Connection Solutions for Wood-frame Structures
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Learning Objectives

• On completion of this course, participants will:

  • Be familiar with current wood connection design philosophy, behavior, and serviceability issues.
  • Be able to identify basic wood material properties and learn how to avoid splits, notching, and net section issues in connection solutions.
  • Be able to recommend fastening guidelines for wood to steel, wood to concrete, and wood to wood connections.
  • Be able to describe effects of moisture on wood connections and implement proper detailing to mitigate issues that may occur.

Outline

• Wood connection design philosophy
• Connection behavior
• Serviceability challenges
• Connection hardware and fastening systems
• Connection techniques
• Design software
• Where to get more information
Outline

- Wood connection design philosophy
- Connection behavior
- Serviceability issues
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information

Basic Concepts

- Model wood cells as a bundle of straws
- Bundle is very strong parallel to axis of the straws

**Parallel**

**Stronger**

**Perpendicular**

**Less strong**
Connecting Wood - Philosophy

- Wood likes compression parallel to grain
  - makes connecting wood very easy
Connecting Wood - Philosophy

- Wood likes to take on load spread over its surface

Concentrated at a single fastener – wood is more prone to split and crush
Connecting Wood - Philosophy

- Wood and tension perpendicular to grain
  - Not recommended

Initiators:
- notches
- large diameter fasteners
- hanging loads

Notching

Problem

Solution
Beam to Concrete

- Notched Beam Bearing
  - may cause splitting
  - not recommended

Beam to Concrete

- Notched Bearing Wall
  - alternate to beam notch
Hanger to Beam

- Load suspended from lower half of beam
  - Tension perpendicular to grain
  - May cause splits

- Lower half of beam
  - May cause splits
  - Not recommended

Exception: light load
- <100 lbs
- >24” o.c.
Hanger to Beam

- Load supported in upper half of beam
- Extended plates puts wood in compression when loaded

Connecting Wood- Philosophy

- Splitting happens because wood is relatively weak perpendicular to grain
  - Nails too close (act like a wedge)
Connecting Wood - Philosophy

Staggered Nailing

- Nailing not staggered
- Nailing staggered

Framing
Wood Structural Panel
Nail
1/8" Gap Between Panels

Connecting Wood - Philosophy

Splitting occurs parallel to grain

Splitting will not occur perpendicular to grain, no matter how close nails are

Staggering a line of nails parallel to wood grain minimizes splitting
Connecting Wood - Philosophy

• Wood, like other hygroscopic materials, moves in varying environments

Connecting Wood - Philosophy

• Fastener selection is key to connection ductility, strength, performance
Connecting Wood - Philosophy

- Mechanical fasteners
  - keep them small
  - use lots of them

- Issue is scale of fastener relative to wood member size

Next...

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information
Connection Behavior

- Balance
  - Strength –
  - Ductility-

Displacement

Load

low strength, good ductility

good strength, good ductility

high strength, poor ductility

Connection Behavior

![Image of connection behavior diagram]
Connection Behavior

Oh Henry!  BIG HUNK  SNICKERS  PayDay  Butterfinger

Connection Behavior

BIG HUNK
Connection Behavior

- Balance
- Strength –
  - Size and number of fasteners
- Ductility –
  - Fastener slenderness
  - Spacing
  - End distance

Load

Displacement

Next...

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information
Connection Serviceability

- Issue: direct water ingress
- Water is absorbed most quickly through wood end grain

No end caps or flashing
Connection Serviceability

- Issue: direct water ingress
- Re-direct the water flow around the connection

end caps and flashing

Connection Serviceability

- Issue: direct water ingress
- Or, let water out if it gets in...

Moisture trap - No weep holes
Moisture Changes In Wood

Causes dimensional changes perpendicular to grain

Growing tree is filled with water

As wood dries, it shrinks perp. to grain

Wood Shrinks

Woodmagazine.com
Connection Serviceability

• Moisture Effects

1% change in dimension for every 4% change MC

Wet Service Factor, CM

• Dowel-type connectors
  • bolts
  • drift pins
  • drift bolts
  • lag screws
  • wood screws
  • nails

<table>
<thead>
<tr>
<th>C_M</th>
<th>Saturated</th>
<th>19% MC</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.7</td>
<td>0.4*</td>
<td></td>
</tr>
</tbody>
</table>

Lateral load (*C_M=0.7 for D<1/4")

1.0 0.7 1.0 Withdrawal load - lag & wood screws only

1.0 0.25 0.25 Withdrawal load - nails & spikes
Wet Service Factor, CM

\[ C_M = 1.0 \text{ if:} \]
- 1 fastener
- 2+ fasteners

Saturated

19% MC

Dry

\[ C_M = 0.4 \]

Lateral load (D>1/4’’)

fabrication MC
in-service MC

Beam to Column

- Full-depth side plates
  - may cause splitting
  - wood shrinkage
**Beam to Column**

- Smaller side plates
  - transmit force
  - allow wood movement

**Beam to Column**

- Problem
  - shrinkage
  - tension perp
Beam to Wall

- **Solution**
  - bolts near bottom
  - minimizes effect of shrinkage

Slotted hardware

Connection Serviceability

- Avoid contact with cementitious materials

  - **Beam on Shelf**
    - prevent contact with concrete
    - provide lateral resistance and uplift
Beam to Concrete

• Beam on Wall
  • prevent contact with concrete
  • provide lateral resistance and uplift
  • slotted to allow longitudinal movement
  • typical for sloped beam

Beam to Masonry

• Application

Need 1/2” air gap between wood and masonry
Column to Base

- Problem
  - no weep holes in closed shoe
  - moisture entrapped
  - decay can result

Column to Base

- Angle brackets
  - anchor bolts in brackets
Column to Base

Where’s the plate?

Hidden Column Base

- Floor slab poured over connection
  - will cause decay
  - not recommended
Column to Base

- Floor slab poured below connection

Next...

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information
Mechanical Connectors

Traditional Connectors

- All-wood solution
- time tested
- practical
- extreme efficiencies available with computer numeric control (CNC) machining

www.tfguild.org
www.timberframe.org
Traditional Connectors

- Long History > 100 years
- Uses automated Computer numerical Control (CNC) milling technology
  - machine joints
  - pre-drill holes
- Timber Framer’s Guild - www.tfguild.org


Mechanical Connectors

- Common Fasteners
  - Nails
  - Staples
  - Wood Screws
  - Metal plate connectors
  - Lag screws
  - Bolts

Fastener Values

- Included in U.S. design literature

<table>
<thead>
<tr>
<th>Fastener Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolts</td>
<td>NDS or ER</td>
</tr>
<tr>
<td>Lag Screws</td>
<td>NDS or ER</td>
</tr>
<tr>
<td>Wood Screws</td>
<td>NDS or ER</td>
</tr>
<tr>
<td>Nails &amp; Spikes</td>
<td>NDS or ER</td>
</tr>
<tr>
<td>Split Ring Connectors</td>
<td>NDS</td>
</tr>
<tr>
<td>Shear Plate Connectors</td>
<td>NDS</td>
</tr>
<tr>
<td>Drift Bolts &amp; Drift Pins</td>
<td>NDS</td>
</tr>
<tr>
<td>Metal Plate Connectors</td>
<td>ER</td>
</tr>
<tr>
<td>Hangers &amp; Framing Anchors</td>
<td>ER</td>
</tr>
<tr>
<td>Staples</td>
<td>ER</td>
</tr>
</tbody>
</table>

Evaluation Reports (ER) are developed for proprietary products.
NDS Chapter 11 – Dowel-type Fasteners

- ASD and LRFD accommodated through Table 10.3.1
- Bolts
- Lag screws
- Wood screws
- Nails & spikes

### Table 10.3.1 Applicability of Adjustment Factors for Connections

<table>
<thead>
<tr>
<th>Fastener Type</th>
<th>ASD Only</th>
<th>ASD and LRFD</th>
<th>LRFD Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowel-type Fasteners</td>
<td>Z = Z s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
<tr>
<td>Split Ring and Shear Plate Connectors</td>
<td>Z = Z s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
<tr>
<td>Timber Nuts</td>
<td>Z = Z s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
<tr>
<td>Metal Plate Connectors</td>
<td>Z = Z s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
<tr>
<td>Split Grubs</td>
<td>Z = Z s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
<tr>
<td>Nails, spikes, lag screws</td>
<td>W = W s</td>
<td>C_0, C_x</td>
<td>C_y, C_z</td>
</tr>
</tbody>
</table>

**Fastener Bending Yield Test**

**Center-Point Bending Test**

![Center-Point Bending Test Diagram](image-url)
Dowel Bearing Strength

Table 11.3.2 Dowel Bearing Strengths

<table>
<thead>
<tr>
<th>Specific Gravity, G</th>
<th>Dowel Bearing Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D=1/4”</td>
</tr>
<tr>
<td>0.73</td>
<td>9300</td>
</tr>
<tr>
<td>0.72</td>
<td>9050</td>
</tr>
<tr>
<td>0.71</td>
<td>8850</td>
</tr>
<tr>
<td>0.70</td>
<td>8600</td>
</tr>
<tr>
<td>0.69</td>
<td>8400</td>
</tr>
<tr>
<td>0.68</td>
<td>8150</td>
</tr>
</tbody>
</table>

Yield Limit Equations

Table 11.3.1A Yield Limit Equations

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;sub&gt;1&lt;/sub&gt;</td>
<td>( Z = \frac{D / 2}{F_{v,1}, R_g^2} ) (11.3-1)</td>
</tr>
<tr>
<td>I&lt;sub&gt;2&lt;/sub&gt;</td>
<td>( Z = \frac{D / 3}{F_{v,2}, R_g^2} ) (11.3-2)</td>
</tr>
<tr>
<td>II</td>
<td>( Z = \frac{k_1 \cdot D / 2}{F_{v,1}, R_g^2} ) (11.3-3)</td>
</tr>
<tr>
<td>III&lt;sub&gt;1&lt;/sub&gt;</td>
<td>( Z = \frac{k_2 \cdot D / 2}{F_{v,1}, (2+R_g), R_g^2} ) (11.3-4)</td>
</tr>
<tr>
<td>III&lt;sub&gt;2&lt;/sub&gt;</td>
<td>( Z = \frac{k_3 \cdot D / 2}{F_{v,2}, (2+R_g), R_g^2} ) (11.3-5)</td>
</tr>
<tr>
<td>IV</td>
<td>( Z = \frac{D^2 / 3}{F_{v,1}, R_g^2} ) (11.3-6)</td>
</tr>
</tbody>
</table>

• 4 Modes of failure
• 6 Yield equations
• Single & double shear
Yield Modes

MODE I
• bearing-dominated yield of wood fibers

MODE II
• pivoting of fastener with localized crushing of wood fibers

MODE III
• fastener yield in bending at one plastic hinge and bearing – dominated yield of wood fibers

MODE IV
• fastener yield in bending at two plastic hinges and bearing – dominated yield of wood fibers
Yield Limit Equations

### Table 11.3.1A Yield Limit Equations

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;sub&gt;m&lt;/sub&gt;</td>
<td>( Z = \frac{D \ell_m F_{e,m}}{R_g} ) (11.3-1)</td>
</tr>
<tr>
<td>I&lt;sub&gt;s&lt;/sub&gt;</td>
<td>( Z = \frac{D \ell_s F_{e,s}}{R_g} ) (11.3-2)</td>
</tr>
<tr>
<td>II</td>
<td>( Z = \frac{k_d D \ell_s F_{e,s}}{R_g} ) (11.3-3)</td>
</tr>
<tr>
<td>III&lt;sub&gt;m&lt;/sub&gt;</td>
<td>( Z &lt; \frac{k_b D \ell_m F_{e,m}}{(1 + 2R_g) R_g} ) (11.3-4)</td>
</tr>
<tr>
<td>III&lt;sub&gt;s&lt;/sub&gt;</td>
<td>( Z &lt; \frac{k_b D \ell_s F_{e,s}}{(2 + R_g) R_g} ) (11.3-5)</td>
</tr>
<tr>
<td>IV</td>
<td>( Z = \frac{D^2}{R_g} \left[ \frac{2F_{e,m} F_{e,s}}{R_g} \right] \sqrt{\frac{3}{1 + R_g}} ) (11.3-6)</td>
</tr>
</tbody>
</table>

Notes:

\[
k_1 = \sqrt{\frac{R_e + 2R_e^2 (1 + R_e + R_s^2) + R_e^2 R_s^2}{(1 + R_e)}}
\]

\[
k_2 = -1 + \sqrt{\frac{2F_{y,b} (1 + 2R_g) D^2}{3F_{e,m} \ell_m^2}}
\]

\[
k_3 = -1 + \sqrt{\frac{2(1 + R_e) + \frac{2F_{y,b} (2 + R_g) D^2}{3F_{e,m} \ell_m^2}}{R_e}}
\]

- \( D \) = diameter, in. (see 11.3.7)
- \( F_{y,b} \) = dowel bending yield strength, psi
- \( R_s \) = reduction term (see Table 11.3.1B)
- \( R_e = \frac{F_{m}}{F_{e,m}} \)
- \( \ell_m \) = main member dowel bearing length, in.
- \( \ell_s \) = side member dowel bearing length, in.
- \( F_{m} \) = main member dowel bearing strength, psi (see Table 11.3.3)
- \( F_{e,m} \) = side member dowel bearing strength, psi (see Table 11.3.3)
Yield Limit Equations

Table 11.3.1B Reduction Term, $R_s$

<table>
<thead>
<tr>
<th>Fastener Size</th>
<th>Yield Mode</th>
<th>Reduction Term, $R_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25&quot; ≤ D ≤ 1&quot;</td>
<td>I&lt;sub&gt;n&lt;/sub&gt;, I&lt;sub&gt;l&lt;/sub&gt;</td>
<td>4 $K_0$</td>
</tr>
<tr>
<td>II</td>
<td>3.6 $K_0$</td>
<td></td>
</tr>
<tr>
<td>III&lt;sub&gt;n&lt;/sub&gt;, III&lt;sub&gt;l&lt;/sub&gt;, IV</td>
<td>3.2 $K_0$</td>
<td></td>
</tr>
<tr>
<td>D &lt; 0.25&quot;</td>
<td>I&lt;sub&gt;f&lt;/sub&gt;, I&lt;sub&gt;s&lt;/sub&gt;, II, III&lt;sub&gt;s&lt;/sub&gt;, III&lt;sub&gt;t&lt;/sub&gt;, IV</td>
<td>$K_D$(^1)</td>
</tr>
</tbody>
</table>

Notes:

- $K_0 = 1 + 0.25(\theta/90)$
- $\theta = \text{maximum angle between the direction of load and the direction of grain (} 0 \leq \theta \leq 90^\circ \text{)}$ for any member in a connection
- $D = \text{diameter, in. (see 11.3.7)}$
- $K_D = 2.2$ for $D ≤ 0.17\"$
- $K_D = 10D + 0.5$ for $0.17\" < D < 0.25\"$

1: For threaded fasteners where nominal diameter (see Appendix L) is greater than or equal to 0.25\" and root diameter is less than 0.25\", $R_s = K_D$ $K_D$.

Chapter 11- Dowels

11.3.6 Dowel Diameter

11.3.6.1 When used in Tables 11.3-1A and 11.3-1B, the fastener diameter shall be taken as $D$ for unthreaded full-body diameter fasteners and $D_t$ for reduced body diameter fasteners or threaded fasteners except as provided in 11.3.6.2.

11.3.7 Dowel Diameter

11.3.7.1 When used in Tables 11.3.1A or 11.3.1B, the fastener diameter shall be taken as $D$ for unthreaded full-body diameter fasteners and $D_t$ for reduced body diameter fasteners or threaded fasteners except as provided in 11.3.7.2.
Updated TR 12


TR 12

• Background and derivation of the mechanics-based approach for calculating lateral connection capacity used in the *NDS*
• Provides additional flexibility and broader applicability to the NDS provisions.
• Simplified Equations
### Table 3-1: General Dowel Equations for Solid Cross Section Members

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
<th>Double Shear</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;sub&gt;n&lt;/sub&gt;</td>
<td>$P = q_{dn}L_m$</td>
<td>$P = q_{dn}L_n$</td>
<td></td>
</tr>
<tr>
<td>I&lt;sub&gt;i&lt;/sub&gt;</td>
<td>$P = q_iL_i$</td>
<td>$P = 2q_iL_i$</td>
<td></td>
</tr>
<tr>
<td>II-IV</td>
<td>$P = \frac{B + \sqrt{B^2 - 4AC}}{2A}$</td>
<td>$p = -\frac{B + \sqrt{B^2 - 4AC}}{A}$</td>
<td>General equation for member bearing and dowel yielding</td>
</tr>
</tbody>
</table>

**Inputs A, B, & C for Yield Modes II-IV**

| II<sup>a</sup> | $A = \frac{1}{4q_{is}}$ | $B = \frac{L_m}{2} + \frac{L_n}{2}$ | $C = \frac{q_{is}L_m}{4}$ |
| III<sub>n</sub> | $A = \frac{1}{2q_{is}}$ | $B = \frac{L_m}{2}$ | $C = -\frac{M_n}{4}$ |
| III<sub>i</sub> | $A = \frac{1}{4q_{is}}$ | $B = \frac{L_m}{2} + g$ | $C = -\frac{M_n}{4}$ |
| IV | $A = \frac{1}{2q_{is}}$ | $B = g$ | $C = M_n$ |

<sup>a</sup>Yield Modes II and III<sub>n</sub> do not apply for double shear connections.

<sup>b</sup>See Section 1.6 for notation.

---

**TR 12**

Allows for evaluation of connections with gaps between connected members.
• 2014 Edition - New information on design of
  • wood members attached to hollow members
  • design of driven-fasteners with tapered tips
  • optimizing connections based on location of threads relative to the connection shear plane.

Chapter 11- Dowels

11.3.7 Dowel Diameter

11.3.7.1 Where used in Tables 11.3.1A or 11.3.1B, the fastener diameter shall be taken as D for unthreaded full-body diameter fasteners and Dₕ for reduced body diameter fasteners or threaded fasteners except as provided in 11.3.7.2.

11.3.7.2 For threaded full-body fasteners (see Appendix L), D shall be permitted to be used in lieu of Dₕ where the bearing length of the threads does not exceed ¾ of the full bearing length in the member holding the threads. Alternatively, a more detailed analysis accounting for the moment and bearing resistance of the threaded portion of the fastener shall be permitted (see Appendix I).
Chapter 11-Dowels

Appendix L (Non-mandatory) Typical Dimensions for Dowel-Type Fasteners and Washers

Table L1 Standard Hex Bolts

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Root Diameter</td>
<td>D₀</td>
<td></td>
</tr>
<tr>
<td>Thread Length</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Bolt Length</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Width of Head Across Flats</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Height of Head</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>

Full-Body Fastener

Table L2 Standard Hex Lag Screws

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Root Diameter</td>
<td>D₀</td>
<td></td>
</tr>
<tr>
<td>Thread Length</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Lag Screw Length</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Number of Threads per Inch</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Width of Head Across Flats</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Height of Head</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>

Chapter 11-Dowels

Threaded length < \( \frac{1}{4} L \)

Dia. Fastener = D

Threaded length < \( \frac{1}{4} L \)

Dia. Fastener = D
Chapter 11-Dowels

Spacing, End, & Edge Distance 2012 NDS

Table 11.5.1D Spacing Requirements Between Rows

<table>
<thead>
<tr>
<th>Direction of Loading</th>
<th>Minimum Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel to Grain</td>
<td>1.5D</td>
</tr>
<tr>
<td>Perpendicular to Grain:</td>
<td></td>
</tr>
<tr>
<td>when $\ell/D \leq 2$</td>
<td>2.5D</td>
</tr>
<tr>
<td>when $2 &lt; \ell/D &lt; 6$</td>
<td>$(5\ell + 10D)/8$</td>
</tr>
<tr>
<td>when $\ell/D \geq 6$</td>
<td>5D</td>
</tr>
</tbody>
</table>

1. The $\ell/D$ ratio used to determine the minimum edge distance shall be the lesser of:
   (a) length of fastener in wood main member$/D = \ell/D$
   (b) total length of fastener in wood side member$/D = \ell/D$

2. The spacing between outer rows of fasteners parallel to the member on a single splice plane shall not exceed $\ell/D$, see Figure 10.10.
• Unless special detailing is provided to accommodate cross-grain shrinkage of the wood member.

Spacing, End, & Edge Distance 2012 NDS

- Adds the following notes to 11.5.1 The perpendicular to grain distance between the outermost fasteners shall not exceed 5" (see Figure 11H) unless special detailing is provided to accommodate cross-grain shrinkage of the wood member. For structural glued laminated timber members, the perpendicular to grain distance between the outermost fasteners shall not exceed the limits in Table 11.5.1F, unless special detailing is provided to accommodate cross-grain shrinkage of the member. For structural glued laminated timber members, the perpendicular to grain distance between the outermost fasteners shall not exceed the limits in Table 11.5.1F, unless special detailing is provided to accommodate cross-grain shrinkage of the member.
• Unless special detailing is provided to accommodate cross-grain shrinkage of the wood member.

### Local Stresses in Fastener Groups

#### 10.1.2 Stresses in Members at Connections

• “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.”
Local Stresses in Fastener Groups

- Closely spaced fasteners
  - brittle failure
  - lower capacity
  - wood failure mechanisms need to be considered in design

Local Stresses in Fastener Groups

- Properly spaced fasteners
  - increased ductility
  - higher capacity
  - spread out the fasteners!
Local Stresses in Fastener Groups

- Appendix E NDS Expressions

  - Net tension:
    \[ Z_{NT} = F_i' A_{net} \]

  - Row tear-out:
    \[ Z_{RT} = n_i F_i' t_{min} \]
    \[ Z_{RT} = \sum_{i=1}^{n_{max}} Z_{RT} \]

- Note: spacing between outer rows of fasteners paralleling the member on a single splice plate ≤ 5″
Chapter 12 – Split Rings and Shear Plates

• **Geometry factor, CD**
  • Side Grain

<table>
<thead>
<tr>
<th>Connector</th>
<th>Angle of Load to Grain (degrees)</th>
<th>S_a m.</th>
<th>S_h m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1/2&quot; split ring or 2-5/8&quot; shear plate</td>
<td>0</td>
<td>6.75</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>6.00</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5.13</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>4.25</td>
<td>4.13</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>3.5</td>
<td>4.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connector</th>
<th>Angle of Load to Grain (degrees)</th>
<th>S_a m.</th>
<th>S_h m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot; split ring or 4&quot; shear plate</td>
<td>0</td>
<td>9.00</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>8.00</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>7.00</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>6.00</td>
<td>5.75</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>5.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>

1 Interpolation shall be permitted for intermediate angles of load to grain.

---

Chapter 12 – Split Rings and Shear Plates

• **Geometry factor, CD**
  • End Grain

<table>
<thead>
<tr>
<th>Connector</th>
<th>Geometry Factor</th>
<th>E_a in.</th>
<th>E_h in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1/2&quot; split ring</td>
<td>C_a = 1.0</td>
<td>5.5</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>C_a = 0.70</td>
<td>3.3</td>
<td>1.5</td>
</tr>
<tr>
<td>2-5/8&quot; shear plate</td>
<td>C_a = 1.0</td>
<td>5.5</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>C_a = 0.83</td>
<td>4.25</td>
<td>1.5</td>
</tr>
<tr>
<td>4&quot; split ring</td>
<td>C_a = 1.0</td>
<td>7.0</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>C_a = 0.70</td>
<td>4.2</td>
<td>2.5</td>
</tr>
<tr>
<td>4&quot; shear plate</td>
<td>C_a = 1.0</td>
<td>7.0</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>C_a = 0.83</td>
<td>5.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>
NDS Chapter 13 – Timber Rivets

- Many applications
  - Canada several decades
  - 2005 NDS
    - Glued Laminated Timber
      - DFL
      - SP

Chapter 13- Timber Rivets

- Plates
  - Steel ASTM A36
  - Hot-dipped galvanized if in wet service
- Perforated Steel Plates
  - Fixed-hole pattern geometry
  - Holes sizes lock and hold rivet to prevent rotation
Timber Rivets - Design

- **Four strength limit states:**
  - Rivet yielding
    - \( P_r \) – parallel to grain
    - \( Q_r \) – perpendicular to grain
  - Wood failure
    - \( P_w \) – parallel to grain
    - \( Q_w \) – perpendicular to grain
  - Plate yielding
    - Enhanced ductility
    - Lowest value governs design

---

Timber Rivets – Design  2005 NDS

**Table 10.3.1 Applicability of Adjustment Factors for Connections**

<table>
<thead>
<tr>
<th>Lateral Loads</th>
<th>ASD Only</th>
<th>ASD and LRFD</th>
<th>LRFD Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowel-type Fasteners</td>
<td>( Z = Z ) x</td>
<td>( C_{10} )</td>
<td>( C_{10} )</td>
</tr>
<tr>
<td>Split Ring and Shear Plate</td>
<td>( P = P ) x</td>
<td>( Q = Q )</td>
<td>( C_{10} )</td>
</tr>
<tr>
<td>Timber Rivets</td>
<td>( P = P ) x</td>
<td>( Q = Q )</td>
<td>( C_{10} )</td>
</tr>
<tr>
<td>Shear Plate Connectors</td>
<td>( Z = Z ) x</td>
<td>( C_{10} )</td>
<td>( C_{10} )</td>
</tr>
<tr>
<td>Spike Guards</td>
<td>( Z = Z ) x</td>
<td>( C_{10} )</td>
<td>( C_{10} )</td>
</tr>
<tr>
<td>Withdrawal Loads</td>
<td>( W = W ) x</td>
<td>( C_{10} )</td>
<td>( C_{10} )</td>
</tr>
</tbody>
</table>
Timber Rivets – Design 2012 NDS

- **2005 NDS**
  - Reiterative process
  - Parallel to grain timber rivet capacity
    - \[ P_r = 280 \, p^{0.32} \, n_R \, n_C \] (13.2-1)
    - 188 2012 NDS
  - Perpendicular to grain timber rivet capacity
    - \[ Q_r = 160 \, p^{0.32} \, n_R \, n_C \]
    - 108 2012 NDS
  - Section 13.3.1: “The maximum distance perpendicular to grain between outermost rows of rivets shall be 12”
Where to Find Design Examples

- Timber Rivet Connections
  - Design Process for a Hanger Connection
  
http://www.awc.org/pdf/WDF17-4-rivet-pw.pdf

Timber Rivets - Design

- Flow chart per the 2005 NDS
  - Reiterative process
Design Example – 2005 NDS

Next...

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information
Connection Techniques

• **Must evaluate:**
  • forces present
  • environmental effects
  • material effects
  • aesthetics

Connection Techniques

• **Wood bolts in all-wood structure**
Pre-engineered Connectors

- Post to Beam
- Beam to Beam

Pre-engineered Connectors

- Joist to Beam (Hanger)
Pre-engineered Connectors

- Column Cap & Base hardware

- Hanger hardware
Pre-engineered Connectors

- **Truss hardware**

Custom Hardware

- **Difficult situations made easy**
Connection Techniques

• **Bolts in heavy trusses**

Connection Techniques

• **Connecting other frame materials:**
  • Steel
Connection Techniques

- Connecting other frame materials:
  - Concrete

- Steel bolts in columns

Hidden kerf plates
Connection Techniques

250 YEAR STRUCTURE
HEAVY TIMBER, CONCRETE & STEEL

Connection Techniques

Connection Techniques

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Connection Techniques

**Operations Centre**

- Larry McFarland
  Architect,
  Vancouver, BC
- CWMM Consulting Engineers, Inc.
  Vancouver, BC
Connection Techniques

Regional District of Nanaimo Administration Building Expansion

Architect: Neale Staniszki Doll Adams Architects Vancouver, BC

Owner: Regional District of Nanaimo Nanaimo, BC

General Contractor: Windley Contracting Ltd Nanaimo, BC

Structural Engineer: Herold Engineering Ltd. Nanaimo, BC
Custom Hardware

- A blend of art and technology

Concealed Connectors

- Proprietary Systems
Concealed Connectors

- Hollow steel connection tube
- Expanding cross pins

Concealed Connectors

- Self-tapping dowel s-w-s
- Threaded screw w-w
Connection Techniques

- Kwantlen Polytechnic University
- Cloverdale Campus

- Bunting Coady Architects, Vancouver, BC
- Bush Bohlman & Partners, Inc., Vancouver, BC
Connection Techniques

Concealed Connectors

- Shaped steel shaft
- Steel pins or dowels
- Non-shrink grout
Connection Techniques

• Raleigh-Durham International Airport
  • Fentress Architects
    • Denver, CO
    • Washington, DC
  • Stewart Engineering, Inc.
    • Raleigh, NC
  • Archer Western Contractors
    • Raleigh, NC

Connection Techniques
Connection Techniques

Concealed Connectors

- Steel pipe
- Stitch bolts
- Tie-Bolt
Concealed Connectors
Connection Techniques

• Arena Stage at the Mead Center for American Theater
  • Bing Thom Architects
  • Fast + Epp Structural Engineers
  • Clark Construction
Connection Techniques

• Richmond Olympic Oval

CANNON Design
Gerald Epp, Fast + Epp
Richmond (south of Vancouver)
Connection Techniques

• Myrick Hixon EcoPark Building - WI

Next...

• Wood connection design philosophy
• Connection behavior
• Serviceability challenges
• Connection hardware and fastening systems
• Connection techniques
• Design software
• Where to get more information
Software Solutions Exist

• WWPA Lumber Design Suite
  • Beams and Joists
  • Post and Studs
  • Wood to Wood Shear Connections (nails, bolts, wood screws and lag screws)


Connection Calculator

AWC.org
Next...

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- Connection hardware and fastening systems
- Connection techniques
- Design software
- Where to get more information

More info...

2012 NDS
M4.4 Special Design Considerations
  • Mechanical Connections
  • Dowel-Type Fasteners
  • Split Ring and Shear Plates Connectors
  • Timber Rivets

More info???

- Technical papers on Timber rivets: http://www.awc.org/helpoutreach/faq/faqFiles/Timber_rivets.html
  - Timber rivets in structural composite lumber
  - Simplified analysis of timber rivet connections
  - Timber rivet connections in U.S. domestic species
  - Timber Rivets-Structure Magazine
  - Seismic Behavior of Timber Rivets in Wood Construction
  - Seismic Performance of Riveted Connections in Heavy Timber Construction
  - Timber rivet suppliers

More info???

Take Home Messages...

- Transfer loads in compression / bearing whenever possible
- Allow for dimensional changes in the wood due to potential in-service moisture cycling
- Avoid the use of details which induce tension perp stresses in the wood
- Avoid moisture entrapment in connections
- Separate wood from direct contact with masonry or concrete
- Avoid eccentricity in joint details
- Minimize exposure of end grain

Connections

...and you thought connecting wood was complicated!
Questions?

www.awc.org
info@awc.org