AITC TECHNICAL NOTE 8

BOLTS IN STRUCTURAL GLUED LAMINATED TIMBER

March 2010

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Steel bolts are commonly used to connect structural glued laminated timber (glulam) members. When designed and detailed properly, bolted connections provide a practical, effective, and economical way to transfer loads and maintain structural integrity throughout the life of the structure. Conversely, poor design and detailing can lead to premature failure of bolted connections, requiring costly repair or replacement of the structure. This technical note provides design recommendations to assist architects and engineers with the design and detailing of bolted connections in structural glued laminated timber. It does not, however, cover all aspects of bolted connection design. Connection capacities must be determined in accordance with the *National Design Specification® (NDS®) for Wood Construction* (American Forest & Paper Association, Washington, DC).

BOLT SIZE LIMITATIONS

The maximum size bolts permitted by the *NDS®* are one inch in diameter (2005 *NDS Commentary* C11.1.2). Research supporting this limitation indicated that negative effects of drying and fabrication imperfections were more pronounced with large, stiff fasteners than for smaller diameter fasteners (Suddarth, S.K., *Test Performance of 1-1/2 Inch Bolts in Glulam—Row Effect and Effect of Subsequent Drying*, Wood Design Focus Issue 1, Volume 1, 1990). Other researchers found close correlation between test results of 1 in. diameter bolts and the yield theory, but that 1-1/2 in. diameter bolts did not perform as well as predicted (Call, R.D and Bjorhawde, R. *Wood Connections with Heavy Bolts and Steel Plates*, ASCE Journal of Structural Engineering Volume 116 Number 11, 1990).

The results of a test program (Khushefati, W.H. *Performance of Bolted Joints Comprised of Glue-Laminated Wood Members Connected with Large Diameter (1-1/4 inch) Bolts*. Master's Thesis, Cornell University, 1985) consisting of single 1-1/4 in. diameter bolts in 4-1/2 in. wide glued laminated timber with ½ in. steel or 2-1/4 in. wood side members compared favorably with fastener capacities determined using the NDS procedures, however, tests were not performed on multiple-fastener joints or in other configurations. Therefore, AITC recommends against the use of bolts larger than 1 in. diameter without further research.

BOLT STRENGTH

ASTM A307 – Grade A or SAE J429 – Grade 1 (F_y = 36,000 ksi, F_u = 60,000 ksi) bolts are typically used in timber construction, and fastener capacities published in the *NDS®* are based on bolts of this strength. A bending yield strength of 45,000 psi is used in the yield mode calculations for these fasteners.

High strength bolts are also permitted to be used to connect timber members. The bending yield strength (F_{yb}) is determined from tests in accordance with ASTM F1575 or may be estimated as the average of the ultimate tensile strength and the tensile yield stress (NDS® Appendix I).

NUT TIGHTENING

For all grades of bolts used in timber construction, nuts should be tightened to the “snug-tight” condition. This is generally sufficient to bring the faces of the joined members into firm contact. However, for U-shaped hangers or saddles, where the side plates are welded to the bearing plate, nuts should be tightened only to bring the nut and bolt head into firm contact with the side plates. For bolts in slotted holes (such as to accommodate cross-grain shrinkage of the timber member or displacement at the end of a pitched beam), nuts should be installed “finger-tight” to allow the members to slide past each other with minimal resistance.

There is no minimum torque or bolt tension requirement, even when high strength bolts are used. Bolt tension will generally be lost due to subsequent shrinkage of the timber members due to drying. “Slip-critical” connections are not used in timber construction, because it is impossible to maintain the bolt tension over time. Over-tightening of nuts should be avoided to prevent localized crushing of the wood fibers or damage to the bolts.

WASHERS

A washer at least as large as a standard cut washer is required between the wood and the bolt head and between the wood and the nut. It is not necessary to use a washer if a steel plate or strap is placed between the bolt head or nut and the wood member. Hardened washers are not required.

BOLT HOLES

Standard holes in metal and glulam members in bolted connections are typically 1/16 in. larger than the bolt diameter. Occasionally, oversized or slotted holes are specified in the metal member to allow for cross-grain shrinkage of the wood member. These holes should not be confused with oversized or slotted holes sometimes used in steel construction for slip-critical connections. As such, washers are not required between the bolt head or nut and the steel plate when slotted holes are used in timber connections, unless specified for aesthetic purposes (See also NUT TIGHTENING).

SPACING AND END DISTANCE

Bolts must be placed with sufficient end distance and spacing to develop the required load without causing member failure in row or group tear-out modes. Minimum end distance and spacing prescribed by the *NDS*® must also be followed. However, the total spacing between outer rows of bolts on a single metal plate should be limited to minimize the potential for splitting the member due to perpendicular-to-grain shrinkage as it dries in service. (See also NDS Ch. 11 and Appendix E).

<u>Preventing Row Tear-out</u>

The critical spacing between fasteners within a row (s_1) required to prevent row tear-out is determined from the following equation:

$$s_1 \geq \frac{Z}{F_v t}$$

where: Z = single bolt yield capacity
F_v = design value for connection shear
t = thickness of member (measured parallel to bolt axis)

Preventing Group Tear-out

Assuming that spacing between fasteners in a row has been adequately established to develop the yield capacity of the fasteners and prevent row tear-out, the minimum spacing between rows (s_2) can be determined from the following equation:

$$s_2 \geq \frac{Zn_i}{F_t t} + d_{bh}$$

where: n_i = number of bolts in a row
d_{bh} = diameter of hole for bolt
F_t = tension design value

Minimizing the Potential for Splitting Due to Shrinkage

Standard size holes (bolt diameter + 1/16 in.) will accommodate a small amount of shrinkage that is normally expected for structural glued laminated timber members in the perpendicular-to-grain direction. However, the spacing (perpendicular-to-grain) between outermost rows of bolts on a single metal plate should not be more than 12 inches when standard holes are used in both the member(s) and side plate(s), unless analysis demonstrates that the expected shrinkage can be tolerated by the connection. The use of multiple side plates, oversized holes, or slotted holes (long axis perpendicular to the wood grain) should be considered when outer rows of bolts exceed a total spacing of 12 inches to minimize the development of cross-grain tension stresses due to shrinkage of the member. AITC 104-2003, *Typical Construction Details* illustrates this and other good detailing practices.

The 12 inch recommendation is a general rule suitable for structural glued laminated timber with metal side plates (with standard size holes in both the timber and metal) in most dry-service conditions, in which the cross-grain shrinkage of glulam is expected to be 1% or less. However, for very dry service conditions (equilibrium moisture content less than 7-8%), greater shrinkage may need to be accommodated. For other conditions, less shrinkage may be expected. For repairs to existing timbers that have already reached moisture equilibrium, wider spacing between outer rows of bolts may be tolerated, because significant additional shrinkage is not expected. It is ultimately the responsibility of the designer to consider the shrinkage based on the anticipated service conditions.

For connections designed to transfer the loads primarily through bearing, such as a beam seat or an arch base, bolts are commonly used to provide positive connection and are typically loaded only occasionally, such as for load reversals, The use of standard holes (bolt diameter +1/16 in.) in both the metal and wood members will accommodate a spacing of approximately 6 inches between the bearing seat and the furthermost bolt, based on an assumption of 1% shrinkage. The use of a hole oversized by 1/8 in. in either the metal or wood member will accommodate approximately 9 inches of space between the bearing seat and the furthermost bolt (assuming 1% shrinkage). When the design requires bolt placement farther away, the use of slotted holes in the metal should be considered to accommodate shrinkage. When oversized or slotted holes are used with multiple bolt connections, detailing must ensure that all bolts necessary to transfer the design load are properly engaged.

These recommendations are based on a simplified analysis that ignores tolerances on alignment of bolt holes, strength of the wood to resist tension perpendicular-to-grain stress, and deformations in the materials and in the bolt. However, it provides a useful guide for determining reasonable spacing limitations for groups of bolts.

SUMMARY

The recommendations in this technical note are based on experience of experts in the field of timber engineering, rational analysis, and connection tests. As such, they are considered “best practices” for detailing bolted connections. Adherence to these recommendations will reduce the occurrence of problems in laminated timber connections due to improper detailing; however there is no guarantee that all problems will be prevented.

Bolt spacing requirements to accommodate structural demands and shrinkage often conflict, requiring engineering judgment to determine appropriate details. This note is not intended to prohibit other detailing practices that have demonstrated satisfactory performance based on rational analysis, testing, or experience. Ultimate design and detailing are the responsibility of the designer.