lecture nineteen

steel construction: bolts & tension members
Connections

• **needed to:**
  – support beams by columns
  – connect truss members
  – splice beams or columns

• **transfer load**

• **subjected to**
  – tension or compression
  – shear
  – bending

(a) Framed beam (shear) connection.
\[ e = \text{Eccentricity}; \ M = P \times e \]

(b) Moment connection (rigid frame).
\[ M = \text{Moment due to beam bending} \]
Bolts

• **bolted steel connections**
Bolts

- **types**
  - **materials**
    - high strength
    - A307, A325, A492
  - **location of threads**
    - included - N
    - excluded - X
  - **friction or bearing (SC)**
    - always tightened
Bolted Connection Design

- **considerations**
  - bearing stress
    - yielding
  - shear stress
    - single & double
  - member
    - rupture
Bolts

- rarely fail in bearing
- holes considered 1/8” larger
- shear & tension
  - single shear or tension
    \[ R_a \leq \frac{R_n}{\Omega} \]
    \[ R_u \leq \phi_v R_n \]
    \[ \phi_v = 0.75 \]
  - double shear
    \[ R_n = F_n A_b \]
    \[ R_n = F_n 2A_b \]
Bolts

Table 7-1
Available Shear Strength of Bolts, kips

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>$\frac{\sigma_{u}}{\Omega}$</th>
<th>$\frac{\sigma_{t}}{\Omega}$</th>
<th>$\frac{\sigma_{t}}{\Omega}$</th>
<th>$\sigma_{t}$</th>
<th>$\psi_{a}$</th>
<th>$\psi_{a}$</th>
<th>$\psi_{a}$</th>
<th>$\sigma_{t}$</th>
<th>$\sigma_{t}$</th>
<th>$\sigma_{t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Bolt Area, in.$^2$</td>
<td>0.307</td>
<td>0.442</td>
<td>0.601</td>
<td>0.785</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Desig. Thread Cond.</td>
<td>( F_{u} / \Omega ) (ksi)</td>
<td>( F_{t} / \Omega ) (ksi)</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
</tr>
<tr>
<td>Group A</td>
<td>N</td>
<td>27.0</td>
<td>40.5</td>
<td>S</td>
<td>D</td>
<td>8.29</td>
<td>12.4</td>
<td>11.9</td>
<td>17.9</td>
<td>16.2</td>
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<tr>
<td>Group B</td>
<td>X</td>
<td>34.0</td>
<td>51.0</td>
<td>S</td>
<td>D</td>
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<td>15.7</td>
<td>15.0</td>
<td>22.5</td>
<td>20.4</td>
</tr>
<tr>
<td>A307</td>
<td>–</td>
<td>13.5</td>
<td>20.3</td>
<td>S</td>
<td>D</td>
<td>8.29</td>
<td>12.5</td>
<td>11.9</td>
<td>17.9</td>
<td>16.2</td>
</tr>
</tbody>
</table>

Table 7-2
Available Tensile Strength of Bolts, kips

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>$\frac{\sigma_{u}}{\Omega}$</th>
<th>$\frac{\sigma_{t}}{\Omega}$</th>
<th>$\frac{\sigma_{t}}{\Omega}$</th>
<th>$\sigma_{t}$</th>
<th>$\psi_{a}$</th>
<th>$\psi_{a}$</th>
<th>$\psi_{a}$</th>
<th>$\sigma_{t}$</th>
<th>$\sigma_{t}$</th>
<th>$\sigma_{t}$</th>
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<tbody>
<tr>
<td>Nominal Bolt Area, in.$^2$</td>
<td>0.307</td>
<td>0.442</td>
<td>0.601</td>
<td>0.785</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Desig. Thread Cond.</td>
<td>( F_{u} / \Omega ) (ksi)</td>
<td>( F_{t} / \Omega ) (ksi)</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
<td>Loading</td>
</tr>
<tr>
<td>Group A</td>
<td>N</td>
<td>45.0</td>
<td>67.5</td>
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<td>D</td>
<td>22.5</td>
<td>33.8</td>
<td>6.90</td>
<td>9.94</td>
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<tr>
<td>Group B</td>
<td>A307</td>
<td>22.5</td>
<td>33.8</td>
<td>S</td>
<td>D</td>
<td>13.5</td>
<td>20.3</td>
<td>13.4</td>
<td>20.2</td>
<td>16.6</td>
</tr>
</tbody>
</table>

For end loaded connections greater than 36 in., see ASTM Specification Table J3.2 footnote b.
Bolts

- **bearing** ($\phi_x$)  
  \[ R_a \leq \frac{R_n}{\Omega} \]
  \[ R_u \leq \phi R_n \]
  \[ \phi = 0.75 \]
  - deformation is concern
  \[ R_n = 1.2 L_c t F_u \leq 2.4 dt F_u \]
  - deformation isn’t concern
  \[ R_n = 1.5 L_c t F_u \leq 3.0 dt F_u \]
  - long slotted holes
  \[ R_n = 1.0 L_c t F_u \leq 2.0 dt F_u \]
  
  $L_c$ – clear length to edge or next hole (ex. $1\frac{1}{4}''$, $3''$)
### Bolts

#### Available Bearing Strength at Bolt Holes Based on Edge Distance

**kips/in. thickness**

<table>
<thead>
<tr>
<th>Hole Type</th>
<th>Edge Distance $L_e$, in.</th>
<th>$F_e$, ksi</th>
<th>$d_6$</th>
<th>$d_{14}$</th>
<th>$d_{18}$</th>
<th>$r_{c}/\Omega$</th>
<th>$\phi_{fc}$</th>
<th>$r_{b}/\Omega$</th>
<th>$\phi_{fb}$</th>
<th>$r_{c}/\Omega$</th>
<th>$\phi_{fc}$</th>
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<tr>
<td>STD SSSLT</td>
<td>1/4</td>
<td>58</td>
<td>31.5</td>
<td>47.3</td>
<td>29.4</td>
<td>44.0</td>
<td>27.2</td>
<td>40.8</td>
<td>25.0</td>
<td>37.5</td>
<td>38.7</td>
<td>AD</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>35.3</td>
<td>53.0</td>
<td>32.9</td>
<td>49.4</td>
<td>30.5</td>
<td>45.7</td>
<td>28.0</td>
<td>57.3</td>
<td>85.9</td>
<td>42.0</td>
<td>AD</td>
</tr>
<tr>
<td>SSSLT</td>
<td>1/4</td>
<td>2</td>
<td>58</td>
<td>43.5</td>
<td>65.3</td>
<td>52.2</td>
<td>78.3</td>
<td>53.3</td>
<td>79.9</td>
<td>51.1</td>
<td>76.7</td>
<td>AD</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>31.7</td>
<td>47.5</td>
<td>29.3</td>
<td>43.9</td>
<td>26.6</td>
<td>40.2</td>
<td>23.2</td>
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<td>48.6</td>
<td>70.1</td>
<td>AD</td>
</tr>
<tr>
<td>SLSL</td>
<td>1/4</td>
<td>58</td>
<td>48.8</td>
<td>73.1</td>
<td>58.5</td>
<td>87.8</td>
<td>56.1</td>
<td>64.1</td>
<td>52.4</td>
<td>78.6</td>
<td>33.4</td>
<td>AD</td>
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<tr>
<td>2</td>
<td>65</td>
<td>48.8</td>
<td>73.1</td>
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<td>52.4</td>
<td>78.6</td>
<td>33.4</td>
<td>78.6</td>
<td>AD</td>
</tr>
</tbody>
</table>

#### Table 7-3 (continued)

**Slip-Critical Connections**

**Available Shear Strength, kips**

(Class A Faying Surface, $\mu = 0.30$)

<table>
<thead>
<tr>
<th><strong>Group B Bolts</strong></th>
<th><strong>Nominal Bolt Diameter, d, in.</strong></th>
<th>$F_e/\Omega$</th>
<th>$\phi_{fb}$</th>
<th>$r_e/\Omega$</th>
<th>$\phi_{fe}$</th>
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<tbody>
<tr>
<td><strong>Hole Type</strong></td>
<td><strong>Loading</strong></td>
<td>AD</td>
<td>LRFD</td>
<td>AD</td>
<td>LRFD</td>
<td>AD</td>
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<tr>
<td>STD/SSLT</td>
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<td>5.42</td>
<td>8.14</td>
<td>7.91</td>
<td>11.9</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>10.8</td>
<td>16.3</td>
<td>15.8</td>
<td>23.7</td>
<td>22.1</td>
</tr>
<tr>
<td>SSSLT</td>
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<td>4.62</td>
<td>6.92</td>
<td>6.74</td>
<td>10.1</td>
<td>9.44</td>
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<td>OVS/SSLT</td>
<td>64</td>
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<td>18.9</td>
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<tr>
<td>SLSL</td>
<td>80</td>
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<td>5.54</td>
<td>8.31</td>
<td>7.76</td>
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<tr>
<td>OS/SSLT</td>
<td>102</td>
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<td>11.1</td>
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<td>15.5</td>
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<tr>
<td>LSL</td>
<td>121</td>
<td>2.80</td>
<td>4.70</td>
<td>3.54</td>
<td>6.06</td>
<td>5.66</td>
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<tr>
<td>LSL</td>
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<td>3.80</td>
<td>5.70</td>
<td>5.54</td>
<td>8.31</td>
<td>7.76</td>
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</tbody>
</table>

**Nominal Bolt Diameter, d, in.**

<table>
<thead>
<tr>
<th><strong>Group B Bolts</strong></th>
<th><strong>Minimum Group B Bolt Pretension, kips</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hole Type</strong></td>
<td><strong>Loading</strong></td>
</tr>
<tr>
<td>STD/SSLT</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>35</td>
</tr>
<tr>
<td>SSSLT</td>
<td>48</td>
</tr>
<tr>
<td>OVS/SSLT</td>
<td>64</td>
</tr>
<tr>
<td>SLSL</td>
<td>80</td>
</tr>
<tr>
<td>OS/SSLT</td>
<td>102</td>
</tr>
<tr>
<td>LSL</td>
<td>121</td>
</tr>
</tbody>
</table>

**Edge distance for full bearing strength**

$L_e \geq L_{e,full}^i$, in.

- **STD, SSSL, SLSL**
  - 1/16
  - 1/14
  - 2/16
  - 2/14
  - 2/18

- **OVS, SSLP, SSLT**
  - 1/16
  - 2/14
  - 2/16
  - 2/18
  - 3/14
Tension Members

- **steel members can have holes**
- **reduced area**
  \[ A_n = A_g - A_{of \ all \ holes} + t\sum\frac{s^2}{4g} \]
- **increased stress**

(AISC - Steel Structures of the Everyday)
Effective Net Area

- likely path to “rip” across
- bolts divide transferred force too
- shear lag \( A_e \leq A_n U \)
Tension Members

- limit states for failure

1. yielding \( \phi_t = 0.90 \) \( P_n = F_y A_g \)

2. rupture* \( \phi_t = 0.75 \) \( P_n = F_u A_e \)

\( A_g \) - gross area
\( A_e \) - effective net area (holes 1/8” + d)
\( F_u \) = the tensile strength of the steel (ultimate)

\[ P_a \leq \frac{P_n}{\Omega} \quad P_u \leq \phi_t P_n \]
Framed Beam Connections

- **angles**
  - bolted
  - welded
Framed Beam Connections

• terms
  – coping

(AISC - Steel Structures of the Everyday)
Framed Beam Connections

- tables for standard bolt sizes & spacings
- # bolts
- bolt diameter, angle leg thickness
- bearing on beam web
Beam Connections

- LRFD provisions
  - shear yielding
  - shear rupture
  - block shear rupture
  - tension yielding
  - tension rupture
  - local web buckling
  - lateral torsional buckling
Beam Connections

\[
R_n = 0.6F_u A_{nv} + U_{bs} F_u A_{nt} \leq 0.6F_y A_{gv} + U_{bs} F_u A_{nt}
\]

\(\phi = 0.75\)

- where \(U_{bs}\) is 1 for uniform tensile stress

Figure 2-1. Block Shear Rupture Limit State
(Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

Figure 2-14. Tension Fracture Limit State
(Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

block shear rupture  tension rupture
Other Bolted Connections

- truss gussets
- base plates
- splices