Multiple-Bolt Wood Connection Design Topics

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Design of *single*-bolt wood connections is relatively straight forward by using the provisions of Chapters 10 and 11 of the *ANSI/AF&PA NDS-2005 National Design Specification® for Wood Construction* (NDS). Design of *multiple*-bolt wood connections is also covered by the NDS. It contains numerous design considerations specific to multiple bolt connections such as spacing in a row, spacing between rows, group action factor, localized stresses in members, and so on. Lateral design values for single bolts are tabulated for various species and connection configurations (NDS Tables 11A through 11I); however, tabulated lateral design values must be adjusted for a specific application based on provisions of the NDS. Before designing multiple-bolt wood connections, careful study of the latest NDS is recommended. The objective of this article is to alert design professionals to two multiple-bolt connection design issues that deserve special attention and explanation: local member stresses and structural glued-laminated timber horizontal shear values for connection design.

Local Stresses in Connections

The NDS requires that the design professional check for "local stresses" in connections with multiple fasteners using "principles of engineering mechanics," but it does not stipulate the engineering method to be used. Referring to NDS on Multiple Fasteners, local stresses are addressed in Section 11.6.3:

> "11.6.3 Local Stresses in Connections
> Local stresses in connections using multiple fasteners shall be evaluated in accordance with principles of engineering mechanics (See 10.1.2)."

Referring to NDS Section 10.1.2:

> "… Local stresses in connections using multiple fasteners shall be checked in accordance with principles of engineering mechanics. One method for determining these stresses is provided in Appendix E."

Appendix E of the NDS is labeled as follows: "Appendix E (Non-mandatory) Local Stresses in Fastener Groups."

Appendix E addresses three potential failure modes: net section tension capacity, row tear-out capacity, and group tear-out capacity. In summary, since NDS is the referenced design standard for wood construction, it is a model code requirement to check local stresses in multiple–bolt connections. The NDS does not limit the design professional on how the check is to be made; however, the NDS offers a "Non-mandatory" appendix as one option.

Net Section Tension Capacity

NDS Section E.2 gives an equation for checking net section capacity. An example of a net section failure is depicted in *Figure 1*.

Row Tear-Out Capacity

NDS Section E.3 gives equations for checking row tear-out capacity. An example of a row tear-out failure is depicted in *Figure 2*, showing two wood shear failure planes on each side of the bolt rows.

Group Tear-Out Capacity

NDS Section E.4 addresses group tear–out capacity. *Figure 3* demonstrates a group tear-out failure mode. Note how an entire "plug" of wood fiber is removed by shear failures on the left and right row of bolts, coupled with a net section tension failure (at any angle) between bolt row at the top of the specimen.

Figure 1: The single shear connection failed in "net tension" in tests at Virginia Tech University (Anderson, 2001).

Figure 2: Tests at Washington State University demonstrated the row tear-out failure mode (Dodson, 2003).

Figure 3: Group tear-out failure mode is demonstrated in laboratory tests at Washington State University (Dodson, 2003).

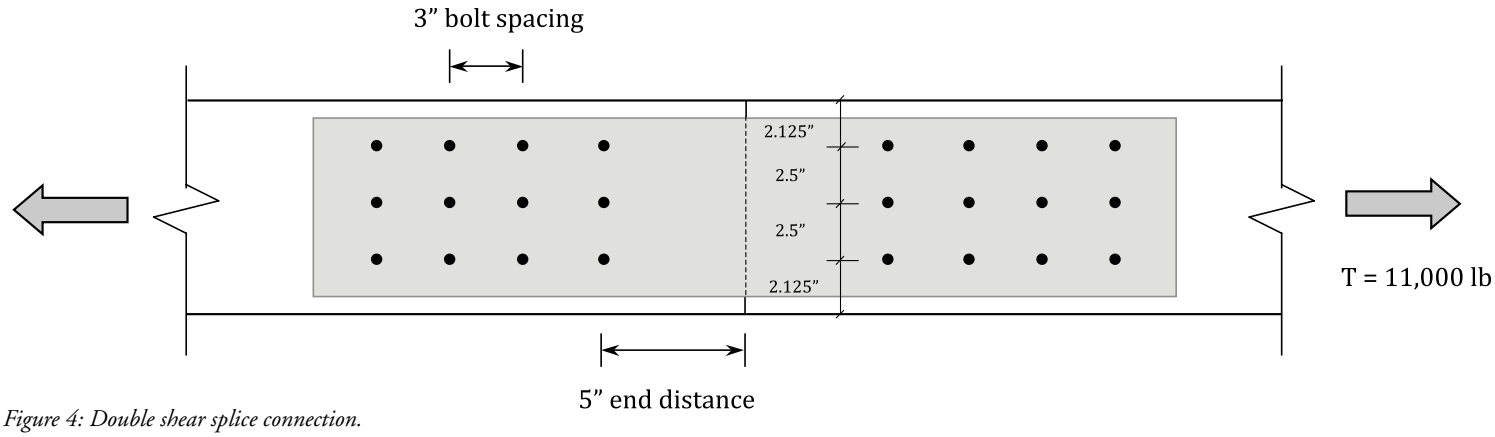

Figure 4: Double shear splice connection.

Allowable Capacity of a Multiple-Bolt Connection

Assuming the design professional uses Appendix E for checking "local stresses in connections using multiple fasteners," the allowable connection design value is the *minimum value* obtained by provisions of Chapters 10 and 11 including net section tension capacity, row tear-out capacity, and group tear-out capacity (for two or more rows of bolts).

Structural Glued-Laminated Timber Horizontal Shear Values

The allowable horizontal shear design value, with all appropriate adjustments, is used for row tear-out and group tear-out checks previously described. For dimension lumber and timbers, reference horizontal shear design values are tabulated in NDS *Supplement* Tables 4A, 4B, 4C, and 4D; and adjustment factors are summarized in Table 4.3.1. Similarly, for structural glued-laminated timber (glulam), reference shear design values are contained in Tables 5A, 5B, 5C, and 5D; and adjustment factors are summarized in Table 5.3.1. *However, an important additional adjustment is required for the allowable horizontal shear value used in connection design for glulam made from softwood lumber.*

Horizontal shear design values for glulam made from softwood lumber have increased in recent years as a result of extensive beam tests. Horizontal shear reference design values are tabulated in NDS *Supplement* Tables 5A and 5B for the X-X and Y-Y axes. It is important to note that these values are for use in designing prismatic glulam beams. Footnote 4 of Table 5A and Footnote 3 of Tables 5A Expanded and 5B stipulate that the *tabulated shear design reference value shall be decreased by multiplying by a factor of 0.72 for connection design* (and for non-prismatic members, notched members and members subject to impact or cyclic loads).

For example, the allowable shear design value for checking localized stresses in a multiple bolt connection in a glulam timber would be:

$$F_v' = F_v * 0.72 * \text{(other applicable factors from NDS Table 5.3.1)}$$

Assuming glulam Combination 3 Douglas fir and unity for Table 5.3.1 adjustment factors,

$$F_v' = 265 \text{ psi} * 0.72 = 191 \text{ psi [NDS } \textit{Supplement} \text{ Table 5B]}$$

In addition to using the correct glulam shear value for connection design, another important issue is proper connection detailing. For guidance, the reader should consult the APA Engineered Wood Association website (**www.apawood.org**) for the free download *APA Technical Note T-300 Glulam Connection Details* (revised Jan 2007).

Design Example for a Multiple-Bolt Connection

The purpose of the worked example is to demonstrate calculations for tension net section, row tear-out, and group tear-out using Appendix E of the NDS. Assumptions and requirements for the connection design are:

- Double shear splice connection with ¼-inch ASTM A36 steel side plates (8 inches wide)
- Main member is 2x10 1800f-1.8E Douglas Fir-Larch (DFL)
- Load combination is Dead + Snow
- Lumber is "dry" at installation and dry in-service
- Required connection capacity is 11,000 lbs tension.

As a starting point, try three rows of ⅝-inch diameter bolts and four bolts per row. Edge spacing is 2.125 inches, end distance is 5 inches, row spacing is 2.5 inches, and fastener spacing is 3 inches as depicted in *Figure 4*.

From NDS *Supplement* Table 4C, the referenced design values of 1800f-1.8E DFL member properties are:

F_t = 1,200 psi; E = 1,800,000 psi [NDS *Supplement*, Table 4C]

F_v = 180 psi [NDS *Supplement*, Table 4C, Footnote 2]

Check Required Number of Bolts

From NDS Table 11G, the single-bolt capacity when the member is loaded parallel to grain is:

$$Z_{||} = 1{,}310 \text{ lb [NDS Table 11G]}$$

The referenced single-bolt design value is adjusted according to NDS Table 10.3.1:

$$Z_{||}' = Z_{||} * C_D * C_g * C_\Delta$$

C_D = load duration factor from NDS Appendix B = 1.15 (for Dead+Snow combination)

C_Δ = geometry factor from NDS Section 11.5.1 = 1.0 since,

- bolt spacing, s = 3 inches, exceeds 4D minimum, per NDS Table 11.5.1C.
- end distance, s = 5 inches, exceeds 7D minimum, per NDS Table 11.5.1B.

C_g = group action factor, calculated according to NDS 10.3.6 = 0.96

The adjusted allowable single-bolt value is:

$$Z' = Z_{||} * C_D * C_g * C_\Delta = 1{,}310 \text{ lb} * 1.15 * 0.956 * 1 = 1{,}440 \text{ lbs}$$

To determine the capacity of 12 bolts, simply multiply by 12 as specified in NDS 10.2.2:

Total bolt capacity = 12 bolts * 1,440 lbs/bolt = **17,280 lbs**

Total bolt capacity > 11,000 lbs, thus with respect to bolt capacity alone, 12 bolts at ⅝-inch diameter are adequate.

Check Net Section Tension Capacity per NDS App. E.2

Allowable tension stress, adjusted by applicable factors from NDS Table 4.3.1 is:

$$F_t' = F_t\,(C_D) = 1{,}200 * 1.15 = 1{,}380 \text{ psi}$$

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Net tension capacity, allowing for 1⁄16-inch oversized bolt holes (per NDS 11.1.2.2), is given by:

T_{net} = (1,380 psi) * [1.5 in. {9.25 in. – 3(⅝ + 1⁄16 in.)}] = **14,878 lbs**

T_{net} > 11,000 lbs, net section capacity is adequate.

Check row tear-out capacity per NDS App. E.3

Allowable tear-out capacity of row of fasteners can be calculated as:

$$Z_{RT}' = n_i \frac{F_v' A_{critical}}{2}$$

where:
Z_{RTi}' = allowable row tear-out capacity of row i,
F_v' = allowable shear design value parallel-to-grain,
$A_{critical}$ = minimum shear area of any fastener in row i, and
n_i = number of fasteners in row i.
Note: The above equation is divided by 2 to account for uneven shear distribution along the row of bolts.
Assuming one shear line on each side of bolts in a row

$$Z_{RT}' = \frac{F_v' t}{2} [n_i s_{critical}](2 \text{ shear lines}) = n_i F_v' t s_{critical}$$

where:
$s_{critical}$ = minimum fastener spacing in row i (or end distance if it is less than fastener spacing)
t = thickness of member
Allowable shear stress, adjusted by applicable factors from NDS Table 4.3.1 is:

$$F_v' = F_v (C_D) = 180 * 1.15 = 207 \text{ psi}$$

$$Z'_{RTi} = n_i F'_v t s_{critical} = (4 \text{ bolts}) (207 \text{ psi}) (1.5 \text{ in.}) (3 \text{ in.}) = 3{,}726 \text{ lbs}$$

Total row tear-out capacity of multiple rows of fasteners is:

$$Z'_{RT} = \sum_{i=1}^{n_{row}} Z'_{RTi} = (3 \text{ rows}) (3{,}726 \text{ lbs/row}) = \mathbf{11{,}178\ lbs}$$

Total row tear-out capacity > 11,000 lbs, thus row tear-out capacity is adequate.

Check group tear-out capacity per NDS Appendix E.4

$$Z_{GT}' = \frac{Z'_{RT\text{-}1}}{2} + \frac{Z'_{RT\text{-}n}}{2} + F_t' A_{group\text{-}net}$$

$$Z_{GT}' = (3{,}726 \text{ lbs} / 2) + (3{,}726 \text{ lbs} / 2) + [1{,}380 * 1.5 \text{ in.} * \{5.0 \text{ in.} - 2(5/8 \text{ in.} + 1/16 \text{ in.})\}]$$

$$Z_{GT}' = 3{,}726 + 7{,}504 = \mathbf{11{,}230\ lbs}$$

Group tear-out capacity > 11,000 lbs, thus group tear-out capacity is adequate.

Discussion of Example

Using NDS bolt tables alone with applicable adjustments produced an allowable connection capacity of 17,280 pounds. With additional required checks indicated in NDS 11.6.3 for "local stresses in connections," capacity is limited to 11,178 pounds. For this example, using the capacity based on bolt tables alone for an actual design requiring 17,280 pounds capacity would produce a non-conservative error of 35%. Tension net section, row tear-out, and group tear-out capacities can be increased by changing placement of bolts in the connection. The example demonstrates the need for checking additional connection failure modes addressed by NDS Appendix E.

If an allowable design capacity is less than the required load, the detail must be adjusted to increase the connection capacity. For example, if row tear-out limits a connection capacity, increased spacing between bolts in a row and end distance will increase row tear-out capacity. Of course, this will also affect the group action factor, C_g, from NDS Section 10.3.6, hence all affected calculations need to be repeated. Similarly, if group tear-out limits connection capacity, increased spacing between bolt rows (without violating edge distance requirements of NDS 11.5.1) will increase the net tension portion of group tear-out.

Summary and Conclusions

Design of *single*-bolt wood connections is relatively straightforward using provisions of NDS Chapters 10 and 11. Design of *multiple*-bolt wood connections is also covered by the NDS, but requires additional consideration to aspects such as bolt spacing in a row, spacing between bolt rows, group action factor, localized stresses in members, etc. This article is intended to alert design professionals to two multiple-bolt connection design issues that deserve special attention and explanation: local member stresses and structural glued-laminated timber horizontal shear values for connection design.

The NDS requires that the design professional check for "local stresses" in connections with multiple fasteners using "principles of engineering mechanics," but does not stipulate the engineering method to be used. Appendix E of the NDS is listed as one method for checking local stresses for three potential failure modes – net section tension capacity, row tear-out capacity, and group tear-out capacity. Since the NDS is the referenced design standard for wood construction, it is a code requirement to check local stresses in multiple-bolt connections.

When designing multiple-bolt connections, NDS (Section 11.5) end and edge distances and spacing requirements are prescriptive and provide a starting point for a bolt connection design. Analyses using NDS bolt tables (NDS Chapter 11) with applicable adjustments (NDS Chapter 10) and Appendix E checks for localized stresses enable a design professional to determine the allowable design load for a trial connection detail using the minimum load calculated. The splice joint connection example demonstrates how localized member stresses can control a multiple-bolt connection design.

The allowable horizontal shear design value, with all appropriate adjustments, is used for row tear-out and group tear-out checks described in NDS Appendix E. However, for glulam, an important additional adjustment is required for the allowable shear value used in connection design for glulam made from softwood lumber. The design professional is alerted to Footnote 4 of Table 5A and Footnote 3 of Tables 5A Expanded and 5B that apply to glulam connection design. It stipulates that the reference shear design value shall be decreased by multiplying by a factor of 0.72 for connection design (and for designing non-prismatic members, notched members, and members subject to impact or cyclic loads).▪

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