Steel construction: bolted & welded connections
Connections

- needed to:
  - support beams by columns
  - connect truss members
  - splice beams or columns
- transfer load
- subjected to
  - tension or compression
  - shear
  - bending
Bolts

- bolted steel connections

http://courses.civil.ualberta.ca
Welds

- welded steel connections

http://courses.civil.ualberta.ca
Bolts

- **types**
  - **materials**
    - high strength
    - A307, A325, A490
  - 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
    \[ R_a \leq \frac{R_n}{\Omega} \quad R_u \leq \phi_v R_n \]
    \[ \phi_v = 0.75 \]
  - double shear
    \[ R_n = F_n A_b \]
    \[ R_n = F_n 2A_b \]
# Bolts

## Table 7-1

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>A</th>
<th>3/8</th>
<th>1/4</th>
<th>1/2</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>
</tr>
<tr>
<td>ASTM Desig. Thread Cond.</td>
<td>ASD</td>
<td>LRFD</td>
<td>ASD</td>
<td>LRFD</td>
</tr>
<tr>
<td>N</td>
<td>S</td>
<td>D</td>
<td></td>
<td></td>
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<tr>
<td>X</td>
<td>S</td>
<td>D</td>
<td></td>
<td></td>
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<tr>
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<td>40.5</td>
<td></td>
</tr>
<tr>
<td>X</td>
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<td>51.0</td>
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<td></td>
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<tr>
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<tr>
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<td></td>
</tr>
<tr>
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## Table 7-2

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<th>Nominal Bolt Diameter, d, in.</th>
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<th>1/4</th>
<th>1/2</th>
</tr>
</thead>
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<tr>
<td>Nominal Bolt Area, in.²</td>
<td>0.994</td>
<td>1.23</td>
<td>1.48</td>
<td>1.77</td>
</tr>
<tr>
<td>ASTM Desig. Thread Cond.</td>
<td>ASD</td>
<td>LRFD</td>
<td>ASD</td>
<td>LRFD</td>
</tr>
<tr>
<td>N</td>
<td>S</td>
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<tr>
<td>X</td>
<td>S</td>
<td>D</td>
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<tr>
<td>Group A</td>
<td>N</td>
<td>27.0</td>
<td>40.5</td>
<td></td>
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<tr>
<td>X</td>
<td>34.0</td>
<td>51.0</td>
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<td></td>
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<tr>
<td>Group B</td>
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<td>51.0</td>
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<tr>
<td>X</td>
<td>42.0</td>
<td>63.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A307</td>
<td>S</td>
<td>13.5</td>
<td>20.3</td>
<td></td>
</tr>
</tbody>
</table>

For end loaded connections greater than 38 in., see ASC Specification Table J3.2 footnote b.
Bolts

- **bearing**

\[
R_a \leq \frac{R_n}{\Omega} \quad R_u \leq \phi R_n \\
\phi = 0.75
\]

- 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”)
### 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>( \phi_{d_b} )</th>
<th>( \phi_{d_h} )</th>
<th>( \phi_{d_f} )</th>
<th>( \phi_{d_r} )</th>
<th>( \phi_{d_t} )</th>
<th>( \phi_{d_s} )</th>
<th>( \phi_{d_i} )</th>
<th>( \phi_{d_k} )</th>
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</thead>
<tbody>
<tr>
<td>STD</td>
<td>( 1 \frac{1}{4} )</td>
<td>58</td>
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<td>65</td>
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<td>53.0</td>
<td>32.9</td>
<td>49.4</td>
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<td>45.7</td>
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<tr>
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<td>( 2 )</td>
<td>58</td>
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<td>73.1</td>
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<td>89.6</td>
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<td>85.9</td>
</tr>
<tr>
<td>OVS</td>
<td>( 1 \frac{1}{4} )</td>
<td>58</td>
<td>28.3</td>
<td>42.4</td>
<td>26.1</td>
<td>39.2</td>
<td>23.9</td>
<td>35.9</td>
<td>20.7</td>
<td>31.0</td>
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<tr>
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<td>65</td>
<td>31.7</td>
<td>47.5</td>
<td>29.3</td>
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<td>26.8</td>
<td>40.2</td>
<td>23.2</td>
<td>34.7</td>
</tr>
<tr>
<td>OVS</td>
<td>( 2 )</td>
<td>58</td>
<td>43.5</td>
<td>65.3</td>
<td>52.2</td>
<td>78.3</td>
<td>50.0</td>
<td>75.0</td>
<td>46.8</td>
<td>70.1</td>
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<tr>
<td>SSLP</td>
<td></td>
<td>65</td>
<td>48.8</td>
<td>73.1</td>
<td>58.5</td>
<td>87.8</td>
<td>56.1</td>
<td>84.1</td>
<td>52.4</td>
<td>76.8</td>
</tr>
<tr>
<td>OVS</td>
<td>( 1 \frac{1}{4} )</td>
<td>58</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>21.8</td>
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<tr>
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<td>65</td>
<td>32.9</td>
<td>49.4</td>
<td>30.5</td>
<td>45.7</td>
<td>28.0</td>
<td>42.0</td>
<td>24.4</td>
<td>36.6</td>
</tr>
<tr>
<td>LSL</td>
<td>( 2 )</td>
<td>58</td>
<td>43.5</td>
<td>65.3</td>
<td>52.2</td>
<td>78.3</td>
<td>51.1</td>
<td>78.7</td>
<td>47.9</td>
<td>71.8</td>
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<tr>
<td>OVS</td>
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<td>65</td>
<td>48.8</td>
<td>73.1</td>
<td>58.5</td>
<td>87.8</td>
<td>57.3</td>
<td>85.9</td>
<td>53.6</td>
<td>80.4</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>Group B Bolts</th>
<th>Nominal Bolt Diameter, ( d ), in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole Type</td>
<td>Loading</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>STD/SSLT</td>
<td>S</td>
</tr>
<tr>
<td>OVS/SSLP</td>
<td>S</td>
</tr>
<tr>
<td>LSL</td>
<td>S</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, ( d ), in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole Type</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>STD</td>
</tr>
<tr>
<td>SSLT</td>
</tr>
<tr>
<td>OVS/SSLP</td>
</tr>
<tr>
<td>LSL</td>
</tr>
</tbody>
</table>

**Notes:**
- Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers.
- See AISC Specification Sections J3.8 and J5 for provisions when fillers are present.
Welded Connection Design

• considerations
  – shear stress
  – yielding
  – rupture
Welded Connection Design

- **weld terms**
  - butt weld
  - fillet weld
  - plug weld
  - throat

- **field welding**

- **shop welding**

(AISC - Steel Structures of the Everyday)
Welded Connection Design

• weld process
  – melting of material
  – melted filler - electrode
  – shielding gas / flux
  – potential defects

• weld materials
  – E60XX
  – E70XX
  \[ F_{EXX} = 70 \text{ ksi} \]
Welded Connection Design

- shear failure assumed
- throat
  - \( T = 0.707 \times \text{weld size} \)
- area
  - \( A = T \times \text{length of weld} \)
- weld metal generally stronger than base metal (ex. \( F_y = 50 \text{ ksi} \))
Welded Connection Design

- **minimum**
  - table
- **maximum**
  - material thickness (to ¼”)
  - 1/16” less
- **min. length**
  - 4 x size min.
  - ≥ 1 ½”

**TABLE J2.4**

Minimum Size of Fillet Welds

<table>
<thead>
<tr>
<th>Material Thickness of Thicker Part Joined, in. (mm)</th>
<th>Minimum Size of Fillet Weld[a] in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To ½ (6) inclusive</td>
<td>⅛ (3)</td>
</tr>
<tr>
<td>Over ⅛ (6) to ½ (13)</td>
<td>⅜ (5)</td>
</tr>
<tr>
<td>Over ½ (13) to 3/4 (19)</td>
<td>⅛ (6)</td>
</tr>
<tr>
<td>Over 3/4 (19)</td>
<td>⅜ (8)</td>
</tr>
</tbody>
</table>

[a] Leg dimension of fillet welds. Single pass welds must be used.
[b] See Section J2.25 for maximum size of fillet welds.
Welded Connection Design

• shear

\[ R_a \leq \frac{R_n}{\Omega} \]

\[ R_u \leq \phi R_n \]

\[ \phi = 0.75 \]

\[ R_n = 0.6 F_{EXX} Tl = Sl \]

area

– table for \( \phi S \)

| Available Strength of Fillet Welds per inch of weld (\( \phi S \)) |
|-----------------|------------------|------------------|
| Weld Size       | E60XX (k/in.)    | E70XX (k/in.)    |
| (in.)           | (k/in.)          | (k/in.)          |
| 3/64            | 3.58             | 4.18             |
| 1/4             | 4.77             | 5.57             |
| 5/64            | 5.34             | 6.96             |
| 3/32            | 7.16             | 8.35             |
| 3/16            | 8.35             | 9.74             |
| 1/2             | 9.55             | 11.14            |
| 7/32            | 11.93            | 13.92            |
| 5/16            | 14.32            | 16.70            |

(not considering increase in throat with submerged arc weld process)
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
Framed Beam Connections

- welded example (shear)

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

• welded moment example

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

• welded/bolted moment example

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

- welded/bolted moment example

(AISC - Steel Structures of the Everyday)
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 Connections

- seated beam
- continuous
  - beam to column
  - beam to beam
Other Connections

• splices
Other Connections

- rigid frame knees
- gussets & joints

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Other Connections

• base plates
  – anchor bolts
  – bearing on steel
  – bending of plate