Connection Design with the NDS and Technical Report 12

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Course Description

This course will feature techniques for designing connections for wood members utilizing AWC’s 2015 National Design Specification® (NDS®) for Wood Construction and Technical Report 12 - General Dowel Equations for Calculating Lateral Connection Values (TR12). Topics will include connection design philosophy and behavior, an overview of common fastener types, changes in the 2015 NDS related to cross-laminated timber, and design examples per TR12.
Learning Objectives

• **On completion of this course, participants will:**

1. Be familiar with current wood member connection solutions and applicable design requirements.
2. Be familiar with Technical Report 12 and provisions for connection design beyond NDS requirements.
3. Be able to recommend fastening guidelines for wood to steel, wood to concrete, and wood to wood connections.
4. Be able to describe effects of moisture on wood member connections and implement proper detailing to mitigate issues that may occur.

Polling Question

1. **What is your profession?**
   a) Architect
   b) Engineer
   c) Code Official
   d) Building Designer
   e) Other
Outline

- Wood connection design philosophy
- Connection behavior
- Serviceability challenges
- 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

Initiators:
- notches
- large diameter fasteners
- hanging loads

Connecting Wood - Philosophy

- Wood and tension perpendicular to grain
  - Not recommended
## Notching

<table>
<thead>
<tr>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Notched Beam Bearing" /></td>
<td><img src="image2.png" alt="Notched Beam Bearing" /></td>
</tr>
</tbody>
</table>

- Notched Beam Bearing
- may cause splitting
- not recommended

## Beam to Concrete

- Notched Beam Bearing
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
Hanger to Beam

Lower half of beam
- may cause splits
- not recommended

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

Hanger to Beam

Full wrap sling option
- Load supported in upper half of beam
- Extended plates puts wood in compression when loaded

Compression
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

- Wood, like other hygroscopic materials, moves in varying environments
Connecting Wood - Philosophy

- Fastener selection is key to connection ductility, strength, performance

Polling Question

2. Tension perpendicular to grain can be caused by?
   a) Notches in the beam
   b) Hanging loads
   c) Large diameter fasteners
   d) All of the above
Outline

- Wood connection design philosophy
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Connection Behavior

- Balance
  - Strength – high strength, poor ductility
  - Ductility – good strength, good ductility
  - Load
  - Displacement
  - high strength, poor ductility
  - good strength, good ductility
  - low strength, good ductility
Connection Behavior
Connection Behavior

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

![Graph showing connection behavior](image)

- Load: high strength, poor ductility
- Load: good strength, good ductility
- Load: low strength, good ductility

Displacement

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Wood Frame Shear Walls

- Elements of a wood shear wall

Sheathing panels of specific grade and thickness
Specific stud species size and spacing requirements
Hold-down anchors
Base shear anchors

Shear Wall Test

- 8 ft x 8 ft wood structural panel shear wall cyclic test
Shear Wall Test

• Typical failure of sheathing nailing

Outline

• 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

• Moisture Effects

1% change in dimension for every 4% change MC
### Wet Service Factor, $C_M$

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

#### Table 10.3.3 footnote 2

| Condition | $C_M$ | Withdrawal Load
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated</td>
<td>1.0</td>
<td>lag &amp; wood screws only</td>
</tr>
<tr>
<td>19% MC</td>
<td>0.7</td>
<td>nails &amp; spikes</td>
</tr>
<tr>
<td>Dry</td>
<td>1.0</td>
<td>Withdrawal load - lag &amp; wood screws only</td>
</tr>
<tr>
<td>1.0</td>
<td>0.7</td>
<td>Withdrawal load - nails &amp; spikes</td>
</tr>
<tr>
<td>1.0</td>
<td>0.25</td>
<td>Withdrawal load - nails &amp; spikes</td>
</tr>
</tbody>
</table>

#### CM = 1.0 if:
- 1 fastener
- 2+ fasteners
- Split splice plates

Table 10.3.3 footnote 2
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

Hidden Column Base

- Floor slab poured over connection
- Will cause decay
- Not recommended
Polling Question

3. Proper detailing of wood members and connections exposed to the exterior environment include:
   a) Redirecting the water flow around the connection.
   b) Separating wood from concrete and masonry
   c) Protecting the end grain
   d) Incorporating weep holes
   e) All of the above
Outline

- Wood connection design philosophy
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- 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

Traditional Connectors

- Wood dowel connection design technology now available


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

Outline

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

2015 NDS referenced in 2015 IBC

ANSI Accreditation

- AWC - ANSI-accredited standards developer
- Consensus Body
  - Wood Design Standards Committee
2015 NDS Chapter Reorganization

2012 NDS

• 1-3 General
• 4-9 Products
• 10-13 Connections
• 14 Shear Walls & Diaphragms
• 15 Special Loading
• 16 Fire

2015 NDS

• 1-3 General
• 4-10 Products +CLT
• 11-14 Connections
• Shear Walls & Diaphragms
• 15 Special Loading
• 16 Fire

NDS Chapter 11 – Mechanical Connections

• ASD and LRFD accommodated through Table 11.3.1
• Dowel fasteners
• Split ring/shear plate
• Timber rivets
• Spike grids

New chapter numbering for 2015 NDS!
NDS Dowel-fastener Connections

• 2015 NDS Chapter 12 (New location)
• Can be used for any dowel-shaped fastener
• Includes lateral and withdrawal provisions
  • Bolts
  • Lag screws
  • Wood screws
  • Nails
  • Spikes
  • Drift bolts
  • Drift pins

Dowel-fastener withdrawal

• Withdrawal calculated based on fastener penetration
  • W value is per inch of fastener penetration
    • Threaded fasteners use thread penetration
  • Lag screws
    • W = 1800 G^{3/2} D^{1/4}
  • Wood screws
    • W = 2850 G^2 D
  • Nails (smooth shank)
    • W = 1380 G^{5/2} D
    No withdrawal in end grain allowed for nails or wood screws!
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
Dowel Bearing Strength

Table 12.3.3 Dowel Bearing Strengths, F₀, for Dowel-Type Fastener

<table>
<thead>
<tr>
<th>Specific Gravity, G</th>
<th>F₀&lt; 1/4”</th>
<th>1/4” &lt; D &lt; 1”</th>
<th>1 1/4”</th>
<th>5/16”</th>
<th>3/8”</th>
<th>7/16”</th>
<th>1/2”</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.73</td>
<td>9300</td>
<td>8200</td>
<td>7750</td>
<td>6000</td>
<td>8300</td>
<td>5850</td>
<td>5450</td>
</tr>
<tr>
<td>0.72</td>
<td>9050</td>
<td>8050</td>
<td>7600</td>
<td>5900</td>
<td>8150</td>
<td>5650</td>
<td>5300</td>
</tr>
<tr>
<td>0.71</td>
<td>8550</td>
<td>7950</td>
<td>7400</td>
<td>5550</td>
<td>7800</td>
<td>5300</td>
<td>5000</td>
</tr>
<tr>
<td>0.70</td>
<td>8600</td>
<td>7800</td>
<td>7250</td>
<td>5500</td>
<td>7750</td>
<td>5250</td>
<td>4950</td>
</tr>
<tr>
<td>0.89</td>
<td>8400</td>
<td>7750</td>
<td>7100</td>
<td>5350</td>
<td>7600</td>
<td>5150</td>
<td>4850</td>
</tr>
<tr>
<td>0.88</td>
<td>8150</td>
<td>7600</td>
<td>6950</td>
<td>5200</td>
<td>7450</td>
<td>5050</td>
<td>4750</td>
</tr>
</tbody>
</table>

F₀< 1/4” = 11200G
F₀< D = 6100G^{1/4}/D
F₀< D < 1/4” = 16600 G^{3/4}

Fastener Bending Yield Test

Center-Point Bending Test

Load

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# Fastener Bending Yield Strength

<table>
<thead>
<tr>
<th>Fastener Type</th>
<th>$F_{yb}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt, lag screw (with $D \geq 3/8''$), drift pin (SAE 1429 Grade 1 - $F_y = 36,000$ psi and $F_p = 50,000$ psi)</td>
<td>45,000</td>
</tr>
<tr>
<td>Common, box, or nail nail, spike, lag screw, wood screw (low to medium carbon steel)</td>
<td></td>
</tr>
<tr>
<td>$0.099'' \leq D \leq 0.142''$</td>
<td>100,000</td>
</tr>
<tr>
<td>$0.142'' &lt; D \leq 0.177''$</td>
<td>90,000</td>
</tr>
<tr>
<td>$0.177'' &lt; D \leq 0.256''$</td>
<td>80,000</td>
</tr>
<tr>
<td>$0.236'' &lt; D \leq 0.273''$</td>
<td>70,000</td>
</tr>
<tr>
<td>$0.273'' &lt; D \leq 0.344''$</td>
<td>60,000</td>
</tr>
<tr>
<td>$0.344'' &lt; D \leq 0.375''$</td>
<td>45,000</td>
</tr>
<tr>
<td>Hardened steel nail (medium carbon steel) including post-frame ring shank nails</td>
<td></td>
</tr>
<tr>
<td>$0.120'' \leq D \leq 0.142''$</td>
<td>130,000</td>
</tr>
<tr>
<td>$0.142'' &lt; D \leq 0.192''$</td>
<td>115,000</td>
</tr>
<tr>
<td>$0.192'' &lt; D \leq 0.207''$</td>
<td>100,000</td>
</tr>
</tbody>
</table>

## Yield Limit Equations

<table>
<thead>
<tr>
<th>Table 12.3.1A Yield Limit Equations</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
<th>Double Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_n$</td>
<td>$Z = \frac{D \cdot f_m}{R_n}$</td>
<td>$Z = D \cdot f_m$</td>
</tr>
<tr>
<td>$I_s$</td>
<td>$Z = \frac{D \cdot f_m}{R_n}$</td>
<td>$Z = \frac{2D \cdot f_m}{R_n}$</td>
</tr>
<tr>
<td>$II$</td>
<td>$Z = k_2 \frac{D \cdot f_m}{R_2}$</td>
<td>$Z = k_2 D \cdot f_m$</td>
</tr>
<tr>
<td>$III_n$</td>
<td>$Z = k_2 \frac{D \cdot f_m}{(1+2R_n)R_n}$</td>
<td>$Z = k_2 D \cdot f_m$</td>
</tr>
<tr>
<td>$III_s$</td>
<td>$Z = k_2 \frac{D \cdot f_m}{(2+R_n)R_n}$</td>
<td>$Z = \frac{2k_2 D \cdot f_m}{(2+R_n)R_n}$</td>
</tr>
<tr>
<td>$IV$</td>
<td>$Z = \frac{D^2}{2F_m f_m R_n \sqrt{3(1+R_n)}}$</td>
<td>$Z = \frac{2D^2}{2F_m f_m R_n \sqrt{3(1+R_n)}}$</td>
</tr>
</tbody>
</table>

- **4 Modes of failure**
- **6 Yield equations**
- **Single & double shear**

Lowest Yield “Z” value = Connection Capacity
Yield Limit Equations

Notes:

\[ k_1 = \frac{\sqrt{R_c + 2R_c^2(1 + R_t + R_c^2) + R_t^2R_c^2} - R_c(1 + R_c)}{(1 + R_c)} \]

\[ k_2 = -1 + \frac{2F_{yb}(1 + 2R_c)D^2}{3F_{cm}E_m^2} \]

\[ k_3 = -1 + \frac{2(1 + R_c)}{R_c} + \frac{2F_{cm}(2 + R_c)D^2}{3F_{cm}E_m^2} \]

\[ D = \text{diameter, in. (see 12.3.7)} \]
\[ F_{yb} = \text{dowel bending yield strength, psi} \]
\[ R_d = \text{reduction term (see Table 12.3.1B)} \]
\[ R_e = \frac{F_{cm}}{F_{cm}} \]
\[ R_t = \frac{E_m}{E} \]
\[ \ell_m = \text{main member dowel bearing length, in.} \]
\[ \ell_s = \text{side member dowel bearing length, in.} \]
\[ F_{cm} = \text{main member dowel bearing strength, psi (see Table 12.3.3)} \]
\[ F_{cm} = \text{side member dowel bearing strength, psi (see Table 12.3.3)} \]

Yield Limit Equations

**Table 12.3.1B Reduction Term, R_d**

<table>
<thead>
<tr>
<th>Fastener Size</th>
<th>Yield Mode</th>
<th>Reduction Term, R_d</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25&quot; ≤ D ≤ 1&quot;</td>
<td>I, II, III_1, IV</td>
<td>4 K_0</td>
</tr>
<tr>
<td>3.6 K_0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 K_0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D &lt; 0.25&quot;</td>
<td>I, II, III_1, IV</td>
<td>K_0 + 0.5</td>
</tr>
</tbody>
</table>

Notes:

\[ K_0 = 1 + 0.25(8/90) \]
\[ \theta = \text{maximum angle between the direction of load and the direction of grain (0° ≤ ψ ≤ 90°) for any member in a connection} \]
\[ D = \text{diameter, in. (see 12.3.7)} \]
\[ K_0 = 2.2 \text{ for } D ≤ 0.17" \]
\[ K_0 = 10D + 0.5 \text{ for } 0.17" < D < 0.25" \]

Also applied in TR 12 equations!
Spacing, End, & Edge Distance

Table 12.5.1A End Distance Requirements

<table>
<thead>
<tr>
<th>Direction of Loading</th>
<th>Minimum End Distance</th>
<th>Minimum End Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perpendicular to Grain</td>
<td>2D</td>
<td>4D</td>
</tr>
<tr>
<td>Parallel to Grain, Compression</td>
<td>2D</td>
<td>4D</td>
</tr>
<tr>
<td>Parallel to Grain, Tension</td>
<td>1.5D</td>
<td>7D</td>
</tr>
<tr>
<td>for softwoods</td>
<td>2.5D</td>
<td>5D</td>
</tr>
</tbody>
</table>

Table 12.5.1C Edge Distance Requirements

<table>
<thead>
<tr>
<th>Direction of Loading</th>
<th>Minimum Edge Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel to Grains</td>
<td>1.5D</td>
</tr>
<tr>
<td>where (E/D \leq 6)</td>
<td>1.5D or (1/2) the spacing between rows, whichever is greater</td>
</tr>
<tr>
<td>where (E/D &gt; 6)</td>
<td></td>
</tr>
<tr>
<td>Perpendicular to Grain</td>
<td>4D</td>
</tr>
<tr>
<td>loaded edge</td>
<td></td>
</tr>
<tr>
<td>unloaded edge</td>
<td>1.5D</td>
</tr>
</tbody>
</table>

Table 12.5.1E Edge and End Distance and Spacing Requirements for Lag Screws Loaded in Wimnawaw and Not Loaded Laterally

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Minimum Distance/Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge Distance</td>
<td>1.5D</td>
</tr>
<tr>
<td>End Distance</td>
<td>4D</td>
</tr>
<tr>
<td>Spacing</td>
<td>4D</td>
</tr>
</tbody>
</table>
• Unless special detailing is provided to accommodate cross-grain shrinkage of the wood member.
Polling Question

4. The NDS Yield Limit Equations are used to determine:
   a) Lateral capacity of connections
   b) Withdrawal capacity of connections
   c) Lateral and withdrawal capacities of connections
   d) None of the above

NDS Appendix E

• Appendix E - Local Stresses in Fastener Groups (Non-mandatory)
  • Groups of closely spaced fasteners loaded parallel to grain
    • Net Section Tension Capacity
    • Row Tear-Out Capacity
    • Group Tear-Out Capacity
  • Example problems
    • Staggered rows of bolts
    • Single row of bolts
    • Row of split rings
Chapter 12-Dowels

12.3.7 Dowel Diameter

12.3.7.1 Where used in Tables 12.3.1A or 12.3.1B, the fastener diameter shall be taken as \( D \) for unthreaded full-body diameter fasteners and \( D_b \) for reduced body diameter fasteners or threaded fasteners except as provided in 12.3.7.2.

12.3.7.2 For threaded full-body fasteners (see Appendix L), \( D \) shall be permitted to be used in lieu of \( D_b \) where the bearing length of the threads does not exceed \( \frac{4}{5} \) 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 L).

Chapter 12-Dowels

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

<table>
<thead>
<tr>
<th>Table L1</th>
<th>Standard Hex Bolts</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D ) = diameter</td>
<td></td>
</tr>
<tr>
<td>( D_b ) = root diameter</td>
<td></td>
</tr>
<tr>
<td>( T ) = thread length</td>
<td></td>
</tr>
<tr>
<td>( L ) = bolt length</td>
<td></td>
</tr>
<tr>
<td>( F ) = width of head across flats</td>
<td></td>
</tr>
<tr>
<td>( H ) = height of head</td>
<td></td>
</tr>
</tbody>
</table>

Full-Body Fastener

<table>
<thead>
<tr>
<th>Table L2</th>
<th>Standard Hex Lag Screws</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D ) = diameter</td>
<td></td>
</tr>
<tr>
<td>( D_b ) = root diameter</td>
<td></td>
</tr>
<tr>
<td>( S ) = unthreaded body length</td>
<td></td>
</tr>
<tr>
<td>( T ) = minimum thread length</td>
<td></td>
</tr>
<tr>
<td>( F ) = length of tapered tip</td>
<td></td>
</tr>
<tr>
<td>( L ) = lag screw length</td>
<td></td>
</tr>
<tr>
<td>( N ) = number of threads/inch</td>
<td></td>
</tr>
<tr>
<td>( F ) = width of head across flats</td>
<td></td>
</tr>
<tr>
<td>( H ) = height of head</td>
<td></td>
</tr>
</tbody>
</table>
**Dowel Diameters**

- **Threaded length ≤ \( \frac{1}{4} \) \( l_m \)**

  - **Dia. Fastener = D**

- **Threaded length ≤ \( \frac{1}{4} \) \( l_m \)**

  - **Dia. Fastener = D**

---

**Dowel Diameters**

- **Dia. Fastener = D**

  - *NDS Chapter 12 Tables use \( D_r \) for lateral yield equations*
  - *Assumes shear plane passes through threads*
12.2.1.5 Where lag screws are loaded in withdrawal from the narrow edge of cross-laminated timber, the reference withdrawal value, \( W \), shall be multiplied by the end grain factor, \( C_{eg} = 0.75 \), regardless of grain orientation.

12.2.2.4 Wood screws shall not be loaded in withdrawal from end-grain of laminations in cross-laminated timber (\( C_{eg} = 0.0 \)).

12.2.3.6 Nails and spikes shall not be loaded in withdrawal from end-grain of laminations in cross-laminated timber (\( C_{eg} = 0.0 \)).
Chapter 12 – Dowel-type Fasteners

12.3.3 Dowel Bearing Strength

12.3.3.5 Dowel bearing strengths, \( F_{d} \), for dowel-type fasteners installed into the panel face of cross-laminated timber shall be based on the direction of loading with respect to the grain orientation of the cross-laminated timber ply at the shear plane.

12.3.3.6 Where dowel-type fasteners are installed in the narrow edge of cross-laminated timber panels, the dowel bearing strength shall be \( F_{d} \), for D\( \geq 1/4'' \) and \( F_{e} \) for D\( <1/4'' \).

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>Gravity G</th>
<th>( F_{d} )</th>
<th>( F_{e} )</th>
<th>Dowel bearing strength in pounds per square inch (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 1/4''</td>
<td>1 1/16''</td>
<td>1 1/8''</td>
<td>1 1/16''</td>
</tr>
<tr>
<td>0.55</td>
<td>5500</td>
<td>6100</td>
<td>5100</td>
<td>4600</td>
</tr>
<tr>
<td>0.54</td>
<td>5500</td>
<td>6000</td>
<td>4900</td>
<td>4450</td>
</tr>
<tr>
<td>0.53</td>
<td>5150</td>
<td>5950</td>
<td>4850</td>
<td>4350</td>
</tr>
</tbody>
</table>

Chapter 12 – Dowel-type Fasteners

12.3.5 Dowel Bearing Length

12.3.5.1 Dowel bearing length in the side member(s) and main member, \( L_{d} \) and \( L_{m} \), shall be determined based on the length of dowel bearing perpendicular to the application of load.

12.3.5.2 For cross-laminated timber where the direction of loading relative to the grain orientation at the shear plane is parallel to grain, the dowel bearing length in the perpendicular plies shall be reduced by multiplying the bearing length of those plies by the ratio of dowel bearing strength perpendicular to grain to dowel bearing strength parallel to grain (\( F_{d}/F_{e} \)).

Non-uniform for CLT
Chapter 12 – Dowel-type Fasteners

- Adjust $l_m$ or $l_s$ to compensate for orthogonal grain orientations in adjacent layers
- Parallel to grain: $F_{el} / F_{e\parallel}$

Example: ½” bolt in southern pine 3-ply CLT with 1-½” laminations

$$l_m = t_{1\parallel} + t_{2\perp} + t_{3\parallel} = 3(1.5) = 4.5”$$

$$l_{m-adj} = t_{1\parallel} + t_{2\perp}(F_{el}/F_{e\parallel}) + t_{3\parallel} = 1.5 + 1.5(3650/6150) + 1.5 = 3.9”$$

---

Table 12.3.3 Dowel Bearing Strengths, $F_r$, for Dowel-Type Fasteners in Wood Members

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>$F_r$</th>
<th>$F_t$</th>
<th>Dowel bearing strength in pounds per square inch (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>D=1”</td>
<td>D=1/4”</td>
<td>D=1/2”</td>
</tr>
<tr>
<td>0.55</td>
<td>5500</td>
<td>5150</td>
<td>5150</td>
</tr>
<tr>
<td>0.54</td>
<td>5350</td>
<td>5000</td>
<td>4450</td>
</tr>
<tr>
<td>0.53</td>
<td>5150</td>
<td>4850</td>
<td>4350</td>
</tr>
</tbody>
</table>

---

Figure 12x  End Distance, Edge Distance and Fastener Spacing Requirements in Narrow Edge of Cross-Laminated Timber

New
Chapter 12 – Dowel-type Fasteners

12.5.2 End Grain Factor, C_{eg}

12.5.2.2 Where dowel-type fasteners are inserted in the end grain of the main member, with the fastener axis parallel to the wood fibers, reference lateral design values, Z, shall be multiplied by the end grain factor, C_{eg} = 0.67.

12.5.2.3 Where dowel-type fasteners with D≥1/4” are loaded laterally in the narrow edge of cross-laminated timber, the reference lateral design value, Z, shall be multiplied by the end grain factor, C_{eg} = 0.67, regardless of grain orientation.

Technical Report 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
  - Connections with gaps between members
  - Connecting wood to members with hollow cross sections

http://www.awc.org/codes-standards/publications
### 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_0 )</td>
<td>( P = q_s L )</td>
<td>( P = q_s L )</td>
<td>-</td>
</tr>
<tr>
<td>( I_1 )</td>
<td>( P = \frac{1}{4} q_i L )</td>
<td>( P = 2 q_i L )</td>
<td>-</td>
</tr>
<tr>
<td>II/IV</td>
<td>( P = -2 + \sqrt{B^2 - 4AC} )</td>
<td>( p = -2 + \sqrt{B^2 - 4AC} )</td>
<td>General equation for member bearing and dowel yielding</td>
</tr>
</tbody>
</table>

\[ A = \frac{B}{4} + \frac{\sqrt{B^2 - 4AC}}{4} \]

\( A = \frac{B}{4} + \frac{\sqrt{B^2 - 4AC}}{4} \)

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\(*Yield Modes II and III. do not apply for double shear connections.*

*See Section 1.6 for notation.*

### Table 3.2: General Dowel Equations for Solid Cross-Section Main Member and Narrow Cross Section Side Member(s)

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
<th>Double Shear</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_0 )</td>
<td>( P = q_s L )</td>
<td>( P = q_s L )</td>
<td>-</td>
</tr>
<tr>
<td>( I_1 )</td>
<td>( P = 2 q_s L )</td>
<td>( P = 4 q_s L )</td>
<td>-</td>
</tr>
<tr>
<td>II/IV</td>
<td>( P = -2 + \sqrt{B^2 - 4AC} )</td>
<td>( p = -2 + \sqrt{B^2 - 4AC} )</td>
<td>General equation for member bearing and dowel yielding</td>
</tr>
</tbody>
</table>

\[ A = \frac{B}{4} + \frac{\sqrt{B^2 - 4AC}}{4} \]

\[ A = \frac{B}{4} + \frac{\sqrt{B^2 - 4AC}}{4} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\[ A = \frac{B}{2} + \frac{\sqrt{B^2 - 4AC}}{2} \]

\(*Yield Modes II and III. do not apply for double shear connections.*

*See Section 1.6 for notation.*
Technical Report 12

Table 1-3 General Dowel Equations for Hollow Cross Section Main Member and Solid Cross Section Side Member

<table>
<thead>
<tr>
<th>Yield Mode</th>
<th>Single Shear</th>
<th>Double Shear</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>w</td>
<td>$P = 2q_{wm}$</td>
<td>$P = 2q_{wm}$</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>$P = q_{Lw}$</td>
<td>$P = 2q_{Lw}$</td>
<td></td>
</tr>
<tr>
<td>B-IV</td>
<td>$P = b = \frac{\sqrt{B^2 - 4AC}}{2A}$</td>
<td>$P = -\frac{b = \sqrt{B^2 - 4AC}}{A}$</td>
<td>General equation for moment, bearing, and dowel withdrawal</td>
</tr>
</tbody>
</table>

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

- $A = \frac{1}{4q_{a}}, \frac{1}{4q_{a}}$  
  $B = t_{wm} + v_{w} + g = \frac{1}{2}$  
  $C = q_{Lw}(t_{wm} + v_{w}) = \frac{q_{Lw}}{4}$

- $B_{w} = \frac{1}{2q_{a}} \frac{1}{2q_{a}}$  
  $C = t_{wm} + v_{w}$  
  $C = q_{Lw}(t_{wm} + v_{w}) = \frac{q_{Lw}}{4}$

- $B_{w} = \frac{1}{2q_{a}} \frac{1}{2q_{a}}$  
  $b = \frac{L}{2} = g$  
  $C = M_{w} + M_{m}$

- $N = \frac{1}{2q_{a}} \frac{1}{2q_{a}}$  
  $b = g$  
  $C = M_{w} + M_{m}$

Yield Modes B-IV do not apply for double shear connections.

See Section 1.6 for notation.

Technical Report 12

- Allows for evaluation of connections with gaps between connected members

![Figure 2-5 Single Shear Connection - Mode II](image-url)
Technical Report 12

- **Tapered tip fasteners**
  - NDS 12.5.3 defines “E” as length of tapered tip
    - Lag screws – E defined in Appendix L
    - Wood screws, nails – E assumed to be 2D
    - Tapered tip does not count towards bearing length \(L_m\) in TR12 Tapered tip equations.

Technical Report 12

- **Tapered tip equations**
  - Mode \(I_m\)
    \[
    P = q_m \left( \frac{E}{2} \right)
    \]
  - Mode \(I_s\)
    \[
    P = q_s \left( 2L_s - \frac{E}{2} \right)
    \]
  - Mode \(II\)
    \[
    P^2 \left( \frac{1}{4q_1} + \frac{1}{4q_2} \right) + P \left( \frac{L_s + g + \frac{E}{2}}{2} \right) = 0
    \]
  - Mode \(III_m\)
    \[
    P^2 \left( \frac{1}{4q_1} + \frac{1}{4q_2} \right) + P \left( \frac{g}{2} + \frac{E}{4} \right) = 0
    \]
  - Mode \(III_s\)
    \[
    P^2 \left( \frac{1}{4q_1} + \frac{1}{4q_2} \right) + P \left( \frac{L_s + g}{2} + \frac{E}{4} \right) = 0
    \]

- **Mode \(IV\)**
  - Single Shear:
    \[
    P^2 \left( \frac{1}{2q_1} + \frac{1}{2q_2} \right) + P \left( g + \frac{E}{4} \right) (M_a + M_w) = 0
    \]
  - Double Shear:
    \[
    P^2 \left( \frac{1}{2q_1} + \frac{1}{2q_2} \right) + \frac{P g}{2} (M_a + M_w) = 0
    \]

TR12 shows NDS approximations are <1% different from using expanded equation!
Technical Report 12

- TR12 presents mechanics-based equations
  - Gives same results as NDS energy-based approach
- Equations in TR12 calculate P, must be divided by $R_d$ (NDS Table 12.3.1B) to convert to NDS Z basis
- TR12 Appendix being released later in 2015

Technical Report 12 Appendix

- New for 2015!
- Contains additional data for TR12 equation inputs
  - Dowel bearing values for:
    - Wood
    - Steel
    - Concrete
    - Stainless steel
    - Aluminum
  - Dowel bending values for fastener materials:
    - Steel and stainless steel bolts and lag screws
    - Low-to-medium carbon steel nails
    - Hardened steel nails (including post-frame ring-shank)
Example Problem #1

- **Calculate W for ¼” diameter, 2.5” long lag screw connecting 2-2x SYP (G = 0.55) members**
  - \( W = 1800 G^{3/2} D^{3/4} = 260 \text{ lbs/in} \) (calculate or NDS Table 12.2A)
  - **Calculate penetration into main member for withdrawal capacity**
    - NDS Appendix L gives lag screw dimensions
      - Length of unthreaded section = ¾”
      - Length of threaded section (including tip) = 1¾”
      - Length of threaded section (excluding tip) = 119/32”
    - \( p = \text{screw length} - \text{length of side member} - \text{length of tip} \)
    - \( p = 2.5” - 1.5” - (1\frac{3}{4}” - 1\frac{19}{32”}) = 0.84” \) of penetration
    - **Unadjusted capacity = \( W \times p = (260 \text{ lbs/in} \times 0.84 \text{ in}) = 219 \text{ lbs} \)**
    - **Apply adjustment factors per Table 11.3.1 to get adjusted \( W' \)**

Example Problem #2

- **Calculate unadjusted \( Z \) for ½” diameter bolt connecting two 2x DF-L (G = 0.5) members with a 1” gap between them**
  - Both members loaded parallel to grain (\( K_g = 1 \))
    - \( D = 0.5” \)
    - \( F_{e_h} = 5600 \text{ psi} \) (NDS Table 12.3.3); \( q_h = q_m = F_{e_h} \times D = 5600 \text{ psi} \times 0.5” = 2800 \text{ lb/in} \)
    - \( L_s = L_m = 1.5” \)
    - \( F_{yb} = 45,000 \text{ psi} \)
    - \( g = 1” \)
    - **Input A, B, & C for Yield Modes II IV**
      - \( A = \frac{1}{4q_m} + \frac{1}{4q_e} \)
      - \( B = \frac{L_s}{2} + g \)
      - \( C = \frac{M_m}{J} \times \frac{q_m}{4} \)
      - **Modes**
      - Mode I
        - \( A = \frac{1}{4q_m} + \frac{1}{4q_e} \)
        - \( B = \frac{L_s}{2} + g \)
        - \( C = \frac{M_m}{J} \times \frac{q_m}{4} \)
      - Mode II
        - \( A = \frac{1}{2q_m} + \frac{1}{2q_e} \)
        - \( B = p + \frac{L_s}{2} \)
        - \( C = \frac{M_m}{J} \times \frac{q_m}{4} \)
      - Mode III
        - \( A = \frac{1}{2q_m} + \frac{1}{2q_e} \)
        - \( B = \frac{L_s}{2} + g \)
        - \( C = \frac{M_m}{J} \times \frac{q_m}{4} \)
      - Mode IV
        - \( A = \frac{1}{2q_m} + \frac{1}{2q_e} \)
        - \( B = g \)
        - \( C = \frac{M_m}{J} \times \frac{q_m}{4} \)
### Example Problem #2

- Calculate unadjusted $Z$ for $\frac{1}{2}”$ diameter bolt connecting two 2x DF-L ($G = 0.5$) members with a 1” gap between them
  
  - $M_m = M_s = \frac{(F_bD^3)}{6} = \frac{(45,000 \text{ psi})*(0.5”^3)}{6} = 937.5 \text{ lb-in}$
  
  - Substituting values into TR12 equations yields $P$ values
  
  - Divide $P$ values by $R_d$ to obtain $Z$

<table>
<thead>
<tr>
<th>Mode</th>
<th>$P$ (lbs)</th>
<th>$R_d$</th>
<th>$Z$ (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_m$</td>
<td>4200</td>
<td>$4K_d = 4$</td>
<td>1050</td>
</tr>
<tr>
<td>$I_s$</td>
<td>4200</td>
<td>$4K_d = 4$</td>
<td>1050</td>
</tr>
<tr>
<td>$II$</td>
<td>1163</td>
<td>$3.6K_d = 3.6$</td>
<td>323</td>
</tr>
<tr>
<td>$III_m$</td>
<td>1211</td>
<td>$3.2K_d = 3.2$</td>
<td>378</td>
</tr>
<tr>
<td>$III_s$</td>
<td>1211</td>
<td>$3.2K_d = 3.2$</td>
<td>378</td>
</tr>
<tr>
<td>$IV$</td>
<td>1285</td>
<td>$3.2K_d = 3.2$</td>
<td>402</td>
</tr>
</tbody>
</table>

$Z = 323 \text{ lbs}$

### Example Problem #3

- Compare lateral $Z$ values for single shear nail connection at 6D, 8D, 10D, and 12D penetration using TR12 tapered tip equations
  
  - 8d common nail $D = 0.131”$, tapered tip length, $E = 2D = 0.262”$
  
  - Main member $F_{em} = 4,700$ psi (loaded parallel to grain); ASTM A653, Grade 33 steel side member, thickness = 0.06”, $F_{es} = 61,850$ psi
  
  - $L_m = p$ (penetration into main member); $L_s = 0.06”$ (side member thickness)

<table>
<thead>
<tr>
<th>Penetration Depth (p)</th>
<th>$Z$ (lbs)</th>
<th>Controlling mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>12D (1.57”)</td>
<td>97</td>
<td>$III_s$</td>
</tr>
<tr>
<td>10D (1.31”)</td>
<td>97</td>
<td>$III_s$</td>
</tr>
<tr>
<td>8D (1.05”)</td>
<td>97</td>
<td>$III_s$</td>
</tr>
<tr>
<td>6D (0.79”)</td>
<td>79</td>
<td>$II$</td>
</tr>
</tbody>
</table>
Example Problem #3

- Compare Z values for single shear nail connection at 6D, 8D, 10D, and 12D penetration using NDS Lm assumption for tapered tip
- 8d common nail D = 0.131”, tapered tip length, E = 2D = 0.262”
- Main member $F_{em} = 4,700$ psi (loaded parallel to grain); ASTM A653, Grade 33 steel side member, thickness = 0.06”, $F_{es} = 61,850$ psi
- $L_m = p - E/2$ (NDS assumption); $L_s = 0.06”$ (side member thickness)

<table>
<thead>
<tr>
<th>Penetration Depth (p)</th>
<th>Z (lbs)</th>
<th>Controlling mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>12D (1.57”)</td>
<td>97</td>
<td>III_s</td>
</tr>
<tr>
<td>10D (1.31”)</td>
<td>97</td>
<td>III_s</td>
</tr>
<tr>
<td>8D (1.05”)</td>
<td>97</td>
<td>III_s</td>
</tr>
<tr>
<td>6D (0.79”)</td>
<td>78</td>
<td>II</td>
</tr>
</tbody>
</table>

Polling Question

5. Technical Report 12 provides a ________ approach for calculating the capacity of laterally loaded connections.
   a) Mechanics-based
   b) Energy-based
   c) Hybrid model
   d) None of the above
Outline

- 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)

Example Problem – Connections Calculator

- **AWC Connections Calculator**
  - Can calculate lateral and withdrawal capacities
    - [http://awc.org/codes-standards/calculators-software/connectioncalc](http://awc.org/codes-standards/calculators-software/connectioncalc)
Outline

- 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???

• Load-carrying behavior of steel-to-timber dowel connections: http://timber.ce.wsu.edu/Resources/papers/2-4-1.pdf
  
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 perpendicular 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?

- This concludes The American Institute of Architects Continuing Education Systems Course

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