Designation: D 1990 – 00 (Reapproved 2002)ε1

Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens[1]

This standard is issued under the fixed designation D 1990; 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.

ε1 NOTE—Ref (14) was added in September 2002.

INTRODUCTION

Visual stress-grades of lumber manufactured in North America have evolved from the procedures of Practice D 245. Allowable stress and modulus of elasticity values were determined for these grades using the procedures of Practice D 245 and the appropriate clear wood values of Test Methods D 2555. The clear wood values of Test Methods D 2555 were developed from tests of small clear specimens.

Development of allowable stress and modulus of elasticity values from tests of full-size structural lumber as commercially produced and marketed has become possible with the development of suitable test equipment that permits rapid rates of loading to test large numbers of pieces from commercial lumber production. These tests can be carried out at the production sites or in a laboratory.

1. Scope

1.1 Due to the number of specimens involved and the number of mechanical properties to be evaluated, a methodology for evaluating the data and assigning allowable properties to both tested and untested grade/size cells is necessary. Sampling and analysis of tested cells are covered in Practice D 2915. The mechanical test methods are covered in Test Methods D 198 and D 4761. This practice covers the necessary procedures for assigning allowable stress and modulus of elasticity values to dimension lumber from In-Grade tests. The practice includes methods to permit assignment of allowable stress and modulus of elasticity values to untested sizes and grades, as well as some untested properties.

1.2 A basic assumption of the procedures used in this practice is that the samples selected and tested are representative of the entire global population being evaluated. This approach is consistent with the historical clear wood methodology of assigning an allowable property to visually-graded lumber which was representative of the entire growth range of a species or species group. Every effort shall be made to ensure the representativeness of the test sample.

1.3 This practice covers the principles and procedures for establishing allowable stress values for bending, tension parallel to grain, compression parallel to grain and modulus of elasticity values for structural design from "In-Grade" tests of full-size visually graded solid sawn dimension lumber. This practice is focused on, but is not limited to, grades which used the concepts incorporated in Practice D 245 and were developed and interpreted under American Softwood Lumber PS 20-70.

NOTE 1—In the implementation of the North American In-Grade test program, allowable stress values for compression perpendicular to grain and shear parallel to grain for structural design were calculated using the procedures of Practice D 245.

1.4 This practice only covers dimension lumber.

1.5 *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 9 Terminology Relating to Wood[2]

D 198 Methods of Static Tests of Timbers in Structural Sizes[2]

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber[2]

D 1165 Nomenclature of Domestic Hardwoods and Softwoods[2]

[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D7.02 on Lumber and Engineered Wood Products.

Current edition approved April 10, 2000. Published June 2000. Originally published as D 1990 – 91. Last previous edition D 1990 – 97.

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

D 2555 Test Methods for Establishing Clear-Wood Strength Values[2]
D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber[2]
D 4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials[2]
D 4444 Test Methods for Use and Calibration of Hand-Held Moisture Meters[2]
D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material[2]
IEEE-SI 10 [3]

2.2 *American Softwood Lumber Standard:*
National Institute of Standards and Technology Voluntary Product Standard PS 20-94 [4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms related to wood, refer to Terminology D 9.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *characteristic size*—the standard dimensions of the piece at which the characteristic value is calculated (Note 2).

NOTE 2—In the North American In-Grade program, the characteristic size used was 1.5 in. (38 mm) thick by 7.25 in. (184 mm) wide by 144 in. (3.658 m) in length at 15 % moisture content.

3.2.2 *characteristic value*—the population mean, median or tolerance limit value estimated from the test data after it has been adjusted to standardized conditions of temperature, moisture content and characteristic size. The characteristic value is an intermediate value in the development of allowable stress and modulus of elasticity values. Typically for structural visual grades, standardized conditions are 73°F (23°C), and 15 % moisture content (Note 3). A nonparametric estimate of the characteristic value is the preferred estimate. If a distributional form is used to characterize the data at the standardized conditions, its appropriateness shall be demonstrated. (See Practice D 2915 for guidance on selection of distribution.)

NOTE 3—The described adjustment factors and allowable stress and modulus of elasticity value assignment procedures were developed based on test data of visual grades of major volume, commercially available North American softwood species groups. For other species (see Nomenclature D 1165) and for other grading methods, it may be necessary to verify that the listed adjustments are applicable. The commercial species groups and grading criteria used in the development of these procedures were as described in the grading rules for Douglas Fir-Larch, Hem-Fir and Southern Pine from the United States, and Spruce-Pine-Fir, Douglas fir(N), and Hem-Fir(N) from Canada (**1**, **2**, **3**, and **4**)[5]. The specific species groupings, together with botanical names are given in Nomenclature D 1165.

3.2.3 *grade quality index* (GQI)—A numerical assessment of the characteristics found in the sample specimens which are considered to be related to strength and are limited as part of the grade description. The grade quality index is a scaling parameter which allows modeling of strength and modulus of elasticity with respect to grade (Note 4).

NOTE 4—In the North American In-Grade test program, lumber produced in accordance with visual stress grading rules developed from the procedures of Practice D 245 was sampled. For each test specimen a strength ratio was calculated for the particular type of failure indicated by the failure code (see Test Methods D 4761). Strength ratios were calculated according to the formulas given in the appendix of Practice D 245 for bending and compression parallel to grain test specimens. Strength ratios for lumber tested in tension were calculated as for bending. The sample grade quality index for each sample was calculated as the nonparametric five percentile point estimate of the distribution of strength ratios. Specimens which failed in clear wood were excluded from the sample for determining the sample GQI.

3.2.4 *In-Grade*—samples collected from lumber grades as commercially produced. Samples collected in this manner are intended to represent the full range of strength and modulus of elasticity values normally found within a grade.

3.2.5 *sampling matrix*—the collective designation used to describe all of the individual test cells. The sampling matrix is intended to characterize the property trends for a range of grades for a single size or a range of sizes for a single grade or a combination of both sizes and grades for a species or species group.

3.2.6 *test cell*—the combined test data for a single size/grade/species/property which is intended to characterize that sampling unit.

3.2.7 *thickness*—the lesser dimension perpendicular to the long axis of lumber.

3.2.8 *tolerance limit (TL)*—refers to the tolerance limit with 95 % content and 75 % confidence.

3.2.9 *width*—the greater dimension perpendicular to the long axis of lumber.

4. Significance and Use

4.1 The procedures described in this practice are intended to be used to establish allowable stress and modulus of elasticity values for solid sawn, visually graded dimension lumber from In-Grade type test data. These procedures apply to the tested and untested sizes and grades when an adequate data matrix of sizes and grades exists. In addition, the methodology for establishing allowable stress and modulus of elasticity values for combinations of species and species groups is covered. Allowable stress and modulus of elasticity values may also be developed for a single size or a single grade of lumber from test data.

4.2 Methods for establishing allowable stress and modulus of elasticity values for a single size/grade test cell are covered in Practice D 2915. The appropriateness of these methods to establish allowable stress and modulus of elasticity values is directly dependent upon the quality and representativeness of the input test data.

4.3 A review and reassessment of values derived from this practice shall be conducted if there is cause to believe that there has been a significant change in the raw material resource or product mix. If a change is found to be significant, retesting or re-evaluation, or both, in accordance with the procedures of this practice may be needed.

[3] *Annual Book of ASTM Standards*, Vol 14.02.
[4] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
[5] The boldface numbers in parentheses refer to the references listed at the end of this practice.

5. Documentation of Results, Adjustments, and Development of Allowable Properties

5.1 *Reporting Test Data*:

5.1.1 *Summarizing Statistics*:

5.1.1.1 Provide a set of summarizing statistics that includes sample size, mean, median, standard deviation, confidence intervals, and nonparametric point estimates and tolerance limits. If parametric methods are used to characterize the data, provide a description of selection procedures and a tabulation of distribution parameters. Document any "best fit" judgments made in the selection of a distribution.

5.1.1.2 Provide a description of all statistical methods used with the summarizing statistics.

5.1.2 *Unadjusted Test Results*—To permit verification of property calculations by regulatory and third party reviewers, unadjusted individual specimen test results shall be maintained in suitable achival form. The archived records shall be retained as long as the derived property values are applicable. Archived records shall be retained by the user of this practice and an independent public institution.

NOTE 5—In the United States, the USDA Forest Products Laboratory, the American Lumber Standards Committee, and colleges and universities are considered suitable independent public institutions. It may be desirable for historical or other purposes to continue to archive the records after the derived values are no longer applicable. In such cases, the records should be maintained by a public institution.

5.1.3 *Significant Digits*—With example calculations, illustrate that adequate significant digits were maintained in intermediate calculations to avoid round-off errors. Table 3 and Section 4 of Practice E 380 provide guidance.

5.2 *Graphical Presentation*—Graphical presentations are recommended to illustrate typical data sets. If parametric methods are used, histograms or cumulative distribution functions shall be shown superimposed on the parametric functions. Class widths shall meet the requirements of Practice D 2915, Table 7.

5.3 *Preparation of Characteristic Values*

5.3.1 *Adjustments to Test Data*:

5.3.1.1 Document each of the adjustments to the test data.

5.3.1.2 If the adjustments to the test data follow procedures found in other ASTM standards or are documented in other sources, reference these sources in a manner permitting the reader to recreate the use of these sources in the same application. Indicate the limitations of application.

5.3.1.3 In the presentation, explain adjustments made to the data which cannot be referenced to acknowledged sources.

5.3.1.4 Provide examples of all adjustment procedures.

5.4 *Development of Allowable Properties*:

5.4.1 Explain each step of the development of allowable properties with reference to the appropriate paragraph of this practice.

5.4.2 *Grouping*—Summarize all grouping calculations in tabular form and examples presented to illustrate application of limiting criteria.

5.4.3 *Allowable Property Adjustments*— Illustrate each of the adjustments for allowable properties for at least one of the size/grade combinations presented. Present all adjustments in tabular form. Examples may be presented.

5.5 *Summary/Index*—Prepare a brief summary of the presentation that highlights each of the major steps. An index or table of contents shall accompany the document that references the content and the corresponding paragraphs of this practice.

6. Development of Stress Grades

6.1 Stress grades for lumber are designed to separate the raw material source into marketable groups of specific quality levels to which allowable stress and modulus of elasticity values can be assigned. Stress grading systems used with this practice shall be internally consistent and continuous (Note 6).

NOTE 6—To be considered internally consistent, a grading system should not be based on two or more methods of determining an allowable property. A continuous system should not skip levels of material strength. For example, the North American In-Grade test program sampled grades which were developed using the stress ratio system of Practice D 245 (see Refs **1**, **2**, **3**, and **4**).

7. Minimum Sampling Matrix

7.1 *General Considerations*—Development of allowable stress and modulus of elasticity values under this practice may be for either a single size (7.3) or a single grade (7.2) or a full matrix of sizes and grades (7.4). The required sampling matrix is determined by the desired end result. The intent of a sample matrix is to provide sufficient data across the sizes or grades, or both, to permit interpolation between data points. Extrapolation beyond the sample matrix may be misleading and therefore is not recommended. Assignment of allowable stress values beyond the sample matrix is permitted when there is additional supporting information to indicate that the assigned values are conservative estimates.

7.2 *Grade*—To adequately model grade performance, it is necessary to sample a minimum of two grades representative of the range of grade quality (Note 4). Grades sampled to model grade relationships shall be separated by no more than one intermediary grade and no more than one quarter of the total possible range (Note 7) in assumed bending GQI.

NOTE 7—For the grading system sampled in the North American In-Grade test program, the total possible range in strength ratio (GQI) is 0 to 100 %. The strength ratio concept is described in greater detail in Practice D 245.

7.3 *Width*—In order to adequately develop the data for width, at least three widths per grade shall be tested, and the maximum difference in width between two adjacent widths shall be 4 in. (10 cm).

7.4 *Minimum Full Matrix*—A full matrix of grades and sizes shall contain a minimum of six test cells composed of at least two grades and three widths for each of the grades, meeting the restrictions of 7.2 and 7.3, to be considered adequate for the development of a full matrix of values, including untested cells (Note 8).

NOTE 8—The sampling matrix judged to be acceptable for the North American In-Grade test program for the major species groups (Note 2) with large geographic range, consisted of six test cells with large samples (at least 360 pieces per cell). The test cells were nominal 2 by 4, 1.5 in. by 3.5 in. (38 mm by 89 mm); nominal 2 by 8, 1.5 in. by 7.25 in. (38 mm by 184 mm); and nominal 2 by 10, 1.5 in. by 9.25 in. (38 mm by 235 mm) dimension lumber of select structural grade (65 % minimum bending strength ratio) and No. 2 grade (45 % minimum bending strength ratio).

Samples were selected for tests of four properties (modulus of elasticity, modulus of rupture, ultimate tensile stress parallel to grain, and ultimate compressive stress parallel to grain). For complete grade descriptions, see Refs. **1, 2, 3,** or **4**). Samples were selected proportional to production from the entire geographic growth and production range of each species group.

8. Input Test Data and Adjustments to Input Test Data

8.1 Methods for sampling and analysis of matrix input test data are found in Practice D 2915. For testing, use Test Methods D 198 or Test Method D 4761. Other standards may be employed if demonstrated to be applicable.

8.2 Because the range of quality within any one specific grade may be large, it is necessary to assess the grade quality of the sampled material in relation to the assumed quality used to establish the matrix (7.2). The following procedures provide one way to make this assessment. The observed GQI of the test data can be used to measure the grade representativeness of the samples by comparing the GQI of the samples with the assumed minimum grade GQI (Note 3). If the difference between the observed GQI of the samples and the assumed GQI of the grade is 5 % or less of the total range of possible GQI, the samples shall be considered to support the intent of 7.2. If the sample GQI varies from the assumed minimum GQI for the grade by more than the 5 % tolerance, the samples and the GQI shall be re-evaluated for appropriateness (Note 9).

NOTE 9—Failure of the sample to meet 8.2 may be due to any of several causes, some of which may be acceptable or correctable. For example, it may be possible to bring the samples into compliance by resampling the necessary test cells. It may also be desirable to reassess the appropriateness of the GQI scale used. A modification of the GQI scale or calculation methodology may be appropriate. If the GQI procedures are modified, use the modified procedures to re-evaluate all test cells and the assumed minimum GQI of the grades for compliance with 8.2.

8.3 *Standardized Conditions*:

8.3.1 *Temperature*—Test samples at 73± 5°F (23 ± 3°C). When this is not possible, adjust individual test data to 73°F (23°C) by an adjustment model demonstrated to be appropriate.

8.3.2 *Moisture*:

8.3.2.1 Where possible, test the samples at the moisture content (15 %) at which the characteristic value is to be determined. When this is not possible, adjust the data to 15 % moisture content by the adjustment procedures in Annex A1 or by procedures documented as adequate for the method adopted prior to developing the characteristic values.

8.3.2.2 Determination of specimen moisture content shall be made in accordance with Test Methods D 4442 and D 4444.

8.4 *Size*:

8.4.1 Adjust specimen dimensions to 15 % moisture content using the adjustment procedure given in Appendix XI or other demonstrably appropriate adjustment model.

8.4.2 For the purposes of the equation in 8.4.3, the standard dressed size may be used in place of actual specimen dimensions when the moisture content adjusted specimen dimensions are within ±1⁄16 in. (2 mm) in thickness and ±1⁄4 in. (6 mm) in width of the standard dressed size.

8.4.3 The property values of all test data shall be adjusted to the characteristic size (for example, 1.5 by 7.25 by 144 in. [38 by 184 by 3658 mm] at 15 % MC) using the following equation (Note 8) or other appropriate size adjustment prior to developing the characteristic value:

$$F_2 = F_1 \left(\frac{W_1}{W_2}\right)^w \left(\frac{L_1}{L_2}\right)^l \left(\frac{T_1}{T_2}\right)^t \quad (1)$$

where:

F_1 = property value at Volume 1, psi,
F_2 = property value at Volume 2, psi,
W_1 = width at F_1, in.,
W_2 = width at F_2, in.,
L_1 = length at F_1, in.,
L_2 = length at F_2, in.,
T_1 = thickness at F_1, in.,
T_2 = thickness at F_2, in.,
w = 0.29 for modulus of rupture (MOR) and ultimate tensile stress parallel to grain (UTS); 0.13 for ultimate compressive stress parallel to grain (UCS); 0 for modulus of elasticity (MOE),
l = 0.14 for modulus of rupture and UTS parallel to grain: 0 for UCS parallel to grain and modulus of elasticity, and
t = 0 for modulus of rupture, UTS parallel to grain, UCS parallel to grain, and modulus of elasticity.

NOTE 10—The adjustments to mechanical properties for piece geometry given in 8.4.2 were developed from test data (adjusted to 15 % MC and 73°F) of visual grades of lumber (**1, 2, 3, 4**) using Test Methods D 4761. The length adjustments given above are based on the actual test clear span between reactions or grips. The bending tests used third point loading with a constant span to depth ratio of 17 to 1. The tension tests were conducted with an 8 ft (2.4 m) clear span for 2 by 4 (Southern Pine was tested on a 12 ft (3.7 m) span) and a 12 ft (3.7 m) clear clear span for 2 by 6 ft and wider. The adjustment equation of 8.4.2 has not been verified for widths less than 3.5 in. (89 mm) nor greater than 9.25 in. (286 mm). Additional information regarding the basis for and recommended limitations to Eq 1 is given in Appendix X2.

9. Establishment of Characteristic Values

9.1 For strength values, the characteristic value (see 3.2.2) for each grade (GQI class) tested shall be the tolerance limit (see 3.2.8) from the data adjusted by the procedures in Section 8 to standardized conditions of temperature, moisture content and size.

9.2 When more than one width is tested, the characteristic value shall be developed using the combined data of all widths adjusted to standardized conditions modified as necessary by the test data check given in 9.3.

9.3 *Test Cell Data Check*:

9.3.1 The purpose of the test cell data check is to minimize the probability of developing nonconservative property estimates by comparing the model generated property values against the confidence interval for each cell in the test matrix. This test ensures that the individual matrix cell estimates generated with the volume adjustment procedures of 8.4.3 and the tolerance limit of the combined data do not lay above the upper limit of the confidence interval for the fifth percentile of any tested cell.

9.3.2 When species are grouped (Section 10), the test cell data check shall be performed after grouping using the combined data of the controlling species in each test cell. An example is given in Appendix X3.

9.3.3 All individual data values shall be converted to the characteristic size by the procedures of 8.4.3, and the tolerance limit shall be determined for the combined data set.

9.3.4 The calculated tolerance limit from 9.3.3 shall be used with the procedures of 8.4.3 to generate a size-adjusted estimate for each cell in the test matrix.

9.3.5 The size-adjusted estimate from 9.3.4 for each test cell shall be compared to the upper limit of the 75 % confidence interval on the nonparametric fifth percentile estimate for the test data in that cell. If the size-adjusted estimate from 9.3.4 for any cell does not exceed the confidence interval limit, the characteristic value shall be the tolerance limit as calculated in 9.3.3.

9.3.6 If the size-adjusted estimate from 9.3.4 does exceed the upper limit of the 75 % confidence interval from 9.3.5 for any cell, reduce the tolerance limit calculated in 9.3.3 until this condition does not exist. The reduced tolerance limit estimate shall be the characteristic value for that grade.

9.4 For modulus of elasticity, the characteristic values for each grade are the mean, median, and the lower tolerance limit (or other measure of dispersion).

9.4.1 When more than one width is tested, the characteristic value shall be based on the combined data of all widths adjusted by the procedures of Section 8 to the standardized conditions.

9.5 *Estimates of Characteristic Values for Untested Properties*:

9.5.1 These formulas were developed from large data bases of several North American commercial species groups, and are intended to produce conservative property estimates when only one property was tested. The derivation of these formulas is discussed in detail in Appendix X4.

9.5.2 *Estimates Based on Modulus of Rupture*:

9.5.2.1 An estimate of the ultimate tensile stress characteristic value (T), in psi, may be calculated from the modulus of rupture characteristic value (R), in psi, with the following formula:

$$T = 0.45 \times R \quad (2)$$

9.5.2.2 An estimate of the ultimate compressive stress characteristic value (C), in psi, may be calculated from the modulus of rupture characteristic value (R), in psi, with the following formula:

For $R \leq 7200$ psi (3)

$$C = [1.55 - (0.32 \times R/1000) + (0.022 \times (R/1000)^2)] \times R$$

For $R > 7200$ psi

$$C = 0.39 \times R$$

9.5.3 *Estimates Based on Ultimate Tensile Stress*:

9.5.3.1 An estimate of the modulus of rupture characteristic value (R), in psi, may be calculated from the ultimate tensile stress characteristic value (T), in psi, with the following formula:

$$R = 1.2 \times T \quad (4)$$

9.5.3.2 An estimate of the ultimate compressive stress characteristic value (C), in psi, may be calculated from the ultimate tensile stress characteristic value (T), in psi, with the following formula:

For $T \leq 5400$ psi (5)

$$C = [2.40 - (0.70 \times T/1000) + (0.065 \times (T/1000)^2)] \times T$$

For $T > 5400$ psi

$$C = 0.52 \times T$$

9.5.4 When both bending and tension parallel to grain data are available, use the lower of the two estimates for the compression parallel to grain value.

9.5.5 Compression parallel to grain tests shall not be used to estimate either the modulus of rupture (R) characteristic value or the ultimate tensile stress (T) characteristic value.

10. Adjustments to Characteristic Values

10.1 *Grouping of Data to Form a New Species Grouping*—Frequently, because of species similarities or marketing convenience, it is desirable to combine two or more species into a single marketing group (Note 9). When this is done, it is necessary to determine the characteristic values for the combined group of species. There are no limitations as to how many or which species can be combined to form a new species grouping, but the group characteristic values shall be determined from the procedures of 10.2 for each median or mean property to be established, and the procedures of 10.3 for each tolerance limit property to be established. When a mean value is to be determined, the group shall be formed using the median values. Sections 10.2 and 10.3 cover procedures for establishing entirely new species groups, as well as adding a new species to an existing species grouping. All grouping is done after the data have been adjusted to standardized conditions of temperature, moisture content and characteristic size in accordance with 8.3 and 8.4 (see Appendix X3 for example).

NOTE 11—For grouping by other appropriate technical criteria, see Appendix X9.

10.2 *Grouping for Median Properties*

10.2.1 *New Species Grouping*:

10.2.1.1 To assign a median or mean characteristic value to a new grouping of species, begin by conducting a nonparametric analysis of variance (Appendix X5) to test for equality of median values of the separate species. This can be done for either a single grade or a matrix of grades. Where the goal is to assign values to a matrix of grades, this grouping procedure shall be conducted on each grade. Perform grouping tests on the data only after it has been adjusted to the characteristic size by the procedures in 8.4.3.

10.2.1.2 If the test is not significant at the 0.01 level, the median or mean characteristic value for the group shall be the median or mean of the combined group data.

10.2.1.3 If the test is significant at the 0.01 level, determine the subgroup of species in the grouping which are indistinguishable from the species with the lowest median characteristic value using a Tukey multiple comparison test (Appendix X4 and Ref (**5**)) on the medians at a 0.01 significance level. The median or mean characteristic value for the group shall be determined from the combined data of all the species in this subgroup.

10.2.2 *Adding New Species to Existing Group*:

10.2.2.1 A new species may be added to an existing species grouping without modification of the group median or mean characteristic value if the median value of the new species is greater than or equal to the existing group median characteristic value.

10.2.2.2 If the requirements of 10.2.2.1 are not met, determine the combined group median or mean characteristic value in accordance with 10.2.1. If the data will not permit the use of 10.2.1, then the group median or mean characteristic value shall be the median or mean of the newly included species.

10.3 *Grouping for Tolerance Limit Properties*:

10.3.1 *New Species Grouping*:

10.3.1.1 To assign a tolerance limit characteristic value to a new grouping, determine the tolerance limit value for the combined grouping (Note 10). Determine the number of pieces in each species group below the group tolerance limit value. Conduct a Chi Square test (Appendix X7) to determine if the percent of pieces below the group value is statistically significant for each species in the group.

NOTE 12—To determine a group tolerance limit value, each species to be included in the group should have a minimum sample size of at least 100 per property in order for the Chi Square test to be sufficiently sensitive (**6**).

10.3.1.2 If the test is not significant at the 0.01 level, the group characteristic value shall be determined from the grouped data of all the species in the new grouping.

10.3.1.3 If the test is significant at the 0.01 level, begin with a subgroup consisting of the two species with the highest percent of pieces below the group value. Use the Chi Square test to determine if the percent of pieces below the group value are comparable. Repeat this process, adding the species with the next highest percent of pieces below the group value to the previous group. Continue adding species until the test is significant at the 0.01 level. The group tolerance limit is determined from the combined data of the last subgroup of species for which the Chi Square test was not significant at the 0.01 level.

10.3.2 *Adding New Species to Existing Group*:

10.3.2.1 A new species may be included with an existing species grouping if the tolerance limit of the new species is equal to or greater than the current characteristic value for the group.

10.3.2.2 If the requirements of 10.3.2.1 are not met, determine the combined species group value in accordance with 10.3.1. If the data will not permit the use of 10.3.1, the group characteristic value shall be the tolerance limit value of the newly included species.

11. Establishing Grade Relationships for Stress and Modulus of Elasticity

11.1 The adjustment model for grade shall be based on relating the characteristic values determined in Section 9 modified for species grouping (Section 10), if appropriate, to the corresponding assumed minimum GQI values (see Appendix X8). The grade model constructed from the data may consist of either a linear relationship connecting the adjacent points or a mathematically fitted curve. The selected relationship shall be demonstrated to be appropriate (Note 13).

NOTE 13—The structural visual grade No. 1 (**1**, **2**, **3**, **4**) has a highly restricted grade description. In the North American In-Grade test program, it was deemed appropriate for bending and tension to use only 85 % of the No. 1 value that linear interpolation between select structural and No. 2 permitted. For compression, 95 % of the permitted No. 1 value was used (see Appendix X8). Alternatively, the No. 1 values could have been set equal to the No. 2 values.

11.2 Estimate the characteristic values for untested grades from the model selected in 11.1. Use the assumed minimum GQI for the grade determined from the minimum grade requirements (see Appendix X8).

11.2.1 If the grade adjustment model is used to extrapolate beyond the sample matrix, provide additional supporting documentation to demonstrate that the procedure is conservative.

12. Establishing Allowable Properties

12.1 The characteristic values established in Section 9 and modified in Sections 10 and 11, and the estimated values for untested grades are based on short term tests adjusted to standardized conditions. These characteristic values shall be further modified for thickness, width, length, moisture content, load duration and safety. The adjustments in this section will convert the characteristic values to allowable stress and modulus of elasticity values for normal loading conditions. Normal loading conditions anticipate fully stressing a member to the full maximum design load for a duration of approximately ten years, either continuously or cumulatively.

12.2 *Adjustments for Width*:

12.2.1 For assignment of allowable properties, adjust the characteristic values for width using the adjustment procedures of 8.4.3 to the standard dressed width.

12.2.2 For assignment of allowable properties, the property values determined for 3.5 in. (89 mm) width (4 in. nominal) may be applied to narrower widths and to all widths used flatwise in bending of nominal 2 in. thick dimension lumber.

12.2.3 For assignment of allowable properties to widths greater than 11.5 in. (292 mm), 12 in. nominal, use 0.9 of the value at 11.5 in. (292 mm).

12.2.4 No adjustment for width is required for modulus of elasticity characteristic values.

12.3 *Adjustments for Thickness*—Allowable bending stresses derived from data on 1.5 in. (38 mm) thick (2 in. nominal) lumber may be multiplied by 1.10 for members greater than 3 in. (76 mm) in net thickness.

12.4 *Adjustment for Length*—For assignment of allowable properties the characteristic values may be adjusted to a representative end-use length using the procedures in 8.4.3. The basis for and recommended limits to application of formula 8.4.3 is in Appendix X2 (Note 14).

12.5 *Adjustment for Moisture Content*:

12.5.1 The allowable properties derived from the characteristic values at 15 % moisture content are applicable to all dimension lumber manufactured at 19 % or less moisture content when used in dry use conditions, where the moisture content of the wood is not expected to exceed 19 %.

12.5.2 For lumber used where end-use conditions are expected to produce moisture contents in the wood in excess of 19 %, multiply the allowable property values at 15 % moisture content by the factors in Table 1 (Note 14).

NOTE 14—The allowable properties derived from the characteristic values at 15 % moisture content and the adjustments in Table 1 account for

TABLE 1 Modification of Allowable Property Values for Use When Moisture Content of the Wood Exceeds 19 %

Property	Adjustment Factor
$F_b \leq 1150$	1.0
$F_b > 1150$	0.85
F_t	1.0
$F_c \leq 750$	1.0
$F_c > 750$	0.8
MOE	0.9

the normal shrinking and swelling of lumber with changes in moisture content, as well as the changes in mechanical property values with moisture content. The basis of the adjustment factors in Table 1 are discussed in Appendix X10.

12.5.3 The adjustment factors in Table 1 assume the standard dressed size at the dry use moisture content. Lumber surfaced unseasoned shall take this into account when establishing characteristic values either by surfacing sufficiently oversize to account for these dimensional changes, or adjusting the allowable property values accordingly. The effects of changes in moisture content on dimensions is discussed further in Appendix X1, and adjustment factors in Table 1 are discussed in Appendix X10.

12.6 Strength property values derived from 9.3 shall not exceed the corresponding test cell nonparametric fifth percentile point estimate (PE) by more than 100 psi or 5 % of the point estimate, whichever is less. The test data in that size/grade cell shall be appropriately adjusted in accordance with preceding paragraphs of Section 12.

12.7 *Adjustment for Duration of Load and Safety*—Adjust the characteristic values determined in Sections 9 and 10 adjusted for grade, width, thickness, and length for safety and normal (10 year) loading by dividing the values by the factors in Table 2.

12.8 *Property Rounding*—Round the allowable properties in 12.7 in accordance with Table 3 and the rounding rules of Practice E 380. Maintain adequate significant digits in all intermediate calculations to avoid round-off errors.

12.9 *Adjustments for Multiple Member Use*—When three or more pieces of dimension lumber are used as joists, rafters, studs, or decking and are contiguous or are spaced not more than 24 in. on center in conventional frame construction and are joined by transverse floor, roof or other load distributing element, the allowable bending stress of such members may be increased by 15 %.

TABLE 2 Property Reduction Factors to Convert Adjusted Characteristic Values to Allowable Properties

Property	Reduction Factor
Modulus of rupture (MOR)	2.1
Ultimate tensile stress (parallel to grain) (UTS)	2.1
Ultimate compressive stress (parallel to grain) (UCS)	1.9
Modulus of elasticity (MOE)	1.0

TABLE 3 Rounding Rules for Allowable Properties Values

Bending stress (F_b) Tensile stress (parallel to grain) (F_t) Compressive stress (parallel to grain) (F_c)	Nearest 50 psi for allowable stress of 1000 psi or greater. Nearest 25 psi for all others.
Modulus of elasticity (MOE)	Nearest 100 000 psi

13. Reassessment and Affirmation

13.1 Conduct reassessment of values derived from this practice if there is cause to believe that there has been a significant change in the raw material resource or product mix. Direct this reassessment to the sampling matrix upon which the characteristic values are based.

13.1.1 Conduct significance tests on the test data to determine if the differences detected between the original and the reassessed data are significant.

13.1.2 If significant differences in matrix data are detected, repeat characteristic values, grouping, and allowable property derivation to determine whether changes in design properties result.

13.2 Reassessment of values derived from this practice shall include the following steps: *1*) definition of objectives, *2*) use of appropriate sampling procedures and sample size, *3*) selection and use of appropriate test methods, and *4*) application of suitable data analysis procedures (see Appendix X11).

ANNEX

(Mandatory Information)

A1. MOISTURE ADJUSTMENT PROCEDURE FOR DEVELOPMENT OF CHARACTERISTIC VALUES FOR MECHANICAL PROPERTIES OF LUMBER

A1.1 For development of characteristic values in this standard, adjust properties of all test data for moisture content to 15 % MC. It is recommended that the test specimens be conditioned as close to 15 % MC as possible, as the adjustments for moisture content decrease in accuracy with increasing change in moisture content. Adjustments of more than five percentage points of moisture content should be avoided. For this standard, adjustment equations are assumed valid for moisture content values between 10 and 23 % (assumed green value).

TABLE A1.1 Constants for Use inEq A1.2

Coefficients	MOR	UTS	UCS
B_1	2415	3150	1400
B_2	40	80	34

TABLE A1.2 Constants for Use in Eq A1.5

Coefficients	MOE
B_1	1.857
B_2	0.0237

A1.2 For modulus of rupture, MOR, ultimate tensile strength parallel to the grain, UTS, and ultimate compression strength parallel to the grain, UCS, adjustments shall be calculated from Eq A1.1 and Eq A1.2.

For MOR ≤ 2415 psi:
UTS ≤ 3150 psi:
UCS ≤ 1400 psi:

$$S_2 = S_1 \qquad \text{(A1.1)}$$

For MOR > 2415 psi:
UTS > 3150 psi:
UCS > 1400 psi:

$$S_2 = S_1 + \left\{\frac{(S_1 - B_1)}{(B_2 - M_1)}\right\}(M_1 - M_2) \qquad \text{(A1.2)}$$

where:

S_1 = property at Moisture Content 1, psi,
S_2 = property at Moisture Content 2, psi,
M_1 = Moisture Content 1, %,
M_2 = Moisture Content 2, %, and
B_1, B_2 = constants from Table A1.1.

A1.2.1 For species with substantially different properties than those used to create the models for adjusting strength properties for changes in moisture content, it may be advisable to "scale" property adjustments relative to those found in the Douglas-fir and Southern pine moisture studies from which the models were created. With this scaling, which is referred to as normalization, the properties of weaker species are first scaled up before entering the moisture adjustment procedure, then adjusted by the moisture adjustment procedure, followed by scaling down after adjustment by the same factor used initially. Scaling is done by adjusting the property going into the moisture adjustment procedures using the equation below:

$$S_1{*} = [(S_1 - C)(A/B)] + C \qquad \text{(A1.3)}$$

After S_1 * is adjusted to S_2 * using the moisture adjustment procedure, S_2 is rescaled as follows:

$$S_2 = [(S_2{*} - C)(B/A)] + C \qquad \text{(A1.4)}$$

A1.3 The procedure scales both the mean and spread of a new data set to match that found in the data of the moisture studies used to create the moisture models. *A* is a measure of center of the data used to create the models at some moisture level. For the moisture data used to create the models, *A* is a mean property of the 2 × 4 Select Structural lumber at 15 %. To use this type of normalization, the value of *B*, a mean property at 15 % moisture content for 2 × 4 Select Structural lumber of the species being adjusted, must be calculated. This requires adjustment of the data of the needed size-grade cell (2 × 4 Select Structural) to 15 % moisture content without normalization. The mean of this adjusted data is then used as the "normalizer" for all of the data for that species. Values of *A* and *C* for different strength properties where the models are affected by normalization are as follows:

Property	Values for *A*	Values for *C*
MOR	10 120.45	1 000.0
UTS	7 452.79	0.0
UCS	5 785.00	0.0

A1.4 Modulus of elasticity in bending, MOE, can be adjusted for changes in moisture content using Eq A1.5.

$$S_2 = S_1 \frac{(B_1 - (B_2 \times M_2))}{(B_1 - (B_2 \times M_1))} \qquad \text{(A1.5)}$$

where:

S_1 = property at Moisture Content 1, psi,
S_2 = property at Moisture Content 2, psi,
M_1 = Moisture Content 1, %
M_2 = Moisture Content 2, % and
B_1, B_2 = constants from Table A1.2.

APPENDIXES

(Nonmandatory Information)

X1. DIMENSIONAL CHANGES IN LUMBER WITH MOISTURE CONTENT

X1.1 Lumber shrinks and swells with changes in moisture content. The amount of change in the dimensions depends on a number of factors, such as species and ring angle. For dimension lumber, the dimensions at one moisture content can be estimated at a different moisture content with the following equation:

$$d_2 = d_1 \frac{1 - \dfrac{(a - bM_2)}{100}}{1 - \dfrac{(a - bM_1)}{100}} \qquad \text{(X1.1)}$$

where:

d_1 = dimension at Moisture Content M_1, in.,
d_2 = dimension at Moisture Content M_2, in.,
M_1 = moisture content at dimension d_1, %;
M_2 = moisture content at dimension d_2, %, and
a, b = variables taken from X1.2.

X1.2 The variables to be used with the shrinkage equation are as follows:

	Width		Thickness	
Species/variable	a	b	a	b
Redwood				
Western red cedar	3.454	0.157	2.816	0.128
Northern white cedar				
Other species	6.031	0.215	5.062	0.181

X1.3 The shrinkage equation given in X7.1 was developed from shrinkage equations recommended by Green (Ref **7**) in FPL-RP-489. The original equations for shrinkage as given in FPL-RP-489 which were developed for Douglas fir and Redwood are as follows:

Douglas fir

$$S_w = 6.031 - 0.215\,M \qquad \text{(X1.2)}$$
$$S_t = 5.062 - 0.181\,M$$

Redwood

$$S_w = 3.454 - 0.157\,M$$
$$S_t = 2.816 - 0.128\,M$$

where:

S_w = shrinkage in width, %,

S_t = shrinkage in thickness, %, and

M = moisture content, %.

NOTE X1.1—These equations were based on an assumed fiber saturation point of 28 % for Douglas fir and 22 % for Redwood.

X2. DEVELOPMENT OF AND RECOMMENDED LIMITS TO VOLUME ADJUSTMENT EQUATION

X2.1 Development of Volume Adjustment Equation

X2.1.1 The volume adjustment equation presented in 8.4.2 was developed primarily from the North American In-Grade testing database with substantial review of other related work. The original proposal was of the same form as the current depth effect formula in Practice D 245, but replaced the 1⁄9 exponent with an exponent developed from the In-Grade database.

X2.1.2 The form of the adjustment was modified to the current form to be consistent with recent research findings and current volumetric adjustment procedures adopted in other wood product lines. Because the database was not readily adaptable to analysis from a volumetric approach, it was necessary to develop the various exponents in a stepwise manner.

X2.1.3 To the present, there has been little research in lumber on the change in mechanical properties with thickness. In Canada the current design code permits a 10 % increase in bending stress for nominal four inch thick dimension lumber. This adjustment is based on a limited study of Douglas fir by Madsen. Due to the limited size of the study, and lack of other comparative studies, no recommendation could be made regarding property adjustment for thickness. However, available data from studies in the U.S. and Canada suggested a 10 % difference between nominal 2 in. and nominal 4 in. thick dimension lumber which was the basis for the adjustment in 12.3.1. The exponent for thickness adjustment was therefore set equal to 0 for MOR, UTS, UCS, and MOE providing an adjustment factor of 1, until further data is available.

X2.2 Length and Width Adjustment Factors

X2.2.1 The length effect adjustment was considered next. While the In-Grade data base was not readily adaptable to provide much guidance in selecting an appropriate exponent, there was substantial recent research on length effect in lumber and other related products. Most of the research has focused on length effects in ultimate tensile stress parallel to the grain. Analysis of the limited In-Grade data relating to length effect in tension indicated an exponent value of about 0.125. Analysis of work by Showalter et al. in FPL-RP-482 Ref (**8**) would indicate an exponent of about 0.14. This value was also indicated by as yet unpublished studies by Bender. Studies on length effect on lumber in Canada gave exponents in the range of 0.13 to 0.19. Madsen, Ref (**9**), in studies on length effect in bending indicated exponent values in the range of 0.17 to 0.25.

X2.2.2 Based on all of these studies an exponent of 0.14 was chosen for the length effect factor for MOR and UTS. Comparative analysis of studies conducted in the U.S. and Canada for UCS as part of the In-Grade program indicated that the exponent for length adjustment of UCS should be set equal to 0, providing an adjustment factor of one.

X2.2.3 Once the exponent for the length adjustment was chosen, the exponent for the width adjustment factor was determined from an analysis of the U.S. and Canadian In-Grade databases. The range in the value of the exponent was 0.21 to 0.35 for MOR and UTS depending on the population percentile selected. At the fifth percentile the exponents value was approximately 0.29. Analysis of the In-Grade compression parallel to grain data indicated that the exponent for width should be about 0.13 for use with the volume adjustment equation.

X2.3 Limits

X2.3.1 Defining the limits over which the volume adjustment equation is applicable is dependent on the range of data on which the equation is based and committee judgment. Because the range of data is not extensive, judgment and experience must be used. The following recommended limits of applicability are only a guideline, and should not be used without consideration for the database on which the volume adjustment model was developed.

X2.3.2 Adjustments generally tend to be more accurate for relatively small changes in volume. Caution must always be emphasized when adjusting for very large changes in volume. Caution should also be employed when using the adjustment equation with species other than those on which it was based.

X2.3.3 The database upon which the exponent for the width adjustment factor was based covered a range of widths from 3.5 to 9.5 in. Limited data from other studies indicate that the adjustment is probably applicable for widths from 2.5 to 12 in. This standard, however, limits the application of the width adjustment for setting allowable stresses to a range from 3.5 to 11.5 in. (12.2.2 and 12.2.3).

X2.3.4 The exponent for the length adjustment factor was based on a number of different studies as discussed above. These studies indicate that the adjustment factor would give acceptable results over a range of span to width ratios of approximately 6 to 30.

X3. EXAMPLE OF ALLOWABLE PROPERTY DEVELOPMENT

X3.1 Scope

X3.1.1 This example is intended to demonstrate the application of this standard to test data (See Fig. X3.1). The samples used are for demonstration only, and are not meant to be representative of any specific species. The grades used in this example are North American structural framing grades (see Note 2 and Note 3).

X3.2 Matrix Definition and Data Collection

X3.2.1 Assume that it was desired to form a new species grouping from four separate species with allowable properties developed for several sizes and grades of nominal 2 in. (1.5 in. actual) thick dimension lumber. To adequately sample this matrix required sampling from at least two grades and three sizes of each grade. For this example, the grading system used was developed from the stress ratio concepts of Practice D 245. Specific grade descriptions are given in Refs **(1, 2, 3,** and **4)**. The sampling matrix used consisted of Select Structural (65 % bending strength ratio) and No. 2 (45 % bending strength ratio) grades, of nominal 2 by 4 (1.5 by 3.5 in.), nominal 2 by 6 (1.5 by 5.5 in.), and nominal 2 by 8 (1.5 by 7.25 in.) widths. (See Fig. X3.2.)

X3.2.2 It was intended to sample a minimum of approximately 200 pieces representative of the entire parent population in each size-grade test cell for each of the four species. The sampling plan chosen required taking a minimum of 10 pieces in a size/grade/species cell at a sampling site to provide additional data on small production lots. The sampling plan and availability of material in specific sizes resulted in actual sample sizes both above and below the target size. The samples were tested at the sites of production under ambient conditions in accordance with Test Methods D 4761. Tests were conducted for modulus of elasticity and modulus of rupture only.

X3.3 Reporting of Test Data

X3.3.1 Summarized test data are shown for the four species in accordance with 5.1. The applicable data are given in Table X3.1.

X3.4 Adjustments to Input Data

X3.4.1 In order to develop characteristic values for the species grouping, it was necessary to bring all of the data to standardized conditions (8.3). For this example the standardized conditions were 73°F (23°C), 15 % moisture content, and 1.5 by 7.25 by 144 in. (38 by 184 by 3658 mm), nominal 2 by 8 by 12 ft. Moisture content was adjusted using the adjustment procedures in Annex A1. Dimensions were adjusted using the adjustment equation in 8.4.2.

X3.4.2 Once adjusted to standardized conditions, the mean, median and lower tolerance limit estimates for modulus of elasticity and the lower tolerance limit estimate for modulus of rupture were calculated for each individual species (Table X3.2) and the pooled data of the four species.

X3.5 Development of Characteristic Values

X3.5.1 *Grouping of Species*:

X3.5.1.1 A nonparametric analysis of variance (Appendix X3) as described in 10.2 was conducted for the median modulus of elasticity estimates (Table X3.3). The test was significant at the 0.01 level for both the Select Structural grade and the No. 2 grade. The Tukey multiple comparison test (Appendix X6) showed that all of the species medians were significantly different from each other for the Select Structural grade, and the highest two species medians were significantly different from the lowest two for the No. 2 grade (Table X3.4). The characteristic values for MOE for the group were then calculated as the median value of the lowest species (*D*) for the Select Structural grade, and the two lowest species (*D, B*) combined for the No. 2 grade.

X3.5.1.2 For the lower tolerance values (10.3), the percent of pieces below the pooled group value was determined for each property and grade of each species. The Chi square test (Appendix X2) was found to be significant at the 0.01 level for both Select Structural and No. 2 grades for modulus of rupture (MOR) (Table X3.5) and modulus of elasticity (MOE) (Table X3.5). The test was repeated using the two species with the highest percent of pieces less than the pooled group value. Again the Chi square test was significant at the 0.01 level for Select Structural MOE. The group tolerance limit for the Select Structural grade for MOE was, therefore, the tolerance limit of the single species (*D*) with the highest percent of low pieces.

X3.5.1.3 The same process was again repeated (adding the species with the next highest percentage of pieces below the group tolerance limit) for the other three grade/property groups. The No. 2 grade MOR, became significant with the addition of the third species to the groupings. The group tolerance limit for the No. 2 grade for MOR was therefore based on the two species with the highest percent of pieces below the pooled group tolerance limit (*B* and *D*). The Select Structural grade MOR and No. 2 grade MOE were still not significant at the 0.01 level after the third species was included. Since the Chi Square test for the Select Structural grade MOR and No. 2 grade MOE had been significant for all four species, the tolerance limit values for MOR for the Select Structural group and MOE for the No. 2 grade group were based on the three species (*B, C,* and *D*) with the highest percentage of pieces below the combined group tolerance limit. Table X3.5 shows the results of the Chi Square tests.

X3.5.1.4 After the grouping procedures of 10.2 and 10.3, an initial table of characteristic values was developed (Table X3.6). Before proceeding to the development of characteristic values for other grades or properties, the initial characteristic values had to be tested in accordance with 9.1.2.

X3.5.2 *Test Cell Data Check*—The test cell data check compared the cell estimates developed from the initial characteristic values using the adjustment equation in 8.4.3 (adjusting the estimates to the size and span actually tested) to the upper limit of the 75 % nonparametric confidence interval (UCI) calculated for each test cell. Confidence interval estimates were based on the combined data sets (9.3.2) of the controlling species as listed in Table X3.6. The characteristic values did