DERIVING ALLOWABLE PROPERTIES OF LUMBER

(A Practical Guide for Interpretation of ASTM Standards)

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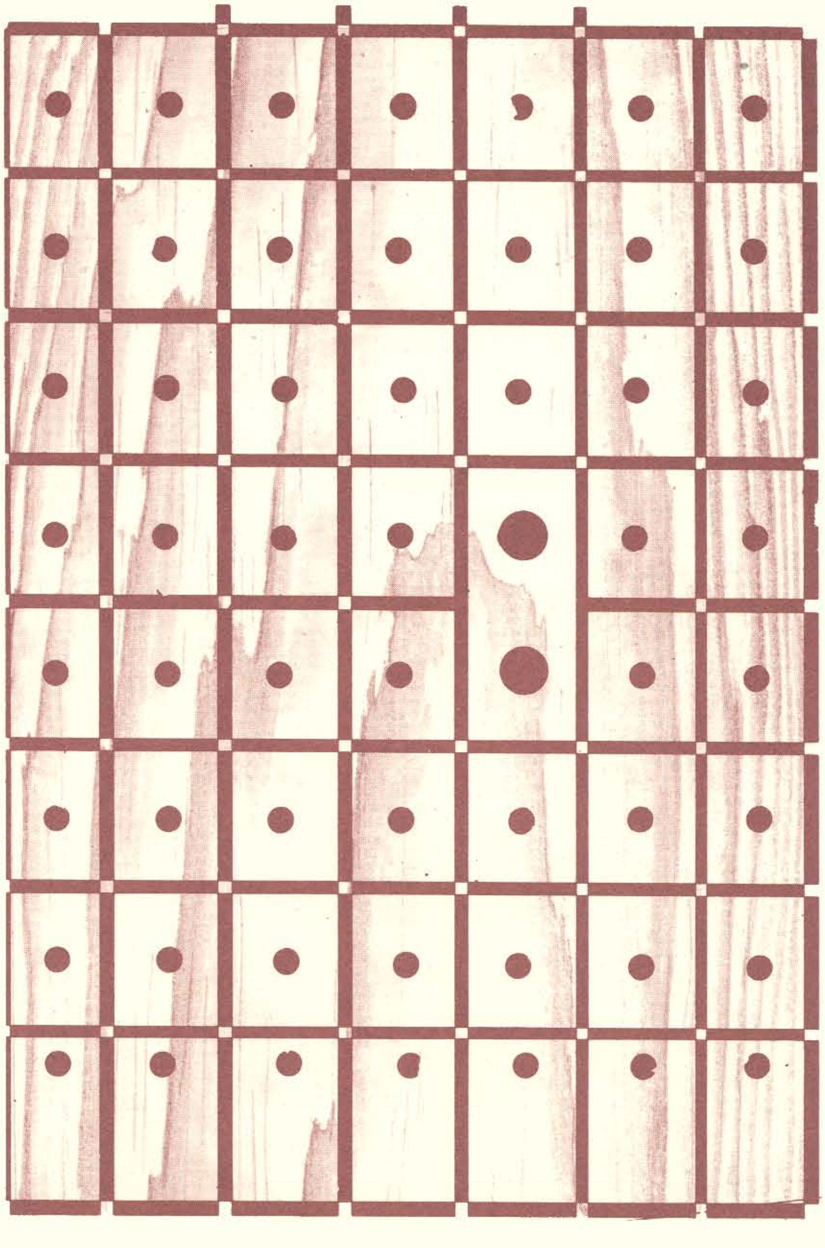

ABSTRACT

The ASTM standards for establishing clear wood mechanical properties and for deriving structural grades and related allowable properties for visually graded lumber can be confusing and difficult for the uninitiated to interpret. This report provides a practical guide to using these standards for individuals not familiar with their application. Sample stress derivations are presented to supplement the text.

TABLE OF CONTENTS

PREFACE

Allowable properties are assigned to lumber to achieve proper recognition of structural capability and to provide for uniformity in design application. The long tradition of successful structural use of lumber in the United States is based on an orderly development of key national standards for both grading and assignment of properties to grades.

The assignment of properties to visually graded lumber follows precepts developed by technical personnel in lumber research and manufacture. Since 1927, these have been recorded as standards of the American Society for Testing and Materials (ASTM). The most common use of the standards is by grading agencies preparing grading rules and grade descriptions for approval under the American Lumber Standard (PS 20-70). The procedures have other users, however, including consultants, research laboratories, and universities. While the lumber rules-writing agencies have extensive experience with these documents, the more uninitiated user often finds some frustration in the somewhat torturous path one must follow through the procedures. This report takes the user step by step through the procedures in the sequence and manner in which these standards are commonly interpreted.

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INTRODUCTION

The visual lumber grading system employed in the United States and Canada is based on two key ASTM Standards, ASTM D 2555-76, "Standard Methods for Establishing Clear Wood Strength Values" (3)[2/] and ASTM D 245-74, "Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber" (2). These standards function in sequence, with clear wood properties cataloged and grouped by D 2555 and the adjustments for design derived from D 245.

These ASTM standards are equally applicable to hardwoods and to softwoods, although they have been applied much more generally to softwoods. This report was prepared as a part of a cooperative effort with the National Bureau of Standards, in which hardwoods for trenching were the target. Consequently, the examples in this report employ hardwood data.

In application of D 245 under American Lumber Standard PS 20-70 (7), lumber nominally 2 to 4 inches thick (termed "dimension") is governed by the National Grading Rule, a document that standardizes many features of lumber grading across the United States. One feature that must be followed uniformly between agencies is the minimum strength ratio in bending applicable to a grade. Strength ratios for other properties also are consistent because the National Grading Rule also specifies knots and other characteristics permitted in dimension lumber.

1/ Maintained at Madison, Wis. in cooperation with the University of Wisconsin.

2/ Underlined numbers in parentheses refer to publications in the Bibliography near the end of this report.

It is recognized that this report does not cover all possible aspects of the derivation process. (In fact, the ASTM standards also fail to do that.) When these procedures become "institutionalized" through repetitive use by a lumber rules-writing agency, key decisions must be made that relate practical concerns for uniformity and standardization to the procedures permitted by ASTM. For example, the strength ratios used by agencies for specific lumber grade-size combinations sometimes exceed those nominally assigned to a grade because the critical defect (for uniformity or efficiency) is more limiting (smaller) than required by the National Grading Rule (see appendix C).

There are no specific strength ratio requirements under PS 20-70 for sizes other than dimension. Consequently, a grade of timber (Beams and Stringers or Posts and Timbers) defined by one grading agency may differ slightly from that of another. In southern pine, for example, timber is graded uniformly along the length; by contrast, some western timber has particular restrictions on the middle third of the piece, corresponding to the presumed region of maximum bending moment in end use. Such differences are permitted under PS 20-70. Similar interpretations of ASTM standards are important, but all cannot be chronicled here. This report emphasizes standard procedures and interpretations.

DERIVATION OF ALLOWABLE PROPERTIES

Allowable properties for visually graded lumber are based on clear wood properties as cataloged in D 2555 (3). D 2555 also provides rules and procedures for developing clear wood properties of species grouped for marketing purposes. Once clear wood properties of a species or market group are established, the steps necessary for allowable property derivation are found in D 245.

Several sample property derivations (tables 1-10) illustrate application of these standards. Yellow-poplar demonstrates the derivation of stresses for a single species; the "aspen" group demonstrates a combination (marketing group) where the composite dispersion factor (CDF) for the group is not limiting; the "maple" group illustrates a combination for which the CDF is controlling; and "cottonwood" illustrates a combination involving both a method A and a method B species. The aspen, maple, and cottonwood groupings are not intended as official marketing groups but were selected arbitrarily to illustrate various possible combination procedures.

For,accurate identification of species both common and botanical names are included here:

Aspen, bigtooth	-	Populus grandidentata
quaking	-	P. tremuloides
Cottonwood, black	-	P. trichocarpa
eastern	-	P. deltoides
Maple, black	-	Acer nigrum
red	-	A. rubrum
silver	-	A. saccharinum
sugar	-	A. saccharum
Yellow-poplar	-	Liriodendron tulipifera

Basic Clear Mechanical Property Statistics and Timber Volume Estimates

Averages and standard deviations for method B species are also listed in table 1. Method B species are those for which mechanical property estimates are established in accordance with D 143 or by random sampling procedures. (Tables 2 and 3 of D 2555 are the data sources for method B

Species Combinations and Weighting Factors

It is frequently desirable for marketing purposes to combine or group species that have relatively similar properties. ASTM procedures seek equitable treatment for each species in a group or combination by weighting factors based upon standing timber volume. A species weighting factor is the ratio of individual species volume to the combined volume of all species in the combination (D 2555, par. 5). Examples of marketing groups, species, and weighting factors are listed in table 2.

Table 1.--Clear wood mechanical property means and measurer of variability and timber volume

Species or region	Modulus of rupture			Modulus of elasticity			Campression parallel			Shear			Compression perpendicular		Volume
	Average	Var. index	Standard deviation	Average	Var. index	Standard deviation	Average	Var. index	Standard deviation	Average	Var. index	Standard deviation	Average	Standard deviation	
	$Lb/in.^2$		$Lb/in.^2$	$1,000\ lb/in.^2$		$1,000\ lb/in.^2$	$Lb/in.^2$		$Lb/in.^2$	$Lb/in.^2$		$Lb/in.^2$	$Lb/in.^2$	$Lb/in.^2$	Million ft^3
							METHOD A SPECIES								
Cottonwood, black	4,890	1.00	951	1,083	1.00	197	2,200	1.00	360	612	1.00	92	165	46	394
							METHOD B SPECIES								
Aspen															
Bigtooth	5,400		864	1,120		246	2,500		450	732		102	206	58	2,970
Quaking	5,130		821	860		189	2,140		385	656		92	181	51	11,093
Maple															
Black	7,920		1,267	1,328		292	3,270		589	1,128		158	601	168	1,801
Red	7,690		1,230	1,386		305	3,280		590	1,151		161	405	113	6,037
Silver	5,820		931	943		207	2,490		448	1,053		147	369	103	5.507
Sugar	9,420		1,507	1,546		340	4,020		724	1,465		205	645	181	8,566
Yellow-poplar	5,950		952	1,222		269	2,660		479	792		111	269	75	6,753
Cottonwood, Eastern	5,260		842	1,013		223	2,280		410	682		95	196	55	1/ 5,000

1/ Timber volume estimates for eastern cottonwood are not available. A fictitious estimate is assumed in order to demonstrate species combinations and property derivation procedures in subsequent tables.

Table 2.--Combinations and combination weighting factors

Combination	Species	Volume	Weighting factor
		Million ft^3	
Aspen	Bigtooth	2,970	0.2112
	Quaking	11,093	.7888
Maple	Black	1,801	.0822
	Red	6,037	.2755
	Silver	5,507	.2513
	Sugar	8,566	.3909
Cottonwood	Black	394	.0730
	Eastern	5,000	.9270

Clear Wood Stresses

This section shows how stresses are assigned for clear, unseasoned wood for individual species and for marketing groups. Modulus of rupture, compression parallel to grain (C||), and shear strength are near minimum property values (5 pct exclusion limits); compression perpendicular to grain (C⊥) and modulus of elasticity (E) are average values. Tables 3 to 6 summarize procedures for assigning c1ear wood stresses. Further application of procedures for assigning clear wood values to combinations as outlined below and in tables 3 to 6 are given in D 2555, 5.5.

Exclusion Limits

Exclusion limits (EL) for individual species are calculated as

$$EL = \bar{x} - 1.645\ s \quad \text{(Note 9, D 2555)}$$

where $\bar{x}$ and s are estimates of species averages and standard deviations from table 1.

Table 3. – Assigned exclusion limits for modulus of rupture, compression parallel, and shear (lb/in.^{2})

Species or combination	Species	$\bar{x}$	VI	s	Exclusion limit or weighted exclusion limit	CDF	CDF check value	Assigned value
				MODULUS OF RUPTURE				
Aspen	Bigtooth	5,400		864	3,814	1.84	NA	3,814
	Quaking	5,130		821		1.60		
Maple	Black	7,920		1,267	4,963	2.33	4,442	4,442
	Red	7,690		1,230		2.22		
	Silver	5,820		931		.92		
	Sugar	9,420		1,507		2.96		
Yellow-poplar		5,950		952	4,384			4,384
Cottonwood	Black	4,890	1.00	951	3,820	1.13	3,768	3,768
	Eastern	5,260		842		1.71		
				COMPRESSION PARALLEL				
Aspen	Bigtooth	2,500		450	1,538	2.14	NA	1,538
	Quaking	2,140		385		1.56		
Maple	Black	3,270		589	2,056	2.06	1,827	1,827
	Red	3,280		590		2.07		
	Silver	2,490		448		.97		
	Sugar	4,020		724		2.71		
Yellow-poplar		2,660		479	1,872			1,872
Cottonwood	Black	2,200	1.00	360	1,606	1.65	NA	1,606
	Eastern	2,280		410		1.64		
				SHEAR				
Asper	Bigtooth	732		102	512	2.15	NA	512
	Quaking	656		92		1.56		
Maple	Black	1,128		158	833	1.55	835	835
	Red	1,151		161		1.67		
	Silver	1,053		147		1.16		
	Sugar	1,465		205		2.84		
Yellow-poplar		792		111	609			609
Cottonwood	Black	612	1.00	92	518	1.02	503	503
	Eastern	682		95		1.73		

Table 4.--Assigned averages for compression perpendicular (lb/in.^{2})

Species or combination	Species	$\bar{x}$	Weighting factor	Weighted $\bar{x}$	Check value ($\bar{x}$min • 1.10)	Assigned value
Aspen	Bigtooth	206	0.2112	186.3	199.1	186
	Quaking	181	.7888			
Maple	Black	601	.0822	505.8	405.9	406
	Red	405	.2755			
	Silver	369	.2513			
	Sugar	645	.3909			
Yellow-poplar		269	NA	NA	NA	269
Cottonwood	Black	165	.0730	194	181.5	182
	Eastern	196	.9270			

Exclusion limits for combinations are the 5th percentile of the volume-weighted frequency distribution (D 2555, 5.2.2.2 and 5.3.2.2). A computer program for computation of a group exclusion limit (GEL) is given in appendix B. However, an estimate can be obtained by computing a volume weighted average GEL for all species in the combination (D 2555, Note 8).

Method A species.--(D 245, 5.2.2.3) GEL is limited by a composite dispersion factor (CDF) value of 1.18. CDF is calculated for each species in the combination as

$$CDF = \frac{(\bar{x}/VI) - GEL}{s} \quad (1)$$

where VI is the variability index from table 1. If CDF for one or more species in a combination is less than 1.18, the assigned value is the minimum GEL calculated as

$$GEL = (\bar{x}/VI) - 1.18\ s \quad (2)$$

for each species having a CDF less than 1.18.

Table 5.--Assigned averages for modulus of elasticity (1,000 lb/in.2)

Species or combination	Species	$\bar{x}$	Weighting factor	Weighted $\bar{x}$	VI	$\bar{x}$/VImin	Method A check (1.16 • $\bar{x}$/VImin)	Method B check ($\bar{x}$min • 1.10)	Assigned value
Aspen	Bigtooth	1,120	0.2112	914.9				946.0	915
	Quaking	860	.7888						
Maple	Black	1,328	.0822	1,335.1				1,037.3	1,037
	Red	1,386	.2775						
	Silver	943	.2513						
	Sugar	1,546	.3909						
Yellow-poplar		1,222							1,222
Cottonwood	Black	1,083	.0730	1,018	1.00	1,083	1,256	1,114	1,018
	Eastern	1,013	.9270						

Table 6.--A sample property derivation (E) when D 2555 tables A1 and A2 ratios are limiting[1/]

Species or combination	Green $\bar{x}$	Seasoning factor[2/]	$\bar{x}_{19}$ or $\bar{x}_{15}$	Weighting factor	Weighted $\bar{x}_{19}$ or $\bar{x}_{15}$	Method B check	Assigned value	Allowable unit stress for clear lumber[3/]
	1,000 lb/in.^{2}		1,000 lb/in.^{2}		1,000 lb/in.^{2}	1,000 lb/in.^{2}	1,000 lb/in.^{2}	1,000 lb/in.^{2}
				19 PERCENT MC				
Black	1,328	1.14	1,514	0.0822	1,508	1,182	1,182	1,257
Red	1,386	1.133	1,570	.2755				
Silver	943	1.14	1,075	.2513				
Sugar	1,546	1.126	1,741	.3909				
				15 PERCENT MC				
Black	1,328	1.20	1,594	.0822	1,582	1,245	1,245	1,324
Red	1,386	1.19	1,649	.2755				
Silver	943	1.20	1,132	.2513				
Sugar	1,546	1.18	1,824	.3909				

1/ This table applies only to modulus of elasticity because it is the lone instance in this paper where D 2555 table A1 or A2 ratios are limiting. The format of the table will vary depending upon whether method A or B species are used or which mechanical property is involved.

2/ The factor for 15 pct MC is the dry/green ratio (D 2555, table A-1) limited by the seasoning factor (D 245, table 11); for 19 pct MC the factor is calculated from the 15 pct MC factor according to D 245, 7.1.2 and is also limited by the seasoning factor (D 245, table11).

3/ Assigned value ÷ 0.94. Enter in table 8.

Method B species.--(D 245, 5.3.2.3) GEL is limited by a CDF value of 1.48. CDF is calculated for each species in the combination as

$$\mathrm{CDF} = (\bar{x} - \mathrm{GEL})/s \qquad (3)$$

If CDF for one or more species in a combination is less than 1.48, the assigned value is the minimum GEL calculated as

$$\mathrm{GEL} = \bar{x} - 1.48\ s \qquad (4)$$

for each species having a CDF less than 1.48.

Both A and B species.--CDF limits are applied to method A species as per equations (1) and (2); to method B species as per equations (3) and (4). If CDF limitations are involved, the lowest result of equations (2) and (4) is assumed for GEL (D 2555, 5.4.2.1).

Mean Values

$C_{\perp}$ and E values for combinations are volume-weighted averages calculated as

$$\bar{\bar{x}} = \sum_{1}^{n} R_i \bar{x}_i \qquad (5)$$

where

$\bar{\bar{x}}$ = volume-weighted average for a combination,

n = number of species in the combination, and

R = ratio of the volume of the ith species to the combined volume of all species in the combination (D 2555, 5.2.1, 5.3.1, and 5.4.1)

$\bar{x}$ = average $C_{\perp}$ or E value of the ith species.

Method A species.--Assigned E values may not exceed the minimum quantity, 1.16 ($\bar{x}$/VI), calculated for each species (D 2555, 5.2.1.1, 5.2.2). $C_{\perp}$ is limited as for method B species.

Method B species.--The assigned $C_{\perp}$ and E values may not exceed the minimum quantity, 1.10 $\bar{x}$, in the combination (D 2555, 5.3.1.1).

Both A and B species.--For combinations containing both method A and method B species, the limitations of method A and method B are applied as appropriate.

Nonvolume Species

A species for which no volume estimates are available may be included in a combination. Assigned values are determined for the combination excluding the "nonvolume" species and for the "nonvolume" species as an individual. If the assigned values for the "nonvolume" species exceed the combination values, the combination values are assumed. If not, the assigned values for the "nonvolume" species are assumed for the combination.

Clear Wood Property Summary

Table 7 summarizes the clear wood property assignments for individual species and marketing combinations as derived in tables 3 to 6. Modulus of rupture values are assumed for clear wood tension values.

Allowable Unit Stresses for Clear, Straight-Grained Lumber

Allowable unit stresses for clear straight-grained lumber are derived from the clear wood values in table 7 by adjustment factors and modifications for seasoning effects and density (in our examples, modification for density is not applicable). The result is shown in table 8.[3/] F_b values apply to lumber 2 inches wide only.

Adjustment Factors (D 245, 6.2, 6.2.1, and table 9)

Fb, Ft, Fc, and Fv adjustment factors include a factor for normal duration of load and a factor of safety.

The factor for E adjusts for span-depthratio from 14 to 21 and from concentrated centerpoint loading to uniform loading.

3/ Allowable properties are symbolized by the notation F_b for bending, F_t for tension, F_c for compression parallel, F_v for shear, $F_{c\perp}$ for compression perpepdicular, and E for modulus of elasticity.

Table 7.--Clear wood values summary

Species or combination	Modulus of rupture	$C_{\parallel}$	Shear	$C_{\perp}$	Modulus of elasticity
	Lb/in.2	Lb/in.2	lb/in.2	Lb/in.2	1,000 lb/in.2
Aspen	3,814	1,538	512	186	915
Maple	4,442	1,827	835	406	1,037
Yellow-poplar	4,384	1,872	609	269	1,222
Cottonwood	3,768	1,606	503	182	1,018

The factor for $F_{C\perp}$ includes adjustment for average ring position and a factor of safety.

F_t is derived as 0.55 F_b. (D 245, 4.2.5)

Seasoning Modifications (D 245, table 11)

Table 8 contains unseasoned values which apply to lumber of all dimensions, except for F_b values which apply to 2-inch depth only.

Allowable stresses, reflecting increases for 19 and 15 percent maximum moisture content in use, are also given in table 8. These increases for seasoning are limited by the Dry/Green clear wood property ratios in D 2555, tables A1 and A2.

Provisions for handling seasoning increases for instances where D 2555 ratios are limiting are given in D 245 (7.1.2) when stresses for a single species are being derived.

D 245 does not provide direction for handling seasoning increases when the D 2555 ratios are limiting for one or more species in a combination, However, the American Lumber Standards Committee (ALSC) Board of Review has approved a procedure that performs seasoning adjustments prior to forming a combination (WWPA Grading Rule, 3rd Edition effective July 1, 1974 (8)). Seasoning adjustments are made to the averages and standard deviations tabulated in table 1 for all species in the combination. For individual species or properties controlled by D 2555 ratios (tables A1 and A2), the adjustments are as per D 245 (7.1.2); other adjustments are as normal (D 245, table ll), except that the seasoning factor is applied to both the average and standard deviation. Using the adjusted values,

Table 8.--Allowable unit stresses for clear straight-grained lumber[1]

Species or combination	F_b [1]	F_t	F_c	F_v	$F_{c\perp}$	E
	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	1,000 lb/in.^{2}
UNSEASONED						
Aspen	1,658	912	732	114	124	973
Maple	1,931	1,062	870	186	271	1,103
Yellow-poplar	1,906	1,048	891	135	179	1,300
Cottonwood	1,638	901	765	112	121	1,083
19 PERCENT MAXIMUM MC						
Aspen	2,072	1,140	1,098	123	186	1,109
Maple	2,414	1,328	1,305	201	406	[2] 1,257
Yellow-poplar	2,382	1,310	1,336	146	268	1,482
Cottonwood	2,048	1,126	1,148	121	182	1,235
15 PERCENT MAXIMUM MC						
Aspen	2,238	1,231	1,281	129	186	1,168
Maple	2,607	1,434	1,522	210	406	[2] 1,324
Yellow-poplar	2,573	1,415	1,559	152	268	1,560
Cottonwood	2,211	1,216	1,339	127	182	1,300
FOR SEASONED MATERIAL THICKER THAN 4 IN.[3]						
Aspen			805			992
Maple			957			1,125
Yellow-poplar			980			1,326
Cottonwood			842			1,105

1/ F_b values apply to 2-inch depth only.

2/ Limited by dry-green ratio (table 6).

3/ F_b, F_t, F_v, and $F_{c\perp}$ are the same as for unseasoned.

combination and derivation procedures are carried out as usual beginning with moisture-adjusted table 1 values. 4/

For lumber sizes thicker than 4 inches, a 10 percent increase over green values is given for compression members and a 2 percent increase is given for modulus of elasticity (D 245, 7.1.3 and 7.1.4). Compression members must be sufficiently seasoned before the increase is applied, and appreciable seasoning of the outer fibers must take place to benefit from an increase in E. Stresses for seasoned lumber thicker than 4 inches are included in table 8.

Modification for Density

Strength properties may be increased by 17 percent and E by 5 percent for lumber meeting dense requirements (D 245, 5.6 and table 8). All species other than Douglas-fir and southern pine must follow the provisions of paragraph 5.6.2 of D 245.

4/ Illustrating this procedure, table 6 was prepared because the dry-green ratios (D 2555, table A1) for the modulus of elasticity of red and sugar maple were limiting.

Allowable Unit Stresses for Lumber Grades

Allowable unit stresses for lumber grades are derived from table 8 values for clear lumber by application of strength ratios (D 245, section 4 and tables 1-6) to strength properties and a quality factor to E values (D 245, 4.2.4 and table 7). Special factors are applied to F_b values to adjust for depth effect, and an additional factor may be applied where applicable for repetitive loading. Adjustments to F_t values conform to reductions recently recommended by the National Forest Products Association (6) and approved by the ALSC Board of Review.

A strength ratio (D 245, 4) is the ratio of the strength of a piece of lumber containing strength-reducing characteristics such as knots to its expected strength if it were a clear, straight-grained piece. Strength ratios for various lumber categories are given in table 9. The F_b strength ratios listed for grades of lumber in the Structural Light Framing (SLF), Light Framing (LF), Studs (S), and Structural Joists and Planks (SJ&P) categories are minimum ratios specified for these grades by the National Grading Rule as developed under PS 20-70 (7). Strength ratios for other lumber categories such as Beams and Stringers and Posts and Timbers are not covered by the National Grading Rule. The strength ratios listed for some of these categories in table 9 are arbitrarily chosen for demonstration purposes only and do not necessarily correspond to any grade description.

Table 9 also lists quality factors to be applied to modulus of elasticity values, The quality factors are related to F_b strength ratios (D 245, 4.2.4, table 7).

An example of stress-grade development comparable to the derivations outlined in tables 7 to 10 is given in D 245, 8 and table 13.

Size effect.--F_b values are adjusted for size effect by a multiplication factor $(2/d)^{1/9}$, where d is the net surfaced depth or width (D 245, 6.3.1). For simplicity, a 11.25-inch depth adjustment factor (0.8254) is commonly applied to members 5 to 12 inches in nominal width and a 3.5-inch depth factor (0.9397) is applied to nominal widths 4 inches and less in SLF and LP categories. In this report (for demonstration only), we have assumed a 20-inch depth factor (0.7743) for grades of Beams and Stringers and Posts and Timbers for actual widths (depth) greater than 12 inches and 12-inch depth factor (0.8195) for nominal widths 12 inches and smaller.

Strength ratio factor.--Rules-writing agencies commonly combine the depth adjustment with F_b strength ratios and refer to the combination as a strength ratio factor (SRF). For consistency and simplicity a minimum SRF is applied to all sizes in a grade. Refer to appendix C for additional detail concerning SRF.

Contiguous members.--An increase in F_b of 15 percent is recommended for design consideration for contiguous members because member interaction provides greater load-carrying capacity than expected from predicted individual member performance (D 245, 7.8.1).

Lumber grades.--Allowable unit stresses for lumber grades (table 10) are obtained by application of strength ratios and other adjustments given in table 9 to clear lumber values given in table 8.

Rounding.--For publication, allowable unit stresses are rounded as per D 245, 6.1.1. Rounded values are included in table 10.

Table 9.--Strength ratios, quality factors. and special adjustments

Category	Grade	F_b 1/, 2/ Strength ratio		Depth 3/	F_t Strength ratio	Special 4/ reduction	Strength ratios F_c	F_v	$F_{c\perp}$	Quality factor E
Structural light framing	Select structural	67	x	0.9397	67		78	50	100	100
	No. 1	55	x	.9397	55		62	50	100	100
	No. 2	45	x	.9397	45		49	50	100	90
	No. 3	26	x	.9397	26		30	50	100	80
Light framing	Construction	34	x	.9397	34		56	50	100	80
	Standard	19	x	.9397	19		46	50	100	80
	Utility	9	x	.9397	9		30	50	100	80
Studs	Studs (2 – 4in. wide)			.9397						
		26	x		26		30	50	100	80
	Studs (5 – 6in. wide)			.8937		0.80				
Structural joists and planks	Select structural	65	x	.8254	65	1.00	69	50	100	100
	No. 1	55	x	.8254	55	1.00	62	50	100	100
	No. 2	45	x	.8254	45	.80	52	50	100	90
	No. 3	26	x	.8254	26	.80	33	50	100	80
Beams and stringers	Strength ratio 86	86	5/ x		86	NA	90	50	100	100
	Strength ratio 72	72	x	.8195	72	NA	80	50	100	100
	Select structural	65	x	.7743	65	NA	75	50	100	100
	No. 1	55	x		55	NA	62	50	100	100
Posts and timbers	Strength ratio 86	86	5/ x		86	NA	90	50	100	100
	Strength ratio 72	72	x	.8195	72	NA	80	50	100	100
	Select structural	65	x	.7743	65	NA	75	50	100	100
	No. 1	55	x		55	NA	62	50	100	100

1/ For multiple member use, see "Allowable Unit Stresses for Lumber Grades."

2/ The strength ratios shown are the minimum ratios specified by the Natural Grading Rule for each grade category; the depth factor reflects adjustment for maximum width. Actual practice most commonly deviates from this simplified presentation (see appendix C).

3/ These depth adjustments assume dry ALS sizes, except as noted.

4/ No adjustment required for 2 – to 4-in. width. Where a factor is given, it applies to 5- and 6-in. nominal widths only. For 8-in. width, the factors are 0.90 for select structural, 0.80 for No. 1, and 0.64 for Nos. 2 and 3. For 10-in. and wider, use 0.80 for select structural, 0.60 for No, 1, and 0.48 for Nos. 2 and 3.

5/ 0.8195 applies to actual widths 12 in. and less; 0.7743 applies to actual widths 12 to 20 in.

Table 10.--Sample allowable unit stresses: Beam and stringers category; Select Structural grade; members greater than 12-inch nominal width[1/]

	F_b		F_t		F_c		F_v		$F_{c\perp}$		E	
	Lb/in.^{2}		Lb/in.^{2}		Lb/in.^{2}		Lb/in.^{2}		Lb/in.^{2}		1,000 lb/in.^{2}	Lb/in.^{2}
UNSEASONED												
Aspen	834	825	593	600	549	550	57	55	124	125	973	1,000,000
Maple	972	975	690	700	652	650	93	95	271	270	1,103	1,100,000
Yellow-poplar	959	950	681	675	668	675	68	70	179	180	1,300	1,300,000
Cottonwood	824	825	586	575	574	575	56	55	121	120	1,083	1,100,000
SEASONED[2/]												
Aspen	834	825	593	600	604	600	57	55	124	125	992	1,000,000
Maple	972	975	690	700	718	725	93	95	271	270	1,125	1,100,000
Yellow-poplar	959	950	681	675	735	725	68	70	179	180	1,326	1,300,000
Cottonwood	824	825	586	575	632	625	56	55	121	120	1,105	1,100,000

1/ The first column for each property is unrounded. The second is rounded according to D 245; 6.1.1.

2/ D 245, 7.1.3 and 7.1.4.

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APPENDIX A--GROWING STOCK VOLUME

Timber growing stock volume data are used as weighting factors in the derivation of allowable design properties for marketing combinations consisting of two or more species. Volume data for many species are presented in D 2555, tables 4 and 5. But timber of species other than those in the tables are used in structural applications. Volume data for additional species was obtained from Resources Evaluation, Forest Service, U.S. Department of Agriculture, by species and State where available. This information is summarized in table A-1 by four major geographic regions: North Central, Northeast, Southeast, and Midsouth. The States or portions of States in each region are as follows:

North Central -- Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, and Wisconsin.

Northeast -- Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia.

Southeast -- Florida, Georgia, North Carolina, South Carolina, and Virginia.

Midsouth -- Alabama, Arkansas, Louisiana, Mississippi, East Oklahoma, Tennessee, and East Texas.

For many of the species listed in table A-1,volume data have not yet been tabulated by Resources Evaluation in every region. Thus, for these species, total species volume estimates are not listed. Nevertheless, the data should still be useful for making combinations within a region or between two or more regions. For example, there may be interest in developing design properties for a combination of all red oaks, all white oaks, or all oaks in the Midsouth region, the Southeast region, or the two regions combined.

The volume estimates in table A-1 should not be considered official in the context of National timber inventories normally published by Resources Evaluation of the Forest Service. Although there may be small discrepancies in the data, we believe they are sufficiently accurate for use as weighting factors for developing species combinations.

These discrepancies exist because the data received from Resources Evaluation contained volume estimates for an "Other Hardwoods" category in each major region. If the volume was not tabulated for a particular species in a region, we could not be certain whether the region contained no volume for that species or whether the species was included in the "Other Hardwoods" category. However, a species included in this category is likely to be of minor importance (low volume) in the region. Also, a volume estimate mag contain more than one species; e.g., "basswood" estimates may contain American and white basswood. In this case, however, white basswood most likely does not make a significant contribution to the total basswood volume. A similar conclusion would probably also apply where other species estimates are combined.

Table A-1.--Growing stock volume for certain hardwood species by major geographic regions (million ft^3)

Species	North central	North-east	Mid-south	South-east	Total
Ash (Fraxinus):					
Green (F. pennsylvanica)	1/ -	-	1,282	-	-
White (F. americana)	-	-	575	-	-
Balsam poplar (Populus balsamifera)	637	-	2/ ---	---	-
Basswood (Tilia sp.)	1,606	995	164	202	2,771
Birch (Betula):					
Gray (B. populifolia)	---	10	---	---	10
Paper (B. papyrifera)	2,114	1,658	---	---	3,773
River (B. nigra)	95	21	160	---	275
Boxelder (Acer negrundo)	20	-	193	25	-
Cherry (Prunus sp.)	331	2,404	-	118	-
Cottonwood, eastern (Populus deltoides)	457	-	472	91	-
Cucumber (Magnolia acuminata)	1	125	49	81	256
Elm (Ulmus):					
American (U. americana)	-	-	884	-	-
Rock (U. thomasii)	-	-	4	-	-
Slippery (U. rubra)	-	-	161	-	-
Holly (Ilex opaca)	---	3	118	68	189
Locust:					
Black locust (Robinia psuedoacacia)	92	365	153	321	931
Honeylocust (Gleditsia triacanthos)	30	---	136	12	178

(Page 1 of 2)

Table A-1.--Growing stock volume for certain hardwood species by major geographic regions (million ft^3)--Con.

Species	North central	North-east	Mid-south	South-east	Total
Magnolia (Magnolia):					
Southern (M. grandiflora)	---	---	142	92	234
Sweetbay (M. virginiana)	---	---	672	606	1,278
Oak red (Quercus sp.)					
Black (Q. velutina)	-	-	2,109	1,458	-
Cherrybark (Q. falcata var. pagodaefolia)	-	-	1,169	204	-
Laurel (Q. laurifolia)	-	-	481	1,572	-
Northern red (Q. rubra)	-	-	1,164	1,842	-
Pin (Q. palustris)	-	-	50	40	-
Scarlet (Q. coccinea)	-	-	774	1,932	-
Shumard (Q. shumardii)	-	-	229	38	-
Southern red (Q. falcata)	-	-	3,392	1,400	-
Willow (Q. phellos)	-	-	1,775	511	-
Oak, white (Quercus sp.)					
Bur (Q. macrocarpa)	-	-	11	---	-
Chestnut (Q. prinus)	-	-	1,222	2,677	-
Chinkapin (Q. muehlenbergii)	-	-	---	10	-
Overcup (Q. lyrata)	-	-	975	179	-
Post (Q. stellata)	-	-	4,041	778	-
Swamp chestnut (Q. michauxii)	-	-	333	267	-
Swamp white (Q. bicolor)	-	-	16	15	-
White (Q. alba)	-	-	4,752	4,608	-
Osage-orange (Maculra pomifera)	1	---	14	---	15
Sassafras (Sassafras albidum)	48	30	114	---	192
Tupelo (Nyssa):					
Blackgum (N. sylvatica)	282	442	2,529	5,400	8,653
Water (N. aquatica)	---	---	1,213	652	1,864
Walnut (Juglans nigra)	374	254	-	107	-

1/ - symbolizes that the volume for the species in the region is unknown.

2/ --- symbolizes that there is no significant volume for the species in the region.

(Page 2 of 2)

APPENDIX B--A COMPUTER PROGRAM FOR CALCULATING EXCLUSION LIMIT FOR A COMBINATION OF SPECIES

ASTM D 2555, Section 5.2.2.2 and others, require calculation of a 5 percent exclusion limit for modulus of rupture, maximum crushing strength parallel to grain, and shear by adding the areas under volume-weighted frequency distributions of each species at successively higher levels of strength until a value is obtained below which 5 percent of the area under the combined frequency distribution will fall.

This appendix presents a computer program for calculating the 5 percent exclusion limit for three mechanical properties. The program is written in Fortran V and has been executed on the Univac 1110. It should be easily adaptable to other computers.

Numerical Procedure

The frequency distribution of a mechanical property for a combination of species is, in general, a heterogeneous distribution. The numerical procedure assumes the heterogeneous distribution is made up of two or more component normal distributions, having sample estimates of the property mean and standard deviations as listed in table 1, with each component distribution weighted according to the volume estimates in that table. These normal distributions overlap one another, and a value of the property is sought such that 95 percent of the wood in the entire combination will exceed it.

The property axis of the combined frequency distribution is subdivided into a set of uniform classes of width (w). Each component normal frequency distribution is integrated from $-\infty$ to an upper class limit (x_i) selected to be below the exclusion limit of the heterogeneous distribution. These integration results are weighted to reflect the timber volume of the species represented by each component distribution. Successive classes are then integrated, the results weighted and accumulatively summed until the summation exceeds 0.05. The last class integrated contains the 5 percent exclusion limit, which is then obtained by straightline interpolation between sumnations of integrations to the lower and upper limits of the last class.

For successful operation of the program, x_i must be below the 5 percent exclusion limit of the combined distribution. Also, w must be small for accurate interpolation of the exclusion limit in the last class. Arbitrarily chosen dimensionless factors are entered as input: to calculate x_i and w as a proportion of the lowest species property average ($\bar{x}$) in the combination. We have found factors of 0.5 and 0.005 appropriate for calculating $\underline{x_i}$ and $\underline{w}$, respecitvely.

Additional details concerning the numerical procedures can be obtained from the Forest Products Laboratory.

Program Input

There are two kinds of card inputs: (1) Species statistics and (2) factors for calculating $\underline{x_i}$ and $\underline{w}$. Type (1) cards each describe one species and are limited 50 in number. Figure B-1is an example of a set of cards for four species and the type (2) card. A species statistics card includes estimates of the mean ($\underline{\bar{x}}$) and standard deviation ($\underline{s}$) for modulus of rupture, maximum crushing strength parallel to grain, and shear; a volume estimate; and any convenient species designation code.

Figure B-1.--Sample input cards

TYPE (1) CARDS

Species designation	Modulus of rupture x	Modulus of rupture s	Compression parallel x	Compression parallel s	Shear x	Shear s	Volume
1	7920	1267	3270	589	1128	158	1801
2	7690	1230	3280	590	1151	161	6037
3	5820	931	2490	448	1053	147	5507
4	9420	1507	4020	724	1465	205	8566

TYPE (2) CARD

Initial integration limit (x_1)	Class width (w)
.5	.005

Program Output

The program output shown in table B-1 is self-explanatory.

Table B-1.--Program output

Species	Average property	Standard deviation	Exclusion limit	Relative weight	Combined exclusion limit
		MODULUS OF RUPTURE			
1	7920.	1267.	5836.	.0822	
2	7690.	1230.	5667.	.2755	4963.
3	5820.	931.	4289.	.2513	
4	9420.	1507.	6941.	.3909	
		COMPRESSION PARALLEL			
1	3270.	589.	2301.	.0822	
2	3280.	590.	2309.	.2755	2056.
3	2490.	448.	1753.	.2513	
4	4020.	724.	2829.	.3909	
		SHEAR			
1	1128.	158.	868.	.0822	
2	1151.	161.	886.	.2755	883.
3	1053.	147.	811.	.2513	
4	1465.	205.	1128.	.3909	

The Program

```
  A PROGRAM FOR CALCULATING PROPERTIES FOR GROUPS OF SPECIES

  DIMENSION STRAT(3,999),EXC(3),JSQ(51),XBAR(51,3),STD(51,3),AVE(3),
 .C(3,3),XM(3),VOL(51)
  DATA ASP/.56418958/A1/.22583684/A2/-.25212866/A3/1.2596951/
  DATA A4/-1.2878224/A5/.94064607/A6/.3275911/

  READ FACTORS FOR CALCULATING INITIAL X AND CLASS WIDTH VALUES,
  FACTORS ARE MULTIPLIED BY THE LEAST AVERAGE PROPERTY OF A GROUP
  TO ARRIVE AT THE ACTUAL VALUES. DATA CARD FORMAT IS
  2F10., RIGHT JUSTIFIED, INCLUDE DECIMAL POINTS.

1 READ 2,XFC,WFC
2 FORMAT(2F10.0)

  DO 4 J=1,3
  EXC(J)=0.
  AVE(J)=0.
  DO 3 K=1,999
3 STRAT(J,K)=0.
4 CONTINUE

  READ A GROUP OF 2-50 DATA CARDS FOLLOWED BY A TRAILER CARD
  THAT HAS 99 PUNCHED IN CC 1-2. DATA IS RIGHT JUSTIFIED,
  WITHOUT DECIMAL POINTS, AS FOLLOWS

  COL 1-2                   ANY NUMERICAL SPECIES DESIGNATION        I2

  COL 3-9,16-21,27-32       SPECIES AVERAGE PROPERTIES

  COL 10-15,22-26,33-37     STANDARD DEVIATION OF PROPERTIES
                              FOR THE SPECIES

  COL 38-44                 TIMBER VOLUME

  COL 45-80                 MAY BE USED FOR REMARKS.  NOT PROCESSED
                              BY THE PROGRAM

  DO 7 J=1,52
  READ 6,JSQ(J),XBAR(J,1),STD(J,1),XBAR(J,2),STD(J,2),XBAR(J,3),
 .STD(J,3),VOL(J)
6 FORMAT(I2,F7.0,F6.0,2(F6.0,F5.0),F7.0)
  IF(JSQ(J).EQ.99)GO TO 8
7 CONTINUE

8 JN=J-1
  AVOL=0.
  DO 12 I=1,3
  TVOL=AVOL
  DO 10 J=1,JN
  AVE(I)=AVE(I)+XBAR(J,I)*VOL(J)
10 TVOL=TVOL+VOL(J)
12 AVE(I)=AVE(I)/TVOL
```

```
   DEVELOP C-ARRAY
   DO 13 J=1,3
13 XM(J)=99999999.
   DO 15 J=1,3
   DO 15 K=1,JN
   IF(XBAR(K,J).GE.XM(J))GO TO 15
   XM(J)=XBAR(K,J)
15 CONTINUE
   DO 17 J=1,3
   C(J,1)=XM(J)*XFC
   C(J,3)=XM(J)*WFC
17 C(J,2)=C(J,1)+997.*C(J,3)
   PRINT 99
99 FORMAT(1H1)
   DO 50 JJ=1,3
   IF(AVE(JJ)),50,
   DO 32 II=1,JN
   N=0
   L=0
   Y=C(JJ,1)
20 IF(Y-C(JJ,2)),21,21
   IF(N-998)22,21,22
21 L=1
22 N=N+1
   X=(Y-XBAR(II,JJ))/STD(II,JJ)
   XX=X
   IF(X),24,24
   X=-X
24 X=X/1.414214
   E=1./(1.+A6*X)
   X2=-(X*X)
   Q=2.*ASP*EXP(X2)
   ERR=.5*(A1*E+A2*E*E+A3*E*E*E+A4*E*E*E*E+A5*E*E*E*E*E)*Q
   IF(XX),25,25
   AREA2=ERR
   GO TO 26
25 AREA2=1.-ERR
26 IF(Y-C(JJ,1))30,,30
   STRAT(JJ,N)=STRAT(JJ,N)+AREA2*VOL(II)
28 Y=Y+C(JJ,3)
   AREA1=AREA2
   GO TO 20
30 STRAT(JJ,N)=STRAT(JJ,N)+(AREA2-AREA1)*VOL(II)
   IF(L-1)28
   N=N+1
   STRAT(JJ,N)=STRAT(JJ,N)+ERR*VOL(II)
   IF(Y-C(JJ,2)),32,32
   PRINT 33,JJ
33 FORMAT(' EXCLUSION LIMIT NOT REACHED FOR PROP',I2)
32 CONTINUE
   DO 38 I=1,999
38 STRAT(JJ,I)=STRAT(JJ,I)/TVOL
   CUM=0.
   DO 46 I=1,999
```

```
      IF(I-1),,42
      IF(.05-STRAT(JJ,I)),,42
      PRINT 40,JJ
   40 FORMAT(/,' LOWEST CLASS CONTAINS EXCLUSION LIMIT FOR PROP',I3)
      GO TO 50
   42 IF(STRAT(JJ,I)-.05+CUM),44,44
      CUM=CUM+STRAT(JJ,I)
      GO TO 46
   44 STEPS=I-2
      EXC(JJ)=C(JJ,1)+STEPS*C(JJ,3)+C(JJ,3)*(.05-CUM)/STRAT(JJ,I)
      GO TO 50
   46 CONTINUE
   50 CONTINUE
      PRINT 99
      DO 80 I=1,3
      IF(AVE(I)),80,
      IF(I-2),53,55
      PRINT 52
   52 FORMAT(' MOR')
      GO TO 63
   53 PRINT 56
   56 FORMAT(////' COMP PAR')
      GO TO 63
   55 PRINT 58
   58 FORMAT(////' SHEAR')
      GO TO 63
   63 PRINT 64
   64 FORMAT(/,' SPECIES  AVE PROP  STD DEV  EXCL LIM  REL WT  COMBINED
     .EXCL LIMIT',/)
      JD=JN/2+1
      DO 70 J=1,JN
      FIVEP=XBAR(J,I)-1.645*STD(J,I)
      WT=VOL(J)/TVOL
      K=JSQ(J)
      IF(JD.EQ.J) GO TO 66
      PRINT 68,K,XBAR(J,I),STD(J,I),FIVEP,WT
      GO TO 70
   66 PRINT 68,K,XBAR(J,I),STD(J,I),FIVEP,WT,EXC(I)
   68 FORMAT(I5,F12.0,2F9.0,F9.4,5X,F8.0)
   70 CONTINUE
   80 CONTINUE
      PRINT 99
      STOP
      END
```

APPENDIX C--DEVELOPMENT OF STRENGTH RATIO FACTORS AND STRENGTH RATIOS FOR GRADING RULES

Strength Ratio Factor

Allowable design properties for structural lumber grades are derived from clear wood lumber properties through application of strength ratios (SR). Basic to this derivation is the concept of a minimum acceptable F_b SR for each lumber grade. For example, in the Structural Joists and Planks lumber category, the minimum acceptable F_b SR's for various grades are Select Structural, 65 percent; No. 1, 55 percent; No. 2, 45 percent; and No. 3, 26 percent. Grade descriptions are written which detail the maximum permissible defects, staying within limitations defined by these minimum F_b strength ratios. Strength ratios for other properties commonly are controlled by the defect limitations pertaining to F_b.

The F_b SR of a grade may exceed the minimum acceptable SR, depending upon the SR associated with critical or limiting defects in the grade description. The SR may also vary between sizes within a grade, again depending upon the limiting defect of the grade description.

For simplicity in derivation procedures and for consistency in allowable properties between sizes within a grade, a minimum F_b strength ratio factor (SRF) is commonly applied to all sizes within a grade. The SRF is the product of the SR corresponding to the limiting defect for a size and grade and the depth factor[5/] for each size. The SRF is calculated for all sizes in a grade to determine the minimum value. An example is shown in table C-1 for No. 2 Joists and Planks:

The minimum or controlling SRF is 0.3771 (14-in. nominal width and 4-1/8 knot) which is applied to clear lumber stresses to obtain F_b for these widths of No. 2 grade. It is noted that only edge knots are shown in this sample SRF derivation for F_b because knots in other locations (centerline and narrow face knots) are less critical for this particular grade description.

5/ Reference (2), paragraph 6.3.1.

Strength Ratios

The SRF applies only to F_b because depth adjustment (D 245 6.3.1) is not required for other properties. Rather, a minimum SR is determined for F_t and $F_{c\perp\perp}$ which is applied to all sizes in a grade. The critical defect for F_t is frequently the same as for F_b. In table C-1, however, the 4-1/8-inch edge knot in combination with depth adjustment for 14 inch width is limiting for F_b (SRF = 0.3771) while the 3-1/4-inch edge knot (10 in. width) is limiting for F_t (SR = 0.4502). Centerline knots are most commonly the critical defect in $F_{c\perp\perp}$. The minimum SR for $F_{c\perp\perp}$ and F_t for a grade are determined by constructing tables similar to table C-1 showing the SR's for limiting defects for all widths in the lumber category.

An SR of 50 percent is commonly assigned to Fv for most grades and sizes although higher values may be permitted depending on shake and split limitations. $F_{c\perp}$ is assumed to be grade independent, and a 100 percent strength ratio is assigned to all grades.

Table C-1.--Example of calculating SRF for No. 2 Joists and Planks

Nominal width	Knot size	Knot location	SR	Depth factor	SRF
In.	In.				
5	1-5/8	Edge	0.4559	0.9138	0.4166
6	1-7/8	Edge	.4733	.8937	.4230
8	2-1/2	Edge	.4662	.8667	.4041
10	3-1/4	Edge	.4502	.8435	.3797
12	3-3/4	Edge	.4684	.8254	.3866
14	4-1/8	Edge	.4653	.8105	.3771

SRF for 1:8 slope of grain is 0.53 x 0.8105 = 0.4296.

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