Designation: D1990 – 16

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

This standard is issued under the fixed designation D1990; 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.

INTRODUCTION

Visual stress-grades of lumber manufactured in North America have evolved from the procedures of Practice D245. Allowable stress and modulus of elasticity values were determined for these grades using the procedures of Practice D245 and the appropriate clear wood values of Practice D2555. The clear wood values of Practice D2555 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 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 also covers procedures for periodic monitoring, and additional procedures, if needed, for evaluation and possible reassessment of assigned design values. This practice is focused on, but is not limited to, grades which used the concepts incorporated in Practice D245 and were developed and interpreted under American Softwood Lumber PS 20.

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 test sample is representative of population by grade and size (see 7.1.1 and 7.1.2).

1.3 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 D2915. The mechanical test methods are covered in Test Methods D198 and D4761. 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. The practice includes procedures for periodic monitoring of the species or species group to quantify potential changes in the product and verification of the assigned design values through, evaluation, and reassessment.

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 D245.

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*

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

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responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D9 Terminology Relating to Wood and Wood-Based Products

D198 Test Methods of Static Tests of Lumber in Structural Sizes

D245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

D1165 Nomenclature of Commercial Hardwoods and Softwoods

D2555 Practice for Establishing Clear Wood Strength Values

D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials

D4444 Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters

D4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material

E380 Practice for Use of the International System of Units (SI) (the Modernized Metric System) (Withdrawn 1997)[3]

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *American Softwood Lumber Standard:*

National Institute of Standards and Technology Voluntary Product Standard PS 20-94[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms related to wood, refer to Terminology D9.

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.

3.2.2.1 *Discussion*—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 D2915 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 D1165) 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 D1165.

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 (**1**, **2**, **3**, **4**, **5**, and **6**) developed from the procedures of Practice D245 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 D4761). Strength ratios were calculated according to the formulas given in the appendix of Practice D245 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.

3.2.4.1 *Discussion*—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 *monitoring, n*—a periodic review of a subset of structural properties of a lumber cell to determine if a potential downward shift from the assigned values indicates a need for an evaluation or reassessment, or both, of allowable properties developed with this practice (Stage 1).

3.2.6 *evaluation, n*—The process of examining data, including that collected over the course of a monitoring program that has detected a shift in cell properties, to determine the likely cause for the detected shift in cell properties, developing the best response to the data, and establishing that the actions are sufficient (Stage 2).

3.2.6.1 *Discussion*—The response to the evaluation can include altering the grade description, or the input resource, or changing the method of processing. Testing is conducted to confirm that the action taken corrected the affected properties.

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

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

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

3.2.7 *reassessment, n*—The recalculation of allowable properties derived by this practice because of a change in product properties (Stage 3).

3.2.8 *statistically significant downward shift, n*—A statistically significant downward change in the monitored size grade cell property in relation to a single cell from the matrix used to derive the current allowable property for which further action is required in this Practice.

3.2.8.1 *Discussion*—The Wilcoxon nonparametric statistical test showing a change that is significant at the 0.05 level has been selected as the consensus statistical method for determining when further action is required in this Standard.

3.2.9 *action level*—The lower property boundary, representing a statistically significant downward shift, used in monitoring to define the property level at which additional confirmation testing during monitoring, or further action beyond monitoring is necessary.

3.2.10 *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.

3.2.10.1 *Discussion*—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.

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

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

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

3.2.14 *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 D2915. 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 monitoring program shall be established to periodically review the continued applicability of allowable properties derived by this practice. A monitoring program will establish data sets that are either the same as, above, or below the data that was used to develop the current allowable properties. Upon detection of a statistically significant downward shift, evaluation of the data and confirmation of remedial actions shall be undertaken. When evaluation is not undertaken or the results of the evaluation indicate an adjustment to allowable properties is appropriate, a reassessment shall be conducted to re-establish allowable properties.

NOTE 5—It is recognized that over time there is the potential for changes in the raw material or product mix. In response to this a monitoring program must be conducted to ensure design values derived by this practice are not invalidated by such changes. If the data collected with a monitoring provides evidence of an statistically significant downward shift in lumber properties an evaluation program in accordance with the procedures of this practice is needed to detect and confirm that responses to such changes are appropriate. Evaluation, if undertaken, provides a means for responding to the data and assessing if the actions taken are sufficient. Following the confirmation of a statistically significant downward shift, reassessment of values shall be conducted if evaluation is either not undertaken or does not adequately address the downward shift.

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

5.1 *Reporting Test Data:*

5.1.1 *Summarizing Statistics:*

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

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

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

NOTE 6—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 E380 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 D2915, 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 7).

NOTE 7—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 D245 (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.

7.1.1 *Population Representativeness*—The sampling plan shall be designed to represent the region to be sampled (see Note 8).

NOTE 8—Consideration should be given to potential sources of variability in the allocation of the random sample and the design of the sampling plan. The North American In-grade test program samples were considered representative because the design of the sampling plan required sampling proportional to production in at least 3 sub regions of the growing range for each of the species groups with substantial production; this resulted in a minimum cell size of 360 pieces. Smaller geographic regions equivalent to several U.S. states had representative samples with sample sizes of 200 or more. The use of large sample sizes is not sufficient by itself to assure that the sample is representative of the population. It is often necessary to sample sub-regions (or locations) to represent variability due to geography, production and growing conditions; in the North American In-Grade Program, this was typically a minimum of three sub-regions, but more for the major volume species groups. If this is not possible justification needs to be provided to demonstrate that an alternate sampling plan adequately represents these sources of variability.

7.1.2 *Grade Representativeness*—The sampling shall be collected in a random sampling design intended to represent the range of strength reducing characteristics allowed by the grade.

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 9) in assumed bending GQI.

NOTE 9—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 D245.

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 10).

NOTE 10—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 D2915. For testing, use Test Methods D198 or Test Method D4761. 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 observed grade quality of the sampled material in relation to the assigned grade quality used to establish the matrix (7.2). The following procedures provide one way to make this assessment.

8.2.1 The observed GQI determined from failure coded data can be used to assess whether the test cells are representative of the visual grade that is the target by comparing the 5th percentile point estimate (5th %tle PE) GQI of the test cells with the assigned GQI for the target grade (Note 4). The observed GQI shall be calculated for all pieces associated with knots, slope of grain, and distorted grain, or other strength reducing characteristics at point of failure. The calculation methodology shall be documented (see X12.6)

8.2.2 When calculating strength ratios using the appendix of Practice D245, two strength ratios shall be calculated for combination knot failures: (*1*) using the total combined knot cross section in the equation for center of wide face knots, and (*2*) using the largest single edge knot from the cross-section in the equation for narrow face knots. The smaller of these two calculated strength ratios shall be permitted to be used in the calculation of fifth percentile point estimate of the distribution of strength ratios.

8.2.3 Fifth percentile point estimates of the distribution of strength ratios shall be presented to decimal place, using the rounding procedures of Section 6.4 in Practice E29.

8.2.4 To comply with the requirements of 7.2 and 8.2 both of the following conditions (Note 11) shall be met:

(1) The average of all individual cell GQIs in one grade shall not exceed the assigned grade GQI by more than 5 percentage points, and

(2) Each individual cell GQI shall not exceed the assigned grade GQI by more than 7 percentage points.

If both conditions are not met one of the options in 8.3 shall be followed.

NOTE 11—GQI evaluation and adjustment is an additional procedure overlaid on the representative sampling requirement to assure final strength property assignments account for the full range of grade characteristics permitted in each visual grade. The basis for these procedures were developed using distribution data of GQI measurements of the major North American species groups as part of the North American In-Grade Lumber Testing program. A modification of the GQI scale or calculation methodology may be appropriate. The GQI for a sample is determined from defects associated with the failure of the pieces in the sample after test loading. The determination of a GQI value depends on the assessment and measurement of knot types, sizes, and their locations as well as the maximum slope of grain of the piece. Sample size, measurement variation, species variability, and methods of analysis can significantly impact the final GQI value (See X12).

8.3 *Standardized Conditions:*

8.3.1 *Grade Quality*

8.3.1.1 If the average of all individual cell GQIs in one grade for a sample is no more than 5 percentage points above the grade GQI, and each individual cell GQI for a sample is no more than 7 percentage points above the grade GQI that sample shall be considered to support the intent of 7.2. Otherwise, it is permissible to re-sample or collect more samples to address non-compliance and re-evaluate the new or augmented sample for grade representativeness using GQI procedures (Note 11). Sampling used for augmentation or re-sampling shall follow the same sampling protocol applied to the original sample and be representative of population and grade as specified in 7.1.1 and 7.1.2. If the requirements of this clause are not met or if re-sampling is not possible, then the following are possible actions to address non-compliance:

(1) If the average of all cell GQIs in one grade does not exceed the grade GQI by more than 5 points, reduce the property value for all specimens in any cell whose GQI exceeds the grade GQI by more than 7 points using the formula in 8.3.1.2. If the average of all individual cell GQIs in the grade exceeds the grade GQI by more than 5 points, reduce the property value for all specimens in each cell that exceeds the grade GQI by more than 5 points using the formula in 8.3.1.2. Cells adjusted, using this procedure, are assumed to be compliant and no further grade quality adjustment is required for the grade in question.

(2) Adjust the grade definition to support a higher grade GQI so that it is within 5 points of the observed GQI.

NOTE 12—Failure of the sample to meet these criteria could be a result of several causes, some of which may be acceptable or correctable by using another method. It could be desirable to reassess the appropriateness of the GQI scale used. A proposal for replacement or augmentation of existing data should include adequate statistical analyses and information to determine if the new data substantiates retaining existing data, augments existing data, or replaces existing data.

8.3.1.2 Where structural property data of a cell is required to be modified to adjust to standardized conditions of assigned GQI, the data for all specimens in the cell shall be multiplied by the following factor (Note 13):

$$Factor = (assigned\ GQI + 5\ \%\ points)/(observed\ GQI) \quad (1)$$

An alternative relationship shall be permitted to be used to modify the modulus of elasticity to standardized GQI conditions, provided this relationship is based on documented evidence. An example equation for the adjustment of modulus of elasticity can be found in X12.5.6.

NOTE 13—The GQI evaluation and adjustment is an additional procedure applied to the final strength property assignments to account for the maximum size of grade characteristics permitted in each visual grade. The adjustment factor is an override that can be applied without further sampling. It has been shown that application of GQI adjustment factors ranging from 0.95 to 0.89 can leave the final design values unchanged or can change the final design values by 1 rounding rule.

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

8.3.3 *Moisture:*

8.3.3.1 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.

8.3.3.2 Determination of specimen moisture content shall be made in accordance with Test Methods D4442 and D4444.

8.4 *Size:*

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

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

8.4.3 The property values of all test data shall be adjusted to the characteristic size (for example, 1.5 by 7.25 by 144 in. [38 by 184 by 3658 mm] at 15 % MC) using the following equation (Note 14) or other appropriate size adjustment prior to developing the characteristic value:

$$F_2 = F_1 \left(\frac{W_1}{W_2}\right)^w \left(\frac{L_1}{L_2}\right)^l \left(\frac{T_1}{T_2}\right)^t \quad (2)$$

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 14—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 D4761. The length adjustments given above are based on the actual test clear span between reactions or grips. The bending tests used third point loading with a constant span to depth ratio of 17 to 1. The tension tests were conducted with an 8 ft (2.4 m) clear span for 2 by 4 (Southern Pine was tested on a 12 ft (3.7 m) span) and a 12 ft (3.7 m) clear clear span for 2 by 6 ft and wider. The adjustment equation of 8.4.2 has not been verified for widths less than 3.5 in. (89 mm) nor greater than 9.25 in. (286 mm). Additional information regarding the basis for and recommended limitations to Eq 2 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 3.2.13) 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:

$$T = 0.45 \times R \quad (3)$$

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:

$$\text{For } R \leq 7200 \text{ psi} \quad (4)$$

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

$$\text{For } R > 7200 \text{ psi}$$

$$C = 0.39 \times R$$

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:

$$R = 1.2 \times T \quad (5)$$

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:

$$\text{For } T \leq 5400 \text{ psi} \quad (6)$$

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

$$\text{For } T > 5400 \text{ psi}$$

$$C = 0.52 \times T$$

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 15). 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 15—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 (**7**)) 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 16). 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 16—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 (**8**) .

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 17).

NOTE 17—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 18).

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 18).

NOTE 18—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 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 E380. 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

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

are joined by transverse floor, roof or other load distributing element, the allowable bending stress of such members may be increased by 15 %.

13. Periodic Corroboration of Assigned Design Values

13.1 The periodic corroboration of assigned allowable properties shall include one or more of the following three stages. (*1*) A monitoring program to periodically check for changes in product performance, (*2*) An evaluation program, upon detection of a statistically significant downward shift, to evaluate monitoring data and confirm effectiveness of remedial actions, and (*3*) a reassessment program to re-establish allowable properties.

14. Monitoring

14.1 The data from a monitoring program shall be used to determine if there is sound evidence to believe that there has been a change in the product performance sufficient to justify an evaluation as described in Section 15, or a reassessment as described in Section 16.

NOTE 19—The monitoring program is based on testing the hypothesis that there has been no change against an alternative that there has been a change.

14.2 The monitoring program shall include: (*1*) definition of objectives, (*2*) use of appropriate sampling procedures and sample size to accomplish those objectives, (*3*) selection and use of appropriate test methods, and (*4*) application of suitable data analysis procedures to collected data (see example in Appendix X11). Any significant deviation from the In-grade program sampling and testing methods shall be justified by comparative data analysis.

14.2.1 For lumber species or species groups with production over 1000 million board feet (MMbf) annually, this monitoring program shall at a minimum include the destructive testing of a representative size-grade cell at least once every five years.

NOTE 20—A new five year cycle begins on the date the national lumber authority having responsibility for the review and approval of lumber design values (for example, the American Lumber Standard Committee in the United States) approved the most recent periodic corroboration results. The destructive testing results for the next cycle of monitoring should be completed and submitted within five years to the national lumber authority having responsibility for the review and approval of lumber design values.

14.2.2 A monitoring program shall also look at results collected over time to determine if the data suggests any trends pointing toward a lack of conformance in the future.

NOTE 21—It is recommended that a multi-stage approach utilizing a combination of destructive and non-destructive testing of lumber production be used (**9**). A monitoring program may involve multiple steps to minimize the sample size during routine periodic tests. It may also be appropriate and more efficient to confine the periodic sampling to a single representative size-grade cell that can be repeatedly sampled on an ongoing basis. As subsequent stages are triggered, the sample sizes and scope of testing can be expanded (for example, other size-grade cells or properties) as appropriate to confirm with a high degree of certainty whether an important change has occurred. For consistency of comparison, any monitoring should employ a sampling method that retains, where appropriate, the elements of sampling done under the In-grade testing program that established the allowable properties for the same species being checked (**10, 11**). The sample is to be representative of the specific lumber product. It is cautioned that statistically significant changes occasionally have no practical significance. Conduct statistical decisions first, followed by practical analysis as a second step.

14.2.3 A Wilcoxon test shall be used to determine whether to proceed to step 2 (an additional destructive sampling of a size-grade cell) of Stage 1. This action level is reached when a comparison of the cell property that was used to determine the current cell value is significantly different from the monitored cell value at an α level of 0.05.

14.3 If the action level for a downward shift in Stage 1, Step 1 is not reached, the original periodic testing shall be re-initiated. If the action level for a downward shift in Stage 1, Step 1 is reached then either a Stage 1, Step 2 is undertaken or an evaluation of the current allowable properties is started.

15. Evaluation

15.1 An evaluation program shall be initiated when a statistically significant downward shift in a monitored cell has been confirmed. Alternatively, a reassessment in accordance with Section 16 shall be initiated.

15.2 The data developed over the course of the monitoring program shall be thoroughly reviewed to (*1*) determine the likely cause for the detected shift in allowable properties, and (*2*) develop the best response to the detected shift. The development of the response shall be documented and discuss implications for the other size-grade cells and properties.

15.3 Acceptable responses include altering the description of the visual grade, changing the method of processing, or restricting the resource that can be processed.

15.4 The evaluation shall include testing to confirm that the response brings the derived values within an acceptable range of the published properties for all affected size-grades and properties.

15.5 Where the evaluation requires an adjustment to some or all allowable properties, the procedures of Section 16 shall be followed.

16. Reassessment

16.1 A 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 detected by the monitoring which has been unresolved by evaluation. This reassessment shall be conducted using the sampling matrix upon which the original characteristic values are based except as provided in X11.1.4, in conjunction with an awareness of changing production conditions.

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

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

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

ANNEX

(Mandatory Information)

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

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

TABLE A1.1 Constants for Use inEq A1.2

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

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

Coefficients	MOE
B_1	1.857
B_2	0.0237

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

For MOR $\leq$ 2415 psi:
UTS $\leq$ 3150 psi:
UCS $\leq$ 1400 psi:

$$S_2 = S_1 \tag{A1.1}$$

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

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

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:

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

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

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

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:

	Width		Thickness	
Species/variable	a	b	a	b
Redwood Western red cedar Northern white cedar	3.454	0.157	2.816	0.128
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 **12**) 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

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

$$S_t = 5.062 - 0.181\,M$$

Redwood

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

where:

S_w = shrinkage in width, %,
S_t = shrinkage in thickness, %, and
M = moisture content, %.

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

X2. DEVELOPMENT OF AND RECOMMENDED LIMITS TO VOLUME ADJUSTMENT EQUATION

X2.1 Development of Volume Adjustment Equation

X2.1.1 The volume adjustment equation presented in 8.4.2 was developed primarily from the North American In-Grade testing database with substantial review of other related work. The original proposal was of the same form as the current depth effect formula in Practice D245, but replaced the ⅑ 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 (**13**) 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 (**14**), 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 D245. 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 D4761. 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

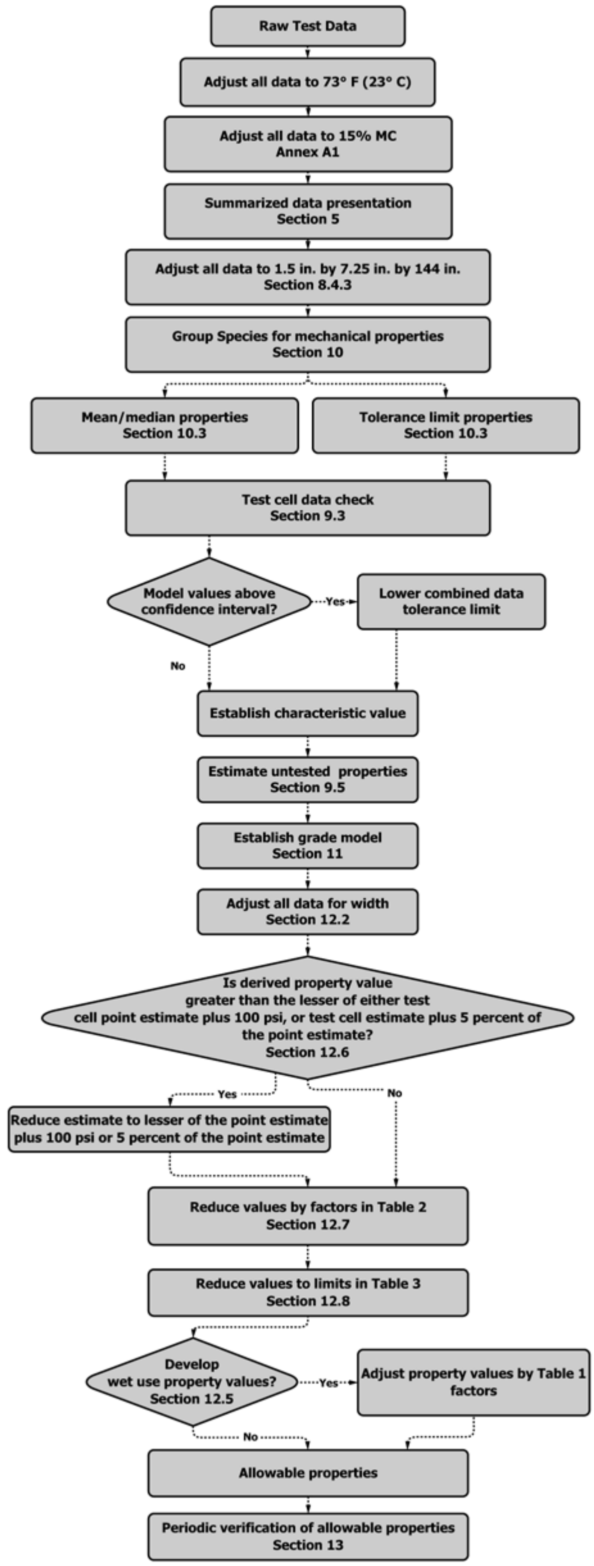


FIG. X3.1 Flow Diagram of Practice

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 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.

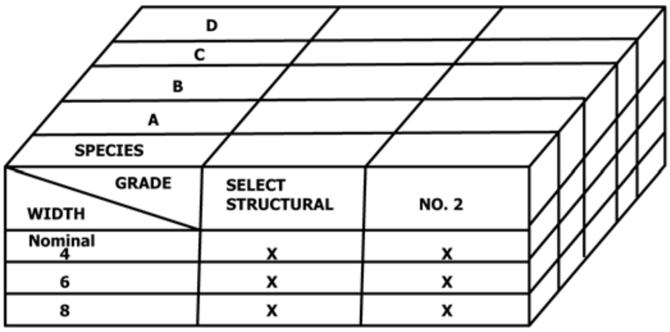


FIG. X3.2 Example of Sampling Matrix

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 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 10^6 psi, MOR is in psi)

Property	Species and Size					
	A			B		
	2 × 4	2 × 6	2 × 8	2 × 4	2 × 6	2 × 8
Select Structural:						
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
No. 2 Grade:						
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
Select Structural:						
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 Percent 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
No. 2 Grade:						
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 10^6 psi, MOR is in psi)

Grade	Species[A]				
	A	B	C	D	All
Select Structural:					
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
No. 2:					
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
Select Structural:					
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			
No. 2 Grade:					
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 A	Select Structural 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 A	No. 2 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 10^6 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	
	2 × 6	555	34	4047		3848	
	2 × 8	489	31	3627		3396	3317
No. 2	2 × 4	420	26	2756	1701	2413	
	2 × 6	384	24	2024		1973	
	2 × 8	353	22	1801		1742	1701
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	
	2 × 6	180	13	0.921		0.846	
	2 × 8	126	10	0.946		0.846	0.846
No. 2	2 × 4	623	38	0.691	0.664	0.664	
	2 × 6	593	36	0.704		0.664	
	2 × 8	563	34	0.739		0.664	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				Mean MOE	Median MOE
		MOR	UTS	UCS	MOE		
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 Committee 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

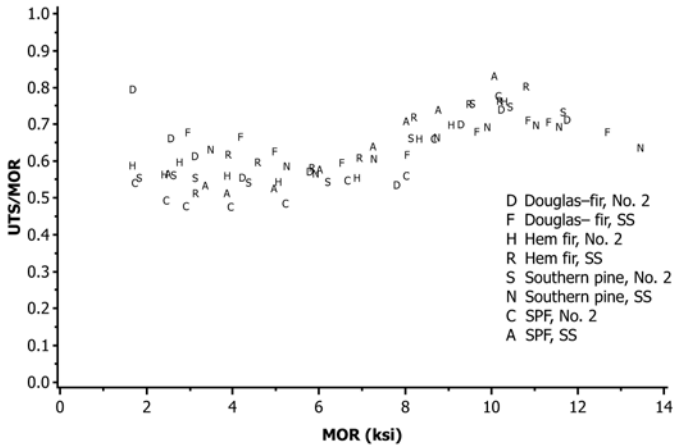


FIG. X4.1 A Plot of UTS/MOR Ratios Against MOR at 15 % Moisture Content

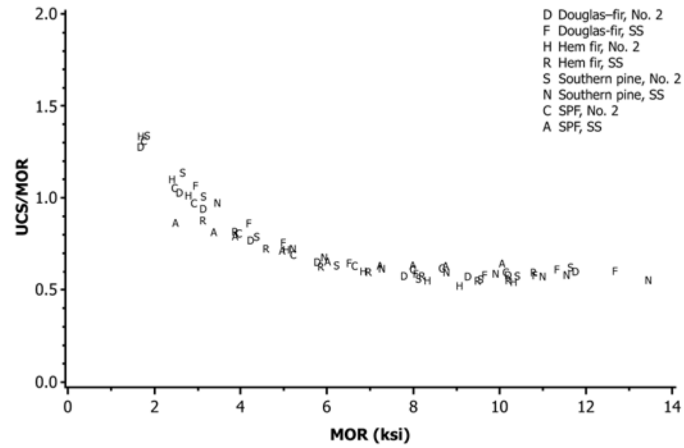


FIG. X4.2 A Plot of UCS/MOR Ratios Against MOR at 15 % Moisture Content

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.

X5. NONPARAMETRIC ANALYSIS OF VARIANCE (Ref 15)

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:

	Original Group Data			Ranked Group Data		
Group:	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:

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

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.

$$q_\alpha = \left(\bar{Y}_{max} - \bar{Y}_{min}\right)/S_{\bar{y}}$$

Error df	α	p = 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

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 *ith* treatment mean and the *jth* treatments mean, substitute:

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

where:

n_i = the number of replications in the *ith* treatment and
n_j = the number of replications in the *jth* 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:

$$n_h = \frac{P}{(1/n_1)+(1/n_2)+\ldots+(1/n_p)} \quad \text{(X6.3)}$$

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.

X7. CHI-SQUARE TEST

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

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

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:

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

where:

O_{ij} = actual number of observations in the cell in the *ith* row and the *jth* column.

E_{ij} = expected number of observations in the cell in the *ith* row and the *jth* column.

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

Row	Column 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	$n_{.1}$	$n_{.2}$	$n_{.3}$	...	$n_{.c}$	$n_{..}$

X7.3.1 In the notation of the table, n_{ij} is the number of observations in the *ith* row and *jth* column. A period as a 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:

$$E_{ij} = \frac{n_{i.} \times n_{.j}}{n_{..}} \quad \text{(X7.3)}$$

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.

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.	χ^2 0.100	χ^2 0.050	χ^2 0.025	χ^2 0.010	χ^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

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 D2915, 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 products' values.

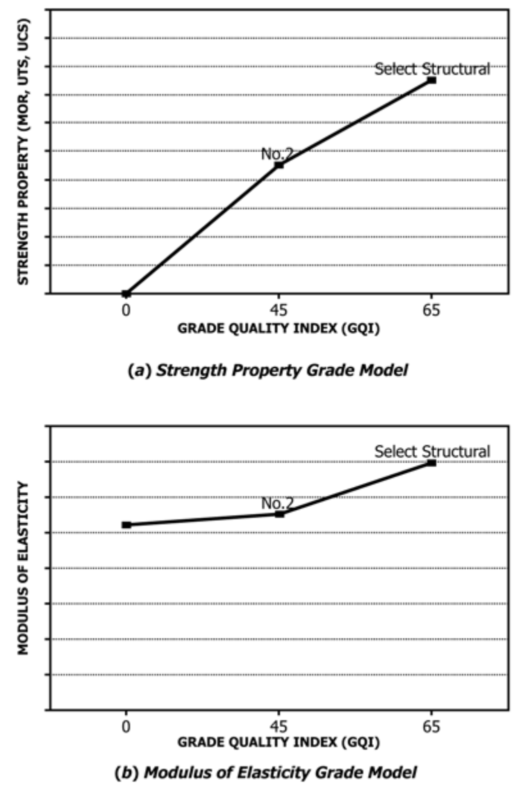
X8.1 Establishing the Grade Model

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.

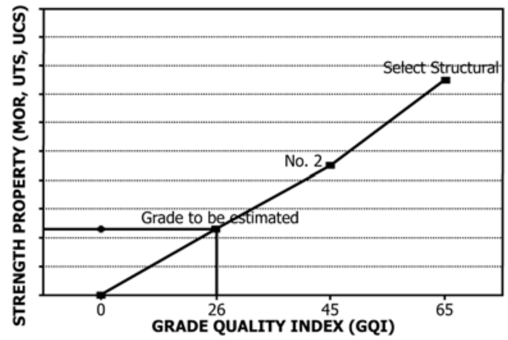


Calculation Procedure:
(*1*) Adjust all data of a single grade to 15 % moisture content with the procedures of Annex A1. Adjust all data to the characteristic size (1.5 × 7.25 × 144 in.) with the procedures of 8.4.3.
(*2*) Determine property estimates (5 % tolerance limit with 75 % confidence) for each 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

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.



Calculation Procedure:

(1) Determine minimum strength ratio for the grade from grade description and Practice D245.
(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

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 Practice D2555, 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.

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 (**16**). 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 PERIODIC VERIFICATION OF LUMBER PROPERTY VALUES DERIVED ACCORDING TO D1990

X11.1 *Scope*:

X11.1.1 This appendix provides guidelines for maintaining allowable property values that have been derived using this practice. There are three stages: monitoring, evaluation, and reassessment. The monitoring stage can have two steps. These stages are to be followed by the entities responsible for the development of the allowable properties. A flow chart illustrating the stages in this process is shown in Fig. X11.1.

X11.1.2 The first stage is a periodic monitoring of a single size-grade cell of lumber that can be repeatedly sampled on an ongoing basis. No. 2 2–by–4 is an example of such a size-grade cell. The size-grade cell's properties are examined by comparing the data obtained from a representative sample to the original allowable property information for that size-grade cell. If a statistically significant downward shift is not reached, the original periodic testing can continue. If the action level for a downward shift in Stage 1, Step 1 is reached then either a Stage 1, Step 2 (an additional destructive sampling of a size grade cell) can be undertaken or an evaluation of the current allowable properties can be started. Alternatively, it is permissible to proceed directly to a reassessment following the confirmation of a shift.

X11.1.3 Initiation of the evaluation stage will occur whenever there is sufficient evidence in the monitoring program to question the appropriateness of existing property values. During the evaluation stage a response will be developed to the information obtained from the monitoring. This response is limited to actions that preserve the existing allowable properties. Actions could include changes in the grade description or production methods, or redefining what subpopulation needs to be excluded from the grade. Some national lumber authorities having responsibility for the review and approval of lumber design values (for example, the American Lumber Standard Committee in the United States) may limit the types of remedial steps that can be taken.

X11.1.4 Reassessment is required when remedial steps taken during the evaluation are unsuccessful, or if the evaluation stage is not selected following a confirmation of a statistically significant downward shift during monitoring. Reassessment of some or all allowable properties shall follow Sections 16 of this standard. In a partial reassessment, some national lumber authorities having responsibility for the review and approval of lumber design values (for example, the American Lumber Standard Committee in the United States) may limit the combinations of size, grade and properties that can be reassessed.

X11.2 Monitoring

X11.2.1 Monitoring is a periodic review of a subset of structural properties of lumber, undertaken by the entity responsible for the allowable properties derived, to determine

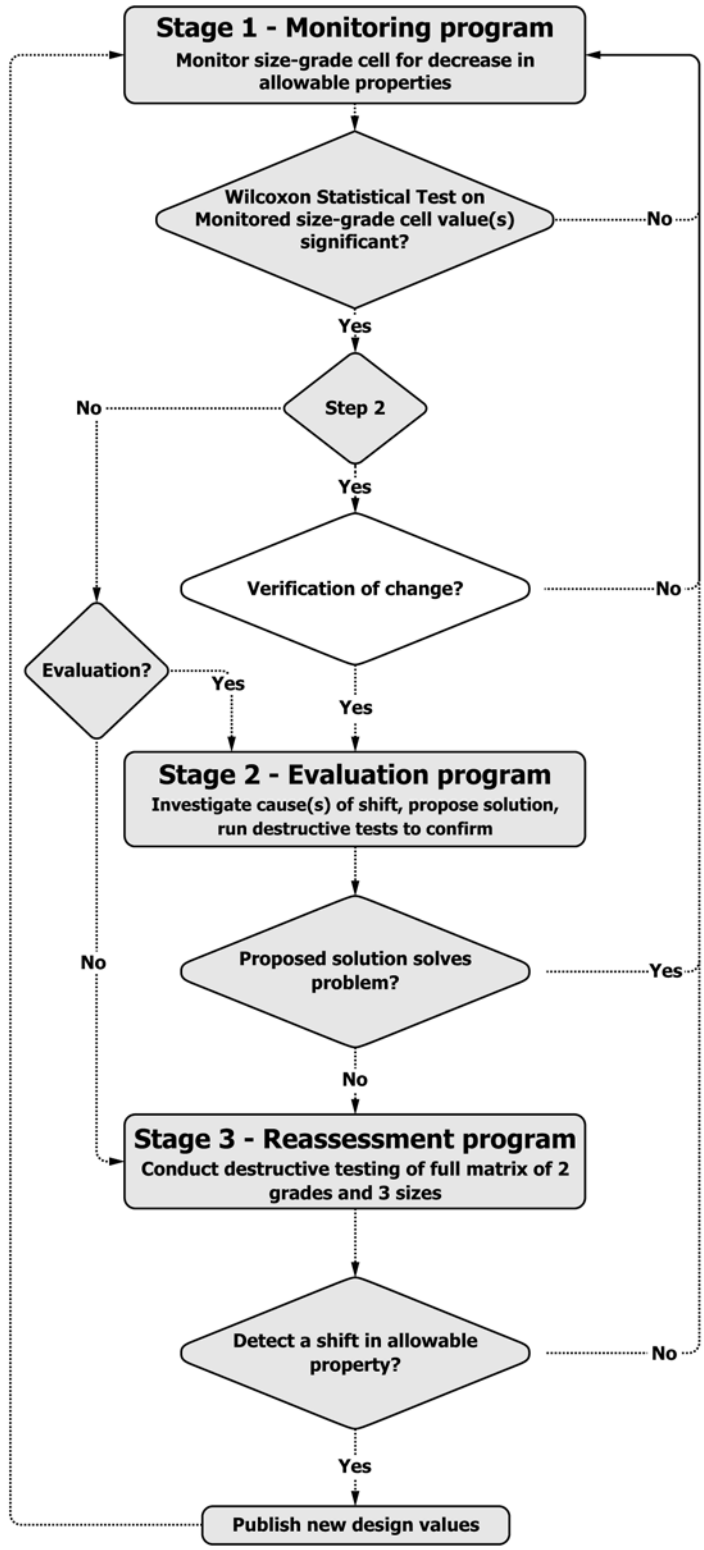


FIG. X11.1 Flowchart of Steps for Maintaining the Design Values for Visually-Graded Dimension Lumber

the need for evaluation of all allowable properties derived from this practice. There are many options available for resource monitoring (**9**). The effectiveness of monitoring depends on the underlying material variability, the sample size selected, the degree of difference to be detected with a specific level of certainty, and the frequency with which a false positive indication of a downward shift may be detected.

NOTE X11.1—The following sections provide guidelines for conducting an effective monitoring program based on the experience gained to-date from agencies that have undertaken monitoring, X11.2.2 *Define Objectives*—Prior to proceeding with the monitoring program, define the objectives so decisions and protocols regarding sampling, testing, data collection and analysis can be developed for achieving the objective.

X11.2.2.1 There can be numerous objectives when monitoring allowable property values. Some examples of objectives of a monitoring program are to test samples taken from a single size-grade cell, or a full size-grade matrix to detect the presence of a lumber property value change in one or more of the following: MOE, MOR, UTS, UCS, and Specific gravity.

X11.2.2.2 Allowable property value changes may be due to changes in: product mixes over time, processing methods, and resource from particular regions.

X11.2.3 *Sampling Procedures and Sample Size*—This practice as well as other consensus standards such as Practice D2915 provides information regarding sampling and minimum sample sizes to meet the specified objective **(11)**. It is important to ensure that the sample is representative of the growth or production region for the grade or size sampled and is of adequate sample size to achieve the level of confidence specified. Decide on the objective of the monitoring program while being cognizant of the practical restraints incurred due to availability of resources. It is recommended the sampling method be similar to and the sample size equal or exceed that used in the reference study for the size-grade cell that is being examined (360 for all species group) so that the statistical uncertainty and representativeness are comparable to the reference. Describe and document all procedures. Sampling procedures should anticipate the analysis to be conducted (see X11.2.4).

NOTE X11.2—Experience has shown that it is important to collect information on growth characteristics and specific gravity during a monitoring program as it may be useful during an evaluation (see Section X11.3) It has also been shown through simulations that multiple samples with sample sizes greater than 360 are unlikely to give a false positive indication of a significant downward shift in properties after multiple-steps **(9)**. For the major commercial species in the In-grade program the size-grade cells were sampled from homogeneous regions based on production with a sample size of 360 **(11)**.

X11.2.4 *Test Methods*—Conduct all tests for resource monitoring in accordance with consensus standards if available. Document all procedures.

X11.2.4.1 The objective of the monitoring program and the practical restraints created by resource availability are essential factors in determining the data that will be collected. A monitoring program can involve several steps including non-destructive and destructive testing.

X11.2.5 *Frequency*—For lumber species or species groups with production over 1000 MMbf annually, this monitoring program at a minimum must include the destructive testing of a representative size-grade cell once every five years.

X11.2.6 *Analysis*—In addition to information provided in this practice, refer to Practice D2915 or Lehmann and D'ABrera 1975 **(17)** for guidance regarding analytical and statistical methods.

X11.2.6.1 *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. The Wilcoxon Rank-Sum Method will be used to determine if a statistically significant change has occurred. If the magnitude of change is to be identified, larger sample sizes than those required in Appendix X2 are often necessary.

X11.2.6.2 *Wilcoxon Rank-Sum Method*—The Wilcoxon method is a nonparametric procedure for comparing a new population to an old population (Lehmann and D'ABrera 1975). In this method there are two data sets: old with m specimens and new with n specimens. The data from the old and new populations are ranked together and have a total of $m + n = N$ pieces. The null hypothesis H of no effect is rejected, and the inferiority of the new cell data is acknowledged, if in this ranking the sum of the n pieces in the new data set, W_s, is sufficiently low. A simple example of the application of the Wilcoxon method is given.

X11.2.6.3 Explanation of terms:

W_s is the sum of the ranks of the new data from the combined sample (Eq X11.1).

$$W_S = S_1 + ... + S_n \tag{X11.1}$$

Where S_i is the rank of the *i*th new piece of data in the combined sample.

If the sum of the new cell data rank values is less than some level c, then the new cell is statistically different from the old cell. The constant c is the critical value and is determined so that under H the probability of getting a value of W_s less than or equal to c is equal to some specified significance level α (Eq X11.2),

$$W_S \le c \tag{X11.2}$$

The constant c is thus determined by the equation (Eq X11.3). Common choices for α are 0.01, 0.025, and 0.05. In wood it is typical to use 0.05.

$$P_H(W_s \le c) = \alpha \tag{X11.3}$$

The subscript H is used to suggest that the probability is calculated under the hypothesis that there is no difference between the old and new samples. With N being the total number of specimens, the number of possible choices of n out of N samples is represented by $\binom{N}{n}$ or as a binomial coefficient and can be computed from Eq X11.4.

$$\binom{N}{n} = \frac{N(N - 1) \times ... \times (N - n + 1)}{1 \times 2 \times ... \times n} \tag{X11.4}$$

An assumption is made that the n pieces in the new sample are selected from the N available in the combined sample at random, making the likelihood of all possible choices of these pieces equally likely so that each has the probability of $1/\binom{N}{n}$. Since each division of the data has a probability of $1/\binom{N}{n}$ it follows that the probability of $W_s = w$ is

$$P_H(W_S = w) = \frac{\#(w\ ;\ n\ ,\ m)}{\binom{N}{n}} \tag{X11.5}$$

Where *#(w;n,m)* denotes the ordinal number of all those divisions of the ranks 1,…., N into n new cell ranks and m old cell ranks for which the sum of the total new sample ranks is equal to w.

X11.2.6.4 *Example Wilcoxon Rank Process*—Ten total tests have been conducted. Suppose two sets of test scores and want to determine if the second group is statistically lower than the first group at an α = 0.05 significance level.

Old test results (5, 0, 16, 2, 9) New test results (6, -5, -6, 1, 4)

In this case

$$N = 10,\ m = 5,\ n = 5$$

If you rank the data, the ranks of the new specimens are 1, 2, 4, 6, and 8 and the ranks of the old specimens are 3, 5, 7, 9, 10 (Table X11.1).

TABLE X11.1 Rank of Wilcoxon Example Test Data

Rank	1	2	3	4	5	6	7	8	9	10
Value	-6	-5	0	1	2	4	5	6	9	16
Data Set	New	New	Old	New	Old	New	Old	New	Old	Old

There are $\binom{10}{5} = 252$ possible sets of values of the five ranks and therefore assuming that each is equally likely to happen, each has a probability of 1/252 of occurring. Since alpha is assumed to be α = 0.05 the following equation x/252=α=0.05 can be used to approximate how many combinations of ranked sets need to be looked at if we start systematically finding the smallest values for the sum of the new data ranks W_s. Solving for x gives x= 252/20 = 12.6. Therefore, it is only needed to look for the first 12 combinations (Table X11.2). For larger sample size data sets this process is easily handled by computer macros. The critical value, c, s equal to the 12th lowest value for the sum of 5 ranks.

TABLE X11.2 Systematic Combination of Ranks

1+2+3+4+5=15	1+2+4+5+6=18
1+2+3+4+6=16	1+2+3+4+9=19
1+2+3+4+7=17	1+2+3+5+8=19
1+2+3+5+6=17	1+2+3+6+7=19
1+2+3+4+8=18	1+2+4+5+7=19
1+2+3+5+7=18	1+3+4+5+6=19

W_s is less than or equal to 19 when α is 0.05 and the P_H (W_s < 19) = 12/252 =0.0476. If the process is continued P_H (W_s < 20) 0.0754. Looking back at the W_s from the examples we see that W_s = 1+2+4+6+8 = 21, which is larger than the critical value c = 19. Therefore, despite the appearance of the new cell values being lower than the original the new values are not significantly different than the old at α = 0.0476 nor α = 0.0754.

For the larger sample size data sets there are equations and software packages available to estimate the required c values for given a given α level.

X11.2.6.5 Test properties of a single representative test cell will be relied upon to infer other properties or other cells in the size/grade matrix. The significance of the change to be detected depends on the representativeness of the test cell and how change in the representative property or test cell translates to change in other test cells and properties.

X11.2.7 *Decision Sequence for Implementation*—The decision sequence emphasizes the practical aspect of implementation of a monitoring program. Statistically significant changes occasionally have no practical significance. Conduct statistical decisions first, followed by practical analysis as a second step.

X11.2.7.1 The following decisions are required prior to implementing the monitoring program:

(1) Determine the monitoring objectives,

(2) Review available data for its adequacy to meet the objectives,

(3) Decide if additional data are required,

(4) Methodology—Choose appropriate consensus standards,

(5) Sample—Select size, type, and how the sample should be distributed or allocated,

(6) Determine the sequence of decisions that will result in the conclusion to reject the null hypothesis that no change has occurred,

(7) From X11.2.6.1, establish the action level(s) for each of these decisions.

(8) Regardless of the statistical significance, conduct appropriate practical significance difference tests such as the presence of consistent trends over time that would either refute or suggest shifts in properties.

X11.2.7.2 If a significant difference as defined in X11.2.7.1, No. 7, or X11.2.7.1, No. 8, is present, evaluation shall be initiated. Otherwise, repeated sampling and analysis as outlined in the monitoring program can proceed.

X11.3 Evaluation

X11.3.1 Evaluation occurs after the monitoring program has detected a significant downward shift in Stage 1, and the decision to undertake the second step of Stage 1 or to move directly to Stage 2 depends on the magnitude of the difference. If the downward change in cell property data does not result in a decrease in published allowable values, Stage 1 monitoring may still be appropriate at this point. The decision to move on to evaluation requires careful consideration of the relationship between test data and design values. Evaluation occurs after the monitoring program has detected a decrease in the allowable properties calculated with this practice. An evaluation program investigates the potential cause(s) of the shift, proposes a response to the detected decrease, and runs tests on representative samples of the new population to confirm that the proposed response is effective. The following sections provide guidelines for conducting an effective evaluation program.

X11.3.2 *Reason(s) for Detected Shift*—Any evaluation program should first review available data and establish a plausible explanation for the detected shift. This could involve looking at trends in monitoring data over time, changes in production methods, changes in resource, or changes in product mixes. There are likely multiple factors responsible for the detected shift. The more information that can be gathered during the monitoring program, the easier it is to find an explanation for a shift. This may lead to expanding the monitoring program to another size-grade cell or cells to look for causes and contributing sources of the shift or to determine the effects on other cells or to determine the scope of the shift by reviewing or evaluating additional properties.

X11.3.3 *Proposed Solution to Correct for Observed Shift*—A study shall be conducted to establish that proposed changes can correct for or modify the identified factors responsible for the decrease in allowable properties. The testing shall demonstrate that the proposed response results in allowable property values that equal or exceed the original values.

X11.3.4 *Sampling Procedures and Sample Size*—At a minimum the sampling must include testing MOE and MOR and be for a full in-grade size-grade cell sampled from homogeneous regions according to production. The minimum size of this sample should be 360 for each size-grade cell examined.

X11.3.5 *Test Methods*—Conduct all tests for evaluation in accordance with consensus standards if available. Document all procedures.

X11.3.6 *Decision Sequence for Implementation*—The decision sequence emphasizes the practical aspect of implementing an evaluation program. Statistically significant changes occasionally have no practical significance. Conduct statistical decisions first, followed by practical analysis as a second step.

X11.3.6.1 The following decisions are required as part of the evaluation plan:

(1) Determine the cause(s) for detected shift in allowable properties,

(2) Review available data for its adequacy to meet the objectives,

(3) Decide if additional data are required,

(4) Expand the testing to another size-grade cell or cells to look for causes and contributing sources, or expand review to other properties if effects are unknown,

(5) Propose possible corrections to return allowable properties to prior level,

(6) Methodology—Conduct study using destructive testing to confirm the adequacy of proposed correction using appropriate consensus standards,

(7) Determine if a significant difference as defined in X11.2.7.1, No. 7, is still present,

(8) If the corrections work, return to original monitoring program, otherwise repeat X11.3.6.1, No. 1, to X11.3.6.1, No. 7, or conduct a full reassessment of assigned allowable properties.

X11.4 *Reassessment of Allowable Properties*—The reassessment of in-grade testing visually-graded dimension lumber allowable property values requires the destructive testing of the full size-grade matrix described in this practice. Many of the same types of decisions mentioned in sections 9.4.1 and 10.2.2.1 must be made when initiating the reassessment of allowable properties. A partial reassessment may be undertaken in some circumstances. In a partial reassessment, national lumber authorities having responsibility for the review and approval of lumber design values (for example, the American Lumber Standard Committee in the United States) may limit the combinations of size, grade, and properties that can be reassessed.

X11.4.1 *Define Objectives:*

X11.4.1.1 Clearly define the objectives prior to proceeding with reassessment since decisions regarding sampling, testing, data collection and analysis are all dependent upon the objective.

X11.4.1.2 There are numerous potential objectives when reassessing lumber property values. Some examples of objectives are: Changes in values for a single size or grade, or a combination of sizes and grades, Modifications in one species or in a species grouping, Changes to grade groupings.

X11.4.2 *Sampling Procedures and Sample Size:*

X11.4.2.1 This practice as well as other consensus standards such as Practice D2915, and publication 19 provide information regarding sampling procedures and sample size appropriate to meet the intended objective of an in-grade testing program. 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 X11.5.5).

X11.4.3 *Test Methods:*

X11.4.3.1 Conduct all tests for property reassessment in accordance with consensus standards if available. Document all procedures.

X11.4.3.2 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.

X11.4.4 *Analysis:*

X11.4.4.1 In addition to information provided in this practice, refer to Practice D2915 for guidance regarding analytical and statistical methods.

X11.4.5 *Decision Sequence for Implementation:*

X11.4.5.1 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.

X11.4.5.2 Decisions required prior to implementation of testing are:

(1) Methodology—Choose an appropriate consensus standard,

(2) Sample—Select size, type, and distribution required using previous North American In-grade Program as guide (**9**),

(3) Decision Tree—Establish a decision tree and appropriate actions to follow for all possible outcomes of the reassessment.

X11.4.5.3 Decisions required following analysis of reassessment data are: evaluate if changes in assigned allowable properties are appropriate, and publish new allowable property values.

X12. GRADE QUALITY INDEX

X12.1 Origin of Grade Quality Index

X12.1.1 The Grade Quality Index (GQI) was conceived in the North American In-Grade Program as a tool to compare the lumber quality of test samples with the assumed quality of the grade. The objective was to provide data that would help to verify that the samples: *(1)* represented the quality range expected in production; and *(2)* included pieces with the maximum knot size and slope of grain described in the grading rules for a specified grade.

X12.1.2 The most comprehensive set of data on grade quality collected by lumber agencies in the In-Grade Program were the sets of failure code measurements made by each agency on lumber specimens at the time of testing. Although there were some differences in the way the information was collected, the overall data included measurements of knots, slope of grain and other strength reducing characteristics that were considered to be associated with the failure.

X12.1.3 The North American In-Grade Technical Committee used these failure code measurements to calculate strength ratios, as a means of placing the data on a reasonably common scale that could be quantified and reviewed.

X12.2 Background on Strength Ratio Calculations

X12.2.1 The strength ratio concept is a method used in Test Method D245 to calculate an estimated strength or stiffness property as a percentage of clear, straight-grained wood properties for the purpose of assigning design values to structural graded lumber. Lumber dimensions, and grade-defined knot sizes and slope of grain ratios, are input into this calculation.

X12.2.2 Strength ratios are also used as the basis on which maximum knot sizes and slope of grain are determined for lumber grades in the National Grading Rule. The calculation provides a means of placing these characteristics on a common measurable scale, ranging theoretically from approximately 0 % for very large knots to near 100 % for very small knots. These strength ratios are used to adjust clear wood strength data to develop design values for specific lumber grades.

X12.2.3 Before in-grade testing, the strength ratio calculation was used to support the assignment of equal design values to different sizes of the same grade. In -grade testing, however, showed greater differences in strength between different sizes than previously accounted.

X12.3 Grade Quality Index Calculations

X12.3.1 As a result of knowledge gained from in-grade testing on visually graded dimension lumber, design values are now derived directly from in-grade tests of Select Structural and No.2 grades of lumber rather than from strength ratio adjustments and clear wood data. Theoretical strength ratio percentages were subsequently removed from the dimension lumber grade descriptions in North American grading rules.

X12.3.2 There remained a need, however, for a method to demonstrate that the visual grade quality of a test sample was appropriate for the commercial grade that it was sampled to represent. Therefore, the North American In-Grade Technical Committee decided to use failure-coded measurements that had been collected by each agency as input into strength ratio calculations as a tool to assess the overall sample grade quality. Through a consensus decision in ASTM a benchmark was set as the nonparametric fifth percentile of the strength ratio distribution later defined as an index derived from Test Method D245 that was later termed Grade Quality Index (GQI).

X12.3.3 The Test Method D245 strength ratio concept was also used as a conservative model to establish values for No.3, Stud and light framing grades (See Appendix X8). The mechanical properties assigned to No.1 grade values were based on interpolation between Select Structural and No. 2 values with a further reduction of 15 % applied to bending and tension values, and 5 % to compression values.

X12.4 Acceptability Considerations of the GQI

X12.4.1 As a general principle, each size-grade cell sample for the major U.S. and Canadian species groups in the North American In-Grade Program was considered to be fully representative of the material produced in that cell by virtue of implementing a sampling plan that took large samples that were maximally distributed over the producing regions and from processes that have been in place for many years.

X12.4.2 A review by the original In-grade technical committee of the overall range for Select Structural and No.2 grades of the major species groups suggested that the lower 5th percentile of the distribution of strength ratios could vary up to 5 % from the assigned GQI for the grade, using agency measurements and calculations. There was no generally accepted methodology to adjust the data at the time of D1990 standard development. Therefore, it was a consensus decision of the ASTM task group to accept the observed GQI of the sample if it was no greater than 5 percentage points above the assigned GQI, the samples supported the intent of the Standard. The original In-grade submissions compared the average of three 5 % tile strength ratios, one for each size and grade, to demonstrate representativeness.

X12.4.3 GQI provisions in this practice were written with limited flexibility in addressing cases where the criteria were not satisfied. Provisions are now included to resample or augment an existing sample so that the representativeness can be reassessed. Failing that or if re-sampling is not possible, data adjustment procedures are provided. Alternatively, the grade description can be made more restrictive to ensure the higher GQI is maintained.

X12.5 Evolution of the GQI

X12.5.1 The application of the GQI evolved later in the 1990s due primarily to new initiatives seeking design values for lumber shipped from outside North America. There were several reasons why lumber grade quality became an issue in some of these initiatives, including:

(1) Lumber production from new regions or sources,

(2) Size of knots in relation to grade requirements, and

(3) Calculated GQI in excess of target grade-defined GQI ranges.

X12.5.2 The North American In-Grade Program was developed on the basis of established commercial grading practices throughout the U.S. and Canada that had a long-established track record of yields and market mixes. Later, as potential graded lumber from other sources became available for testing, there was some uncertainty about how this production from smaller geographic regions and sub-regions would relate to North American practices. In some cases there was also limited inventory available for selection of test samples. Therefore, it was thought necessary to re-examine some of the resource and grade quality assumptions. A cell by cell analysis of each grade size GQI is now believed to be a necessary method for insuring representativeness of a given sample. The original ingrade test data was revisited and a cell by cell analysis of GQI was conducted. It was determined that all test data for the original In-grade program fell within a boundary of 7 %.

X12.5.3 The size of knots in a lumber sample can vary for a number of reasons. One possible reason is that the material in the sample is at the higher or lower end of the quality range permitted within a grade; another possible reason is that some non strength reducing characteristics are causing samples to be placed in a particular GQI category, and another possible reason relates to the characteristics of the natural resource, since some species tend to have smaller knots especially in wider widths. The magnitude of GQI variability in a new species group is difficult to establish if the group is not in production. Any adjustment to design values using GQI should involve review of special circumstances involved in the sampling and testing program; such as, sampling plan, sampling matrix, sample size, test methods, commercial production experience, species type and characteristics.

X12.5.4 The GQI values calculated for some of the new regions or sources for graded lumber exceeded the 5 % overall range. This suggested that some of these lumber samples might be of higher quality than expected in future production, however, it should be noted that not all species have the same knot distributions as some typical North American species. As noted in X12.4, there are several possible explanations and courses of action to respond to this issue.

X12.5.5 GQI is calculated as a point estimate representing the characteristics of pieces at the bottom of the strength ratio distribution. Since the number of pieces in this bottom tail can be very small for some size-grade cells, the calculated GQI can vary significantly with relatively small shifts in sizes of characteristics. Calculation of point estimates from small samples will increase the variability of the GQI estimate. Also, the relationship between the distribution of strength ratios and structural properties is not strongly correlated. For these reasons, a larger sample is preferable to making design value adjustments based on GQI.

X12.5.6 This is written with enough flexibility to allow for alternate methods for adjusting structural properties to standardized GQI levels. The correlation between GQI and the strength property of interest has been judged to provide a rational adjustment to standardized GQI levels. Alternative procedures that yield higher correlations between GQI and the strength property of interest should be considered when they are available. An example of a method of adjusting MOE based on strength ratio target levels of 45 and 65 has been developed and accepted by the American Lumber Standard Committee in February of 2003 and is shown below (Note X12.1):

Target GQI of 65 (Select Structural)

$$Factor = 1/\left(1 + \left[0.0077*\left(observed\ GQI - 65\right)\right]\right) \quad (X12.1)$$

Target GQI of 45 (No. 2)

$$Factor = 1/\left(1 + \left[0.00908*\left(observed\ GQI - 45\right)\right]\right) \quad (X12.2)$$

NOTE X12.1—The above factors were derived from relationships of strength ratios versus strength and stiffness for the major species groups (Douglas fir-Larch, Southern Pine, Hem-Fir, S-P-F, Douglas Fir-Larch (N), and Hem-fir (N) Select Structural and No. 2 grades) in the North American In-grade program.

X12.6 Further Notes on Grade Quality Measurement and Calulations

X12.6.1 Interpretation of the grade quality concept needs to take into consideration possible sources of error in four different areas: measurement, calculations, strength relationships, and resource differences. This may influence the choice of method to demonstrate the representativeness of the sample. It is important to describe the coding system and assumptions used by the evaluator when documenting the sample. It is important to fully document the assumptions used to compute the grade quality index of the test data from the failure coding records. Examples of the calculation used to determine the GQI for each class and subclass of strength reducing characteristics such as edge knots, center line knots, narrow face knots, knot combinations, and off-grade pieces should be given and related to the failure code system provided in Test Method D4761.

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