Designation: D 2915 – 98$^{\epsilon 1}$

Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber[1]

This standard is issued under the fixed designation D 2915; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ[1] NOTE—Equation 5 was corrected in October 2000.

INTRODUCTION

The mechanical properties of structural lumber depend upon natural growth characteristics and manufacturing practices. Several procedures can be used to sort lumber into property classes or stress grades, the most widely used being the visual methods outlined in Practice D 245. With each, a modulus of elasticity and a set of from one to five allowable stresses may be associated with each stress grade. The allowable stresses are extreme fiber stress in bending, tension parallel to the grain, compression parallel to the grain, shear, and compression perpendicular to the grain. This test method for evaluation of the properties of structural lumber defines an allowable property as the value of the property that would normally be published with the grade description.

This practice is useful in assessing the appropriateness of the assigned properties and for checking the effectiveness of grading procedures.

For situations where a manufactured product is sampled repeatedly or lot sizes are small, alternative test methods as described in Ref **(1)**[2] may be more applicable.

1. Scope

1.1 This practice covers sampling and analysis procedures for the investigation of specified populations of stress-graded structural lumber. Depending on the interest of the user, the population from which samples are taken may range from the lumber from a specific mill to all the lumber produced in a particular grade from a particular geographic area, during some specified interval of time. This practice generally assumes that the population is sufficiently large so that, for sampling purposes, it may be considered infinite. Where this assumption is inadequate, that is, the population is assumed finite, many of the provisions of this practice may be employed but the sampling and analysis procedure must be designed to reflect a finite population. The statistical techniques embodied in this practice provide procedures to summarize data so that logical judgments can be made. This practice does not specify the action to be taken after the results have been analyzed. The action to be taken depends on the particular requirements of the user of the product.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *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:*

D 198 Methods of Static Tests of Timber in Structural Sizes[3]

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber[3]

E 105 Practice for Probability Sampling of Materials[4]

3. Statistical Methodology

3.1 Two general analysis procedures are described under this practice, parametric and nonparametric. The parametric approach assumes a known distribution of the underlying population, an assumption which, if incorrect, may lead to inaccurate results. Therefore, if a parametric approach is used, appropriate statistical tests shall be employed to substantiate this choice along with measures of test adequacy **(2, 3, 4, 5, 6,**

[1] This practice is under the jurisdiction of ASTM Committee D-7 on Wood and is the direct responsibility of Subcommittee D07.02 on Lumber and Engineered Wood Products.

Current edition approved Oct. 10, 1998. Published March 1999. Originally published as D 2915 – 70 T. Last previous edition D 2915 – 94.

[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] *Annual Book of ASTM Standards*, Vol 04.10.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

7). Alternatively a nonparametric approach requires fewer assumptions, and is generally more conservative than a parametric procedure.

3.2 *Population*:

3.2.1 It is imperative that the population to be evaluated be clearly defined, as inferences made pertain only to that population. In order to define the population, it may be necessary to specify (*1*) grade name and description, (*2*) geographical area over which sampling will take place (nation, state, mill, etc.), (*3*) species or species group, (*4*) time span for sampling (a day's production, a month, a year, etc.), (*5*) lumber size, and (*6*) moisture content.

3.2.2 Where possible, the sampling program should consider the location and type of log source from which the pieces originated, including types of processing methods or marketing practices with respect to any influence they may have on the representative nature of the sample. Samples may be collected from stock at mills, centers of distribution, at points of end use or directly from current production at the grading chains of manufacturing facilities.

3.3 *Sampling Procedure*:

3.3.1 *Random Sampling*— The sampling unit is commonly the individual piece of lumber. When this is not the case, see 3.3.3. The sampling shall assure random selection of sampling units from the population described in 3.2 with all members of the population sharing equal probability of selection. The principles of Practice E 105 shall be maintained. When sampling current production, refer to Practice E 105 for a recommended sampling procedure (see Appendix X3 of this practice for an example of this procedure). If samples are selected from inventory, random number tables may be used to determine which pieces will be taken for the sample.

3.3.2 *Sampling with Unequal Probabilities*—Under some circumstances, it may be advisable to sample with unequal but known probabilities. Where this is done, the general principles of Practice E 105 shall be maintained, and the sampling method shall be completely reported.

3.3.3 *Sequential Sampling*—When trying to characterize how a certain population of lumber may perform in a structure, it may be deemed more appropriate to choose a sampling unit, such as a package, that is more representative of how the lumber will be selected for use. Such a composite sampling unit might consist of a sequential series of pieces chosen to permit estimation of the properties of the unit as well as the pieces. Where this is done, the principles in 3.3.1 and 3.3.2 apply to these composite sampling units and the sampling method shall be completely reported.

3.4 *Sample Size*:

3.4.1 Selection of a sample size depends upon the property or properties to be estimated, the actual variation in properties occurring in the population, and the precision with which the property is to be estimated. For the five allowable stresses and the modulus of elasticity various percentiles of the population may be estimated. For all properties, nonparametric or parametric techniques are applicable. Commonly the mean modulus of elasticity and the mean compression perpendicular to the grain stress for the grade are estimated. For the four other allowable stresses, a near-minimum property is generally the objective.

3.4.2 Determine sample size sufficient for estimating the mean by a two-stage method, with the use of the following equation. This equation assumes the data is normally distributed and the mean is to be estimated to within 5 % with specified confidence:

$$n = (ts/0.05\,\bar{X})^2 = \left(\frac{t}{0.05}CV\right)^2 \quad (1)$$

where:

n = sample size,
s = standard deviation of specimen values,
$\bar{X}$ = specimen mean value,
CV = coefficient of variation, $s/\bar{X}$,
0.05 = precision of estimate, and
t = value of the t statistic from Table 1.

Often the values of s, $\bar{X}$, and t or CV and t are not known before the testing program begins. However, s and $\bar{X}$, or CV, may be approximated by using the results of some other test program, or they may simply be guessed (see example, Note 1).

NOTE 1—An example of initial sample size calculation is:

TABLE 1 Values of the t Statistics Used in Calculating Confidence Intervals[A]

df *n* − 1	*CI* = 75 %	*CI* = 95 %	*CI* = 99 %
1	2.414	12.706	63.657
2	1.604	4.303	9.925
3	1.423	3.182	5.841
4	1.344	2.776	4.604
5	1.301	2.571	4.032
6	1.273	2.447	3.707
7	1.254	2.365	3.499
8	1.240	2.306	3.355
9	1.230	2.262	3.250
10	1.221	2.228	3.169
11	1.214	2.201	3.106
12	1.209	2.179	3.055
13	1.204	2.160	3.012
14	1.200	2.145	2.977
15	1.197	2.131	2.947
16	1.194	2.120	2.921
17	1.191	2.110	2.898
18	1.189	2.101	2.878
19	1.187	2.093	2.861
20	1.185	2.086	2.845
21	1.183	2.080	2.831
22	1.182	2.074	2.891
23	1.180	2.069	2.807
24	1.179	2.064	2.797
25	1.178	2.060	2.787
26	1.177	2.056	2.779
27	1.176	2.052	2.771
28	1.175	2.048	2.763
29	1.174	2.045	2.756
30	1.173	2.042	2.750
40	1.167	2.021	2.704
60	1.162	2.000	2.660
120	1.156	1.980	2.617
∞	1.150	1.960	2.576

[A] Adapted from Ref **(8)**. For calculating other confidence levels, see Ref **(8)**.

Sampling a grade of lumber for modulus of elasticity (E). Assuming a 95 % confidence level, the t statistic can be approximated by 2.

s = 300 000 psi (2067 MPa)
$\bar{X}$ = assigned E of the grade = 1 800 000 psi (12 402 MPa)
CV = (300 000/1 800 000) = 0.167
t = 2

$$n = \left(\frac{2}{0.05} \times 0.167\right)^2 = 44.622 \text{ (45 pieces)}$$

Calculate the sample mean and standard deviation and use them to estimate a new sample size from Eq 1, where the value of t is taken from Table 1. If the second sample size exceeds the first, the first sample was insufficient; obtain and test the additional specimens.

NOTE 2—More details of this two-stage method are given in Ref **(8).**

3.4.3 To determine sample size based on a tolerance limit (TL), the desired content (C) (Note 3) and associated confidence level must be selected. The choice of a specified content and confidence is dependent upon the end-use of the material, economic considerations, current design practices, code requirements, etc. For example, a content of 95 % and a confidence level of 75 % may be appropriate for a specific property of structural lumber. Different confidence levels may be suitable for different products or specific end uses. Appropriate content and confidence levels shall be selected before the sampling plan is designed.

NOTE 3—The content, C, is an estimate of the proportion of the population that lies above the tolerance limit. For example, a tolerance limit with a content of 95 % describes a level at which 95 % of the population lies above the tolerance limit. The confidence with which this inference is to be made is a separate statement.

3.4.3.1 To determine the sample size for near-minimum properties, the nonparametric tolerance limit concept of Ref **(8)** may be used (Table 2). This will provide the sample size suitable for several options in subsequent near-minimum analyses. Although the frequency with which the tolerance limit will fall above (or below) the population value, corresponding to the required content, is controlled by the confidence level selected, the larger the sample size the more likely the tolerance limit will be close to the population value. It is, therefore, desirable to select a sample size as large as possible commensurate with the cost of sampling and testing (see also 4.7).

3.4.3.2 If a parametric approach is used, then a tolerance limit with stated content and confidence can be obtained for any sample size; however, the limitation expressed in 3.4.3.1 applies. That is, although the frequency that the tolerance limit falls above (or below) the population value, corresponding to the required content is controlled, the probability that the tolerance limit will be close to the population value depends on the sample size. For example, if normality is assumed, the parametric tolerance limit (PTL) will be of the form PTL = $\bar{X} - Ks$, (see Ref **(8)**), and the standard error (SE) of this statistic may be approximated by the following equation:

$$SE = s\sqrt{\frac{1}{n} + \frac{K^2}{2(n-1)}} \quad (2)$$

where:
s = standard deviation of specimen values,
n = sample size, and
K = confidence level factor.

The sample size, n, may be chosen to make this quantity sufficiently small for the intended end use of the material (Note 4).

NOTE 4—An example of sample size calculation where the purpose is to estimate a near minimum property is shown in the following calculation:

Estimate the sample size, n, for a compression parallel strength test in which normality will be assumed. A CV of 22 % and a mean C_{11} of 4600 psi are assumed based on other tests. The target PTL of the lumber grade is 2700 psi. The PTL is to be estimated with a content of 95 % (5 % PTL) and a confidence of 75 %.

CV = 0.22
$\bar{X}$ = 4600 psi (31.7 MPa)
s = (0.22) (4600) = 1012 psi (7.0 MPa)
K = ($\bar{X}$ − PTL)/s = 1.878

From Table 3:
K = 1.869 for n = 30
Therefore $n \approx 30$ specimens.

$$SE = 1012\sqrt{\frac{1}{30} + \frac{1.878^2}{2(30-1)}} \quad (3)$$
$$= 310.7 \text{ psi (2.1 MPa)}$$

Consequently, although 30 specimens is sufficient to estimate the 5 % PTL with 75 % confidence, the standard error (approximately 12 % of the PTL) illustrates that, with this size sample, the PTL estimated by test may not be as close to the true population fifth percentile as desired. A larger n may be desirable.

3.4.4 Often the objective of the evaluation program will be to estimate mean and near-minimum properties simultaneously. When this is the case, only one sample size need be used. It should be the greater of the two obtained in accordance with 3.4.2 and 3.4.3.

3.4.5 If a sampling unit other than an individual piece of lumber is to be used, as provided for in 3.3.3, then the required sample size must be determined by procedures that are

TABLE 2 Sample Size and Order Statistic for Estimating the 5 % Nonparametric Tolerance Limit, NTL[A]

75 % Confidence		95 % Confidence		99 % confidence	
Sample Size[B]	Order Statistic[C]	Sample Size	Order Statistic	Sample Size	Order Statistic
28	1	59	1	90	1
53	2	93	2	130	2
78	3	124	3	165	3
102	4	153	4	198	4
125	5	181	5	229	5
148	6	208	6	259	6
170	7	234	7	288	7
193	8	260	8	316	8
215	9	286	9	344	9
237	10	311	10	371	10
259	11	336	11	398	11
281	12	361	12	425	12
303	13	386	13	451	13
325	14	410	14	478	14
347	15	434	15	504	15
455	20	554	20	631	20
562	25	671	25	755	25
668	30	786	30	877	30
879	40	1013	40	1115	40
1089	50	1237	50	1349	50

[A] Adapted from Ref **(12)**. For other tolerance limits or confidence levels, see Ref **(12)** or **(8)**.
[B] Where the sample size falls between two order statistics (for example, 27 and 28 for the first order statistic at 75 confidence), the larger of the two is shown in the table, and the confidence is greater than the nominal value.
[C] The rank of the ordered observations, beginning with the smallest.

TABLE 3 K Factors for One-Sided Tolerance Limits for Normal Distributions[A]

	75 % Confidence (γ = 0.25)				95 % Confidence (γ = 0.05)				99 % Confidence (γ = 0.01)			
1 − p	0.75	0.90	0.95	0.99	0.75	0.90	0.95	0.99	0.75	0.90	0.95	0.99
n												
3	1.464	2.501	3.152	4.397	3.805	6.156	7.657	10.555	8.726	13.997	17.374	23.900
4	1.255	2.134	2.681	3.726	2.617	4.162	5.145	7.044	4.714	7.381	9.085	12.389
5	1.151	1.962	2.464	3.422	2.149	3.407	4.203	5.742	3.453	5.362	6.580	8.941
6	1.087	1.859	2.336	3.244	1.895	3.007	3.708	5.063	2.847	4.412	5.407	7.336
7	1.043	1.790	2.251	3.127	1.732	2.756	3.400	4.643	2.490	3.860	4.729	6.413
8	1.010	1.740	2.189	3.042	1.617	2.582	3.188	4.355	2.253	3.498	4.286	5.813
9	0.984	1.702	2.142	2.978	1.532	2.454	3.032	4.144	2.083	3.241	3.973	5.390
10	0.964	1.671	2.104	2.927	1.465	2.355	2.912	3.982	1.954	3.048	3.739	5.075
11	0.946	1.646	2.074	2.886	1.411	2.276	2.816	3.853	1.852	2.898	3.557	4.830
12	0.932	1.625	2.048	2.852	1.366	2.210	2.737	3.748	1.770	2.777	3.411	4.634
13	0.919	1.607	2.026	2.823	1.328	2.156	2.671	3.660	1.702	2.677	3.290	4.473
14	0.908	1.591	2.008	2.797	1.296	2.109	2.615	3.585	1.644	2.593	3.189	4.338
15	0.899	1.577	1.991	2.776	1.267	2.069	2.566	3.521	1.595	2.522	3.103	4.223
16	0.890	1.565	1.977	2.756	1.242	2.033	2.524	3.465	1.552	2.460	3.028	4.124
17	0.883	1.555	1.964	2.739	1.220	2.002	2.487	3.415	1.514	2.405	2.963	4.037
18	0.876	1.545	1.952	2.724	1.200	1.974	2.453	3.371	1.480	2.357	2.906	3.961
19	0.869	1.536	1.942	2.710	1.182	1.949	2.424	3.331	1.450	2.314	2.854	3.893
20	0.864	1.528	1.932	2.697	1.166	1.926	2.396	3.296	1.423	2.276	2.808	3.832
21	0.858	1.521	1.924	2.686	1.151	1.906	2.372	3.263	1.398	2.241	2.767	3.777
22	0.854	1.514	1.916	2.675	1.138	1.887	2.349	3.234	1.376	2.209	2.729	3.727
23	0.849	1.508	1.908	2.666	1.125	1.869	2.329	3.207	1.355	2.180	2.695	3.682
24	0.845	1.502	1.901	2.657	1.113	1.853	2.310	3.182	1.336	2.154	2.663	3.640
25	0.841	1.497	1.895	2.648	1.103	1.838	2.292	3.159	1.319	2.129	2.634	3.602
30	0.825	1.475	1.869	2.614	1.058	1.778	2.220	3.064	1.247	2.030	2.516	3.447
35	0.812	1.458	1.849	2.588	1.025	1.732	2.167	2.995	1.194	1.958	2.430	3.335
40	0.802	1.445	1.834	2.568	0.999	1.697	2.126	2.941	1.154	1.902	2.365	3.249
45	0.794	1.434	1.822	2.552	0.978	1.669	2.093	2.898	1.121	1.857	2.312	3.181
50	0.788	1.426	1.811	2.539	0.960	1.646	2.065	2.863	1.094	1.821	2.269	3.125
60	0.777	1.412	1.795	2.518	0.932	1.609	2.023	2.808	1.051	1.764	2.203	3.039
70	0.769	1.401	1.783	2.502	0.911	1.581	1.990	2.766	1.019	1.722	2.153	2.974
80	0.762	1.393	1.773	2.489	0.894	1.560	1.965	2.733	0.994	1.689	2.114	2.924
90	0.757	1.386	1.765	2.479	0.881	1.542	1.944	2.707	0.974	1.662	2.083	2.884
100	0.753	1.380	1.758	2.470	0.869	1.527	1.927	2.684	0.957	1.639	2.057	2.850
120	0.745	1.371	1.747	2.456	0.851	1.503	1.900	2.650	0.930	1.604	2.016	2.797
140	0.740	1.364	1.739	2.446	0.837	1.485	1.879	2.623	0.909	1.577	1.985	2.758
160	0.736	1.358	1.733	2.438	0.826	1.471	1.862	2.602	0.893	1.556	1.960	2.726
180	0.732	1.353	1.727	2.431	0.817	1.460	1.849	2.585	0.879	1.539	1.940	2.700
200	0.729	1.350	1.723	2.425	0.809	1.450	1.838	2.570	0.868	1.524	1.923	2.679
250	0.723	1.342	1.714	2.414	0.794	1.431	1.816	2.542	0.846	1.496	1.891	2.638
300	0.719	1.337	1.708	2.406	0.783	1.417	1.800	2.522	0.830	1.476	1.868	2.609
350	0.715	1.332	1.703	2.400	0.775	1.407	1.788	2.507	0.818	1.461	1.850	2.586
400	0.712	1.329	1.699	2.395	0.768	1.398	1.778	2.495	0.809	1.449	1.836	2.568
450	0.710	1.326	1.696	2.391	0.763	1.391	1.770	2.484	0.801	1.438	1.824	2.553
500	0.708	1.324	1.693	2.387	0.758	1.385	1.763	2.476	0.794	1.430	1.815	2.541
600	0.705	1.320	1.689	2.382	0.750	1.376	1.753	2.462	0.783	1.416	1.799	2.521
700	0.703	1.317	1.686	2.378	0.745	1.369	1.744	2.452	0.775	1.406	1.787	2.506
800	0.701	1.315	1.683	2.374	0.740	1.363	1.738	2.443	0.768	1.398	1.777	2.493
900	0.699	1.313	1.681	2.371	0.736	1.358	1.732	2.436	0.762	1.391	1.769	2.483
1000	0.698	1.311	1.679	2.369	0.733	1.354	1.728	2.431	0.758	1.385	1.763	2.475
1500	0.694	1.306	1.672	2.361	0.722	1.340	1.712	2.411	0.742	1.365	1.741	2.447
2000	0.691	1.302	1.669	2.356[B]	0.715	1.332	1.703	2.400[B]	0.733	1.354	1.727	2.431[B]
2500	0.689	1.300[B]	1.666[B]	2.353[B]	0.711	1.326	1.697[B]	2.392[B]	0.727	1.346	1.719[B]	2.419[B]
3000	0.688	1.299[B]	1.664[B]	2.351[B]	0.708	1.323[B]	1.692[B]	2.386[B]	0.722	1.340[B]	1.712[B]	2.411[B]
inf	0.674	1.282	1.645	2.326	0.674	1.282	1.645	2.326	0.674	1.282	1.645	2.326

[A] Obtained from a noncentral *t* inverse approach; see Ref **(15)**.
[B] Computed using formula X5.2.

statistically appropriate for the sampling method chosen. In the case of multisource data, as in the sampling of some or all mills in a defined region, special procedures may be required, for example, those based on the methodology introduced in Ref **(9)**. In all cases, the procedures shall be fully described.

4. Analysis and Presentation of Results

4.1 The results of the tests performed in accordance with

Methods D 198 or other standard testing procedures shall beanalyzed and presented as (*1*) a set of summarizing statistics, and (*2*) an appendix of unadjusted individual test specimen results. If parametric procedures are to be used, a description of the selection procedures and a tabulation of distribution parameters shall be provided. Any "best-fit" judgment (Note 5) between competing distributions shall be documented.

NOTE 5—A best-fit procedure should recognize the low power of some published procedures. To check the fit, the series of tests outlined in Ref **(10)** represents several alternatives. Also, tests based on the Anderson-Darling statistic **(2, 3, 4)** have been shown to be among the more powerful tests **(6, 7)**. It should be noted, however, that not all tests are valid for all distributions and that these procedures are effective for checking central tendency. For instance, revised standard tables of the Kolmogorov-Smirnov statistic are presently available only for the normal, logistic, and exponential distributions **(5)**.

4.2 Properties shall be adjusted to a single moisture content appropriate for the objective of the testing program. Although test results can be adjusted for moisture content, these adjustments decrease in accuracy with increasing change in moisture content. For this reason, it is suggested that the specimens be conditioned as closely as possible to the target moisture content prior to test, and that adjustments for more than five percentage points of moisture content are to be avoided. The adjustment equation is:

$$P_2 = P_1[(\alpha - \beta M_2)/(\alpha - \beta M_1)] \quad (4)$$

where:
P_1 = property measured at moisture content M_1,
P_2 = property adjusted to moisture content M_2,
M_1, M_2 = moisture contents, %, and
α,β = moisture content constants (Table 4).

Eq 4 yields adjustments consistent with the moisture factors given in Table 11 of Practice D 245. Moisture contents M_1 greater than 22 % are taken as 22 % for Eq 4. M_2 must be less than or equal to 22 %.

4.3 Modulus of elasticity values of primary concern are apparent values, E_{ai}, used in deflection equations that attribute all deflection to moment. These apparent moduli may be standardized for a specific span-depth ratio and load configuration. Standardization should reflect, as far as pos-sible, conditions of anticipated end use.[5,6] When tests at standardized conditions of load and span are not possible, to adjust E_{ai} to standardized conditions, it is necessary to account for the effect of shear deflection on beam deflection. Factors to adjust E_{ai} for span-depth ratio and load configuration may be derived from Eq 5, (Ref **(11)**). To determine the apparent modulus of elasticity, E_{ai2}, based on any set of conditions of span-depth ratio and load configuration, when the modulus, E_{ai}, based on some other set of conditions is known, solve the equation:

$$E_{ai2} = \frac{1 + K_1 \left(\frac{h_1}{L_1}\right)^2 \left(\frac{E}{G}\right)}{1 + K_2 \left(\frac{h_2}{L_2}\right)^2 \left(\frac{E}{G}\right)} E_{ai} \quad (5)$$

where:
h = depth of the beam,
L = total beam span between supports,
E = shear free modulus of elasticity,
G = modulus of rigidity, and
K_i = values are given in Table 5.

The equations were derived using simple beam theory for a simply supported beam composed of isotropic, homogeneous material. Experimental evidence suggests that these equations produce reasonable results with solid wood when converting between load conditions at a fixed span-depth ratio. Care must be exercised when converting between different span-depth ratios to assure that the adjustments are appropriate for the end use.

4.3.1 Often, lumber is not homogeneous within a piece with respect to modulus of elasticity. The apparent modulus, therefore, may be affected by the location of growth characteristics, such as knots, with respect to loads and supports. It is further cautioned that conversions may be less appropriate when converting between edgewise and flatwise specimen orientations.

4.3.2 If modulus of elasticity results are not measured at standardized conditions, separate justification shall be provided for factors used to adjust test values to standardized conditions.

4.3.3 In calculations using Eq 5 and that involve mean trends of large populations, a single E/G ratio is usually assumed.[7] If this assumption is critical for the intended application, it is recommended that the moduli of elasticity and rigidity of the individual pieces be measured (see Methods D 198).

4.4 The adjustment factors used to reduce the test statistics to the level of allowable properties depend on the property and

[5] Spans, which customarily serve as a basis for design range, go from 17 times the depth of the specimen to 21 times the depth.

[6] A uniform load distribution is commonly encountered in use. This load configuration is difficult to apply in testing, but may be closely approximated by applying the load at the one-third points of the span, if the L/h ratio is the same.

[7] When using these conversion equations with solid wood, historically it has been assumed that the modulus of rigidity (G) is one sixteenth the shear free modulus of elasticity (E). Limited data indicate the ratio of E/G for individual pieces of lumber can vary significantly from this value depending upon the number, size, and location of knots present, the slope of grain in the piece, and the spans over which deflections are measured **(13)**.

TABLE 4 Constants to Be Used in Eq 4

Property	α	β
Modulus of elasticity	1.44	0.0200
Bending strength	1.75	0.0333
Tensile strength	1.75	0.0333
Compressive strength parallel to grain	2.75	0.0833
Shear strength	1.33	0.0167
Compressive strength perpendicular to grain	1.00	0

TABLE 5 K Factors for Adjusting Apparent Modulus of Elasticity of Simply Supported Beams[A]

Loading	Deflection measured at	K_i
Concentrated at midspan	midspan	1.200
Concentrated at third points	midspan	0.939
Concentrated at third points	load points	1.080
Concentrated at outer quarter-points	midspan	0.873
Concentrated at outer quarter-points	load points	1.20
Uniformly distributed	midspan	0.960

[A] See Appendix X4 for an example of use of Table 5.

are shown in Table 6. They are taken from Practice D 245, which includes a safety factor and a 10-year cumulative duration of load effect (normal loading).

4.5 Statistics shall be shown with three significant digits. Adequate significant digits shall be maintained in all intermediate calculations to avoid rounding errors in the statistics.

4.5.1 The sample mean is calculated as follows:

$$\bar{X} = \sum_{i=1}^{n} x_i/n \tag{6}$$

where:

x_i = individual observations, and
n = sample size.

The sample mean is an unbiased estimator of the true population mean.

4.5.2 The sample standard deviation is calculated as follows:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i{}^2 - [(\Sigma\, x_i)^2/n]}{n-1}} \text{ or} \tag{7}$$

$$= \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{X})^2}{n-1}}$$

4.5.3 The confidence interval (CI) for the mean is calculated as follows:

$$\text{CI} = \bar{X} \pm (ts/\sqrt{n}) \tag{8}$$

where t depends on the sample size and confidence level, and is given in Table 1. A CI of this type provides that, if the population is normally distributed, a given percent of all intervals found in this manner are expected to contain the true population mean.

4.5.4 The sample nonparametric percent point estimate (NPE) may be interpolated from the sample. To perform the interpolation, arrange the test values in ascending order. Symbolically, call them x_1, x_2, x_3, ... x_n. Beginning with the lowest value (that is, first order statistic, see Note 6), calculate $i/(n + 1)$, where i is the order of the value, for each successively higher value until $i/(n + 1) \geq k/100$, call it the j^{th} value, equals or exceeds the sample k percentile point estimate. Interpolate the nonparametric k percentage point estimate by:

$$\text{NPE} = \left[\frac{k}{100}(n + 1) - (j - 1)\right] [x_j - x_{(j-1)}] + x_{(j-1)} \tag{9}$$

where k is the desired percentile point estimate sought.

NOTE 6—Order statistics are ranked test values from the lowest to the highest. For example, the first order statistic is the lowest test value or the weakest piece in the sample, the second order statistic is the second weakest piece, etc.

4.5.5 The nonparametric lower tolerance limit (NTL) of a specified content is the m^{th} order statistic, where m depends upon the sample size and confidence level. Table 2 depicts the order statistic required to determine the lower-5 % NTL at a given sample size and three confidence levels. For example, if the sample size was 93 and the confidence level was chosen to be 95 %, $m = 2$. That is, the lower-5 % NTL with at least 95 % confidence would be the second order statistic. If other lower percentiles are estimated, the corresponding NTLs can be determined **(8, 12)**.

4.5.6 If parametric methods are used, the parametric point estimate (PPE) and lower parametric tolerance limit (PTL) shall be estimated by procedures documented as adequate for the method adopted **(1, 8, 12)**.

4.5.7 A histogram, or an empirical cumulative distribution function, or both, shall be presented. The class widths for a histogram depend on the property; maximum widths are given in Table 7. If parametric procedures are used for analysis, either a cumulative distribution function or a probability density function can be shown superimposed on the empirical cumulative distribution function or the histogram respectively.

NOTE 7—Two examples of typical test data and a summary of the results that meet the requirements of 4.1-4.5 are given in Appendix X1 and Appendix X2.

4.5.8 If a sampling unit other than an individual piece of lumber is used, then the calculation of sample means, standard deviations, confidence intervals, tolerance limits, and exclusion limits must be made in a manner statistically consistent with the sampling procedure chosen.

4.6 If the purpose of the testing program is to evaluate the accuracy of existing allowable properties for the population sampled, this is done using the results of 4.5.3, 4.5.5, 4.5.6, or 4.5.8. If an allowable mean property for a population falls within the confidence interval obtained in accordance with 4.5.3, the testing program bears out the value allowed for the population with the associated confidence. The accuracy of existing near-minimum properties may be assessed using the results of 4.5.4, or 4.5.5, 4.5.6, and 4.5.8, or combination thereof. If the existing property falls at or below the point estimate as calculated in 4.5.4, the testing program may bear out the existing values, but no confidence statement may be associated with this conclusion. In order to associate a confidence statement, the existing value must fall below the tolerance limit as calculated in 4.5.5, 4.5.6, or 4.5.8.

4.7 If the purpose of the testing program is to establish allowable properties for the population, this is done using the results of 4.5.1, 4.5.4, 4.5.5, 4.5.6, or 4.5.8. The allowable

TABLE 6 Reduction Factors to Relate Test Statistics to Allowable Properties

Property	Factor
Modulus of elasticity	1
Bending strength	1/2.1
Tensile strength	1/2.1
Compressive strength parallel to grain	1/1.9
Shear strength	1/4.1
Compressive strength perpendicular to grain	1/1.67

TABLE 7 Maximum Class Width to Be Used in Histogram Plots

Property	Class Width, psi (MPa)
Modulus of elasticity	100 000 (690)
Bending strength	500 (3.4)
Tensile strength	500 (3.4)
Compressive strength parallel to grain	500 (3.4)
Shear strength	50 (0.34)
Compressive strength perpendicular to grain	50 (0.34)