In steel design it is often necessary to design bolted connections. In order to design the bolted connections according to LRFD, a variety of provisions must be considered. The type of loading, the type of bolted connection, bolt bearing and bolt hole geometry must all be considered. Each of these provisions are considered in this tutorial. These provisions are organized into the following list:

A. Bolt Shear & Bolt Bearing.
B. Bolt hole geometry.
C. Bolt Tension.
D. Combined Loading - Shear & Tension

Note: Wherever mentioned “see text” refers to the textbook by Salmon, Johnson, and Malhas 5th edition.

For the bolt shear strength limit state, $\phi R_n$, based on the bolt cross-section, bolt slip, or bolt bearing on the steel plate material the smallest value of $\phi R_n$ governs the design and must satisfy the following basic LRFD formula:

$$\phi R_n \geq R_u.$$ 

For the bolt tension strength limit state, $\phi T_n$, the following must be satisfied:

$$\phi T_n \geq T_u.$$ 

Bolt geometry guidelines must be followed as specified by AISC. Special provisions are also provided for load conditions where bolts are load in both shear and tension. Each of items A, B, C, and D are summarized below.
A. Bolt Shear & Bolt Bearing. (see also LRFD Tables 7-1, 7-2, 7-3, 7-4, 7-5, 7-6, 7-15, 7-16, 7-17, 7-18)

The smallest value of $\phi R_n$ must be calculated as follows:

(i) For bearing connections with threads included in the shear plane

$$\phi R_n = \phi 0.4A_b F_u m$$

(ii) For bearing connections with threads excluded from the shear plane

$$\phi R_n = \phi 0.5A_b F_u m$$

(iii) For slip critical connections (the following $\phi R_n$ is compared to factored loads regardless of which $\phi$ value, 1.0 or 0.85, is used.)

$$\phi R_n = \phi \mu D_u h_{sc} T_b N_s$$

$D_u = 1.13$, ratio of mean installed bolt pretension to specified minimum bolt pretension

$h_{sc} = 1.00$ for standard holes

$h_{sc} = 0.85$ for oversized and short slotted holes

$h_{sc} = 0.70$ for long slotted holes

$\mu = 0.35$ class A surface (unpainted clean mill scale or class A coating on blast-cleaned steel)

$\mu = 0.50$ class B surface (unpainted blast-cleaned surface or class B coating on blast-cleaned steel)

$T_b = \text{minimum fastener tension given in LRFD Table J3.1 (page 16.1-103)}$

$N_s = \text{number of slip planes}$

(iv) For items (i),(ii) and (iii) above $\phi R_n$ must also be calculated based on the bearing of the bolt shank on the steel plate material as follows:

- For standard, oversized, or short-slotted holes, regardless of the direction of loading, or a hole with a slot parallel to the direction of the bearing force, if deformation around the bolt hole at service load is a consideration (the most common case)

$$\phi R_n = \phi 1.2 L_c t F_u \leq \phi 2.4 t d F_u.$$  

- If deformation around the bolt hole at service load is not a consideration

$$\phi R_n = \phi 1.5 L_c t F_u \leq \phi 3.0 t d F_u.$$  

- For long slotted holes perpendicular to the direction of load

$$\phi R_n = \phi 1.0 L_c t F_u \leq \phi 2.0 t d F_u.$$
where for cases (i) to (iv) listed above,
\[ \phi = 0.75 \text{ for cases (i), (ii), and (iv)} \]
\[ \phi = 1.0 \text{ is recommended for case (iii) for standard holes or slotted holes transverse to the direction of load} \]
\[ \phi = 0.85 \text{ is recommended for case (iii) for oversized holes or slotted holes parallel to the direction of load} \]

\[ R_n = \text{nominal shear strength for each limit state, kips} \]
\[ F^b_u = \text{ultimate stress of the bolt material, ksi, (for A325 bolts with diameter 1 inch or less} F^b_u = 120 \text{ ksi, for A490 bolts} F^b_u = 150 \text{ ksi}) \]
\[ F_u = \text{ultimate stress of the plate material being connected, ksi} \]
\[ A_b = \text{the cross-sectional area of the bolt, in}^2 \]
\[ L_c = \text{clear distance between edges of bolt holes or edge of bolt hole and edge of plate in the direction of the applied load. This distance is equal to center to center of bolt hole distance minus the bolt diameter plus 1/8 in or the distance from the center of bolt hole to the edge of plate minus one half of the bolt diameter plus 1/8 in.} \]
\[ m = \text{the number of shear planes} \]
\[ t = \text{thickness of the thinner plate material being connected, in} \]

**B. Bolt hole geometry.**

The placement of bolt holes is prescribed by AISC. The prescribed limitations are summarized below.

**(i.)** Minimum spacing of bolts (see AISC section J3.3)(see text page 103))
   The preferred spacing is
   \[ s = 3d \]
   , but shall not be less than
   \[ s = \frac{2}{3}d \]

**(ii.)** Minimum edge distance
   See LRFD Table J3.4 (page 16.1-107) for standard holes (or see Table 4.7.4 p. 104 in text).
   See LRFD Table J3.5 (page 16.1-108) for oversized, short slotted, and long slotted holes for required edge distance increase increment. See LRFD section J3.4.

**(iii.)** Maximum spacing (see LRFD section J3.5)
   - For painted members or unpainted members *not* subjected to corrosion
     \[ \text{spacing} \leq 24t \leq 12 \text{ in} \]
   - For unpainted members of weathering steel subjected to atmospheric corrosion
     \[ \text{spacing} \leq 14t \leq 7 \text{ in} \]
(iv.) Maximum edge distance

\[\text{edge distance} \leq 12t \leq 6 \text{ in}\]

where,

- \(t\) = thickness of the thinner plate being connected, in
- \(d\) = bolt diameter, in

C. Bolt Tension

The strength of bolts loaded in tension is calculate as follows:

\[\phi T_n = \phi 0.75 A_b F_{b u}\]

where,

- \(\phi = 0.75\)
- \(T_n\) = nominal tensile strength for the bolt, kips
- \(A_b\) = the cross-sectional area of the bolt, \(in^2\)
- \(F_{b u}\) = the ultimate stress of the bolt material, ksi

D. Combined Loading - Shear and Tension

For load combinations on bolts of shear and tension two cases must be considered.

(i.) Bearing connection in shear and tension

See LRFD Table J3.7 or equations presented in text on page 142.

(ii.) Slip Critical connection in shear and tension

See LRFD Section J3.9. and see equation 4.14.7 on page 140 in text. The available (shear) slip resistance shall be multiplied by the following reduction factor when tension is also acting on the bolt.

\[k_s = 1 - \frac{T_u}{D_u N_b T_b}\]

References
