Designation: D 2555 – 06

Standard Practice for Establishing Clear Wood Strength Values[1]

INTRODUCTION

The development of safe and efficient working stresses for lumber, laminated timber, plywood, round timbers, and other solid wood products, each with its own special requirements has, as a common starting point, the need for an authoritative compilation of clear wood strength values for the commercially important species. Also required are procedures for establishing, from these data, values applicable to groups of species or to regional groupings within a species where necessitated by marketing conditions. This standard has been developed to meet these needs and to provide, in addition, information on factors for consideration in the adjustment of the clear wood strength values to the level of working stresses for design. Since factors such as species preference, species groupings, marketing practices, design techniques, and safety factors vary with each type of product and end use, it is contemplated that this standard will be supplemented where necessary by other appropriate standards relating to specific work stresses for each such product. Practice D 245 is an example of such a standard applicable to the interpretation of the clear wood strength values in terms of working stresses for structural lumber.

A primary feature of this practice is the establishment of tables presenting the most reliable basic information developed on the strength of clear wood and its variability through many years of testing and experience. The testing techniques employed are those presented in Test Methods D 143. Among the recognized limitations of such strength data are those resulting from the problems of sampling material from forests extending over large regions, and the uneconomical feasibility of completely testing an intensive sample. A practical approach to the improvement of strength data is through the application of the results of density surveys in which the specific gravity of the entire forest stand for each species is determined on a sound statistical basis. Through regression equations derived from presently available strength data, revised strength values are established from the specific gravity-strength relationship for clear wood. This procedure greatly extends current capabilities to develop new estimates of strength and to improve or verify estimates made in the past.

1. Scope

1.1 This practice covers the determination of strength values for clear wood of different species in the unseasoned condition, unadjusted for end use, applicable to the establishment of working stresses for different solid wood products such as lumber, laminated wood, plywood, and round timbers. Presented are:

1.1.1 Procedures by which test values obtained on small clear specimens may be combined with density data from extensive forest surveys to make them more representative,

1.1.2 Guidelines for the interpretation of the data in terms of assigned values for combinations of species or regional divisions within a species to meet special marketing needs, and

1.1.3 Information basic to the translation of the clear wood values into working stresses for different solid wood products for different end uses.

1.1.4 For species where density survey data are not as yet available for the re-evaluation of average strength properties, the presently available data from tests made under the sampling methods and procedures of Test Methods D 143 or Practice E 105 are provided with appropriate provision for their application and use. Because of the comprehensive manner in which the density survey is undertaken, it follows that the re-evaluated strength data are intended to be representative of the forest stand, or rather large forest subdivisions.

[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and are the direct responsibility of Subcommittee D07.01 on Fundamental Test Methods and Properties.

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1.1.5 Some useful mechanical properties (tensile strengths parallel and perpendicular to grain and modulus of rigidity for a longitudinal-transverse plane) have not been extensively evaluated. Methods are described for estimating these properties by their relation to other properties.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 143 Test Methods for Small Clear Specimens of Timber

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber

E 105 Practice for Probability Sampling Of Materials

3. Summary of Methods

3.1 Two methods are presented for establishing tables of clear wood strength properties for different species and regional subdivisions thereof in the unseasoned condition and unadjusted for end use. These are designated Method A and Method B.

3.1.1 Method A provides for the use of the results of surveys of wood density involving extensive sampling of forest trees, in combination with the data obtained from standard strength tests made in accordance with Test Methods D 143. The average strength properties are obtained from wood density survey data through linear regression equations establishing the relation of specific gravity to the several strength properties.

NOTE 1—Density surveys have been completed for only a limited number of species. Data are thus not currently available for the use of Method A on all commercial species. As such data become available they will be incorporated in revisions of this practice.

3.1.2 Method B provides for the establishment of tables of strength values based on standard tests of small clear specimens in the unseasoned condition for use when data from density surveys are not available. Separate tables are employed to present the data on woods grown in the United States and on woods grown in Canada.

4. Procedure for Establishing Clear Wood Strength Values

4.1 *Method A*—Six steps are involved in establishing strength values by the wood density survey procedure. These are: conducting the wood density survey, development of unit areas, determination of average specific gravity for a unit area, determination of strength-specific gravity relations, estimation of average strength properties for a unit area, and combining values for unit areas into basic groups and establishing average strength properties and estimates of variance for the groups. In these methods a basic group is a combination of unit areas representing a species or a regional division thereof.

4.1.1 *Conducting Wood Density Survey*—A well-designed and thorough wood density survey is required to provide needed data on specific gravity for the reevaluation of strength properties. Such a survey requires consideration of the geographic range to be covered, the representativeness of the sample, the techniques of density evaluation, and adequate data analysis.

NOTE 2—Detailed information on an acceptable method of conducting wood density surveys, together with survey data, are presented in the *U.S. Forest Service Research Paper FPL 27*, "Western Wood Density Survey Report No. 1."

4.1.2 *Development of Unit Areas*—Subdivide the geographical growth range of each species into unit areas that contain 1 % or more of the estimated cubic foot volume of standing timber of the species and are represented by reliable estimates of specific gravity of at least 20 trees. Make up unit areas of U.S. Forest Service Survey Units, or similar units or subdivisions of units, for which reliable estimates of timber volume are available. Develop unit areas objectively by means of the following steps:

4.1.2.1 Select a base survey unit or subdivision of a survey unit to be grouped with others,

4.1.2.2 Group with similar adjacent areas to make up a unit area on the basis of a timber volume, and

4.1.2.3 Determine the number of tree specific gravity samples available in the proposed unit area.

NOTE 3—The rules for developing unit areas should represent an effort to subdivide objectively and uniquely the range of a species into small geographic areas, which are assumed to be considerably more homogeneous with respect to the mechanical properties of the species than is the entire range itself. The number of unit areas associated with a species is a function of the volume of timber on the smallest usable areas and the number of tree specific gravity samples taken. In general, the larger the range and the greater the commercial importance of the species, the greater are the number of unfit areas. One acceptable procedure for establishing unit areas is presented in *U.S. Forest Service Research Paper FPL 27*, "Western Wood Density Survey Report No. 1," Appendix C.

4.1.3 *Determination of Average Specific Gravity for a Unit Area*—Calculate the average specific gravity of trees in each unit area as the simple average of individual estimates of specific gravity of trees within the unit area.

4.1.4 *Determination of Strength-Specific Gravity Relations*—From matched specific gravity and strength data on small clear specimens of wood, establish relationships of the form:

$$y = a + bx \qquad (1)$$

where:

y = estimated strength value,
a, b = constants for the species, and
x = specific gravity of the species.

for each species, using standard statistical methods of regression analysis. Equations for modulus of rupture, modulus of elasticity, maximum crushing strength, and maximum shearing strength are established in this manner. The distribution of specific gravity in the samples used to compute regressions

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

should be representative of the species and, in particular, shall represent the full specific gravity range. The nature of the true distribution of specific gravity can be obtained from results of wood density surveys. Obtain the data from specimens tested in accordance with Test Methods D 143.

4.1.4.1 Several methods are available for securing suitable samples for obtaining data to compute strength-specific gravity relationships, as follows: strength and specific gravity values from samples obtained in conformance with Test Methods D 143 may be employed solely or in combination with data secured by sampling techniques described below or test samples may be obtained from the forest resource in the form of trees, logs, or lumber. Select samples that are representative of all growing stock from each of at least five different locations within the growth range of a species that include the scope of environmental conditions of the range. This implies that the sample from a single location must be such that all of the growing stock from that location is represented.

4.1.4.2 Where relationships between strength and specific gravity are shown to have a statistically significant difference at the 5 % level within a species growth range, subdivide the range to permit the development of more accurate estimating equations for each subdivision. Develop equations for subdivisions of a species growth range only if specimens from at least five distinctly different places in the proposed subdivision are available and if the correlation coefficients from the strength-specific gravity regressions are 0.50 or greater.

4.1.5 *Estimation of the Average Strength Properties for a Unit Area*—Given a set of strength-specific gravity estimating equations for each species or subdivision thereof, compute average strength properties for each unit area using these equations and the average specific gravity for the unit area.

4.1.6 *Combining Unit Areas into Basic Groups and Development of Average Strength Properties and Estimates of Variance for the Groups*—Combine all unit areas containing timber whose properties are described by the same strength-specific gravity relationships to produce a basic group of unit areas. Develop the following information for these basic groups:

4.1.6.1 For each unit area, obtain, from reliable volume data, the volume of the species being considered and estimate strength properties from appropriate equations. Determine average strength properties for a group of unit areas for a species or a subdivision thereof by the following equation:

$$\bar{\bar{Y}} = \Sigma_i \, (\bar{Y}_i V_i / V) \tag{2}$$

where:

$\bar{\bar{Y}}$ = weighted average strength property for the group of unit areas,
$\bar{Y}_i$ = average strength property for the ith unit area,
V_i = percentage of standing timber volume of the species for the ith unit area, and
V = total percentage of standing timber volume of the species in the group of unit areas being combined.

4.1.6.2 Compute the variability index, which is a measure of the homogeneity among average values for unit areas within a group, by dividing the group average by the lowest unit area average included in the group.

4.1.6.3 Estimate a standard deviation, providing a measure of the dispersion of individual strength values about the group average, for each basic group of unit areas using information on variance obtained from density survey and standard strength data. Compute estimates of standard deviation for each property as:

$$s = \sqrt{b^2(s_w^{\,2} + s_a^{\,2}) + \mathrm{RMS}} \tag{3}$$

where:

s = standard deviation
b = slope of the strength-specific gravity relation,
$s_w^{\,2}$ = within-tree variance in specific gravity estimated from data used to obtain strength-specific gravity relations,
$s_a^{\,2}$ = among-tree variance in specific gravity obtained from density survey data,
$(s_w^{\,2} + s_a^{\,2})$ = estimate of total variance in specific gravity, and
RMS = residual mean square from the strength-specific gravity relation.

NOTE 4—When a sampling technique is used that ensures only one specimen will be taken per tree (such as a suitably designed mill sample), the quantity $(s_w^{\,2} + s_a^{\,2})$ is automatically obtained as a total variance of specific gravity.

NOTE 5—An alternative procedure for developing average strength values where all unit areas are contained within a single species or regional subdivision thereof consists of combining the volume weighted unit area specific gravities to establish a species or regional subdivision specific gravity and then computing the average strength properties by substituting the average specific gravity in the strength-specific gravity regression equations.

4.1.6.4 Average compression perpendicular to the grain values have not been developed by the procedures described in the preceding paragraphs but are based on available standard strength data alone as in Method B.

4.1.6.5 Table 1 gives basic information on the strength properties of the commercially important species for which wood density survey data are available. Listed are averages and standard deviations for modulus of rupture, modulus of elasticity, maximum crushing strength parallel to grain, horizontal shear strength, proportional limit in compression perpendicular to grain, and specific gravity. These properties are for clear wood in the unseasoned condition. Variability indexes are given for the first four properties.

4.2 *Method B*:

4.2.1 Base average strength properties for clear wood of species for which density survey data are not available on standard strength test data obtained in accordance with Test Methods D 143. Estimate approximate standard deviations for these species as follows:

TABLE 1 Clear Wood Strength Values Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition (Method A)[A]

NOTE 1—All digits retained in the averages and standard deviations through the units position to permit further computation with minimum round-off error (specific gravity excepted).

Species or Region, or Both	Property																	
	Modulus of Rupture[B]			Modulus of Elasticity[C]			Compression Parallel to Grain, Crushing Strength			Shear Strength			Compression, Perpendicular to Grain[D]			Specific Gravity		
													Stress at Proportional Limit		Stress at 0.04 in.			
	Avg., psi	Variability Index	Std. Dev., psi	Avg., 1000 psi	Variability Index	Std. Dev., 1000 psi	Avg., psi	Variability Index	Std. Dev., psi	Avg., psi	Variability Index	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi[E]	Avg.	Variability Index	Std. Dev.
Douglas fir:[F]																		
Coast	7665	1.05	1317	1560	1.05	315	3784	1.05	734	904	1.03	131	382	107	700	0.45	...	0.057
Interior West	7713	1.03	1322	1513	1.04	324	3872	1.04	799	936	1.02	137	418	117	707	0.46	...	0.058
Interior North	7438	1.04	1163	1409	1.04	274	3469	1.04	602	947	1.03	126	356	100	669	0.45	...	0.049
Interior South	6784	1.01	908	1162	1.00	200	3113	1.01	489	953	1.00	153	337	94	578	0.43	...	0.045
White fir	5854	1.01	949	1161	1.02	249	2902	1.02	528	756	1.01	78	282	79	491	0.37	...	0.045
California red fir	5809	1.01	885	1170	1.01	267	2758	1.01	459	767	1.00	146	334	94	573	0.36	...	0.043
Grand fir	5839	1.03	680	1250	1.03	164	2939	1.04	363	739	1.04	97	272	76	475	0.35	...	0.043
Pacific silver fir	6410	1.07	1296	1420	1.05	255	3142	1.06	591	746	1.05	114	225	63	414	0.39	...	0.058
Noble fir	6169	1.07	966	1380	1.08	310	3013	1.08	561	802	1.04	136	274	77	478	0.37	...	0.043
Western hemlock	6637	1.03	1088	1307	1.02	258	3364	1.03	615	864	1.02	105	282	79	457	0.42	...	0.053
Western larch	7652	1.04	1001	1458	1.02	249	3756	1.04	564	869	1.03	85	399	112	676	0.48	...	0.048
Black cottonwood	4890	1.00	951	1083	1.00	197	2200	1.00	360	612	1.00	92	165	46	305	0.31	...	0.034
Southern pine:																		
Loblolly	7300	1.08	1199	1402	1.08	321	3511	1.09	612	863	1.05	112	389	109	661	0.47	1.06	0.053
Longleaf	8538	1.07	1305	1586	1.07	295	4321	1.07	707	1041	1.05	120	479	134	804	0.54	1.05	0.058
Shortleaf	7435	1.04	1167	1388	1.04	268	3527	1.05	564	905	1.05	125	353	99	573	0.47	1.05	0.051
Slash	8692	1.09	1127	1532	1.08	295	3823	1.07	547	964	1.05	128	529	148	883	0.54	1.09	0.062

[A] For tension parallel and perpendicular to grain and modulus of rigidity, see 4.3.
[B] Modulus of rupture values are applicable to material 2 in. (51 mm) in depth.
[C] Modulus of elasticity values are applicable at a ratio of shear span to depth of 14.
[D] Based on a 2-in. wide steel plate bearing on the center of a 2-in. wide by 2-in. thick by 6-in. long specimen oriented with growth rings parallel to load.
[E] A coefficient of variation of 28 % can be used as an approximate measure of variability of individual values about the stresses tabulated.
[F] The regional description of Douglas fir is that given on pp. 54–55 of U.S. Forest Service Research Paper FPL 27, "Western Wood Density Survey Report No. 1."

$$s = c\bar{\bar{Y}} \tag{4}$$

where:

s = standard deviation,
$\bar{\bar{Y}}$ = the average value for the species, and
c = 0.16 for modulus of rupture,
0.22 for modulus of elasticity,
0.18 for maximum crushing strength parallel to grain,
0.14 for maximum shear strength,
0.28 for compression perpendicular to grain strength, and
0.10 for specific gravity.

Alternatively, calculate the average strength properties for clear wood and standard deviations from data from a random sample obtained in accordance with Practice E 105.

4.2.2 Table 2 and Table 3 present basic information on the strength properties of various species in the unseasoned condition as determined from standard strength tests of small clear specimens. Table 2 covers data on woods grown in the United States, and Table 3 woods grown in Canada.

4.3 Tensile strength parallel and perpendicular to grain and modulus of rigidity associated with a longitudinal-transverse plane are sometimes needed for design considerations. These properties have not been evaluated extensively. They may, however, be estimated from the clear wood properties of any combination of species, as described in the following criteria:

4.3.1 *Tension Parallel to Grain*—For clear wood strength in tension parallel to grain, the clear wood strength value for modulus of rupture may be used.

4.3.2 *Tension Perpendicular to Grain*—For clear wood strength in tension perpendicular to grain, 0.33 times the clear wood strength value for shear may be used.

4.3.3 *Modulus of Rigidity*—For clear wood modulus of rigidity, 0.069 times the modulus of elasticity may be used.

NOTE 6—The factor 0.069 is 1/16 times 11/10 where the 11/10 converts the apparent moduli of elasticity tabulated in this practice to true moduli, and the 1/16 is an empirically determined ratio of shear modulus to elastic modulus.

TABLE 2 Clear Wood Strength Values Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition (Method B) (for Woods Grown in the United States)[A]

NOTE 1—All digits retained in the averages and standard deviations through the units position to permit further computation with minimum round-off error (specific gravity excepted).

NOTE 2—Values of standard deviation have been calculated using the values for c given in 4.2.

Species (Official Common Tree Names)	Modulus of Rupture[B]		Modulus of Elasticity[C]		Compression Parallel to Grain, Crushing Strength		Shear Strength		Compression, Perpendicular to Grain[D] Stress at Proportional Limit		Compression, Perpendicular to Grain[D] Stress at 0.04 in.	Specific Gravity	
	Avg., psi	Std. Dev., psi	Avg., 1000 psi	Std. Dev., 1000 psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi[E]	Avg.	Std. Dev.
SOFTWOODS													
Baldcypress	6640	1062	1184	260	3580	644	812	114	403	113	683	0.43	0.043
Cedar:													
Alaska	6450	1032	1135	260	3050	549	842	118	349	98	597	0.42	0.042
Incense	6220	995	840	185	3150	567	834	117	369	103	629	0.35	0.035
Port Orford	6598	860	1297	247	3145	397	842	122	301	71	521	0.39	0.034
Atlantic white	4740	758	752	165	2390	430	694	97	244	68	430	0.31	0.031
Northern white	4250	680	643	141	1990	358	616	86	234	66	414	0.29	0.029
Eastern red	7030	1125	649	143	3570	643	1008	141	700	196	1155	0.46	0.046
Western red	5184	761	939	223	2774	493	771	115	244	65	430	0.31	0.027
Fir:													
Balsam	5517	552	1251	143	2631	283	662	83	187	31	340	0.32	0.025
Subalpine	4900	664	1052	182	2301	363	696	103	192	44	348	0.31	0.032
Hemlock:													
Eastern	6420	1027	1073	236	3080	554	848	119	359	101	613	0.39	0.039
Mountain	6270	1003	1038	228	2880	518	933	131	371	104	632	0.42	0.042
Pine:													
Jack	6030	965	1068	235	2950	531	754	106	296	83	513	0.40	0.040
Eastern white	4930	789	994	219	2440	439	678	95	218	61	389	0.35	0.035
Lodgepole	5490	878	1076	237	2610	470	685	96	252	71	443	0.39	0.039
Monterey	6625	1060	1420	312	3330	599	875	123	440	123	742	0.46	0.046
Ponderosa	5130	821	997	219	2450	441	704	99	282	79	491	0.39	0.039
Red	5820	931	1281	282	2730	491	686	96	259	73	454	0.42	0.042
Sugar	4893	663	1032	193	2459	386	718	105	214	43	382	0.34	0.027
Western white	4688	693	1193	257	2434	406	677	98	192	46	348	0.35	0.034
Pine, southern yellow:													
Pitch	6830	1093	1200	264	2950	531	860	120	365	102	622	0.47	0.047
Pond	7450	1192	1281	282	3660	659	936	131	441	123	743	0.51	0.051
Spruce	6004	1102	1002	286	2835	580	895	136	279	95	486	0.41	0.041
Sand	7500	1200	1024	225	3440	619	1143	160	450	126	757	0.46	0.046
Virginia	7330	1173	1218	268	3420	616	888	124	390	109	662	0.46	0.046
Redwood:													
Old growth	7500	1202	1177	259	4210	758	803	112	424	119	716	0.39	0.039
Second growth	5920	947	955	210	3110	560	894	125	269	75	470	0.34	0.034
Spruce:													
Black	6118	759	1382	193	2836	417	739	79	242	34	427	0.38	0.028
Engelmann	4705	692	1029	207	2180	427	637	64	197	50	358	0.33	0.033
Red	6003	627	1328	145	2721	313	754	95	262	59	459	0.37	0.025
Sitka	5660	906	1230	271	2670	481	757	106	279	78	486	0.38	0.038
White	4995	878	1141	265	2349	439	636	68	210	51	402	0.33	0.034
Tamarack	7170	1147	1236	272	3480	626	863	121	389	109	661	0.49	0.049
HARDWOODS													
Alder, red	6540	1044	1167	257	2960	484	770	108	250	70	440	0.38	0.038
Ash:													
Black	6000	960	1043	229	2300	414	861	120	347	97	594	0.45	0.045
Green	9460	1514	1400	308	4200	756	1261	176	734	206	1209	0.53	0.053
White	9500	1520	1436	316	3990	718	1354	190	667	187	1102	0.54	0.054
Aspen:													
Bigtooth	5400	864	1120	246	2500	450	732	102	206	58	370	0.36	0.036

TABLE 2 *Continued*

Species (Official Common Tree Names)	Property												
	Modulus of Rupture[B]		Modulus of Elasticity[C]		Compression Parallel to Grain, Crushing Strength		Shear Strength		Compression, Perpendicular to Grain[D]			Specific Gravity	
									Stress at Proportional Limit		Stress at 0.04 in.		
	Avg., psi	Std. Dev., psi	Avg., 1000 psi	Std. Dev., 1000 psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi[E]	Avg.	Std. Dev.
Quaking	5130	821	860	189	2140	385	656	92	181	51	272	0.35	0.035
Basswood, American	4960	794	1038	228	2220	400	599	84	170	48	313	0.32	0.032
Beech, American	8570	1371	1381	304	3550	639	1288	180	544	152	907	0.57	0.057
Birch:													
Paper	6380	1021	1170	257	2360	425	836	117	273	76	476	0.48	0.048
Sweet	9390	1502	1650	363	3740	673	1245	174	473	132	794	0.60	0.060
Yellow	8260	1322	1504	331	3380	608	1106	155	428	120	723	0.55	0.055
Cottonwood:													
Eastern	5260	842	1013	223	2280	410	682	95	196	55	354	0.37	0.037
Elm:													
American	7190	1150	1114	245	2910	524	1002	140	355	99	607	0.46	0.046
Rock	9490	1518	1194	263	3780	680	1274	178	610	171	1012	0.57	0.057
Slippery	8010	1282	1232	271	3320	598	1106	155	415	116	702	0.49	0.049
Hackberry	6480	1037	954	210	2650	477	1070	150	399	112	676	0.49	0.049
Hickory:													
Pecan	9770	1563	1367	301	3990	718	1482	207	777	218	1277	0.61	0.061
Water	10740	1718	1563	344	4660	839	1440	202	881	247	1442	0.63	0.063
Mockernut	11080	1773	1574	346	4480	806	1277	179	812	227	1333	0.64	0.064
Pignut	11740	1878	1652	363	4810	866	1370	192	923	258	1509	0.67	0.067
Shagbark	11020	1763	1566	344	4580	824	1520	213	843	236	1382	0.64	0.064
Shellbark	10530	1685	1343	295	3920	706	1186	166	808	226	1326	0.63	0.063
Bitternut	10280	1645	1399	308	4570	823	1237	173	799	224	1312	0.62	0.062
Nutmeg	9060	1450	1289	284	3980	716	1032	144	760	213	1250	0.56	0.056
Magnolia:													
Cucumbertree	7420	1187	1565	344	3140	565	991	139	330	92	567	0.44	0.044
Southern magnolia	6780	1085	1106	243	2700	486	1044	146	462	129	777	0.46	0.046
Maple:													
Bigleaf	7390	1182	1095	241	3240	583	1108	155	449	126	756	0.44	0.044
Black	7920	1267	1328	292	3270	589	1128	158	601	168	997	0.52	0.052
Sugar	9420	1507	1546	340	4020	724	1465	205	645	181	1067	0.57	0.057
Red	7690	1230	1386	305	3280	590	1151	161	405	113	686	0.50	0.050
Silver	5820	931	943	207	2490	448	1053	147	369	103	629	0.44	0.044
Oak, red:													
Black	8220	1315	1182	260	3470	625	1222	171	706	198	1164	0.56	0.056
Cherrybark	10850	1736	1790	394	4620	832	1321	185	765	214	1258	0.60	0.060
Northern red	8300	1328	1353	298	3440	619	1214	170	614	172	987	0.56	0.056
Southern red	6920	1107	1141	251	3030	545	934	131	547	153	912	0.53	0.053
Laurel	7940	1270	1393	306	3170	571	1182	165	573	160	953	0.56	0.056
Pin	8330	1333	1318	290	3680	662	1293	181	715	200	1179	0.58	0.058
Scarlet	10420	1667	1476	325	4090	736	1411	198	834	234	1368	0.61	0.061
Water	8910	1426	1552	341	3740	673	1240	174	620	174	1028	0.56	0.056
Willow	7400	1184	1286	283	3000	540	1184	166	611	171	1013	0.55	0.055
Oak, white:													
Chestnut	8030	1285	1372	302	3520	634	1212	170	532	149	888	0.58	0.058
Live	11930	1909	1575	346	5430	977	2210	309	2039	571	3282	0.81	0.081
Post	8080	1293	1086	239	3480	626	1278	179	855	239	1401	0.60	0.060
Swamp chestnut	8480	1357	1350	297	3540	637	1262	177	573	160	953	0.60	0.060
White	8300	1328	1246	274	3560	641	1249	175	671	188	1109	0.60	0.060
Bur	7180	1149	877	193	3290	592	1354	190	677	190	1118	0.60	0.060
Overcup	8000	1280	1146	252	3370	607	1315	184	539	151	899	0.56	0.056
Swamp white	9860	1578	1593	350	4360	785	1296	181	764	214	1256	0.64	0.064
Poplar, balsam	3860	618	748	165	1690	304	504	71	136	38	259	0.30	0.030
Sycamore, American	6470	1035	1065	234	2920	526	996	139	365	102	622	0.46	0.046

TABLE 2 *Continued*

Species (Official Common Tree Names)	Property												
	Modulus of Rupture[B]		Modulus of Elasticity[C]		Compression Parallel to Grain, Crushing Strength		Shear Strength		Compression, Perpendicular to Grain[D]			Specific Gravity	
									Stress at Proportional Limit		Stress at 0.04 in.		
	Avg., psi	Std. Dev., psi	Avg., 1000 psi	Std. Dev., 1000 psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi[E]	Avg.	Std. Dev.
Sweetgum	7110	1138	1201	264	3040	547	992	139	367	103	626	0.46	0.046
Tanoak	10470	1675	1550	341	4650	837	...	...	...	...	...	0.58	0.058
Tupelo:													
Black	7040	1126	1031	227	3040	547	1098	154	485	136	813	0.47	0.047
Water	7300	1168	1052	231	3370	607	1194	167	480	134	805	0.46	0.046
Yellow-poplar	5950	952	1222	269	2660	479	792	111	269	75	470	0.40	0.040

[A] For tension parallel and perpendicular to grain and modulus of rigidity, see 4.3.

[B] Modulus of rupture values are applicable to material 2 in. (51 mm) in depth.

[C] Modulus of elasticity values are applicable at a ratio of shear span to depth of 14.

[D] Based on a 2-in. wide steel plate bearing on the center of a 2-in. wide by 2-in. thick by 6-in. long specimen oriented with growth rings parallel to load.

[E] A coefficient of variation of 28 % can be used as an approximate measure of variability of individual values about the stresses tabulated.

5. Procedures for Assigning Values to Combinations

5.1 *General Requirements*—Administrative and marketing considerations often make it necessary or desirable to combine basic groups having relatively similar properties into a single marketing combination. When species are to be combined, it is necessary to give consideration to the species within the combination having the lowest strength and stiffness properties. This can be done by setting limits that determine when a species may be included in a combination without reducing the average properties for the combination. If a species is to be included and the limits are exceeded, the assigned property value for the combination must be reduced to a value such that the limits are not exceeded. In any combination of species, equitable treatment for each species in the combination is assured by using a weighting factor based on the standing timber volume of that species in relation to the total standing timber volume of the combination. Table 4 and Table 5 list cubic foot timber volume data for some commercially important species. The criteria in 5.1.1, 5.2, 5.3, and 5.4, based on experience with past accepted species groupings, are for use in developing clear wood strength and stiffness assignments for any combination of species or unit areas.

5.1.1 While strength values assigned to combinations under these methods do not necessarily require mixing of all the group members in a particular shipment, the assigned values shall reflect the probability of obtaining the higher strength as well as the lower strength members as the combination is used. If a portion of a combination is separately identified and marketed to utilize fully its higher properties, the effect of such a separation shall be recognized by a re-evaluation of the remainder of the combination to assure that it also is marketed in accordance with its lower properties.

5.2 *Combinations of Table 1 Species (Method A)*:

5.2.1 The modulus of elasticity value assigned to any combination of species and regional subdivisions of a species shall be the weighted average value for all species or regional subdivisions thereof included in the combination, subject to the following limitations:

NOTE 7—The weighted average modulus of elasticity and compression perpendicular to grain values are obtained by weighting the Table 1 values in proportion to the volume of standing timber in accordance with the data of Table 4, and then dividing the weighted values by the total volume they represent.

5.2.1.1 The modulus of elasticity value assigned to the combination shall not be more than 16 % greater than the lowest average value for any unit area included in the combination. The average modulus of elasticity for the lowest unit area of any species or subdivisions thereof may be computed from the information in Table 1. It is the quotient of the average modulus of elasticity divided by the associated variability index (see 4.1.6.2).

5.2.1.2 A species for which no timber volume data are available may be included in a previously established combination if the modulus of elasticity of the new species equals or exceeds the value assigned to the existing combination.

5.2.2 Establish compression perpendicular to grain values for combinations as described in 5.3.1. Establish other strength value assignments for combinations, which represent a value associated with the lower 5 % exclusion limit, as follows:

5.2.2.1 Strength values assigned to any combination of species and regional subdivisions of a species shall not exceed the 5 % exclusion value of the combined frequency distribution of all species or subdivisions included in the combination.

5.2.2.2 Determine the 5 % exclusion value for a combination of species and regional subdivisions of a species by adding the areas under the volume weighted frequency distribution of

TABLE 3 Clear Wood Strength Values Unadjusted for End Use and Measures of Variation for Commercial Species of Wood in the Unseasoned Condition (Method B) (for Woods Grown in Canada)[A]

NOTE 1—Information on the strength properties of additional hardwood species can be obtained from Department of Forestry, Canada, *Publication No. 1104*.

NOTE 2—Values of standard deviation have been calculated using the values for *c* given in 4.2.

Species (Official Common Tree Names)	Property												
	Modulus of Rupture[B]		Modulus of Elasticity[C]		Compression Parallel to Grain, Crushing Strength, max		Shear Strength		Compression, Perpendicular to Grain[D]			Specific Gravity	
									Fiber Stress at Proportional Limit		Stress at 0.04 in		
	Avg., psi	Std. Dev., psi	Avg., 1000 psi	Std. Dev., 1000 psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi	Std. Dev., psi	Avg., psi[D,E]	Avg.	Std. Dev.
SOFTWOODS													
Cedar:													
Eastern (northern) white	3860	618	515	113	1890	340	660	92	196	55	354	0.30	0.030
Western red	5300	848	1046	230	2780	500	696	97	279	78	486	0.31	0.031
Cypress, yellow (Alaska cedar)	6640	1062	1336	294	3240	583	880	123	350	98	599	0.42	0.042
Douglas fir	7540	1206	1613	355	3610	650	922	129	460	129	773	0.45	0.045
Fir:													
Alpine	5158	825	1258	277	2502	450	684	96	258	72	452	0.33	0.033
Amabilis (Pacific silver)	5480	877	1347	296	2770	499	714	100	234	66	414	0.36	0.036
Balsam	5290	846	1129	248	2440	439	679	95	243	68	429	0.34	0.034
Hemlock:													
Eastern	6780	1085	1268	279	3430	617	914	128	404	113	684	0.40	0.040
Western	6960	1114	1476	325	3580	644	752	105	373	104	635	0.41	0.041
Tamarack	6820	1091	1238	272	3130	563	919	129	413	116	699	0.48	0.048
Larch, western	8680	1389	1654	364	4420	796	920	129	519	145	867	0.55	0.055
Pine:													
Jack	6310	1010	1167	257	2950	531	822	115	335	94	575	0.42	0.042
Lodgepole	5650	904	1274	280	2860	515	724	101	276	77	481	0.40	0.040
Red	5010	802	1066	235	2370	427	711	100	281	79	489	0.39	0.039
Western white	4830	773	1187	261	2520	454	652	91	235	66	416	0.36	0.036
Ponderosa	5700	912	1130	249	2840	511	720	101	349	98	597	0.44	0.044
Eastern white	5140	822	1176	259	2590	466	635	89	238	67	421	0.36	0.036
Spruce:													
Black	5870	939	1320	290	2760	497	796	111	300	84	519	0.41	0.041
Engelmann	5660	906	1251	275	2810	506	702	98	268	75	468	0.38	0.038
Red	5880	941	1325	292	2810	506	807	113	273	76	476	0.38	0.038
Sitka	5420	867	1370	301	2560	461	634	89	291	81	505	0.35	0.035
White	5100	816	1150	253	2470	445	670	94	245	69	432	0.35	0.035
HARDWOODS													
Aspen:													
Largetooth	5340	854	1082	238	2390	430	789	110	212	59	379	0.39	0.039
Quaking	5460	874	1307	288	2350	423	718	101	199	56	359	0.37	0.037
Cottonwood:													
Black	4060	650	971	214	1860	335	558	78	101	28	202	0.30	0.030
Eastern	4740	758	869	191	1970	355	770	108	210	59	376	0.35	0.035
Poplar, balsam	5010	802	1151	253	2110	380	666	93	178	50	325	0.37	0.037

[A] For tension parallel and perpendicular to grain and modulus of rigidity, see 4.3.
[B] Modulus of rupture values are applicable to material 2 in. (51 mm) in depth.
[C] Modulus of elasticity values are applicable at a ratio of shear span to depth of 14.
[D] Based on a 2-in. wide steel plate bearing on the center of a 2-in. wide by 2-in. thick by 6-in. long specimen oriented with growth rings parallel to load.
[E] A coefficient of variation of 28 % can be used as an approximate measure of variability of individual values about the stresses tabulated.

TABLE 4 Standing Timber Volume for Commercially Important Species Grown in the United States

Species	Volume MMCF[AB]4.3	Species	Volume MMCF[AB]4.3
Alder, red	7764	Larch, western	5984
Ash	11 595	Maple:	
Aspen:		Black	52
Bigtooth	3974	Red	31 398
Quaking	17 445	Silver	1913
Baldcypress	4200	Sugar	21 950
Beech, American	9262	Oak:[C]	
Birch:		Select red	22 867
Sweet	2601	Other red	42 455
Yellow	4008	Select white	29 776
Cedar:		Other white	19 780
Alaska	105	Pine:	
Atlantic white	311	Eastern white	13 483
Eastern red	1612	Jack	1561
Incense	3611	Lodgepole	28 420
Northern white	5354	Ponderosa	36 223
Port-Orford	272	Red	4084
Western red	7736	Southern yellow:	
Cottonwood:		Loblolly	57 990
Black	781	Longleaf	4795
Douglas-fir:		Pitch	1436
Coast	58 722	Pond	1251
Interior West	19 761	Shortleaf	15 284
Interior North	30 020	Slash	10 891
Interior South	5779	Spruce	576
Fir:		Virginia	7206
Balsam	5655	Sugar	3373
California red	3150	Western white	1227
Grand	11 134	Redwood	4631
Noble	1152	Spruce:	
Pacific silver	5671	Black	1599
Subalpine	11 939	Engelmann	17 804
White	14 471	Red	4803
Hackberry	1133	Sitka	1470
Hemlock:		White	1790
Eastern	8530	Sweetgum	18 388
Mountain	3040	Sycamore	2658
Western	20 894	Tamarack	1202
Hickory	7888	Tupelo[D]	6507
		Yellow-poplar	23 203

[A] Million cubic feet.

[B] Source: Miles, Patrick D.; Pugh, Scott A.; Smith, W. Brad; Vissage, John S., *Forest Resources of the United States*, 2002 Gen. Tech. Rep. NC-241, 137 p, St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. The attribute of interest is volume of growing stock in timberland (cuft) (live growing stock volume ≥5" DBH, on timberland). Based on survey data from 2000 or earlier.

[C] Select white oaks are *Quercus alba*(white)*, Q. michauxii* (swamp chestnut)*, Q. muehlenbergii* (chinkapin)*, Q. durandii*Durand*, Q. bicolor* (swamp white)*, and Q. macrocarpa* (bur)*. Select red oaks are Q. rubra* (northern red)*, Q. falcata var. pagodaefolia* (cherry bark)*, and Q. shumardii* (shumard)*. Other Red and White are from Hardwoods of North America by Harry Alden. Definitions of other White are Q. garryana* (Oregon White), *Q. lyrata* (overcup), *Q. stellata* (post), and *Q. prinus* (chestnut). Other Reds are *Q. falcate* (southern red), *Q. coccinea* (scarlet), *Q. kelloggi* (California black), *Q. laurifolia* (laurel), *Q. nigra* (water), *Q. nuttalli* (nuttal), *Q. palusris* (pin), *Q. phellos* (willow), and *Q. velutina* (black).

[D] Includes black gum.

each species or subdivision thereof at successively higher levels of strength until a value is obtained below which 5 % of the area under the combined frequency distribution will fall.

NOTE 8—An approximate value for the 5 % exclusion limit of a combination can be obtained by computing the volume weighted average 5 % exclusion value for all included species or regional subdivisions thereof from the appropriate standard deviations.

5.2.2.3 In addition, the composite dispersion factor (CDF) (Eq 5) shall not be less than 1.18 for any included species or subdivision thereof. For basic groups using Method A procedure:

$$CDF = [(\bar{\bar{Y}}/\text{V.I.}) - A]/s \qquad (5)$$

where:

$\bar{\bar{Y}}$ = average value for each species or basic group of unit areas of a species included in the combination,

V.I. = variability index for each species or basic group of unit areas of a species included in the combination,

s = standard deviation for each species or basic group of unit areas of a species included in the combination, and

A = the computed 5 % exclusion value of the combined frequency distribution.

TABLE 5 Standing Timber Volume for Commercially Important Species Grown in Canada[A]

Species	Volume MMCF[B]	Species	Volume MMCF[B]
Aspen:			
Largetooth	11 179		
Quaking	53 952	Tamarack	3613
Cottonwood:		Larch, western	2608
Black	10 871		
Eastern	73		
		Pine:	
Cedar:		Red	1235
Eastern (northern) white	7686	Ponderosa	640
Western red	20 690	Western white	657
Cypress, yellow (Alaska cedar)	5494	Eastern white	6779
		Jack	30 767
Douglas Fir	26 171	Lodgepole	86 860
Fir:		Spruce	
Amabilis	13 793	White	57 193
Grandis	10	Black	140 539
Alpine	27 415	Red	21 077
Balsam	45 566	Sitka	12 231
		Engelmann	15 528
Hemlock:			
Eastern	2108	Poplar, balsam	15 426
Western	46 231		

[A] From Canada's National Forest Inventory, 2001. Timber volumes are compiled for not-reserved forest stock greater than 60 years in age and conforming to the definition of mature or older forests.
[B] Million cubic feet, converted from thousand cubic metres by a factor of .0353.

5.2.2.4 A species for which no timber volume data are available may be included in a previously established combination if the 5 % exclusion values of the new species equal or exceed the strength property values assigned the combination.

NOTE 9—An exclusion limit is a level of strength below which a selected percentage of the strength values are expected to fall and corresponds to a selected probability point from the frequency distribution of strength values. A 5 % exclusion limit for a species of regional subdivision is obtained by multiplying the standard deviation for the strength property under consideration by 1.645 and subtracting the product from the average strength value.

5.3 *Combinations of Table 2 and Table 3 Species (Method B)*:

5.3.1 The modulus of elasticity and stress in compression perpendicular to grain values assigned to any combination of species shall be the weighted average value for all species included in the combination, subject to the following limitations (Note 7):

5.3.1.1 Neither property value assigned to the combination shall be more than 10 % larger than the average value for any included species or regional subdivision.

5.3.1.2 A species for which no timber volume data are available may be included in a previously established combination if the property of the new species equals or exceeds the value assigned to the existing combination.

5.3.2 Establish strength value assignments to combinations, which represent a value associated with the lower 5 % exclusion limit, as follows:

5.3.2.1 Strength values assigned to any combination of species shall not exceed the 5 % exclusion value of the combined frequency distribution of all species included in the combination.

5.3.2.2 Determine the 5 % exclusion value for a combination of species by adding the areas under the volume weighted frequency distribution of each species at successively higher levels of strength until a value is obtained below which 5 % of the area under the combined frequency distribution will fall (Note 8).

5.3.2.3 In addition, the composite dispersion factor (CDF) shall not be less than 1.48 for Method B, as established by the following equation:

$$\mathrm{CDF} = (\overline{\overline{Y}} - A)/s \ (see\ 5.2.2.3) \tag{6}$$

5.3.2.4 A species for which no timber volume data are available may be included in a previously established combination if the 5 % exclusion values of the new species equals or exceeds the strength property values assigned the combination.

5.4 *Combinations of Table 1 and Table 2 and Table 3 Species (Methods A and B Combined)*:

5.4.1 Establish compression perpendicular to grain values for combinations as described in 5.3.1. The modulus of elasticity value assigned to any combination involving species analyzed by Method A and species analyzed by Method B shall be the weighted average value for all species and regional subdivisions thereof included in the combination and shall be subject to the following limitations (Note 7):

5.4.1.1 The modulus of elasticity value assigned to the combination shall not exceed the weighted average value for all species included in the combination. In addition, it shall conform to all requirements of 5.2.1.1 for those included species or regional subdivisions thereof analyzed by Method A; and shall conform to all the requirements of 5.3.1.1 for those included species or regional subdivisions thereof analyzed by Method B.

5.4.1.2 A species for which no timber volume data are available may be included in a previously established combination if the modulus of elasticity of the new species equals or exceeds the value assigned to the existing combination.

5.4.2 Strength values assigned to any combination involving species analyzed by Method A and species analyzed by Method B shall represent a value associated with the lower 5 % exclusion limit and shall be established as follows:

5.4.2.1 Strength values assigned to the combination shall not exceed the 5 % exclusion value of the combined frequency distribution of all species or subdivisions thereof included in the combination. The 5 % exclusion values shall be determined by the method described in 5.2.2.2 and 5.3.2.2. In addition, strength values shall conform to all the requirements of 5.2.2.3 and 5.3.2.3 for those species or regional subdivisions thereof analyzed by Methods A and B, respectively (Note 8).

5.4.2.2 A species for which no timber volume data are available may be included in a previously established combination if the 5 % exclusion values of the new species equal or exceed the strength property values assigned the combination.

5.5 *Illustration of the Application of Procedures for Assigning Values to Combinations*—The following examples, using hypothetical values, illustrate the procedures used to establish modulus of elasticity and strength assignments for species groupings:

Example 1—Modulus of Elasticity (MOE) Assignment for Combination of Three Species Analyzed by the Unit Area Procedure (Method A):

Column 1	Column 2	Column 3	Column 4	Column 5[A]
Species	Avg. MOE, 1000 psi	Variability Index	Percent of Total Volume	Avg. MOE of Lowest Unit Area, 1000 psi
A	1503	1.06	40	1418
B	1296	1.05	40	1234
C	1214	1.08	20	1124

[A] Column 5 values = column 2/column 3.
Applicable grouping limit = 16 %.
Weighted average MOE of combination = [(1503 × 40) + (1296 × 40) + (1214 × 20)]/100 = 1362.
Lowest unit area MOE value × 1.16 = 1124 × 1.16 = 1304.
Lowest unit area MOE value governs, and the MOE value assigned to the combination is 1 300 000 psi.

Example 2—Modulus of Elasticity Assignment for Combination of Three Species Not Analyzed by the Unit Area Procedure (Method B):

Species	Avg. MOE, 1000 psi	Percent of Total Volume
D	1585	25
E	1413	30
F	1292	45

Applicable grouping limit = 10 %.
Weighted average MOE of = [(1585 × 25) + (1413 × 30) + (1292 × 45)]/100 = 1402.
Lowest species MOE value in combination × 1.10 = 1292 × 1.10 = 1421.
Weighted average value governs, average MOE assigned to combination shall not exceed 1 400 000 psi.

Example 3—Modulus of Elasticity Assignment for Combination of Two Species Analyzed by the Unit Area Procedure (Method A) and a Species Not Analyzed by the Unit Area Procedure (Method B):

Species	Avg. MOE, 1000 psi	Variability Index	Percent of Total Volume	Avg. MOE of Lowest Unit Area, 1000 psi
G	1613	1.04	35	1551
H	1492	1.06	40	1408
I	1348	...	25	...

Applicable grouping limit = 16 % (Method A).
Applicable grouping limit = 10 % (Method B).
Weighted average MOE of combination = [(1613 × 35) + (1492 × 40) + (1348 × 25)]/100 = 1498.
Lowest unit area MOE value × 1.16 = 1408 × 1.16 = 1633.
Lowest species value × 1.10 = 1348 × 1.10 = 1483.
Lowest species MOE value governs and the MOE value assigned to the combination is 1 483 000 psi.

Example 4—Modulus of Rupture (MOR) Assignment for Combination of Three Species Analyzed by the Unit Area Procedure (Method A):

Species	Avg. MOR, psi	Variability Index	Std. Dev.	5 % Exclusion Value for Species	Percent of Total Volume	Composite Dispersion Factor (CDF)
A	5700	1.04	850	4302	40	1.23 (lowest)
B	6150	1.06	940	4604	40	1.46
C	5980	1.04	920	4467	20	1.43

Minimum allowable CDF = 1.18.
5 % exclusion value of combination = 4432.
The lowest CDF exceeds 1.18, hence the computed value governs, and the exclusion value assigned to the combination shall not exceed 4432 psi.

Example 5—Modulus of Rupture Assignment for Combination of Three Species Not Analyzed by the Unit Area Procedure (Method B):

Species	Avg. MOR, psi	Std. Dev.	5 % Exclusion Value for Species	Percent of Total Volume	Composite Dispersion Factor (CDF)
D	6951	1112	5121	25	1.86
E	7202	1152	5305	30	2.02
F	6301	1008	4642	45	1.41

Minimum allowable CDF = 1.48.
5 % exclusion value for combination = 4880.
The lowest CDF is less than the minimum allowable value. The exclusion value assigned to the combination shall not exceed 6301 − (1.48 × 1008) = 4809 psi.

Example 6—Modulus of Rupture Assignment for Combination of One Species Analyzed by the Unit Area Procedure (Method A) and Two Species Not Analyzed by the Unit Area Procedure (Method B):

Species	Avg. MOR, psi	Variability Index	Std. Dev.	5 % Exclusion Value for Species	Percent of Total Volume	Composite Dispersion Factor (CDF)
G	7000	1.05	1040	5289	50	1.74
H	6850	...	1096	5047	40	1.82
I	5400	...	864	3979	10	1.29 (lowest)

Minimum allowable CDF for G = 1.18. Minimum allowable CDF for H and I = 1.48.
5 % exclusion value for combination = 4853.
The lowest CDF is less than the minimum allowable value. The exclusion value assigned to the combination shall not exceed 5400 − (1.48 × 864) = 4121 psi.

6. Requirements for Evaluation of New Data

6.1 New clear wood property data are reviewed for acceptance to determine if the new data adequately represent the target species. It is not the intent to address specific product-line concerns for practical implementation. Such concerns are addressed by the product-line subcommittees. Where clear wood values are already tabulated in these test methods for a species, new data may be presented to substantiate, augment, or replace the existing data used to establish tabulated information. The following requirements shall be met before submission of the new data to the responsible subcommittee of Committee D07 for evaluation and recommended action (see Appendix X2).

6.1.1 *Replacement*—Before new data are considered for replacement of existing data (the latter defined as those data used to establish the property information tabulated in these test methods), the species shall have been representatively sampled and appropriate statistical tests conducted to show that the new data describing the species are significantly different than the existing data, with respect to mean, variance, fifth percentile, or any combination thereof. In the absence of analyses showing significant differences between new and existing data, the new data still may be submitted for replacement of existing data if documentation is provided showing that the new data represent a more adequate sample or are more completely documented than existing data, or both.

6.1.2 *Augment Existing Data*—Where new data are demonstrated to be representative of the species, but do not show the significant differences prescribed in 6.1.1, and where existing data are documented and are shown to be in need of additional precision, new data may be submitted for consideration for combining with existing data to obtain a more precise estimate of the target population parameters.

6.1.3 *Substantiation*—Where new data are demonstrated to be representative of the species, but do not present the significant differences stated in 6.1.1, and where it is not possible or feasible to augment existing data, the new data analysis may be submitted for inclusion in permanent ASTM files as substantiation of the specific clear wood values to which the data apply. When acceptance of new data as substantiation of existing clear wood data is approved by action of subcommittee and committee, a footnote shall be added to the appropriate values tabulated in these test methods that references the document providing the substantiation and gives the date substantiation was approved.

7. Keywords

7.1 clear wood; density survey; laminated wood; lumber modulus of elasticity; plywood; round timber; species combinations; specific gravity; strength properties; timber volumes; variability

APPENDIXES

(Nonmandatory Information)

X1. PRINCIPLES FOR CONVERSION TO WORKING STRESSES

X1.1 General

X1.1.1 This section gives general principles and information that are applicable to all wood products to convert standard clear-wood strength values to working stresses in design. These principles deal with duration of load, moisture content, temperature, strength-reducing characteristics, shape and form, factor of safety, and rounding of the calculated values. Working stress standards for a product should show how these or other factors have been taken into account and should give reference to adequate supporting data or analysis.

X1.2 Duration of Load

X1.2.1 Standard strength values for wood are based on tests of 5 to 10-min duration, and all except modulus of elasticity are subject to adjustment for other durations of load. Fig. X1.1 shows the generalized relation of strength to duration of load. Repeated loads have a cumulative effect that may have to be considered in some designs. Combinations of loads may be critical at the stress for the permanent part of the load or at some higher stress of shorter duration. Plastic flow effects may be taken into account where stiffness over a period of time is important. These factors are discussed in greater detail in "Duration of Load and Fatigue in Wood Structures," Paper 1361 of the *Proceedings* of the American Society of Civil Engineers, 1957.

X1.3 Moisture Content

X1.3.1 Wood increases in strength and modulus of elasticity as it dries below the fiber saturation point, which is at about 30 % moisture content. The average increases in properties of small clear specimens dried to 12 % moisture content, when compared with properties of matched specimens in the green condition, are tabulated in Table X1.1 and Table X1.2. Increases in strength and modulus of elasticity of the clear wood may not be fully realized in products because of the interaction of drying with type of product, form, size, occurrence of drying defects, and to some extent, species. Working stress standards for wood products should recognize the net gain of strength or stiffness from drying and should show how it is to be applied.

X1.3.2 Although drying results in increases of strength in many structural members, the size of a member is reduced by shrinkage resulting from drying. The net gain of strength or modulus of elasticity of a wood product and the rules for applying it with recognition of the effects of shrinkage are left to the appropriate working stress standard for that product.

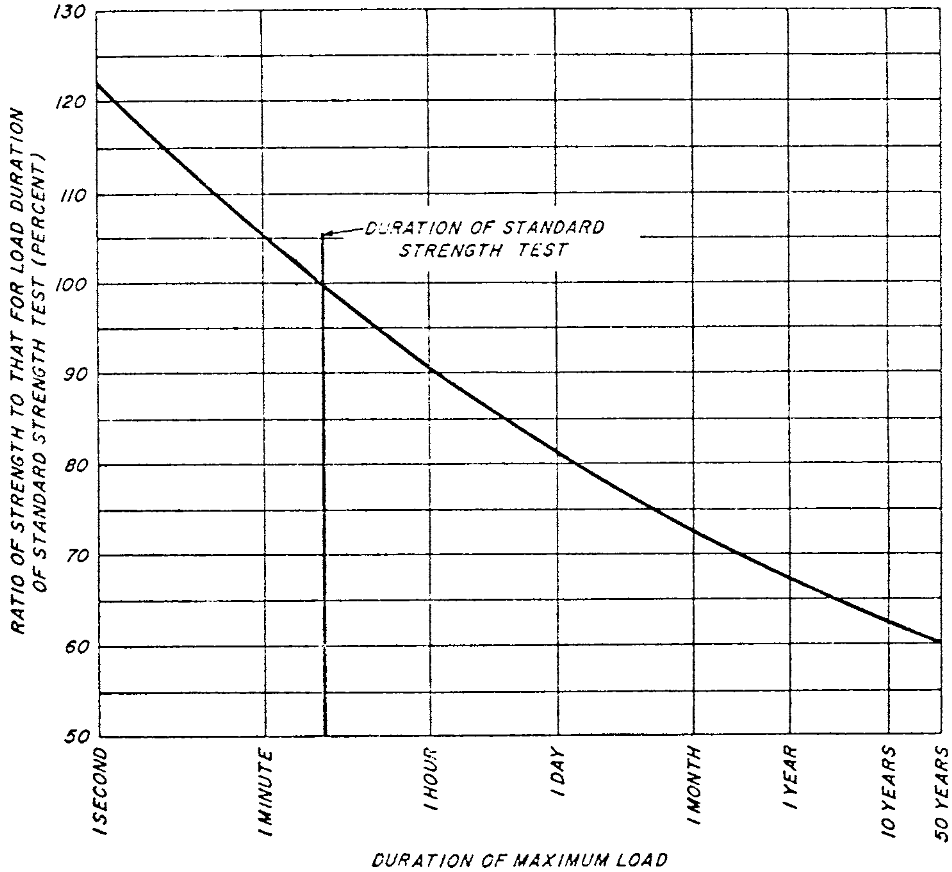

FIG. X1.1 Relation of Strength to Duration of Load

TABLE X1.1 Ratios of Dry[A] to Green Clear Wood Properties for Woods Grown in the United States

Species or Region, or Both (Official Common Tree Names)	Property				
	Modulus of Rupture	Modulus of Elasticity	Compression Parallel to Grain, Crushing Strength	Shear Strength	Compression Perpendicular to Grain, Stress at Proportional Limit
Softwoods					
Baldcypress	1.60	1.22	1.78	1.23	1.81
Cedar:					
Alaska	1.73	1.25	2.07	1.35	1.78
Atlantic white	1.44	1.24	1.97	1.16	1.67
Eastern red	1.25	1.36	1.69	...	1.32
Incense	1.28	1.24	1.65	1.05	1.59
Northern white	1.54	1.24	1.99	1.39	1.32
Port Orford	1.93	1.31	1.99	1.62	2.38
Western red	1.46	1.18	1.64	1.29	1.89
Douglas fir:					
Coast	1.62	1.25	1.91	1.25	2.08
Interior North	1.76	1.27	1.99	1.48	2.16
Interior South	1.75	1.28	2.00	1.59	2.20
Interior West	1.64	1.21	1.92	1.38	1.82
Fir:					
Balsam	1.66	1.16	2.01	1.43	2.16
California red	1.81	1.28	1.98	1.36	1.82
Grand	1.53	1.26	1.80	1.22	1.85
Noble	1.74	1.25	2.03	1.31	1.90
Pacific silver	1.71	1.24	2.04	1.64	1.98
Subalpine	1.76	1.23	2.11	1.54	2.01
White	1.67	1.29	2.00	1.46	1.89

TABLE X1.1 *Continued*

Species or Region, or Both (Official Common Tree Names)	Property: Modulus of Rupture	Modulus of Elasticity	Compression Parallel to Grain, Crushing Strength	Shear Strength	Compression Perpendicular to Grain, Stress at Proportional Limit
Hemlock:					
Eastern	1.39	1.11	1.76	1.25	1.81
Mountain	1.83	1.28	2.24	1.65	2.32
Western	1.71	1.25	2.14	1.49	1.94
Larch, western	1.70	1.28	2.03	1.56	2.32
Pine:					
Eastern white	1.74	1.24	1.97	1.33	2.01
Jack	1.64	1.27	1.92	1.55	1.95
Lodgepole	1.70	1.24	2.06	1.28	2.41
Monterey	2.00	1.27	2.22	1.69	2.11
Ponderosa	1.84	1.30	2.17	1.61	2.05
Red	1.88	1.27	2.22	1.77	2.31
Sugar	1.67	1.16	1.81	1.58	2.32
Western white	2.06	1.22	2.07	1.54	2.45
Pine, southern yellow:					
Loblolly	1.75	1.28	2.03	1.61	2.04
Longleaf	1.70	1.25	1.96	1.45	2.01
Pitch	1.59	1.19	2.01	1.58	2.23
Pond	1.56	1.37	2.06	1.48	2.06
Sand	1.54	1.38	2.01	.96	1.86
Shortleaf	1.76	1.26	2.06	1.54	2.31
Slash	1.87	1.29	2.13	1.74	1.93
Spruce	1.73	1.23	1.99	1.66	2.63
Virginia	1.77	1.25	1.96	1.52	2.32
Redwood	1.34	1.15	1.68	1.25	1.93
Spruce:					
Black	1.77	1.16	2.10	1.67	2.27
Engelmann	1.98	1.26	2.06	1.89	2.06
Red	1.80	1.25	2.04	1.71	2.09
Sitka	1.81	1.27	2.10	1.51	2.07
White	1.89	1.25	2.20	1.53	2.06
Tamarack	1.62	1.33	2.06	1.49	2.07
HARDWOODS					
Alder, red	1.50	1.18	1.97	1.40	1.73
Ash:					
Black	2.10	1.53	2.60	1.82	2.20
Green	1.49	1.18	1.69	1.52	1.78
Oregon	1.67	1.20	1.72	1.50	2.36
White	1.57	1.21	1.86	1.41	1.73
Aspen:					
Bigtooth	1.68	1.27	2.12	1.48	2.19
Quaking	1.64	1.37	1.99	1.30	2.04
Beech, American	1.74	1.25	2.06	1.56	1.86
Basswood, American	1.76	1.41	2.13	1.65	2.16
Birch:					
Paper or white	1.92	1.36	2.41	1.45	2.20
Sweet	1.80	1.32	2.28	1.80	2.29
Yellow	2.01	1.34	2.42	1.70	2.26
Butternut	1.51	1.21	2.11	1.55	2.08
Cherry, black	1.54	1.14	2.01	1.51	1.91
Chestnut, American	1.53	1.32	2.15	1.36	2.00

TABLE X1.1 *Continued*

Species or Region, or Both (Official Common Tree Names)	Property: Modulus of Rupture	Modulus of Elasticity	Compression Parallel to Grain, Crushing Strength	Shear Strength	Compression Perpendicular to Grain, Stress at Proportional Limit
Cottonwood:					
Black	1.73	1.18	2.05	1.69	1.82
Eastern	1.62	1.35	2.15	1.36	1.95
Elm:					
American	1.65	1.20	1.90	1.51	1.95
Cedar	1.47	1.27	1.61	1.70	1.57
Rock	1.56	1.29	1.87	1.51	2.02
Slippery	1.62	1.21	1.92	1.48	1.97
Winged	1.61	1.36	1.83	1.82	1.61
Hackberry	1.70	1.25	2.05	1.49	2.23
Hickory:					
Bitternut	1.66	1.28	1.98	1.58	2.10
Mockernut	1.74	1.41	2.00	1.36	2.13
Nutmeg	1.83	1.32	1.74	1.79	2.06
Pecan	1.40	1.26	1.97	1.40	2.22
Pignut	1.71	1.37	1.91	1.57	2.15
Shagbark	1.83	1.38	2.01	1.60	2.08
Shellbark	1.72	1.41	2.04	1.78	2.23
Water	1.65	1.30	1.85	...	1.75
Honeylocust	1.44	1.27	1.70	1.36	1.60
Locust, black	1.40	1.11	1.50	1.41	1.58
Magnolia:					
Cucumber tree	1.66	1.16	2.01	1.35	1.74
Southern magnolia	1.66	1.27	2.02	1.47	1.86
Maple:					
Bigleaf	1.45	1.32	1.84	1.56	1.68
Black	1.68	1.22	2.04	1.61	1.69
Red	1.75	1.19	1.99	1.61	2.48
Silver	1.53	1.21	2.10	1.41	2.00
Sugar	1.67	1.18	1.95	1.59	2.27
Oak, red:					
Black	1.69	1.39	1.88	1.56	1.32
Cherrybark	1.67	1.27	1.89	1.51	1.63
Laurel	1.59	1.21	2.20	1.55	1.85
Northern red	1.72	1.35	1.97	1.46	1.65
Pin	1.69	1.31	1.85	1.61	1.42
Scarlet	1.67	1.30	2.04	1.34	1.34
Southern red	1.58	1.31	2.01	1.49	1.60
Water	1.72	1.30	1.81	1.63	1.65
Willow	1.96	1.48	2.35	1.40	1.85
Oak, white:					
Bur	1.43	1.18	1.84	1.35	1.78
Chestnut	1.65	1.16	1.94	1.23	1.58
Live	1.54	1.25	1.64	1.20	1.39
Overcup	1.57	1.24	1.84	1.52	1.50
Post	1.63	1.39	1.90	1.44	1.67
Swamp chestnut	1.64	1.31	2.05	1.58	1.93
Swamp white	1.80	1.28	1.97	1.54	1.56
White	1.83	1.43	2.09	1.60	1.59
Poplar, balsam	1.76	1.47	2.38	1.57	2.18
Sweetgum	1.76	1.37	2.08	1.61	1.70
Sycamore, American	1.55	1.33	1.84	1.47	1.91
Tupelo:					
Black, blackgum	1.36	1.16	1.82	1.22	1.92
Water	1.32	1.19	1.76	1.33	1.81

TABLE X1.1 *Continued*

Species or Region, or Both (Official Common Tree Names)	Property				
	Modulus of Rupture	Modulus of Elasticity	Compression Parallel to Grain, Crushing Strength	Shear Strength	Compression Perpendicular to Grain, Stress at Proportional Limit
Walnut, black	1.54	1.18	1.76	1.13	2.08
Yellow-poplar	1.70	1.29	2.08	1.50	1.85

[A] Dry, here, means 12 % moisture content.

X1.4 Temperature

X1.4.1 Wood is stronger at low than at high temperature. Prolonged exposure to high temperature also causes a permanent reduction of strength. These effects are discussed in the *Wood Handbook* of the U.S. Department of Agriculture. Strength values tabulated in this practice are derived from tests made at temperatures of 70 to 75°F (21 to 23.9°C). Working stress standards for wood products are expected to be suitable for the range of temperatures encountered in normal use or to include appropriate factors to compensate for the effects of abnormal temperatures if needed.

X1.5 Strength-Reducing Characteristics

X1.5.1 Standard clear-wood strength values, including moduli of elasticity, provided by these methods are intended to be appropriately modified to account for effects of natural or induced strength-reducing characteristics. Strength-reducing effects specifically associated with the general grade or quality of each manufactured wood product should be expressed as grade strength ratios or other technically equivalent parameters derived from and justified by appropriate scientific studies.

X1.6 Shape and Form

X1.6.1 Shape or form has an effect on the strength or stiffness of many wood structural products that is taken into account in developing working stress standards. Factors for shape or form are discussed at several points in *Wood Handbook No. 72*, U.S. Department of Agriculture.

X1.7 Factor of Safety

X1.7.1 Working stress standards for marketed wood products should take into account, after applying the foregoing factors, whether a further reduction of stress for factor of safety should be made, and if so how much. The accounting should be made preferably by considering the factor of safety as multivalued and as depending upon conditions of both strength and use. The factor of safety may recognize differences in the hazards and the consequences of failure appropriate to the expected uses of the various marketed wood products. An extended discussion of the factor of safety is found in ASCE *Transactions*, Paper No. 3051, "Factor of Safety in Design of Timber Structures" (1960).

X1.8 Rounding of Values

X1.8.1 Table 1 and Table 2 and similar data indicate the degree of significance of the tabulated strength values and point out that these are to be used for computations. After computations of group or other values are made, the values should be suitably rounded for design use as may be determined by each product subcommittee to be appropriate in a working stress standard.

X1.9 Compression Perpendicular to Grain

X1.9.1 Compression perpendicular to grain stress at 0.04-in. deformation in Tables 1-3 is based on the following equation:

$$Y_{04} = 42.44 + 1.589 \text{ P.L.} \tag{X1.1}$$

where P.L. is the average proportional limit stress in the corresponding Tables 1-3 except for values for Douglas fir—Coast, Douglas fir—interior north, shortleaf pine, western hemlock, Pacific sliver fir, Englemann spruce, white spruce, northern red oak, and quaking aspen. The stresses at 0.04-in. deformation for these species are the mean values from Table 1 of the literature.[3]

[3] *Mean and Tolerance Limit Stresses and Stress Modelling for Compression Perpendicular to Grain in Hardwood and Softwood Species*, Research Paper FPL 337, Forest Products Laboratory, USDA Forest Service. 1979.

TABLE X1.2 Ratios of Dry[A] to Green Clear Wood Properties for Woods Grown in Canada

Species or Region, or Both (Official Common Tree Names)	Property				
	Modulus of Rupture	Modulus of Elasticity	Compression Parallel to Grain, Crushing Strength	Shear Strength	Compression Perpendicular to Grain, Stress at Proportional Limit
			SOFTWOODS		
Cedar:					
Cypress, yellow (Alaska cedar)	1.74	1.19	2.05	1.52	1.96
Eastern (northern) white	1.59	1.23	1.90	1.52	1.98
Western red	1.47	1.14	1.77	1.16	1.78
Douglas fir	1.70	1.22	2.01	1.50	1.89
Fir:					
Alpine	1.59	1.18	2.11	1.44	2.08
Amabilis (Pacific silver)	1.82	1.22	2.14	1.53	2.24
Balsam	1.60	1.24	2.04	1.34	1.90
Hemlock:					
Eastern	1.43	1.11	1.74	1.38	1.55
Western	1.69	1.21	1.89	1.25	1.76
Larch, western	1.79	1.26	2.00	1.46	2.04
Pine:					
Eastern white	1.84	1.16	2.02	1.39	2.07
Jack	1.79	1.27	1.99	1.45	2.47
Lodgepole	1.95	1.24	2.19	1.71	1.92
Ponderosa	1.86	1.22	2.16	1.42	2.17
Red	2.02	1.29	2.32	1.53	2.56
Western white	1.92	1.23	2.08	1.41	2.00
Spruce:					
Black	1.94	1.15	2.19	1.57	2.06
Engelmann	1.78	1.24	2.19	1.56	2.00
Red	1.76	1.21	1.99	1.65	2.00
Sitka	1.87	1.19	2.14	1.55	2.04
White	1.78	1.26	2.17	1.47	2.04
Tamarack	1.62	1.10	2.08	1.42	2.18
			HARDWOODS		
Aspen:					
Largetooth	1.78	1.16	1.99	1.39	2.23
Quaking	1.79	1.25	2.24	1.36	2.57
Cottonwood:					
Black	1.76	1.32	2.16	1.54	2.56
Eastern	1.58	1.30	1.95	1.50	2.25
Poplar, balsam	2.02	1.45	2.38	1.33	2.38

[A] Dry, here, means 12 % moisture content.

X2. DECISION SEQUENCE FOR ANALYSIS OF NEW DATA AND SUBSEQUENT DECISIONS

TABLE X2.1 Example Sequence

	Mean and Variances	*i* th Quantile	Action
1.	Unequal	Unequal	Data are accepted for replacement. Product subcommittees may assess the practical significance.
2.	Unequal	Equal	Examine distribution fit (see Practice D 2915). a. If normal, consult power table to assure adequate sample size. If adequate, data are accepted for replacement or augmentation. Product subcommittees may assess practical significance. b. If not normal, see 4b.
3.	Equal	Equal	No changes in tabulated values. Data substantiates existing data.
4.	Equal	Unequal	Examine distribution fit (see Practice D 2915) a. If normal, accept new data for replacement or augmentation. Product subcommittees may assess practical significance. b. If not normal, further analysis required to determine appropriate action.