MOISTURE CONTENT-STRENGTH ADJUSTMENTS FOR WOOD

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MOISTURE CONTENT-STRENGTH ADJUSTMENTS FOR WOOD[1]

It is often desirable to adjust strength values for wood at one moisture content to what they would be under some other condition. This can be done quite accurately when the data apply to small clear specimens which are quite uniformly dried so that the moisture content is approximately the same at all points of the cross section.

Three general methods, differing materially in their accuracy, and in simplicity and facility of application, may be used for moisture-strength adjustments. These are referred to as the (1) approximate method, (2) the equation method, and (3) the graphical method.

Approximate Method

The approximate method of moisture-strength adjustment consists simply in an application of the percentage figures of table 1 for the property under consideration, regardless of species. For example, if the maximum crushing strength of Sitka spruce at 12-percent moisture content is 5,610 pounds per square inch, what is the approximate value at 10-percent moisture? From table 1 it may be noted that the average change in maximum crushing strength for 1-percent change in moisture is 6 percent. For

Table 1.--Average increase (or decrease) in value effected by lowering (or raising) the moisture content 1 percent

Property:	Percent
Static bending:	
Fiber stress at proportional limit	5
Modulus of rupture, or cross-breaking strength	4
Modulus of elasticity or stiffness	2
Work to proportional limit	8
Work to maximum load or shock-resisting ability	1/2
Impact bending:	
Fiber stress at proportional limit	3
Work to proportional limit	4
Height of drop of hammer causing complete failure	- 1/2
Compression parallel to grain:	
Fiber stress at proportional limit	5
Maximum crushing strength	6
Compression perpendicular to grain:	
Fiber stress at proportional limit	5-1/2
Hardness, end grain	4
Hardness, side grain	2-1/2
Shearing strength parallel to grain	3
Tension perpendicular to grain	1-1/2

[1]This mimeograph is one of a series of progress reports issued by the Forest Products Laboratory to aid the Nation's defense effort.

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2-percent change in moisture content (12-percent moisture to 10-percent moisture) the average expected change in maximum crushing strength would consequently be 12 percent. Since this property increases with decrease in moisture content, the approximate increase in strength is 12 percent of 5,610 = 673, and the approximate maximum crushing strength at 10-percent moisture is 5,610 + 673 = 6,283 pounds per square inch.

This is the least accurate of the several methods described, and is useful only for making rough approximations. For comparison it may be noted that application of the equation method to the foregoing example gives a value of 6,194 pounds per square inch.

Equation Method

Studies at the Forest Products Laboratory have led to the derivation of a formula for strength adjustment, the numerical solution of which affords more accurate estimates than any other method. This formula, known as the exponential formula, is based on the fact that for any one species and strength property, moisture-content values within certain limits and the logarithms of corresponding strength values have been found to conform closely to a straight-line relationship.

The formula may be written

$$\text{Log } S_d = \log S_c + (C - D) \frac{\log (S_b \div S_a)}{A - B}$$

where A, B, C, and D, are values of moisture content and S_a, S_b, S_c, and S_d are corresponding strength values; S_c is the strength value from tests made at moisture content C and S_d is this strength value adjusted to moisture content D. The expression

$$\frac{\log (S_b \div S_a)}{A - B}$$

which is equivalent to

$$\frac{\log S_b - \log S_a}{A - B}$$

measures the change in strength property caused by a change of 1 percent in the moisture content. Required for evaluation of this expression are strength values S_a and S_b found from tests made at two different moisture contents A and B on matched specimens; that is, specimens than can be assumed to be alike except for the single factor of moisture content, such as specimens from closely adjacent positions within the same annual growth layers.

When in any instance a strength value is that for green material, the corresponding moisture content to be used for the species under consideration is listed in table 2.

Table 2.--Moisture Content

Species[1]	Percent
Ash, white	24
Birch, yellow	27
American chestnut	24
Douglas-fir	24
Hemlock, western	28
Larch, western	28
Pine:	
Loblolly	21
Longleaf	21
Red	24
Redwood	21
Spruce:	
Red	27
Sitka	27
Tamarack	24

[1]The exact value has been determined only for the species listed here. For other species the value of 24 percent may be assumed to apply.

Three types of moisture-strength adjustment differing with respect to the source of the data for evaluating the expression

$$\frac{\log (S_b \div S_a)}{A - B}$$

are defined and illustrated in the following paragraphs:

Type 1.--From tests on matched groups of material at two different moisture-content values, a strength value corresponding to a third value of moisture content is computed, the data for evaluating the expression

$$\frac{\log(S_b \div S_a)}{A - B}$$

being supplied by the tests on the material under consideration.

Example.--The average maximum crushing strength of Sitka spruce as listed either in table 1, U.S. Department of Agriculture Technical Bulletin 479 "Strength and Related Properties of Wood Grown in the United

States" or table 8 of the "Wood Handbook"[2] is 2,670 pounds per square inch for green material and 5,610 pounds per square inch for material at 12 percent moisture. Compute the maximum crushing strength corresponding to a moisture content of 14 percent.

S_a = 2,670 from either Technical Bulletin 479 or the "Wood Hand-Book" and A for green material is 27.

S_b - 5,610, B = 12. C may be taken either as 27 or 12 with corresponding choice of S_c; that is, either the value for green material or that for material at 12-percent moisture may be adjusted to 14-percent moisture content.
D = 14

Taking C = 12, and S_c = 5,610.

$$\text{Log } S_{14} = \log 5{,}610 + (12 - 14)\,\frac{\log (5{,}610 \div 2{,}670)}{27 - 12}$$

$$= 3.7490 - 2 \times \frac{0.3224}{15}$$

$$= 3.7490 - 0.0430 = 3.7060$$

Then S_{14} = antilog 3.7060 = 5,082.
or
Taking C = 27 and S_c = 2,670

$$\text{Log } S_{14} = \log 2{,}670 + (27 - 14)\,\frac{\log (5{,}610 \div 2{,}670)}{27 - 12}$$

$$= 3.4265 + 13 \times \frac{0.3224}{15}$$

$$= 3.4265 + 0.2794 = 3.7059$$

Then S_{14} = antilog 3.7059 = 5,082 as before, and the maximum crushing strength of Sitka spruce at 14-percent moisture content, as obtained by adjusting to this moisture content the average values given in either Technical Bulletin 479 or the "Wood Handbook" is 5,082 pounds per square inch.

Type 2.—A strength value obtained at one moisture content is adjusted to a second value of moisture content, the data for evaluating the expression

$$\frac{\log (S_b \div S_a)}{A - B}$$

as found in other tests on the same species being assumed to apply.

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[2]For sale by the Superintendent of Documents, Washington, D. C., for 35¢ each.

Example.—A specimen of longleaf pine at 9.8-percent moisture content was found from test to have a modulus of rupture of 13,500 pounds per square inch. Estimate the value of modulus of rupture that would have resulted had the test been made at a moisture content of 12 percent.

Values of modulus of rupture on matched specimens of longleaf pine are given in either table 1 of Technical Bulletin 479 or table 8 of the "Wood Handbook" as 8,700, which is equal to S_a, and 14,700, which is equal to S_b, pounds per square inch for the green and 12-percent moisture conditions, respectively. A, from table 2 = 21, B = 12, C = 9.8, and D = 12.

Then substituting in the formula

$$\text{Log } S_{12} = \log 13{,}500 + (9.8 - 12)\ \frac{\log (14{,}700 \div 8{,}700)}{21 - 12}$$

$$= 4.1303 - 2.2 \times \frac{0.2278}{9}$$

$$= 4.1365 - 0.0557 = 4.0746$$

S_{12} = antilog 4.0746 = 11,874

and the modulus of rupture at 12-percent moisture as estimated from the value determined at 9.8 percent moisture is 11,874 pounds per square inch.

Type 3.—As in type 2, except that the data for evaluating the expression

$$\frac{\log (S_b \div S_a)}{A - B}$$

for the same species not being known, an average value as computed from tests of other species is assumed to apply.

Example.—The modulus of rupture of a sample of a hardwood species tested at 9-percent moisture content was 11,700 pounds per square inch. Estimate the value at 12-percent moisture. Here S_c = 11,700, C = 9, and D = 12. No values of S_a and S_b for the same species being available, it is assumed that the strength-moisture relationship for this hardwood is similar to that for the hardwood species in general and 1.59, the value of $\frac{S_{12}}{S_g}$ as given for modulus of rupture of hardwood species in table 3 is used for $\frac{S_a}{S_b}$. A = 12 and for B the value of 24 from table 2 is taken. Substituting in the formula:

$$\text{Log } S_{12} = \log 11{,}700 + (9 - 12)\ \frac{\log 1.59}{24 - 12}$$

$$= 4.0682 - 3 \times \frac{0.2014}{12}$$

$$= 4.0682 - 0.0503 = 4.0179$$

S_{12} = antilog 4.0179 = 10,400

Obviously, adjustments of type 1 are most, and those of type 3 least accurate. The inaccuracy in types 2 and 3 is due to the fact that the assumed values of the expression

$$\frac{\log (S_b \div S_a)}{A - B}$$

are not definitely applicable.

In types 2 and 3 the accuracy of the computed or estimated value decreases with increase in moisture difference for which adjustment is made.

Table 3.--Average strength ratios $\left(\frac{S_{12}}{S_g}\right)$ for species in drying from a green condition to 12-percent moisture content

Property	Hardwoods (113 species)	Softwoods (54 species)
Static bending:		
Fiber stress at proportional limit	1.80	1.81
Modulus of rupture	1.59	1.61
Modulus of elasticity	1.31	1.28
Work to proportional limit	2.49	2.56
Work to maximum load	1.05	1.13
Impact bending:		
Fiber stress at proportional limit	1.44	1.39
Work to proportional limit	1.68	1.59
Height of drop causing complete failure	.89	1.03
Compression parallel to grain:		
Fiber stress at proportional limit	1.74	1.86
Maximum crushing strength	1.95	1.97
Compression perpendicular to grain: Fiber stress at proportional limit	1.84	1.96
Hardness:		
End	1.55	1.67
Side	1.33	1.40
Shear parallel to grain: Maximum shearing strength	1.43	1.37
Tension perpendicular to grain: Maximum tensile strength	1.20	1.23

Graphical Method

The graphical method consists of using the accompanying chart (figure 1) for the solution of the formula described under the equation method, thus avoiding the use of logarithms as required in the arithmetical calculation. This method is, therefore, simpler than the equation method.

but due to the personal equation in reading the chart and the small scale of the chart, the adjustment is less accurate.

The procedure in the use of the chart is as follows:

1. First determine K, the ratio of the strength when dry to the strength when green for the strength property and species under consideration. This ratio should be determined from one of the three following sources, with preference in the order named:

(a) From the tests of matched green and dry material for which the adjustment is to be made.
(b) From the data for green and dry material in either table 1 of Technical Bulletin 479 or table 8 of the "Wood Handbook".
(c) From the ratios of table 3.

2. Determine the difference in moisture between the value to be used for green material and the moisture content of the dry material on which the preceding dry to green strength ratio is based.

3. Determine the difference between the moisture content of the material at test and the moisture content to which adjustment is to be made. This difference represents the range in moisture over which the adjustment is to be made.

4. Locate on the chart a point corresponding to the difference in moisture content as determined under 2 and the ratio K as determined under 1. From the line joining this point with the lower left-hand corner of the chart, the ratio corresponding to any difference in moisture content can be found.

5. Locate on this line the point that corresponds to the difference in the moisture content as determined under 3, and read the corresponding new strength ratio K on the left-hand scale.

6. (a) If the adjustment is being made to a lower moisture content than that at which the tests were made, multiply the strength at test by the new ratio (as obtained in 5 above) to get the adjusted strength value.

(b) If the adjustment is being made to a higher moisture content than that at which the tests were made, divide the strength at test by the new ratio (as obtained in 5 above) to get the adjusted strength value.

Example 1.—Tests of matched specimens of Douglas-fir gave values of maximum crushing strength of 3,940 and 10,680 pounds per square inch, respectively, for green wood and wood at 6.2-percent moisture content. What is the strength at 12-percent moisture content?

1. The ratio $K = \frac{10,680}{3,940} = 2.71$.

2. The difference between the moisture content to be used for green material (see table 2) and that at test is 24 - 6.2 = 17.8 which is the difference in moisture content to which the ratio 2.71 applies.

3. The difference between the moisture content of the dry material at test and the moisture content to which adjustment is desired is 12 - 6.2 = 5.8.

4. Starting with the ratio 2.71 on the left-hand margin of figure 1, and following horizontally to the vertical representing the 17.8 percent moisture difference, locate a point.

5. Following the converging line on which this point is located to its intersection with a vertical corresponding to the moisture difference of 5.8 (step 3), and thence horizontally to the left-hand margin a new ratio K of 1.38 is found.

6. The maximum crushing strength at 12 percent moisture is $\frac{10,680}{1.38} = 7,740$ pounds per square inch. The moisture content of 12 percent to which adjustment is made is higher than the moisture content at test. Consequently the strength value at test is divided by the ratio.

<u>Example 2</u>.--The modulus of rupture of a sample of hardwood species tested at 13-percent moisture content was 10,030 pounds per square inch. What is the estimated value at 9-percent moisture?

1. Since data on matched green and dry material are not available, the average ratio of strength when dry (12-percent moisture content) to that when green for a hardwood is taken from table 3, and is 1.59.

2. From table 2 the moisture content to be used for green material is assumed to be 24-percent moisture content. The ratio of 1.59 applies to material at 12-percent moisture content. The moisture difference is, therefore, 24 - 12 = 12-percent moisture content.

3. The difference between the moisture content of the sample at test and the moisture to which adjustment is desired is 13 - 9 = 4 percent.

4. Starting with the ratio 1.59 on the left-hand margin of figure 1, and, following horizontally to the vertical representing 12-percent moisture difference, locate a point.

5. Following the converging line through this point to its intersection with the vertical corresponding to the moisture difference of 4 percent (step 3), and thence horizontally to the left-hand margin, the ratio K of 1.165 is found.

6. The modulus of rupture at 9-percent moisture content is 10,030 x 1.165 = 11,680 pounds per square inch. In this instance the moisture

content of 9 percent to which adjustment is made is lower than the moisture content at test and the strength value at test is multiplied by the ratio K.

Limitations to Moisture-Strength Adjustments

When the strength data are from tests on material in which the moisture is not uniformly distributed in the cross section, moisture-strength adjustments on the basis of the methods just outlined cannot be considered as reliable, and no acceptable general method for the adjustment of such data is available.

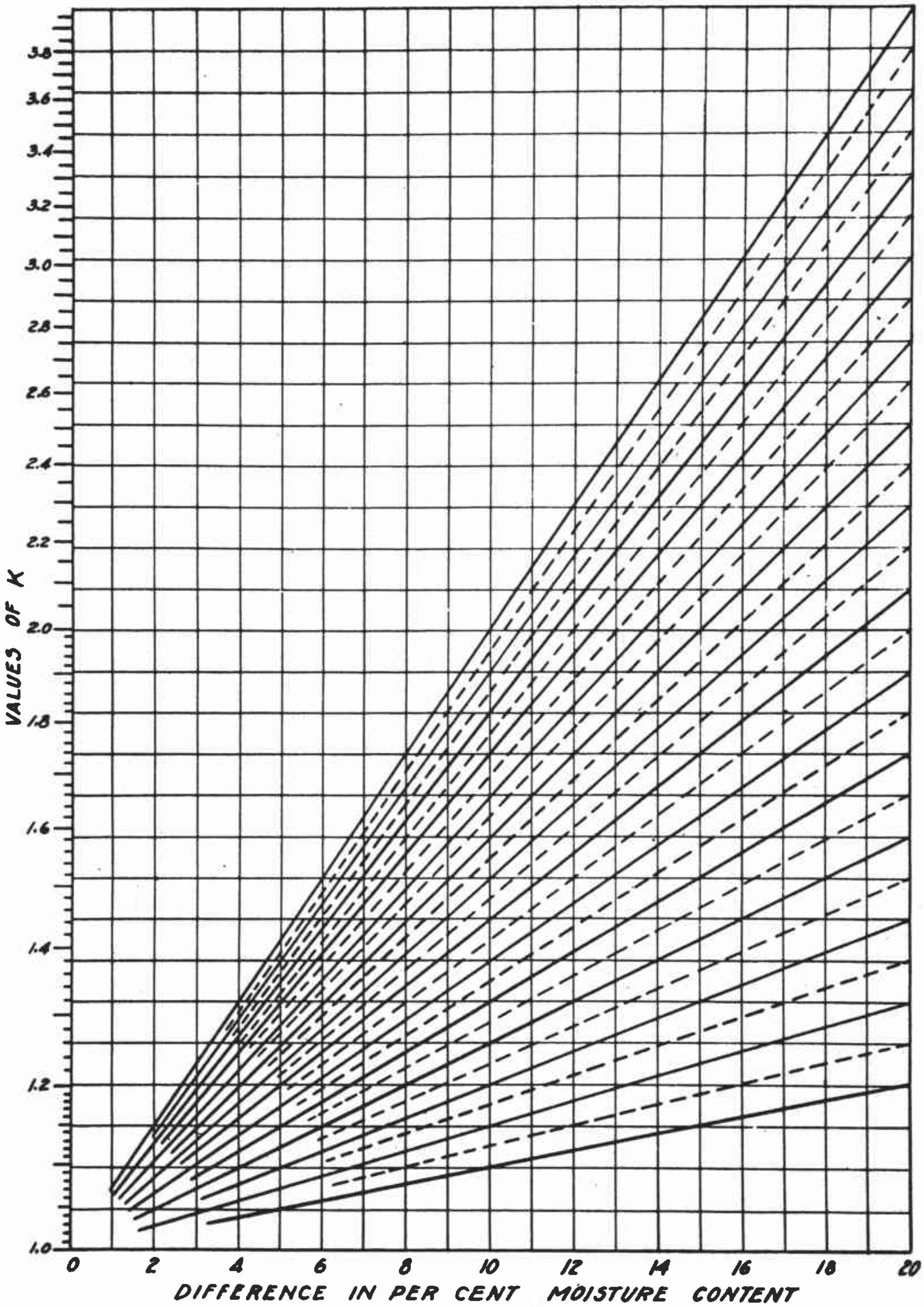

Fig. 1. Chart for making strength-moisture adjustments.

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