Bulletin No. 2018-09

First Release:	March 2018	**Revised:**	
Prepared by:	Ron Anthony & Jim DeStefano, P.E., AIA, F.SEI		
Title:	Effect of Moisture Content on Bending Strength of Timber		

Introduction

The moisture content (MC) of wood has a significant effect on its strength and stiffness. Timbers in the green condition have a MC at or above the fiber saturation point (FSP). FSP is the amount of water, expressed as a percent, required for saturation of the cell walls but with no liquid water within the cell cavities. FSP is approximately 28% depending on the species. Strength properties are unaffected by increases in MC above FSP.

Timbers that air-dry within a climate-controlled space will eventually achieve an equilibrium moisture content (EMC), which occurs when the MC is in equilibrium with the surrounding environmental conditions (specifically, the vapor pressure). EMC typically ranges between 6% and 12%, depending on environmental conditions where the structure is located and where the timber is within the structure (attic vs. crawlspace, for example). Timbers that have been dried in a radio frequency kiln typically leave the kiln with a maximum MC of 19% and continue to dry until they reach EMC in service.

As wood seasons and dries below FSP, the strength and stiffness will increase until the wood reaches a MC of approximately 4-5%, at which point no further increase in strength occurs. Studies have found that the Modulus of Rupture (MOR), or bending strength, of small clear specimens increases, on average, by approximately 69% as the wood dries from FSP to 12% MC. The increase in strength and stiffness is less for dimension lumber and timbers.

The reference design values that are published in Table 4D of the Supplement to the *National Design Specification for Wood Construction (NDS)* for timbers in bending are based on the timbers being in a green condition (moisture content at or above FSP). Consequently, the increase in strength for dried timbers is seldom considered when evaluating existing structures where the timbers are fully seasoned, or in the design of timber structures fabricated from material that has dried to a MC below FSP.

Measuring the Moisture Content of Timber

Figure 1 Hand-held resistance-type moisture meter with short pins inserted into the timber measures the MC near the surface of the timber

To take advantage of possible increases in strength and apply the increase to the allowable design stresses, the MC of the timber must be known. The true MC of wood can be determined only by oven drying a sample. However, portable moisture meters using electrical capacitance or electrical conductance can display the approximate moisture content of wood. Capacitance-type meters measure the electrical field within a small area of a piece of wood. They do not require penetration of probes into the wood and generally provide the average moisture content throughout a certain depth, typically less than an inch; however, a wet surface (e.g., rain on a window sill) can dramatically affect the reading. These meters are particularly useful for measuring the moisture content of interior and exterior woodwork (doors, windows, trim, etc.) and dimension lumber.

For thicker material, such as structural timber, a conductance meter, often called a resistance moisture meter, will provide a better indication of the internal moisture content. A conductance-type meter conducts electric current through wood between two probes (Figure 1). The probes, which come in different lengths, can be inserted into the wood to various depths, thus allowing for determining the moisture content at different depths of larger timbers. Since timbers that have not fully seasoned will typically have a lower MC near the surface than in the core of the timber, caution should be used in interpreting moisture meter readings. Use of a resistance-type moisture meter with 2 or 3-inch insulated pins (electrodes) will provide better information about the internal MC of larger timbers. Longer probes on a resistance-type moisture meter are useful for determining whether wood is drying or taking up moisture.

Structural Design Values

Guidance in establishing allowable design stresses for structural timbers is given in ASTM standard D245. Table 10 of the Standard provides modification factors to strength and stiffness values for lumber 4 inches thick and less that has been seasoned to 19% MC and 15% MC (see Figure 2). The applicability of the modification factors in Figure 2 are restricted to lumber 4 inches and less in nominal thickness because of (1) limited test data on full-size timbers and (2) an assumption that the reduction in cross section and the development of seasoning checks as the timber dries offsets any increase in strength gained from drying. While such reasoning is rational, test data from research identified below suggests that an increase is warranted for timbers as well.

TABLE 10 Modification of Allowable Stresses for Seasoning Effects for Lumber 4 in. and Less in Nominal Thickness (9)[A]

Property	Percentage Increase in Allowable Property Above That of Green Lumber When Maximum Moisture Content is	
	19 %	15 %
Bending	25	35
Modulus of elasticity	14	20
Tension parallel to grain	25	35
Compression parallel to grain	50	75
Horizontal shear	8	13
Compression perpendicular to grain	50[A]	50[A]

[A]The increase in compression perpendicular to grain is the same for all degrees of seasoning below fiber saturation since the outer fibers which season rapidly have the greatest effect on this strength property regardless of the extent of the seasoning of the inner fibers.

Figure 2 - Modification Factors for Seasoning Effect from ASTM D245

Research conducted by Betts (1909), Cline and Knapp (1911), Markwardt (1931), and Littleford (1967) - all summarized in the paper by Green and Evans (2001) - on the strength ratios of dry-to-green wood in bending, including tests of small clear specimens, dimension lumber, and full-size timbers, showed increases at both the mean strength and the lower 5th percentile. Based on their test results, the adjustments given as C_M in Table 1 can be applied to reference design values for the bending strength of timbers 5" x 5" and larger.

Moisture Content	C_M for F_b
19%	1.09
15%	1.15
10%	1.20

Table 1 - Modification Factors, C_M, to be Applied to Timbers at Various Moisture Contents

Research sponsored by the TFEC and funded by the National Parks Service's National Center for Preservation Technology and Training (NCPTT) is focused on how to capitalize on potential strength increases for various design stresses, including bending (Anthony, in progress). Once completed in 2018, additional adjustment factors to recognize the increase in strength properties as timbers dry to EMC are anticipated.

Finally, it is imperative that any structural analysis of seasoned timbers that takes advantage of the increased strength values associated with seasoning be based on the actual section properties and not the nominal section properties based on green dimensions.

References

American Wood Council. 2015. *National Design Specification for Wood Construction*, Washington, D.C.

Anthony, Ronald. *Using Timber Grading to Capitalize on Hidden Capacity in Existing Timber Structures,* National Center for Preservation Technology and Training (in progress).

American Society for Testing and Materials, 2016, Annual Book of Standards, Vol. 04.10: D245, *Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber*; D2555, *Standard Test Methods for Establishing Clear Wood Strength Values*. ASTM, West Conshohocken, Pennsylvania.

Betts, H.S. 1909. *Properties and uses of southern pines*. Circular 164. Washington, DC: U.S. Department of Agriculture, Forest Service.

Cline, M.; Knapp, J.B. 1911. *Properties and Uses of Douglas-fir*. Bull. 88. Washington, DC: U.S. Department of Agriculture, Forest Service.

Green, David W. and Evans, James W. 2001. *Evolution of Standardized Procedures for Adjusting Lumber Properties for Change in Moisture Content*, FPL General Technical Report FPL-GTR-127. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Littleford, T.W. 1967. *A Comparison of Flexural Strength– Stiffness Relationships for Clear Wood and Structural Grades of Lumber*. Inf. Rep. VP–X–30. Vancouver, BC: Forestry Branch, Forest Products Laboratory.

Markwardt, L.J. 1931. *The Distribution and Mechanical Properties of Alaska Woods*. Tech. Bull. 226. Washington, DC: U.S. Department of Agriculture.

Ron Anthony is a wood scientist and is the President of Anthony & Associates, Inc. located in Fort Collins, CO. He is a member of TFEC, a Fellow in the Association of Preservation Technology International, and has served as the Chair of ASCE's Forensic Engineering Division. He is the 2002 recipient of the James Marston Fitch Foundation Grant for his approach to evaluating timber in historic buildings.

Jim DeStefano, P.E., AIA, F.SEI is President of DeStefano & Chamberlain, Inc., Fairfield, CT. Jim is a founder and past-chairman of the TFEC.