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Procedures for Developing Allowable Properties for a Single Species Under ASTM D1990 and Computer Programs Useful for the Calculations

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Abstract

ASTM D1990, "Establishing Allowable Properties for Visually Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens," is the consensus standard used to make submissions of allowable properties for many U.S., Canadian, and foreign species to the Board of Review of the American Lumber Standards Committee. Recently, it has become apparent how difficult it is to perform the calculations for such a submission. Some calculations are clearly specified in the standard; in some cases the standard merely indicates a need to make an adjustment but does not specify how to do so. This report discusses in detail how to develop allowable properties under the standard in a manner that is consistent with current practice. Many calculations in the standard are difficult and errors are easily made, particularly when using a spreadsheet; this report introduces a set of computer programs that perform some of the difficult calculations, thereby reducing the potential for errors. These computer programs can be run over the World Wide Web, or Fortran versions of the programs can be downloaded, compiled, and run on a user's computer.

Keywords: allowable properties, computer program, ASTM D1990, moisture adjustment, strength ratios, In-Grade

Metric equivalents

Inch–pound unit	Conversion factor	Metric unit
inch (in.)	25.4	mm
pound (lb)	4.4482	N
lb/in^2	6.8948×10^3	Pa
temperature in °F (T_F)	$(T_F - 32)/1.8$	temperature in °C
board foot	2.3597×10^{-3}	m^3

Nominal lumber size (in.)	Standard lumber size (mm)
2 by 4	38 by 89
2 by 6	38 by 140
2 by 8	38 by 184
2 by 10	38 by 235
2 by 12	38 by 286

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Contents

Procedures for Developing Allowable Properties for a Single Species Under ASTM D1990 and Computer Programs Useful for the Calculations

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A. Introduction

The purpose of this report is to explain and simplify the process of developing allowable properties for visually graded dimension lumber under ASTM D1990 (ASTM 1998). This report provides a brief background of ASTM D1990 followed by a discussion of issues to consider when obtaining a representative sample. Then a step-by-step "walk through" of the standard for a single species is described. This walk through follows the pattern of the most recent submissions to the Board of Review (BOR) of the American Lumber Standard Committee (ALSC) in that it assumes the specimens were tested in bending only. The standard does allow testing in tension and compression, but for economic reasons, recent submissions have used only bending tests. Finally, a series of computer programs (available on the internet) that perform many of the calculations needed in a submission are outlined. This report is not intended to replace ASTM D1990 or to document the reasoning behind the standard. It assumes that anyone developing allowable properties has a copy of and is following the standard.

B. Background

B.1 ASTM D1990

ASTM D1990, "Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens," is a by-product of the U.S. In-Grade Testing Program begun in 1977 by the USDA Forest Service, Forest Products Laboratory, in cooperation with the major rules-writing grading agencies in the United States. The objectives of the program were to evaluate the mechanical properties of 2-in. dimension lumber sold in the United States and to develop analytical models to predict the performance of light-frame structures constructed using this lumber. Green and Evans (1988e) discuss in detail some of the decisions required in carrying out such a program.

The result of the program was the testing of more than 70,000 specimens, totalling approximately 1,000,000 board feet of lumber, in bending, tension parallel to grain, and compression parallel to grain. This 10-year, $7 million dollar effort was one of the largest single research efforts ever undertaken in forest products research. To coordinate this effort, the In-Grade Program Technical Committee was formed. Initially composed of technical representatives of the Forest Products Laboratory, West Coast Lumber Inspection Bureau, Western Wood Products Association, and Southern Pine Inspection Bureau, the committee expanded over time to include representatives of the Northern Hardwood and Pine Manufacturers Association, Northeastern Lumber Manufacturers' Association, Canadian Wood Council, University of British Columbia, Forintek Canada Corp., and Fletcher Challenge Canada. Representatives of the American Forest and Paper Association were often present at meetings. This combined program is called the North American In-Grade Testing Program.

The In-Grade Program Technical Committee was faced with the task of taking physical and mechanical property information on 33 species or species groups and using it to establish allowable design properties. This required numerous supporting research studies and the gathering of current research information to make a series of decisions on how to adjust raw data taken in the field, under a variety of temperature and humidity conditions, to common conditions. Adjustments for moisture content, temperature, and species differences in moisture meter readings are just three of many adjustments that are part of the process of converting the data to allowable properties. Many of these decisions and the technical basis for them are found in Green and others (1989). Performing these adjustments resulted in a series of publications of adjusted property values (Green and Evans 1988a–d, Evans and Green 1988a–d).

Implementation of In-Grade procedures resulted in modification of an existing ASTM standard and development of two new ASTM standards. ASTM D2915 was modified to incorporate more information on sampling procedures, to allow for both parametric and nonparametric calculations, and to expand the significance levels allowed in calculations. ASTM D4761 was developed to provide methods for testing lumber under field conditions. ASTM D1990 was developed to provide procedures for calculating allowable properties from In-Grade data. ASTM D1990 does not follow exactly all the decisions made by the In-Grade Program Technical Committee, but it does incorporate most of them. ASTM D1990 also leaves out information on how to make certain adjustments that are often part of the process of calculating allowable properties. This report draws together the information needed to make this calculation.

B.2 Need for this report

Developers of any ASTM standard find it difficult, if not impossible, to anticipate all possible uses of its procedures. This is especially true of new standards. Having been established in 1991, ASTM D1990 is a relatively new standard. Under the provisions of Voluntary Product Standard PS20 (Green and Hernandez 1998), the BOR of the ALSC approves assignments of allowable properties using ASTM standards and other technically sound criteria. This means that the BOR must make technically sound interpretations of ASTM D1990 provisions for those situations where the standard is vague. Since the original submissions of allowable properties to the BOR using ASTM D1990, several submissions have been made for foreign species (Green and Shelley 1994). In most cases, the calculations were performed by individuals who did not participate in the original submissions or the In-Grade Program, and the difficulty in making the calculations became apparent. Some calculations are clearly specified in the standard. However, in some cases the standard merely indicates a need to make an adjustment but does not specify how to do so. In addition, several years have elapsed since the original submissions were made under ASTM D1990. Part of any system of developing allowable properties should be consistency in calculations across species. That becomes more difficult as more people become involved in performing the calculations. Therefore, some record of what has been done in the past is also important. Finally, many of the calculations in the standard are difficult, and mistakes are easily made, particularly when trying to integrate the calculations in a spreadsheet, as most recent submissions have done. The development of computer programs to perform some of the calculations can simplify the process and eliminate some potential errors.

C. Factors affecting the representativeness of the sample

ASTM D1990 defines “In-Grade” as samples collected from lumber grades as commercially produced. Section 1.2 of ASTM D1990 states “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.” In the In-Grade Testing Program, great care was taken to ensure that this was the case (see Jones (1989) for a detailed discussion). First, the lumber was sampled to ensure geographic representativeness. For major species, the geographic area over which the species grew was divided into regions judged to be homogeneous. Historical clear wood property data and information on variation in climatic factors known to effect tree growth were used to make this judgment. Specimens were sampled by region in proportion to production, with a total sample size of 360 to 400 samples per size–grade–test mode combination. At a mill, samples were selected from randomly chosen bunks of lumber, with no more than 20 specimens taken at a mill for a given size–grade cell combination. The size–grade combinations were chosen to be representative of most lumber production. For major species, two grades (Select Structural and No. 2) and three sizes (nominal 2 by 4, 2 by 8, and 2 by 10 in., hereafter referred to as 2×4, 2×8, and 2×10, respectively) were sampled. ASTM D1990 calls the combination of grades and sizes tested for a given species and test mode the “sampling matrix.” Finally, the lumber was chosen to be representative of lumber sold within a specific grade. The “grade quality index” (GQI) provides a numerical assessment of the characteristics found in the sampled specimens that are considered to be related to strength and that are limited as part of the grade description. GQIs were calculated for each piece of lumber tested in the In-Grade Program.

C.1 Grade quality index

An “In-Grade” sample is assumed to be representative of commercial lumber production. Such samples are thus intended to represent the full range of strength and modulus of elasticity values normally found in the grade. ASTM D1990 (paragraph 8.2) states that if the observed GQI from the sample varies from the assumed GQI for the grade by more than 5%, the sample and the GQI shall be reevaluated for appropriateness. In practice, the primary concern has been for samples with a GQI more than 5% above the assumed GQI for the grade, because such samples would be expected to have properties that are greater than those typical for the grade.

The GQI based on strength ratios and used in the In-Grade Program has been also used in all subsequent submissions to the BOR. The type of failure of a specimen was recorded using the appropriate failure code found in table X1.1 of the appendix in ASTM D4761. Strength ratios, as defined in ASTM D245, were calculated according to the formulas in ASTM D245, with the exception that narrow face knots were converted to equivalent edge of wide face knots. After excluding specimens that failed in clear wood, and therefore had strength ratios of 100%, and specimens whose failure code did not allow calculation of a strength ratio, such as local slope of grain, the 5^{th} percentile of the remaining strength ratios was calculated and compared with the strength ratio associated with the grade. If it was within 5% of the GQI for the grade based on the total GQI range (that is, with the strength ratio range of 0 to 100, a No. 2 grade with assumed strength ratio of 45 should be within 40 to 50), the sample was said to be representative of the grade.

The vagueness of the discussion of GQI in the standard raises several issues:

1. GQI has a very broad definition. ASTM D1990 allows something other than strength ratios to be used. No one has used anything else in a submission to date. It would clearly present a challenge if someone proposed some other method of determining grade quality index.

2. The standard does not specifically state what to do if you fail a GQI test. In the In-Grade Program, the GQI for every size–grade cell of every major species was within the 5% GQI limit. This has not been the case with many foreign species. For foreign species, four methods of adjustment have been proposed and three methods have been used in submissions. To illustrate the four methods, assume that for a sample of 2×4 No. 2 structural dimension lumber, the 5^{th}-percentile strength ratio was 51%, which exceeds by more than 5% the assumed 45% strength ratio of the grade and brings into question the representativeness of the sample for the grade. To this point, submissions failing the GQI test have made an adjustment to the mechanical properties that is designed to provide the mechanical properties that a representative sample would have produced. The four adjustments that have been identified are all calculated numbers that by which property values in the cell would be multiplied. Methods 1 and 2 are ratio adjustments, the difference being whether the data are adjusted to the assumed mean of the size–grade cell or the upper bound of what might be allowable. So in method 1, the properties are multiplied by 45/51, and in method 2 by 50/51. The other two methods calculate the percentage that the sample GQI exceeds the assumed GQI. Again the assumed GQI can be either the mean or upper bound. So in method 3 the properties are multiplied by $1 – [(51–45)/45]$, and in method 4 by $1 – [(51–50)/ 50]$. All but method 4 have been used in submissions. Method 1 is probably the best and is the method that all recent submissions have used.

3. There is also no discussion of how to apply the GQI data check for species that are to be grouped under the standard. Should every size–grade cell of every species tested have to meet the GQI test? In the process of grouping data, all the species are combined. Should the combined data have to meet the GQI test? Finally, as part of grouping, a controlling subgroup of species that are indistinguishable from the weakest species is created for each grade. Should the controlling subgroup have to pass the GQI test? Clearly having every species pass the GQI test in every size–grade cell tested is the most conservative approach and probably the most defensible. However, sample sizes for species to be grouped were often small (approximately 60 per size–grade cell instead of 360). With smaller sample sizes, a species will more likely fail the GQI test because of the greater variability of a 5^{th}-percentile estimate.

C.2 Choosing a sampling matrix

Another representativeness issue is how many size–grade cells are to be sampled. The standard, in section 7, recognizes three conditions:

1. Condition 1 is when only one size (such as 2×4) of lumber is to be sampled. In this situation, it is necessary to sample “two grades representative of the range of grade quality.” In practice, this means sampling Select Structural (SS) and No. 2 grade material because the grade model of section X8, which is used to create values for untested grades, is anchored by the SS and No. 2 values. This case allows the calculation of allowable properties for all grades of one size.

2. Condition 2 is when only one grade (such as No. 2) is to be sampled. In this situation, three widths of material must be tested where the maximum difference in any two widths is 4 in. In the In-Grade Program, major species were tested as 2×4, 2×8, and 2×10, and minor species as 2×4, 2×6, and 2×8. Recent foreign submissions have been for 2×4, 2×6, and 2×8. This case allows the calculation of allowable properties for all sizes of one grade.

3. Condition 3 is called a full matrix. In this case, three sizes of each of two grades are tested. The standard does place some limits on the choice of sizes and grades. The grade model in the standard appendix uses SS and No. 2 grades, and the sizes chosen must be such that “the maximum difference in width between two adjacent widths shall be 4 in. (10 cm).” This condition allows development of allowable properties for the full range of sizes and grades. Additional grades and sizes can also be tested.

   At least two other conditions (called conditions 4 and 5 for purposes of discussion) could occur:

4. Condition 4 is when two grades, such as SS and No. 2, are sampled for each of two sizes, usually 2×4 and 2×6. Clearly, the standard would allow this to be considered as two separate cases of condition 1 in calculating allowable properties for all grades of the two sizes. What the standard does not say is whether the calculations for each size should be done independently of each other or to use some of the size smoothing models of the full matrix approach. This condition has arisen once, and the decision reached by the agency submitting the species and approved by the BOR was to treat this partial matrix as a full matrix in the calculations, so as to preserve size relationships. When completed, however, only values for the two sizes (and all grades) were claimed.

5. Condition 5 is when one size–grade cell is tested, such as 2×4 No. 2. Section 4.2 of the standard states that this condition should be covered in ASTM D2915. This option has not been utilized since ASTM D1990 was established. There are two notable differences between the ASTM D1990 and ASTM D2915 approaches. First, ASTM D2915 does not give guidelines as to what sample size might constitute a "representative" sample, whereas ASTM D1990 provides these guidelines. Second, ASTM D245 is referenced in D2915 for moisture content adjustments (Green and Evans 2000b). While these adjustments might be appropriate for tests involving clear wood, they are not appropriate for adjusting test data for dimension lumber. ASTM D1990 guidelines should be followed for these two items if one contemplates submissions of a single size–grade cell of In-Grade data to the BOR.

C.3. Collecting the test data

How the test data are determined and recorded has a direct impact on the ability of the BOR to judge its representativeness. Three key aspects of the testing need to be considered: equipment calibration, information to be collected, and testing procedures. What is recorded depends on the test modes (bending, tension, and/or compression) to be evaluated.

C.3.1 Equipment calibration

The calibration of equipment is critical for accurate test results. Guidance for calibrations of testing machines is given in ASTM D4761 and an article in the "In-Grade Testing of Structural Materials" proceedings (Shelley 1989). The following suggested practices should be considered particularly important:

1. Allow enough time for warm-up of the electronics and hydraulics before calibration.

2. Identify and document the method used for calibrating load cells (proof ring or aluminum bars).

3. Make sure that the proper machine correction information is known for the test equipment used. The machine correction information is meant to compensate for the flexibility in the test frame.

4. Make sure that a calibration procedure is used that will calibrate the test equipment at the beginning of each day and every 4 hours during testing.

5. Finally, the thermometers used to determine the temperature at the time of test should be calibrated so that the relationship between their readings and a reference thermometer are known.

C.3.2 Information to be collected

For each piece of lumber the following test information should be measured or recorded if possible:

1. *Piece no.* — An identification number unique to each piece tested
2. *Size* — Actual size to nearest 1/32 in. (0.03 in.) for width and thickness, both measured at the center of the piece
3. *Actual grade* — Actual grade as determined by the quality supervisor of a grading agency
4. *Moisture content* — Preferably determined by ovendry measurements, otherwise using a resistance meter with a two-pin insulated probe inserted to 5/16-in. depth at the center of the piece length (being sure to appropriately apply a species correction factor)
5. *Temperature* — Ambient and representative lumber surface temperatures for each day (Judgment should be applied here. If temperature remains relatively constant throughout the day, once a day is sufficient. If temperature changes throughout the day, readings should be taken more often.)
6. *Rings per inch* — Estimate of growth rings per inch for each piece
7. *Percent summer wood* — Estimate of percentage summer wood when distinct rings are present
8. *Pith present* — Whether or not the pith is present in the piece
9. *Loading rate* — The rate at which the material has been loaded (in./min)
10. *Load deflection record* — A load deflection history of sufficient length to determine the modulus of elasticity from the initial linear portion of the curve. (For stress-graded lumber, data obtained for loads corresponding to a maximum stress in the specimen between 400 and 1,000 lb/in^2 will usually be adequate.)

11. *Max load* — Maximum load (lb) for each test
12. *Failure code* — Description of defect that initiated the failure according to the suggested scheme from table X1.1 of ASTM D4761 (***This is perhaps the most critical defect information as this code is used to establish the GQI.***)
13. *MOE* — Edgewise modulus of elasticity
14. *MOR* — Modulus of rupture.
15. *SPGR* — Specific gravity based on volume at time of test and preferably ovendry weight
16. *Time to failure* — For each piece

C3.3 Test procedures

The testing procedures are covered in D198 and D4761. Note that D198 and D4761 do not give identical results, but under D1990 either is an acceptable method. Pellerin and Gerhards (1980) showed that testing under D4761 is slightly more conservative than under D198. The test procedures used in the original In-Grade Program are discussed in detail by Shelley (1989). The procedures of particular importance are the following:

1. Make sure that the test span is within the range of 17 to 21 times the depth. 17 to 1 was used in the In-Grade Program.
2. Make sure that the loading rate produces failure in about 1 to 2 min.
3. When establishing MOE value for a test specimen, repeat sufficient times to verify its repeatability. In the In-Grade Program this was usually done three times. The resulting readings were then averaged.
4. For the bending test, place the defects up or down and right or left randomly within the constant moment zone.
5. If shear and compression perpendicular to the grain are required, make sure the numbering scheme employed allows any clear wood specimens cut from a piece of lumber to be traced back to original piece.

D. Step by step through D1990 for one species

After the data are collected and the GQI evaluated, MOE and MOR values must be adjusted to standard conditions and certain summary statistics reported. The standard is vague when discussing the adjustments to be used in several places. For example, section 8.3.1 states “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.” The following section discusses, step by step, how allowable properties for a representative sample of one species, tested in bending only, are calculated. Included is discussion of how various nonstandard conditions have been handled in previous submissions to the BOR. This is not to imply that they are the only acceptable way of making adjustments. However, they do offer a way that has been judged acceptable in the past. Also, because some of the adjustments are not simply multiplication of a factor times a strength property, the order of adjustment can be important. The adjustments are presented in the most logical order. Figure 1 shows the flow chart published in the standard, which may be helpful in understanding the steps of the process.

D.1 Adjust for loading conditions

ASTM D1990 refers to ASTM D198 and ASTM D4761 for mechanical test methods. These standards offer a wealth of information on the mechanical test methods that can be used. Missing from these standards is identification of test conditions that are consistent with adjustments used in calculating allowable properties. All submissions of allowable properties for MOR to the BOR from the In-Grade Program are based on bending tests that are third-point loaded with a 17-to-1 span-to-depth ratio. The MOE values have deflections measured at the load heads. Generally, they have also been measured at 17 to 1. The standard does not require that third-point loading be done with a 17-to-1 span-to-depth ratio. However, many of the data adjustments (such as moisture content) were based on models developed from tests done at 17 to 1 with third-point loading. Their applicability to the test conditions depends upon how different those test conditions are from the assumed conditions.

If not tested at 17 to 1, third-point loading, with deflections measured at the load heads, the MOE values should be adjusted to these conditions. To determine the apparent modulus of elasticity at the assumed test configuration (E_{ai2}) based on some other set of conditions for which the apparent modulus of elasticity are known (E_{ai1}), the following equation from ASTM D2915 can be used to adjust the data to 17 to 1, third-point loading, with deflections measured at the load heads:

$$E_{ai2} = \frac{1 + K_1 (h_1/L_1)^2 (E/G)}{1 + K_2 (h_2/L_2)^2 (E/G)} E_{ai1}$$

where

h is depth of beam,

L total beam span between supports,

E shear free modulus of elasticity,

G modulus of rigidity, and

K_i correction factors given in Table 1.

Figure 1. Flow chart of ASTM D1990 adjustment process.

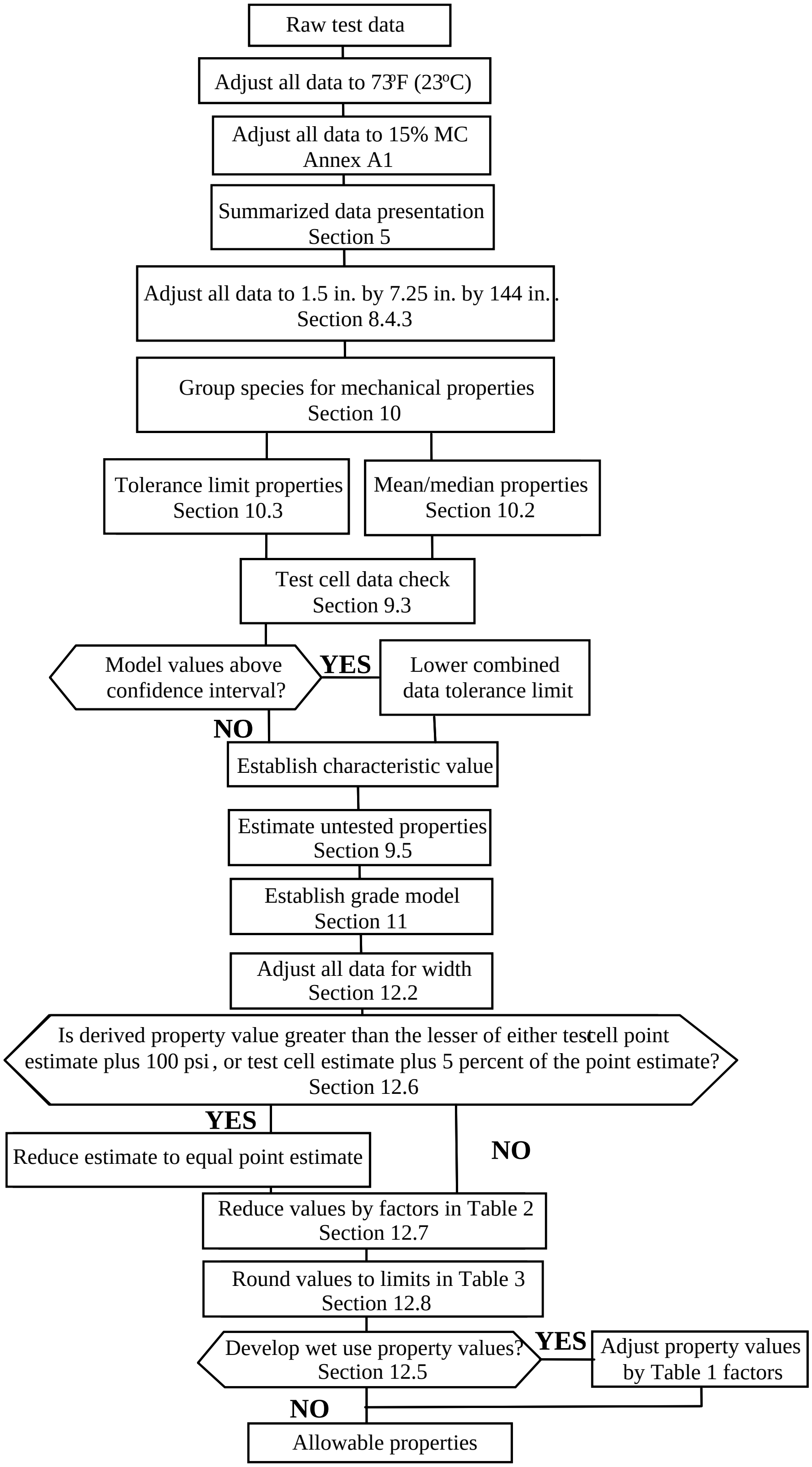


Table 1—*K* factors for adjusting apparent modulus of elasticity of simply supported beams

Loading	Deflection measurement location	K_i
Concentrated at midspan	Midspan	1.200
Concentrated at third points	Midspan	0.939
Concentrated at third points	Load points	1.080
Concentrated at outer quarter-points	Midspan	0.873
Concentrated at outer quarter-points	Load points	1.200
Uniformly distributed	Midspan	0.960

D.2 Adjust for GQI

The second adjustment should be for any cells that fail the GQI test. As previously mentioned, method 1, which uses a ratio of the assumed cell GQI over the actual cell GQI, is probably the best method. In calculating the actual cell GQI, the number produced most likely has a decimal representation, such as 51.246, because the 5th percentile of the GQI values that are not 100% is usually an interpolated value. These values should be rounded up, preferably to the next integer value (52 in this example), although some submissions have rounded up in the first decimal (51.3 in this example).

D.3 Adjust recorded temperature

The thermometer used to measure temperature is often assumed to be accurate. In the In-Grade Program, the thermometers used to measure air and wood temperature were actually calibrated. In cases where these same thermometers were used in other submissions, the values were adjusted based on the earlier calibrations.

D.4 Adjust moisture content readings

When using an electrical moisture meter to determine moisture content, two potential adjustments could be applied to the recorded moisture contents (Garrahan 1989). Both of these can be avoided if ovendry moisture contents are used, which is the preferable method. If a four-pin moisture meter is used, the first adjustment is to convert the measured moisture content from a four-pin moisture meter to a two-pin moisture meter. This is necessary because later corrections are based on a two-pin meter. The formula for the conversion is

Two pin moisture content = 0.292 + (0.908)(Four-pin moisture content)

After adjustment to a two-pin value, the moisture content reading must be adjusted for both temperature and species. Garrahan gives the formulas as

$$\mathrm{MC} = \left[\frac{R_s + \left(0.567 - 0.0260x + 0.000051x^2\right)}{0.881(1.0056^x)} - b\right] \div a$$

where

MC is moisture content at 73°F (23°C),

R_s two-pin meter scale reading,

x temperature of the wood (°C), and

a,b species correction regression coefficients.

Correction factors a and b are given for several species by Garrahan (1989, table 1) and are repeated in Table 2. Hybrid coefficients for species and species groups are also given in Table 2. These hybrid coefficients are averages of the species making up the group. Values in Table 2 missing from Garrahan (1989) were supplied to the In-Grade Program Technical Committee from a number of sources or calculated from values in Garrahan.

For species not in the table, the procedure used in submissions to date has been to average the values for similar species. For example, Austrian spruce is not in the table. However, the following spruce values are in the table:

	a	*b*
Sitka spruce	0.853	0.398
Western white spruce	0.828	–0.621
Eastern white spruce	0.702	0.818
Black spruce	0.820	–0.378
Red spruce	0.723	–0.024
Average	0.7852	0.0386

These average values would be used as correction factors for Austrian spruce. Note that Norway spruce and eastern white spruce are treated as the same species and so the correction values were included only once.

D.5 Adjust strength properties for temperature

Barrett and others (1989) discuss in detail strength property adjustment procedures that were developed in an independent study for use with In-Grade data. These procedures, which adjust properties to a common reference temperature of 73°F, have been used for all submissions to the BOR to date. Given a property value P (for MOR, MOE, or UTS) measured at moisture content M and temperature T (in °F), a percentage change in property value is calculated as if the material is green (23% or higher moisture content), denoted PCG, and as if it were dry (12% or lower moisture content), denoted PCD. This is done as follows:

Table 2—Regression coefficients for equations used for species effects on moisture meters

Species or species group	*a*	*b*	Source
Eastern hemlock	0.904	–0.051	Pfaff, 1974
Sitka spruce	0.853	0.398	Salamon, 1971
Red pine	0.730	0.793	Pfaff, 1974
Eastern white pine	0.821	0.556	Pfaff, 1974
Western white pine	0.969	–0.391	Salamon, 1971
Ponderosa pine	0.849	0.233	Anonymous; Moore moisture meter
Western red cedar	1.019	–0.455	Salamon, 1971
Yellow Red Cedar	0.922	–0.751	Salamon, 1971
Trembling Aspen	0.91	2.75	Bramhall and Salamon, 1978
Western white spruce	0.828	–0.621	Salamon, 1971
Eastern white spruce	0.702	0.818	Pfaff, 1974
Lodgepole pine	0.835	–0.545	Salamon, 1971
Jack pine	0.749	0.467	Pfaff, 1974
Alpine Fir	1.07	–2.95	Bramhall and Salamon, 1978
Balsam Fir	0.900	0.35	Pfaff, 1974
Black spruce	0.820	–0.378	Cech and Pfaff, 1975
Red spruce	0.820	–0.378	Pfaff and Garrahan, 1984
Eastern White Cedar	0.812	0.171	Letter from Pfaff
Douglas-fir (coastal)	0.813	1.888	Letter from Pfaff
Douglas-fir (interior)	0.857	0.726	Letter from Pfaff
Douglas-fir	0.835	1.307	Average of Douglas fir (coast) and Douglas fir (interior)
Western larch	0.843	–0.534	Letter from Pfaff
Douglas Fir–Larch	0.838	0.693	Average of two Douglas firs and Western larch
Amabilis fir	0.882	–0.385	Letter from Pfaff
Western hemlock	0.822	0.202	Letter from Pfaff
Hem–Fir	0.852	–0.092	Average of Amabilis fir and Western Hemlock
Aspen	0.772	0.866	
Southern Pine[a]			

[a]Southern Pine is a special case in which the meter used was a two-pin Delmhorst Douglas Fir meter (Delmhorst Instrument Company, Towaco, New Jersey) that came with a modified scale for Southern Pine. The In-Grade Program Technical Committee decided that this adjustment was appropriate. Anyone using another meter without this modification would need to supply a species adjustment for Southern Pine.

For MOR of material No. 1 grade or lower, PCD = 0 and PCG = $56.8904 - 1.56207T + 0.007154281T^2$ if $T < 46$°F or PCG = 0 if $T \geq 46$°F. For MOR of Select Structural material, use 60% of these values. For MOE of all grades, PCG = $27.91398 - 0.613821T$ if $T < 45$°F (PCG = 0 otherwise) and PCD = $4.843212 - 0.113983T$ if $T < 42$°F (PCD = 0 otherwise). The temperature limits are the approximate temperatures where PCD = PCG = 0. If PCD < 0 or PCG < 0, then 0 is used.

Given the percentage changes, the correction is the green change, the dry change, or an interpolation between them based on the actual moisture content M. So

PC	= PCD	if $M \leq 12$
	= PCG	if $M \geq 23$
	= PCD + [(M – 12)/11](PCG – PCD)	if $12 < M < 23$

The property is then divided by the percentage change, 1 + (PC/100), to adjust it for temperature.

These adjustments for temperature can be avoided if testing is done at temperatures above the temperature where no change is taken in the property. Note that the adjustments are not considered appropriate for temperatures outside the range of –10°F to 90°F. However, they have been used for data as high as 102°F. Because the properties should have lower values at higher temperatures, using no adjustment for specimens up to this limit was considered conservative.

Recent research results reported by Green and others (1999) and Green and Evans (2001a,b) suggest that a better adjustment procedure for MOE is available. Appendix 1 provides details of this approach.

D.6 Adjust data to 15% moisture content

The standard suggests that samples be tested at 15% moisture content and that if this is not possible, the properties should be adjusted to 15% moisture content using procedures in Annex A1 or "by procedures documented as adequate for the method adopted prior to developing the characteristic values." All submissions to the BOR have used one of the two procedures in Annex A1. A word of caution is needed for the MOR model in Annex A1. The initial moisture model for MOR proposed for the standard (Green and Evans 1989) required a computer program to run. This original model was designed for adjusting specimens for the whole distribution of MOR values. The simplified MOR model in ASTM D1990 was an approximation of the lower end of the more complex model. As such it might not be suitable for making moisture adjustments where the distributional form of the adjusted values is important.

The adjustment of MOR and MOE values to 15% moisture content starts with the formulas from Annex A1 of the standard, which state that a property at one moisture content is adjusted to its value at a second moisture content as follows:

For MOR ≤ 2,415 lb/in^2,

$$P_2 = P_1$$

For MOR > 2,415 lb/in^2,

$$P_2 = P_1 + [(P_1 - B_1)/(B_2 - M_1)](M_1 - M_2)$$

For MOE,

$$P_2 = P_1[B_1 - (B_2M_2)]/ [B_1 - (B_2M_1)]$$

where in each formula

P_1 is property at moisture content M_1 (lb/in^2 for MOR, $\times 10^6$ lb/in^2 for MOE),

P_2 property at moisture content M_2 (lb/in^2 for MOR, $\times 10^6$ lb/in^2 for MOE),

M_1 moisture content 1 (%),

M_2 moisture content 2 (%), and

B_1 =	2,415	for MOR
=	1.857	for MOE
B_2 =	40	for MOR
=	0.0237	for MOE

Thus, property P_1 measured at moisture content M_1 can be converted to property P_2 at 15% moisture content (that is, M_2 = 15%). The standard indicates that these adjustments are valid for moisture contents between 10% and 23%. Because 23% is the assumed fiber saturation point for these models, any moisture content above 23% is changed to 23% for use in the formulas. For moisture contents less than 10%, previous submissions have either assumed no change below 10% or used the formulas down to 8% and assumed no change below 8%. This latter approach is a bit more conservative as it will result in a slightly lower property value at 15% moisture content.

For most submissions, this completes the adjustment. However, the standard does allow "normalization" of data. Only the In-Grade submissions from Canada have used this process. This procedure is supposed to help "match" the mean and spread of a species being adjusted to the mean and the spread of the species used to create the moisture model. This procedure is not used on MOE because that model is "self-normalized." The concern that led to the concept of normalization was that the MOR, UTS, and UCS models flatten out and show no change in properties in the lower tails of the species used to create the models. Without some type of adjustment, a much weaker species might have a significant portion of its distribution below this limit. There was some concern by members of the In-Grade Program Technical Committee that if the models had been based on these weaker species, it would have been scaled down so that the same percentage of specimens in the lower tail would have no adjustment. Normalization was an attempt to fit the data to the model. In practice, it had very little effect and hence is probably not worth the calculation. However, it is allowed under the standard. To "normalize" the data, values are first adjusted to 15% moisture content, and the mean of the 2×4 Select Structural values at 15% is calculated. The data at the original moisture content are then adjusted to "fit" the model using

$$P_1^* = [(P_1 - C)(A/B)] + C$$

where A is the mean property of the 2×4 Select Structural 15% moisture content values of the species used to create the model (which is 10,120.45 for MOR), B is the mean property of the 2×4 Select Structural 15% moisture content values of the species being adjusted, and C = 1,000 for MOR.

This "adjusted property value" P_1^* at the original moisture content M_1 is then modified to an adjusted property value P_2^* at 15% moisture content using the standard procedure. This adjusted property value P_2^* must then be "unadjusted" or scaled back to its original scale using

$$P_2 = [(P_2^* - C)(B/A)] + C$$

Again, because it makes little difference, it is recommended that it not be used.

D.7 Calculate summary statistics

For each size–grade cell of data adjusted to 15% moisture content, a set of summarizing statistics must be calculated for every property. These statistics are sample size, mean property, median property, standard deviation, estimate of the 5th percentile, 75% lower tolerance limit for the 5th percentile, and 75% upper and lower confidence intervals on the 5th percentile. Sample size, mean, median, and standard deviation are common statistics available in spreadsheets and statistical packages. The 5th percentile, 75% lower tolerance limit for the 5th percentile, and 75% upper and lower confidence intervals on the 5th percentile are not so easily available. They can be estimated nonparametrically or based on a distributional form. The standard clearly prefers the nonparametric estimates, and all submissions to date have used nonparametric estimates. The standard does state "if a distributional form is used to characterize the data at the standardized conditions, its appropriateness shall be demonstrated" and then refers to ASTM D2915 for "guidance on the selection of distribution." The standard also states that you must "document any 'best fit' judgments made in the selection of a distribution."

Calculation of a 5th percentile, a 75% lower tolerance limit on a 5th percentile, and 75% upper and lower confidence intervals on the 5th percentile is not a simple procedure, whether the statistics are nonparametric or based on a distribution. In the In-Grade Program, these estimates were calculated nonparametrically and based on the normal, log-normal, two-parameter Weibull, and three-parameter Weibull distributions. Because of the extent and depth of the In-Grade Program, detailed fit analyses were carried out to study the appropriateness of different distributions. Many other distributional forms may be appropriate to consider. The method of performing these calculations is beyond the scope of this report.

Whether or not nonparametric estimates are used, the standard asks for graphical presentations of the data. Typically this has been interpreted to be histograms for every size–grade cell. If a distributional form is to be used, the standard asks for the histograms or cumulative distribution functions of the sample to be superimposed on the parametric function. For example, if a normal distribution is used, the standard requires for every size–grade cell for each property either (1) a graph of the bell curve of the normal distribution superimposed on the histogram or (2) the cumulative distribution function of the data superimposed on the cumulative distribution function of the fitted distribution. Most spreadsheets can create a histogram but not the graphics required for a distributional fit. So a nonparametric approach has been easier. The standard says the class widths of any histogram produced should meet the requirements of ASTM D2915 table 7, which gives widths for different strength properties.

The standard does not require additional summary statistics or graphics. However, prudent data analysis would suggest that for each size–grade cell, histograms or box plots be made for the data from each variable measured, including dimensions, moisture content, temperature, and strength properties, to make sure that errors have not crept into the data set. In addition, it makes sense to produce scatter plots of combinations of variables, such as MOR against MOE. This has helped find recording problems in many data sets. The process of calculating allowable properties from ASTM D1990 is time consuming enough that it usually pays to spend extra time making sure there are no problems with the data.

D.8 Adjust dimensions of the specimens to 15% moisture content

The next step is to adjust the dimensions of the specimens to what they would have been if they were measured at 15% moisture content. This is done using the formula given in appendix X.1 of ASTM D1990. The formula to obtain the dimensions at one moisture content when the specimen was measured at a different moisture content is

$$d_2 = d_1 \frac{1 - [(a - bM_2)/100]}{1 - [(a - bM_1)/100]}$$

where

d_1 is dimension (in.) at moisture content M_1,

d_2 dimension (in.) at moisture content M_2,

M_1 moisture content (%) at dimension d_1,

M_2 moisture content (%) at dimension d_2, and

a and b are given in the following tabulation:

	Width		Thickness	
	a	*b*	*a*	*b*
Most species	6.031	0.215	5.062	0.181
Redwood, western red cedar, and northern white cedar	3.454	0.157	2.816	0.128

To use this model, enter the dimension at time of test as d_1, the adjusted moisture content from step D.4 as M_1, and 15 as M_2. The standard indicates that the assumed fiber saturation point for this model is 28% for most species. For redwood, western red cedar, and northern white cedar, the assumed fiber saturation point is 22%. This means that any moisture content above the assumed fiber saturation point should be changed to the assumed fiber saturation point for use in this model. Because the assumed fiber saturation point for the models adjusting strength properties to 15% in section D.6 was 23%, submissions under ASTM D1990 need to use the appropriate limit for each model.

D.9 Adjust property values to the characteristic size

Design values developed under ASTM D1990 are not determined cell by cell. Instead, for all sizes tested of each grade, the MOR and MOE values at 15% moisture content are adjusted to a characteristic size of nominal 2×8 at 144 in. This removes some of the irregularities in real data sets and stabilizes the design values. Because there are recognized size effects in many properties, a model must be used to adjust the properties to a common size called the characteristic size. The model given in the standard is

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

where

F_1 is property value (lb/in^2) at volume 1,

F_2 property value (lb/in^2) at volume 2,

W_1 width (in.) at F_1,

W_2 width (in.) at F_2,

L_1 length (in.) at F_1,

L_2 length (in.) at F_2,

T_1 thickness (in.) at F_1,

T_2 thickness (in.) at F_2, and

$$w = 0.29, \quad l = 0.14, \quad t = 0 \quad \text{for MOR}$$
$$w = l = t = 0 \quad \text{for MOE}$$

The dimensions adjusted to 15% moisture content from D.8 are entered as W_1 and T_1. L_1 is the test span (such as 59.5 in. for a 2×4). Then W_2 = 7.25, T_2 = 1.50, and L_2 = 144. Note there is no thickness adjustment, so T_1 and T_2 are not needed. Depending upon the property, other values may not be needed. The standard cautions that this formula has not been verified for widths less than 3.5 in. or greater than 9.25 in. The formula is also appropriate only for specimens with nominal thicknesses of 2 to 4 in.

The standard does allow use of the standard dressed size of a specimen if its actual dimensions are within ±1/16 in. in thickness and ±1/4 in. in width. So if the actual dimensions of a specimen after being adjusted to 15% moisture content in step D.8 were 1.53 by 3.47 in., 1.50 and 3.50 could be used in the formula above. This means if there were 100 specimens and 90 had dimensions within these limits, the standard dressed dimensions for the 90 specimens and the actual moisture-adjusted dimensions for the 10 specimens that did not meet the requirement could be used. In practice, this is not a good idea. Trying to mix actual dimensions for some specimens and standard dressed dimension for others is not very convenient in a spreadsheet and can easily lead to errors. It is recommended that any submission under this standard to the BOR use the actual dimensions.

D.10 Establish the characteristic values

Once all the data have been adjusted to the characteristic size, it is time to calculate the characteristic values. The characteristic value for a grade is the 75% lower tolerance limit for the 5th percentile for MOR, UTS, and UCS values adjusted to 15% moisture content and the characteristic size. There is a characteristic value for each grade and property combination tested. The standard states in section 9.4 that the characteristic value for MOE is “the mean, median and the lower tolerance limit (or other measure of dispersion).” What exactly this means is unclear. However, every submission based on this standard has used the mean value as the characteristic value for MOE. Current practice in regard to calculating the characteristic values has been to repeat the summary statistics of step 7 for all data adjusted to the characteristic size. This means that the mean, median, standard deviation, 5th percentile, 75% lower tolerance limit, and 75% lower and upper confidence limits on the 5th percentile are available for every property. The characteristic values are then readily availble to be used to develop design values.

D.11 Conduct the section 9.3 and section 12.6 data checks

To ensure that the resulting design values are not substantially greater than the experimental data obtained for any size–grade cell, two data checks are included in the standard. These data checks are performed on MOR, UTS, and UCS. There is no data check for MOE.

D.11.1 The section 9.3 data check

The first data check is given in section 9.3 of the standard. To perform this check, the characteristic value for each grade is entered into the size model of step D.9 and adjusted to each size of each grade tested. It is compared to the 75% upper confidence limit on the 5th percentile of the data in the cell. This value is part of the summary statistics calculated in step D.7. If the adjusted characteristic value for each grade is below the 75% upper confidence limit on the 5th percentile in every size tested in that grade, the characteristic value passes the check and nothing is done. If the adjusted characteristic value is above the 75% upper confidence limit for any given size, the grade's characteristic value is lowered to a value at which it will pass in every size cell of that grade. For example, suppose for MOR the Select Structural characteristic value is 2,988 lb/in^2 and the 2×4 Select Structural 75% upper confidence limit on the 5th percentile is 4,107 lb/in^2. Using the size model to adjust the characteristic value from a width of 7.25 in. and a length of 144 in. to a width of 3.50 in. and a length of 60 in. (assuming testing was at about a 17-to-1 span-to-depth ratio) gives a value of 4,172 lb/in^2, which is greater than the 75% upper confidence limit of 4,107 lb/in^2. The new characteristic value can be found by adjusting the 75% upper confidence limit on the 5th percentile to the characteristic size. Thus the characteristic value in the example would need to be lowered to 2,941 lb/in^2.

D.11.2 Section 12.6 data check

The next step is to perform the section 12.6 data check. To perform this check, the individual grade characteristic value resulting from the 9.3 data check are put back into the size model of step D.9 and adjusted to every size tested. These values are compared to the test cell nonparametric 5th percentile instead of the upper 75% confidence limit on the 5th percentile as in the 9.3 data check. If it is no more than 100 lb/in^2 or 5% (whichever is smaller) above the 5th percentile, the value passes. However, if the value calculated from the characteristic value is too high, something must be done. In the In-Grade Program, the Southern Pine Inspection Bureau lowered the estimated property in the cells that failed. All other submissions in the In-Grade Program and subsequent submissions have lowered the characteristic values for a grade if any size cell in the grade failed the 12.6 check. This preserves the size effect curve in allowable properties that are developed and is the method that this report in subsequent discussion will assume is being used. To continue the example from above, suppose the 5th percentile of the 2×4 Select Structural data is 3,917 lb/in^2. The 5th percentile plus 100 lb/in^2 is 4,017 lb/in^2, and 5% over the 5th percentile is 4,113 lb/in^2. The smaller of these values is 4,017 lb/in^2. As seen in the example of above, the estimated value for this cell based on the reduced characteristic value of 2,941 lb/in^2 is 4,107 lb/in^2, which is above the limits of the 12.6 data check. To pass the 12.6 data check, the characteristic value for this grade must be further reduced to 2,877 lb/in^2.

Recent submissions of foreign species to the BOR have tested only properties in bending. The standard does contain a conservative procedure to estimate the characteristic values for properties not tested from the MOR characteristic value. The location of this conservative procedure in the standard and the standard's flow diagram would imply that it be done before the 12.6 data check. However, if the characteristic values for properties not tested is estimated using the procedures of section 9.5.2 of ASTM D1990 and the MOR characteristic value is later lowered from the 12.6 data check, the other estimated characteristic values might not be conservative. Therefore, all submissions to the BOR that have estimated characteristic values for untested properties have performed the 12.6 data check before estimating the characteristic values. Because any submission to the BOR is based in part on historical precedence, it is recommended to continue the practice of performing the 12.6 data check before estimating other characteristic values.

D.12 Estimate characteristic values for untested properties

Following the recommendation to do the 12.6 data check before calculating the characteristic values of untested properties, it is now time to take the resulting characteristic value for MOR from the 12.6 data check and estimate characteristic values for UTS and UCS. The characteristic value for UTS (T) can be calculated from the characteristic value for MOR (R) using the formula

$$T = 0.45R$$

and the characteristic value for UCS (C) can be calculated from the characteristic value for MOR (R) using

$$\begin{aligned} C &= \left[1.55 - 0.32\frac{R}{1{,}000} + 0.022\left(\frac{R}{1{,}000}\right)^2\right]R & R &\le 7{,}200 \\ &= 0.39R & R &> 7{,}200 \end{aligned}$$

where R is measured in pounds per square inch.

D.13 Develop allowable properties from the final characteristic values for a full sampling matrix

At this point the final characteristic values are available for MOR, MOE, UTS, and UCS. A series of calculations, some of which are not specified in the standard, can convert these characteristic values into the allowable property values typically submitted to the BOR for a full sampling matrix. Each of the properties MOR, UTS, UCS, and MOE are discussed separately. The general procedure for MOR, UTS, and UCS follows four steps:

1. Get final characteristic values for every grade at the characteristic size (1.5 by 7.25 by 144 in.).
2. Use the size models of section D.9 to adjust the final characteristic values to a set of specific different sizes.
3. Make some specific adjustments to these numbers for factor of safety and DOL effects.
4. Round the values according to specified rounding rules.

MOE has a slightly different order of steps, which are discussed later.

D.13.1 MOR

Starting with the MOR characteristic values for Select Structural and No. 2 grades, labeled RSS and R2 respectively, the grade model for MOR says the characteristic values for the other major structural grades of dimension lumber are calculated as follows:

Grade	Calculation
No. 1	R1 = [(RSS + R2)/2]0.85
No. 3	R3 = (26.0/45.0)R2
Construction	Rcon = (34.0/45.0)R2
Standard	Rstan = (19.0/45.0)R2
Utility	Rutil = (9.0/45.0)R2
Stud	Rstud = R3

These characteristic values for each grade are at the characteristic size of 1.5 in. thick, 7.25 in. wide, and 144 in. long. For each grade, the equation in step D.9 is used to calculate values for the following specified widths and lengths (in inches):

Grade	Width	Length
Select Structural	11.25	240
No.1	11.25	240
No.2	11.25	240
No.3	11.25	240
Construction	3.50	144
Standard	3.50	144
Utility	3.50	144
Stud	5.50	120

After adjusting the values for each grade to these widths and lengths, adjustments to the values are made. For MOR, all size-adjusted values are divided by 2.1, as discussed in section 12.7 of the standard. The adjustments in ASTM D1990 are for softwoods. ASTM D245 gives adjustments for hardwoods.

Finally, the numbers are rounded to the nearest 50 lb/in^2 for stresses of 1,000 lb/in^2 or greater and to the nearest 25 lb/in^2 for stresses less than 1,000 lb/in^2, as specified by the standard's rounding rules given in table 3 of the standard. These are the allowable properties that would be submitted to the BOR for MOR.

D.13.2 UTS

Starting with the UTS characteristic values for Select Structural and No. 2 grades, labeled TSS and T2, respectively, the grade model for UTS specifies that the characteristic values for the other major structural grades of dimension lumber are calculated as follows:

Grade	Calculation
No. 1	T1 = [(TSS + T2)/2]0.85
No. 3	T3 = (26.0/45.0)T2
Construction	Tcon = (34.0/45.0)T2
Standard	Tstan = (19.0/45.0)T2
Utility	Tutil = (9.0/45.0)T2
Stud	Tstud = T3

These characteristic values for each grade are at the characteristic size of 1.5 in. thick, 7.25 in. wide and 144 in. long. For each grade, the equation in step D.9 is used to calculate values for the following specified widths and lengths in inches:

Grade	Width	Length
Select Structural	11.25	240
No.1	11.25	240
No.2	11.25	240
No.3	11.25	240
Construction	3.50	144
Standard	3.50	144
Utility	3.50	144
Stud	5.50	120

After adjusting the values for each grade to these widths and lengths, adjustments to the values are made. For UTS, all the size-adjusted values are divided by 2.1, as discussed in section 12.7 of the standard.

Finally, the numbers are rounded to the nearest 50 lb/in^2 for stresses of 1,000 lb/in^2 or greater and to the nearest 25 lb/in^2 for stresses less than 1,000 lb/in^2. These are the allowable properties that would be submitted to the BOR for UTS.

D.13.3 UCS

Starting with the UCS characteristic values for Select Structural and No. 2 grades, labeled CSS and C2, respectively, the grade model for UCS specifies that the characteristic values for the other major structural grades of dimension lumber are calculated as follows:

Grade	Calculation
No. 1	C1 = 0.95[(10/17)(CSS – C2) + C2]
No. 3	C3 = (30.0/52.0)C2
Construction	Ccon = (4/17)(CSS – C2) + C2
Standard	Cstan = (46.0/52.0)C2
Utility	Cutil = (30.0/52.0)C2
Stud	Cstud = C3

These characteristic values for each grade are at the characteristic size of 1.5 in. thick, 7.25 in. wide and 144 in. long. For each grade, the equation in step D.9 is used to calculate values for the following specified widths (recall there is no length effect in UCS):

Grade	Width
Select Structural	11.25
No.1	11.25
No.2	11.25
No.3	11.25
Construction	3.50
Standard	3.50
Utility	3.50
Stud	5.50

After adjusting the values for each grade to the these widths and lengths, adjustments to the values are made. For UCS, all values are divided by 1.9, as discussed in section 12.7 of the standard.

Finally, the numbers are rounded to the nearest 50 lb/in^2 for stresses of 1,000 lb/in^2 or greater and to the nearest 25 lb/in^2 for stresses less than 1,000 lb/in^2. These are the allowable properties that would be submitted to the BOR for UCS.

D.13.4 MOE

Starting with the MOE characteristic values for Select Structural and No. 2 grades, labeled ESS and E2, respectively, the first step for MOE is to convert these characteristic values to a 21-to-1 uniformly loaded value. Using the equation in step D.1 from ASTM D2915 and assuming testing was at 17-to-1 third point loaded with deflections measured at the load points, this would mean multiplying our characteristic values ESS and E2 by

$$\frac{1+[(1.080)(1/17)^2(16)]}{1+[(0.960)(1/21)^2(16)]}$$

The grade model for MOE specifies that the characteristic values for the other major structural grades of dimension lumber are calculated as follows:

Grade	Calculation
No. 1	E1 = (ESS + E2)/2
No. 3	E3 = (17/36)(0.2)(E2) + (0.8)(E2)
Construction	Econ = (25/36)(0.2)(E2) + (0.8)(E2)
Standard	Estan = (10/36)(0.2)(E2) + (0.8)(E2)
Utility	Eutil = 0.8(E2)
Stud	Estud = E3

There is no thickness, width, or length effect for MOE, and the property reduction factor of section 12.7 of the standard is 1. So all that remains is to round the numbers. For MOE, the numbers are rounded to the nearest 100,000 lb/in^2. These are the allowable properties that would be submitted to the BOR for MOE.

D.14 Values for other sizes and grades and handling a less than full sampling matrix

Every species submission based on a full test matrix, except Southern Pine, has developed values at the widths and length given in section D.13. A table of size adjustments (AF&PA 1997) can then be used to adjust these values to different dimensions and at implied lengths for use in structural design. For example, the MOR size adjustment for a 2×4 SS piece would multiply the value in section D.13.1 by 1.5, resulting in a 2×4 number that would correspond to the value found when adjusting to a length of 149 in. This 149-in. length is not normally produced, but it has been argued that it is close enough to the standard length of 144 in. for the value to be representative of a 2×4 at the standard length. Southern Pine values for different dimensions to be marketed were calculated individually, instead of using a size adjustment table, and are published for each width at a stated length. So the Southern Pine 2×4 SS allowable property is calculated at 144 in. in length. The 2×4 SS value calculated using the 1.5 factor is smaller than the value produced by actually taking it to 144 in. At 2×10, this is reversed. The 2×10 SS factor of 1.1 results in a value that would be equal to that based on a length of 182 in., whereas the Southern Pine value is calculated at 240 in., which yields a smaller 2×10 allowable property. Nothing is wrong with either approach. It is important, however, to know what each approach is doing and for submissions from an organization to the BOR to be consistent with their past practices in order to prevent confusion. It would not be acceptable, for example, to use the 1.1 factor for 2×10 SS values and to claim it is for 240 in. Nor would it be appropriate for an organization to claim a 2×10 SS allowable property at 182 in. for one species and at 240 in. for another. This can only lead to confusion in designing with wood. Finally, because all submissions, except Southern Pine, have used the factor approach, it would seem reasonable to standardize on it to further remove confusion in designing with wood.

The difference in these two approaches is important when dealing with less than the full sampling matrix discussed in section C.2. For example, with only one grade of material but three sizes, allowable properties can be calculated for all sizes of that grade using either the factors found in the size adjustment tables (AF&PA 1997) or by adjusting to a claimed length. Because rounding of values for less than a full matrix usually occurs after the size adjustment, consistency would appear to be important. Going to 149 in. for 2×4s of one species by using the 1.5 factor and going to 144 in. with the size model of step D.9 (which produces a factor of 1.507) for a different species could look like an attempt to be able to round a species up instead of down. In an effort to address this issue, the BOR recently decided that submissions of less than full matrices would be for set lengths. The lengths chosen are as follows:

Size	Length
2×4	144
2×6	144
2×8	144
2×10	192
2×12	240

This ensures consistency with future submissions tested with less than a full matrix, but there could be an inconsistency between two species with exactly the same final values at the end of the calculations of section D.13.1, as in the following example: Suppose species A was tested with a full matrix, and species B was tested only with 2×4s. Both species have a select structural MOR of 4.872×10^3 lb/in^2 after taking the value to 2×12 at 240 in. long. For species A, this value is divided by 2.1 to give 2.320 and rounded to 2.300. Someone designing anything with a 2×4 for species A would use 1.5 times 2.300, which is 3.450×10^3 lb/in^2. However, for species B, the 4.872 value is adjusted to 2×4 at 144 in. (using the factor of 1.507), giving 7.342, which when divided by 2.1 to yield 3.496. This is rounded to 3.500 as an allowable 2×4 number and used as a design value for species B 2×4s. Some of this difference is due to the point at which rounding of values occurs and some to the difference in factors 1.5 and 1.507. In the interest of consistency, allowable properties for partial matrices should probably still be given at the dimensions and lengths of full matrix submissions with a footnote indicating that the allowable properties can be used only when designing for the sampling matrix actually tested. Using the factors for consistency would eliminate differences in implied lengths.

E. Computer programs useful in developing allowable properties

Developing allowable properties under ASTM D1990 is a complicated process. A series of computer programs has been developed that can greatly simplify the process. This section introduces the programs and discusses at what point in the process they might be useful.

These programs are available over the Internet at http://www1.fpl.fs.fed.us, following the links to “Executable Software and Downloadable Programs” and then “Computer programs useful in developing allowable properties for a single species under ASTM D1990.” This last link will load the beginning web page for these programs (Fig. 2). This page allows access to this report and to a set of programs that will do many of the calculations necessary in making a submission under ASTM D1990. The programs can be run over the Internet, which is how they will be described, or a more basic version is available to download as Fortran source code that the user could compile and run. Following the link “go to the programs” will load a page containing links to all the programs discussed here (Fig. 3). For simplicity in the rest of this report, this page will be referred to as “the ASTM D1990 computer program index page.”

E.1 Anonymous ftp

Before proceeding, a user of these programs must be able to transfer a data file via anonymous ftp to the pub/data directory. Not every program discussed will require an input data set. However, several do, and it is important to be able to place the data file where the programs can find it. Ftp can be run from the command line of all UNIX systems and from the command line of a DOS window session for Windows 95 (Microsoft, Redmond, Washington) systems. Alternatively, mouse-based ftp programs are available for most systems. If using a Windows system, TCP/IP stack software and ftp software will be needed. Direction on how to install and run ftp software should be sought from the user’s Internet service provider. The user can also search on the Internet for sources of ftp software.

Once TCP/IP and ftp are running, enter the directory that contains the data to be sent and enter

ftp www1.fpl.fs.fed.us

This will result in a prompt for a login name. Enter

anonymous

When prompted next for a password, enter your e-mail address (for example, vherian@fs.fed.us). To access the directory where the data are to be placed, enter

cd pub/data

followed by

put filename

Figure 2

Computer Programs Useful in Developing Allowable Properties for a Single Species Under ASTM D1990

ASTM D1990, "Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens," is the consensus standard used to make submissions to the Board of Review (BOR) of the American Lumber Standards Committee (ALSC) of allowable properties for many U.S., Canadian and foreign species. Recently, it has become apparent how difficult it is to make the calculations for such a submission. Some of the calculations are clearly specified in the standard. But in some cases, the standard just indicates you need to make an adjustment, but does not tell one how to do so.

Evans, Kretschmann, Herian and Green (2001) discuss in detail how one can develop design values under this standard that are consistent with how past species have been done. Since many of the calculations in the standard are difficult and therefore easy to make mistakes on, particularly when trying to do the calculations in a spreadsheet as most recent submission have been done, they introduce a set of computer programs that handle some of the calculations and can reduce the difficulties and potential errors in the process.

This web page links to computer programs that can be run over the web and the Fortran versions of the programs that can be downloaded, compiled and run on your computer.

Go to interactive programs

where filename is the name of the data file to be transferred. A word of caution: If a data file already in the directory shares the filename you enter, the data transfer will not occur. To determine filenames already used in the *pub/data* directory, enter

ls

after accessing the directory. This will provide a list of files in the directory. Files are purged from this directory at least twice a week to minimize the problem of duplicate names. After the data file has been successfully transferred (again, an *ls* command might be useful to ensure that the file transferred successfully), enter

quit

Now the data file is ready to be read by the program for which it was prepared. When a program uses a transferred data file, it performs a set of calculations and writes the results, along with the original input data, to the file called *filename.res*, where *filename* is the name of the data file used. Programs that use a data file will prompt the user for the *filename* and offer a "submit" button to start the program. After the program runs, a message will indicate that the data and results have been written to the pub/data directory and are ready for retrieval.

When using ftp to retrieve a file, enter the directory where the results are to be placed and then enter

ftp www1.fpl.fs.fed.us

This will result in a prompt for a login name. Enter

anonymous

When prompted for a password, enter your e-mail address. Next enter

cd pub/data

followed by

get filename.res

where *filename* is the name of the data file that was used by

Figure 3

Interactive Computer Programs Useful in Developing Allowable Properties Under ASTM D1990

DISCLAIMER: *These programs are meant to be an aid to people developing design values under ASTM D-1990. Many of them are still in development, so we can take no responsibility for any results that you get from using them. If you find what you perceive as an error in a program, please let us know so that we can continue to improve these programs.*

SRATIO - a program to calculate strength ratios from failure codes

TEMPADJ - a program to adjust specimen properties from one temperature to another

MCADJ - a program to adjust specimen properties from one moisture content to another

NONPAR - a program to calculate nonparametric percentile estimates, tolerance limits and confidence intervals for percentiles

DATACHECK - a program to do the 9.3 and 12.6 datachecks

ALLFROMR - a program to calculate MOR, UTS, and UCS design values from MOR characteristic values

EDESIGN - a program to calculate MOE design values from MOE characteristic values

the program. After the data transfer has been completed, exit ftp by typing

quit

The data file returned will contain all the original information plus an appended column(s) (depending on the program) of calculated information.

E.2 Grade quality index (strength ratio) program SRATIO

Section C of this report discusses the importance of obtaining a representative sample and the concept of a grade quality index. As previously mentioned, all submissions to the BOR have used strength ratios calculated from failure codes as GQI values. The GQI program calculates strength ratios from failure codes found in table X1.1 of ASTM D4761. The program expects a failure code of the form XX–YY where XX is the two digit code showing the characteristic associated with the failure and YY is the two digit code describing the extent of this characteristic, as discussed in ASTM D4761. It does not calculate a strength ratio for every failure code in ASTM D4761. The codes for which it will calculate strength ratios and the formulas it uses are discussed in Appendix 2.

E.2.1 Ftp data format

The input data should be in the following format:

Columns 1–10	Specimen ID
Columns 12–16	Specimen thickness (in.) (for example, 1.540)
Columns 18–23	Specimen width (in.) (for example, 3.541)
Columns 27–28	Two-digit characteristic code (for example, 17 for an edge of wide face knot)
Columns 30–31	Two-digit size of characteristic code (for example, 08 for ½-in. edge of wide face knot)

E.2.2 Example

To illustrate the use of the SRATIO program, consider the following 10-specimen data set, called *sratio_example*, which has all the requested information in the proper columns:

```
4K2011     1.489 3.396    18 20
4K2091     1.491 3.410    17 21
4K2123     1.504 3.367    14 20
4K2198     1.504 3.476    19 21
4K2247     1.500 3.477    20 41
6KS016     1.517 5.512    51 12
6KS166     1.503 5.543    11 13
8K2193     1.515 7.306    42 11
8KS097     1.505 7.309    10 00
8V2118     1.501 7.293    34 30
```

Following the instructions on anonymous ftp (section E.1), the data file is moved to the pub/data directory of www1.fpl.fs.fed.us. Using a web browser, the SRATIO program is accessed as previously described (section E). Enter the data set name, *sratio_example,* in the box (Fig. 4) and click on "submit." The program indicates when the calculations are completed and anonymous ftp can be used to retrieve the file *sratio_example.res,* which contains the following:

```
 4K2011     1.489 3.396    18 20  46.182
 4K2091     1.491 3.410    17 21  39.353
 4K2123     1.504 3.367    14 20  67.709
 4K2198     1.504 3.476    19 21  40.246
 4K2247     1.500 3.477    20 41  64.073
 6KS016     1.517 5.512    51 12  68.700
 6KS166     1.503 5.543    11 13  78.372
 8K2193     1.515 7.306    42 11
 8KS097     1.505 7.309    10 00 100.000
 8V2118     1.501 7.293    34 30  52.504
```

Note that for codes for which a strength ratio cannot be calculated, the program returns a blank value for the strength ratio. Also note that the first column is blank and all values from the original data set are shifted one column to the right (this is to prevent possible printing problems). The strength ratios calculated by this program are used to calculate the GQI. Many programs, including NONPAR (section E.5), can be used on these strength ratios to calculate the 5th percentile after missing strength ratios and strength ratios of 100 are removed (see section C.1 for further discussion of GQI values).

E.3 Temperature adjustment program TEMPADJ

Step D.5 of the process of getting allowable properties using ASTM D1990 is to adjust lumber properties to room temperature. For many studies under laboratory conditions, no adjustment is needed. However, for the In-Grade Program data and some recent submissions tested in the field, such a correction has been necessary. The temperature adjustment program, TEMPADJ, is accessed from the ASTM D1990 computer program index page. This program adjusts MOR values from any one temperature to any other temperature using the procedures of Barrett and others (1989). It also allows adjustments for MOE using either the procedures of Barrett and others (1989) or Green and others (1999). The program provides capability to either look at property adjustments interactively or to run the program against a data set. Because this latter approach is what would normally be done with a submission, this is how the program will be discussed.

E.3.1 Ftp data format

The input data should be in the following format:

Columns 1–10	Specimen ID
Columns 12–16	Initial moisture content (up to two decimal points allowed, such as 15.39, but most commonly rounded to one, such as 15.4)
Columns 18–26	Specimen property (MOR in lb/in^2, thousand lb/in^2, kPa, or MPa; MOE in 10^6 lb/in^2 or MPa)
Columns 28–32	Specimen temperature (°F) (for example, 23 for 23°F).

E.3.2 Example

To illustrate the use of TEMPADJ, an example data set will again be used. This data set is one with MOE values taken at different moisture contents and temperatures. The MOE values will be adjusted to 73°F. The example data set, called *tempadj_example*, is as follows:

```
4K2011      12.2      1.304   102
4K2091       9.9      1.604    54
4K2123      12.6      1.695     5
4K2198      11.4      1.089    80
4K2247      14.9      1.142    73
6KS016      18.2      1.352    43
6KS166      19.1      1.515    23
8KS097      15.4      1.142    91
8V2118      16.1      1.041    65
8K2193      15.0      1.305    32
```

Again the data set must be moved to the pub/data directory on www1.fpl.fs.fed.us by ftp (section E.1). Using a web browser to view the initial page for the TEMPADJ program (Fig. 5), users can choose to adjust individual specimens or an entire data set. Clicking on "Analyze a data set" displays a page (Fig. 6) offering a choice of properties to be adjusted—MOR or MOE. Selecting MOE for this example displays the MOE page (Fig. 7). Entered on this page are the data set name (*tempadj_example*, for this example), the units of measurement used in the data set (10^6 lb/in^2), the ASTM D1990 model chosen, and a target temperature (73 for 73°F). As noted in section D.5, the ASTM D1990 models have one adjustment for moisture content of 12% or less and another for 23% or greater. Moisture content adjustments between 12% and 23% are interpolated between the 12% and 23% adjustments. After the program executes, it will indicate that

Figure 4

WWW Computer Program for Calculating Strength Ratios from Failure Codes in ASTM D4761, Table X1.1.

This program calculates strength ratios from failure codes in ASTM D 4761 Table X1.1. These codes are of the form 'XX-YY', where XX is a 2-digit code showing the characteristic associated with a failure and YY is a 2-digit code describing the extent of the characteristic. Some examples are: 15-08 is a 1/2 inch wide face knot, center line encased. 51-12 is slope of grain 1 inch for every 12 inches. See ASTM D 4761 Table X1.1 for a complete list of failure codes.

This program will read a data set with the following format:

- Columns 1-10 contain a specimen id
- Coluumns 12-16 contain the specimen thickness in inches (e.g., 1.540)
- Columns 18-23 contain the specimen width in inches (e.g., 3.541)
- Columns 27-28 contain the 2-digit characteristic code (e.g., 17 for an edge of wide face knot)
- Columns 30-31 contain the 2-digit size of characteristic code (e.g., 08 for 1/2-inch edge of wide face knot)

WARNING!! You must have data for each variable. If data is missing, you must enter a period (.) to hold its place. If not, the program will put a 0.000 in its place when it writes out the results. This could cause you further problems in future calculations.

Before you proceed, you must transfer this datafile to ws13.fpl.fs.fed.us via anonymous ftp. You must place it in the pub/data directory. (If ftp does not run on your machine, e-mail your data to the address given below and it will be placed in the directory.)

The program will calculate a strength ratio for each specimen, and write it out, along with your original input data, to a file that has your original filename with an extension of .res added to it. (For example, if you sent a data set called **himom**, you will get back a data set called **himom.res**.) You can then retrieve your file via anonymous ftp from the pub/data directory.

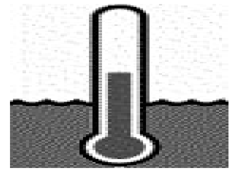
Please enter the name of the data set you have put in our /pub/data directory for which you would like estimated percentiles.

sratio_example

Submit | Clear Form

Figure 5

WWW Computer Program for Adjusting Mechanical Properties of Dimension Lumber for Changes in Temperature



This program calculates changes in dimension lumber properties associated with changes in temperature.

- Modulus of Rupture (ASTM D-1990)
- Modulus of Elasticity (ASTM D-1990, New MOE Model)

You may choose either of the following methods of running the program:

- Individual piece or property - Interactive input from keyboard
- Analyze a data set via anonymous ftp

Figure 6

Input From Your Data Set

Which property would you like to adjust? (Available models follow the property choice.)

- Modulus of Rupture (ASTM D-1990)
- Modulus of Elasticity (ASTM D-1990, New MOE Model)

Figure 7

MODULUS OF Elasticity (MOE)
(From Your Data Set)

Format of Your Data - Your data should be in the following format:

- Columns 1-10 contain a specimen id
- Columns 12-16 contain the initial moisture content (i.e. 15.00 or 15.0)
- Columns 18-26 contain the specimen property (in10^6psi or MPa)
- Columns 28-32 contain the temperature (degrees in Fahrenheit, i.e., 23)

WARNING!! You must have data for each variable. If data is missing, you must enter a period (.) to hold its place. If not, the program will put a 0.000 in its place when it writes out the results. This could cause you further problems in future calculations.

Before you proceed, you must transfer this datafile to ws13.fpl.fs.fed.us via anonymous ftp. You must place it in the pub/data directory. (If ftp does not run on your machine, e-mail your data to the address given below and it will be placed in the directory.)

The program will calculate an adjusted MOE for the targeted temperature for each specimen, and write it out, along with your original input data, to a file that has your original filename with an extension .res added to it. (For example, if you sent a data set called **himom**, you will get back a data set called **himom.res**.) You can then retrieve your file via anonymous ftp from the pub/data directory.

Please enter the **name of the data set** you have put in our /pub/data directory for which you would like adjusted MOE values. tempadj_example

Initial Property Value Format *(PICK ONE)*

- (•) 10^6psi (e.g., 1.8711)
- ( ) MPa (e.g., 12900)

Please pick one model

- (•) ASTM D-1990 Model
- ( ) New MOE Model

Please Enter Your Target Temperature

- (•) Fahrenheit
- ( ) Centigrade

73

Submit | Clear Form

the results are in *filename.res* (*tempadj_example.res* for this example). The resulting data file, retrieved by anonymous ftp, will appear as follows:

```
4K2011     12.20     1.304 102.0  73.0    1.304
4K2091      9.90     1.604  54.0  73.0    1.604
4K2123     12.60     1.695   5.0  73.0    1.608
4K2198     11.40     1.089  80.0  73.0    1.089
4K2247     14.90     1.142  73.0  73.0    1.142
6KS016     18.20     1.352  43.0  73.0    1.341
6KS166     19.10     1.515  23.0  73.0    1.381
8KS097     15.40     1.142  91.0  73.0    1.142
8V2118     16.10     1.041  65.0  73.0    1.041
8K2193     15.00     1.305  32.0  73.0    1.265
```

E.4 Moisture content adjustment program MCADJ

In step D.6 of the process of getting allowable properties from ASTM D1990, the data are adjusted to 15% moisture content. The moisture content adjustment program, MCADJ, may be used to do this. It allows the user either to interactively adjust one piece at a time or to adjust a whole data set using ftp. This latter approach is probably more useful for developing allowable properties. MCADJ contains several methods of adjusting properties to different moisture contents. Many of these methods are the result of as yet unpublished research. MCADJ will be discussed in detail in a separate paper. This report focuses on how to use MCADJ for calculating allowable properties.

MCADJ adjusts properties from one moisture content to another. It can be accessed through the ASTM D1990 computer program index page. Once the MCADJ program is selected, an introductory page lists all the properties and methods that the program will handle. It provides the choice of adjusting an individual piece or property or submitting an entire data set and adjusting several specimens at once. For calculation of allowable properties, the example will assume that an entire data set is to be adjusted.

E.4.1 Ftp data format

The data should be in the following format:

Columns 1–10	Specimen id
Columns 12–16	Initial moisture content (up to two decimal points allowed, such as 15.39, but most commonly rounded to one, such as 15.4)
Columns 18–26	Specimen property (MOR, UTS, and UCS in lb/in^2, thousand lb/in^2, kPa, or MPa; MOE in 10^6 lb/in^2 or MPa)

E.4.2 Example

To illustrate the use of MCADJ, an example data set will again be used. This data set, called *mcadj_example*, has MOE values taken at different moisture contents that are to be adjusted to 15% moisture content.

```
4K2011      12.2      1.304
4K2091       9.9      1.604
4K2123      12.6      1.695
4K2198      11.4      1.089
4K2247      14.9      1.142
6KS016      18.2      1.352
6KS166      19.1      1.515
8KS097      15.4      1.142
8V2118      16.1      1.041
8K2193      15.0      1.305
```

The data set must again be moved to the pub/data directory on www1.fpl.fs.fed.us by ftp (section E.1). Using a web browser to view the initial page for the MCADJ program (Fig. 8) users can choose to adjust individual specimens or an entire data set. Clicking on “Analyze a data set” displays a page (Fig. 9) offering a choice of properties to be adjusted—MOR, MOE, UTS, or UCS. Selecting MOE for this example displays the MOE page (Fig. 10). Entered on this page are the data set name (*mcadj_example* in this example), the units of measurement used in the data set (10^6 lb/in^2), the ASTM D1990 model chosen, and a target moisture content (15.0 for 15%). The program automatically converts moisture contents above 23% to 23% in the calculations. For values less than 10%, the program follows the conservative recommendation in the discussion of section D.6 and assumes the model is good to 8% with no change below 8%. Each time the moisture content limits are exceeded, a message is displayed. The program also follows the more current practice and does not normalize data. After the program executes, it indicates that the results are in *filename.res* (in this example, *mcadj_example.res*). The resulting data file, retrieved by ftp, appears as follows:

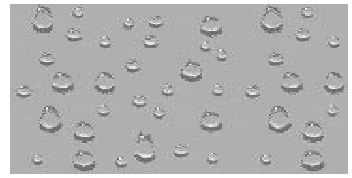
```
4K2011     12.20      1.304 15.00     1.234
4K2091      9.90      1.604 15.00     1.450
4K2123     12.60      1.695 15.00     1.616
4K2198     11.40      1.089 15.00     1.014
4K2247     14.90      1.142 15.00     1.140
6KS016     18.20      1.352 15.00     1.440
6KS166     19.10      1.515 15.00     1.643
8KS097     15.40      1.142 15.00     1.151
8V2118     16.10      1.041 15.00     1.064
8K2193     15.00      1.305 15.00     1.305
```

E.5 Nonparametric estimation program NONPAR

The nonparametric estimation program NONPAR will be discussed in detail in a separate paper. This report focuses on how to use it in the process of calculating allowable properties. Recall that step D.7 of the process is to calculate summary statistics for each size–grade cell of data adjusted to 15% moisture content and 73° F. It should be simple enough to use a spreadsheet to calculate the sample size, mean, standard deviation, and median. However, most spreadsheets do not give a 5th percentile, a 75% lower tolerance limit for

Figure 8

WWW Computer Program for Adjusting



Mechanical Properties of Dimension Lumber for Changes in Moisture Content

Lumber strength properties vary with changes in moisture content. This program allows you to predict a property (P2) of dimension lumber at a target moisture content (MC2) given that you know the value of the property (P1) at an initial moisture content (MC1). Properties and models for which this program provides estimates include:

- Modulus of Rupture (ASTM D-1990 and Quadratic Surface Models)
- Modulus of Elasticity (ASTM D-1990, Simple Interest, and Compound Interest Models)
- Ultimate Tensile Strength (ASTM D-1990 and Quadratic Surface Models)
- Compression Parallel to the Grain (ASTM D-1990 and Quadratic Surface Models)
- Compression Perpendicular to the Grain (ASTM D-2915)
- Shear (ASTM D-2915)

You may choose either of the following methods of running the program:

- Individual piece or property - Interactive input from keyboard
- Analyze a data set via anonymous ftp

Figure 9

Input From Your Data Set

Which property would you like to adjust? (Available models follow the property choice.)

- Modulus of Rupture (ASTM D-1990 and Quadratic Surface Models)
- Modulus of Elasticity (ASTM D-1990, Simple Interest, and Compound Interest Models)
- Ultimate Tensile Strength (ASTM D-1990 and Quadratic Surface Models)
- Compression Parallel to the Grain (ASTM D-1990 and Quadratic Surface Models)

Figure 10

MODULUS OF Elasticity (MOE) (From Your Data Set)

Format of Your Data - Your data should be in the following format:

- Columns 1-10 contain a specimen id
- Columns 12-16 contain the initial moisture content, i.e. 15.00 or 15.0
- Columns 18-26 contain the specimen property (in10^6psi or MPa)
- No moisture content can be below 8.0 or above 23.0

WARNING!! You must have data for each variable. If data is missing, you must enter a period (.) to hold its place. If not, the program will put a 0.000 in its place when it writes out the results. This could cause you further problems in future calculations.

Before you proceed, you must transfer this datafile to ws10.fpl.fs.fed.us via anonymous ftp. You must place it in the pub/data directory. (If ftp does not run on your machine, e-mail your data to the address given below and it will be placed in the directory.)

The program will calculate an adjusted MOE for the targeted moisture content for each specimen, and write it out, along with your original input data, to a file that has your original filename with an extension .res added to it. (For example, if you sent a data set called **himom**, you will get back a data set called **himom.res**.) You can then retrieve your file via anonymous ftp from the pub/data directory.

Please enter the **name of the data set** you have put in our /pub/data directory for which you would like adjusted MOE values. [mcadj_example]

Initial Property Value Format*(PICK ONE)*

- (•) 10^6psi (e.g., 1.8711)
- ( ) MPa (e.g., 12900.090)

Please pick one model

- (•) ASTM D-1990 Model
- ( ) Simple Interest Model
- ( ) Compound Interest Model

Please Enter Your Target Moisture Content (DO NOT USE %, USE 15.0 or 15.00, for example) [15.0]

[Submit] [Clear Form]

Figure 11

FPL Statistics Unit

NONPAR: Nonparametric Estimation Program

This program calculates nonparametric estimates of percentiles, associated confidence intervals, and tolerance limits of the percentiles from a data set. It can also give the order statistics needed for any sample size to create the same estimates. For more information concerning the *nonpar* program, a link to documentation will eventually be provided.

What do you want to do?

- Analyze a data set for estimates.
- Find order statistics for estimates.
- Do both procedures at the same time.

the 5^{th} percentile, or a 75% upper confidence interval for a 5^{th} percentile. NONPAR can be used to make these calculations two different ways.

NONPAR is accessible by following the link from the ASTM D1990 computer program index page. (Links to NONPAR are found elsewhere, as well, because it is useful for more than calculating allowable properties.) The NONPAR introductory page (Fig. 11) offers a choice of

- analyzing a data set,
- finding for any sample size order statistics associated with point estimates, tolerance limits and confidence intervals for different percentiles,
- or both.

If the “find order statistics” link is followed, the resulting page offers a choice of percentiles to estimate. The 5^{th} and 50^{th} percentiles are offered as options because they are part of the ASTM D1990 process. The user can also specify any percentile. For an ASTM D1990 calculation, the 5^{th} percentile would be selected. The user is then asked to enter the sample size of the data. So, for example, if a 2×4 Select Structural data set had 381 observations, the user would enter 381 and click the button to execute the program. The program would return a table showing that for 381 observations, the point estimate of a 5^{th} percentile should be the 19.10 order statistic. This means that if the property values are ordered from smallest to largest, the 5^{th}-percentile estimate should be $1/10^{th}$ the distance from the 19^{th} smallest number to the 20^{th} smallest number. So, if the 19^{th} smallest number is 2.841 and the 20^{th} smallest number is 2.961, the estimate is $2.841 + [0.10 \times (2.961 - 2.841)] = 2.853$. The table similarly gives the order statistics for 95% and 75% lower tolerance limits for the 5^{th} percentile and order statistics for 95% and 75% confidence limits for the 5^{th} percentile. By going through every size–grade cell and entering its sample size, the order statistics needed to get the 5^{th} percentile, 75% lower tolerance limit on the 5^{th} percentile, and 75% confidence limits on the 5^{th} percentile will be given. These order statistics allow an ASTM D1990 calculation, because the data in each size–grade cell can be sorted and the estimates gotten through interpolation.

NONPAR can also be used to calculate the initial characteristic values of step D.10. After the data have been adjusted to the characteristic size in step D.9, the 75% lower tolerance limits for the 5th percentile of each grade can be calculated using NONPAR. Again this can be done either by getting the appropriate order statistic for each grade's collective sample size or by having the program analyze this adjusted data set.

Most likely in a submission, "analyze a data set" or "both" will be chosen. The data set needed for each size–grade cell should have one observation per line. So the data set would be a column of numbers such as the following example data set called *nonpar_example*:

2.544
5.049
4.985
7.908
6.318
6.481
6.692
7.119
6.917
5.454
6.972
4.636
7.866
7.251
7.448
6.352
3.778
5.133
2.953
4.257
6.159
7.936
4.782
6.824
6.401
3.237
3.662
4.833
7.725
5.221
7.174
3.681
2.851
6.755
6.739
7.750
6.441
6.565
7.302
4.282
7.327
7.147
8.908
4.829
6.844
2.458
6.545

This data set should be moved to pub/data using ftp as previously described. When the "analyze a data set" link is followed, the resulting page (Fig. 12) offers a choice of percentiles to estimate. Selecting a percentile links to a page (Fig. 13) asking for the name of the data set. If a default percentile (5 or 50) was selected on the previous page, that value will already be entered in the block for the percentile to estimate. After the program executes, it will return a table (Fig. 14) with the estimated percentile, estimated 95% and 75% lower tolerance limits on the percentile, and 95% and 75% confidence limits on the percentile. For this example data set, a choice of 5th percentile would return the information that the data set has 47 observations. The estimated 5th percentile is 2.667. If both "analyze a data set" and "get order statistics" were chosen, the table would show that the 5th-percentile estimate is based on the 2.40 order statistic, which puts it 0.4 of the way between the second smallest observation (2.544) and the third smallest (2.851). The 95% lower tolerance limit on the 5th percentile is given as 2.458 with an indication that it is the smallest observation. The order statistics would show that this tolerance limit should be based on the 0.8 order statistic. Because this is below the first observation, the program returns the first observation and marks that the order statistic should have been below this. For sample sizes common in submissions under ASTM D1990, this should not occur. The 75% lower tolerance bound is also 2.458 but is not marked as a value below the first order statistic. The order statistics in this case should be the 1.80 order statistic. The estimated tolerance limit could have been interpolated between the two smallest observations (2.458 and 2.544). However, in the In-Grade Program it was decided to be conservative and round down in order statistics, in this case 1.8 rounds down to 1. This philosophy is similar to that found in ASTM D2915, where the sample size required to use particular order statistics as tolerance limits is rounded up. This ensures that the nonparametric estimates are conservative. With the large samples required of most submissions under ASTM D1990, rounding down instead of interpolation should result in only a slightly smaller value. The 95% confidence limits on the 5th percentile are 2.458 to 3.662. Again the lesser value is the smallest observation because the calculated order statistic is below 1 (actually –0.59). The upper limit order statistic is 5.39, which in the In-Grade Program was rounded up to 6 to be more conservative. Finally, the 75% confidence limits on the 5th percentile are 2.458 to 3.237.

Is it wrong to interpolate a tolerance limit that comes out 1.80 for an order statistic instead of rounding down? It is not wrong, and some past submissions have done this. However, the calculations that NONPAR uses to get these order statistics require some numerical approximations that are fairly complex (as will be discussed in a future publication). These approximations do not always produce conservative estimates. Thus, while the interpolated answer is probably closer to the true tolerance limit, it may have a confidence level

Figure 12

Analyzing the Data

Which percentile do you want to estimate?

- **5**
- **50**
- **user's choice**

Figure 13

Analyzing the Data

Before you proceed, you must transfer this data file to ws13.fpl.fs.fed.us via anonymous ftp. You must place it in the pub/data directory. (If ftp does not run on your machine, e-mail your data to the address given on the home page of the nonpar program, and it will be placed in the directory.)

Note that this program is limited to handling data sets of sample size 9999 or less. It assumes that the data set has one observation per line. If the data set does not meet these requirements, the program can still be used to identify the order statistics needed to estimate population percentiles. By sorting the data by increasing value, the calculations can then be done by hand.

Enter the name of the data set.

nonpar_example

What is the percentile?

5

Execute the program

Figure 14

Nonparametric point estimates of population percentiles

		POINT	TOLERANCE LIMITS		CONFIDENCE INTERVALS	
%	N	ESTIMATE	95%	75%	95%	75%
5	47	2.667	2.458	2.458	(2.458, 3.662)	(2.458, 3.237)
			@		@	@

WARNING- The @ indicates that the correct order statistic for this estimate is below the first order statistic. In that case, the first observation is given.

Order statistics associated with nonparametric estimates

		POINT	TOLERANCE LIMITS		CONFIDENCE INTERVALS	
%	N	ESTIMATE	95%	75%	95%	75%
5	47	2.40	0.80	1.80	(-0.59, 5.39)	(0.64, 4.16)

Return to nonpar homepage

slightly smaller than claimed. Thus, the more conservative approach was chosen for the In-Grade Program. A revised version of NONPAR in development will allow the user to choose between interpolation or conservative rounding. When this revised version is ready, the technical details—including details on its approximations—will be published. Again, for sample sizes of past submissions, it seemed preferable to err on the conservative side, as this program does.

E.6 Testing cell data checks of section 9.3 and 12.6 of ASTM D1990 DATACHECK

Performing the data checks of section 9.3 and 12.6 in D.11 of the process can be difficult. Recall that the data checks are done for MOR, UTS, and UCS but not for MOE. Because all submissions since the In-Grade Program have been based on testing specimens only in bending, the program called DATACHECK was developed to perform the data checks of 9.3 and 12.6 for MOR only. This program should eliminate problems performing the data checks for MOR. The program DATACHECK (which is accessed in the same way as the other programs discussed) begins by requesting the MOR characteristic values for Select Structural and No. 2 in pounds per square inch. These are the 75% lower tolerance limits found for the data all adjusted to the characteristic size of 7.25 in. wide and a span of 144 in. If a value for only one grade of material is available, enter the value for that grade and enter 0 for the other grade. While it is allowed under the standard to test a different grade and get an allowable property for this one grade, it would be very unusual.

The program can still be used in this case—just enter the values for this other grade as if it were either Select Structural or No. 2 material. In addition to the initial characteristic values, the program asks that for every size–grade cell tested, the 5th percentile for that cell (lb/in^2), the 75% upper confidence interval for the cell (lb/in^2), and the span on which these values are based (in.) be entered. These are part of the summary statistics calculated in step D.7 for the data at 15% moisture content. The program will perform the data checks, show where the data checks caused a reduction in a characteristic value, and write out the final characteristic values.

After the sizes and grades of lumber tested are adjusted to the characteristic size in D.9 and the initial characteristic values established in D.10 (using NONPAR), it is time to perform the data checks of sections 9.3 and 12.6. To illustrate the use of the program DATACHECK, consider a situation in which 2×4, 2×6, and 2×8 dimension lumber in the two grades, Select Structural and No. 2, were tested. For this example, initial MOR characteristic values of 2,988 lb/in^2 for Select Structural and 1,805 lb/in^2 for No. 2 have been calculated. Assume the 5th-percentile estimates, 75% upper confidence limits on the 5th percentile, and spans listed in Table 3 are known from the earlier calculation of summary statistics.

Table 3—DATACHECK example values

	Select Structural			No. 2		
	2×4	2×6	2×8	2×4	2×6	2×8
5th percentile	3,917	3,609	3,790	2,255	2,137	2,145
75% upper confidence limit on 5th percentile	4,106	3,660	4,010	2,349	2,273	2,240
Span (in.)	60	94	123	60	94	123

The DATACHECK program is accessed from the ASTM D1990 computer program index page. The initial page for the program (Fig. 15) asks for all the information. The tables returned by the program after execution (Fig. 16) show that the data check of section 9.3 reduced the characteristic value for Select Structural to 2,940 lb/in^2 because of failing the test for the 2×4 data, and the characteristic value for No.2 was reduced to 1,682 lb/in^2 because of failing the test for the 2×4 data. The tables also show that data check 12.6 further reduced the characteristic value for Select Structural to 2,877 lb/in^2 because of failing the test for the 2×4 data. Thus, the final characteristic values would be 2,877 lb/in^2 for Select Structural and 1,682 lb/in^2 for No.2.

E.7 ALLFROMR—Program to calculate MOR, UTS, and UCS design values from MOR characteristic values

After calculating the final characteristic values, it is necessary to estimate any characteristic values for any untested properties (D.12) and develop the design values (D.13). As previously mentioned, recent submissions to the BOR have all been based on testing specimens in bending and then using the conservative estimates in ASTM D1990 to derive tension and compression values. The program ALLFROMR takes the final MOR characteristic values and calculates the characteristic values for UTS and UCS using the formulas in section 9.5.2 of ASTM D1990. It then calculates values for each grade at the characteristic size using the grade models in the standard. These values are then adjusted to the widths and lengths discussed in step D.13. Finally, the program rounds the values using the rounding rules of table 3 of ASTM D1990. The program reports results of each step.

The ALLFROMR program is accessed from the ASTM D1990 computer program index page. The initial page for the program (Fig. 17) asks for the final MOR characteristic values for the two grades (Select Structural and No. 2). If the final MOR characteristic values are 2,877 for Select Structural and 1,682 for No.2, the program calculates characteristic values of 1,294.65 and 756.90 for UTS (Select Structural and No. 2, respectively) and 2,334.56 and 1,806.47 for UCS. Provided in a series of tables (Fig. 18) are results of the grade model, values adjusted to unrounded design numbers, and finally values rounded according to ASTM D1990 rounding rules. The resulting design values are as follows:

	MOR	UTS	UCS
SS at 2×12, 240 in.	1,100	500	1,150
No.1 at 2×12, 240 in.	750	350	1,000
No. 2 at 2×12, 240 in.	650	300	900
No. 3 at 2×12, 240 in.	375	175	525
Stud at 2×6, 120 in.	525	225	575
Construction at 2×4, 144 in.	750	325	1100
Standard at 2×4, 144 in.	425	200	925
Utility at 2×4, 144 in.	200	100	600

E.8 EDESIGN—Program to calculate MOE design values from MOE characteristic values

The next step after calculating the final characteristic values for MOE in D.10 is to calculate the design values for MOE (D.13). The program EDESIGN performs the calculations of D.13 by first converting the MOE characteristic values to 21-to-1 uniformly loaded values and then using the MOE grade model. Finally, the values are rounded according to ASTM D1990 rounding rules.

The EDESIGN program is accessed through the ASTM D1990 computer program index page. The initial page for the program (Fig. 19) asks for the final MOE characteristic values for the two grades (Select Structural and No. 2) and if the MOE values are based on deflections measured at the load points or at the center between the load points. If the final MOE characteristic values are entered as 1.469 for Select Structural and 1.106 for No.2 and if “deflection measured at load point” is selected, the program returns tables (Fig. 20) that report the unrounded results of the grade model on the 21-to-1 uniformly loaded values and the final rounded design values, which are as follow:

	MOE
SS	1.5
No.1	1.3
No. 2	1.1
No. 3	1.0
Construction	1.1
Standard	1.0
Utility	0.9
Stud	1.0

Figure 15 (page 1 of 2)

WWW Computer Program for Testing Cell Data Checks of Section 9.3 and 12.6 of ASTM D1990

This program assumes that we have one or more sizes of specimens for both Select Structural and Number 2 grades of dimension lumber. We will deal with the Modulus of Rupture (MOR) characteristic.

Please enter your MOR Select Structural Characteristic value in psi 2988

Please enter your MOR No. 2 Characteristic value in psi 1805

Please input the estimated 5th percentile, the 75% upper confidence interval for the 5th percentile and the test span width for each cell that you have data. All values are assumed to be at 15% moisture content. These values are the summary statistics before adjusting to the charcteristic size.

- 2x4 Select Structural
  - 3917 5th Percentile (psi)
  - 4106 75th Upper Confidence Interval for 5th Percentile (psi)
  - 60 Span Width, i.e. 60.4 (inches)
- 2x6 Select Structural
  - 3609 5th Percentile (psi)
  - 3660 75th Upper Confidence Interval for 5th Percentile (psi)
  - 94 Span Width, i.e. 60.4 (inches)
- 2x8 Select Structural
  - 3790 5th Percentile (psi)
  - 4010 75th Upper Confidence Interval for 5th Percentile (psi)
  - 123 Span Width, i.e. 60.4 (inches)
- 2x10 Select Structural
  - 5th Percentile (psi)
  - 75th Upper Confidence Interval for 5th Percentile (psi)
  - Span Width, i.e. 60.4 (inches)
- 2x12 Select Structural
  - 5th Percentile (psi)
  - 75th Upper Confidence Interval for 5th Percentile (psi)
  - Span Width, i.e. 60.4 (inches)

Figure 15 (page 2 of 2)

- 2x4 Number 2
  - 2255 5th Percentile (psi)
  - 2349 75th Upper Confidence Interval for 5th Percentile (psi)
  - 60 Span Width, i.e. 60.4 (inches)
- 2x6 Number 2
  - 2137 5th Percentile (psi)
  - 2273 75th Upper Confidence Interval for 5th Percentile (psi)
  - 94 Span Width, i.e. 60.4 (inches)
- 2x8 Number 2
  - 2145 5th Percentile (psi)
  - 2240 75th Upper Confidence Interval for 5th Percentile (psi)
  - 123 Span Width, i.e. 60.4 (inches)
- 2x10 Number 2
  - 5th Percentile (psi)
  - 75th Upper Confidence Interval for 5th Percentile (psi)
  - Span Width, i.e. 60.4 (inches)
- 2x12 Number 2
  - 5th Percentile (psi)
  - 75th Upper Confidence Interval for 5th Percentile (psi)
  - Span Width, i.e. 60.4 (inches)

Submit Clear Form

Figure 16 (page 1 of 2)

Section 9.3 Test Cell Data Check	
MOR SS	**psi**
Initial SS Characteristic Value	2988.0
Final SS Characteristic Value	2940.0

Size	75% UCL on 5th Percentile	Initial Size Model	Final Size Model
2x4	4106.0	4171.8	4104.8
2x6	3660.0	3436.4	3381.2
2x8	4010.0	3054.7	3005.6

MOR Number 2	psi
Initial No. 2 Characteristic Value	1805.0
Final No. 2 Characteristic Value	1682.0

Size	75% UCL on 5th Percentile	Initial Size Model	Final Size Model
2x4	2349.0	2520.1	2348.4
2x6	2273.0	2075.9	1934.4
2x8	2240.0	1845.3	1719.5

Figure 16 (page 2 of 2)

Section 12.6 Test Cell Data Check	
MOR SS	**psi**
Initial SS Characteristic Value	2940.0
Final SS Characteristic Value	2877.0

Size	Cell +5%	Cell +100	Initial Size Model	Final Size Model
2x4	4112.8	4017.0	4104.8	4016.9
2x6	3789.4	3709.0	3381.2	3308.8
2x8	3979.5	3890.0	3005.6	2941.2

MOR Number 2	psi
Initial No. 2 Characteristic Value	1682.0
Final No. 2 Characteristic Value	1682.0

Size	Cell +5%	Cell +100	Initial Size Model	Final Size Model
2x4	2367.8	2355.0	2348.4	2348.4
2x6	2243.8	2237.0	1934.4	1934.4
2x8	2252.2	2245.0	1719.5	1719.5

Figure 17

WWW Computer Program for Producing Unrounded and Rounded Design Values for MOR, UTS, and UCS

This program takes ASTM D1990 characteristic values for MOR and produces unrounded and rounded design values for Modulus of Rupture (MOR), Ultimate Tensile Strength (UTS) and Ultimate Compression Strength (UCS). Property reduction factors for softwoods were used.

Please enter the MOR SS Characteristic value in psi 2877

Please enter the MOR No. 2 Characteristics value in psi 1682

Submit Clear Form

Figure 18 (page 1 of 2)

The Characteristic Values			
	MOR	**UTS**	**UCS**
SS	2877.00	1294.65	2334.56
No. 2	1682.00	756.90	1806.47

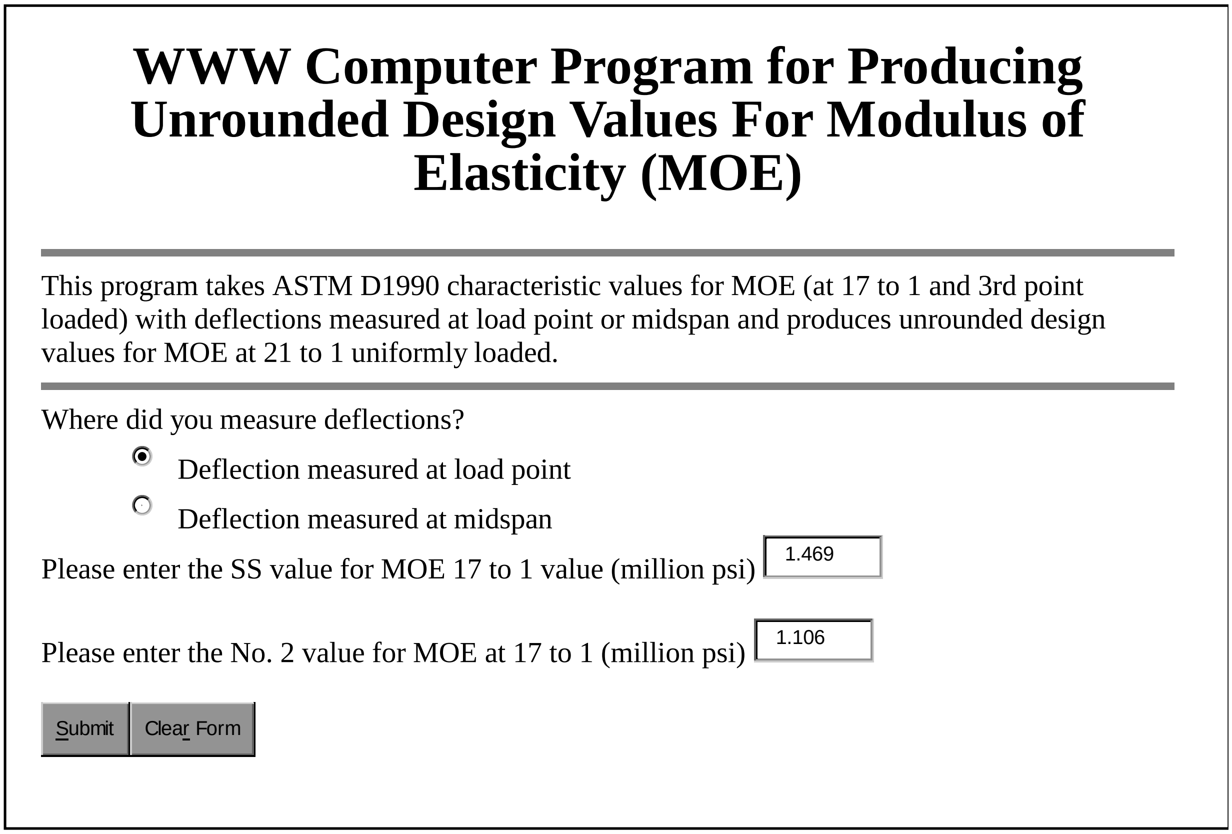
Results of the Grade Model			
	MOR	**UTS**	**UCS**
SS	2877.00	1294.65	2334.56
No. 1	1937.58	871.91	2011.26
No. 2	1682.00	756.90	1806.47
No. 3	971.82	437.32	1042.19
Cons	1270.84	571.88	1930.73
Stan	710.18	319.58	1598.03
Util	336.40	151.38	1042.19
Stud	971.82	437.32	1042.19

Figure 18 (page 2 of 2)

Unrounded Design Values			
	MOR	**UTS**	**UCS**
SS at 2x12 240	1122.86	505.29	1160.50
No. 1 at 2x12 240	756.21	340.30	999.79
No. 2 at 2x12 240	656.47	295.41	897.99
No. 3 at 2x12 240	379.29	170.68	518.07
Stud at 2x6 120	514.33	231.45	568.58
Construction at 2x4 144	747.47	336.36	1117.07
Standard at 2x4 144	417.70	187.97	924.58
Utility at 2x4 144	197.86	89.04	602.99

Rounded Design Values			
	MOR	**UTS**	**UCS**
SS at 2x12 240	1100.00	500.00	1150.00
No. 1 at 2x12 240	750.00	350.00	1000.00
No. 2 at 2x12 240	650.00	300.00	900.00
No. 3 at 2x12 240	375.00	175.00	525.00
Stud at 2x6 120	525.00	225.00	575.00
Construction at 2x4 144	750.00	325.00	1100.00
Standard at 2x4 144	425.00	200.00	925.00
Utility at 2x4 144	200.00	100.00	600.00

Figure 19



WWW Computer Program for Producing Unrounded Design Values For Modulus of Elasticity (MOE)

This program takes ASTM D1990 characteristic values for MOE (at 17 to 1 and 3rd point loaded) with deflections measured at load point or midspan and produces unrounded design values for MOE at 21 to 1 uniformly loaded.

Where did you measure deflections?

- Deflection measured at load point
- Deflection measured at midspan

Please enter the SS value for MOE 17 to 1 value (million psi) 1.469

Please enter the No. 2 value for MOE at 17 to 1 (million psi) 1.106

Submit Clear Form

Figure 20

Unrounded Results of Grade Interpolation and Conversion to Uniform Load	
Size	**Modulus of Elasticity**
SS	1.50444
No. 1	1.31856
No. 2	1.13268
No. 3	1.01312
Construction	1.06346
Standard	0.96907
Utility	0.90614
Stud	1.01312

Rounded Results of Grade Interpolation and Conversion to Uniform Load	
Size	**Modulus of Elasticity**
SS	1.5
No. 1	1.3
No. 2	1.1
No. 3	1.0
Construction	1.1
Standard	1.0
Utility	0.9
Stud	1.0

F. Discussion and Summary

This report is intended to explained and simplified the process of developing allowable properties under ASTM D1990. There is no one single way to obtain allowable properties. However, where multiple approaches have been used, we generally try to show the different approaches and indicate any differences.

We offer several recommendations for the better approach in some cases and for specific clarification of the standard:

- The standard should be modified to specify what to do when a species fails the grade quality index (GQI) test.
- The concept of a GQI test is vague in situations where several species are to be grouped—this should be addressed in the standard.
- Data should be collected in a way that eliminates as many adjustments as possible. This includes using ovendry moisture contents, testing at 73°F, and testing at 17-to-1 span-to-depth ratio using third point loading and measuring deflection at the load heads.
- The new temperature adjustment model for MOE should be used and incorporated in the standard.
- We recommend against normalization in adjustments of strength properties to different moisture contents.
- Anyone developing allowable properties under ASTM D1990 should perform many of the necessary calculation using the series of computer programs developed by the Forest Products Laboratory and available on the World Wide Web.

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H. Appendix 1—New temperature adjustment procedure

Recent research results (Green and others 1999, Green and Evans 2001a) suggest a better temperature adjustment procedure for MOE:

For green lumber,

$$\begin{aligned} \mathrm{PC23} &= 22.0326 - 0.4589T \quad \text{if } T \le 32°\mathrm{F} \\ &= 13.0819 - 0.1792T \quad \text{if } T > 32°\mathrm{F} \end{aligned}$$

At 12% moisture content,

$$\mathrm{PC12} = 8.0075 - 0.1097T$$

At 4% moisture content,

$$\mathrm{PC4} = 3.7921 - 0.05195T$$

where T is temperature (°F) of the wood.

The percentage change is then found by linear interpolation:

$$\begin{aligned} \mathrm{PC} &= \mathrm{PC4} && M \le 4 \\ &= \mathrm{PC12} + \frac{12 - M}{8}(\mathrm{PC4} - \mathrm{PC12}) && 4 < M < 12 \\ &= \mathrm{PC12} + \frac{M - 12}{11}(\mathrm{PC23} - \mathrm{PC12}) && 12 \le M < 23 \\ &= \mathrm{PC23} && M \ge 23 \end{aligned}$$

where M is moisture content.

The MOE value is then divided by the percentage change 1 + (PC/100) to adjust it to a temperature of 73%. This adjustment is considered appropriate for temperatures between 0°F and 150°F. Because ASTM D1990 does not specify a temperature adjustment, either this or the adjustment procedure in section D.5 would be acceptable. However, evidence suggests that this new temperature adjustment model is better.

I. Appendix 2—Strength ratio calculations

As discussed in section E.2, the grade quality index program SRATIO calculates strength ratios from failure codes found in table X1.1 of ASTM D4761. The program expects a failure code of the form XX-YY where XX is the two digit code showing the characteristic associated with the failure and YY is the two digit code describing the extent of this characteristic as discussed in ASTM D4761. It will not calculate a strength ratio for every failure code in ASTM D4761. The codes for which it will calculate strength ratios and the formulas it uses are discussed in this appendix.

I.1 Narrow face knots or spike knots

Failure codes 11, 12, and 13 are all narrow face or spike knots. The YY part of the code is the percentage displacement. As mentioned in section C.1, industry practice has been to convert these knots to equivalent edge of wide face knots. First the program calculates the knot size k (in.) using the formula $k = h$(YY/100), where h is the width (in.) of the specimen. Then the program uses the equations from ASTM D245 that are used are given in section X1.3 of appendix X1 as follows:

If h < 6 in., the strength ratio is calculated using the formula

$$S = 100\left[1 - \frac{k - (1/24)}{h + (3/8)}\right]^2$$

If 6 h
formula

$$S = 100\left[1 - \frac{k - (1/24)}{h + (1/2)}\right]^2$$

If S comes out less than 45, the strength ratio is recalculated using the formula

$$S = 100\left[1 - \frac{k - (1/24)}{h}\right]^2$$

I.2 Center of wide face knots

Failure codes 14, 15, and 16 are center of wide face knots. The YY code gives the knot size in 1/16-in. increments, so a code of 08 is 8/16, or a ½-in. knot. The program takes this knot size k and the width of the specimen h and calculates strength ratios using the following formulas from section X1.2 of ASTM D245:

If h < 6 in., the strength ratio is calculated using the formula

$$S = 100\left[1 - \frac{k - (1/24)}{h + (3/8)}\right]$$

If 6 h
formula

$$S = 100\left[1 - \frac{k - (1/24)}{+ (1/2)}\right]$$

If S comes out less than 45, the strength ratio is recalculated using the formula

$$S = 100\left[1 - \frac{k - (1/24)}{h}\right]$$

I.3 Edge of wide face knots

Failure codes 17, 18, and 19 are edge of wide face knots. The YY code gives the knot size to the nearest 1/16-in. increments, so again a code of 08 is a ½-in. knot. The program then uses the formulas for edge of wide face knots covered in section H.1.

I.4 Combination knots

Failure code 20 is combination knots or knots not well spaced. The YY code is the percentage cross section. First the program calculates the knot size *k* (in.) using the formula $k = h(\text{YY}/100)$, where *h* is the width (in.) of the specimen. This knot is then handled as a center of wide face knot using the formulas of section H.2.

I.5 Distorted grain

Failure code 34 is distorted grain. The YY code is percentage displacement. The program calculates an equivalent knot size using $k = h(\text{YY}/100)$, and this is handled as an edge of wide face knot using the formulas in section H.1.

I.6 Slope of grain

Failure code 51 is slope of grain. The YY code is the run of the slope expressed in inches. So a code of 10 means 1 in. up for every 10 in. along the specimen. The program uses a regression formula based on the data in table 1 of ASTM D245 to calculate strength ratios. The parameters in the regression formula depend upon the slope of grain as shown in the following table:

YY code	*a*	*b*
YY	–50	7.5
12	36.3	2.7
8	21.0	4.0
YY < 8	1.0	6.5

The strength ratio is then $S = a + b(\text{YY})$. Note that the program does round off extreme strength ratios that are outside the range of values in table 1 of ASTM D245. Table 1 limits slope of grain to be tio of 100. So a value of 22 would result in a value of 115. To solve this problem, the program rounds any number greater than 20 to 20. At the low end, table 1 does not go below 1 in 6. However, the program does not place a lower limit on slope of grain and will continue to use the <8 formula.

I.7 Clear wood or no failure

Failure code 10 is a clear wood failure, and failure code 00 indicates the piece did not fail. In both cases the program gives the piece a strength ratio of 100.