AITC TECHNICAL NOTE 21
VOLUME FACTOR FOR STRUCTURAL GLUED LAMINATED TIMBER
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AMERICAN INSTITUTE OF TIMBER CONSTRUCTION

It has long been recognized by the wood industry that the size of a timber bending member has an influence on its apparent strength. Factors to adjust for this effect on the design of wood members have evolved and changed over time. This technical note is intended to document the history of these factors and the development of the current factors that are used for structural glued laminated timber design in the United States.

Depth Factors

In the 1920's, scientists at the U.S. Forest Products Laboratory (FPL) in Madison, WI, recommended the use of a depth factor to adjust the allowable bending strength for solid sawn timber members having depths (d) greater than two inches. Tests supporting this factor were conducted on lumber beams up to 12 in. deep. This depth factor, first published in 1924 (Newlin et. al. 1924), had the form:

$$F = 1.07 - 0.07\left(\frac{d}{2\ \text{in.}}\right)^{1/2}$$

Equation 1

where d = depth of the member in inches

With the introduction of structural glued laminated timbers (glulam) to the U.S. in the mid 1930's came the ability to manufacture larger bending members than traditionally available with solid sawn timbers. To acknowledge these potentially larger members, additional research related to the effect of the depth of a timber member as it related to the member's load carrying capacity was conducted at the FPL. This work led to the development of a revised depth factor, which was published in 1954 (Freas et. al. 1954) as:

$$F = 0.81\left(\frac{d^2 + 143\ \text{in}^2}{d^2 + 88\ \text{in}^2}\right)$$

Equation 2

This equation was based on a standard depth of twelve inches. The depth factors described in Equations 1 and 2 were assumed to be governed by failure on the compression side of the beam (Freas et. al. 1954).

Size Factor

FPL continued to research the effects of member size on strength. In 1966, Bohannan presented a derivation of a size factor based on Weibull weak link theory (Bohannan 1966). This theory relates the apparent strength of a beam to its volume and assumes beam strength is governed by tension failure.

Beam tests reviewed by Bohannan did not show any effect of width on the apparent strength of timber beams from 1 to 6 inches wide. Modifying his equations to include only depth and length, Bohannan showed good agreement between his test results and theory. Beams tested to validate his modified theory included three glued laminated timber members 31½ inches deep. On the basis of the findings from this research activity, the wood industry adopted the use of a size factor, C_F, to replace the depth factor as given by Equation 2. The equation for this size factor was:

$$C_F = \left(\frac{12 \text{ in.}}{d} \right)^{1/9} \qquad\qquad \text{Equation 3}$$

This factor was applied as a modifier to the published allowable bending stresses for members having a depth other than twelve inches. The use of this equation assumes a bending member supporting a uniformly distributed load and having a span-to depth ratio (L/d) of 21. For other conditions of loading or L/d ratios other than 21, appropriate modifications can be made to the base value calculated by Equation 3. While only the depth of the member is shown as a variable in equation 3, the effect of member length was also considered in development of the size factor.

The size factor defined by Equation 3 was recommended to adjust bending design values for both vertically-laminated and horizontally-laminated structural glued laminated timber members until 1991. For horizontally laminated members, this factor was limited to a maximum value of 1.0.

Volume Factor

In 1987, a small series of tests on structural glued laminated timber beams indicated that the size factor defined by Equation 3 might not adequately describe the effects of beam size on strength. This information caused considerable concern within the laminated timber industry. More stringent quality control measures were instituted throughout the industry including the requirement of tension tests for end joints and statistical process control (AITC 1992, ANSI/AITC 1992). Research was also commissioned to evaluate the existing database to better quantify the size effect for structural glued laminated timber.

An evaluation of these various test data was reported in *Analysis of Size Effect in Glulam Beams* (Moody et. al.1988). This study included beams up to a maximum size of 9 in. wide by 31.5 in. deep. The results of the study, indicated that the effects of depth and length on the bending strength of glulam beams were different than previously accounted for by the use of the size factor. In addition, the results of this analysis indicated that the width of the member also has an effect on overall beam bending strength. The authors recommended adoption of a volume factor (C_V) as defined by Equation 4.

$$C_V = k \left(\frac{5.125 \text{ in.}}{b} \right)^{\frac{1}{x}} \left(\frac{12 \text{ in.}}{d} \right)^{\frac{1}{y}} \left(\frac{21 \text{ ft}}{L} \right)^{\frac{1}{z}} \qquad\qquad \text{Equation 4}$$

where k = adjustment factor for method of loading
         = 1.0 for uniform load
         = 0.96 for concentrated loads located at third points of span
         = 1.09 for a single concentrated load at mid-span
      d = depth of the member (in.)
      b = width of the member (in.) (for multiple piece laminations across the width, the width factor is based on the width of the widest piece used in the layup).
      L = the length of the member(ft), defined as the distance between points of zero moment
      x, y, z = empirically derived coefficients
      x   = 9
      y   = 10
      z   = 10

Although there had been no indications of in-service problems associated with the use of the size factor in the design of laminated beams, the structural glued laminated timber industry initiated a series of large scale beam tests to determine if changes were needed. As an interim measure, AITC recommended the adoption of the volume factor (C_V), proposed by Moody et. al. to replace the size factor (C_F) as a stress adjustment factor for horizontally laminated structural glued laminated timbers (AITC 1990).

In 1989, AITC completed a series of full scale bending tests of large Douglas fir glued laminated timber beams at Washington State University. These beams, believed to be the largest glulam beams ever tested, had a cross section of 8-3/4" x 48" with a test span of 64 ft. The results of these tests and numerous other full size beam test programs of Douglas fir, as reported in *Strength of Glulam Beams - Volume Effects* (Moody et. al. 1990), support the use of the volume factor as indicated by Equation 4 for determining the design bending stresses for Douglas fir. Based on these

tests and other available data, AITC recommended the use of the volume factor for determining the allowable bending stresses for glulam beams laminated from Western species with the coefficients of x, y, z all set equal to 10.

An AITC test program to evaluate the effect of member size on large glulam beams laminated using Southern pine was conducted at Louisiana State University in 1990 (Gopu 1992). These test beams were 8-1/2" x 48-1/8" in cross-section with a test span of 63-1/2 feet. The results from these Southern pine beam tests did not support the use of the empirical exponential coefficient of 10 for use in the volume effect equation as derived for Western species. Based on engineering judgment, AITC recommended the use of an empirical exponential coefficient of 20 for use in the volume effect equation for Southern pine. This exponent was chosen to make the volume factor for Southern Pine timbers roughly equal to the size factor previously used.

The glued laminated timber industry recommended the use of a volume factor as defined by Equation 5 for the design of structural glued laminated timber members in 1991. This factor was adopted in the 1991 edition of the *National Design Specification*® *(NDS*®*) for Wood Construction* (AF&PA 1991).

$$C_V = k \left(\frac{5.125 \text{ in.}}{b} \right)^{\frac{1}{x}} \left(\frac{12 \text{ in.}}{d} \right)^{\frac{1}{x}} \left(\frac{21 \text{ ft}}{L} \right)^{\frac{1}{x}} \leq 1.0 \qquad \text{Equation 5}$$

where k = adjustment factor for method of loading
                 = 1.0 for uniform load
                 = 0.96 for concentrated loads located at third points of span
                 = 1.09 for a single concentrated load at mid-span
      d = depth of the member (in.)
      b = width of the member (in.) (for multiple piece laminations across the width, the width factor is based on the width of the widest piece used in the layup).
      L = the length of the member(ft), defined as the distance between points of zero moment
      x   = 20 for Southern Pine
                 = 10 for all other species

Subsequent studies conducted at the Forest Products Laboratory verified that the use of a volume factor with x equal to 10 was appropriate for several hardwood species (Manbeck et. al 1993, Moody et. al 1993, Shedlauskas et. al. 1996). In 2001, the "k" factor was dropped from the volume factor equation in the *NDS* for design purposes (AF&PA 2001). The "k" factor is still recommended for use in adjusting test data to the standard case of a uniform load. The volume factor was officially adopted as part of *ASTM D3737* in 2003 (ASTM 2003).

Application of the Volume Factor

The volume factor described by Equation 5 is applied to the design bending stress, F_{bx}, for horizontally laminated timbers. For timbers with loads applied parallel to the bond lines (vertically laminated timbers), the size factor (also known as the flat-use factor) should be used to adjust the design bending stress, F_{by}, for size effect.

Structural glued laminated timbers with variable depths require special consideration. For tapered beams or pitched and tapered curved beams, the volume factor should be calculated using the depth at each cross section of interest, with *L*=span.

The volume factor is not applied cumulatively with the stress interaction factor or beam stability factor. Application of the volume factor is illustrated and discussed in more detail in the Timber Construction Manual (AITC 2004).

References

Newlin, J.A. and G.W. Trayer. 1924. Form factors of beams subjected to transverse loading only. Report No. 181, National Advisory Committee for Aeronautics, Washington, D.C. (Reprinted as Report 1310, Forest Products Laboratory, October 1941.)

Freas, A.D. and M.L. Selbo. 1954. Fabrication and design of glued laminated wood structural members. Technical Bulletin 1069. Madison, Wisconsin: U.S. Forest Products Laboratory. 220 p.

Bohannon, B. 1966. Effect of size on bending strength of wood members. Research Paper FPL 56. Madison, Wisconsin: U.S. Forest Products Laboratory.

Moody, R.C.; C. Dedolph; and P.L. Plantinga. 1988. Analysis of size effect for glulam beams. In: Proceedings of the International Conference on Timber Engineering; 1988 September; Seattle, WA. 1:892-898.

Moody, R.; R. Falk; and T. Williamson. 1990. Strength of glulam beams-volume effects. In: Proceedings of the 1990 International Timber Engineering Conference; 1990; Tokyo. 1:176-182.

AITC. 1992. Inspection manual for structural glued laminated timber. AITC 200-92. Centennial, Colorado: American Institute of Timber Construction. 117 p.

ANSI/AITC. 1992. American national standard for wood products---structural glued laminated timber. ANSI/AITC A190.1-1992. Centennial, Colorado: American Institute of Timber Construction. Gopu, V.K.A. 1992. "Large" southern pine beam tests, final report - projected conducted for American Institute of Timber Construction. Baton Rouge, Louisiana: Louisiana State University.

AITC. 2004. Timber construction manual. Hoboken, New Jersey: John Wiley and Sons, Inc. 477 p.

Manbeck, H., J. Janowiak, P. Blankenhorn, P. Labosky, R. Moody, and R. Hernandez. 1993. Performance of Red Maple Glulam Timber Beams. Research Paper FPL-RP-519. Madison, Wisconsin: U.S. Forest Products Laboratory.

Moody, R. R. Hernandez, J. Davolos, and S. Somnath. 1993. Yellow Poplar Glulam Timber Beam Performance. Research Paper FPL-RP-520. Madison, Wisconsin: U.S. Forest Products Laboratory.

Shedlauskas, J.P., H. Manbeck, J. Janowiak, R. Hernandez, R. Moody, P Blankenhorn, and Labosky, P. 1996 Efficient use of red oak for glued-laminated beams. Transactions of ASCE, 39(1):203-209.

ANSI/AF&PA. 1991. National design specification for wood construction. Washington, D.C.: American Wood Council.

ANSI/AF&PA. 2001. National design specification for wood construction.   ANSI/AF&PA NDS-2001. Washington, D.C.: American Wood Council.

ASTM. 2003. Standard practice for establishing allowable properties for structural glued laminated timber (glulam). ASTM D3737-03. West Conshohocken, Pennsylvania: ASTM International.