



Designation: D 1990 – 00^{€1}

Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens¹

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.

^{€1} NOTE—Equation A1.1 was corrected editorially in October 2000.

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 Wood²

D 198 Methods of Static Tests of Timbers in Structural Sizes²

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber²

D 1165 Nomenclature of Domestic Hardwoods and Softwoods²

¹ This practice is under the jurisdiction of ASTM Committee D-7 on Wood and is the direct responsibility of Subcommittee D7.02 on Lumber and Engineered Wood Products.

Current edition approved Apr. 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 Values²
- D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber²
- D 4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials²
- D 4444 Test Methods for Use and Calibration of Hand-Held Moisture Meters²
- D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material²
- IEEE-SI 10³
- 2.2 *American Softwood Lumber Standard:*
National Institute of Standards and Technology Voluntary Product Standard PS 20-94⁴

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 archival 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 $73 \pm 5^\circ\text{F}$ ($23 \pm 3^\circ\text{C}$). 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 $\pm 1/16$ in. (2 mm) in thickness and $\pm 1/4$ 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 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 the normal shrinking and swelling of lumber with changes in moisture content, as well as the changes in mechanical property values with



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

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

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 %.

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 in Eq 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.

$$\left. \begin{array}{l} \text{For MOR} \leq 2415 \text{ psi:} \\ \text{UTS} \leq 3150 \text{ psi:} \\ \text{UCS} \leq 1400 \text{ psi:} \end{array} \right\} S_2 = S_1 \quad (\text{A1.1})$$

$$\left. \begin{array}{l} \text{For MOR} > 2415 \text{ psi:} \\ \text{UTS} > 3150 \text{ psi:} \\ \text{UCS} > 1400 \text{ psi:} \end{array} \right\} S_2 = S_1 + \left\{ \frac{(S_1 - B_1)}{(B_2 - M_1)} \right\} (M_1 - M_2) \quad (\text{A1.2})$$

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:

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

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

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

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.

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

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:

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

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:

Species/variable	Width		Thickness	
	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

$$S_w = 6.031 - 0.215 M \quad (\text{X1.2})$$



Redwood

$$S_i = 5.062 - 0.181 M$$

$$S_w = 3.454 - 0.157 M$$

$$S_t = 2.816 - 0.128 M$$

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 $1/6$ 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

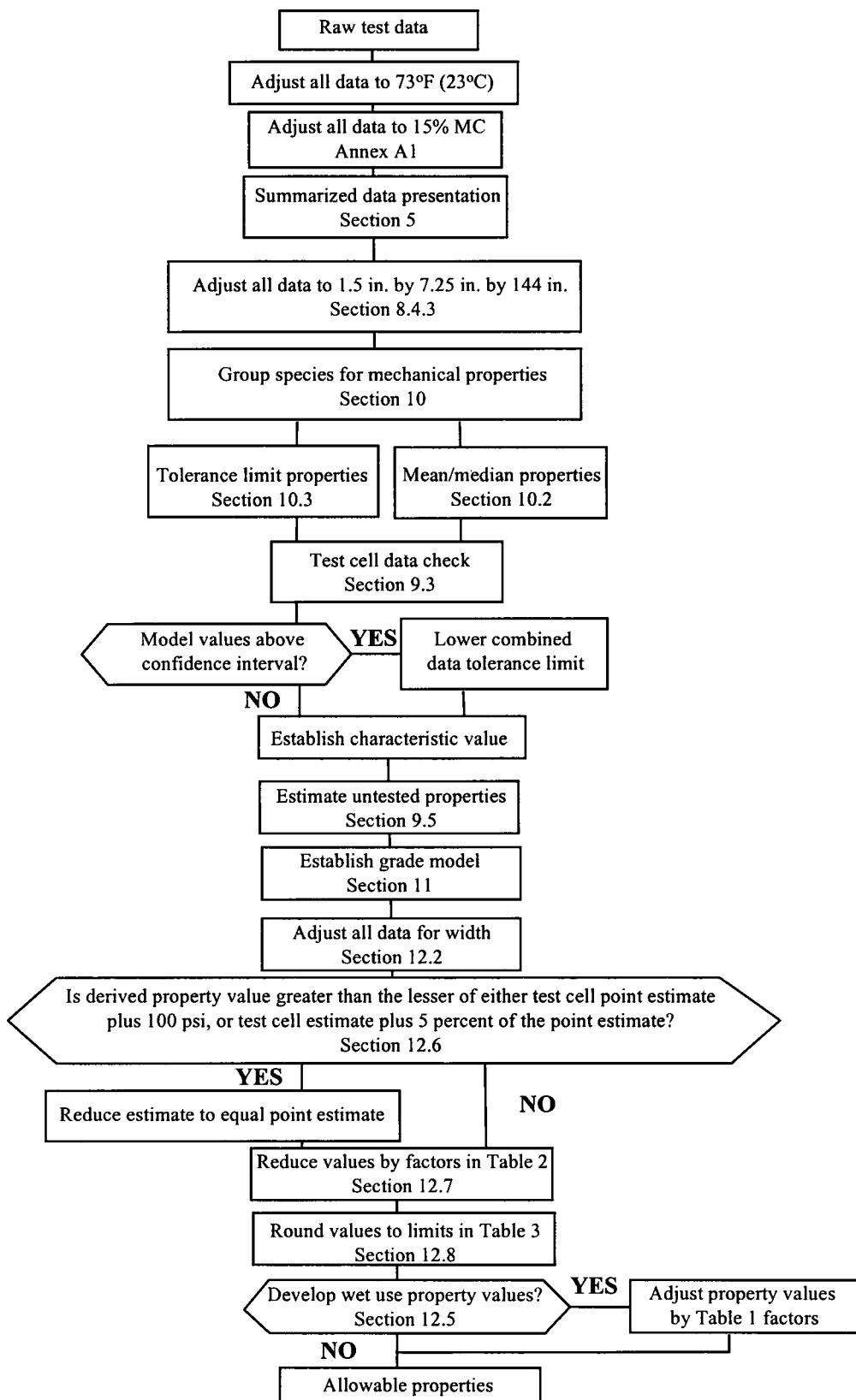
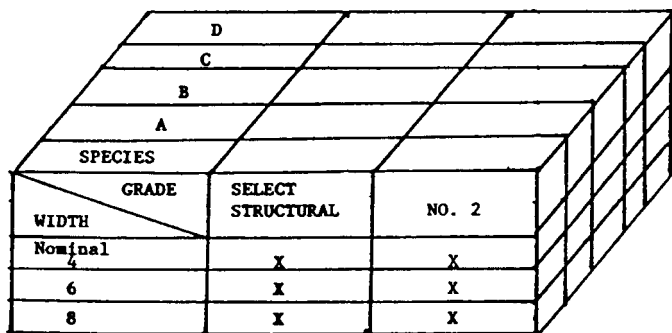


FIG. X3.1 Flow Diagram of Standard

not have to be lowered for any test cell. All of the model-generated estimates were less than the test cell upper confidence interval value.

X3.5.3 *Estimates for Untested Properties*—Once the group estimates for the characteristic values for median and tolerance limits for modulus of rupture and modulus of elasticity have



SPECIES	GRADE	SELECT STRUCTURAL	NO. 2
	Width		
	Nominal 4	X	X
	6	X	X
	8	X	X

FIG. X3.2 Example of Sampling Matrix

been determined and adjusted as needed with the test cell data check (9.3), estimates for ultimate tensile stress and ultimate compressive stress parallel to the grain were determined from the formulas in 9.5.2.

X3.5.4 Developing Grade Relationships—After the group characteristic values were established for the Select Structural (65 % strength ratio grade) and the No. 2 (45 % strength ratio grade) grades (Table X3.7 and Table X3.8), the grade model given in Section 11 as illustrated by Appendix X8 was used to estimate characteristic values for the other grades (Table X3.9).

X3.5.5 Establishing Allowable Properties—Once the characteristic values had been developed for each grade, the next step was to develop allowable properties for each cell of the size grade matrix desired. In this example, allowable properties were to be developed for three grades (Select Structural, No. 1, No. 2) and three widths (nominal 4, 6, 8 in.; actual 3.5, 5.5, 7.25 in.). To fill the desired matrix, the characteristic value estimates for each grade were adjusted for width using the equation in 8.4.3. Property estimates were determined at the

standardized length of 144 in. (3658 mm) at which the characteristic value was determined. The results are given in Table X3.10.

X3.5.6 Test Check of 12.6:

X3.5.6.1 These initial strength estimates had to be compared (in accordance with 12.6) with the non-parametric fifth percentile point estimate adjusted appropriately for temperature, moisture content and volume of the tested size/grade cells. The values for the test cells are given in Table X3.11. The test cell values were developed using the same species groupings used for the cell check in 9.3 (see X3.5.1).

X3.5.6.2 Based on the results, the strength property estimates for 2 × 8 No. 2 grade bending strength had to be lowered to the cell value of 1650 psi. The cell value was further adjusted for length from the test span of 17 times the width to 144 in., the length at the characteristic size. The resulting value is 1695 psi for No. 2. The estimates for tensile and compressive strength parallel to the grain also had to be recalculated using the new estimate. The new estimates are given in Table X3.12.

X3.5.7 Reduction and Rounding of Allowable Properties—The final steps consist of reducing and rounding the individual cell estimates in accordance with 12.7 and 12.8. The final rounded allowable properties (see 12.8) for the desired matrix are given in Table X3.13.

X3.5.8 Allowable Properties for Wet Use Conditions—It was also desired for this example to provide allowable properties for wet use. The properties in Table X3.14 list the property values of Table X3.13 adjusted in accordance with 12.5.2 and reduced (see 12.7) and rounded (see 12.8). Alternatively, the dry use properties prior to reduction and rounding may have been adjusted for wet use followed by reduction (see 12.7) and rounding (see 12.8).



TABLE X3.1 Test Cell Summary Data
(All data given at 15 % MC, 73°F, length as tested, MOE is in 10⁶ psi, MOR is in psi)

Property	Species and Size					
	A			B		
	2 × 4	2 × 6	2 × 8	2 × 4	2 × 6	2 × 8
<i>Select Structural:</i>						
Sample Size (N)	180	180	198	209	198	180
Mean MOE	1.477	1.440	1.382	1.226	1.215	1.203
Median MOE	1.480	1.455	1.381	1.202	1.215	1.198
5 Percentile MOE (PE)	1.166	1.012	0.953	0.942	0.940	0.904
5 Percentile MOE (TL)	1.163	0.985	0.919	0.936	0.931	0.892
75 % Confidence Interval						
upper limit	1.187	1.062	1.025	0.958	0.955	0.922
lower limit	1.152	0.938	0.913	0.925	0.906	0.873
Mean MOR	10 201	9100	7887	7355	6323	5858
Median MOR	10 276	9243	8024	7479	6370	6021
5 Percentile MOR (PE)	6473	5938	5189	4472	3816	3162
5 Percentile MOR (TL)	6302	5696	4988	4343	3430	3031
75 % Confidence Interval						
upper limit	6752	6148	5443	4922	4047	3492
lower limit	6125	5187	4792	4115	3373	2721
<i>No. 2 Grade:</i>						
Sample Size (N)	213	210	221	210	216	209
Mean MOE	1.173	1.173	1.156	0.964	0.931	1.109
Median MOE	1.158	1.145	1.146	0.974	0.913	1.108
5 Percentile MOE (PE)	0.894	0.877	0.840	0.629	0.724	0.727
5 Percentile MOE (TL)	0.881	0.858	0.829	0.584	0.709	0.690
75 % Confidence Interval						
upper limit	0.909	0.893	0.855	0.637	0.732	0.793
lower limit	0.879	0.827	0.813	0.565	0.707	0.682
Mean MOR	7390	5979	5540	5044	3578	4189
Median MOR	7294	5552	5370	4827	3035	3617
5 Percentile MOR (PE)	3250	3263	3274	2575	1919	1830
5 Percentile MOR (TL)	3113	3186	3181	2489	1868	1748
75 % Confidence Interval						
upper limit	3713	3506	3423	2807	1973	1901
lower limit	3026	3080	3149	2428	1842	1732

Property	Species and Size					
	C			D		
	2 × 4	2 × 6	2 × 8	2 × 4	2 × 6	2 × 8
<i>Select Structural:</i>						
Sample Size (N)	180	177	183	147	180	126
Mean MOE	1.353	1.318	1.365	1.095	1.172	1.230
Median MOE	1.315	1.301	1.351	1.058	1.173	1.240
5 Percentile MOE (PE)	0.981	0.804	0.995	0.794	0.884	0.842
5 Percentile MOE (TL)	0.977	0.775	0.989	0.744	0.871	0.781
75 % Confidence Interval						
upper limit	1.045	0.868	1.037	0.853	0.921	0.946
lower limit	0.950	0.755	0.928	0.738	0.851	0.644
Mean MOR	8891	6969	6844	7317	6653	6100
Median MOR	8822	6700	7012	7420	6491	6024
5 Percentile MOR (PE)	5575	3961	4038	4715	4098	3162
5 Percentile MOR (TL)	5217	3712	3847	4456	3740	2801
75 % Confidence Interval						
upper limit	5963	4145	4188	5068	4311	3519
lower limit	4390	3603	3679	4295	3577	2703
<i>No. 2 Grade:</i>						
Sample Size (N)	203	209	210	210	168	144
Mean MOE	0.970	1.081	1.020	0.998	0.919	0.998
Median MOE	0.950	1.063	0.982	1.022	0.890	0.976
5 Percentile MOE (PE)	0.700	0.716	0.730	0.680	0.636	0.709
5 Percentile MOE (TL)	0.695	0.699	0.725	0.636	0.632	0.686
75 % Confidence Interval						
upper limit	0.706	0.743	0.746	0.719	0.664	0.731
lower limit	0.680	0.691	0.671	0.606	0.617	0.677
Mean MOR	5336	4550	4090	5417	4753	4294
Median MOR	4926	4177	3751	5599	4756	4006
5 Percentile MOR (PE)	3155	2675	1741	2439	2133	1387
5 Percentile MOR (TL)	3011	2577	1722	2225	2076	1337
75 % Confidence Interval						
upper limit	3219	2787	1888	2784	2331	1521
lower limit	2946	2478	1702	2110	2015	1301



TABLE X3.2 Summarized Test Data for Four Species
(All data adjusted to 1.5 × 7.25 × 144 in. at 15 % MC 73°F, MOE is in 10⁶ psi, MOR is in psi)

Grade	Species ^A				
	A	B	C	D	All
<i>Select Structural:</i>					
Sample Size (N)	558	587	540	453	2138
Mean MOE	1.431	1.215	1.346	1.163	1.294
Median MOE	1.436	1.202	1.331	1.162	1.280
5 Percentile (TL)					
MOE	1.025	0.925	0.924	0.846	0.920
MOR	4759	3061	3573	3224	3506
Pieces Less Than Combined (TL)					
MOR Count	4	46	22	28	100
Sample, %	0.7	7.8	4.1	6.2	4.7
MOE Count	11	21	21	47	100
Sample, %	2.0	3.6	3.9	10.4	4.7
<i>No. 2:</i>					
Sample Size (N)	644	635	622	522	2423
Mean MOE	1.167	1.001	1.024	0.972	1.045
Median MOE	1.148	0.993	0.986	0.964	1.029
5 Percentile (TL)					
MOE	0.855	0.686	0.704	0.661	0.707
MOR	2774	1707	2028	1588	1860
Pieces Less Than Combined Tolerance Limit					
MOR Count	2	56	18	37	113
Sample, %	0.3	8.8	2.9	7.1	4.7
MOE Count	0	43	29	41	113
Sample, %	0	6.8	4.7	7.9	4.7

TABLE X3.3 Nonparametric Analysis of Variance

Source	Degrees of Freedom	Sums of Squares	Mean Square	F	Significance
<i>Select Structural:</i>					
Species	3	152 323 507.33	50 774 502.44	163.65	highly significant
Error	2134	662 081 518.92	310 253.76		
Total	2137	814 405 026.25			
<i>No. 2 Grade:</i>					
Species	3	133 877 314.36	44 625 771.45	102.66	highly significant
Error	2419	1 051 556 703.14	434 707.19		
Total	2422	1 185 434 017.50			



TABLE X3.4 Tukey Multiple Comparison

Species	Grade		Select Structural	
	A	B	C	D
Rank Mean,	1424.72	866.89	1198.22	741.05
n	558	587	540	453
Comparisons				
Species Pair	W		Actual Difference	
D B	108.38		125.84	
D C	110.41		457.17	
D A	109.60		683.67	
B C	103.33		331.33	
B A	102.46		557.83	
C A	104.61		226.50	
Test Result: D B C A				

Species	Grade		No. 2	
	A	B	C	D
Rank Mean,	1594.76	1087.75	1127.08	992.11
n	644	635	622	522
Comparisons				
Species Pair	W		Actual Difference	
D B	121.19		95.64	
D C	121.76		134.97	
D A	120.81		602.65	
B C	115.72		39.33	
B A	114.72		507.01	
C A	115.32		467.68	
Test Result: D B C A				

TABLE X3.5 Chi Square Test

Property	Group	Critical Value	Significance Level	Group Value	Result
MOR	Select Structural (all)	11.345	0.01	35.509	signif. at 0.01
	Select Structural (B, D)	6.635	0.01	1.060	not signif. at 0.01
	Select Structural (B, D, C)	7.378	0.01	6.989	not signif. at 0.01
	No. 2 (all)	11.345	0.01	63.389	signif. at 0.01
	No. 2 (B, D)	6.635	0.01	1.161	not signif. at 0.01
	No. 2 (B, D, C)	9.210	0.01	19.765	signif. at 0.01
MOE	Select Structural (all)	11.345	0.01	44.497	signif. at 0.01
	Select Structural (D, C)	6.635	0.01	16.248	signif. at 0.01
	No. 2 (all)	11.345	0.01	49.803	signif. at 0.01
	No. 2 (B, D)	6.635	0.01	0.499	not signif. at 0.01
	No. 2 (B, D, C)	9.210	0.01	5.154	not signif. at 0.01



TABLE X3.6 Initial Grouped Characteristic Values

Grade	Property ^A	Value Limiting Species
Select Structural	Median MOE 1.162	D
	Mean MOE 1.163	D
	MOE 5 percentile TL ^B 0.846	D
	MOR 5 percentile TL 3316.8	B, D, C
No. 2	Median MOE 0.983	D, B
	Mean MOE 0.988	D, B
	MOE 5 % TL 0.664	D, B, C
	MOR 5 % TL 1701.0	B, D

^A MOE is in 10⁶ psi; MOR is in psi.

^B TL—Tolerance Limit.

TABLE X3.7 Test Cell Data Check

NOTE 1—Combined data for limiting species.

MOR							
Grade	Size	Sample Size, N	Upper Confidence Interval Order Statistic	MOR Upper Confidence Interval	Characteristic Value	Model Predicted Value	Final Characteristic Value
Select Structural	2 × 4	536	33	4997	3317	4706	3317
	2 × 6	555	34	4047		3848	
	2 × 8	489	31	3627		3396	
No. 2	2 × 4	420	26	2756	1701	2413	1701
	2 × 6	384	24	2024		1973	
	2 × 8	353	22	1801		1742	
MOE							
Grade	Size	Sample Size, N	Upper Confidence Interval Order Statistic	MOE Upper Confidence Interval	Characteristic Value	Model Predicted Value	Final Characteristic Value
Select Structural	2 × 4	147	11	0.853	0.846	0.846	0.846
	2 × 6	180	13	0.921		0.846	
	2 × 8	126	10	0.946		0.846	
No. 2	2 × 4	623	38	0.691	0.664	0.664	0.664
	2 × 6	593	36	0.704		0.664	
	2 × 8	563	34	0.739		0.664	

TABLE X3.8 Estimated Property Characteristic Values

Property	Select Structural	No. 2
UTS (psi)	1492.6	765.4
UCS (psi)	2423.4	1818.9

TABLE X3.9 Group Characteristic Values Adjusted for Grade

Grade	GQI	Mean MOE 10 ⁶ psi	Median MOE, 10 ⁶ psi	5 percentile TL			Comparative GQI	5 percentile TL UCS, psi
				MOE 10 ⁶ psi	MOR, psi	UTS, psi		
Select Structural	65	1.163	1.162	0.846	3317	1493	78	2423
No. 1	55	1.075	1.072	0.755	2133	960	62	1986
No. 2	45	0.988	0.983	0.664	1701	765	49	1819



TABLE X3.10 Property Estimates for Species Group ABCD

NOTE 1—Length at characteristic size.

Grade	Size	Tolerance Limits				Mean MOE	Median MOE
		F _b	F _t	F _c	MOE		
Select Structural	2 × 4	4097	1844	2664	0.846	1.163	1.162
	2 × 6	3593	1617	2512	0.846	1.163	1.162
	2 × 8	3317	1493	2423	0.846	1.163	1.162
No. 1	2 × 4	2634	1185	2184	0.755	1.075	1.072
	2 × 6	2310	1040	2059	0.755	1.075	1.072
	2 × 8	2133	960	1986	0.755	1.075	1.072
No. 2	2 × 4	2101	945	1999	0.664	0.988	0.983
	2 × 6	1843	829	1885	0.664	0.988	0.983
	2 × 8	1701	765	1819	0.664	0.988	0.983

TABLE X3.11 Test Cell Data Check (See 12.6)

Grade	Size	Test Cell 5 Percentile PE MOR	Model Estimate	Controlling Value
Select Structural	2 × 4	4865	4631	model
	2 × 6	3948	3820	model
	2 × 8	3369	3390	model
No. 2	2 × 4	2557	2375	model
	2 × 6	1978	1959	model
	2 × 8	1650	1739	test cell

TABLE X3.12 Adjusted Property Estimates for Species Group ABCD

NOTE 1—Length at characteristic size.

Grade	Size	Tolerance Limits			MOE	Mean MOE	Median MOE
		MOR	UTS	UCS			
Select Structural	2 × 8	3317	1493	2423	0.846	1.163	1.162
No. 2	2 × 8	1695	763	1815	0.664	0.988	0.983

TABLE X3.13 Property Estimates for Species Group ABCD for Dry Use Conditions Reduced and Rounded

Grade	Size	Tolerance Limits				Mean MOE	Median MOE
		F _b	F _t	F _c	MOE		
Select Structural	2 × 4	1950	875	1400	0.8	1.2	1.2
	2 × 6	1700	775	1300	0.8	1.2	1.2
	2 × 8	1600	700	1300	0.8	1.2	1.2
No. 1	2 × 4	1250	575	1150	0.8	1.1	1.1
	2 × 6	1100	500	1100	0.8	1.1	1.1
	2 × 8	1000	450	1050	0.8	1.1	1.1
No. 2	2 × 4	1000	450	1050	0.7	1.0	1.0
	2 × 6	875	400	1000	0.7	1.0	1.0
	2 × 8	800	350	950	0.7	1.0	1.0



TABLE X3.14 Property Estimates for Species Group ABCD for Wet Use Conditions Rounded

Grade	Size	Tolerance Limits				Mean MOE	Median MOE
		F_b	F_t	F_c	MOE		
Select Structural	2 × 4	1650	875	1100	0.7	1.1	1.1
	2 × 6	1450	775	1050	0.7	1.1	1.1
	2 × 8	1350	700	1050	0.7	1.1	1.1
No. 1	2 × 4	1050	575	900	0.7	1.0	1.0
	2 × 6	1100	500	875	0.7	1.0	1.0
	2 × 8	1000	450	850	0.7	1.0	1.0
No. 2	2 × 4	1000	450	850	0.6	0.9	0.9
	2 × 6	875	400	800	0.6	0.9	0.9
	2 × 8	800	350	750	0.6	0.9	0.9

X4. DISCUSSION AND DERIVATION OF FORMULAS USED TO ESTIMATE UNTESTED PROPERTIES IN 9.5

DISCUSSION

The development of formulas to estimate untested properties was prompted by the need for multiple assigned properties even for small commercial volume species. The volume of some of these species is such that the expense of a full scale In-Grade type program would be hard to justify. If a way could be found to infer conservative estimates of some mechanical properties from test data of other properties, the amount of testing to establish property values for these types of species could be greatly reduced.

The U.S. Forest Products Laboratory in cooperation with the North American In-Grade Testing Technical Advisory Committee compiled data from a number of studies in addition to the large In-Grade database on Douglas fir (U.S., Canada, and DF South), Hem-Fir (U.S. and Canada), Southern Pine, and Canadian Spruce-Pine-Fir.

For each data set, either ratio of UTS/MOR or ratio of UCS/MOR was plotted against modulus of rupture (MOR). The data pairs of 2 × 8 lumber were plotted for several percentile levels (1, 5, 10, 25, 50, 75, and 90) from each data set. These plots are shown in Figs. X4.1 and X4.2.

The North American In-Grade Technical Advisory Commit-

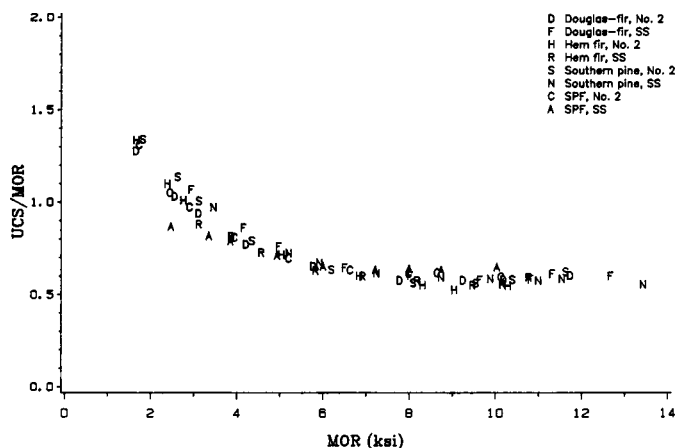


FIG. X4.2 A Plot of UCS/MOR Ratios Against MOR at 15% Moisture Content

tee originally recommended (based on Fig. X4.1) setting the estimates for near minimum ultimate tensile stress at 0.5 times the near minimum MOR. The factor was changed to 0.45 for inclusion in this practice. The factor for estimating near minimum MOR from near minimum UTS was set at 1.2 times UTS by taking the inverse of the near maximum ratio (0.83) from Fig. X4.1.

The relationship between ultimate compressive stress (UCS) and MOR tends to be more consistent than for UTS/MOR. The North American In-Grade Testing Technical Advisory Committee originally recommended using 0.7 times the near minimum MOR for grades with a minimum strength ratio of 65% or greater, and 1.0 times MOR for a 45% strength ratio grade. Because the relationship between MOR and UCS was so consistent, a quadratic equation was fit to the data for inclusion into this standard in 9.5.2.2. A quadratic equation was also fit to the data for the UCS/UTS relationship.

Analysis of the data sets also indicated that UCS was not acceptable as a predictor for conservative estimation of either MOR or UTS and therefore was excluded in this standard.

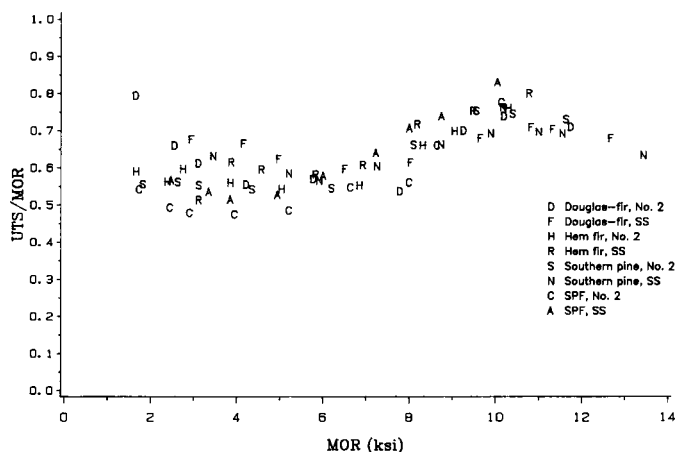


FIG. X4.1 A Plot of UTS/MOR Ratios Against MOR at 15% Moisture Content



X5. NONPARAMETRIC ANALYSIS OF VARIANCE (Ref 10)

X5.1 For a one-way nonparametric analysis of variance to test the equality of the medians of k independent random samples, simply replace the data with their ranks and then apply the usual parametric analysis of variance to the ranks. Thus, given k groups that we want to test equality of medians, we rank all the data from smallest observation to largest as shown in the following example:

Group:	Original Group Data			Ranked Group Data		
	A	B	C	A	B	C
	1.4	1.1	2.2	9	3	12
	1.3	1.2	1.8	7.5	5	11
	1.2	1.2	1.5	5	5	10

1.0	...	1.3	2	...	7.5
...	...	0.9	1

Note that the ranking is for all data with average ranks being assigned for ties. The usual parametric F test of the hypothesis of equal means, when applied to the ranked data, is equivalent to the traditional nonparametric Kruskal-Wallis test.

X5.2 Any of the popular multiple comparison procedures, including Tukey's (Appendix X6), can be applied to the ranked data in the same manner as done in the parametric case.

X6. TUKEY MULTIPLE COMPARISON

X6.1 After an analysis of variance (ANOVA) has rejected the hypothesis that the means from p treatments are equal, the Tukey multiple comparison procedure can be used to determine which means are different. To run this test where each of the treatments has the same sample size n , calculate as follows:

$$W = q_e(p, f_e) S_w \sqrt{1/n} \tag{X6.1}$$

where:

$q_e(p, f_e)$ = the upper percent point of the studentized range given in the table below. To enter the table, p is the number of treatments and f is the error degrees of freedom in the ANOVA that rejected the equality of the means. The table gives critical values for tests at both the 0.05 and 0.01 level.

S_w = $\sqrt{\text{error means square (EMS) from the ANOVA}}$, and

n = sample size of treatments

The Tukey test is run then by comparing all paired combinations of means. Any two means more than W apart are significantly different.

X6.2 For unequal sample sizes, to compare the i th treatment mean and the j th treatments mean, substitute:

$$n_{ij} = \frac{2}{((1/n_i) + (1/n_j))} \tag{X6.2}$$

where:

n_i = the number of replications in the i th treatment and

n_j = the number of replications in the j th treatment.

Then proceed as before by calculating a separate W value for every two means compared and comparing the difference in the means to the appropriate W value.

X6.3 Note that a reasonable approximation that reduces the number of calculations is to replace n with the harmonic mean as follows:

$$n_h = \frac{P}{(1/n_1) + (1/n_2) + \dots + (1/n_p)} \tag{X6.3}$$

This approximation works quite well when the sample sizes are nearly equal. Care should be taken if the sample sizes are greatly different to use the n_{ij} value instead of n_h .



TABLE X6.1 Upper Percentage Points of the Studentized Range

NOTE 1—Adapted from *Principles and Procedures of Statistics*, 2nd ed., R. Steel, J. Torrie, McGraw-Hill, 1980.

$$q_\alpha = (\bar{Y}_{\max} - \bar{Y}_{\min})/S_y$$

Error df	α	$p = \text{number of}$									
		2	3	4	5	6	7	8	9	10	11
5	0.05	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99	7.17
	0.01	5.70	6.97	7.80	8.42	8.91	9.32	9.67	9.97	10.24	10.48
6	0.05	3.46	4.34	4.90	5.31	5.63	5.89	6.12	6.32	6.49	6.65
	0.01	5.24	6.33	7.03	7.56	7.97	8.32	8.61	8.87	9.10	9.30
7	0.05	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16	6.30
	0.01	4.95	5.92	6.54	7.01	7.37	7.68	7.94	8.17	8.37	8.55
8	0.05	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92	6.05
	0.01	4.74	5.63	6.20	6.63	6.96	7.24	7.47	7.68	7.87	8.03
9	0.05	3.20	3.95	4.42	4.76	5.02	5.24	5.43	5.60	5.74	5.87
	0.01	4.60	5.43	5.96	6.35	6.66	6.91	7.13	7.32	7.49	7.65
10	0.05	3.15	3.88	4.33	4.65	4.91	5.12	5.30	5.46	5.60	5.72
	0.01	4.48	5.27	5.77	6.14	6.43	6.67	6.87	7.05	7.21	7.36
11	0.05	3.11	3.82	4.26	4.57	4.82	5.03	5.20	5.35	5.49	5.61
	0.01	4.39	5.14	5.62	5.97	6.25	6.48	6.67	6.84	6.99	7.13
12	0.05	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.40	5.51
	0.01	4.32	5.04	5.50	5.84	6.10	6.32	6.51	6.67	6.81	6.94
13	0.05	3.06	3.73	4.15	4.45	4.69	4.88	5.05	5.19	5.32	5.43
	0.01	4.26	4.96	5.40	5.73	5.98	6.19	6.37	6.53	6.67	6.79
14	0.05	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36
	0.01	4.21	4.89	5.32	5.63	5.88	6.08	6.26	6.41	6.54	6.66
15	0.05	3.01	3.67	4.08	4.37	4.60	4.78	4.94	5.08	5.20	5.31
	0.01	4.17	4.83	5.25	5.56	5.80	5.99	6.16	6.31	6.44	6.55
16	0.05	3.00	3.65	4.05	4.33	4.56	4.74	4.90	5.03	5.15	5.26
	0.01	4.13	4.78	5.19	5.49	5.72	5.92	6.08	6.22	6.35	6.46
17	0.05	2.98	3.63	4.02	4.30	4.52	4.71	4.86	4.99	5.11	5.21
	0.01	4.10	4.74	5.14	5.43	5.66	5.85	6.01	6.15	6.27	6.38
18	0.05	2.97	3.61	4.00	4.28	4.49	4.67	4.82	4.96	5.07	5.17
	0.01	4.07	4.70	5.09	5.38	5.60	5.79	5.94	6.08	6.20	6.31
19	0.05	2.96	3.59	3.98	4.25	4.47	4.65	4.79	4.92	5.04	5.14
	0.01	4.05	4.67	5.05	5.33	5.55	5.73	5.89	6.02	6.14	6.25
20	0.05	2.95	3.58	3.96	4.23	4.45	4.62	4.77	4.90	5.01	5.11
	0.01	4.02	4.64	5.02	5.29	5.51	5.69	5.84	5.97	6.09	6.19
24	0.05	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92	5.01
	0.01	3.96	4.54	4.91	5.17	5.37	5.54	5.69	5.81	5.92	6.02
30	0.05	2.89	3.49	3.84	4.10	4.30	4.46	4.60	4.72	4.83	4.92
	0.01	3.89	4.45	4.80	5.05	5.24	5.40	5.54	5.65	5.76	5.85
40	0.05	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.74	4.82
	0.01	3.82	4.37	4.70	4.93	5.11	5.27	5.39	5.50	5.60	5.69
60	0.05	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65	4.73
	0.01	3.76	4.28	4.60	4.82	4.99	5.13	5.25	5.36	5.45	5.53
120	0.05	2.80	3.36	3.69	3.92	4.10	4.24	4.36	4.48	4.56	4.64
	0.01	3.70	4.20	4.50	4.71	4.87	5.01	5.12	5.21	5.30	5.38
∞	0.05	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55
	0.01	3.64	4.12	4.40	4.60	4.76	4.88	4.99	5.08	5.16	5.23

X7. CHI-SQUARE TEST

X7.1 The Chi-Square test statistic is calculated as:

$$X^2 = \left\{ \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}} \right\} \quad (X7.1)$$

where the summation is across all the cells where data is to be compared.

X7.2 When data is classified into a table with r rows and c columns, called an r by c contingency table, the formula is written as follows:

$$X^2 = \left\{ \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \right\} \quad (X7.2)$$

where:

O_{ij} = actual number of observations in the cell in the i th row and the j th column.

E_{ij} = expected number of observations in the cell in the i th row and the j th column.

X7.3 To calculate the expected value in a cell, first calculate row and column totals as shown:

Row	1	2	3	...	c	Totals
1	n_{11}	n_{12}	n_{13}	...	n_{1c}	$n_{1.}$
2	n_{21}	n_{22}	n_{23}	...	n_{2c}	$n_{2.}$
3	n_{31}	n_{32}	n_{33}	...	n_{3c}	$n_{3.}$
•	•	•	•	...	•	•
•	•	•	•	...	•	•
•	•	•	•	...	•	•
r	n_{r1}	n_{r2}	n_{r3}	...	n_{rc}	$n_{r.}$
Totals	$n_{.1}$	$n_{.2}$	$n_{.3}$...	$n_{.c}$	$n_{..}$



TABLE X7.1 Critical Values of Chi-Square Test

NOTE 1—From “Tables of the Percentage Points of the χ^2 -Distribution.” *Biometrika*, Vol 32 (1941), pp. 188–189, by Catherine M. Thompson.

d.f.	$\chi^2_{0.100}$	$\chi^2_{0.050}$	$\chi^2_{0.025}$	$\chi^2_{0.010}$	$\chi^2_{0.005}$	d.f.
1	2.70554	3.84146	5.02389	6.63490	7.87944	1
2	4.60517	5.99147	7.37776	9.21034	10.5966	2
3	6.25139	7.81473	9.34840	11.3449	12.8381	3
4	7.77944	9.48773	11.1433	13.2767	14.8602	4
5	9.23635	11.0705	12.8325	15.0863	16.7496	5
6	10.6446	12.5916	14.4494	16.8119	18.5476	6
7	12.0170	14.0671	16.0128	18.4753	20.2777	7
8	13.3616	15.5073	17.5346	20.0902	21.9550	8
9	14.6837	16.9190	19.0228	21.6660	23.5893	9
10	15.9671	18.3070	20.4831	23.2093	25.1882	10
11	17.2750	19.6751	21.9200	24.7250	26.7569	11
12	18.5494	21.0261	23.3367	26.2170	28.2995	12
13	19.8119	22.3621	24.7356	27.6883	29.8194	13
14	21.0642	23.6848	26.1190	29.1413	31.3193	14
15	22.3072	24.9958	27.4884	30.5779	32.8013	15
16	23.5418	26.2962	28.8454	31.9999	34.2672	16
17	24.7690	27.5871	30.1910	33.4087	35.7185	17
18	25.9894	28.8693	31.5264	34.8053	37.1564	18
19	27.2036	30.1435	32.8523	36.1906	38.5822	19
20	28.4120	31.4104	34.1696	37.5662	39.9968	20
21	29.6151	32.6705	35.4789	38.9321	41.4010	21
22	30.8133	33.9244	36.7807	40.2894	42.7956	22
23	32.0069	35.1725	38.0757	41.6384	44.1813	23
24	33.1963	36.4151	39.3641	42.9798	45.5585	24
25	34.3816	37.6525	40.6465	44.3141	46.9278	25
26	35.5631	38.8852	41.9232	45.6417	48.2899	26
27	36.7412	40.1133	43.1944	46.9630	49.6449	27
28	37.9159	41.3372	44.4607	48.2782	50.9933	28
29	39.0675	42.5569	45.7222	49.5879	52.3356	29
30	40.2560	43.7729	46.9792	50.8922	53.6720	30
40	51.8050	55.7585	59.3417	63.6907	66.7659	40
50	63.1671	67.5048	71.4202	76.1539	79.4900	50
60	74.3970	79.0819	83.2976	88.3794	91.9517	60
70	85.5271	90.5312	95.0231	100.425	104.215	70
80	96.5782	101.879	106.629	112.329	116.321	80
90	107.565	113.145	118.136	124.116	128.299	90
100	118.496	124.342	129.561	135.807	140.169	100

subscript means we have summed over that subscript. Thus $n_{1.}$ is the sum of the number of observations in the first row. Using this notation, the expected number of observations for use in the Chi-Square test is as follows:

$$E_{ij} = \frac{n_{i.} \times n_{.j}}{n_{..}} \tag{X7.3}$$

X7.3.2 When used in the Chi-Square formula in X7.3.1, the resulting statistic will have $(r - 1)(c - 1)$ degrees of freedom. The null hypothesis that the percentage of observations in each row is the same for each column is rejected if the Chi-Square statistic is greater than the critical value from the Table X7.1.

X7.3.1 In the notation of the table, n_{ij} is the number of observations in the i th row and j th column. A period as a



X8. EXAMPLE OF GRADE MODEL APPLICATION

INTRODUCTION

In order to provide for uniform application and interpretation of the grade model developed for the North American In-Grade Test Program, the U.S.-Canadian In-Grade Technical Advisory Committee has adopted these guidelines. It is important to point out that the intent of the grade model is to provide conservative estimates of properties for visual structural grades for a species or species group. While it is possible to claim the actual data cell value for any test cell through the use of Practice D 2915, it is also very desirable to provide designers and engineers with values which reflect a logical relationship between grade description and assigned property values. Assigning property values directly from the test results would not provide this systematic relationship between grades. The inherent variability of sampling and testing would create aberrations in the trends between grades.

The In-Grade testing technical advisory committee, therefore, recommended that the assigned property values for all grades be generated from the grade model. This grade model was based on large data sets of Select Structural and No. 2 grade material sampled to represent the entire production range and geographic area of the species or species group. A basic assumption of this model is that the Select Structural and No. 2 grade samples selected and tested are representative of the population being evaluated. Every effort should be made to ensure the validity of this assumption. The model's application to other types of testing programs may or may not be appropriate. A review and reassessment of the species or species group values derived from this model should be conducted whenever there is cause to believe that there has been a significant change in the raw material resource.

X8.1 Establishing the Grade Model

X8.1.1 The grade model for the In-Grade testing program was anchored with the test data from the Select Structural (SS) and No. 2 grade material of all widths (of 2 in. nominal thickness) tested. An outline of the process to anchor the model is listed in Fig. X8.1.

X8.1.2 All of the raw data was first adjusted to 15 % moisture content at 73°F (23°C) using the appropriate adjustment models developed for the In-Grade test program. The data was then adjusted with the volume adjustment model developed for the In-Grade test program to a nominal 2 by 8 (actual 1.5 by 7.25 inches) cross section and 144 in. length, then grouped in accordance with the species grouping procedures, if needed, and reduced as required by the test cell data check. For the adjusted data sets, the estimate to be used for design for each property, modulus of rupture (MOR), modulus of elasticity (MOE), ultimate tensile stress parallel to grain (UTS), and ultimate compressive stress parallel to grain (UCS), was determined from the combined adjusted data for both the select structural and No. 2 grades. These values defined the anchor points of the grade model.

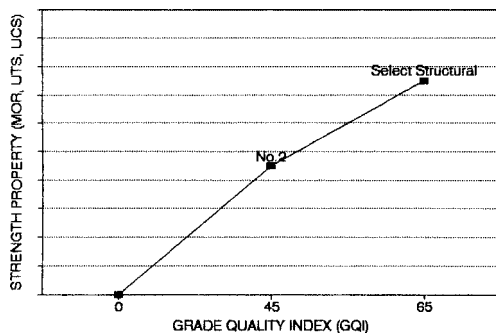
X8.1.3 To complete the model, the appropriate estimate of the property values was plotted against the corresponding grade minimum strength ratio. The remainder of the model was

constructed by drawing two straight lines. One of the straight lines was drawn connecting the Select Structural and No. 2 data points. Then for the lower quantile estimates (except MOE), the second straight line was drawn connecting the No. 2 data point and the origin (see Note). For the MOE model, the second line was drawn from the No. 2 data point to the ordinate passing through a point equal to 80 % of the No. 2 value at a strength ratio of 9 %. This completed the grade model for each of the properties.

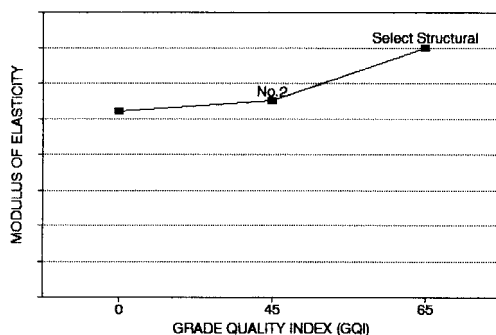
NOTE X8.1—In addition to the Select Structural and No. 2 grades, smaller samples (approximately 120 to 150 pieces) of Construction, Standard, and Utility grades were also tested. The additional data provided the necessary supporting evidence that the extrapolation procedure used was conservative.

X8.2 Application of the Grade Model

X8.2.1 Property estimates for all grades below No. 2 are estimated as the model predicted value at the grade minimum strength ratio (as listed in the grading rules). See Fig. X8.2. For No. 1 grade, the limited data available indicated that for bending and tension only 85 % of the value determined from linear interpolation should be used in order to provide conservative estimates. For compression parallel to grain, 95 % of the value determined from linear interpolation should be used.



(a) Strength Property Grade Model



(b) Modulus of Elasticity Grade Model

Calculation Procedure:

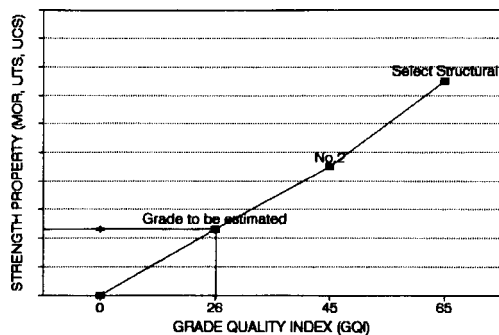
- (1) Adjust all data of a single grade to 15 % moisture content with the procedures of Annex A1. Adjust all data to the characteristic size (1.5 × 7.25 × 144 in.) with the procedures of 8.4.3.
- (2) Determine property estimates (5 % tolerance limit with 75 % confidence) for each grade (Select Structure and No.2).
- (3) Determine minimum grade strength ratio (Select Structural = 65 %, No. 2 = 45 %).
- (4) Plot pair values from (2) and (3).
- (5) Draw straight line between points for Select Structural and No. 2.
- (6a) Draw straight line between No. 2 and origin for MOR, UTS, UCS.
- (6b) Draw straight line between No. 2 and ordinate passing through a point equal to 80 % of No. 2 value at strength ratio of 9 % for MOE.

FIG. X8.1 Grade Model Development for Any Species or Species Group

X9. DISCUSSION OF GROUPING BY OTHER APPROPRIATE TECHNICAL CRITERIA

X9.1 The grouping procedures in Section 10 provide a method of obtaining design values for a grouping of species or species groups when each has been sampled and evaluated individually in accordance with the procedure of this practice. These grouping criteria are not intended to prohibit the sampling of a proposed species group as if it were an individual species, which was the procedure followed for the “major” species groups sampled in the In-Grade program in the United

States and Canada. Thus, the same technical criteria used in establishing these “major” species groups, which include those found in Test Methods D 2555, are available for the formation of new species groups. In this context, proposed species groups which do not exceed the variability permitted in the “major” species groupings should be considered as a single species grouping for sampling and analysis purposes in this practice.



Calculation Procedure:

- (1) Determine minimum strength ratio for the grade from grade description and Practice D 245.
- (2) Project from abscissa at strength ratio to intersection with model.
- (3) Determine property estimate at intersection point.

NOTE 1—For bending and tension of No. 1 grade, use 0.85 of value between Select Structural and No. 2. For compression parallel to grain, use 0.95 of value.

FIG. X8.2 Strength Property Grade Model

X10. COMPARISON OF LUMBER DESIGN CAPACITIES AT VARIOUS MOISTURE CONTENTS

X10.1 The factors in Table 1 are based on the change in capacities of lumber with moisture content relative to a 15 % MC base. The factors selected provide acceptable estimates in the range of property values normally assigned for lumber design. Changes in property values with moisture content were

calculated using the adjustment procedure in Annex A1. Dimensional changes were calculated using the shrinkage formulas given in Appendix X1. Table X10.1 lists the relative changes in allowable properties, dimensions, and capacities at three moisture contents and several property levels.



TABLE X10.1 Relative Design Capacity of Lumber at Three Moisture Contents

NOTE 1—The values shown were calculated by multiplying the property value at 15 % MC by the appropriate factor in Table 2, then adjusting for moisture change. The new property estimate was then reduced by dividing by the appropriate factor from Table 2.

Property	Value at 15 % MC	Ratio of Property to Property at 15 % MC			Comparative Section	Ratio of Dimensions to Dimensions at 15 % MC			Ratio of Capacity to Capacity at 15 % MC		
		10 % MC	12 % MC	23 % MC		10 % MC	12 % MC	23 % MC	10 % MC	12 % MC	23 % MC
F_b	1000	1.00	1.00	1.00	Section modulus (Z)	0.978	0.987	1.036	0.978	0.987	1.036
	2000	1.085	1.051	0.864		0.978	0.987	1.036	1.061	1.037	0.895
	3000	1.123	1.074	0.803		0.978	0.987	1.036	1.099	1.060	0.831
	4000	1.143	1.086	0.772		0.978	0.987	1.036	1.117	1.071	0.800
	5000	1.154	1.092	0.754		0.978	0.987	1.036	1.129	1.078	0.781
F_t	500	1.00	1.00	1.00	Area (A)	0.979	0.988	1.033	0.979	0.988	1.033
	1000	1.00	1.00	1.00		0.979	0.988	1.033	0.979	0.988	1.033
	1500	1.00	1.00	1.00		0.979	0.988	1.033	0.979	0.988	1.033
	2000	1.019	1.012	0.969		0.979	0.988	1.033	0.998	0.999	1.002
	2500	1.031	1.018	0.951		0.979	0.988	1.033	1.010	1.006	0.983
	3000	1.038	1.023	0.938		0.979	0.988	1.033	1.017	1.010	0.970
	3500	1.044	1.026	0.930		0.979	0.988	1.033	1.023	1.014	0.961
	4000	1.048	1.029	0.923		0.979	0.988	1.033	1.027	1.016	0.954
F_c	500	1.00	1.00	1.00	Area (A)	0.979	0.988	1.033	0.979	0.988	1.033
	1000	1.069	1.042	0.889		0.979	0.988	1.033	1.047	1.029	0.919
	1500	1.134	1.080	0.786		0.979	0.988	1.033	1.111	1.067	0.812
	2000	1.166	1.100	0.734		0.979	0.988	1.033	1.142	1.086	0.759
	2500	1.186	1.111	0.703		0.979	0.988	1.033	1.161	1.098	0.727
	3000	1.179	1.119	0.682		0.979	0.988	1.033	1.174	1.105	0.705
	4000	1.215	1.129	0.657		0.979	0.988	1.033	1.190	1.115	0.678
MOE	0.5	1.079	1.047	0.874	Moment of Inertia (I)	0.967	0.980	1.054	1.044	1.027	0.921
	1.0	1.079	1.047	0.874		0.967	0.980	1.054	1.044	1.027	0.921
	1.5	1.079	1.047	0.874		0.967	0.980	1.054	1.044	1.027	0.921
	2.0	1.079	1.047	0.874		0.967	0.980	1.054	1.044	1.027	0.921
	2.5	1.079	1.047	0.874		0.967	0.980	1.054	1.044	1.027	0.921

X11. GUIDELINES FOR REASSESSMENT OF LUMBER PROPERTY VALUES DERIVED ACCORDING TO D 1990

X11.1 Scope—This appendix provides guidelines for reassessment of lumber property values that have been derived using this standard. Initiation of a reassessment procedure is possible whenever there is a desire to evaluate the appropriateness of existing property values. Reassessment is initiated, in accordance with 13.1, when there is sufficient reason to believe that a significant (statistical and practical) global change in lumber property values has occurred (such as resulting from periodic property monitoring, developed and conducted by the rules writing agency).

X11.2 Define Objectives:

X11.2.1 Clearly define the objectives prior to proceeding with reassessment since decisions regarding sampling, testing, data collection and analysis are all dependent upon the objective.

X11.2.2 There are numerous potential objectives when reassessing lumber property values. Some examples of objectives are:

X11.2.2.1 Changes in values for a single size or grade, or a combination of sizes and grades,

X11.2.2.2 Modifications in one species or in a species grouping,

X11.2.2.3 Reevaluation of the grade model used in lumber property development, and

X11.2.2.4 Changes to grade groupings.

X11.2.3 Two distinct examples of testing and analysis objectives are substantiation of current values and verification of changes in values.

X11.3 Sampling Procedures and Sample Size—This standard as well as other consensus standards such as Practice D 2915, provide information regarding sampling procedures and sample size appropriate to meet the intended objective. Exercise caution to ensure that the sample is representative of the grade sampled and adequate to achieve the objective. Decide on the objective of the reassessment cognizant of the practical restraints incurred due to availability of resources. Describe and document all procedures. Sampling procedures anticipate the analysis to be conducted (see X11.6).

X11.4 Test Methods:

X11.4.1 Conduct all tests for property reassessment in accordance with consensus standards if available. Document all procedures.

X11.4.2 The objective of the reassessment and practical restraints due to resource availability are essential factors in



determining the data that will be collected. Consensus standards identify minimum data requirements.

X11.5 Analysis:

X11.5.1 In addition to information provided in this standard, refer to Practice D 2915 for guidance regarding analytical and statistical methods.

X11.5.2 *Identifying Changes*—When the objective is to identify if a change has occurred, the basic null hypothesis is that no change has occurred. Testing this null hypothesis requires identifying a significant difference and developing confidence statements.

X11.5.3 *Identifying the Magnitude of a Change*—If the magnitude of change is to be identified, larger sample sizes than those required in X11.6.2 are often necessary.

X11.6 Decision Sequence for Implementation:

X11.6.1 The decision sequence emphasizes the practical aspect of implementation. Statistically significant changes occasionally have no practical significance. Conduct statistical decisions first, followed by practical analysis as a second step.

X11.6.2 Decisions required prior to implementation of testing are:

X11.6.2.1 Determine the reassessment objective,

X11.6.2.2 Review available data to evaluate its adequacy to meet the objective,

X11.6.2.3 Decide if additional data are required,

X11.6.2.4 If additional data are required, determine what data are adequate to meet the objective,

X11.6.2.5 *Methodology*—Choose an appropriate consensus standard,

X11.6.2.6 *Sample*—Select size, type, and distribution required,

X11.6.2.7 Establish required program sensitivity to detect a significant difference from previous findings, and

X11.6.2.8 Establish a decision tree and appropriate actions to follow for all possible outcomes of the reassessment.

X11.6.3 Decisions required following analysis of reassessment data are:

X11.6.3.1 Determine if a significant difference as defined in X11.6.2.7 is present,

X11.6.3.2 If the identified difference is significant, conduct appropriate practical significance tests,

X11.6.3.3 Evaluate if changes in assigned design values are appropriate, and

X11.6.3.4 Determine whether further reassessment is required to confirm current findings.

REFERENCES

- (1) National Lumber Grades Authority, *Standard Grading Rules for Canadian Lumber*, National Lumber Grades Authority, Burnaby, British Columbia, Canada, 1996.
- (2) Southern Pine Inspection Bureau, *Standard Grading Rules*, Southern Pine Inspection Bureau, Pensacola, Florida, 1994.
- (3) West Coast Lumber Inspection Bureau, *Standard Grading Rules for West Coast Lumber No. 17*, West Coast Lumber Inspection Bureau, Portland, Oregon, 1991 Revised 1996.
- (4) Western Wood Products Association, *Standard Grading Rules for Western Lumber*, Western Wood Products Association, Portland, Oregon, 1995.
- (5) Steel, R., and J. Torrie, *Principles and Procedures of Statistics*, Second Ed., McGraw-Hill, 1980.
- (6) Cochran, W. G., "Some Methods for Strengthening the Common Chi-Square Test," *Biometrics*, 10:417–451, 1954.
- (7) Green, D. W., "Moisture Content And The Shrinkage of Lumber," *FPL-RP-489*, USDA Forest Products Laboratory, 1989.
- (8) Showalter K. L., Woeste, F. E., Bendtsen, B. A., Effect of Length on Tensile Strength in Structural Lumber, FPL-RP-482, Madison, WI, U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 1987.
- (9) Madsen, B. and Neilsen, P. C., In-grade testing; Size investigations on lumber subjected to bending, Res. Ser. Rept. No. 15, Dept. of Civil Eng., Univ. of British Columbia, Vancouver, B.C., Canada.
- (10) Conover, W. J., and Iman, Ronald L., "Rank Transformations as a Bridge Between Parametric and Nonparametric Statistics", *The American Statistician*, Vol 35, No. 3, pp. 124–129, 1981.
- (11) Devore, J. L., "*Probability & Statistics for Engineering and the Sciences*," Second Ed., Brooks-Cole, 1987.
- (12) Green, D. W., and J. W. Evans. "Moisture content and the mechanical properties of dimension lumber: decisions for the future." *Workshop on In-Grade Testing of Structural Lumber*. Madison, Wisconsin. April 25 and 26, 1988. Proceedings 88–. Forest Products Research Society.
- (13) Mendenhall, W., *Introduction To Probability And Statistics*, Fourth Ed., Duxbury Press, 1975.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).