	31.1	33.1	34.3	66	15.4	14.9	14.5	15.6	18.7	18.6	18.2	19.1	21.2
47	26.5	27.5	26.1	29.5	31.6	31.5	31.5	33.0	32.7	67	16.1	16.8	16.7	17.0	18.9	19.5	19.0	19.6	21.1
48	24.1	28.2	26.1	28.0	29.6	32.8	31.0	32.2	34.4	68	15.9	16.2	15.6	17.1	18.9	18.8	18.3	19.7	20.3
49	29.2	32.6	26.8	33.5	32.6	34.4	32.1	36.5	35.4	69	15.6	16.6	15.9	16.2	18.9	19.5	18.9	19.5	20.6
50	33.3	37.7	28.5	34.0	36.9	40.3	38.4	39.2	38.9	70	16.4	15.1	15.4	16.9	19.0	18.6	18.9	19.1	20.6
51	24.5	31.0	29.9	28.0	34.4	37.3	35.6	33.1	37.6	71	16.0	16.4	16.2	17.4	18.9	20.5	20.0	20.5	21.8
52	27.1	30.0	29.1	31.1	34.0	34.9	35.4	35.5	35.5	72	15.7	15.9	15.1	16.1	18.7	18.6	18.5	18.7	20.9
53	25.5	34.0	28.4	26.9	35.6	40.1	42.1	37.1	37.4	73	14.9	15.5	14.2	14.2	18.1	18.1	17.3	18.1	20.3
54	27.5	36.1	29.1	29.4	35.4	41.9	41.0	39.1	39.9	74	17.6	16.9	15.9	17.5	20.4	20.0	19.5	20.1	23.5
55	30.5	34.8	32.4	28.5	44.0	45.4	46.8	44.0	49.4	75	15.7	15.2	14.9	16.4	20.1	19.1	19.0	20.6	22.7
56	26.5	26.5	25.9	26.3	32.1	32.9	30.4	35.0	38.6	76	15.9	16.0	15.6	16.6	18.6	19.6	19.1	19.8	21.9
57	20.1	27.9	24.0	26.5	31.0	34.6	31.8	32.0	36.5	77	14.0	15.0	15.0	15.9	18.0	17.7	18.2	18.6	20.2
58	25.9	30.3	24.2	25.4	32.1	33.5	29.0	30.9	33.7	78	14.9	14.6	15.1	16.4	18.2	17.3	18.0	18.6	20.1
59	26.0	26.0	24.0	27.5	29.9	29.0	29.5	29.6	31.0	79	16.9	16.9	16.1	15.5	20.1	19.6	20.1	17.9	21.5
60	23.2	23.7	22.4	25.1	28.6	28.3	27.3	29.0	31.1	80	16.9	16.0	16.6	16.5	18.7	19.5	20.1	18.9	21.6

[1] Sectional numbers correspond to the standard sections of Figure 7.

Table 10.—*Percentage moisture distribution in 12 by 12 by 1 inch sections cut from southern yellow pine structural timbers*

Green

Column No.	Sectional No.[1]— 1	2	3	4	5	6	7	8	9
1	43.0	41.2	66.3	79.5	50.4	40.7	57.0	93.9	61.1
2	25.6	22.8	19.4	21.6	29.4	30.1	26.8	29.0	28.6
3	24.1	24.9	22.6	22.6	33.3	34.6	31.3	39.8	39.8
4	54.1	57.9	31.1	72.5	58.6	45.0	30.9	58.1	37.8
5	29.3	29.2	28.1	23.3	29.4	30.5	28.9	24.9	29.6
6	26.3	35.6	55.8	30.1	30.1	31.2	41.0	34.4	32.1
7	26.8	22.6	23.8	23.1	27.8	28.1	27.8	28.1	28.8
8	31.3	30.5	25.8	32.6	32.0	36.5	37.4	35.3	35.0
9	29.9	24.5	36.0	47.1	29.1	27.8	31.4	30.6	31.3
10	24.7	34.1	29.7	24.9	29.3	33.1	32.3	31.8	31.9
21	23.6	24.3	21.9	23.6	28.2	30.5	28.1	27.3	30.6
22	27.0	25.0	29.5	29.5	28.3	30.1	31.8	30.9	31.1
23	22.1	20.9	21.1	21.1	25.5	23.9	26.5	30.0	29.8
24	30.4	25.9	37.9	32.9	36.7	35.1	42.6	41.8	41.9
25	33.1	36.4	30.3	30.0	39.5	42.4	37.9	33.6	41.8
26	38.8	30.8	24.5	27.7	20.7	27.9	27.4	29.1	29.0
27	109.8	51.4	26.6	62.6	111.8	37.7	28.5	50.8	37.2
28	62.9	30.2	52.5	68.1	54.8	33.5	43.5	100.2	37.2
29	20.3	22.9	31.8	29.0	33.5	36.9	34.8	32.2	36.7
30	21.0	25.0	30.0	22.2	27.2	30.2	31.8	25.2	32.3
41	41.0	42.5	46.0	28.9	33.6	35.0	35.2	30.2	33.1
42	28.5	24.1	51.7	59.1	30.8	32.0	41.5	32.5	31.5
43	33.4	30.2	26.3	27.8	39.5	36.5	37.1	32.7	43.5
44	28.1	27.1	37.9	40.5	30.4	31.2	32.8	34.0	31.6
45	28.9	27.4	30.3	31.9	33.8	35.1	34.3	36.4	36.1
46	40.4	37.5	36.5	33.0	38.0	36.3	36.5	38.4	36.0
47	29.5	28.6	28.5	31.6	28.4	39.6	31.9	36.6	34.1
48	24.6	27.2	24.4	24.0	29.0	32.1	29.4	43.3	29.4
49	26.2	31.1	54.5	34.6	31.8	34.0	33.9	32.4	34.4
50	59.9	42.7	42.1	45.6	39.5	35.7	34.0	33.8	32.2
61	24.6	29.8	26.4	30.3	32.0	33.5	31.5	39.6	28.2
62	26.7	28.3	28.5	28.0	32.7	32.0	33.7	31.5	31.0
63	33.5	35.3	34.0	29.6	33.8	32.3	34.4	34.3	31.4
64	28.2	33.5	30.2	32.4	41.5	41.6	38.7	41.5	40.3
65	83.9	52.5	68.8	92.0	48.4	35.5	39.5	38.3	35.0
66	34.4	37.2	45.4	33.2	35.1	36.0	37.6	37.5	35.5
67	27.8	32.6	37.9	26.4	34.5	34.0	35.8	33.8	33.3
68	37.5	28.0	30.1	37.0	39.0	35.6	33.0	36.5	35.0
69	26.1	30.3	30.9	32.7	33.4	36.2	36.9	37.3	38.5
70	25.6	29.5	41.0	29.6	28.5	30.8	30.0	31.1	31.6

Air-dry

Column No.	Sectional No.[1]— 1	2	3	4	5	6	7	8	9
11	14.4	14.7	14.5	13.9	17.6	17.5	16.6	16.8	19.0
12	15.3	16.2	16.8	16.4	17.5	18.2	17.5	18.7	20.4
13	16.4	15.5	15.8	15.4	18.4	17.5	17.9	18.5	20.1
14	14.7	14.5	14.4	14.0	16.0	16.3	16.0	15.5	17.1
15	14.9	15.0	15.8	15.2	18.0	18.5	18.8	18.8	21.2
16	15.5	19.0	18.0	15.0	18.6	20.5	19.4	20.0	24.0
17	16.4	16.2	16.4	16.5	18.1	18.4	19.0	18.1	19.8
18	16.1	15.8	15.9	15.5	18.0	17.4	18.1	18.1	19.1
19	16.9	16.4	16.0	16.8	19.2	19.1	18.6	19.0	20.8
20	14.9	16.1	15.0	14.9	16.9	14.8	15.1	14.6	18.4
31	16.3	16.6	17.0	17.0	17.5	18.0	17.4	19.0	19.2
32	17.9	17.1	17.1	17.6	18.7	20.9	20.7	20.4	22.5
33	17.0	15.8	17.0	17.8	18.8	17.8	18.0	19.4	20.5
34	16.6	16.5	15.8	16.5	18.2	18.5	18.0	18.4	20.7
35	15.4	15.8	15.2	15.3	16.8	16.8	17.0	17.0	18.4
36	15.9	16.3	15.8	16.4	18.9	18.5	16.8	19.5	21.1
37	16.9	16.5	15.3	15.4	19.1	19.8	17.8	18.9	20.5
38	15.2	14.6	16.3	14.8	19.1	17.7	18.3	17.5	26.2
39	15.0	15.6	16.4	15.3	17.3	18.5	20.1	17.4	20.0
40	15.7	16.1	15.0	15.1	18.3	18.5	19.0	17.1	21.2
51	17.0	17.1	16.4	17.5	19.5	18.0	19.9	20.4	21.2
52	16.1	16.6	16.1	16.2	17.7	19.4	18.6	18.6	19.5
53	15.5	16.0	16.3	16.0	19.8	20.3	19.4	19.2	20.6
54	16.0	16.0	15.9	16.7	19.4	19.3	20.5	20.2	20.9
55	17.0	18.4	17.5	17.9	21.1	22.3	20.7	22.3	22.2
56	16.1	15.3	15.4	16.0	20.0	19.4	18.4	20.0	21.4
57	16.6	17.3	17.0	18.1	20.5	20.9	20.9	20.9	22.4
58	18.0	17.5	17.0	17.6	23.9	21.0	21.9	21.3	23.7
59	16.6	18.4	17.8	16.8	20.0	22.0	22.0	21.5	20.8
60	15.3	16.6	17.1	17.3	22.6	21.0	20.4	22.6	21.8
71	15.8	16.2	16.0	15.5	18.6	18.8	19.1	19.5	20.4
72	15.9	17.4	16.5	16.5	19.4	19.1	19.4	20.3	20.5
73	17.2	18.1	25.0	17.5	19.0	21.2	18.1	29.5	20.0
74	15.2	15.6	16.0	15.8	19.3	18.9	19.5	19.5	20.4
75	16.2	17.0	15.3	16.1	20.6	19.9	19.3	20.0	20.0
76	15.2	16.2	16.5	16.0	19.4	20.4	18.7	19.8	20.2
77	17.5	17.7	16.3	17.6	20.9	21.2	19.9	21.5	20.9
78	17.0	17.6	17.2	16.5	20.5	20.7	19.3	20.0	22.2
79	15.3	17.4	15.5	16.6	18.8	21.2	18.7	20.7	20.2
80	18.0	17.2	16.8	17.5	19.9	19.3	18.7	19.9	21.0

[1] Sectional numbers correspond to the standard sections of Figure 7.

total moisture determination was made upon one section of each pair and a moisture distribution determination was made on the other. A position diagram of the standard moisture-distribution specimen is shown in Figure 7 by means of which corresponding positions for the specimens given in Tables 9 and 10 may be ascertained. All moisture determinations were made according to standard laboratory practice (*1*).

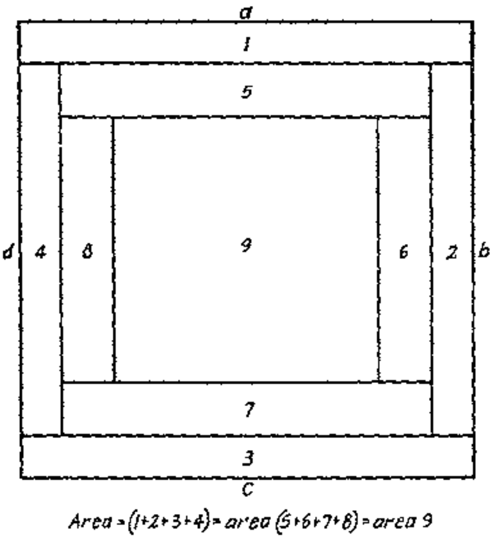


FIGURE 7.—Standard position diagram for moisture-distribution determinations

LITERATURE CITED

(1) AMERICAN SOCIETY FOR TESTING MATERIALS.
1927. STANDARD METHODS OF CONDUCTING STATIC TESTS OF TIMBERS IN STRUCTURAL SIZES. SERIAL DESIGNATION: D198–27. A. S. T. M. Standards . . . 1927 (Pt. 2): 664–682, illus.

(2) ———
1927. STANDARD METHODS OF TESTING SMALL CLEAR SPECIMENS OF TIMBER. SERIAL DESIGNATION: D143–27. A. S. T. M. Standards . . . 1927 (Pt. 2): 627–663, illus.

(3) ———
1927. STANDARD SPECIFICATIONS FOR STRUCTURAL WOOD JOIST, PLANKS, BEAMS, STRINGERS, AND POSTS. SERIAL DESIGNATION D245–27. A. S. T. M. Standards . . . 1927 (Pt.2): 581–622.

(4) NEWLIN, J. A., and TRAYER, G. W.
1924. THE INFLUENCE OF THE FORM OF A WOODEN BEAM ON ITS STIFFNESS AND STRENGTH. II. FORM FACTORS OF BEAMS SUBJECTED TO TRANSVERSE LOADING ONLY. Natl. Advisory Com. for Aeronautics Ann. Rpt. 9: 377–393. (Tech. Rpt. 181).

(5) ——— and TRAYER, G. W.
1925. THE INFLUENCE OF THE FORM OF A WOODEN BEAM ON ITS STIFFNESS AND STRENGTH. III. STRESSES IN WOOD MEMBERS SUBJECTED TO COMBINED COLUMN AND BEAM ACTION. Natl. Advisory Com. for Aeronautics Ann. Rpt. 10: 95–105. (Tech. Rpt. 188).

(6) SALMON, E. H.
[1921]. COLUMNS; A TREATISE ON THE STRENGTH AND DESIGN OF COMPRESSION MEMBERS. 279 p., illus. London.

(7) WILSON, T. R. C.
1921. EFFECT OF SPIRAL GRAIN ON THE STRENGTH OF WOOD. Jour. Forestry 19: 740–747, illus.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

January 18, 1930

Secretary of Agriculture	ARTHUR M. HYDE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	A. F. WOODS.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension	C. W. WARBURTON.
Director of Personnel and Business Administration.	W. W. STOCKBERGER.
Director of Information	M. S. EISENHOWER.
Solicitor	E. L. MARSHALL.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	R. Y. STUART, *Chief.*
Bureau of Chemistry and Soils	H. G. KNIGHT, *Chief.*
Bureau of Entomology	C. L. MARLATT, *Chief.*
Bureau of Biological Survey	PAUL G. REDINGTON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Agricultural Economics	NILS A. OLSEN, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Plant Quarantine and Control Administration	LEE A. STRONG, *Chief.*
Grain Futures Administration	J. W. T. DUVEL, *Chief.*
Food, Drug, and Insecticide Administration	WALTER G. CAMPBELL, *Director of Regulatory Work, in Charge.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*

This bulletin is a contribution from

Forest Service	R. Y. STUART, *Chief.*
Branch of Research	EARLE H. CLAPP, *Assistant Forester, in Charge.*
Forest Products Laboratory	CARLILE P. WINSLOW, *Director.*
Section of Timber Mechanics	J. A. NEWLIN, *in Charge.*

U. S. GOVERNMENT PRINTING OFFICE: 1930

END