## **Steel Design**

#### **Notation:**

= name for width dimension a A = name for area = area of a bolt  $A_h$ = effective net area found from the  $A_e$ product of the net area  $A_n$  by the shear lag factor U= gross area, equal to the total area  $A_{g}$ ignoring any holes = gross area subjected to shear for  $A_{gv}$ block shear rupture = net area, equal to the gross area  $A_n$ subtracting any holes, as is  $A_{net}$ = net area subjected to tension for  $A_{nt}$ block shear rupture = net area subjected to shear for block  $A_{nv}$ shear rupture = area of the web of a wide flange  $A_w$ section AISC= American Institute of Steel Construction ASD = allowable stress design = name for a (base) width = total width of material at a horizontal section = name for height dimension = width of the flange of a steel beam  $b_f$ cross section = factor for determining  $M_u$  for  $B_1$ combined bending and compression = largest distance from the neutral caxis to the top or bottom edge of a = coefficient for shear stress for a  $c_1$ rectangular bar in torsion = lateral torsional buckling  $C_{h}$ modification factor for moment in ASD & LRFD steel beam design  $C_c$ = column slenderness classification constant for steel column design = modification factor accounting for  $C_m$ combined stress in steel design  $C_{v}$ = web shear coefficient = calculus symbol for differentiation = depth of a wide flange section

= nominal bolt diameter

 $d_h$ = nominal bolt diameter D = shorthand for dead load DL= shorthand for dead load = eccentricity е E= shorthand for earthquake load = modulus of elasticity = axial compressive stress  $f_c$  $f_b$ = bending stress = bearing stress  $f_p$ = shear stress  $f_v$  $f_{v-max}$ = maximum shear stress = yield stress F= shorthand for fluid load  $F_{allow(able)}$  = allowable stress = allowable axial (compressive) stress  $F_a$ = allowable bending stress  $F_b$  $F_{cr}$ = flexural buckling stress = elastic critical buckling stress  $F_{\rho}$  $F_{EXX}$  = yield strength of weld material = nominal strength in LRFD  $F_n$ = nominal tension or shear strength of a bolt  $F_p$ = allowable bearing stress  $F_t$ = allowable tensile stress = ultimate stress prior to failure  $F_u$  $F_{v}$ = allowable shear stress  $F_{v}$ = yield strength = yield strength of web material  $F_{vw}$ F.S. = factor of safety = gage spacing of staggered bolt g holes G= relative stiffness of columns to beams in a rigid connection, as is  $\Psi$ = name for a height h = height of the web of a wide flange  $h_c$ steel section = shorthand for lateral pressure load Н = moment of inertia with respect to neutral axis bending = moment of inertia of trial section = moment of inertia required at  $I_{rea'd}$ limiting deflection = moment of inertia about the y axis  $I_y$ 

= polar moment of inertia

k = distance from outer face of W flange to the web toe of fillet

= shape factor for plastic design of steel beams

Example 8 = effective length factor for columns, as is k

l = name for length

 $\ell_b$  = length of beam in rigid joint

 $\ell_c$  = length of column in rigid joint

L = name for length or span length

= shorthand for live load

 $L_b$  = unbraced length of a steel beam

L<sub>c</sub> = clear distance between the edge of a hole and edge of next hole or edge of the connected steel plate in the direction of the load

 $L_e$  = effective length that can buckle for column design, as is  $\ell_e$ 

 $L_r$  = shorthand for live roof load

= maximum unbraced length of a steel beam in LRFD design for inelastic lateral-torsional buckling

L<sub>p</sub> = maximum unbraced length of a steel beam in LRFD design for full plastic flexural strength

L' = length of an angle in a connector with staggered holes

LL = shorthand for live load

LRFD = load and resistance factor design

M = internal bending moment

 $M_a$  = required bending moment (ASD)

 $M_n$  = nominal flexure strength with the full section at the yield stress for LRFD beam design

 $M_{max}$  = maximum internal bending moment

 $M_{max-adj}$  = maximum bending moment adjusted to include self weight

 $M_p$  = internal bending moment when all fibers in a cross section reach the vield stress

 $M_u$  = maximum moment from factored loads for LRFD beam design

 $M_y$  = internal bending moment when the extreme fibers in a cross section reach the yield stress

n = number of bolts

n.a. = shorthand for neutral axis

N = bearing length on a wide flange steel section

> = bearing type connection with threads included in shear plane

p = bolt hole spacing (pitch)

P = name for load or axial force vector

 $P_a$  = allowable axial force

= required axial force (ASD)

 $P_{allowable}$  = allowable axial force  $P_c$  = available axial strength

 $P_{e1}$  = Euler buckling strength

 $P_n$  = nominal column load capacity in LRFD steel design

 $P_r$  = required axial force

P<sub>u</sub> = factored column load calculated from load factors in LRFD steel design

Q = first moment area about a neutral

= generic axial load quantity for LRFD design

r = radius of gyration

 $r_y$  = radius of gyration with respect to a y-axis

R = generic load quantity (force, shear, moment, etc.) for LRFD design

= shorthand for rain or ice load

= radius of curvature of a deformed beam

 $R_a$  = required strength (ASD)

 $R_n$  = nominal value (capacity) to be multiplied by  $\phi$  in LRFD and divided by the safety factor  $\Omega$  in ASD

 $R_u$  = factored design value for LRFD design

s = longitudinal center-to-center spacing of any two consecutive holes

S = shorthand for snow load

= section modulus

= allowable strength per length of a weld for a given size

 $S_{req'd}$  = section modulus required at allowable stress

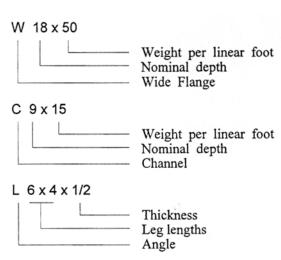
 $S_{req'd-adj}$  = section modulus required at allowable stress when moment is adjusted to include self weight

SC = slip critical bolted connection

= thickness of the connected material = vertical distance Z= thickness of flange of wide flange = plastic section modulus of a steel  $t_f$ = thickness of web of wide flange beam  $t_w$  $Z_{req'd}$  = plastic section modulus required T= torque (axial moment) = shorthand for thermal load = plastic section modulus of a steel = throat size of a weld beam with respect to the x axis U= shear lag factor for steel tension = method factor for  $B_1$  equation member design  $\Delta_{actual}$  = actual beam deflection = reduction coefficient for block  $U_{bs}$  $\Delta_{allowable}$  = allowable beam deflection shear rupture  $\Delta_{limit}$  = allowable beam deflection limit = internal shear force V $\Delta_{max}$  = maximum beam deflection = required shear (ASD) = yield strain (no units)  $\mathcal{E}_{v}$  $V_{max}$  = maximum internal shear force = resistance factor  $V_{max-adj}$  = maximum internal shear force = diameter symbol adjusted to include self weight = resistance factor for bending for = nominal shear strength capacity for  $\phi_h$  $V_n$ LRFD beam design **LRFD** = maximum shear from factored loads  $V_u$  $\phi_c$ = resistance factor for compression for LRFD beam design for LRFD = name for distributed load = resistance factor for tension for  $\phi_{t}$  $w_{adjusted}$  = adjusted distributed load for **LRFD** equivalent live load deflection limit = resistance factor for shear for  $\phi_{v}$  $w_{equivalent}$  = the equivalent distributed load derived from the maximum bending = load factor in LRFD design moment γ  $w_{self wt}$  = name for distributed load from self  $= pi (3.1415 \text{ radians or } 180^{\circ})$  $\pi$ weight of member  $\theta$ = slope of the beam deflection curve = shorthand for wind load W= radial distance  $\rho$ = horizontal distance x = safety factor for ASD  $\Omega$ X= bearing type connection with = symbol for integration threads excluded from the shear  $\Sigma$ = summation symbol plane

## **Steel Design**

Structural design standards for steel are established by the *Manual of Steel Construction* published by the American Institute of Steel Construction, and uses **Allowable Stress Design** and **Load and Factor Resistance Design**. With the 13<sup>th</sup> edition, both methods are combined in one volume which provides common requirements for analyses and design and requires the application of the same set of specifications.



#### Materials

American Society for Testing Materials (ASTM) is the organization responsible for material and other standards related to manufacturing. Materials meeting their standards are guaranteed to have the published strength and material properties for a designation.

A36 – carbon steel used for plates, angles  $F_y = 36 \text{ ksi}, F_u = 58 \text{ ksi}, E = 29,000 \text{ ksi}$  A572 – high strength low-alloy use for some beams A992 – for building framing used for most beams  $F_y = 60 \text{ ksi}, F_u = 75 \text{ ksi}, E = 29,000 \text{ ksi}$   $F_y = 50 \text{ ksi}, F_u = 65 \text{ ksi}, E = 29,000 \text{ ksi}$  (A572 Grade 50 has the same properties as A992)

 $\underline{\text{ASD}} \qquad R_a \leq \frac{R_n}{\Omega}$ 

where  $R_a$  = required strength (dead or live; force, moment or stress)  $R_n$  = nominal strength specified for ASD

 $\Omega$  = safety factor

Factors of Safety are applied to the limit stresses for allowable stress values:

 $\begin{array}{ll} \text{bending (braced, $L_b < L_p$)} & \Omega = 1.67 \\ \text{bending (unbraced, $L_p < L_b$ and $L_b > L_r$)} & \Omega = 1.67 \text{ (nominal moment reduces)} \\ \text{shear (beams)} & \Omega = 1.5 \text{ or } 1.67 \\ \text{shear (bolts)} & \Omega = 2.00 \text{ (tabular nominal strength)} \\ \text{shear (welds)} & \Omega = 2.00 \end{array}$ 

- L<sub>b</sub> is the unbraced length between bracing points, laterally
- L<sub>p</sub> is the limiting laterally unbraced length for the limit state of yielding
- $L_r$  is the limiting laterally unbraced length for the limit state of inelastic lateral-torsional buckling

LRFD  $R_u \leq \phi R_n \qquad where \cdots R_u = \Sigma \gamma_i R_i$  where  $\phi = \text{resistance factor}$   $\gamma = \text{load factor for the type of load}$  R = load (dead or live; force, moment or stress)  $R_u = \text{factored load (moment or stress)}$   $R_n = \text{nominal load (ultimate capacity; force, moment or stress)}$ 

Nominal strength is defined as the

capacity of a structure or component to resist the effects of loads, as determined by computations using specified material strengths (such as yield strength,  $F_y$ , or ultimate strength,  $F_u$ ) and dimensions and formulas derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modeling effects and differences between laboratory and field conditions

## Factored Load Combinations

The design strength,  $\phi R_n$ , of each structural element or structural assembly must equal or exceed the design strength based on the ASCE-7 (2010) combinations of factored nominal loads:

1.4D  
1.2D + 1.6L + 0.5(
$$L_r$$
 or  $S$  or  $R$ )  
1.2D + 1.6( $L_r$  or  $S$  or  $R$ ) + ( $L$  or 0.5 $W$ )  
1.2D + 1.0 $W$  +  $L$  + 0.5( $L_r$  or  $S$  or  $R$ )  
1.2D + 1.0 $E$  +  $L$  + 0.2 $S$   
0.9D + 1.0 $W$   
0.9D + 1.0 $E$ 

## Criteria for Design of Beams

Allowable normal stress or normal stress from LRFD should not be exceeded:

$$F_b \text{ or } \phi F_n \ge f_b = \frac{Mc}{I}$$

$$(M_a \le M_n / \Omega \text{ or } M_u \le \phi_b M_n)$$

Knowing M and F<sub>y</sub>, the minimum plastic section modulus fitting the limit is:

$$Z_{req'd} \ge \frac{M_a}{F_y \Omega} \qquad \left( S_{req'd} \ge \frac{M}{F_b} \right)$$

## **Determining Maximum Bending Moment**

Drawing V and M diagrams will show us the maximum values for design. Remember:

$$V = \Sigma(-w)dx$$

$$M = \Sigma(V)dx$$

$$\frac{dV}{dx} = -w$$

$$\frac{dM}{dx} = V$$

### **Determining Maximum Bending Stress**

For a prismatic member (constant cross section), the maximum normal stress will occur at the maximum moment.

For a *non-prismatic* member, the stress varies with the cross section AND the moment.

#### Deflections

If the bending moment changes, M(x) across a beam of constant material and cross section then the curvature will change:  $\frac{1}{R} = \frac{M(x)}{EI}$ 

The slope of the n.a. of a beam,  $\theta$ , will be tangent to the radius of  $\theta = slope = \frac{1}{EI} \int M(x) dx$  curvature, R:

The equation for deflection, y, along a beam is:  $y = \frac{1}{EI} \int \theta dx = \frac{1}{EI} \iint M(x) dx$ 

Elastic curve equations can be found in handbooks, textbooks, design manuals, etc...Computer programs can be used as well. Elastic curve equations can be superimposed ONLY if the stresses are in the elastic range.

The deflected shape is roughly the same shape flipped as the bending moment diagram but is constrained by supports and geometry.

## Allowable Deflection Limits

All building codes and design codes limit deflection for beam types and damage that could happen based on service condition and severity.

$$y_{\text{max}}(x) = \Delta_{actual} \le \Delta_{allowable} = \frac{L}{value}$$

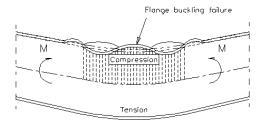
| Use                       | LL only     | DL+LL |
|---------------------------|-------------|-------|
| Roof beams:               |             |       |
| Industrial                | L/180       | L/120 |
| Commercial                |             |       |
| plaster ceiling           | L/240       | L/180 |
| no plaster                | L/360       | L/240 |
| Floor beams:              |             |       |
| Ordinary Usage            | L/360       | L/240 |
| Roof or floor (damageable | e elements) | L/480 |

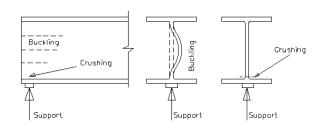
### Lateral Buckling

With compression stresses in the top of a beam, a sudden "popping" or buckling can happen even at low stresses. In order to prevent it, we need to brace it along the top, or laterally brace it, or provide a bigger  $I_y$ .

## Local Buckling in Steel Wide-flange Beams- Web Crippling or Flange Buckling

Concentrated forces on a steel beam can cause the web to buckle (called **web crippling**). Web stiffeners under the beam loads and bearing plates at the supports reduce that tendency. Web stiffeners also prevent the web from shearing in plate girders.





The maximum support load and interior load can be determined from:

$$P_{n\,(\text{max-end})} = (2.5k + N)F_{yw}t_w$$

$$P_{n \text{ (interior)}} = (5k + N)F_{vw}t_{w}$$

where

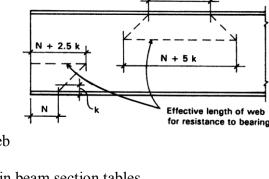
 $t_w$  = thickness of the web

 $F_{yw}$  = yield strength of the web

N = bearing length

k = dimension to fillet found in beam section tables

$$\phi = 1.00 \, (LRFD)$$
  $\Omega = 1.50 \, (ASD)$ 



## Beam Loads & Load Tracing

In order to determine the loads on a beam (or girder, joist, column, frame, foundation...) we can start at the top of a structure and determine the <u>tributary area</u> that a load acts over and the beam needs to support. Loads come from material weights, people, and the environment. This area is assumed to be from half the distance to the next beam over to halfway to the next beam.

The reactions must be supported by the next lower structural element *ad infinitum*, to the ground.

## LRFD - Bending or Flexure

For determining the flexural design strength,  $\phi_b M_n$ , for resistance to pure bending (no axial load) in most flexural members where the following conditions exist, a single calculation will suffice:

$$\Sigma \gamma_i R_i = M_u \le \phi_b M_n = 0.9 F_y Z$$

where

 $M_u$  = maximum moment from factored loads

 $\phi_b$  = resistance factor for bending = 0.9

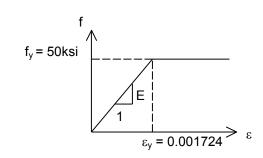
 $M_n$  = nominal moment (ultimate capacity)

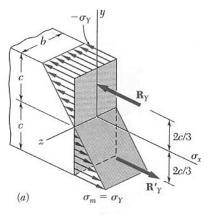
 $F_y$  = yield strength of the steel

Z = plastic section modulus

#### Plastic Section Modulus

Plastic behavior is characterized by a yield point and an increase in strain with no increase in stress.





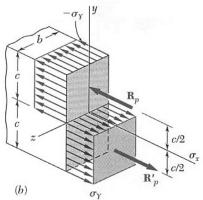
## Internal Moments and Plastic Hinges

Plastic hinges can develop when all of the material in a cross section sees the yield stress. Because all the material at that section can strain without any additional load, the member segments on either side of the hinge can rotate, possibly causing instability.

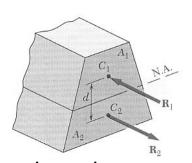
For a rectangular section:

Elastic to 
$$f_y$$
:  $M_y = \frac{I}{c} f_y = \frac{bh^2}{6} f_y = \frac{b(2c)^2}{6} f_y = \frac{2bc^2}{3} f_y$ 

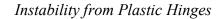
Fully Plastic: 
$$M_{ult}$$
 or  $M_p = bc^2 f_y = \frac{3}{2} M_y$ 

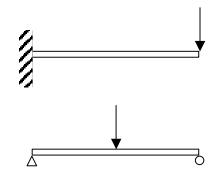


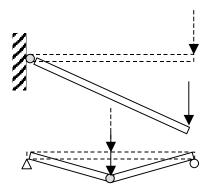
For a non-rectangular section and internal equilibrium at  $\sigma_y$ , the n.a. will not necessarily be at the centroid. The n.a. occurs where the  $A_{tension} = A_{compression}$ . The reactions occur at the centroids of the tension and compression areas.



 $A_{tension} = A_{compression}$ 







## Shape Factor:

The ratio of the plastic moment to the elastic moment at yield:

$$k = \frac{M_p}{M_v}$$

k = 3/2 for a rectangle

 $k \approx 1.1$  for an I beam

Plastic Section Modulus

$$Z = \frac{M_p}{f_y} \qquad and \qquad k = \frac{Z}{S}$$

Design for Shear

$$V_a \leq V_n / \Omega$$
 or  $V_u \leq \phi_v V_n$ 

The nominal shear strength is dependent on the cross section shape. Case 1: With a thick or stiff web, the shear stress is resisted by the web of a wide flange shape (with the exception of a handful of W's). Case 2: When the web is not stiff for doubly symmetric shapes, singly symmetric shapes (like channels) (excluding round high strength steel shapes), inelastic web buckling occurs. When the web is very slender, elastic web buckling occurs, reducing the capacity even more:

Case 1) For 
$$h/t_w \le 2.24 \sqrt{\frac{E}{F_y}}$$
  $V_n = 0.6 F_{yw} A_w$   $\phi_v = 1.00 \text{ (LRFD)}$   $\Omega = 1.50 \text{ (ASD)}$ 

where *h* equals the clear distance between flanges less the fillet or corner radius for rolled shapes

 $V_n$  = nominal shear strength  $F_{yw}$  = yield strength of the steel in the web  $A_w$  =  $t_w$ d = area of the web

Case 2) For 
$$h/t_w > 2.24 \sqrt{\frac{E}{F_v}}$$
  $V_n = 0.6 F_{yw} A_w C_v$   $\phi_v = 0.9 \text{ (LRFD)}$   $\Omega = 1.67 \text{ (ASD)}$ 

where  $C_v$  is a reduction factor (1.0 or less by equation)

Design for Flexure

$$M_a \le M_n / \Omega$$
 or  $M_u \le \phi_b M_n$   $\phi_b = 0.90 \text{ (LRFD)}$   $\Omega = 1.67 \text{ (ASD)}$ 

The nominal flexural strength  $M_n$  is the *lowest* value obtained according to the limit states of

- 1. yielding, limited at length  $L_p = 1.76r_y \sqrt{\frac{E}{F_y}}$ , where  $r_y$  is the radius of gyration in y
- 2. lateral-torsional buckling limited at length  $L_r$
- 3. flange local buckling
- 4. web local buckling

Beam design charts show available moment,  $M_n/\Omega$  and  $\phi_b M_n$ , for unbraced length,  $L_b$ , of the compression flange in one-foot increments from 1 to 50 ft. for values of the bending coefficient  $C_b = 1$ . For values of  $1 < C_b \le 2.3$ , the required flexural strength  $M_u$  can be reduced by dividing it by  $C_b$ . ( $C_b = 1$  when the bending moment at any point within an unbraced length is larger than that at both ends of the length.  $C_b$  of 1 is conservative and permitted to be used in any case. When the free end is unbraced in a cantilever or overhang,  $C_b = 1$ . The full formula is provided below.)

*NOTE*: the self weight is not included in determination of  $M_n/\Omega$   $\phi_b M_n$ 

## **Compact Sections**

For a laterally braced *compact* section (one for which the plastic moment can be reached before local buckling) only the limit state of yielding is applicable. For unbraced compact beams and non-compact tees and double angles, only the limit states of yielding and lateral-torsional buckling are applicable.

Compact sections meet the following criteria:  $\frac{b_f}{2t_f} \le 0.38 \sqrt{\frac{E}{F_y}}$  and  $\frac{h_c}{t_w} \le 3.76 \sqrt{\frac{E}{F_y}}$ 

where:

 $b_f$  = flange width in inches

 $t_f$  = flange thickness in inches

E =modulus of elasticity in ksi

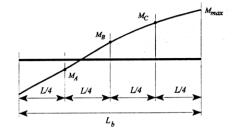
 $F_v = \text{minimum yield stress in ksi}$ 

 $h_c$  = height of the web in inches

 $t_w$  = web thickness in inches

With lateral-torsional buckling the nominal flexural strength is

$$M_n = C_b \left[ M_p - (M_p - 0.7F_y S_x) \left( \frac{L_b - L_p}{L_r - L_p} \right) \right] \le M_p$$



where  $M_p = M_n = F_y Z_x$ 

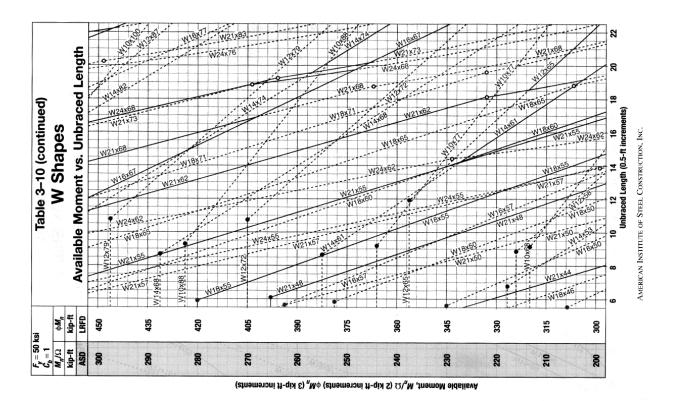
and C<sub>b</sub> is a modification factor for non-uniform moment diagrams where, when both ends of the beam segment are braced:

$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C}$$

 $M_{max}$  = absolute value of the maximum moment in the unbraced beam segment  $M_A$  = absolute value of the moment at the quarter point of the unbraced beam segment  $M_B$  = absolute value of the moment at the center point of the unbraced beam segment  $M_C$  = absolute value of the moment at the three quarter point of the unbraced beam segment length.

### Available Flexural Strength Plots

Plots of the available moment for the unbraced length for wide flange sections are useful to find sections to satisfy the design criteria of  $M_a \leq M_n / \Omega$  or  $M_u \leq \phi_b M_n$ . The maximum moment that can be applied on a beam (taking self weight into account),  $M_a$  or  $M_u$ , can be plotted against the unbraced length,  $L_b$ . The limiting length,  $L_p$  (fully plastic), is indicated by a solid dot ( $\bullet$ ), while the limiting length,  $L_r$  (for lateral torsional buckling), is indicated by an open dot ( $\circ$ ). Solid lines indicate the most economical, while dashed lines indicate there is a lighter section that could be used.  $C_b$ , which is a lateral torsional buckling modification factor for non-zero moments at the ends, is 1 for simply supported beams (0 moments at the ends). (see *figure*)



## Design Procedure

The intent is to find the most light weight member (which is economical) satisfying the section modulus size.

- 1. Determine the unbraced length to choose the limit state (yielding, lateral torsional buckling or more extreme) and the factor of safety and limiting moments. Determine the material.
- 2. Draw V & M, finding  $V_{max}$  and  $M_{max}$ .for unfactored loads (ASD,  $V_a \& M_a$ ) or from factored loads (LRFD,  $V_u \& M_u$ )
- 3. Calculate  $Z_{\text{req'd}}$  when yielding is the limit state. This step is equivalent to determining if  $f_b = \frac{M_{max}}{S} \leq F_b, \ Z_{req'd} \geq \frac{M_{max}}{F_b} = \frac{M_{max}}{F_y} \text{ and } \ Z_{req'd} \geq \frac{M_u}{\phi_b F_y} \text{ to meet the design criteria that}$

$$M_a \le M_n / \Omega$$
 or  $M_u \le \phi_b M_n$ 

If the limit state is something other than yielding, determine the nominal moment,  $M_n$ , or use plots of available moment to unbraced length,  $L_b$ .

4. For steel: use the section charts to find a trial Z and remember that the beam self weight (the second number in the section designation) will increase  $Z_{req'd}$ . The design charts show the lightest section within a grouping of similar Z's.

TABLE 9.1 Load Factor Resistance Design Selection

|                   |                          |          | $F_y = 3$                 | 6 ksi        |                          |
|-------------------|--------------------------|----------|---------------------------|--------------|--------------------------|
| Designation       | $Z_{x}$ in. <sup>3</sup> | $L_p$ ft | $\frac{L_r}{\mathrm{ft}}$ | $M_p$ kip-ft | M <sub>r</sub><br>kip-ft |
| W 33 × 141        | 514                      | 10.1     | 30.1                      | 1,542        | 971                      |
| W 30 × 148        | 500                      | 9.50     | 30.6                      | 1,500        | 945                      |
| W 24 $\times$ 162 | 468                      | 12.7     | 45.2                      | 1,404        | 897                      |
| W 24 × 146        | 418                      | 12.5     | 42.0                      | 1,254        | 804                      |
| W 33 × 118        | 415                      | 9.67     | 27.8                      | 1,245        | 778                      |
| W 30 × 124        | 408                      | 9.29     | 28.2                      | 1,224        | 769                      |
| W 21 $\times$ 147 | 373                      | 12.3     | 46.4                      | 1,119        | 713                      |
| $W 24 \times 131$ | 370                      | 12.4     | 39.3                      | 1,110        | 713                      |
| W $18 \times 158$ | 356                      | 11.4     | 56.5                      | 1,068        | 672                      |
|                   |                          |          |                           |              |                          |

<sup>\*\*\*\*</sup> Determine the "updated"  $V_{max}$  and  $M_{max}$  including the beam self weight, and verify that the updated  $Z_{req'd}$  has been met. \*\*\*\*\*

- 5. Consider lateral stability.
- 6. Evaluate horizontal shear using  $V_{\text{max}}$ . This step is equivalent to determining if  $f_v \leq F_v$  is satisfied to meet the design criteria that  $V_a \leq V_n/\Omega$  or  $V_u \leq \phi_v V_n$

For I beams: 
$$f_{v-\text{max}} = \frac{3V}{2A} \approx \frac{V}{A_{web}} = \frac{V}{t_w d}$$
 
$$V_n = 0.6F_{yw}A_w \quad or \quad V_n = 0.6F_{yw}A_w C_v$$
 Others: 
$$f_{v-\text{max}} = \frac{VQ}{Ib}$$

- 7. Provide adequate bearing area at supports. This step is equivalent to determining if  $f_p = \frac{P}{A} \le F_p$  is satisfied to meet the design criteria that  $P_a \le P_n / \Omega$  or  $P_u \le \phi P_n$
- 8. Evaluate shear due to torsion  $f_{v} = \frac{T\rho}{J} \text{ or } \frac{T}{c_{1}ab^{2}} \le F_{v} \text{ (circular section or rectangular)}$
- 9. Evaluate the deflection to determine if  $\Delta_{maxLL} \leq \Delta_{LL-allowed}$  and/or  $\Delta_{maxTotal} \leq \Delta_{Totalallowed}$
- \*\*\*\* note: when  $\Delta_{calculated} > \Delta_{limit}$ ,  $I_{req'd}$  can be found with: and  $Z_{req'd}$  will be satisfied for similar self weight \*\*\*\*\*  $I_{req'd} \geq \frac{\Delta_{loobig}}{\Delta_{limit}} I_{trial}$

#### FOR ANY EVALUATION:

Redesign (with a new section) at any point that a stress or serviceability criteria is NOT satisfied and re-evaluate each condition until it is satisfactory.

## Load Tables for Uniformly Loaded Joists & Beams

Tables exist for the common loading situation of uniformly distributed load. The tables either provide the safe distributed load based on bending and deflection limits, they give the allowable span for specific live and dead loads including live load deflection limits. If the load is *not uniform*, an *equivalent uniform load* can be calculated  $M_{max} = \frac{w_{equivalent}L^2}{8}$  from the maximum moment equation:

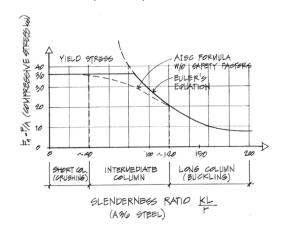
If the deflection limit is less, the design live load to check against allowable must be increased, ex.

$$w_{adjusted} = w_{ll-have} \left( \frac{L/360}{L/400} \right)$$
 table limit wanted

## Criteria for Design of Columns

If we know the loads, we can select a section that is adequate for strength & buckling.

If we know the length, we can find the limiting load satisfying strength & buckling.



Allowable Stress Design

# American Institute of Steel Construction (AISC) Manual of ASD, 9<sup>th</sup> ed:

<u>Long and slender</u>: [  $L_e/r \ge C_c$ , preferably  $\le 200$ ]

$$F_{allowable} = \frac{F_{cr}}{F.S.} = \frac{12\pi^2 E}{23(Kl/r)^2}$$

The yield limit is idealized into a parabolic curve that blends into the Euler's Formula at C<sub>c</sub>.

With 
$$F_y = 36$$
 ksi,  $C_c = 126.1$ 

With 
$$F_y = 50$$
 ksi,  $C_c = 107.0$ 

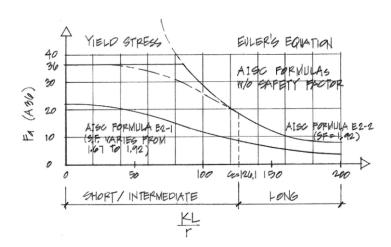
$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$$

Short and stubby:  $[L_e/r < C_c]$ 

$$F_a = \left[1 - \frac{\left(\frac{Kl}{r}\right)^2}{2C_c^2}\right] \frac{F_y}{F.S.}$$

with:

$$F.S. = \frac{5}{3} + \frac{3(Kl/r)}{8C_c} - \frac{(Kl/r)^3}{8C_c^3}$$



Design for Compression

# American Institute of Steel Construction (AISC) Manual 14<sup>th</sup> ed:

$$P_a \le P_n / \Omega$$
 or  $P_u \le \phi_c P_n$  where  $P_u = \sum \gamma_i P_i$ 

γ is a <u>load factor</u>

P is a <u>load</u> type

φ is a <u>resistance factor</u>

P<sub>n</sub> is the <u>nominal load capacity (strength)</u>

$$\phi = 0.90 \text{ (LRFD)}$$
  $\Omega = 1.67 \text{ (ASD)}$ 

For compression  $P_n = F_{cr} A_g$ 

where :  $A_g$  is the cross section area and  $F_{cr}$  is the flexural buckling stress

The flexural buckling stress,  $F_{cr}$ , is determined as follows:

when 
$$\frac{KL}{r} \le 4.71 \sqrt{\frac{E}{F_y}}$$
 or  $(F_e \ge 0.44F_y)$ :
$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y$$
when  $\frac{KL}{r} > 4.71 \sqrt{\frac{E}{F_y}}$  or  $(F_e < 0.44F_y)$ :
$$F_{cr} = 0.877 F_e$$

where  $F_e$  is the elastic critical buckling stress:

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

## Design Aids

Tables exist for the value of the flexural buckling stress based on slenderness ratio. In addition, tables are provided in the AISC Manual for Available Strength in Axial Compression based on the effective length with respect to least radius of gyration,  $r_y$ . If the critical effective length is about the largest radius of gyration,  $r_x$ , it can be turned into an effective length about the y axis by dividing by the fraction  $r_x/r_y$ .

| Second Period  | ## ST  |                |             | ₹     | Axial                         |                   | mpr         | Compression,      | on,                           | kips              | <b>'</b> 0        | $\dashv$ |      |
|--|--|----------------|-------------|-------|-------------------------------|-------------------|-------------|-------------------|-------------------------------|-------------------|-------------------|----------|------|
| ## WITSY    P_1/\(\text{D}_2\)   \(\phi_2\)  | ## ASS   Part  |                |             |       |                               |                   | Ë<br>N<br>≥ | abes              |                               |                   |                   | W12      |      |
| MATHER   966   | ASD         RT         79         79         77           ASD         LRFD         Φ <sub>c</sub> P <sub>m</sub> P <sub>m</sub> /Ω <sub>c</sub> Φ <sub>c</sub> P <sub>m</sub> P <sub>m</sub> /Ω <sub>c</sub> Φ <sub>c</sub> P <sub>m</sub> P <sub>m</sub> /Ω <sub>c</sub> ASD         LRFD         ASD  | र्क            | abe         |       |                               | -                 |             | ¥                 | <br> ×                        |                   |                   | 1        | 2    |
| Mathematical Part   Math   | ASD         LRFD         Φ <sub>0</sub> P <sub>n</sub> P <sub>µ</sub> Ω <sub>0</sub> Φ <sub>0</sub> P <sub>n</sub> P <sub>µ</sub> Ω <sub>0</sub> Φ <sub>0</sub> P <sub>n</sub> P <sub>µ</sub> Ω <sub>0</sub> ASD         LRFD         ASD         LRFD         ASD         LRFD         ASD         LRPD         ASD           844         1270         766         1150         694         1040         633           772         1120         735         1100         667         1000         607         588           772         1140         685         1100         667         1000         607         588           772         1140         685         1010         667         100         607         588         577         588           772         1140         685         1010         667         970         657         589         587         588         567         588         567         588         587         587         588         587         587         587         588         587         587         588         589         489         587         587         588         589         489         587         587         588         589         588         589         589         589  | 3              | ##          | 6     |                               | 8                 | - 1         | 7                 |                               | -                 |                   | 9        | 89   |
| Main  | MAIN   LINED   ASD   LINED   ASD   LINED   ASD   | ě              | ngis        | P,100 | ф <sub>с</sub> Р <sub>п</sub> | P,/Ω <sub>c</sub> | ф°Р         | P,/Ω <sub>c</sub> | φ <sub>c</sub> P <sub>n</sub> | P,/Ω <sub>c</sub> | ф <sub>с</sub> Р, | P,/Ω     | ¢00  |
| State  | 844         1270         766         1150         684         1040         633           8 11         1220         725         1110         667         1040         633           7 77         1160         699         1050         657         987         588           1 772         1160         699         1050         634         952         565           2 772         1160         689         1050         634         952         565           3 1140         688         1030         689         1050         634         952         565           3 1140         688         1010         606         91         551         88         573           4 680         1020         634         953         573         88         506         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590         890         590   |                |             | ASD   | LRFD                          | ASD               | LRFD        | ASD               | LRFD                          | ASD               | EE.               | ASD      | LRFD |
| 811   1220   735   1110   667   1000   607   913   548     800   1200   725   1090   657   997   588   899   540     777   1160   699   1050   634   952   577   867   520     778   11160   699   1050   624   952   577   867   520     778   11160   689   1050   624   952   577   867   520     720   1080   652   980   590   897   588   899   549     721   1080   652   980   590   897   538   899   549     722   1080   652   980   590   897   537   867   867     723   1110   689   1050   634   952   577   867   520     724   1050   634   953   573   862   526   761   445     669   1020   615   898   538   801   481   722   441     722   888   533   801   481   722   445   684   409     724   447   672   402   605   362   544   328   440   587     725   495   774   446   670   402   664   401   602   380     726   441   672   402   605   362   544   328   440   587     727   447   672   402   605   362   544   328   440   587     728   248   386   141   212   114     727   117   226   117   226   141   212   114     728   248   349   377   141   212   141   114     728   248   349   349   349   349   349   349   349     728   241   328   143   323   441   212   140     728   241   342   343   349   374   349   349   349   349     728   242   174   262   141   212   127   130   349     728   248   328   141   212   141   212   140     728   249   141   212   141   1  | State  |                | •           | 844   | 1270                          | 992               | 1150        | 694               | 1040                          | 633               | 951               | 571      | 829  |
| National N   | National Properties    | 4              | 91          | 811   | 1220                          | 735               | 1110        | 299               | 1000                          | 209               | 913               | 548      | 824  |
| 772         1100         699         1070         679         971         971         972         973         973         973         973         973         973         973         973         973         973         974         973         973         974         447         973         973         974         447<   | 772 1160 685 1030 634 952 577 772 1160 685 1030 684 952 577 772 1160 685 1030 684 952 577 857 1160 685 1030 685 886 987 537 882 771 1020 685 980 590 887 537 882 771 1020 615 924 556 886 506 990 595 885 538 889 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 490 595 887 537 882 509 4419 888 536 534 882 539 816 441 602 360 541 323 486 293 176 526 534 319 479 286 440 526 534 141 572 116 526 534 141 572 117 526 526 534 141 572 117 526 526 534 141 572 117 526 526 534 141 572 117 526 527 117 526 526 534 141 572 117 526 526 526 526 526 526 526 526 526 526   | ש ל            | ~ •         | 800   | 1200                          | 25                | 1090        | 657               | 987                           | 298               | 886               | 540      | 811  |
| 756         1140         685         1030         620         932         565         849         509           2         720         1140         686         1010         606         910         551         828         497           2         720         1080         652         980         590         887         553         807         444           6         669         1020         654         953         594         556         836         506         751         447           6         669         1020         654         953         597         887         447   | 756         1140         685         1030         620         932         565           2         720         1110         669         1010         606         910         551           2         720         1080         652         980         590         887         537           4         669         1010         666         910         561         887         537           5         1020         634         955         896         590         887         537           6         659         990         595         895         896         896         596           6         659         990         595         895         896         896         590           8         653         990         595         895         896         896         490           9         663         967         876         873         871         472         486         401           9         743         86         534         876         442         664         401           9         743         872         442         664         401         402         603 <t< td=""><td>otte</td><td></td><td>772</td><td>1160</td><td>669</td><td>1050</td><td>634</td><td>952</td><td>577</td><td>867</td><td>520</td><td>782</td></t<>  | otte           |             | 772   | 1160                          | 669               | 1050        | 634               | 952                           | 577               | 867               | 520      | 782  |
| 739         1110         669         1010         606         910         551         828         497           3         720         1080         652         980         590         887         537         807         484           660         1020         6134         953         596         573         865         552         784         470         484           660         1020         6136         895         558         809         490         776         441         440         667         441         440         460         776         441         440         470         441         440         670         441         472         441         473         441         440         670         441         670         441         670         441         670         441         670         441         670         441         670         441         670         441         670         441         670         441         470         470         470         470         470         470         470         470         470         470         470         470         470         470         470         470         470 <td>1         739         1110         669         1010         606         910         551           2         720         1080         652         980         590         887         537           4         689         1020         634         953         573         882         582           5         669         990         595         895         538         809         490           6         659         990         595         884         550         781         495           6         637         957         575         864         520         781         495           5         614         923         551         789         461         670         401           8         557         885         511         789         461         670         402         664         401           8         567         874         446         670         402         664         401           9         744         602         360         576         442         664         401           1         401         602         402         605         376         44</td> <td>aλı</td> <td>2</td> <td>756</td> <td>1140</td> <td>685</td> <td>1030</td> <td>620</td> <td>932</td> <td>595</td> <td>849</td> <td>200</td> <td>765</td>   | 1         739         1110         669         1010         606         910         551           2         720         1080         652         980         590         887         537           4         689         1020         634         953         573         882         582           5         669         990         595         895         538         809         490           6         659         990         595         884         550         781         495           6         637         957         575         864         520         781         495           5         614         923         551         789         461         670         401           8         557         885         511         789         461         670         402         664         401           8         567         874         446         670         402         664         401           9         744         602         360         576         442         664         401           1         401         602         402         605         376         44   | aλı            | 2           | 756   | 1140                          | 685               | 1030        | 620               | 932                           | 595               | 849               | 200      | 765  |
| 2         720         1080         652         980         590         887         537         804         484           6         660         1020         654         983         573         862         586         784         470         470           6         680         900         596         885         586         889         590         770         456         770         456         770         456         770         456         770         456         470         770         456         470  | 2         720         1080         662         980         590         887         537           4         680         1050         615         924         556         880         582           5         680         990         596         884         550         781         473           7         614         923         554         883         569         490         490           8         637         967         575         864         520         781         473           8         591         882         533         801         481         723         455           9         614         923         564         820         781         491           9         66         441         723         441         664         401           8         551         816         490         736         442         664         401           8         567         816         670         402         664         401           8         724         446         670         402         664         401           8 356         534         327   | to a           | =           | 739   | 1110                          | 699               | 1010        | 909               | 910                           | 551               | 828               | 497      | 74   |
| 3         701         1050         664         993         573         862         522         784         470           6         660         1020         615         924         556         886         506         761         466           6         614         923         554         883         501         752         455         684         409           7         614         923         554         833         501         752         455         684         409           8         591         888         533         801         481         723         437         770         441           957         744         446         670         605         362         544         409         776         442         664         409         776         442         664         401         603         307           4         477         672         402         605         362         544         409         776         442         664         401         603         307           4         401         672         402         605         362         544         409         779  | 3         701         1050         634         953         573         862         522           4         680         1050         615         924         556         836         506           7         614         923         554         833         501         752         456           8         631         980         563         884         507         781         473           8         591         882         533         801         481         723         456           9         563         816         490         736         442         664         401           8         563         816         490         736         442         664         401           8         563         816         490         736         442         664         401           8         567         786         442         664         401         401         401           8         774         446         670         402         663         365         364           8         356         534         319         479         286         430         286 <tr< td=""><td>snib</td><td>12</td><td>720</td><td>1080</td><td>652</td><td>086</td><td>290</td><td>887</td><td>537</td><td>807</td><td>484</td><td>727</td></tr<>   | snib           | 12          | 720   | 1080                          | 652               | 086         | 290               | 887                           | 537               | 807               | 484      | 727  |
| 669         1020         615         924         536         836         506         761         456           67         675         990         595         895         536         836         506         772         470         425           614         923         554         883         501         752         455         684         409         776         441         402         402         664         401         663         367         376         667         393         393         377         445         667         393         367         548         440         667         440         667         440         667         360         541         420         664         401         663         362         548         327         440         667         360         541         323         440         667         360         541         323         440         667         360         541         323         440         667         360         541         325         548         327         360         360         360         360         360         360         360         360         360         360         360  | 4         680         1020         615         924         556         836         506           6         659         990         595         895         538         809         490           6         614         923         557         575         664         520         781         473           8         591         888         533         801         481         723         437           9         567         875         875         670         726         455         457           4         567         875         672         405         664         419         419           8         567         877         405         667         402         664         419           9         740         672         405         667         302         846         283           8         356         534         319         479         286         486         283         176           8         312         420         250         377         195         286         486         283         176           8         326         194         220         174 <td>en :</td> <td><u>e</u></td> <td>701</td> <td>1050</td> <td>634</td> <td>953</td> <td>573</td> <td>862</td> <td>522</td> <td>784</td> <td>470</td> <td>206</td>  | en :           | <u>e</u>    | 701   | 1050                          | 634               | 953         | 573               | 862                           | 522               | 784               | 470      | 206  |
| 637         957         575         864         500         781         473         770         425           614         957         957         575         864         500         781         473         770         426           614         957         888         533         801         481         723         456         664         400         657         393           657         888         533         801         481         723         437         657         393           657         888         533         801         481         723         437         657         393           657         888         533         801         481         723         449         664         401         663         367           407         602         864         402         664         401         663         367         368         449         268         348         327         369         244         328         440         262         664         401         663         367         368         340         262         241         328         440         262         262         341         <  | 6 637 957 575 864 520 781 473 6 149 888 533 801 481 723 437 8 591 888 533 801 481 723 437 8 6 149 888 533 801 481 723 437 8 6 149 888 533 801 481 723 437 8 6 149 672 605 362 544 328 8 356 534 446 670 402 603 342 8 135 534 319 479 286 430 259 8 135 534 319 479 286 430 259 8 135 274 412 246 369 220 331 199 8 135 292 174 262 174 261 157 8 137 206 121 181 104 157 90.9 1 176 264 157 256 157 84.0 1 10.9 10.8 10.8 10.8 1 176 282 275 176 863 869 101 152 84.0 1 10.9 10.9 10.8 10.8 10.8 1 176 283 740 662 39.9 1 176 1177 1178 1181 1181 1183 1183 1 10.9 10.9 10.8 10.8 10.8 1 176 283 740 662 59.9 1 177 286 185 779 869 100 1175 1176 1 1183 740 662 39.9 1 1184 745 740 662 39.9 1 1185 740 662 39.9 1 1187 286 185 778 142 1 1188 740 662 59.9 1 1188 740 662 59.9 1 1188 740 662 59.9 1 1188 740 662 59.9 1 1188 740 662 59.0 1 1189 1176 1175 1176 1195 1 1189 1176 1175 1176 1176 1 1189 1176 1175 1176 1 1189 1176 1176 1176 1 1189 1176 1176 1176 1 1189 1176 1176 11779 1 1189 1176 1176 11779 1 1189 1176 1176 11779 1 1189 1176 1176 11779 1 1189 1176 1176 11779   | 1266           | <b>4</b>    | 089   | 1020                          | 615               | 924         | 556               | 836                           | 206               | 761               | 456      | 685  |
| 637         958         958         958         958         958         958         958         958         958         958         958         959         950 <td>614         937         957         864         950         752         455         875         875         875         485         487         286         487         286         487         286         487         286         487         286         487         286         487         286         487         286         487         286         287         141         287         142         286         187         286         187         287         141         287         286         187         287         143         287         142         287         143         287         143         287         143         143         143         143         143<td>el 01</td><td>2 9</td><td>600</td><td>990</td><td>8</td><td>682</td><td>238</td><td>808</td><td>964</td><td>740</td><td>144</td><td>700</td></td> | 614         937         957         864         950         752         455         875         875         875         485         487         286         487         286         487         286         487         286         487         286         487         286         487         286         487         286         487         286         287         141         287         142         286         187         286         187         287         141         287         286         187         287         143         287         142         287         143         287         143         287         143         143         143         143         143 <td>el 01</td> <td>2 9</td> <td>600</td> <td>990</td> <td>8</td> <td>682</td> <td>238</td> <td>808</td> <td>964</td> <td>740</td> <td>144</td> <td>700</td>  | el 01          | 2 9         | 600   | 990                           | 8                 | 682         | 238               | 808                           | 964               | 740               | 144      | 700  |
| 614         923         394         853         901         752         455         694         419         657         495           567         882         511         769         461         694         419         657         964         419         657         967         461         667         462         664         401         663         366         548         373         867         387         667         387         667         389         387         469         387         667         389         387         389         493         387  | 8         591         928         538         801         481         752         450           8         567         882         511         769         461         604         401           8         567         862         511         769         461         604         401           4         405         605         362         544         402         603         365           4         401         602         360         541         323         486         491           8         356         534         319         479         286         430         259           8         356         534         319         479         286         430         259           4         401         602         360         541         322         486         430         259           4         212         246         279         420         250         376         256           8         195         292         174         262         156         234         141           9         176         262         156         234         141         173  | t to           | 9 ;         | 637   | 957                           | 575               | 864         | 250               | 781                           | 473               | 710               | 425      | 639  |
| 567         686         517         789         461         789         491         481         630         375           495         744         446         670         402         603         366         548         386         548         387         548         387         548         387         548         387         386         387         386         387         386         387  | 567         852         511         769         461         451         475         471         475         471         475         471         475         471         472         473         473         474         476         473         474 <td>eds</td> <td>≥ \$</td> <td>614</td> <td>923</td> <td>254</td> <td>833</td> <td>201</td> <td>752</td> <td>455</td> <td>684</td> <td>409</td> <td>61</td>  | eds            | ≥ \$        | 614   | 923                           | 254               | 833         | 201               | 752                           | 455               | 684               | 409      | 61   |
| 2         495         736         442         664         401         603         360           495         744         446         670         402         603         365         548         327           4         477         672         605         362         544         328         489         329           8         356         534         319         479         286         543         289         289         289         289         280         <  | 495         744         490         736         442         664         401           495         744         446         670         402         663         365           4 47         672         360         541         323         486         238           8         356         534         312         486         570         323         486         238           2         74         469         279         420         250         376         256           2         274         412         246         389         220         376         226           2         274         412         246         389         220         376         226           4         243         366         174         262         165         293         141           8         195         292         174         262         156         234         141           9         176         264         157         258         144         212         143           183         275         172         258         146         143         246           165         284  | eu i           | <u> </u>    | 567   | 852                           | 213               | 769         | 461               | 694                           | 419               | 630               | 377      | 566  |
| 495         744         446         670         402         663         365         544         328         548         327           4 47         672         360         541         328         449         289         294         493         289         294         493         289         289         289         289         289         280   | 495         744         446         670         402         603         365           4 47         672         402         605         385         544         328           8         356         534         312         486         323         486         328           2 1         401         286         534         319         270         286         330         259           2 274         412         246         389         220         376         226         376         226           2 273         326         174         282         174         281         177         281         177           8 195         292         174         282         165         234         141           9 176         264         157         262         156         234         141           1 2 2         174         262         166         273         174         261         141           1 3 2         264         157         258         144         212         143           1 3 3         275         172         258         148         278         143           1 4 5   | tiw            | 8           | 543   | 816                           | 490               | 736         | 442               | 664                           | 401               | 603               | 360      | 541  |
| 4         447         672         460         362         544         328         493         294           8         356         541         323         446         328         440         262           8         356         541         323         440         262         340         262         263         389         294           2         274         412         246         369         220         371         199         299         177           4         243         365         214         226         146         286         174         261         157         236         149         209         177           8         195         292         174         262         156         234         141         212         140         217         236         147         212         140         217         236         147         212         141         212         141         212         140         114         212         140         114         212         140         114         212         140         114         212         140         114         212         140         114         212  | 4 47         672         402         605         382         544         328           8 356         534         360         541         323         486         328           2 312         469         279         420         250         376         226           2 274         412         246         389         220         371         199           4 243         326         194         226         377         226         376         226           8 195         292         174         262         156         234         141           9 176         264         157         262         156         234         141           1 20         176         264         157         262         156         234         141           1 3         264         157         262         156         234         141           1 3         264         265         157         262         156         240         167           1 4         264         275         142         143         143         143           1 4         27         173         366         185         173   | (H)            | 8           | 495   | 744                           | 446               | 029         | 402               | 603                           | 365               | 548               | 327      | 491  |
| 8         350         351         352         450         253         349         252         349         252         349         253         349         252         349         252         349         253         349         253         349         253         349         253         349         253         349         253         349         253         177         252         341         352         183         253         140         252         177         252         187         253         140         252         141         272         141         272         141         272         141         272         140         272         141         272         141         272         141         272         141         272         141         272         141         272         141         272         141         272         142         144         272         141         272         141         272         141         272         141         272         141         272         141         272         142         272         142         142         272         142         142         272         142         142         142         142  | 8         401         602         360         371         692         376         259         279         370         259         400         259         279         240         266         376         226         376         226         376         226         376         226         376         226         377         259         176         226         376         226         376         226         376         226         376         226         376         226         377         174         261         157         250         176         253         177         276         141         272         141         272         141         272         141         272         142         141         272         142         141         272         142         141         272         142         142         272         142         272         142         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272         143         272  | KT             | <b>₹</b> 8  | 447   | 672                           | 402               | 605         | 362               | 544                           | 328               | 493               | 294      | 442  |
| 274 412 246 369 220 331 199 299 177 246 369 220 331 199 299 177 243 365 218 327 195 293 176 265 157 236 140 202 177 266 157 265 140 202 177 266 157 266 140 202 296 445 245 243 366 185 278 142 213 110 28 275 17.2 258 15.7 23.5 14.3 21.5 13.0 296 445 243 366 185 278 142 213 106 28.5 15.7 28.5 14.3 21.5 13.0 296 445 243 366 185 278 142 213 106 28.5 15.7 28.5 14.3 21.5 13.0 28.2 228 12.5 24.0 39.9 37.4 31.0 28.2 228 22.5 25.6 23.2 23.0 39.9 37.4 31.0 28.2 270 241 216 195 117 11.0 11.0 11.0 11.0 11.0 11.0 11.5 21.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   | 274 449 279 420 250 376 226 286 226 274 4412 246 369 220 331 199 220 371 199 220 371 286 217 326 194 292 174 261 157 286 141 212 127 286 141 212 127 286 141 212 286 244 152 243 366 185 275 14.3 286 185 278 142 282 286 245 243 366 185 278 142 282 282 282 282 282 282 282 282 282 2  | цß             | 8 8         | 356   | 534                           | 310               | 146         | 323               | 486                           | 250               | 380               | 297      | 393  |
| 2 274         412         246         369         220         331         199         299         177           6 217         326         194         282         174         261         157         286         140           176         264         157         286         141         212         126         140         212         141         212         126         141         212         126         141         212         126         141         212         142         121         126         141         212         141         212         142         114         212         141         212         141         212         142         114         212         142         141         212         142         141         142         142         142         143         144         142         143         144 <td>2         274         412         246         369         220         331         199           6         217         326         194         292         174         261         157           8         195         293         176         293         176         293         176           19         292         174         262         166         234         141           19         175         286         141         212         141           183         27.5         17.2         28.8         157         23.5         14.3           296         445         243         366         185         278         14.3           103         10.8         10.8         10.8         10.8         10.8           46.6         45.0         3.0         3.9         3.7           28.2         25.0         23.0         3.0         3.0           28.3         740         662         597           3.09         3.05         3.05         3.0           3.09         2.1.75         1.75         1.100           c-in.3         2.300         6180         6180</td> <td>uəj a</td> <td>8</td> <td>312</td> <td>469</td> <td>279</td> <td>420</td> <td>250</td> <td>376</td> <td>226</td> <td>340</td> <td>202</td> <td>303</td>   | 2         274         412         246         369         220         331         199           6         217         326         194         292         174         261         157           8         195         293         176         293         176         293         176           19         292         174         262         166         234         141           19         175         286         141         212         141           183         27.5         17.2         28.8         157         23.5         14.3           296         445         243         366         185         278         14.3           103         10.8         10.8         10.8         10.8         10.8           46.6         45.0         3.0         3.9         3.7           28.2         25.0         23.0         3.0         3.0           28.3         740         662         597           3.09         3.05         3.05         3.0           3.09         2.1.75         1.75         1.100           c-in.3         2.300         6180         6180  | uəj a          | 8           | 312   | 469                           | 279               | 420         | 250               | 376                           | 226               | 340               | 202      | 303  |
| 4         243         365         218         327         195         293         176         265         167           8         175         326         174         261         157         234         140         157         140         157         140         170         140         170         140         171         140         171         140         171         140         171         141         212         141         212         140         171         141         212         141         212         141         212         141         212         141         212         141         212         141         212         141         212         142         141  | 4         243         365         218         327         195         293         176           8         217         326         194         282         174         261         157           90         176         264         157         262         156         234         141           Properties           Properties           Properties           Properties           183         27.5         172         258         157         235         14.3           296         445         243         366         186         278         14.3           152         228         123         185         101         152         84.0           46.6         43.0         38.3         740         662         39.9         37.           270         241         276         23.2         3.05         3.05         3.05           3.09         3.00         3.00         3.00         3.00         5580           4.1.75         1.75         1.75         1.70           4.1.75         1.75         1.70           4.1.75         3.00  | gve            | 8           | 274   | 412                           | 246               | 369         | 220               | 331                           | 199               | 588               | 177      | 267  |
| 6         217         326         194         292         174         261         157         236         140           8         195         292         174         262         156         234         141         212         126         126         166         234         141         212         126         176         176         176         176         176         176         177         179         174         179         174         179         174         179         174         176         176         176         178         188         178         178         188         178         178         178         178         178         178         178         178         178         178         178         178         178         179         178         178         179         178         178         178         178         178         178  | 6         217         326         194         292         174         261         157           8         176         264         157         286         141         212         141           Properties           Properties           Properties           Properties           Properties           Properties           137         2.06         121         183         28.5         16.7         23.8         143           296         445         243         366         185         278         143         142           296         445         243         366         185         278         143           46.6         445         243         366         185         37.8         10.8           46.6         43.0         38.3         740         662         597           270         241         216         195           3.09         3.07         3.05         3.05         3.05           4.1.76         1.75         1.75         1.70           2.1.76         2.200         6900         6180         5580 </td <td>oej,</td> <td>ಸ</td> <td>243</td> <td>365</td> <td>218</td> <td>327</td> <td>195</td> <td>293</td> <td>176</td> <td>265</td> <td>157</td> <td>236</td>   | oej,           | ಸ           | 243   | 365                           | 218               | 327         | 195               | 293                           | 176               | 265               | 157      | 236  |
| 176   264   157   286   141   212   126   126   137   212   126   137   212   136   141   212   126   141   212   126   141   212   126   141   212   126   141   212   126   141   212   126   141   212   141  | 176   264   157   236   141   212   127  | 13             | 8           | 217   | 326                           | 194               | 292         | 174               | 261                           | 157               | 236               | 140      | 211  |
| Properties  137  | Properties  Proper |                | <b>≋</b> ₹  | 195   | 292                           | 174               | 262         | 156               | 234                           | 141               | 212               | 126      | 189  |
| 137   2.06   121   181   104   157   90.9   136   78.2     18.3   27.5   17.2   25.8   15.7   23.5   14.3   21.5   13.0     296   445   243   366   185   278   142   213   106     152   228   123   185   101   152   84.0   126   68.5     10.9   10.8   10.8   10.7   1     28.2   25.6   23.2   21.1   1     28.2   27.0   24.1   216   195   17     3.09   3.07   3.05   3.04     1.76   1.75   1.75   1.75     1.870   6900   6180   5580   498   | 137   206   121   181   157   90.9     18.3   27.5   17.2   25.8   15.7   23.5   14.3     296   445   243   366   185   278   142     152   228   123   185   101   152   84.0     10.9   10.8   10.8   10.8   10.8     46.6   43.0   39.9   37.5     28.2   25.6   23.2   21.8     270   241   216   195     3.09   3.07   3.07   3.05     1.76   1.75   1.75   1.75     1.80   21200   6180   5580     5580   5580   5580     1890   5580   5580     1890    |                | 2           | :     |                               |                   |             |                   |                               |                   |                   |          |      |
| 137   206   121   181   104   157   90.9   136   182   182   296   425   248   366   185   278   14.3   21.5   13.0   296   425   248   366   185   101   152   84.0   126   68.5   13.0   10.8   10.8   10.8   10.7   10.9   10.8   10.8   10.7   10.8   10.8   10.8   10.7   10.8   10.8   10.8   10.7   10.8   10.8   10.8   10.7   10.8   10.8   10.7   10.8   10.8   10.7   10.8   10   | 18.7 206 121 181 104 157 90.9 296 445 243 366 185 278 143 296 445 123 185 101 152 84.0 10.9 10.8 10.8 10.8 28.2 25.6 23.2 21.6 28.3 740 652 270 241 216 195 3.09 3.07 3.05 3.05 1.76 1.75 1.75 1.75 1.86 23800 6180 5580   |                |             |       |                               |                   | Lube        | sam               |                               |                   |                   |          |      |
| 296 27.3 27.3 17.5 23.0 19.7 23.3 14.3 21.3 10.8 10.8 10.8 10.8 10.8 10.8 10.8 10.8  | 296 445 228 185 101 152 142 246 185 278 143 142 142 143 145 142 144 145 143 145 144 144  | SE (KIDS       | - 3         | 137   | 206                           | 121               | 181         | 104               | 157                           | 90.9              | 136               | 78.2     | = 5  |
| 152         228         123         185         101         152         84.0         126         68.5           10.9         10.8         10.8         10.8         10.7         1         1         1         1         46.6         68.5         10.7         1 </td <td>152         228         123         185         101         152         84.0           10.9         10.8         10.8         10.8         10.           46.6         43.0         39.9         37.           28.2         25.6         23.2         27.           270         241         216         195           3.09         3.07         3.05         3.           1.76         1.75         1.75         1.           23800         21200         6180         5580           7730         6900         6180         5580           LRFD         1.8FD         5840</td> <td>(kips</td> <td></td> <td>296</td> <td>445</td> <td>243</td> <td>366</td> <td>185</td> <td>278</td> <td>142</td> <td>213</td> <td>106</td> <td>159</td>  | 152         228         123         185         101         152         84.0           10.9         10.8         10.8         10.8         10.           46.6         43.0         39.9         37.           28.2         25.6         23.2         27.           270         241         216         195           3.09         3.07         3.05         3.           1.76         1.75         1.75         1.           23800         21200         6180         5580           7730         6900         6180         5580           LRFD         1.8FD         5840   | (kips          |             | 296   | 445                           | 243               | 366         | 185               | 278                           | 142               | 213               | 106      | 159  |
| 10.9         10.8         10.8         10.7         1           46.6         43.0         39.9         37.4         3           28.2         28.2         23.2         23.2         21.1         1           83.3         740         662         597         53           270         241         216         195         17           3.09         3.07         3.05         3.04         17           1.75         1.75         1.75         1.75         1.75           23800         21200         6180         5580         498           1.RFD  | 10.9         10.8 <th< td=""><td>(kips)</td><td></td><td>152</td><td>228</td><td>123</td><td>185</td><td>101</td><td>152</td><td>84.0</td><td>126</td><td>68.5</td><td>10</td></th<>   | (kips)         |             | 152   | 228                           | 123               | 185         | 101               | 152                           | 84.0              | 126               | 68.5     | 10   |
| 28.2 25.6 23.2 21.1 1 2 25.0 23.2 21.1 1 2 25.0 23.2 21.1 1 2 25.0 241 216 195 17 2 23.0 241 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.1 2.  | 28.2 25.6 23.2 2<br>833 740 662 59<br>270 241 216 19<br>3.09 3.07 3.05<br>1.76 1.75 1.75 1.75<br>7730 6900 6180 558  | €€             |             | - 7   | 0.0                           | 100               | 9.0         | 1                 | 9.0                           | 1881              | 0.7               | 1 8      | 11.9 |
| 28.2 25.0 25.7 21.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1  | 270 230 241 245 252 253.2 253.2 253.2 241 216 216 216 215 253.0 25 | 6              |             |       | 2 6                           | 1                 | 2 2         |                   | 2 2                           | ,                 |                   | ,        |      |
| 270         241         216         195         17           3.09         3.07         3.05         3.04         17           2.3800         21200         18900         17100         1530           7730         6900         6180         5580         498           LRFD   | 270         241         216         15           3.09         3.07         3.05         15           1.76         1.75         1.75         1.75           23800         21200         18900         1710           7730         6900         6180         558           LRFD  | ()<br>()<br>() |             | × 88  | 3.6                           | 74                | 0.0         | 99                | 23.2                          | 2 65              | 1.1.              | - 53     | 33.5 |
| 23800  | 23800 6900 6180 558<br>LIRED   | E 6            |             | 27    | 9                             | 24                | 1           | 23                | 9                             | 16                | 22                | -1       | 200  |
| 23800 21200 18900 17100 1530 7730 6900 6180 5580 498   | 23800 21200 18900 1710<br>7730 6900 6180 558   | zijo 7. /      |             |       | 1.76                          |                   | 1.75        |                   | 175                           |                   | 1.75              |          | 1.75 |
| LRFO   | LRFD   | (KI 2)         | 04 (k-in.2) |       |                               | 2120              |             | 1890              |                               | 1710              | 0.0               | 1530     | 00   |
|  |  | A              | 99          |       | 9                             | o 91 leaper       |             |                   |                               | 8                 |                   |          | 15   |
|  |  |                |             |       |                               |                   |             |                   |                               |                   |                   |          |      |

Sample AISC Table for Available Strength in Axial Compression

### Procedure for Analysis

- 1. Calculate KL/r for each axis (if necessary). The largest will govern the buckling load.
- 2. Find F<sub>a</sub> or F<sub>cr</sub> as a function of KL/r from the appropriate equation (above) or table.
- 3. Compute  $P_{allowable} = F_a \cdot A$  or  $P_n = F_{cr} \cdot A_g$ or alternatively compute  $f_c = P/A$  or  $P_u/A$
- 4. Is the design satisfactory?

Is 
$$P \le P_{allowable}$$
 (or  $P_a \le P_n/\Omega$ ) or  $P_u \le \phi_c P_n$ ?  $\Rightarrow$  yes, it is; no, it is no good or Is  $f_c \le F_a$  (or  $\le F_{cr}/\Omega$ ) or  $\phi_c F_{cr}$ ?  $\Rightarrow$  yes, it is; no, it is no good

## Procedure for Design

- 1. Guess a size by picking a section.
- 2. Calculate KL/r for each axis (if necessary). The largest will govern the buckling load.
- 3. Find F<sub>a</sub> or F<sub>cr</sub> as a function of KL/r from appropriate equation (above) or table.
- 4. Compute  $P_{allowable} = F_a \cdot A$  or  $P_n = F_{cr} \cdot A_g$ or alternatively compute  $f_c = P/A$  or  $P_u/A$
- 5. Is the design satisfactory?
  - Is  $P \le P_{\text{allowable}} (P_a \le P_n/\Omega)$  or  $P_u \le \phi_c P_n$ ? yes, it is; no, pick a bigger section and go back to step 2.
  - Is  $f_c \le F_a$  ( $\le F_{cr}/\Omega$ ) or  $\phi_c F_{cr}$ ?  $\Rightarrow$  yes, it is; no, pick a bigger section and go back to step 2.
- 6. Check design efficiency by calculating percentage of stress used:

$$\frac{P}{P_{allowable}} \cdot 100\% \left( \frac{P_a}{P_n/\Omega} \cdot 100\% \right) or \frac{P_u}{\phi_c P_n} \cdot 100\%$$

If value is between 90-100%, it is efficient.

If values is less than 90%, pick a smaller section and go back to step 2.

### **Columns with Bending (Beam-Columns)**

In order to *design* an adequate section for allowable stress, we have to start somewhere:

- 1. Make assumptions about the limiting stress from:
  - buckling
  - axial stress
  - combined stress
- 2. See if we can find values for  $\underline{r}$  or  $\underline{A}$  or  $\underline{Z}$ .
- 3. Pick a trial section based on if we think r or A is going to govern the section size.

- 4. Analyze the stresses and compare to allowable using the allowable stress method or interaction formula for eccentric columns.
- 5. Did the section pass the stress test?
  - If not, do you *increase* r or A or Z?
  - If so, is the difference really big so that you could *decrease* r or A or Z to make it more efficient (economical)?
- 6. Change the section choice and go back to step 4. Repeat until the section meets the stress criteria.

## Design for Combined Compression and Flexure:

The interaction of compression and bending are included in the form for two conditions based on the size of the required axial force to the available axial strength. This is notated as  $P_r$  (either P from ASD or  $P_u$  from LRFD) for the axial force being supported, and  $P_c$  (either  $P_n/\Omega$  for ASD or  $\phi_c P_n$  for LRFD). The increased bending moment due to the P- $\Delta$  effect must be determined and used as the moment to resist.

For 
$$\frac{P_r}{P_c} \ge 0.2$$
:  $\frac{P}{P_n/\Omega} + \frac{8}{9} \left( \frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \right) \le 1.0$   $\frac{P_u}{\phi_c P_n} + \frac{8}{9} \left( \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \le 1.0$  (ASD) (LRFD)

For  $\frac{P_r}{P_c} < 0.2$ :  $\frac{P}{2P_n/\Omega} + \left( \frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \right) \le 1.0$   $\frac{P_u}{2\phi_c P_n} + \left( \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \le 1.0$ 

where:

 $\begin{array}{ll} \text{for compression} & \phi_c = 0.90 \; (LRFD) & \Omega = 1.67 \; (ASD) \\ \text{for bending} & \phi_b = 0.90 \; (LRFD) & \Omega = 1.67 \; (ASD) \end{array}$ 

For a <u>braced</u> condition, the moment magnification factor  $B_I$  is determined by  $B_1 = \frac{C_m}{1 - \alpha(P_u/P_{e1})} \ge 1.0$  where  $C_m$  is a modification factor accounting for end conditions

When not subject to transverse loading between supports in plane of bending:

= 0.6 - 0.4 (M<sub>1</sub>/M<sub>2</sub>) where M<sub>1</sub> and M<sub>2</sub> are the end moments and M<sub>1</sub><M<sub>2</sub>. M<sub>1</sub>/M<sub>2</sub> is positive when the member is bent in reverse curvature (same direction), negative when bent in single curvature.

(LRFD)

When there is transverse loading between the two ends of a member:

= 0.85, members with restrained (fixed) ends

= 1.00, members with unrestrained ends

 $P_{e1} = \frac{\pi^2 EA}{\left(\frac{Kl}{r}\right)^2}$ 

 $\alpha = 1.00 \text{ (LRFD)}, 1.60 \text{ (ASD)}$ 

(ASD)

 $P_{el}$  = Euler buckling strength

## **Criteria for Design of Connections**

Connections must be able to transfer any axial force, shear, or moment from member to member or from beam to column.

Connections for steel are typically high strength bolts and electric arc welds. Recommended practice for ease of construction is to specified *shop welding* and *field bolting*.

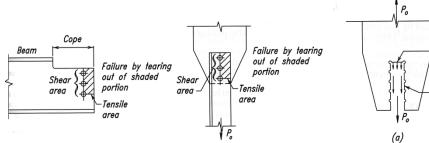


Fig. C-J4.1. Failure for block shear rupture limit state.

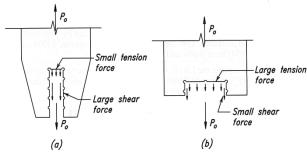


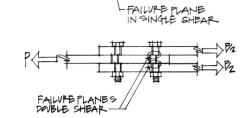
Fig. C-J4.2. Block shear rupture in tension

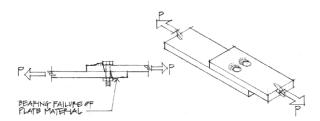
## **Bolted and Welded Connections**

The limit state for connections depends on the loads:

- 1. tension yielding
- 2. shear yielding
- 3. bearing yielding
- 4. bending yielding due to eccentric loads
- 5. rupture

Welds must resist shear stress. The design strengths depend on the weld materials.





## **Bolted Connection Design**

Bolt designations signify material and type of connection where

SC: slip critical

N: bearing-type connection with bolt threads *included* in shear plane

X: bearing-type connection with bolt threads *excluded* from shear plane

A307: similar in strength to A36 steel (also known as ordinary, common or unfinished bolts)

A325: high strength bolts (Group A)

A490: high strength bolts (higher than A325) (Group B)

Bearing-type connection: no frictional resistance in the contact surfaces is assumed and slip between members occurs as the load is applied. (Load transfer through bolt only).

Slip-critical connections: bolts are torqued to a high tensile stress in the shank, resulting in a clamping force on the connected parts. (Shear resisted by clamping force). Requires inspections and is useful for structures seeing dynamic or fatigue loading. Class A indicates the *faying* (contact) surfaces are clean mill scale or adequate paint system, while Class B indicates blast cleaning or paint for  $\mu = 0.50$ .

Bolts rarely fail in **bearing**. The material with the hole will more likely yield first.

For the determination of the net area of a bolt hole the width is taken as 1/16" greater than the nominal dimension of the hole. Standard diameters for bolt holes are 1/16" larger than the bolt diameter. (This means the net width will be 1/8" larger than the bolt.)

Design for Bolts in Bearing, Shear and Tension

Available shear values are given by bolt type, diameter, and loading (Single or Double shear) in AISC manual tables. Available shear value for slip-critical connections are given for limit states of serviceability or strength by bolt type, hole type (standard, short-slotted, long-slotted or oversized), diameter, and loading. Available tension values are given by bolt type and diameter in AISC manual tables.

Available bearing force values are given by bolt diameter, ultimate tensile strength,  $F_u$ , of the connected part, and thickness of the connected part in AISC manual tables.

### For shear OR tension (same equation) in bolts:

$$R_a \le R_n / \Omega$$
 or  $R_u \le \phi R_n$   
where  $R_u = \sum \gamma_i R_i$ 

- single shear (or tension)  $R_n = F_n A_b$
- double shear  $R_n = F_n 2A_b$

where  $\phi =$  the resistance factor

 $F_n$  = the nominal tension or shear strength of the bolt

 $A_b$  = the cross section area of the bolt

$$\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$$

## For bearing of plate material at bolt holes:

$$R_a \le R_n / \Omega \text{ or } R_u \le \phi R_n$$
  
where  $R_u = \sum \gamma_i R_i$ 

• deformation at bolt hole is a concern

$$R_n = 1.2L_c t F_u \le 2.4 dt F_u$$

deformation at bolt hole is not a concern

$$R_n = 1.5L_c t F_u \le 3.0 dt F_u$$

long slotted holes with the slot perpendicular to the load

$$R_n = 1.0 L_c t F_u \le 2.0 dt F_u$$

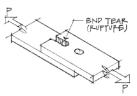


Figure 10.11 End tear-out

where  $R_n$  = the nominal bearing strength

 $F_n$  = specified minimum tensile strength

 $L_c$  = clear distance between the edges of the hole and the next hole or edge in the direction of the load

d = nominal bolt diameter

t = thickness of connected material

 $\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$ 

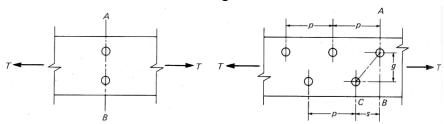
The *minimum* edge desistance from the center of the outer most bolt to the edge of a member is generally 1¾ times the bolt diameter for the sheared edge and 1¼ times the bolt diameter for the rolled or gas cut edges.

The *maximum* edge distance should not exceed 12 times the thickness of thinner member or 6 in.

Standard bolt hole spacing is 3 in. with the minimum spacing of  $2\frac{2}{3}$  times the diameter of the bolt,  $d_b$ . Common edge distance from the center of last hole to the edge is  $1\frac{1}{4}$  in..

## Tension Member Design

In steel tension members, there may be bolt holes that reduce the size of the cross section.



g refers to the row spacing or gage

p refers to the bolt spacing or pitch

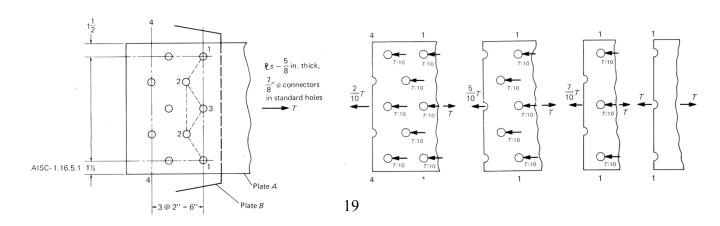
s refers to the longitudinal spacing of two consecutive holes

### Effective Net Area:

The smallest effective are must be determined by subtracting the bolt hole areas. With staggered holes, the shortest length must be evaluated.

A series of bolts can also transfer a portion of the tensile force, and some of the effective net areas see reduced stress.

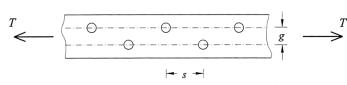
The effective net area,  $A_e$ , is determined from the net area,  $A_n$  multiplied by a shear lag factor, U, which depends on the element type and connection configuration. If a portion of a connected member is not fully connected (like the leg of an angle), the unconnected part is not subject to the



full stress and the shear lag factor can range froi

The staggered hole path area is determined by:

$$A_n = A_g - A_{of \ all \ holes} + t\Sigma \frac{s^2}{4g}$$



where t is the plate thickness, s is each stagger spacing, and g is the gage spacing.

## For tension elements:

$$R_a \le R_n / \Omega$$
 or  $R_u \le \phi R_n$   
where  $R_u = \sum \gamma_i R_i$ 

1. yielding 
$$R_n = F_y A_g$$
 
$$\phi = 0.90 \text{ (LRFD)} \qquad \Omega = 1.67 \text{ (ASD)}$$

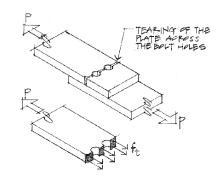
2. rupture 
$$R_n = F_u A_e$$
 
$$\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$$

where  $A_g$  = the gross area of the member (excluding holes)

 $A_e$  = the effective net area (with holes, etc.)

 $F_v$  = the yield strength of the steel

 $F_u$  = the tensile strength of the steel (ultimate)



### **Welded Connections**

Weld designations include the strength in the name, i.e. E70XX has Fy = 70 ksi. Welds are weakest in shear and are assumed to always fail in the shear mode.

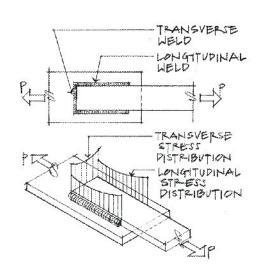
The throat size, T, of a fillet weld is determined trigonometry by:  $T = 0.707 \times \text{weld size*}$ 

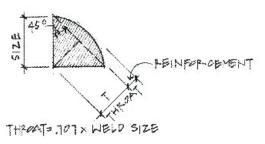
\* When the submerged arc weld process is used, welds over 3/8" will have a throat thickness of 0.11 in. larger than the formula.

Weld sizes are limited by the size of the parts being put together and are given in AISC manual table J2.4 along with the allowable strength per length of fillet weld, referred to as *S*.

The maximum size of a fillet weld:

- a) can't be greater than the material thickness if it is 1/4" or less
- b) is permitted to be 1/16" less than the thickness of the material if it is over 1/4"





The minimum length of a fillet weld is 4 times the nominal size. If it is not, then the weld size used for design is 1/4 the length.

Intermittent fillet welds cannot be less than four times the weld size, not to be less than 1 ½".

TABLE J2.4 Minimum Size of Fillet Welds

| Material Thickness of Thicker | Minimum Size of Fillet  |
|-------------------------------|-------------------------|
| Part Joined (in.)             | Weld <sup>a</sup> (in.) |
| To 1/4 inclusive              | 1/6                     |
| Over 1/4 to 1/2               | 3/16                    |
| Over 1/2 to 3/4               | 1/4                     |
| Over 3/4                      | 5/16                    |

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For fillet welds:

$$R_a \le R_n / \Omega$$
 or  $R_u \le \phi R_n$   
where  $R_u = \sum \gamma_i R_i$ 

for the weld metal:  $R_n = 0.6F_{EXX}Tl = Sl$ 

$$R_n = 0.6F_{EXX}Tl = Sl$$

$$\phi = 0.75 \text{ (LRFD)}$$
  $\Omega = 2.00 \text{ (ASD)}$ 

where:

T is throat thickness *l* is length of the weld

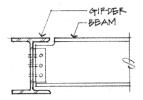
For a connected part, the other limit states for the base metal, such as tension yield, tension rupture, shear yield, or shear rupture **must** be considered.

| Available                    | Strength of Fil  | let Welds |
|------------------------------|------------------|-----------|
|                              | r inch of weld ( | φS)       |
| Weld Size                    | E60XX            | E70XX     |
| (in.)                        | (k/in.)          | (k/in.)   |
| <sup>3</sup> / <sub>16</sub> | 3.58             | 4.18      |
| 1/4                          | 4.77             | 5.57      |
| 5/16                         | 5.97             | 6.96      |
| 3/8                          | 7.16             | 8.35      |
| 7/16                         | 8.35             | 9.74      |
| 1/2                          | 9.55             | 11.14     |
| 5/8                          | 11.93            | 13.92     |
| 3/4                          | 14.32            | 16.70     |

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

### Framed Beam Connections

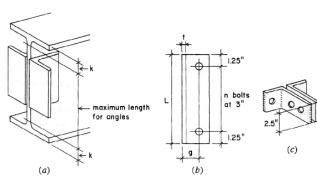
Coping is the term for cutting away part of the flange to connect a beam to another beam using welded or bolted angles.



AISC provides tables that give bolt and angle available strength knowing number of bolts, bolt type, bolt diameter, angle leg thickness, hole type and coping, and the wide flange beam being connected. For the connections the limit-state of bolt shear, bolts bearing on the angles, shear yielding of the angles, shear rupture of the angles, and block shear rupture of the angles, and bolt bearing on the beam web are considered.

Group A bolts include A325, while Group B includes A490.

There are also tables for bolted/welded double-angle connections and all-welded double-angle connections.



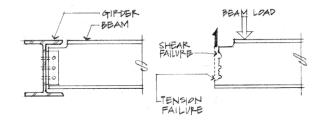
## Sample AISC Table for Bolt and Angle Available Strength in **All-Bolted Double-Angle Connections**

| e)           | r <sub>u</sub> = 65 KSI  | (3)        | ₹                                  | All-Bolted Double-Angle   | ¥  | 었  | 2                      | <u>5</u> 5 | 6                            | Y<br>DO   | <u>e</u> | 5           | 4         | 7/4-in    |
|--------------|--|------------|------------------------------------|---|--|--|------------------------|------------|------------------------------|---|----------|-------------|-----------|-----------|
| igr<br>igr   | l II   |            |                                    |   | ŏ  | Connections  | ec                     | Ę          | ns                           | ,   |          |             | Bolts     | ts        |
| À<br>آع      | = 58 ksi   | (E)        |                                    | 316 91  | 8  | It and   | Angle                  | Availab    | le Stre                      | Bolt and Angle Available Strength, kips   | ips      | 3<br>3<br>3 |           | 3 P.\<br> |
| 4            | 4 Rows   | 100        | Ě                                  | Y   | ٤  | ٩  | ole                    | 3          | A                            | Angle Thickness, in.  | ckness   | Ë           | NON       |           |
|              |  | 10 6       |                                    | Cond  | £ 2  | 10 E   | -08                    | 1,4        | 5,                           | 5/16  | 3        | 3/8         |           | 1/2       |
| W24,         | W24, 21, 18, 16  | 084        |                                    | asa   | 8483   | 922  | ASD                    | LRFD       | ASD                          | LRFD  |          | ASD LRFD    | ASD       | ASD LRFD  |
|              |  |            | - '                                | z   | လ ပ  | ers ers  | 67.1                   | 5          | 83.9                         | _   | 95.5     |             | 95.5      |           |
|              |  |            |                                    |   | ٥١٥  |  | - 2                    | 101        | 10                           | 071   |          | ᅩ           |           | -1        |
|              |  | Cura       | S                                  | သ   | <i>y</i> 6   | O S  | 20.6                   | 64.5       | 90.6                         | 73.9  | 50.6     | 75.9        | 50.6      | 67.5      |
| 3            | 1  | dioip<br>A | Clas                               | Class A   | - W  | SSIT   | 50.6                   | 75.9       | 8.100                        | 75.9  |          |             |           | - 1       |
| 1            | 6-   | 100        |                                    |   | S  | STD  | 67.1                   | 101        | 1000                         | 126   |          | -           | 84.4      | -         |
|              | ce c   |            | Clas                               | Class B   | 0  | SNO  | 65.3                   | 97.9       | 10000                        | 108   | 71.9     |             | 71.9      |           |
| 7            | -  |            |                                    |   | SS   | SSLT   | 65.8                   | 98.7       | 82.2                         | 123   | 84.4     | 127         | 84.4      |           |
| P7           |  |            | <b>z</b> >                         | <b>z</b> >  | s s  | STO  | 67.1                   | 5 5        | 83.9                         | 126   | <u> </u> | 15.         | 120       | 180       |
| 6-08         | ^  |            |                                    |   | 0 60   | STD  | 63.3                   | 94.9       | 63.3                         | 94.9  | 633      | 94.9        | 63.3      | 949       |
| 1            |  | Group      | SS                                 | ٠<br>د  | 6  | SAO  | 53.9                   | 80.7       | 200                          | 80.7  | 53.9     | 80.7        | 53.9      |           |
|              |  | 80         | Sas                                | Class A   | SS   | SSLT   | 63.3                   | 94.9       | 100                          | 94.9  | 63.3     | 94.9        | 63.3      |           |
|              |  |            | S                                  | ٠   | S  | STD  | 67.1                   | 101        | CHAIN                        | 126   | 5        | 151         | 105       |           |
|              |  |            | Clas                               | Class B   | Ó  | ovs  | 65.3                   | 97.9       |                              | 122   | 89.9     | 134         | 89.9      |           |
|              |  |            |                                    |   | SS   | SSLT   | 65.8                   | 98.7       | 82.2                         | 123   | 98.7     | 148         | 105       | 128       |
|              |  | Be         | am We                              | b Avail.  | able S   | rength   | per In                 | ch Thic    | kness,                       | Beam Web Available Strength per Inch Thickness, kips/in.  | -        |             |           |           |
|              | Hole Tyne  |            |                                    | STD   | و  |  |                        | 6          | OVS                          |   |          | SSLT        | 17        |           |
|              | add: am.   |            |                                    | 1.1   | - 3  |  |                        | Let,       | <i>L<sub>eh</sub></i> *, in. |   |          |             |           |           |
|              | ei j   | 1 - 4      | 11/2                               | /2  | +  | 13/4   | 1                      | 11/2       | 7                            | 13/4  | -        | 11/2        | 1         | 13/4      |
|              | -04,   | GRA.       | ASD                                | LRFD  | ASD  | LRFD   | ASD                    | LRFD       | ASD                          | LRFD  | ASD      | LRFD        | ASD       | LRFD      |
|              |  | 11/4       | 167                                | 250   | 175  | 262  | 156                    | 234        | 164                          | 246   | 164      | 245         | 172       | 257       |
| į            |  | <u>۾</u>   | 2 5                                | 407   | > 4  | 907  | 200                    | 238        | /91                          | 22  | 2 5      | 249         | 1/4       | 197       |
| 3 5          | Coped at 10p   | 1.72       | 121                                | 767   | 30 50  | 273  | 101                    | 245        | 2 5                          | 257   | 9 7      | 256         | 170       | 090       |
|              | ge celli   | ,          | 1 5                                | 273   | 100  | 284  | 3 5                    | 256        | - 6                          | 268   | 2 2      | 267         | 100       | 270       |
|              |  | ۰ ۳        | 201                                | 305   | 209  | 313  | 190                    | 285        | 198                          | 297   | 198      | 296         | 200       | 309       |
|              |  | 11/4       | 156                                | 234   | 156  | 234  | 146                    | 219        | 146                          | 219   | 156      | 234         | 156       | 234       |
|              |  | 13/8       | 191                                | 241   | 161  | 241  | 151                    | 227        | 151                          | 227   | 161      | 241         | 161       | 241       |
| Sope         | Coped at Both  | 11/2       | 166                                | 249   | 166  | 249  | 156                    | 234        | 156                          | 234   | 166      | 546         | 166       | 249       |
| Ë            | Flanges  | 15/8       | 171                                | 256   | 171  | 256  | 161                    | 241        | 161                          | 241   | 171      | 526         | 171       | 256       |
|              |  | 2          | 181                                | 272   | 185  | 278  | 171                    | 256        | 176                          | 263   | 178      | 267         | 185       | 278       |
|              |  | 8          | 201                                | 301   | 209  | 313  | 190                    | 285        | 198                          | 297   | 198      | 596         | 206       | 309       |
|              | Uncoped  | 37.5       | 234                                | 351   | 234  | 351  | 234                    | 351        | 234                          | 351   | 234      | 351         | 234       | 351       |
| S or         | Support Available<br>Strength per<br>Inch Thickness,<br>kips/in. | e          | Notes:<br>STD =<br>OVS =<br>SSLT = | STD = Standard holes OVS = Oversized holes SSLT = Short-slotted h                       | Standard holes<br>Oversized holes<br>Short-slotted holes<br>to direction of load | Notes:<br>STD = Standard holes<br>OVS = Oversized holes<br>SSLT = Short-slotted holes transverse<br>to direction of load   | sverse                 |            | N = Th<br>X = Th<br>SC = Sli | N = Threads included<br>X = Threads excluded<br>SC = Silp critical  | papnic   |             |           |           |
| Type<br>Type | ASD  | LRFD       | * Tabula                           | ated valu   | les inclu  | de 1/4-in  | . reducti              | on in en   | d distan                     | *Tabulated values include ½-in. reduction in end distance, $\mathcal{L}_{\mathrm{eh}}$ , to account for possible  | o accour | nt for pos  | ssible    | SQE?      |
| SSI T        | 468  | 702        | Note: St<br>been ad                | underrun in beam lengtn.<br>ote: Slip-critical bolt value<br>een added to distribute lo | eam len<br>al bolt va<br>distribute  | underrun in beam lengtn.<br>Note: Slip-critical bolt values assume no mo<br>been added to distribute loads in the fillers. | sume no<br>n the fills | more tt.   | an one                       | underrun in beam lengtin.<br>Note: Silp-critical bolt values assume no more than one filler has been provided or bolts have<br>been added to distribute loads in the fillers. | peen pr  | ovided or   | r bolts h | ave       |

Limiting Strength or Stability States

In addition to resisting shear and tension in bolts and shear in welds, the connected materials may be subjected to shear, bearing, tension, flexure and even prying action. Coping can significantly reduce design strengths and may require web reinforcement. All the following must be considered:

- shear yielding
- shear rupture
- block shear rupture failure of a block at a beam as a result of shear and tension
- tension yielding
- tension rupture
- local web buckling
- lateral torsional buckling



Block Shear Strength (or Rupture):

the ar Strength (or Rupture): 
$$R_a \leq R_n / \Omega \text{ or } R_u \leq \phi R_n$$
 where 
$$R_u = \sum \gamma_i R_i$$
 
$$R_n = 0.6 F_u A_{nv} + U_{bs} F_u A_{nt} \leq 0.6 F_y A_{gv} + U_{bs} F_u A_{nt}$$

where:

 $A_{nv}$  is the net area subjected to shear

 $A_{nt}$  is the net area subjected to tension

 $A_{gv}$  is the gross area subjected to shear

 $U_{bs} = 1.0$  when the tensile stress is uniform (most cases)

= 0.5 when the tensile stress is non-uniform

### **Gusset Plates**

Gusset plates are used for truss member connections where the geometry prevents the members from coming together at the joint "point". Members being joined are typically double angles.

## **Decking**

Shaped, thin sheet-steel panels that span several joists or evenly spaced support behave as continuous beams. Design tables consider a "1 unit" wide strip across the supports and determine maximum bending moment and deflections in order to provide allowable loads depending on the depth of the material.

The other structural use of decking is to construct what is called a *diaphragm*, which is a horizontal unit tying the decking to the joists that resists forces parallel to the surface of the diaphragm.

When decking supports a concrete topping or floor, the steel-concrete construction is called *composite*.

#### Frame Columns

Because joints can rotate in frames, the effective length of the column in a frame is harder to determine. The stiffness (EI/L) of each member in a joint determines how rigid or flexible it is. To find k, the relative stiffness, G or  $\Psi$ , must be found for both ends, plotted on the alignment charts, and connected by a line for braced and unbraced fames.

$$G = \Psi = \frac{\sum \frac{EI}{l_c}}{\sum \frac{EI}{l_b}}$$

where

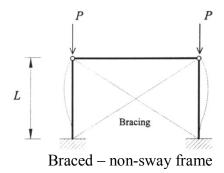
E = modulus of elasticity for a member

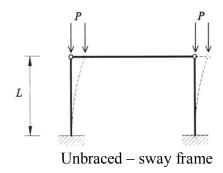
I = moment of inertia of for a member

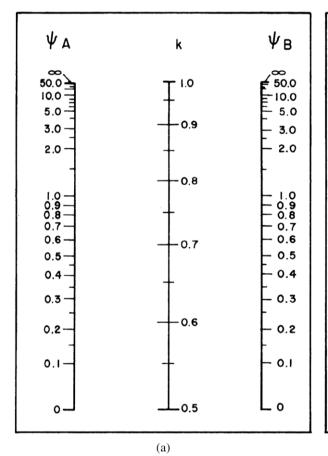
 $l_{\rm c}$  = length of the column from center to center

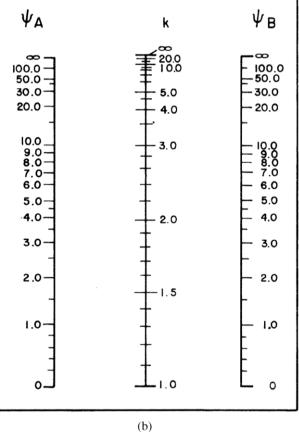
 $l_{\rm b}$  = length of the beam from center to center

- For pinned connections we typically use a value of 10 for  $\Psi$ .
- For fixed connections we typically use a value of 1 for  $\Psi$ .









Nonsway Frames

**Sway Frames** 

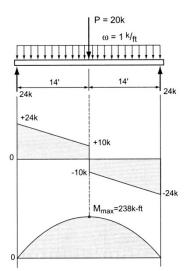
## Example 1 (pg 330)

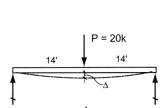
\*Hypothetically determine the size of section required when the deflection criteria is NOT met

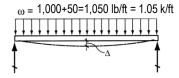
## Example Problem 9.16 (Figures 9.76 to 9.78)

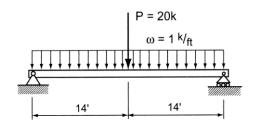
A steel beam (A572/50) is loaded as shown. Assuming a deflection requirement of  $\Delta_{\rm total}$  = L/240 and a depth restriction of 18" nominal, select the most economical section. (unified ASD)

$$F_b = 30 \text{ ksi}$$
;  $F_v = 20 \text{ ksi}$ ;  $E = 30 \times 10^3 \text{ ksi}$   $F_v = 50 \text{ ksi}$ 



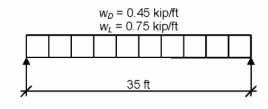






#### Given:

Select an ASTM A992 W-shape beam with a simple span of 35 feet. Limit the member to a maximum nominal depth of 18 in. Limit the live load deflection to L/360. The nominal loads are a uniform dead load of 0.45 kip/ft and a uniform live load of 0.75 kip/ft. Assume the beam is continuously braced. Use ASD of the Unified Design method.



Beam Loading & Bracing Diagram (full lateral support)

#### **Solution:**

#### **Material Properties:**

ASTM A992

 $F_v = 50 \text{ ksi}$ 

 $F_u = 65 \text{ ksi}$ 

- 1. The unbraced length is 0 because it says it is fully braced.
- 2. Find the maximum shear and moment from unfactored loads:

 $w_a = 0.450 \text{ k/ft} + 0.750 \text{ k/ft} = 1.20 \text{ k/ft}$ 

$$V_a = 1.20 \text{ k/ft}(35 \text{ ft})/2 = 21 \text{ k}$$

$$M_a = 1.20 \text{ k/ft}(35 \text{ ft})^2/8 = 184 \text{ k-ft}$$

If  $M_a \le M_n/\Omega$ , the maxmimum moment for design is  $M_a\Omega$ :  $M_{max} = 184$  k-ft

3. Find Zreg'd:

 $Z_{\text{reg'd}} \ge M_{\text{max}}/F_b = M_{\text{max}}/\Omega)/F_v = 184 \text{ k-ft}(1.67)(12 \text{ in/ft})/50 \text{ ksi} = 73.75 \text{ in}^3 (F_v \text{ is the limit stress when fully braced})$ 

4. Choose a trial section, and also limit the depth to 18 in as instructed:

W18 x 40 has a plastic section modulus of 78.4 in<sup>3</sup> and is the most light weight (as indicated by the bold text) in Table 9.1

Include the self weight in the maximum values:

$$w^*_{a-adjusted} = 1.20 \text{ k/ft} + 0.04 \text{ k/ft}$$

$$V_{a-adjusted}^* = 1.24 \text{ k/ft}(35 \text{ ft})/2 = 21.7 \text{ k}$$

$$M^*_{a-adjusted} = 1.24 \text{ k/ft}(35 \text{ ft})^3/8 = 189.9 \text{ k}$$

 $Z_{\text{reg/d}} \ge 189.9 \text{ k-ft} (1.67) (12 \text{ in/ft}) / 50 \text{ ksi} = 76.11 \text{ in}^3$  And the Z we have (78.4) is larger than the Z we need (76.11), so OK.

Evaluate shear (is V<sub>a</sub> ≤ V<sub>0</sub>/Ω): A<sub>w</sub> = dt<sub>w</sub> so look up section properties for W18 x 40: d = 17.90 in and t<sub>w</sub> = 0.315 in

$$V_n/\Omega = 0.6F_{vw}A_w/\Omega = 0.6(50 \text{ ksi})(17.90 \text{ in})(0.315 \text{ in})/1.5 = 112.8 \text{ k which is much larger than } 21.7 \text{ k, so OK}$$
.

9. Evaluate the deflection with respect to the limit stated of L/360 for the live load. (If we knew the **total** load limit we would check that as well). The moment of inertia for the W18 x 40 is needed. I<sub>x</sub> = 612 in<sup>4</sup>

 $\Delta$  live load limit = 35 ft(12 in/ft)/360 = 1.17 in

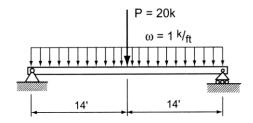
 $\Delta$  = 5wL<sup>4</sup>/384EI = 5(0.75 k/ft)(35 ft)<sup>4</sup>(12 in/ft)<sup>3</sup>/384(29 x 10<sup>3</sup> ksi)(612 in<sup>4</sup>) = 1.42 in! This is TOO BIG (not less than the limit. Find the moment of inertia needed:

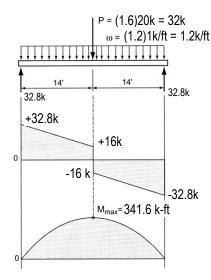
$$I_{req'd} \ge \Delta_{too\ big} (I_{trial})/\Delta_{limit} = 1.42\ in(612\ in^4)/(1.17\ in) = 742.8\ in^4$$

From Table 9.1, a W16 x 45 is larger (by Z), but not the most light weight (efficient), as is W10 x 68, W14 x 53, W18 x 46, (W21 x 44 is too deep) and W18 x 50 is bolded (efficient). (Now look up I's). (In order:  $I_x = 586$ , 394, 541, 712 and 800 in<sup>4</sup>)

### Choose a W18 x 50

For the same beam and loading of Example 1, select the most economical beam using Load and Resistance Factor Design (LRFD) with the 18" depth restriction. Assume the distributed load is dead load, and the point load is live load.  $F_v = 50$  ksi and  $E = 30 \times 10^3$  ksi





- 1. To find  $V_{u\text{-max}}$  and  $M_{u\text{-max}}$ , factor the loads, construct a *new* load diagram, shear diagram and bending moment diagram.
- 2. To satisfy  $M_u \le \phi_b M_{n_i}$  we find  $M_n = \frac{M_u}{\phi_b} = \frac{341.6^{k-ft}}{0.9} = 379.6^{k-ft}$  and solve for Z needed:  $Z = \frac{M_n}{F_v} = \frac{379.6^{k-ft}(12^{in}/f_t)}{50ksi} = 91.1in^3$ 
  - Choose a *trial* section from the <u>Listing of W Shapes in Descending Order of Z</u> by selecting the **bold** section at the top of the grouping satisfying our Z and depth requirement W18 x 50 is the *lightest* with Z = 101 in<sup>3</sup>. (W22 x 44 is the lightest without the depth requirement.) Include the additional self weight (dead load) and find the maximum shear and bending moment:

$$\begin{split} &V_{u-adjusted}^* = 32.8k + \frac{1.2(50\,^{lb}\!/_{fl})28\,ft}{2(1000\,^{lb}\!/_{k})} = 33.64k \\ &M_{u-adjusted}^* = 341.6^{k-fl} + \frac{1.2(50\,^{lb}\!/_{fl})(28\,ft\,)^2}{8(1000\,^{lb}\!/_{k})} = 347.5^{k-fl} \\ &Z_{req'd}^* \geq \frac{M_u}{\phi_b F_v} = \frac{347.5^{k-fl}\,(12\,^{in}\!/_{fl})}{0.9(50ksi)} = 92.7in^3 \,, \, \text{so Z (have) of 101 in}^3 \, \text{is greater than the Z (needed)}. \end{split}$$

- 3. Check the shear capacity to satisfy  $V_u \le \phi_v V_n$ :  $A_{web} = dt_w$  and d=17.99 in.,  $t_w = 0.355$  in. for the W18x50  $\phi_v V_n = \phi_v 0.6 F_{vw} A_w = 1.0(0.6)50 ksi(17.99in)0.355in = 191.6k$  So 33.64k  $\le$  191.6 k OK
- 4. Calculate the deflection from the *unfactored* loads, including the self-weight now because it is known, and satisfy the deflection criteria of Δ<sub>LL</sub>≤Δ<sub>LL-limit</sub> and Δ<sub>total</sub>≤Δ<sub>total-limit</sub>. (This is <u>identical</u> to what is done in Example 1.) I<sub>x</sub> =800 in<sup>3</sup> for the W18x50

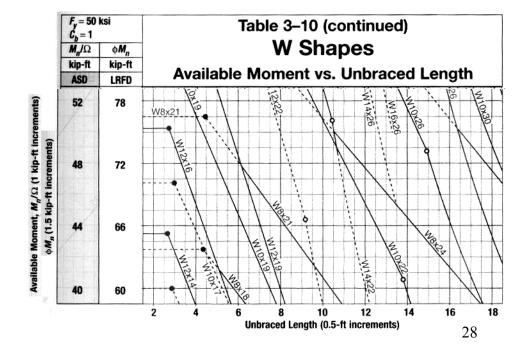
$$\Delta_{\text{total-limit}}$$
 = L/240 = 1.4 in., say  $\Delta_{\text{LL}}$  = L/360 = 0.93 in

$$\Delta_{total} = \frac{PL^3}{48EI} + \frac{5wL^4}{384EI} = \frac{20k(28ft)^3(12^{in}/f_t)^3}{48(30x10^3ksi)800in^4} + \frac{5(1.050^{k/f_t})(28ft)^4(12^{in}/f_t)^3}{384(30x10^3ksi)800in^4} = 0.658 + 0.605 = 1.26in$$

So 1.26 in. ≤ 1.4 in., and 0.658 in. ≤ 0.93 in. <u>OK</u>

.: FINAL SELECTION IS W18x50

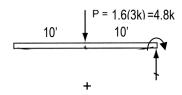
A steel beam with a 20 ft span is designed to be simply supported at the ends on columns and to carry a floor system made with open-web steel joists at 4 ft on center. The joists span 28 feet and frame into the beam from *one side only* and have a self weight of 8.5 lb/ft. Use A992 (grade 50) steel and select the most economical wide-flange section for the beam with LRFD design. Floor loads are 50 psf LL and 14.5 psf DL.



Select a A992 W shape flexural member ( $F_v = 50$  ksi,  $F_u = 65$  ksi) for a beam with distributed loads of 825 lb/ft (dead) and 1300 lb/ft (live) and a live point load at midspan of 3 k using the Available Moment tables. The beam is simply supported, 20 feet long, and braced at the ends and midpoint only ( $L_b = 10$  ft.) The beam is a roof beam for an institution without plaster ceilings. (LRFD)

#### SOLUTION:

To use the Available Moment tables, the maximum moment required is plotted against the unbraced length. The first solid line with capacity or unbraced length above what is needed is the most economical.



w = 1.2(825 lb/ft) + 1.6(1300 lb/ft) = 3.07 k/ft

$$3.07 \frac{1}{2} (20 \text{ ft}) + 4.8 k = 66.2 k$$

DESIGN LOADS (load factors applied on figure):

$$M_{u} = \frac{wl^{2}}{2} + Pb = \frac{3.07 \frac{k}{ft} (20 ft)^{2}}{2} + 4.8k(10 ft) = 662^{k-ft} \quad V_{u} = wl + P = 3.07 \frac{k}{ft} (20 ft) + 4.8k = 66.2k$$

Plotting 662 k-ft vs. 10 ft lands just on the capacity of the W21x83, but it is dashed (and not the most economical) AND we need to consider the contribution of self weight to the total moment. Choose a trial section of W24 x 76. Include the new dead load:

$$M_{u-adjusted}^* = 662^{k-ft} + \frac{1.2(76^{\frac{10}{ft}})(20ft)^2}{2(1000^{\frac{10}{k}})} 680.2^{k-ft} \qquad V_{u-adjusted}^* = 66.2k + 1.2(0.076^{\frac{k}{ft}})(20ft) = 68.0k$$

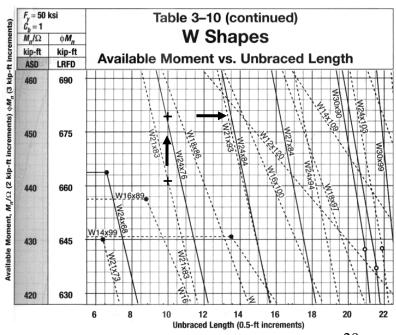
Replot 680.2 k-ft vs. 10ft, which lands above the capacity of the W21x83. We can't look up because the chart ends, but we can look for that capacity with a longer unbraced length. This leads us to a W24 x 84 as the most economical. (With the additional self weight of 84 - 76 lb/ft = 8 lb/ft, the increase in the factored moment is only 1.92 k-ft; therefore, it is still OK.)

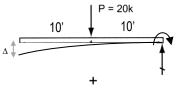
Evaluate the shear capacity:

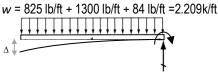
$$\phi_v V_n = \phi_v 0.6 F_{vw} A_w = 1.0(0.6)50 ksi(24.10in)0.47in = 338.4k$$
 so yes, 68 k  $\leq$  338.4k OK

Evaluate the deflection with respect to the limits of L/240 for live (unfactored) load and L/180 for total (unfactored) load: L/240 = 1 in. and L/180 = 1.33 in.

$$\Delta_{total} = \frac{Pb^2(3l-b)}{6EI} + \frac{wL^4}{24EI} = \frac{3k(10ft)^2(3\cdot20-10ft)(12\frac{iv}{ft})^3}{6(30x10^3ksi)2370in^4} + \frac{(2.209\frac{k/ft}{ft})(20ft)^4(12\frac{iv}{ft})^3}{24(30x10^3ksi)2370in^4} = 0.06 + 0.36 = 0.42in$$







So.  $\Delta LL \leq \Delta LL$ -limit and  $\Delta total \leq \Delta total$ -limit:

 $0.06 \text{ in.} \le 1 \text{ in.}$  and  $0.42 \text{ in.} \le 1.33 \text{ in.}$ 

(This section is so big to accommodate the large bending moment at the cantilever support that it deflects very little.)

.: FINAL SELECTION IS W24x84

Select the most economical joist for the 40 ft grid structure with floors and a flat roof. The roof loads are 10 lb/ft² dead load and 20 lb/ft² live load. The floor loads are 30 lb/ft² dead load 100 lb/ft² live load. (Live load deflection limit for the roof is L/240, while the floor is L/360). Use the (LRFD) K and LH series charts provided.

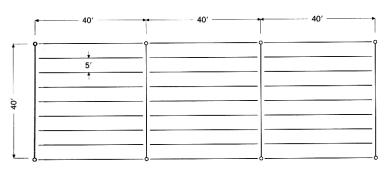


Figure 7.218 Framing plan for joists, girders, and columns on 40 ft  $\times$  40 ft grid.

(Top values are maximum total factored load in lb/ft, while the lower (lighter) values are maximum (unfactored) live load for a deflection of L/360)

|   |      |            | Ва         | sed or   |               |            |            |           |            |            |            |            |            | TS, K-S    |            |            | (plf)      |            |            |            |            |
|---|------|------------|------------|----------|---------------|------------|------------|-----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Joist<br>Designation                    | 18K3 | 18K4       | 18K5       | 18K6     | 18K7          | 18K9       | 18K10      | 20K3      | 20K4       | 20K5       | 20K6       | 20K7       | 20K9       | 20K10      | 22K4       | 22K5       | 22K6       | 22K7       | 22K9       | 22K10      | 22K11      |
| Depth (In.)                             | 18   | 18         | 18         | 18       | 18            | 18         | 18         | 20        | 20         | 20         | 20         | 20         | 20         | 20         | 22         | 22         | 22         | 22         | 22         | 22         | 22         |
| Approx. Wt.<br>(lbs./ft.)               | 6.6  | 7.2        | 7.7        | 8.5      | 9             | 10.2       | 11.7       | 6.7       | 7.6        | 8.2        | 8.9        | 9.3        | 10.8       | 12.2       | 8          | 8.8        | 9.2        | 9.7        | 11.3       | 12.6       | 13.8       |
| Span (ft.)<br>↓                         |      |            |            |          |               |            |            |           |            |            |            |            |            |            |            |            |            |            |            |            |            |
| 38                                      |      |            |            |          |               |            |            | 211<br>74 | 255<br>87  | 286<br>98  | 312<br>106 | 348<br>118 | 418<br>139 | 496<br>164 | 280<br>107 | 316<br>119 | 345<br>130 | 384<br>144 | 462<br>170 | 549<br>200 | 628<br>228 |
| 39                                      |      |            |            |          |               |            |            | 199<br>69 | 241        | 271<br>90  | 297<br>98  | 330<br>109 | 397<br>129 | 471<br>151 | 267<br>98  | 300        | 327<br>120 | 364<br>133 | 438<br>157 | 520<br>185 | 595<br>211 |
| 40                                      |      |            |            |          |               |            |            | 190       | 229        | 258<br>84  | 282<br>91  | 313        | 376        | 447        | 253        | 285        | 310        | 346<br>123 | 417        | 495        | 565        |
| 41                                      |      |            |            |          |               |            |            | 64        | 75         | 84         | 91         | 101        | 119        | 140        | 91<br>241  | 102<br>271 | 111<br>295 | 330        | 146<br>396 | 171<br>471 | 195<br>538 |
|   |      |            |            |          |               |            |            |           |            |            |            |            |            |            | 85         | 95         | 103        | 114        | 135        | 159        | 181        |
| Joist<br>Designation                    | 2    | 4K4        | 24K5       | 24       | <b>&lt;</b> 6 | 24K7       | 24K8       | 24        | (9         | 24K10      | 24K1       | 2   ;      | 26K5       | 26K6       | 26K        | 7 2        | 26K8       | 26K9       | 26         | K10        | 26K12      |
| Depth (In.)                             |      | 24         | 24         | 2        | 4             | 24         | 24         | 24        | 4          | 24         | 24         |            | 26         | 26         | 26         |            | 26         | 26         | 2          | 26         | 26         |
| Approx. Wt.<br>(lbs./ft.)               |      | 8.4        | 9.3        | 9.       | 7             | 10.1       | 11.5       | 12        | .0         | 13.1       | 16.0       |            | 9.8        | 10.6       | 10.9       | 9          | 12.1       | 12.2       | 10         | 3.8        | 16.6       |
| Span (ft.)                              |      |            |            |          |               |            |            |           |            |            |            |            |            |            |            |            |            |            |            |            |            |
| 38                                      |      | 307<br>128 | 346<br>143 | 37<br>15 | -             | 421<br>172 | 465<br>189 | 50<br>20  |            | 601<br>240 | 691<br>275 |            | 376<br>169 | 411<br>184 | 457<br>204 |            | 505<br>223 | 550<br>241 | _          | 54<br>84   | 691<br>299 |
| 39                                      |      | 292        | 328<br>132 | 35       |               | 399<br>159 | 441<br>174 | 48<br>18  | -          | 570<br>222 | 673<br>261 |            | 357<br>156 | 390<br>170 | 433        |            | 480<br>206 | 522<br>223 |            | 19<br>62   | 673<br>283 |
| 40                                      | 2    | 277        | 312<br>122 | 34       | 10            | 379<br>148 | 420<br>161 | 45<br>17  | 6          | 541<br>206 | 657<br>247 |            | 340<br>145 | 370<br>157 | 412        | 2          | 456<br>191 | 496<br>207 | 5          | 89<br>43   | 657<br>269 |
| 41                                      | 2    | 264        | 297        | 32       | 4             | 361<br>137 | 399<br>150 | 43        | 5          | 516<br>191 | 640<br>235 |            | 322<br>134 | 352<br>146 | 393        | 3          | 433<br>177 | 472<br>192 | 5          | 61<br>25   | 640<br>256 |
|   |      |            |            | 12       |               |            |            | 10        |            |            |            |            |            |            | .02        |            |            | 102        |            |            |            |
| Joist<br>Designation                    |      | 28K6       |            | BK7      | 28            |            | 28K9       |           | K10        | 28K        |            | 30K        |            | 30K8       |            | K9         | 30K        |            | 30K11      | 3          | 0K12       |
| Depth (In.)<br>Approx. Wt<br>(lbs./ft.) |      | 28<br>11.4 |            | 1.8      | 12            |            | 28<br>13.0 |           | 28<br>4.3  | 17         |            | 12.        |            | 30<br>13.2 |            | 3.4        | 30<br>15.  |            | 30<br>16.4 |            | 30<br>17.6 |
| Span (ft.)                              |      |            |            |          |               |            |            |           |            |            |            |            |            |            |            |            |            |            |            |            |            |
| 38                                      |      | 444<br>214 | 2          | 93<br>37 | 54<br>26      | 0          | 594<br>282 | 3         | 91<br>825  | 69<br>32   | 5          | 531<br>274 | 1          | 586<br>300 | 3          | 39<br>25   | 691<br>353 | 3          | 691<br>353 |            | 691<br>353 |
| 39                                      |      | 420<br>198 | 2          | 69<br>19 | 51<br>24      | 0          | 564<br>260 | 3         | 370<br>306 | 67<br>30   | 8          | 504<br>253 | 3          | 556<br>277 | 30         | 06<br>00   | 673<br>333 | 3          | 673<br>333 |            | 673<br>333 |
| 40                                      |      | 399<br>183 | 2          | 45<br>03 | 49<br>22      | 2          | 535<br>241 | 2         | 36<br>84   | 65<br>29   | 1          | 478<br>234 | 1          | 529<br>256 | 2          | 76<br>78   | 657<br>315 | 5          | 657<br>315 |            | 657<br>315 |
| 41                                      |      | 379<br>170 |            | 24<br>89 | 46<br>20      |            | 510<br>224 |           | 606<br>263 | 64<br>27   |            | 454<br>217 |            | 502<br>238 |            | 47<br>58   | 640<br>300 |            | 640<br>300 |            | 640<br>300 |

# Example 6 (continued)

(Top values are maximum total factored load in lb/ft, while the lower (lighter) values are maximum (unfactored) live load for a deflection of L/360)

| loiet                | Approx. Wt               | Depth         | SAFE LOAD*         |                  |                  |             |             |                  |             | CLE              | AR SP            | ANI IN E         | EET              |             |             |            |                  |            |    |
|----------------------|--------------------------|---------------|--------------------|------------------|------------------|-------------|-------------|------------------|-------------|------------------|------------------|------------------|------------------|-------------|-------------|------------|------------------|------------|----|
| Joist<br>Designation | in Lbs. Per<br>Linear Ft | in<br>inches  | in Lbs.<br>Between |                  |                  |             |             |                  |             | CLE              | AH SP/           | AN IN F          | EEI              |             |             |            |                  |            |    |
| Designation          | (Joists only)            |               | 22-24              | 25               | 26               | 27          | 28          | 29               | 30          | 31               | 32               | 33               | 34               | 35          | 36          | 37         | 38               | 39         | 4  |
| 20LH02               | 10                       | 20            | 16950              | 663              | 655              | 646         | 615         | 582              | 547         | 516              | 487              | 460              | 436              | 412         | 393         | 373        | 355              | 337        | 3  |
|                      |                          |               |                    | 306              | 303              | 298         | 274         | 250              | 228         | 208              | 190              | 174              | 160              | 147         | 136         | 126        | 117              | 108        | 10 |
| 20LH03               | 11                       | 20            | 18000              | 703              | 694              | 687         | 678         | 651              | 621         | 592              | 558              | 528              | 499              | 474         | 448         | 424        | 403              | 382        | 3  |
|                      |                          |               |                    | 337              | 333              | 317         | 302         | 280              | 258         | 238              | 218              | 200              | 184              | 169         | 156         | 143        | 133              | 123        | 1  |
| 20LH04               | 12                       | 20            | 22050              | 861              | 849              | 837         | 792         | 744              | 700         | 660              | 624              | 589              | 558              | 529         | 502         | 477        | 454              | 433        | 4  |
|                      |                          |               |                    | 428              | 406              | 386         | 352         | 320              | 291         | 265              | 243              | 223              | 205              | 189         | 174         | 161        | 149              | 139        | 12 |
| 20LH05               | 14                       | 20            | 23700              | 924              | 913              | 903         | 892         | 856              | 816         | 769              | 726              | 687              | 651              | 616         | 585         | 556        | 529              | 504        | 48 |
| 0011100              |                          |               |                    | 459              | 437              | 416         | 395         | 366              | 337         | 308              | 281              | 258              | 238              | 219         | 202         | 187        | 173              | 161        | 15 |
| 20LH06               | 15                       | 20            | 31650              | 1233             | 1186             | 1144        | 1084        | 1018             | 952         | 894              | 840              | 790              | 745              | 703         | 666         | 631        | 598              | 568        | 54 |
| 0011107              | 47                       | 00            | 00750              | 606              | 561              | 521         | 477         | 427              | 386         | 351              | 320              | 292              | 267              | 246         | 226         | 209        | 192              | 178        | 16 |
| 20LH07               | 17                       | 20            | 33750              | 1317             | 1267             | 1221        | 1179        | 1140             | 1066        | 1000             | 940              | 885              | 834              | 789         | 745         | 706        | 670              | 637        | 60 |
| 20LH08               | 19                       | 20            | 34800              | 647<br>1362      | 599<br>1309      | 556<br>1263 | 518<br>1219 | 484<br>1177      | 438<br>1140 | 398<br>1083      | 362<br>1030      | 331<br>981       | 303<br>931       | 278<br>882  | 256<br>837  | 236<br>795 | 218<br>754       | 202<br>718 | 6  |
| ZULTUO               | 19                       | 20            | 34600              | 669              | 619              | 575         | 536         | 500              | 468         | 428              | 395              | 365              | 336              | 309         | 285         | 262        | 242              | 225        | 20 |
| 20LH09               | 21                       | 20            | 38100              | 1485             | 1429             | 1377        | 1329        | 1284             | 1242        | 1203             | 1167             | 1132             | 1068             | 1009        | 954         | 904        | 858              | 816        | 7  |
| LOLITOS              |                          | 20            | 1                  | 729              | 675              | 626         | 581         | 542              | 507         | 475              | 437              | 399              | 366              | 336         | 309         | 285        | 264              | 244        | 22 |
| 20LH10               | 23                       | 20            | 41100              | 1602             | 1542             | 1486        | 1434        | 1386             | 1341        | 1297             | 1258             | 1221             | 1186             | 1122        | 1060        | 1005       | 954              | 906        | 86 |
|                      |                          |               |                    | 786              | 724              | 673         | 626         | 585              | 545         | 510              | 479              | 448              | 411              | 377         | 346         | 320        | 296              | 274        | 2  |
|                      |                          |               |                    | 33               | 34               | 35          | 36          | 37               | 38          | 39               | 40               | 41               | 42               | 43          | 44          | 45         | 46               | 47         | -  |
| 24LH03               | 11                       | 24            | 17250              | 513              | 508              | 504         | 484         | 460              | 439         | 418              | 400              | 382              | 366              | 351         | 336         | 322        | 310              | 298        | 2  |
|                      |                          |               |                    | 235              | 226              | 218         | 204         | 188              | 175         | 162              | 152              | 141              | 132              | 124         | 116         | 109        | 102              | 96         | (  |
| 24LH04               | 12                       | 24            | 21150              | 628              | 597              | 568         | 540         | 514              | 490         | 468              | 447              | 427              | 409              | 393         | 376         | 361        | 346              | 333        | 3  |
| 0.41 1.105           | 10                       | 24            | 00050              | 288              | 265              | 246         | 227         | 210              | 195         | 182              | 169              | 158              | 148              | 138         | 130         | 122        | 114              | 107<br>387 | 1  |
| 24LH05               | 13                       | 24            | 22650              | 673<br>308       | 669<br>297       | 660<br>285  | 628<br>264  | 598<br>244       | 570<br>226  | 544<br>210       | 520<br>196       | 496<br>182       | 475<br>171       | 456<br>160  | 436<br>150  | 420<br>141 | 403<br>132       | 124        | 1  |
| 24LH06               | 16                       | 24            | 30450              | 906              | 868              | 832         | 795         | 756              | 720         | 685              | 655              | 625              | 598              | 571         | 546         | 522        | 501              | 480        | 4  |
| 2-121100             |                          |               | 00100              | 411              | 382              | 356         | 331         | 306              | 284         | 263              | 245              | 228              | 211              | 197         | 184         | 172        | 161              | 152        | 1  |
| 24LH07               | 17                       | 24            | 33450              | 997              | 957              | 919         | 882         | 847              | 811         | 774              | 736              | 702              | 669              | 639         | 610         | 583        | 559              | 535        | 5  |
|                      |                          |               |                    | 452              | 421              | 393         | 367         | 343              | 320         | 297              | 276              | 257              | 239              | 223         | 208         | 195        | 182              | 171        | 1  |
| 24LH08               | 18                       | 24            | 35700              | 1060             | 1015             | 973         | 933         | 895              | 858         | 817              | 780              | 745              | 712              | 682         | 652         | 625        | 600              | 576        | 5  |
| 24LH09               | 21                       | 24            | 42000              | 480<br>1248      | 447<br>1212      | 416<br>1177 | 388<br>1146 | 362<br>1096      | 338<br>1044 | 314<br>994       | 292<br>948       | 272<br>903       | 254<br>861       | 238<br>822  | 222<br>786  | 208<br>751 | 196<br>720       | 184<br>690 | 6  |
| 24LI109              | 21                       | -4            | 42000              | 562              | 530              | 501         | 460         | 424              | 393         | 363              | 337              | 313              | 292              | 272         | 254         | 238        | 223              | 209        | 1  |
| 24LH10               | 23                       | 24            | 44400              | 1323             | 1284             | 1248        | 1213        | 1182             | 1152        | 1105             | 1053             | 1002             | 955              | 912         | 873         | 834        | 799              | 766        | 7  |
|                      |                          |               |                    | 596              | 559              | 528         | 500         | 474              | 439         | 406              | 378              | 351              | 326              | 304         | 285         | 266        | 249              | 234        | 2  |
| 24LH11               | 25                       | 24            | 46800              | 1390             | 1350             | 1312        | 1276        | 1243             | 1210        | 1180             | 1152             | 1101             | 1051             | 1006        | 963         | 924        | 885              | 850        | 8  |
|                      |                          | $\rightarrow$ |                    | 624              | 588              | 555         | 525         | 498              | 472         | 449              | 418              | 388              | 361              | 337         | 315         | 294        | 276              | 259        | 2  |
| 28LH05               | 10                       | 28            | 33-40              | <b>41</b><br>505 | <b>42</b><br>484 | 43          | 44<br>445   | <b>45</b><br>429 | 46<br>412   | <b>47</b><br>397 | <b>48</b><br>382 | <b>49</b><br>367 | <b>50</b><br>355 | <b>51</b>   | <b>52</b>   | <b>53</b>  | <b>54</b><br>309 | <b>55</b>  |    |
| 20LHU5               | 13                       | 20            | 21000              | 219              | 205              | 465<br>192  | 180         | 169              | 159         | 150              | 142              | 133              | 126              | 119         | 113         | 107        | 102              | 97         | 2  |
| 28LH06               | 16                       | 28            | 27900              | 672              | 643              | 618         | 592         | 568              | 546         | 525              | 505              | 486              | 469              | 451         | 436         | 421        | 406              | 393        | 3  |
|                      |                          |               |                    | 289              | 270              | 253         | 238         | 223              | 209         | 197              | 186              | 175              | 166              | 156         | 148         | 140        | 133              | 126        | 1  |
| 28LH07               | 17                       | 28            | 31500              | 757              | 726              | 696         | 667         | 640              | 615         | 591              | 568              | 547              | 528              | 508         | 490         | 474        | 457              | 442        | 4  |
| 0011100              | - 10                     |               | 00750              | 326              | 305              | 285         | 267         | 251              | 236         | 222              | 209              | 197              | 186              | 176         | 166         | 158        | 150              | 142        | 1  |
| 28LH08               | 18                       | 28            | 33750              | 810              | 775<br>325       | 744<br>305  | 712<br>285  | 684<br>268       | 657<br>252  | 630<br>236       | 604<br>222       | 580              | 556              | 535         | 516         | 496<br>165 | 478              | 462<br>148 | 4  |
| 28LH09               | 21                       | 28            | 41550              | 348<br>1000      | 958              | 918         | 879         | 844              | 810         | 778              | 748              | 209<br>721       | 196<br>694       | 185<br>669  | 175<br>645  | 622        | 156<br>601       | 580        | 5  |
| 2011103              | -1                       | 20            | 41000              | 428              | 400              | 375         | 351         | 329              | 309         | 291              | 274              | 258              | 243              | 228         | 216         | 204        | 193              | 183        | 1  |
| 28LH10               | 23                       | 28            | 45450              | 1093             | 1056             | 1018        | 976         | 937              | 900         | 864              | 831              | 799              | 769              | 742         | 715         | 690        | 666              | 643        | 6  |
|                      |                          |               |                    | 466              | 439              | 414         | 388         | 364              | 342         | 322              | 303              | 285              | 269              | 255         | 241         | 228        | 215              | 204        | 1  |
| 28LH11               | 25                       | 28            | 48750              | 1170             | 1143             | 1104        | 1066        | 1023             | 982         | 943              | 907              | 873              | 841              | 810         | 781         | 753        | 727              | 702        | 6  |
|                      |                          |               |                    | 498              | 475              | 448         | 423         | 397              | 373         | 351              | 331              | 312              | 294              | 278         | 263         | 249        | 236              | 223        | 2  |
| 28LH12               | 27                       | 28            | 53550              | 1285             | 1255             | 1227        | 1200        | 1173             | 1149<br>435 | 1105<br>408      | 1063<br>383      | 1023             | 984              | 948         | 913         | 880<br>285 | 849              | 819        | 7  |
| 28LH13               | 30                       | 28            | 55800              | 545<br>1342      | 520<br>1311      | 496<br>1281 | 476<br>1252 | 454<br>1224      | 1198        | 1173             | 1149             | 361<br>1126      | 340<br>1083      | 321<br>1041 | 303<br>1002 | 964        | 270<br>930       | 256<br>897 | 8  |
| ZOLITIO              | 55                       | 20            | 55500              | 569              | 543              | 518         | 495         | 472              | 452         | 433              | 415              | 396              | 373              | 352         | 332         | 314        | 297              | 281        | 2  |

#### Example 7 (LRFD)

## EXAMPLE 5.1 Open-Web Steel Joist Design

A fully exposed roof system for a commercial building, spanning 35 ft, located in Muncie, Indiana, in an urban environment.

IBC specifies a **20 psf snow live load** for Muncie, Indiana, home of Ball State University. Table 1.3 indicates the snow exposure factor:  $C_e = 0.9$ . Table 1.4 indicates the snow thermal factor:  $C_t = 1.0$ . Table 1.7 indicates an occupancy importance factor (for Category II):  $I_S = 1.0$ . Fig. 1.2 indicates the ground snow load:  $p_q = 20$  psf

$$P_S = 0.7(0.9)1.0(1.0)20 \text{ psf} = 13.9 \text{ psf}$$

### A typical roof construction might consist of:

Membrane roofing 1.0 psf 4 in. average tapered rigid insulation 6.0 psf Steel deck (2–4 ft span) 1.0 psf

Estimated joist weight:

35 ft span would be a minimum 18 in. joist An average 18 in. joist weight = 9.0 plf

Spaced @ 4 ft-0 in. o.c. 9.0 plf/4 ft 2.3 psf Ceiling suspension system 1.0 psf  $1_2$  in. gypsum ceiling 2.0 psf

Mechanical system estimates should also be included; the heavy sprinkler/drain piping running parallel to a joist or pair of joists is especially critical.

Miscellaneous ductwork/electrical 1.0 psf

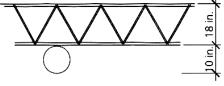
Total dead load 14.3 psf  $\times$  4 ft o.c. = 57.2 plf Total live load 13.9 psf  $\times$  4 ft o.c. = 55.6 plf

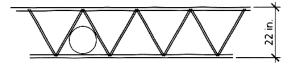
Total factored live snow load + dead load = 1.2(55.6) + 1.6(57.2) = 158.2 plf

Use joist load tables to select the best section:

At 35 ft, 18K3 joists carry 237 plf TFL and 84 plf LL LL: deflection controls and the weight is 6.4 plf.

At least on the surface, this is the best choice, but depending upon the need to integrate mechanical systems into the joist space, a 20K3 at 6.5 plf or even a 22K4 at 7.3 plf which is both deeper and heavier than the previous selection may be best:

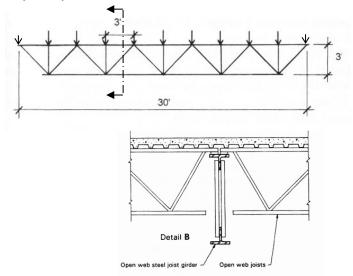




#### LRFD

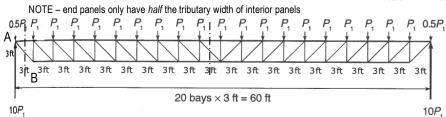
|                           |      | Е    | Based |      |      |      | LOAD 1<br>imum \ |      |      |      |      |      |      |       |      |      | oot (p | lf)  |      |       |       |
|---------------------------|------|------|-------|------|------|------|------------------|------|------|------|------|------|------|-------|------|------|--------|------|------|-------|-------|
| Joist<br>Designation      | 18K3 | 18K4 | 18K5  | 18K6 | 18K7 | 18K9 | 18K10            | 20K3 | 20K4 | 20K5 | 20K6 | 20K7 | 20K9 | 20K10 | 22K4 | 22K5 | 22K6   | 22K7 | 22K9 | 22K10 | 22K11 |
| Depth (In.)               | 18   | 18   | 18    | 18   | 18   | 18   | 18               | 20   | 20   | 20   | 20   | 20   | 20   | 20    | 22   | 22   | 22     | 22   | 22   | 22    | 22    |
| Approx. Wt.<br>(lbs./ft.) | 6.4  | 7.2  | 7.7   | 8.4  | 8.9  | 10.1 | 11.6             | 6.5  | 7.2  | 7.7  | 8.4  | 8.9  | 10.1 | 11.6  | 7.3  | 7.7  | 8.5    | 9.0  | 10.2 | 11.7  | 11.9  |
| Span (ft.)<br>↓           |      |      |       |      |      |      |                  |      |      |      |      |      |      |       |      |      |        |      |      |       |       |
| 34                        | 237  | 285  | 321   | 349  | 390  | 468  | 555              | 264  | 318  | 358  | 391  | 435  | 523  | 621   | 352  | 397  | 432    | 481  | 579  | 687   | 774   |
|                           | 84   | 98   | 110   | 120  | 132  | 156  | 184              | 105  | 122  | 137  | 149  | 165  | 195  | 229   | 149  | 167  | 182    | 202  | 239  | 280   | 314   |
| 35                        | 223  | 268  | 303   | 330  | 367  | 441  | 523              | 249  | 300  | 339  | 369  | 411  | 493  | 585   | 331  | 373  | 408    | 454  | 546  | 648   | 741   |
|                           | 77   | 90   | 101   | 110  | 121  | 143  | 168              | 96   | 112  | 126  | 137  | 151  | 179  | 210   | 137  | 153  | 167    | 185  | 219  | 257   | 292   |

A floor with multiple bays is to be supported by open-web steel joists spaced at 3 ft. on center and spanning 30 ft. having a dead load of  $70 \text{ lb/ft}^2$  and a live load of  $100 \text{ lb/ft}^2$ . The joists are supported on joist girders spanning 30 ft. with 3 ft.-long panel points (shown). Determine the member forces at the location shown in a horizontal chord and the maximum force in a web member for an interior girder. Use factored loads. Assume a self weight for the openweb joists of 12 lb/ft, and the self weight for the joist girder of 35 lb/ft.



A floor is to be supported by trusses spaced at 5 ft. on center and spanning 60 ft. having a dead load of 53 lb/ft<sup>2</sup> and a live load of 100 lb/ft<sup>2</sup>. With 3 ft.-long panel points, the depth is assumed to be 3 ft with a span-to-depth ratio of 20. With 6 ft.-long panel points, the depth is assumed to be 6 ft with a span-to-depth ratio of 10. Determine the maximum force in a horizontal chord and the maximum force in a web member. Use factored loads. Assume a self weight of 40 lb/ft.

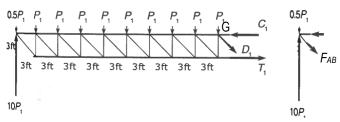
|              |                      |               |          |                      | tributary       | widths /         | Floor       |   |   |                                 |                                 | Factored   |
|--------------|----------------------|---------------|----------|----------------------|-----------------|------------------|-------------|---|---|---------------------------------|---------------------------------|--|
|              |                      | <u>area</u>   | loads    |                      | Node-<br>to-    | Truss-<br>to-    | Area<br>per | D   | D   | Factored<br>Dead                | Factored<br>Live                | Total<br>Load  |
|              |                      | <b>W</b> dead | w        | live                 | Node<br>Spacing | Truss<br>Spacing | Node<br>A   | $P_{\text{dead}}$<br>(= $W_{\text{dead}} \cdot A$ ) | $P_{\text{live}}$<br>(= $w_{\text{live}} \cdot A$ ) | Load<br>1.2 · P <sub>dead</sub> | Load<br>1.6 • P <sub>live</sub> | 1.2 • P <sub>dead</sub> +<br>1.6 • P <sub>live</sub> |
| Truss        | (#/ft <sup>2</sup> ) | (K/ft²)       | (#/ft²)  | (K/ft <sup>2</sup> ) | (ft)            | (ft)             | (ft²)       | (K)   | (K)   | (K)                             | (K)                             | (K)  |
| 3 ft<br>deep | 53                   | 0.053         | 100      | 0.100                | 3               | 5                | 15          | 0.795   | 1.50  | 0.954                           | 2.40                            | 3.35 + 0.14 = 3.49                                   |
| 6 ft<br>deep | 53                   | 0.053         | 100      | 0.100                | 6               | 5                | 30          | 1.59  | 3.00  | 1.908                           | 4.80                            | 6.71 + 0.29 = 7.00                                   |
| self w       | eight                | 0.04 k/ft     | (distrib | uted)                | 3               |                  |             | 1.2P <sub>dead</sub> =                              | 1.2w <sub>dead</sub> · tri                          | butary widti                    | h = 0.14 K                      |  |



FBD 3: Maximum web force will be in the end diagonal (just like maximum shear in a beam)

$$\Sigma F_y = 10P_1 - 0.5P_1 - F_{AB} \cdot \sin 45^\circ = 0$$
  
 $F_{AB} = 9.5P_1 / \sin 45^\circ = 9.5(3.49 \text{ k}) / 0.707 = 46.9 \text{ k}$ 

FBD 1 for 3 ft deep truss



FBD 2 of cut just to the left of midspan

FBD 3 of cut just to right of left support

FBD 2: Maximum chord force (top or bottom) will be at midspan

$$\Sigma M_G = -9.5 P_1(27^{\hat{n}}) + P_1(24^{\hat{n}}) + P_1(21^{\hat{n}}) + P_1(18^{\hat{n}}) + P_1(15^{\hat{n}})$$

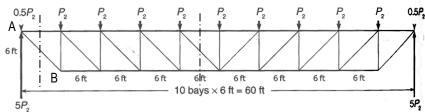
$$+ P_1(12^{\hat{n}}) + P_1(9^{\hat{n}}) + P_1(6^{\hat{n}}) + P_1(3^{\hat{n}}) + T_1(3^{\hat{n}}) = 0$$

$$T_1 = P_1(148.5^{\hat{n}})/3^{\hat{n}} = (3.49 \text{ k})(49.5) = 172.8 \text{ k}$$

$$\Sigma F_y = 10P_1 - 9.5P_1 - D_1 \cdot \sin 45^\circ = 0$$

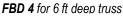
 $D_1 = 0.5(3.49 \text{ k})/0.707 = 2.5 \text{ k}$  (minimum near midspan)

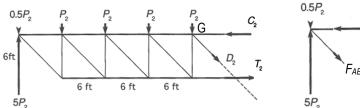
$$\Sigma F_x = -C_1 + T_1 + D_1 \cdot \cos 45^\circ = 0$$



FBD 6: Maximum web force will be in the end diagonal

$$\Sigma F_y = 5P_2 - 0.5P_2 - F_{AB} \cdot \sin 45^\circ = 0$$
  
 $F_{AB} = 4.5P_2 / \sin 45^\circ = 4.5(7 \text{ k}) / 0.707 = 44.5 \text{ k}$ 





FBD 5 of cut just to the left of midspan



of left support

FBD 5: Maximum chord (top or bottom) force will be at midspan

$$\Sigma M_G = -4.5P_2(24^{ft}) + P_2(18^{ft}) + P_2(12^{ft}) + P_2(6^{ft}) + T_2(6^{ft}) = 0$$

$$T_2 = P_2(72^{ft})/6^{ft} = (7 \text{ k})(12) = 84 \text{ k}$$

$$\Sigma F_{v} = 5P_{2} - 4.5P_{1} - D_{s} \cdot \sin 45^{\circ} = 0$$

 $D_2 = 0.5(7 \text{ k})/0.707 = 4.9 \text{ k}$  (minimum near midspan)

**FBD 6** of cut just to right 
$$\Sigma F_x = -C_2 + T_2 + D_2 \cdot \cos 45^\circ = 0$$

 $C_2 = 87.5 k$ 

## Example 10 (pg 367) + LRFD Example Problem 10.10 (Figure 10.41)

A 24-ft.-tall, A572 grade 50, steel column (W14×82) with an  $F_y$  = 50 ksi has pins at both ends. Its weak axis is braced at midheight, but the column is free to buckle the full 24 ft. in the strong direction. Determine the safe load capacity for this column. using ASD and LRFD.

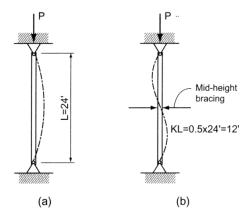
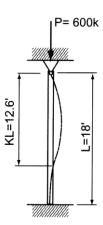


Figure 10.41 (a) Strong axis buckling. (b) Weak axis buckling.

## Example 11 (pg 371) + chart method Example Problem 10.14: Design of Steel Columns (Figure 10.48)

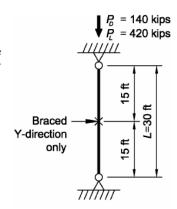
Select the most economical W12  $\times$  column 18' in height to support an axial load of 600 kips using A572 grade 50 steel. Assume that the column is hinged at the top but fixed at the base. Use LRFD assuming that the load is a dead load (factor of 1.4)

**ALSO**: Select the W12 column using the Available Strength charts.



#### Given:

Redesign the column from Example E.1a assuming the column is laterally braced about the y-y axis and torsionally braced at the midpoint. Use both ASD and LRFD.  $F_y = 50 \text{ ksi.}$  (Not using Available Strength charts)



#### **Solution:**

#### ASD:

- 1.  $P_a = 140 k + 420 k = 560 k$
- 2. The effective length in the weak (y-y) axis is 15 ft, while the effective length in the strong (x-x) axis is 30 ft. (K = 1, KL = 1×30 ft). To find kL/ $r_x$  and kL/ $r_y$  we can assume or choose values from the wide flange charts.  $r_y$ 's range from 1 to 3 in., while  $r_x$ 's range from 3 to 14 inches. Let's try  $r_y$  = 2 in and  $r_x$  = 9 in. (something in the W21 range, say.)

kL/r<sub>y</sub> 
$$\cong$$
 15 ft(12 in/ft)/2 in. = 90  $\leftarrow$  GOVERNS (is larger)

$$kL/r_x \cong 30 \text{ ft}(12 \text{ in/ft})/9 \text{ in.} = 40$$

3. Find a section with sufficient area (which then will give us "real" values for r<sub>x</sub> and r<sub>y</sub>):

If 
$$P_a \le P_n/\Omega$$
, and  $P_n = F_{cr} A$ , we can find  $A \ge P_a \Omega/F_{cr}$  with  $\Omega = 1.67$ 

The tables provided have  $\phi F_{cr}$ , so we can get  $F_{cr}$  by dividing by  $\phi = 0.9$ 

$$\phi F_{cr}$$
 for 90 is 24.9 ksi,  $F_{cr} = 24.9 \text{ ksi}/0.9 = 27.67 \text{ ksi}$  so  $A \ge 560 \text{ k}(1.67)/27.67 \text{ ksi} = 33.8 \text{ in}^2$ 

4. Choose a trial section, and find the effective lengths and associated available strength, F<sub>cr</sub>:

Looking from the smallest sections, the W14's are the first with a big enough area:

Try a W14 x 120 (A = 35.3 in²) with 
$$r_y$$
 = 3.74 in and  $r_x$  = 6.24 in.:  $kL/r_y$  = 48.1 and  $\underline{kL/r_x}$  = 57.7 (GOVERNS)

 $\phi F_{cr}$  for 58 is 35.2 ksi,  $F_{cr} = 39.1$  ksi so A  $\geq$  560 k(1.67)/39.1 ksi = 23.9 in<sup>2</sup>

Choose a W14 x 90 (Choosing a W14 x 82 would make kL/r<sub>x</sub> = 59.5, and A<sub>req'd</sub> = 24.3 in<sup>2</sup>, which is more than 24.1 in<sup>2</sup>!)

#### LRFD:

- 1.  $P_u = 1.2(140 \text{ k}) + 1.6(420 \text{ k}) = 840 \text{ k}$
- 2. The effective length in the weak (y-y) axis is 15 ft, while the effective length in the strong (x-x) axis is 30 ft. (K = 1, KL = 1×30 ft). To find  $kL/r_x$  and  $kL/r_y$  we can assume or choose values from the wide flange charts.  $r_y$ 's range from 1 to 3 in., while  $r_x$ 's range from 3 to 14 inches. Let's try  $r_y$  = 2 in and  $r_x$  = 9 in. (something in the W21 range, say.)

$$kL/r_y \cong 15 \text{ ft}(12 \text{ in/ft})/2 \text{ in.} = 90 \iff GOVERNS \text{ (is larger)}$$

$$kL/r_x \cong 30 \text{ ft}(12 \text{ in/ft})/9 \text{ in.} = 40$$

3. Find a section with sufficient area (which then will give us "real" values for rx and ry):

If 
$$P_u \le \phi P_n$$
, and  $\phi P_n = \phi F_{cr} A$ , we can find  $A \ge P_u/\phi F_{cr}$  with  $\phi = 0.9$ 

$$\phi F_{cr}$$
 for 90 is 24.9 ksi, so A  $\geq$  840 k/24.9 ksi = 33.7 in<sup>2</sup>

4. Choose a trial section, and find the effective lengths and associated available strength, φF<sub>cr</sub>:

Looking from the smallest sections, the W14's are the first with a big enough area:

Try a W14 x 120 (A = 35.3 in<sup>2</sup>) with 
$$r_y$$
 = 3.74 in and  $r_x$  = 6.24 in.:  $kL/r_y$  = 48.1 and  $kL/r_x$  = 57.7 (GOVERNS)

 $\phi F_{cr}$  for 58 is 35.2 ksi, so A  $\geq$  840 k/35.2 ksi = 23.9 in<sup>2</sup>

Choose a W14 x 90 (Choosing a W14 x 82 would make kL/r<sub>x</sub> = 59.5, and A<sub>req'd</sub> = 24.3 in<sup>2</sup>, which is more than 24.1 in<sup>2</sup>!)

#### Example 6-1:

For the building frame shown in Fig. 6-20, determine the effective column length factor, K, the slenderness ratio, KL/r for each column. Assume the columns buckle and the beams bend about their strong axis.

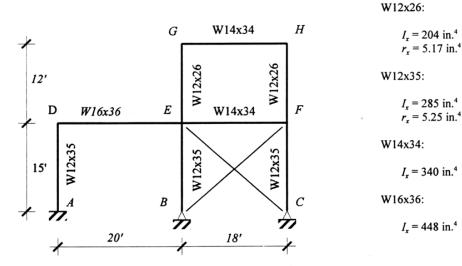


Figure 6-20: Building frame for Example 6-1.

#### Solution:

Note: The diagonal bracing prevents sidesway of the first story columns only.

$$G_{\rm A} = 1.0 \text{ (fixed support)} \qquad G_{\rm B} = G_{\rm C} = 10.0 \text{ (pinned support)}$$

$$G_{\rm D} = \frac{\frac{285}{15}}{\frac{448}{20}} = 0.85 \qquad G_{\rm E} = \frac{\frac{285}{15} + \frac{204}{12}}{\frac{448}{20} + \frac{340}{18}} = 0.87$$

$$G_{\rm F} = \frac{\frac{285}{15} + \frac{204}{12}}{\frac{340}{18}} = 1.91 \qquad G_{\rm G} = G_{\rm H} = \frac{\frac{204}{12}}{\frac{340}{18}} = 0.90$$

| Column | $G_{Top}$ | $G_{\mathtt{Bot}}$ | K    |          | KL/r                     |
|--------|-----------|--------------------|------|----------|--------------------------|
| AD     | 0.85      | 1.0                | 0.76 | Braced   | 0.76(15)(12)/5.25 = 26.1 |
| BE     | 0.87      | 10.0               | 0.85 | Braced   | 0.85(15)(12)/5.25 = 29.1 |
| CF     | 1.91      | 10.0               | 0.90 | Braced   | 0.90(15)(12)/5.25 = 30.9 |
| EG     | 0.90      | 0.87               | 1.29 | Unbraced | 1.29(12)(12)/5.17 = 35.9 |
| FH     | 0.90      | 1.91               | 1.43 | Unbraced | 1.43(12)(12)/5.17 = 39.8 |

Table 6-1: Column effective length factors and slenderness ratios for Example 6-1.

Investigate the accepatbility of a W16 x 67 used as a beam-column under the unfactored loading shown in the figure. It is A992 steel ( $F_y = 50 \text{ ksi}$ ). Assume 25% of the load is dead load with 75% live load.

#### SOLUTION:

DESIGN LOADS (shown on figure):

Axial load = 1.2(0.25)(350k)+1.6(0.75)(350k)=525k

Moment at joint =  $1.2(0.25)(60^{k-ft}) + 1.6(0.75)(60^{k-ft}) = 90^{k-ft}$ 

Determine column capacity and fraction to choose the appropriate interaction equation:

$$\frac{kL}{r_x} = \frac{15 ft (12 \frac{iv}{f_t})}{6.96 in} = 25.9 \text{ and } \frac{kL}{r_y} = \frac{15 ft (12 \frac{iv}{f_t})}{2.46 in} = 73 \text{ (governs)}$$

$$P_c = \phi_c P_n = \phi_c F_{cr} A_g = (30.5 ksi) 19.7 in^2 = 600.85 k$$

$$P_c = 525 k_c = 2.5 k_c =$$

$$\frac{P_r}{P_c} = \frac{525k}{600.85k} = 0.87 > 0.2 \quad \text{so use} \quad \frac{P_u}{\phi_c P_n} + \frac{8}{9} \left( \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \le 1.0$$

There is no bending about the y axis, so that term will not have any values.

Determine the bending moment capacity in the x direction:

The unbraced length to use the full plastic moment ( $L_p$ ) is listed as 8.69 ft, and we are over that so of we don't want to determine it from formula, we can find the beam in the Available Moment vs. Unbraced Length tables. The value of  $\phi M_n$  at  $L_b$  =15 ft is 422 k-ft.

Determine the magnification factor when  $M_1 = 0$ ,  $M_2 = 90$  k-ft:

$$C_{m} = 0.6 - 0.4 \frac{M_{1}}{M_{2}} = 0.6 - \frac{0^{k-ft}}{90^{k-ft}} = 0.6 \le 1.0$$

$$P_{el} = \frac{\pi^{2} EA}{\left(\frac{Kl}{r}\right)^{2}} = \frac{\pi^{2} (30x10^{3} ksi)19.7 in^{2}}{\left(25.9\right)^{2}} = 8,695.4k$$

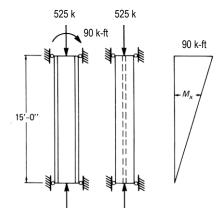
$$B_1 = \frac{C_m}{1 - (P_u/P_{ol})} = \frac{0.6}{1 - (525k/8695.4 \, k)} = 0.64 \ge 1.0$$
 USE 1.0 Mu = (1)90 k-ft

Finally, determine the interaction value:

$$\frac{P_u}{\phi_c P_n} + \frac{8}{9} \left( \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) = 0.87 + \frac{8}{9} \left( \frac{90^{k-ft}}{422^{k-ft}} \right) = 1.06 \le 1.0$$

## Example 15

**10.9** Determine the maximum load carrying capacity of this lap joint., assuming A36 steel with E60XX electrodes.



525 k

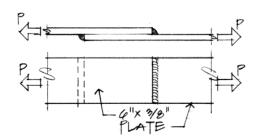
350 k

350 k

350 k

60 ft-kips

This is **NOT OK.** (and outside error tolerance). The section should be larger.



**10.7** Determine the capacity of the connection in Figure 10.44 assuming A36 steel with E70XX electrodes.

#### Solution:

Capacity of weld:

For a  $\frac{5}{16}$ " fillet weld,  $\phi S = 6.96$  k/in

Weld length = 8 in + 6 in + 8 in = 22 in.

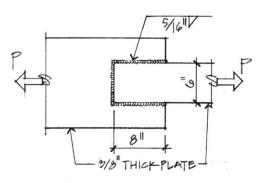
Weld capacity =  $22'' \times 6.96$  k/in = 153.1 k

Capacity of plate:

$$\phi P_n = \phi F_y A_g \quad \phi = 0.9$$

Plate capacity =  $0.9 \times 36 \text{ k/in}^2 \times 3/8'' \times 6'' = 72.9 \text{ k}$ 

∴ Plate capacity governs,  $P_{\text{allow}} = 72.9 \text{ k}$ 



The weld size used is obviously too strong. What size, then, can the weld be reduced to so that the weld strength is more compatible to the plate capacity? To make the weld capacity  $\approx$  plate capacity:

 $22'' \times \text{(weld capacity per in.)} = 72.9 \text{ k}$ 

Weld capacity per inch =  $\frac{72.9 \text{ k}}{22 \text{ in}}$  - 3.31 k/in.

From Available Strength table, use 3/16'' weld  $(\phi S = 4.18 \text{ k/in.})$ 

Minimum size fillet =  $\frac{3}{16}$ " based on a  $\frac{3}{8}$ " thick plate.

## Example 17

**10.5** Using the AISC framed beam connection bolt shear in Table 7-1, determine the shear adequacy of the connection shown in Figure 10.28. What thickness and angle length are

required? Also determine the bearing capacity of the wide flange sections.

Factored end beam reaction = 90 k.

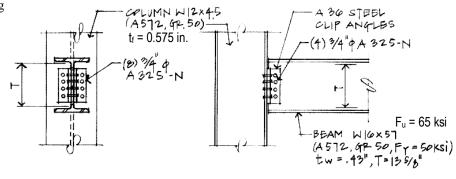


Figure 10.28 Typical beam-column connection.

**10.2** The butt splice shown in Figure 10.22 uses two  $8 \times 3\%$ " plates to "sandwich" in the  $8 \times 1\%$ " plates being joined. Four 7% % A325-SC bolts are used on both sides of the splice. Assuming A36 steel and standard round holes, determine the allowable capacity of the connection.

# P TEAHNY ACROSS FIRST NOWOF BUTS CENTER PLATE

#### SOLUTION:

Shear, bearing and net tension will be checked to determine the critical conditions that governs the capacity of the connection.

Shear: Using the AISC available shear in Table 7-3 (Group A):

$$\phi R_0 = 26.4 \text{ k/bolt x 4 bolts} = 105.6 \text{ k}$$

Bearing: Using the AISC available bearing in Table 7-4:

There are 4 bolts bearing on the center (1/2") plate, while there are 4 bolts bearing on a total width of two sandwich plates (3/4") total). The thinner bearing width will govern. Assume 3 in. spacing (center to center) of bolts. For A36 steel,  $F_u = 58$  ksi.

$$\phi R_n = 91.4 \text{ k/bolt/in. x } 0.5 \text{ in. x } 4 \text{ bolts} = 182.8 \text{ k} \text{ (Table 7-4)}$$

With the edge distance of 2 in., the bearing capacity might be smaller from Table 7-5 which says the distance should be  $2\frac{1}{4}$  in for full bearing (and we have 2 in.).

$$\phi R_0 = 79.9 \text{ k/bolt/in. x } 0.5 \text{ in. x } 4 \text{ bolts} = 159.8 \text{ k}$$

*Tension:* The center plate is critical, again, because its thickness is less than the combined thicknesses of the two outer plates. We must consider tension yielding and tension rupture:

$$\phi R_n = \phi F_v A_g$$
 and  $\phi R_n = \phi F_u A_e$  where  $A_e = A_{net} U$ 

$$A_g = 8 \text{ in. } x \frac{1}{2} \text{ in.} = 4 \text{ in}^2$$

The holes are considered 1/8 in. larger than the bolt hole diameter = (7/8 + 1/8) = 1.0 in.

$$A_n = (8 \text{ in.} - 2 \text{ holes } x 1.0 \text{ in.}) x \frac{1}{2} \text{ in.} = 3.0 \text{ in}^2$$

The whole cross section sees tension, so the shear lag factor U = 1

$$\phi F_{\nu} A_g = 0.9 \text{ x } 36 \text{ ksi x } 4 \text{ in}^2 = 129.6 \text{ k}$$

$$\phi F_u A_e = 0.75 \text{ x } 58 \text{ ksi x } (1) \text{ x } 3.0 \text{ in}^2 = 130.5 \text{ k}$$

The maximum connection capacity (smallest value) so far is governed by bolt shear:  $\phi R_n = 105.6 \text{ k}$ 

*Block Shear Rupture:* It is possible for the center plate to rip away from the sandwich plates leaving the block (shown hatched) behind:

$$\phi R_n = \phi (0.6F_u A_{nv} + U_{bs} F_u A_{nt}) \le \phi (0.6F_v A_{gv} + U_{bs} F_u A_{nt})$$

where  $A_{nv}$  is the area resisting shear,  $A_{nt}$  is the area resisting tension,  $A_{gv}$  is the gross area resisting shear, and  $U_{bs} = 1$  when the tensile stress is uniform.

$$A_{gv} = 2 \times (4 + 2 \text{ in.}) \times \frac{1}{2} \text{ in.} = 6 \text{ in}^2$$

$$A_{nv} = A_{gv} - 1 \frac{1}{2}$$
 holes areas = 6 in<sup>2</sup> - 1.5 x 1 in. x  $\frac{1}{2}$  in. = 5.25 in<sup>2</sup>

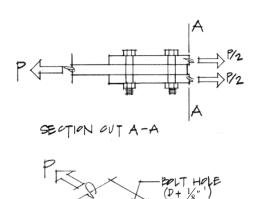
$$A_{nt} = 3.5 \text{ in. } x \text{ t} - 2(\frac{1}{2} \text{ hole areas}) = 3.5 \text{ in. } x \frac{1}{2} \text{ in} - 1 \text{ x} 1 \text{ in. } x \frac{1}{2} \text{ in.} = 1.25 \text{ in}^2$$

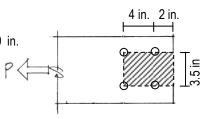
$$\phi(0.6F_uA_{nv} + U_{bs}F_uA_{nt}) = 0.75 \text{ x} (0.6 \text{ x} 58 \text{ ksi x} 5.25 \text{ in}^2 + 1 \text{ x} 58 \text{ ksi x} 1.25 \text{ in}^2) = 191.4 \text{ k}$$

$$\phi(0.6F_vA_{qv} + U_{bs}F_vA_{nt}) = 0.75 \text{ x} (0.6 \text{ x} 36 \text{ ksi x} 6 \text{ in}^2 + 1 \text{ x} 58 \text{ ksi x} 1.25 \text{ in}^2) = 151.6 \text{ k}$$

The maximum connection capacity (*smallest value*) is governed by block shear rupture:





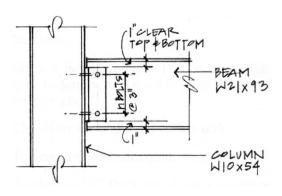


The steel used in the connection and beams is A992 with  $F_y = 50$  ksi, and  $F_u = 65$  ksi. Using A490-N bolt material, determine the maximum capacity of the connection based on shear in the bolts, bearing in all materials and pick the number of bolts and angle length (not staggered). Use A36 steel for the angles.

W21x93: d = 21.62 in,  $t_w = 0.58$  in,  $t_f = 0.93$  in

W10x54:  $t_f = 0.615$  in

#### SOLUTION:



The maximum length the angles can be depends on how it fits between the top and bottom flange with some clearance allowed for the fillet to the flange, and getting an air wrench in to tighten the bolts. This example uses 1" of clearance:

Available length = beam depth - both flange thicknesses - 1" clearance at top & 1" at bottom

$$= 21.62 \text{ in} - 2(0.93 \text{ in}) - 2(1 \text{ in}) = 17.76 \text{ in}.$$

With the spaced at 3 in. and 1 ½ in. end lengths (each end), the maximum number of bolts can be determined:

Available length  $\geq$  1.25 in. + 1.25 in. + 3 in. x (number of bolts – 1)

number of bolts  $\leq$  (17.76 in - 2.5 in. - (-3 in.))/3 in. = 6.1, so 6 bolts.

It is helpful to have the All-bolted Double-Angle Connection Tables 10-1. They are available for ¾", 7/8", and 1" bolt diameters and list angle thicknesses of ¼", 5/16", 3/8", and ½". Increasing the angle thickness is likely to increase the angle strength, although the limit states include shear yielding of the angles, shear rupture of the angles, and block shear rupture of the angles.

For these diameters, the available **shear** (double) from Table 7-1 for 6 bolts is (6)45.1 k/bolt = 270.6 kips, (6)61.3 k/bolt = 367.8 kips, and (6)80.1 k/bolt = 480.6 kips.

Tables 10-1 (not all provided here) list a bolt and angle available strength of 271 kips for the ¾" bolts, 296 kips for the 7/8" bolts, and 281 kips for the 1" bolts. It appears that increasing the bolt diameter to 1" will not gain additional load. <u>Use 7/8" bolts.</u>

| Beam   | $F_y = 50 \text{ ksi}$<br>$F_u = 65 \text{ ksi}$ | 010           | Ta<br><b>AII-B</b> e |      | Do   | ubl  | e-A  | •       | jle    |       | 7/8<br>Bol |      |
|--------|--|---------------|----------------------|------|------|------|------|---------|--------|-------|------------|------|
| Angle  | $F_y = 36 \text{ ksi}$<br>$F_u = 58 \text{ ksi}$ | 22.00         | (P.C)                | Coni | nec  |      |      | ngth, k | ips    | 4 B   | БО         | ္    |
|        | 6 Rows   | 28 15. "      | Negation .           |      |      |      | An   | gle Thi | ckness | , in. | entil i    |      |
| W4     | 0, 36, 33, 30, 27,                               | Bolt<br>Group | Thread<br>Cond.      | Hole | 1    | /4   | 5    | /16     | 3      | /8    | S (1       | /2   |
|        | 24, 21   | агоир         | Collu.               | Туре | ASD  | LRFD | ASD  | LRFD    | ASD    | LRFD  | ASD        | LRFI |
|        | Sylven   |               | N                    | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 195        | 292  |
|        |  |               | X                    | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 197        | 296  |
|        |  |               | 00                   | STD  | 98.6 | 148  | 106  | 159     | 106    | 159   | 106        | 159  |
|        | Varies t   | Group         | SC Class A           | OVS  | 90.1 | 135  | 90.1 | 135     | 90.1   | 135   | 90.1       | 135  |
| F      | neh in   | Α             | Class A              | SSLT | 97.3 | 146  | 106  | 159     | 106    | 159   | 106        | 159  |
|        | 81 = 18  |               | 00                   | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 176        | 264  |
|        | . 8  |               | SC                   | OVS  | 93.5 | 140  | 117  | 175     | 140    | 210   | 150        | 225  |
| ,      | 3  |               | Class B              | SSLT | 97.3 | 146  | 122  | 182     | 146    | 219   | 176        | 264  |
| ě,     | , con  | 557           | N                    | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 197        | 296  |
| 1      | ¥ 1785   | - 7           | X                    | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 197        | 296  |
| 563=15 |  | 881           | SC                   | STD  | 98.6 | 148  | 123  | 185     | 133    | 199   | 133        | 199  |
| 39     | H to fine  | Group         |                      | OVS  | 93.5 | 140  | 113  | 169     | 113    | 169   | 113        | 169  |
| 19     | E)   | В             | Class A              | SSLT | 97.3 | 146  | 122  | 182     | 133    | 199   | 133        | 199  |
|        |  |               | SC                   | STD  | 98.6 | 148  | 123  | 185     | 148    | 222   | 197        | 296  |
|        |  |               |                      | OVS  | 93.5 | 140  | 117  | 175     | 140    | 210   | 187        | 281  |
|        |  | , .           | Class B              | SSLT | 97.3 | 146  | 122  | 182     | 146    | 219   | 195        | 292  |

 $\phi R_n = 367.8$  kips for double shear of 7/8" bolts

 $\phi R_n = 296$  kips for limit state in angles

We also need to evaluate **bearing** of bolts on the beam web, and column flange where there are bolt holes. Table 7-4 provides available bearing strength for the material type, bolt diameter, hole type, and spacing per inch of material thicknesses.

a) Bearing for beam web: There are 6 bolt holes through the beam web. This is typically the critical bearing limit value because there are two angle legs that resist bolt bearing and twice as many bolt holes to the column. The material is A992 (F<sub>u</sub> = 65 ksi), 0.58" thick, with 7/8" bolt diameters at 3 in. spacing.

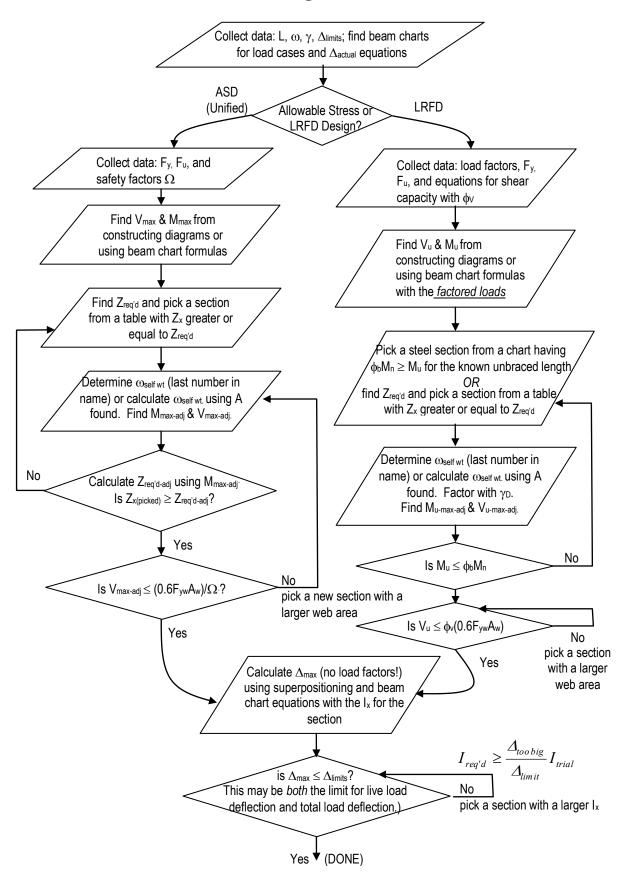
 $\phi R_n = 6 \text{ bolts} \cdot (102 \text{ k/bolt/inch}) \cdot (0.58 \text{ in}) = 355.0 \text{ kips}$ 

b) Bearing for column flange: There are 12 bolt holes through the column. The material is A992 (F<sub>u</sub> = 65 ksi), 0.615" thick, with 1" bolt diameters.

 $\phi R_n = 12 \text{ bolts} \cdot (102 \text{ k/bolt/inch}) \cdot (0.615 \text{ in}) = 752.8 \text{ kips}$ 

Although, the bearing in the beam web is the smallest at 355 kips, with the shear on the bolts even smaller at 324.6 kips, the maximum capacity for the simple-shear connector is 296 kips limited by the critical capacity of the angles.

# **Beam Design Flow Chart**



Listing of W Shapes in Descending order of  $Z_x$  for Beam Design

| $Z_x - US$          | $I_x - US$          | 1       | $I_x - SI$            | $Z_x - SI$           | 7 IIC                          | $I_x - US$          |         | $I_x - SI$            | $Z_x - SI$           |
|---------------------|---------------------|---------|-----------------------|----------------------|--------------------------------|---------------------|---------|-----------------------|----------------------|
| (in. <sup>3</sup> ) | (in. <sup>4</sup> ) | Section | $(10^6 \text{mm.}^4)$ | $(10^3 \text{mm.3})$ | $Z_x - US$ (in. <sup>3</sup> ) | (in. <sup>4</sup> ) | Section | $(10^6 \text{mm.}^4)$ | $(10^3 \text{mm.3})$ |
| 514                 | 7450                | W33X141 | 3100                  | 8420                 | 289                            | 3100                | W24X104 | 1290                  | 4740                 |
| 511                 | 5680                | W24X176 | 2360                  | 8370                 | 287                            | 1900                | W14X159 | 791                   | 4700                 |
| 509                 | 7800                | W36X135 | 3250                  | 8340                 | 283                            | 3610                | W30X90  | 1500                  | 4640                 |
| 500                 | 6680                | W30X148 | 2780                  | 8190                 | 280                            | 3000                | W24X103 | 1250                  | 4590                 |
| 490                 | 4330                | W18X211 | 1800                  | 8030                 | 279                            | 2670                | W21X111 | 1110                  | 4570                 |
| 487                 | 3400                | W14X257 | 1420                  | 7980                 | 278                            | 3270                | W27X94  | 1360                  | 4560                 |
| 481                 | 3110                | W12X279 | 1290                  | 7880                 | 275                            | 1650                | W12X170 | 687                   | 4510                 |
| 476                 | 4730                | W21X182 | 1970                  | 7800                 | 262                            | 2190                | W18X119 | 912                   | 4290                 |
| 468                 | 5170                | W24X162 | 2150                  | 7670                 | 260                            | 1710                | W14X145 | 712                   | 4260                 |
| 467                 | 6710                | W33X130 | 2790                  | 7650                 | 254                            | 2700                | W24X94  | 1120                  | 4160                 |
| 464                 | 5660                | W27X146 | 2360                  | 7600                 | 253                            | 2420                | W21X101 | 1010                  | 4150                 |
| 442                 | 3870                | W18X192 | 1610                  | 7240                 | 244                            | 2850                | W27X84  | 1190                  | 4000                 |
| 437                 | 5770                | W30X132 | 2400                  | 7160                 | 243                            | 1430                | W12X152 | 595                   | 3980                 |
| 436                 | 3010                | W14X233 | 1250                  | 7140                 | 234                            | 1530                | W14X132 | 637                   | 3830                 |
| 432                 | 4280                | W21X166 | 1780                  | 7080                 | 230                            | 1910                | W18X106 | 795                   | 3770                 |
| 428                 | 2720                | W12X252 | 1130                  | 7010                 | 224                            | 2370                | W24X84  | 986                   | 3670                 |
| 418                 | 4580                | W24X146 | 1910                  | 6850                 | 221                            | 2070                | W21X93  | 862                   | 3620                 |
| 415                 | 5900                | W33X118 | 2460                  | 6800                 | 214                            | 1240                | W12X136 | 516                   | 3510                 |
| 408                 | 5360                | W30X124 | 2230                  | 6690                 | 212                            | 1380                | W14X120 | 574                   | 3470                 |
| 398                 | 3450                | W18X175 | 1440                  | 6520                 | 211                            | 1750                | W18X97  | 728                   | 3460                 |
| 395                 | 4760                | W27X129 | 1980                  | 6470                 | 200                            | 2100                | W24X76  | 874                   | 3280                 |
| 390                 | 2660                | W14X211 | 1110                  | 6390                 | 198                            | 1490                | W16X100 | 620                   | 3240                 |
| 386                 | 2420                | W12X230 | 1010                  | 6330                 | 196                            | 1830                | W21X83  | 762                   | 3210                 |
| 378                 | 4930                | W30X116 | 2050                  | 6190                 | 192                            | 1240                | W14X109 | 516                   | 3150                 |
| 373                 | 3630                | W21X147 | 1510                  | 6110                 | 186                            | 1530                | W18X86  | 637                   | 3050                 |
| 370                 | 4020                | W24X131 | 1670                  | 6060                 | 186                            | 1070                | W12X120 | 445                   | 3050                 |
| 356                 | 3060                | W18X158 | 1270                  | 5830                 | 177                            | 1830                | W24X68  | 762                   | 2900                 |
| 355                 | 2400                | W14X193 | 999                   | 5820                 | 175                            | 1300                | W16X89  | 541                   | 2870                 |
| 348                 | 2140                | W12X210 | 891                   | 5700                 | 173                            | 1110                | W14X99  | 462                   | 2830                 |
| 346                 | 4470                | W30X108 | 1860                  | 5670                 | 172                            | 1600                | W21X73  | 666                   | 2820                 |
| 343                 | 4080                | W27X114 | 1700                  | 5620                 | 164                            | 933                 | W12X106 | 388                   | 2690                 |
| 333                 | 3220                | W21X132 | 1340                  | 5460                 | 163                            | 1330                | W18X76  | 554                   | 2670                 |
| 327                 | 3540                | W24X117 | 1470                  | 5360                 | 160                            | 1480                | W21X68  | 616                   | 2620                 |
| 322                 | 2750                | W18X143 | 1140                  | 5280                 | 157                            | 999                 | W14X90  | 416                   | 2570                 |
| 320                 | 2140                | W14X176 | 891                   | 5240                 | 153                            | 1550                | W24X62  | 645                   | 2510                 |
| 312                 | 3990                | W30X99  | 1660                  | 5110                 | 150                            | 1110                | W16X77  | 462                   | 2460                 |
| 311                 | 1890                | W12X190 | 787                   | 5100                 | 147                            | 833                 | W12X96  | 347                   | 2410                 |
| 307                 | 2960                | W21X122 | 1230                  | 5030                 | 147                            | 716                 | W10X112 | 298                   | 2410                 |
| 305                 | 3620                | W27X102 | 1510                  | 5000                 | 146                            | 1170                | W18X71  | 487                   | 2390                 |
| 290                 | 2460                | W18X130 | 1020                  | 4750                 |                                |                     |         | (                     | (continued)          |

Listing of W Shapes in Descending order of  $Z_x$  for Beam Design (Continued)

| $Z_x - US$ (in. <sup>3</sup> ) | $I_x - US$ (in. <sup>4</sup> ) | Section | $I_{x} - SI$ $(10^{6} \text{mm.}^{4})$ | $\frac{Z_x - SI}{(10^3 \text{mm.3})}$ | $Z_x - US$ (in.3) | $I_x - US$ (in. <sup>4</sup> ) | Section | $\frac{I_x - SI}{(10^6 \text{mm.}^4)}$ | $\frac{Z_x - SI}{(10^3 \text{mm.3})}$ |
|--------------------------------|--------------------------------|---------|--|---------------------------------------|-------------------|--------------------------------|---------|--|---------------------------------------|
| 144                            | 1330                           | W21X62  | 554                                    | 2360                                  | 66.5              | 510                            | W18X35  | 212                                    | 1090                                  |
| 139                            | 881                            | W14X82  | 367                                    | 2280                                  | 64.2              | 348                            | W12X45  | 145                                    | 1050                                  |
| 134                            | 1350                           | W24X55  | 562                                    | 2200                                  | 64.0              | 448                            | W16X36  | 186                                    | 1050                                  |
| 133                            | 1070                           | W18X65  | 445                                    | 2180                                  | 61.5              | 385                            | W14X38  | 160                                    | 1010                                  |
| 132                            | 740                            | W12X87  | 308                                    | 2160                                  | 60.4              | 272                            | W10X49  | 113                                    | 990                                   |
| 130                            | 954                            | W16X67  | 397                                    | 2130                                  | 59.8              | 228                            | W8X58   | 94.9                                   | 980                                   |
| 130                            | 623                            | W10X100 | 259                                    | 2130                                  | 57.0              | 307                            | W12X40  | 128                                    | 934                                   |
| 129                            | 1170                           | W21X57  | 487                                    | 2110                                  | 54.9              | 248                            | W10X45  | 103                                    | 900                                   |
| 126                            | 1140                           | W21X55  | 475                                    | 2060                                  | 54.6              | 340                            | W14X34  | 142                                    | 895                                   |
| 126                            | 795                            | W14X74  | 331                                    | 2060                                  | 54.0              | 375                            | W16X31  | 156                                    | 885                                   |
| 123                            | 984                            | W18X60  | 410                                    | 2020                                  | 51.2              | 285                            | W12X35  | 119                                    | 839                                   |
| 119                            | 662                            | W12X79  | 276                                    | 1950                                  | 49.0              | 184                            | W8X48   | 76.6                                   | 803                                   |
| 115                            | 722                            | W14X68  | 301                                    | 1880                                  | 47.3              | 291                            | W14X30  | 121                                    | 775                                   |
| 113                            | 534                            | W10X88  | 222                                    | 1850                                  | 46.8              | 209                            | W10X39  | 87.0                                   | 767                                   |
| 112                            | 890                            | W18X55  | 370                                    | 1840                                  | 44.2              | 301                            | W16X26  | 125                                    | 724                                   |
| 110                            | 984                            | W21X50  | 410                                    | 1800                                  | 43.1              | 238                            | W12X30  | 99.1                                   | 706                                   |
| 108                            | 597                            | W12X72  | 248                                    | 1770                                  | 40.2              | 245                            | W14X26  | 102                                    | 659                                   |
| 107                            | 959                            | W21X48  | 399                                    | 1750                                  | 39.8              | 146                            | W8X40   | 60.8                                   | 652                                   |
| 105                            | 758                            | W16X57  | 316                                    | 1720                                  | 38.8              | 171                            | W10X33  | 71.2                                   | 636                                   |
| 102                            | 640                            | W14X61  | 266                                    | 1670                                  | 37.2              | 204                            | W12X26  | 84.9                                   | 610                                   |
| 101                            | 800                            | W18X50  | 333                                    | 1660                                  | 36.6              | 170                            | W10X30  | 70.8                                   | 600                                   |
| 97.6                           | 455                            | W10X77  | 189                                    | 1600                                  | 34.7              | 127                            | W8X35   | 52.9                                   | 569                                   |
| 96.8                           | 533                            | W12X65  | 222                                    | 1590                                  | 33.2              | 199                            | W14X22  | 82.8                                   | 544                                   |
| 95.4                           | 843                            | W21X44  | 351                                    | 1560                                  | 31.3              | 144                            | W10X26  | 59.9                                   | 513                                   |
| 92.0                           | 659                            | W16X50  | 274                                    | 1510                                  | 30.4              | 110                            | W8X31   | 45.8                                   | 498                                   |
| 90.7                           | 712                            | W18X46  | 296                                    | 1490                                  | 29.3              | 156                            | W12X22  | 64.9                                   | 480                                   |
| 87.1                           | 541                            | W14X53  | 225                                    | 1430                                  | 27.2              | 98.0                           | W8X28   | 40.8                                   | 446                                   |
| 86.4                           | 475                            | W12X58  | 198                                    | 1420                                  | 26.0              | 118                            | W10X22  | 49.1                                   | 426                                   |
| 85.3                           | 394                            | W10X68  | 164                                    | 1400                                  | 24.7              | 130                            | W12X19  | 54.1                                   | 405                                   |
| 82.3                           | 586                            | W16X45  | 244                                    | 1350                                  | 23.1              | 82.7                           | W8X24   | 34.4                                   | 379                                   |
| 78.4                           | 612                            | W18X40  | 255                                    | 1280                                  | 21.6              | 96.3                           | W10X19  | 40.1                                   | 354                                   |
| 78.4                           | 484                            | W14X48  | 201                                    | 1280                                  | 20.4              | 75.3                           | W8X21   | 31.3                                   | 334                                   |
| 77.9                           | 425                            | W12X53  | 177                                    | 1280                                  | 20.1              | 103                            | W12x16  | 42.9                                   | 329                                   |
| 74.6                           | 341                            | W10X60  | 142                                    | 1220                                  | 18.7              | 81.9                           | W10X17  | 34.1                                   | 306                                   |
| 73.0                           | 518                            | W16X40  | 216                                    | 1200                                  | 17.4              | 88.6                           | W12X14  | 36.9                                   | 285                                   |
| 71.9                           | 391                            | W12X50  | 163                                    | 1180                                  | 17.4<br>17.0      | 61.9                           | W8X18   | 25.8                                   | 279                                   |
| 70.1                           | 272                            | W8X67   | 113                                    | 1150                                  | 16.0              | 68.9                           | W10X15  | 28.7                                   | 262                                   |
| 69.6                           | 428                            | W14X43  | 178                                    | 1140                                  | 13.6              | 48.0                           | W8X15   | 20.0                                   | 223                                   |
| 66.6                           | 303                            | W10X54  | 126                                    | 1090                                  | 12.6              | 53.8                           | W10X12  | 22.4                                   | 206                                   |
|                                |                                |         |  |                                       | 11.4              | 39.6                           | W8X13   | 16.5                                   | 187                                   |
|                                |                                |         |  |                                       |                   |                                |         |  |                                       |
|                                |                                |         |  |                                       | 8.87              | 30.8                           | W8X10   | 12.8                                   | 145                                   |

Available Critical Stress,  $\phi_c F_{cr}$ , for Compression Members, ksi ( $F_y = 36$  ksi and  $\phi_c = 0.90$ )

| KL/r | $\phi_c F_{cr}$ |
|------|-----------------|------|-----------------|------|-----------------|------|-----------------|------|-----------------|
| 1    | 32.4            | 41   | 29.7            | 81   | 22.9            | 121  | 15.0            | 161  | 8.72            |
| 2    | 32.4            | 42   | 29.5            | 82   | 22.7            | 122  | 14.8            | 162  | 8.61            |
| 3    | 32.4            | 43   | 29.4            | 83   | 22.5            | 123  | 14.6            | 163  | 8.50            |
| 4    | 32.4            | 44   | 29.3            | 84   | 22.3            | 124  | 14.4            | 164  | 8.40            |
| 5    | 32.4            | 45   | 29.1            | 85   | 22.1            | 125  | 14.2            | 165  | 8.30            |
| 6    | 32.3            | 46   | 29.0            | 86   | 22.0            | 126  | 14.0            | 166  | 8.20            |
| 7    | 32.3            | 47   | 28.8            | 87   | 21.8            | 127  | 13.9            | 167  | 8.10            |
| 8    | 32.3            | 48   | 28.7            | 88   | 21.6            | 128  | 13.7            | 168  | 8.00            |
| 9    | 32.3            | 49   | 28.6            | 89   | 21.4            | 129  | 13.5            | 169  | 7.91            |
| 10   | 32.2            | 50   | 28.4            | 90   | 21.2            | 130  | 13.3            | 170  | 7.82            |
| 11   | 32.2            | 51   | 28.3            | 91   | 21.0            | 131  | 13.1            | 171  | 7.73            |
| 12   | 32.2            | 52   | 28.1            | 92   | 20.8            | 132  | 12.9            | 172  | 7.64            |
| 13   | 32.1            | 53   | 27.9            | 93   | 20.5            | 133  | 12.8            | 173  | 7.55            |
| 14   | 32.1            | 54   | 27.8            | 94   | 20.3            | 134  | 12.6            | 174  | 7.46            |
| 15   | 32.0            | 55   | 27.6            | 95   | 20.1            | 135  | 12.4            | 175  | 7.38            |
| 16   | 32.0            | 56   | 27.5            | 96   | 19.9            | 136  | 12.2            | 176  | 7.29            |
| 17   | 31.9            | 57   | 27.3            | 97   | 19.7            | 137  | 12.0            | 177  | 7.21            |
| 18   | 31.9            | 58   | 27.1            | 98   | 19.5            | 138  | 11.9            | 178  | 7.13            |
| 19   | 31.8            | 59   | 27.0            | 99   | 19.3            | 139  | 11.7            | 179  | 7.05            |
| 20   | 31.7            | 60   | 26.8            | 100  | 19.1            | 140  | 11.5            | 180  | 6.97            |
| 21   | 31.7            | 61   | 26.6            | 101  | 18.9            | 141  | 11.4            | 181  | 6.90            |
| 22   | 31.6            | 62   | 26.5            | 102  | 18.7            | 142  | 11.2            | 182  | 6.82            |
| 23   | 31.5            | 63   | 26.3            | 103  | 18.5            | 143  | 11.0            | 183  | 6.75            |
| 24   | 31.4            | 64   | 26.1            | 104  | 18.3            | 144  | 10.9            | 184  | 6.67            |
| 25   | 31.4            | 65   | 25.9            | 105  | 18.1            | 145  | 10.7            |      | 6.60            |
| 26   | 31.3            | 66   | 25.8            | 106  | 17.9            | 146  | 10.6            | 186  | 6.53            |
| 27   | 31.2            | 67   | 25.6            | 107  | 17.7            | 147  | 10.5            | 187  | 6.46            |
| 28   | 31.1            | 68   | 25.4            | 108  | 17.5            | 148  | 10.3            | 188  | 6.39            |
| 29   | 31.0            | 69   | 25.2            | 109  | 17.3            | 149  | 10.2            | 189  | 6.32            |
| 30   | 30.9            | 70   | 25.0            | 110  | 17.1            | 150  | 10.0            | 190  | 6.26            |
| 31   | 30.8            | 71   | 24.8            | 111  | 16.9            | 151  | 9.91            | 191  | 6.19            |
| 32   | 30.7            | 72   | 24.7            | 112  | 16.7            | 152  | 9.78            | 192  | 6.13            |
| 33   | 30.6            | 73   | 24.5            | 113  | 16.5            | 153  | 9.65            | 193  | 6.06            |
| 34   | 30.5            | 74   | 24.3            | 114  | 16.3            | 154  | 9.53            | 194  | 6.00            |
| 35   | 30.4            | 75   | 24.1            | 115  | 16.2            | 155  | 9.40            | 195  | 5.94            |
| 36   | 30.3            | 76   | 23.9            | 116  | 16.0            | 156  | 9.28            | 196  | 5.88            |
| 37   | 30.1            | 77   | 23.7            | 117  | 15.8            | 157  | 9.17            | 197  | 5.82            |
| 38   | 30.0            | 78   | 23.5            | 118  | 15.6            | 158  | 9.05            | 198  | 5.76            |
| 39   | 29.9            | 79   | 23.3            | 119  | 15.4            | 159  | 8.94            | 199  | 5.70            |
| 40   | 29.8            | 80   | 23.1            | 120  | 15.2            | 160  | 8.82            | 200  | 5.65            |

Available Critical Stress,  $\phi_c F_{cr}$ , for Compression Members, ksi ( $F_y$  = 50 ksi and  $\phi_c$  = 0.90)

| KL/r | $\phi_c F_{cr}$ |
|------|-----------------|------|-----------------|------|-----------------|------|-----------------|------|-----------------|
| 1    | 45.0            | 41   | 39.8            | 81   | 27.9            | 121  | 15.4            | 161  | 8.72            |
| 2    | 45.0            | 42   | 39.6            | 82   | 27.5            | 122  | 15.2            | 162  | 8.61            |
| 3    | 45.0            | 43   | 39.3            | 83   | 27.2            | 123  | 14.9            | 163  | 8.50            |
| 4    | 44.9            | 44   | 39.1            | 84   | 26.9            | 124  | 14.7            | 164  | 8.40            |
| 5    | 44.9            | 45   | 38.8            | 85   | 26.5            | 125  | 14.5            | 165  | 8.30            |
| 6    | 44.9            | 46   | 38.5            | 86   | 26.2            | 126  | 14.2            | 166  | 8.20            |
| 7    | 44.8            | 47   | 38.3            | 87   | 25.9            | 127  | 14.0            | 167  | 8.10            |
| 8    | 44.8            | 48   | 38.0            | 88   | 25.5            | 128  | 13.8            | 168  | 8.00            |
| 9    | 44.7            | 49   | 37.8            | 89   | 25.2            | 129  | 13.6            | 169  | 7.91            |
| 10   | 44.7            | 50   | 37.5            | 90   | 24.9            | 130  | 13.4            | 170  | 7.82            |
| 11   | 44.6            | 51   | 37.2            | 91   | 24.6            | 131  | 13.2            | 171  | 7.73            |
| 12   | 44.5            | 52   | 36.9            | 92   | 24.2            | 132  | 13.0            | 172  | 7.64            |
| 13   | 44.4            | 53   | 36.6            | 93   | 23.9            | 133  | 12.8            | 173  | 7.55            |
| 14   | 44.4            | 54   | 36.4            | 94   | 23.6            | 134  | 12.6            | 174  | 7.46            |
| 15   | 44.3            | 55   | 36.1            | 95   | 23.3            | 135  | 12.4            | 175  | 7.38            |
| 16   | 44.2            | 56   | 35.8            | 96   | 22.9            | 136  | 12.2            | 176  | 7.29            |
| 17   | 44.1            | 57   | 35.5            | 97   | 22.6            | 137  | 12.0            | 177  | 7.21            |
| 18   | 43.9            | 58   | 35.2            | 98   | 22.3            | 138  | 11.9            | 178  | 7.13            |
| 19   | 43.8            | 59   | 34.9            | 99   | 22.0            | 139  | 11.7            | 179  | 7.05            |
| 20   | 43.7            | 60   | 34.6            | 100  | 21.7            | 140  | 11.5            | 180  | 6.97            |
| 21   | 43.6            | 61   | 34.3            | 101  | 21.3            | 141  | 11.4            | 181  | 6.90            |
| 22   | 43.4            | 62   | 34.0            | 102  | 21.0            | 142  | 11.2            | 182  | 6.82            |
| 23   | 43.3            | 63   | 33.7            | 103  | 20.7            | 143  | 11.0            | 183  | 6.75            |
| 24   | 43.1            | 64   | 33.4            | 104  | 20.4            | 144  | 10.9            | 184  | 6.67            |
| 25   | 43.0            | 65   | 33.0            | 105  | 20.1            | 145  | 10.7            | 185  | 6.60            |
| 26   | 42.8            | 66   | 32.7            | 106  | 19.8            | 146  | 10.6            | 186  | 6.53            |
| 27   | 42.7            | 67   | 32.4            | 107  | 19.5            | 147  | 10.5            | 187  | 6.46            |
| 28   | 42.5            | 68   | 32.1            | 108  | 19.2            | 148  | 10.3            | 188  | 6.39            |
| 29   | 42.3            | 69   | 31.8            | 109  | 18.9            | 149  | 10.2            | 189  | 6.32            |
| 30   | 42.1            | 70   | 31.4            | 110  | 18.6            | 150  | 10.0            | 190  | 6.26            |
| 31   | 41.9            | 71   | 31.1            | 111  | 18.3            | 151  | 9.91            | 191  | 6.19            |
| 32   | 41.8            | 72   | 30.8            | 112  | 18.0            | 152  | 9.78            | 192  | 6.13            |
| 33   | 41.6            | 73   | 30.5            | 113  | 17.7            | 153  | 9.65            | 193  | 6.06            |
| 34   | 41.4            | 74   | 30.2            | 114  | 17.4            | 154  | 9.53            | 194  | 6.00            |
| 35   | 41.1            | 75   | 29.8            | 115  | 17.1            | 155  | 9.40            | 195  | 5.94            |
| 36   | 40.9            | 76   | 29.5            | 116  | 16.8            | 156  | 9.28            | 196  | 5.88            |
| 37   | 40.7            | 77   | 29.2            | 117  | 16.5            | 157  | 9.17            | 197  | 5.82            |
| 38   | 40.5            | 78   | 28.8            | 118  | 16.2            | 158  | 9.05            | 198  | 5.76            |
| 39   | 40.3            | 79   | 28.5            | 119  | 16.0            | 159  | 8.94            | 199  | 5.70            |
| 40   | 40.0            | 80   | 28.2            | 120  | 15.7            | 160  | 8.82            | 200  | 5.65            |

# **Bolt Strength Tables**

# Table 7-1 Available Shear Strength of Bolts, kips

| No                | minal Bolt        | Diamete               | er, <i>d</i> , in.               |            | 5                 | /8                      | 3,                | 4                       | 7                        | /8              | oitosi            | 1               |
|-------------------|-------------------|-----------------------|----------------------------------|------------|-------------------|-------------------------|-------------------|-------------------------|--------------------------|-----------------|-------------------|-----------------|
|                   | Nominal B         | olt Area              | in. <sup>2</sup>                 | eVi omi    | 0.3               | 07                      | 0.4               | 142                     | 0.6                      | 601             | 0.                | 785             |
| ASTM /            | Thread            | $F_{nv}/\Omega$ (ksi) | φ <i>F<sub>nv</sub></i><br>(ksi) | Load-      | r <sub>n</sub> /Ω | φrn                     | r <sub>n</sub> /Ω | φ <b>r</b> n            | <b>r</b> <sub>n</sub> /Ω | φr <sub>n</sub> | r <sub>n</sub> /Ω | φr <sub>n</sub> |
| Desig.            | Cond.             | ASD                   | LRFD                             | ing        | ASD               | LRFD                    | ASD               | LRFD                    | ASD                      | LRFD            | ASD               | LRFC            |
| Group             | Chipago           | 27.0                  | 40.5                             | S          | 8.29<br>16.6      | 12.4<br>24.9            | 11.9<br>23.9      | 17.9<br>35.8            | 16.2<br>32.5             | 24.3<br>48.7    | 21.2<br>42.4      | 31.8<br>63.6    |
| 184,8-8           | ∂‡, <b>X</b> .qq  | 34.0                  | 51.0                             | S<br>D     | 10.4<br>20.9      | 15.7<br>31.3            | 15.0<br>30.1      | 22.5<br>45.1            | 20.4<br>40.9             | 30.7<br>61.3    | 26.7<br>53.4      | 40.0<br>80.1    |
| Group             | N N               | 34.0                  | 51.0                             | S          | 10.4<br>20.9      | 15.7<br>31.3            | 15.0<br>30.1      | 22.5<br>45.1            | 20.4<br>40.9             | 30.7<br>61.3    | 26.7<br>53.4      | 40.0<br>80.1    |
| gn ( <b>g</b> uid | ers, Desi<br>X    | 42.0                  | 63.0                             | D S        | 12.9<br>25.8      | 19.3<br>38.7            | 18.6<br>37.1      | 27.8<br>55.7            | 25.2<br>50.5             | 37.9<br>75.7    | 33.0<br>65.9      | 49.5<br>98.9    |
| A307              | ling <u>.</u> " M | 13.5                  | 20.3                             | S<br>TD    | 4.14<br>8.29      | 6.23<br>12.5            | 5.97<br>11.9      | 8.97<br>17.9            | 8.11<br>16.2             | 12.2<br>24.4    | 10.6              | 15.9<br>31.9    |
| SuipaaNo          | minal Bolt        | Diamete               | er, <i>d</i> , in.               | ons to     | nnect             | ing <b>%</b>            | Fran              | ylqmi8                  | " . ( <b>`}</b>          | 3/8             | L.D.              | 1/2             |
|                   | Nominal B         | olt Area              | , in. <sup>2</sup>               | 1-0E.      | 0.9               | 94                      | iatalac           | 23                      | <b>J</b> .               | 48              | S Ibas            | .77             |
| ASTM              | Thread            | $F_{nv}/\Omega$ (ksi) | φ <i>F<sub>nv</sub></i><br>(ksi) | Load-      | r <sub>n</sub> /Ω | φ <b>r</b> <sub>n</sub> | $r_n/\Omega$      | φ <b>r</b> <sub>n</sub> | <b>r</b> <sub>n</sub> /Ω | φr <sub>n</sub> | r <sub>n</sub> /Ω | φrn             |
| Desig.            | Cond.             | ASD                   | LRFD                             | ing        | ASD               | LRFD                    | ASD               | LRFD                    | ASD                      | LRFD            | ASD               | LRF             |
| Group             | N                 | 27.0                  | 40.5                             | S<br>D     | 26.8<br>53.7      | 40.3<br>80.5            | 33.2<br>66.4      | 49.8<br>99.6            | 40.0<br>79.9             | 59.9<br>120     | 47.8<br>95.6      | 71.7<br>143     |
| Α                 | x                 | 34.0                  | 51.0                             | S<br>D     | 33.8<br>67.6      | 50.7<br>101             | 41.8<br>83.6      | 62.7<br>125             | 50.3<br>101              | 75.5<br>151     | 60.2<br>120       | 90.3            |
| Group             | N                 | 34.0                  | 51.0                             | S<br>D     | 33.8<br>67.6      | 50.7<br>101             | 41.8<br>83.6      | 62.7<br>125             | 50.3<br>101              | 75.5<br>151     | 60.2<br>120       | 90.3<br>181     |
| В                 | . x               | 42.0                  | 63.0                             | S<br>D     | 41.7<br>83.5      | 62.6<br>125             | 51.7<br>103       | 77.5<br>155             | 62.2<br>124              | 93.2<br>186     | 74.3<br>149       | 112<br>223      |
| A307              | -                 | 13.5                  | 20.3                             | S<br>D     | 13.4<br>26.8      | 20.2<br>40.4            | 16.6<br>33.2      | 25.0<br>49.9            | 20.0<br>40.0             | 30.0<br>60.1    | 23.9<br>47.8      | 35.9<br>71.9    |
| ASD               | LRFD              | For end               | loaded co                        | onnections | greater t         | han 38 in               | ., see AISO       | Specific Specific       | ation Table              | e J3.2 foo      | otnote b.         |                 |
| $\Omega = 2.00$   | $\phi = 0.75$     | 1                     |                                  |            |                   |                         |                   |                         |                          |                 |                   |                 |

# Table 7-2 Available Tensile Strength of Bolts, kips

| Nominal Bo      | It Diameter,                | d, in.                           | 5            | /8                      | . · · · · · · · • | /4                      | 7                 | /8                      |                   | 1                       |
|-----------------|-----------------------------|----------------------------------|--------------|-------------------------|-------------------|-------------------------|-------------------|-------------------------|-------------------|-------------------------|
| Nominal         | Bolt Area, in               | .2                               | 0.3          | 307                     | 0.                | 442                     | 0.0               | 601                     | 0.                | 785                     |
| ASTM Desig      | F <sub>nt</sub> /Ω<br>(ksi) | φ <i>F<sub>nt</sub></i><br>(ksi) | $r_n/\Omega$ | φ <b>r</b> <sub>n</sub> | $r_n/\Omega$      | φr <sub>n</sub>         | $r_n/\Omega$      | φ <b>r</b> <sub>n</sub> | r <sub>n</sub> /Ω | φ <b>r</b> <sub>n</sub> |
|                 | ASD                         | LRFD                             | ASD          | LRFD                    | ASD               | LRFD                    | ASD               | LRFD                    | ASD               | LRFD                    |
| Group A         | 45.0                        | 67.5                             | 13.8         | 20.7                    | 19.9              | 29.8                    | 27.1              | 40.6                    | 35.3              | 53.0                    |
| Group B         | 56.5                        | 84.8                             | 17.3         | 26.0                    | 25.0              | 37.4                    | 34.0              | 51.0                    | 44.4              | 66.6                    |
| A307            | 22.5                        | 33.8                             | 6.90         | 10.4                    | 9.94              | 14.9                    | 13.5              | 20.3                    | 17.7              | 26.5                    |
| Nominal Bo      | It Diameter,                | d, in.                           | E   EM       | 1/8 88                  | 9 1               | 1/4                     | 2 15 1            | 3/8                     | 145               | 1/2                     |
| Nominal         | Bolt Area, in               | 1.2                              | 0.9          | 994                     | 1                 | .23                     | nostii 1          | .48                     |                   | .77                     |
| ASTM Desig      | F <sub>nt</sub> /Ω (ksi)    | φ <i>F<sub>nt</sub></i> (ksi)    | $r_n/\Omega$ | φ <b>r</b> <sub>n</sub> | r <sub>n</sub> /Ω | φ <b>r</b> <sub>n</sub> | r <sub>n</sub> /Ω | φ <b>r</b> <sub>n</sub> | r <sub>n</sub> /Ω | φr <sub>n</sub>         |
| 710 1111 20019  | ASD                         | LRFD                             | ASD          | LRFD                    | ASD               | LRFD                    | ASD               | LRFD                    | ASD               | LRFD                    |
| Group A         | 45.0                        | 67.5                             | 44.7         | 67.1                    | 55.2              | 82.8                    | 66.8              | 100                     | 79.5              | 119                     |
| Group B         | 56.5                        | 84.8                             | 56.2         | 84.2                    | 69.3              | 104                     | 83.9              | 126                     | 99.8              | 150                     |
| A307            | 22.5                        | 33.8                             | 22.4         | 33.5                    | 27.6              | 41.4                    | 33.4              | 50.1                    | 39.8              | 59.6                    |
| ASD             | LRFD                        | 1001002013                       | Hoa R qu     | 1010 111011             | INTERNATION SAL   | Design The State        | 5 T-10 10 11      | paibsou                 | 90                | yT sloh                 |
| $\Omega = 2.00$ | φ = 0.75                    | 85                               |              |                         |                   |                         |                   |                         |                   |                         |

|   | S   | Slip-Critical Connections  | itic                         | <b>5</b> 20 20 20 20 20 20 20 20 20 20 20 20 20 | Table 7-3 (continued)<br>Critical Connec | od)<br>ctio            | ns                            | Group B<br>Bolts  | roup B<br>Bolts         |
|---|---|--|------------------------------|---|--|------------------------|-------------------------------|---|-------------------------|
|   | <b>~</b> <u>D</u>   | Available Shear Strength, kips (Class A Faying Surface, $\mu$ = 0.30)  | le Sh<br>Fayin               | ear Sing Sur                                    | trengi<br>face,                          | th, kip                |                               | A490, A490M<br>F2280<br>A354 Grade BD   | 90M                     |
| den   | 100   |  | 9                            | Group B Bolts                                   | olts                                     |                        |                               | 108   | 2                       |
| And about   | E Second  | Dhite (1)  | 000                          | Non   | Nominal Bolt Diameter, d, in.            | Diameter,              | d, in.                        | 20 S 10   | 070                     |
| 2   | LINE OHELL  | 8/9  |                              | COST ALL OF                                     | 3/4                                      | 1 0 8 1 1 N            | 8/2                           | 2   | -                       |
| 60  | incol   | 1886   | 0 Sa.                        | Minimum   | Minimum Group B Bolt Pretension, kips    | Bolt Preter            | ısion, kip                    | s   | 3 8                     |
| Hole Type   | Loading   | 24   |                              |   | 35                                       | 7                      | 49                            |   | 64                      |
|   | 100 l   | Ω/″ν   | or <sub>n</sub>              | Ω/u <sub>1</sub>                                | φŁ                                       | Γη/Ω                   | φŁ                            | Ω/η   | φľ                      |
| -1 60   |   | ASD  | LRFD                         | ASD   | LRFD                                     | ASD                    | LRFD                          | ASD   | LRFD                    |
| STD/SSLT  | s a   | 5.42   | 8.14                         | 7.91  | 11.9                                     | 11.1                   | 16.6                          | 14.5  | 21.7                    |
| OVS/SSLP  | s a   | 4.62   | 6.92                         | 6.74  | 10.1                                     | 9.44                   | 14.1                          | 12.3  | 18.4                    |
| TST   | sa  | 3.80   | 5.70                         | 5.54  | 8.31                                     | 7.76                   | 11.6                          | 10.1  | 15.2                    |
| -13   | 7 20 00 E   | 10000  | 5                            | Non   | Nominal Bolt Diameter, d, in.            | Diameter,              | d, in.                        | S (2.8) 0   | 0                       |
| la e  |   | 11/8   | 8,                           | 0.00  | 11/4                                     |                        | 13/8                          | 22  | 11/2                    |
| 100   | 33  | 0.00   | E                            | Minimum   | Minimum Group B                          | Bolt Pretension, kips  | nsion, kip                    | S   | 1                       |
| Hole Type   | Loading   | 80   |                              |   | 102                                      |                        | 121                           | ĺ   | 148                     |
| 5 (6)   |   | Ω/"  | φŁu                          | Γ <sub>n</sub> /Ω                               | φŁ                                       | r <sub>n</sub> /Ω      | ofn                           | r <sub>n</sub> /Ω   | φ <b>r</b> <sub>n</sub> |
|   | 2 4   | ASD  | LRFD                         | ASD   | LRFD                                     | ASD                    | LRFD                          | ASD   | LRFD                    |
| STD/SSLT  | s   | 18.1   | 27.1                         | 23.1  | 34.6                                     | 27.3                   | 41.0                          | 33.4  | 50.2                    |
|   | Q   | 36.2   | 54.2                         | 46.1  | 2.69                                     | 54.7                   | 82.0                          | 6.99  | 3                       |
| 0VS/SSLP  | s o   | 15.4   | 23.1                         | 19.6  | 29.4                                     | 23.3                   | 34.9                          | 28.5  | 42.6                    |
| S   | S   | 12.7   | 19.0                         | 16.2  | 24.2                                     | 19.2                   | 28.7                          | 23.4  | 35.1                    |
| 200   | d hole  | 25.3   | 38.0                         | 32.3  | 48.4                                     | S = single shear       | 57.4<br>shear                 | 46.9  | 70.7                    |
| UVS = oversized hole<br>SSLT = short-slotted h<br>SSLP = short-slotted h<br>LSL = long-slotted ho | VVS = oversized hole SSLI = short-slotted hole transverse to the line of force SSLP = short-slotted hole parallel to the line of force SSLP = long-slotted hole transverse or parallel to the line of force SSL = long-slotted hole transverse or parallel to the line of force | sverse to that the line of the | e line of force allel to the | orce<br>e<br>line of fo                         | 90                                       | D = double shear       | e shear                       |   |                         |
| Hole Type   | ASD   | LRFD   | Note: Slip                   | o-critical bol                                  | t values assi                            | ume no mor             | e than one                    | Note: Sip-critical bolt values assume no more than one filler has been provided   | n provide               |
| STD and SSLT  | $\Omega = 1.50$   | φ = 1.00   | See AISC                     | Specification                                   | aded to distr<br>on Sections .           | Dute loads 13.8 and J5 | n the Tillers<br>for provisio | or botts have been added to distribute loads in the fillers.  See AISC Specification Sections J3.8 and J5 for provisions when fillers | 20                      |
| OVS and SSLP  | $\Omega = 1.76$   | $\phi = 0.85$  | are present.                 | ent.  | rfaces, mult                             | inly the tabu          | lated avails                  | are present.<br>For Class B faving surfaces multiply the fabulated available strength by 1.67   | by 1.67.                |
| CI  |   | 020  | ו מו מומיים                  | D laying ~                                      | Hares, men                               | Iply tile teles        | ומופח מגמייי                  | IDIo oncube.  | Dy 1.01.                |

| Bolts  | ⋖  | Table 7-3 Slip-Critical Connections                                   | riti 🕆                       | Table 7-3                   | -3<br>onne                    | ctio                                 | SU   |                 |                 |
|--|--|---|------------------------------|-----------------------------|-------------------------------|--------------------------------------|--|-----------------|-----------------|
| A325, A325M<br>F1858<br>A354 Grade E   | າ ຕ  | Available Shear Strength, kips (Class A Faying Surface, $\mu$ = 0.30) | ole Sh<br>Fayir              | ear S<br>ng Sur             | treng<br>face,                | th, kiļ<br>μ = 0                     | .30)   |                 |                 |
| A449   | at Bott Dismit   | ter, 0, in.   | .p                           | Group A Bolts               | olts                          |                                      |  |                 |                 |
| 287.0%   | Ding Soft 108.   | 2 LL 2  | SAN D                        | Non                         | Nominal Bolt Diameter, d, in. | Diameter,                            | ď, in.   |                 | 100             |
|  | 7/29   | 2   | 2/8                          | " ā                         | 3/4                           |                                      | 8/2  |                 | -               |
| Hele There   | 0.000  | 5 4   | 100                          | Minimum                     | Group A                       | Bolt Prete                           | Minimum Group A Bolt Pretension, kips  | 8               |                 |
| ное іуре   | Loading  | 7,5425  | 19                           | 100                         | 28                            |                                      | 39   |                 | 21              |
|  |  | r <sub>n</sub> /Ω   | φŁ                           | ς/Ω                         | φŁ                            | ν,/Ω                                 | φŁ   | Ω/″             | φr <sub>n</sub> |
| 2 12 2   | 7,0%   | ASD   | LRFD                         | ASD                         | LRFD                          | ASD                                  | LRFD   | ASD             | LRFD            |
| STD/SSLT   | s o  | 4.29  | 6.44                         | 6.33                        | 9.49                          | 17.6                                 | 13.2   | 11.5            | 17.3            |
| OVS/SSLP   | sc   | 3.66  | 5.47                         | 5.39                        | 8.07                          | 7.51                                 | 11.2   | 9.82            | 14.7            |
| rsr  | S  | 3.01  | 4.51                         | 4.44                        | 6.64                          | 6.18                                 | 9.25   | 8.08            | 12.1            |
|  | 2  | 20.0  | 3.02                         | Non<br>Non                  | =                             | Diameter.                            | d. in.   | 16.2            | 24.2            |
|  | 0  |   | 11/8                         | 5                           | 11/4                          | 8 20                                 | 13/8   | E 65            | 11/2            |
|  |  |   |                              | Minimum                     | Group A                       | Bolt Prete                           | Minimum Group A Bolt Pretension, kips  |                 | 100             |
| noie lype  | Loading  | ū   | 26                           | S O                         | 1                             | 200                                  | 82   |                 | 103             |
|  | 0.53   | $r_n/\Omega$  | φľn                          | Γη/Ω                        | φľn                           | Ω/″J                                 | φŁ   | Ω/uJ            | φŁ              |
|  |  | ASD   | LRFD                         | ASD                         | LRFD                          | ASD                                  | LRFD   | ASD             | LRFD            |
| STD/SSLT   | s o  | 12.7  | 19.0                         | 16.0                        | 24.1                          | 19.2                                 | 28.8   | 23.3            | 34.9            |
| OVS/SSLP   | s  | 10.8  | 16.1                         | 13.7                        | 20.5                          | 16.4                                 | 24.5   | 19.8            | 29.7            |
| rsr  | s a  | 8.87  | 13.3                         | 11.2                        | 16.8                          | 13.5                                 | 20.2   | 16.3            | 24.4            |
| STD = standard hole OVS = oversized hole SSLT = short-slotted h SSLP = short-slotted h LSL = long-slotted hc | STD = standard hole  OVS = oversized hole  SSLT = short-slotted hole transverse to the line of force  SSLP = short-slotted hole parallel to the line of force  LSL = long-slotted hole transverse or parallel to the line of force | sverse to the   | e line of force allel to the | orce                        | 92                            | S = single shear<br>D = double shear | s shear<br>e shear   |                 | 8 8 5           |
| Hole Type  | ASD  | LRFD  | Note: Slip                   | -critical bolt              | values assu                   | ume no mor                           | Note: Slip-critical bolt values assume no more than one filler has been provided   | ller has beer   | provided r      |
| STD and SSLT   | $\Omega = 1.50$  | φ = 1.00  | See AISC                     | ave been ac<br>Specificatio | nded to distr<br>n Sections J | Dute loads   3.8 and J5              | or boits nave been added to distribute loads in the fillers.<br>See AISC <i>Specification</i> Sections J3.8 and J5 for provisions when fillers | s when filler   | s               |
| OVS and SSLP   | $\Omega = 1.76$  | φ = 0.85  | are present                  | nt.<br>D faving gur         | focos multi                   | olt the teh                          | 1000   | 4               |                 |
| TST  | $\Omega = 2.14$  | φ = 0.70  | ZI CIBS                      | D laying su                 | Taces, mun                    | ply the tabu                         | ror class o taying surfaces, muruply the tabulated available strength by 1.67.   | ile strengtii i | Jy 1.57.        |

| 11/6   ASD   LRFD   ASD   LRFD   ASD   LRFD   ASD   CR-2   ASD   CR-2   ASD   | 11  |
|---|---|
| Spacing, Fu, Ksi         Fu, Ksi         fn/fQ         ofn         fn/fQ           2s, in.         48D         LRFD         ASD           2s/s de         65         63.1         94.6         70.3           3in.         65         70.7         106         —           2s/s de         65         58.5         78.3         59.5           3in.         66         58.5         87.8         —           2s/s de         65         60.9         91.4         61.6           2s/s de         65         60.9         91.4         61.6           2s/s de         65         60.9         91.4         —           2s/s de         65         7.31         11.0         8.13           3in.         65         6.93         97.9         —           2s/s de         65         7.31         11.0         8.13           3in.         65         58.9         88.4         65.7   | No.   No.   Orn   No.   Orn   No.   Orn   No.   |
| $    \begin{array}{ccccccccccccccccccccccccccccccccc$   | 4FD         ASD         LRFD         ASD         LRFD         ASD           4.6         78.8         118         86.9         130         95.1           6         78.8         118         86.9         130         95.1           6.8         78.8         118         86.6         110         74.0           7.8         3.5         89.2         66.7         100         74.0           7.8         66.6         99.9         74.8         112         82.4           7.8         66.6         99.9         74.8         112         82.4           7.8         66.6         99.9         76.1         82.0         82.0           7.8         66.6         99.9         77.2         116         81.3         76.1           1.4         69.1         104         77.2         116         81.3         16.9         79.2           1.0         8.1         12.2         8.94         13.4         97.0         79.2           1.0         8.2         64.6         97.0         79.2         109         79.2           1.0         1.0         1.0         107         161         117   |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$   | 4.6 70.3 105 77.6 116 84.8 6.6 78.8 118 86.9 130 95.1 6.6 78.8 118 86.9 130 95.1 6.6 7 100 74.0 74.0 74.0 74.0 74.0 74.0 74.0 74  |
| 31n.     58     63.1     94.6     — $2^2/3$ $d_b$ 56     58.5     70.7     106     — $2^2/3$ $d_b$ 66     58.5     78.3     59.5       31n.     66     58.5     87.8     — $2^2/3$ $d_b$ 65     50.9     11.4     61.6 $2^2/3$ $d_b$ 65     60.9     91.4     60.1       31n.     66     60.9     91.4     — $2^2/3$ $d_b$ 66     7.31     11.0     8.13 $3^2/3$ $d_b$ 66     7.31     11.0     8.13 $3^2/3$ $d_b$ 66     7.31     11.0     8.13 $3^2/3$ $d_b$ 66     58.9     88.4     65.7 $3^2/3$ $d_b$ 65     58.9     88.4     65.7 $3^2/3$ $d_b$ 65     58.9     88.4     65.7 $3^2/3$ $d_b$ 66     58.9     88.4     — $3^2/3$ $d_b$ 66     58.9 </th <td>  10</td>  | 10  |
| $22/3$ $d_b$ $58$ $52.2$ $78.3$ $59.5$ $3$ in. $58$ $52.2$ $78.3$ $ 2^2/3$ $d_b$ $65$ $58.5$ $77.8$ $ 2^2/3$ $d_b$ $65$ $54.4$ $81.6$ $61.6$ $2^2/3$ $d_b$ $65$ $54.4$ $81.6$ $ 3$ in. $65$ $54.4$ $81.6$ $ 2^2/3$ $d_b$ $65$ $54.4$ $81.6$ $ 2^2/3$ $d_b$ $65$ $60.9$ $91.4$ $ 2^2/3$ $d_b$ $65$ $60.9$ $91.4$ $ 3$ in. $65$ $65.3$ $97.9$ $ 3$ in. $65$ $52.6$ $78.8$ $ 3$ in. $65$ $58.9$ $88.4$ $65.7$ $65.7$ $3$ in. $65$ $58.9$ $88.4$ $65.7$ $65.7$ $3$ in. $65$ $58.9$ $88.4$ $65.7$ $97.5$ $11$ $8 \ge s_{tull}$ $65$ $58.9$ $88.4$ $65.7$ $97.5$ $11$ $8 \ge s_{tull}$ $65$ $78.3$ $117.7$ $87.5$ $11$ $8 \ge s_{tull}$ $65$  | 8.3 59.5 66.7 100 74.0  7.8 66.6 99.9 74.8 112 82.9  7.8  |
| 3 in.     58     52.2 $78.3$ — $2^2/3$ $d_b$ 58     58.4     81.6     61.6     61.6 $3^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $3^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $3^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $2^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $3^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $3^2/3$ $d_b$ 65     60.9     91.4     69.1     1 $3^2/3$ $d_b$ 65     6.5     9.79     7.25     1 $3^2/3$ $d_b$ 65     65.3     97.9     1     1 $3^2/3$ $d_b$ 65     58.9     88.4     65.7     1 $3^2/3$ $d_b$ 65     72.5     1 $3^2/3$ $d_b$ 4/16       <  | 1.0   2.0 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$   | 1.6 61.6 92.4 68.9 103 76.1 1.4 69.1 104 77.2 116 88.3 1.4 — — — — — — — — — — — — — — — — — — —  |
| 3 in.     58     544     81.6     — $2^2l_3 d_b$ 58     6.53     91.4     — $2^2l_3 d_b$ 68     6.53     9.79     7.25       3 in.     65     6.53     9.79     — $2^2l_3 d_b$ 68     6.53     9.79     — $2^2l_3 d_b$ 68     58.9     88.4     65.7       3 in.     65     58.9     88.4     65.7       3 in.     66     58.9     88.4     65.7 $8 \ge s_{full}$ 66     58.9     88.4     65.7 $s \ge s_{full}$ 66     58.9     98.4     65.7 $s \ge s_{full}$ 66     58.9     97.9     72.5     11       strength     0VS     317/16     47/16       i.in.     SSLT     47/16     47/16   | 1.6 — — — — — — — — — — — — — — — — — — —   |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$   | 9.79 7.25 10.9 7.98 12.0 8.7 1.0 8.13 12.2 8.94 13.4 9.7 1.0 8.13 12.2 8.94 13.4 9.7 1.0  |
| 3 in.     58     6.53 $9.79$ — $2^2/3 d_b$ 58     58.6 $7.31$ $11.0$ — $2^2/3 d_b$ 58     58.9 $88.4$ $65.7$ 3 in.     58     58.9 $78.8$ — $s \ge s_{tull}$ 58 $78.3$ $11.7$ $87.0$ $11.7$ $s \ge s_{tull}$ 58 $87.8$ $11.7$ $87.0$ $11.7$ $s \ge s_{tull}$ 56 $65.3$ $97.9$ $11.7$ $97.5$ $11.7$ for tull $11.7$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ sylvin $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ sylvin $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ $11.0$ sylvin $11.0$   | 9.79 — — — — — — — — — — — — — — — — — — —  |
| $2^2/3$ db $\frac{58}{65}$ $\frac{52}{659}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{58.6}{65}$ $\frac{78.8}{65}$ — $s \ge s_{full}$ $\frac{58}{65}$ $\frac{78.3}{65}$ $\frac{117}{110}$ $\frac{87.0}{81.3}$ $\frac{11}{3}$ $s \ge s_{full}$ $\frac{58}{65}$ $\frac{65}{73.1}$ $\frac{11}{110}$ $\frac{81.3}{81.3}$ $\frac{1}{110}$ for full $\frac{581}{11}$ $\frac{37}{11}$ $\frac{4}{116}$ strength $\frac{39}{11}$ $\frac{4}{116}$ i.in. $\frac{581}{110}$ $\frac{39}{11}$ $\frac{4}{116}$  | 8.8 58.6 87.9 64.6 97.0 70.7 88.8 — — — — — — — — — — — — — — — — —   |
| 3 in. 65 52.6 78.8 —  s ≥ stull 65 87.8 117 87.0  s ≥ stull 65 87.8 132 97.5  s ≥ stull 65 73.1 110 81.3  subject that contain contai | 8.8 — — — — — — — — — — — — — — — — — —   |
| $s \ge s_{full}$ 58<br>56<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57<br>57   | 7 87.0 131 96.7 144 104<br>17.9 72.5 109 79.8 120 87.0<br>17.9 81.3 122 89.4 134 97.2<br>313/16 4 <sup>1</sup> /16 4 <sup>1</sup> /2<br>55/8 6 <sup>3</sup> /16 5 <sup>3</sup> /16  |
| 58   65.3   97.9   72.5     STD,   SSLT,   110   81.3     SSLT,   37/16   313/4     SSLP   33/4   41/8  | 313/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 43/16 55/16 33/14/16 35/16 31/14   |
| SSLT, 37/16 LSLT OVS 31 <sup>1</sup> /16 SSLP 33/4  | 313/16 43/16<br>41/16 47/16<br>41/8 41/2<br>55/8 63/16  |
| <b>OVS</b> 31/ <sub>16</sub> SSLP 33/ <sub>4</sub>  | 41/16 47/16 11/16<br>41/8 41/2 11/16<br>55/8 63/16 31/16  |
| SSLP 33/4   | 41/8 41/2<br>55/8 69/16<br>35/16 311/16   |
|   | 55/8 63/16<br>35/16 311/16  |
| <b>LSLP</b> 51/16   | 31/16   |
| Minimum Spacing <sup>a</sup> = $2^2/3d$ , in. 3 33/16   |   |

|   |  |                        | EL<br>U                               |                            | Nominal Bolt      | inal Bolt [  | Nominal Bolt Diameter, d, in. | d, in.  |                   |        |
|---|--|------------------------|---------------------------------------|----------------------------|-------------------|--------------|-------------------------------|---|-------------------|--------|
|   | Bolt   | 1                      |                                       | 2/8                        | Si quot           | 3/4          |                               | 1/8   |                   | -      |
| Hole lype   | spacing,<br>s, in.   | Liv KS                 | <b>Γ</b> η/Ω                          | φ <b>Γ</b> <sub>0</sub>    | Ω/uJ              | φľ           | Ω/uJ                          | φŁ  | r <sub>n</sub> /Ω | or.    |
|   |  | 81                     | ASD                                   | LRFD                       | ASD               | LRFD         | ASD                           | LRFD  | ASD               | LRFD   |
| STD   | 22/3 db  | <b>58</b>              | 34.1                                  | 51.1                       | 41.3              | 62.0         | 48.6                          | 72.9  | 55.8<br>62.6      | 83.7   |
| SSLT  | 3 in.  | 58                     | 43.5                                  | 65.3                       | 52.2              | 78.3         | 60.9                          | 91.4  | 67.4              | 101    |
|   | 22/3 db  | 85<br>65               | 27.6                                  | 41.3                       | 34.8              | 52.2<br>58.5 | 42.1                          | 63.1  | 47.1 52.8         | 70.7   |
| SEL   | 3 in.  | 85 58                  | 43.5                                  | 65.3                       | 52.2              | 78.3         | 60.9                          | 91.4  | 58.7              | 88.1   |
| 910   | 22/3 db  | 85<br>65               | 29.7                                  | 44.6                       | 37.0              | 55.5<br>62.2 | 44.2                          | 66.3  | 49.3              | 74.0   |
| 8   | 3 in.  | 85<br>65               | 43.5                                  | 65.3                       | 52.2              | 78.3         | 60.9                          | 91.4  | 60.9              | 91.4   |
|   | 22/3 db  |                        | 3.62                                  | 5.44 6.09                  | 4.88              | 6.53         | 5.08                          | 7.61  | 5.80              | 8.70   |
| 135   | 3 in.  | 85<br>85               | 43.5                                  | 65.3                       | 39.2              | 58.7         | 28.3                          | 42.4  | 17.4              | 26.1   |
|   | 2 <sup>2</sup> / <sub>3</sub> d <sub>b</sub>   | 58<br>65               | 28.4                                  | 42.6                       | 34.4              | 51.7         | 40.5                          | 68.0  | 46.5              | 69.8   |
| 1   | 3 in.  | 28<br>65               | 36.3                                  | 54.4                       | 43.5              | 65.3         | 50.8                          | 76.1  | 56.2              | 84.3   |
| STD, SSLT,<br>SSLP, OVS,<br>LSLP                                    | S ≥ Sfull  | 92 93                  | 43.5                                  | 65.3<br>73.1               | 52.2<br>58.5      | 78.3         | 60.9                          | 91.4  | 69.6              | 104    |
| LSLT  | S ≥ Sfull  | 58<br>65               | 36.3                                  | 54.4                       | 43.5              | 65.3         | 50.8                          | 76.1  | <b>58.0</b> 65.0  | 87.0   |
| Spacing for full  | for full   | STD,<br>SSLT,<br>LSLT  | · ·                                   | 115/16                     | 25                | 25/16        | 211                           | 211/16  | 31                | 31/16  |
| bearing strength  | strength   | SAO                    | 21                                    | 21/16                      | 27                | 27/16        | 213                           | 213/16  | 3.                | 31/4   |
| Sfull <sup>a</sup> , III.   | i  | SSLP                   | 2 - 2                                 | 21/8                       | 2                 | 21/2         | 27                            | 27/8  | 35                | 35/16  |
|   |  | LSLP                   | 21                                    | 213/16                     | 33                | 33/8         | 316                           | 315/16  | 4                 | 41/2   |
| STD = standard StD = standard SSLT = shord SSLP = shord OVS = overs | Winimum Spacing* = 2434, in.  STD = standard hole SSLT = short-slotted hole oriented transverse to the line of force SSLP = short-slotted hole oriented parallel to the line of force OVS = oversized hole | 9 oriented             | transverse                            | rse to the line of         | 2                 | 2            | 200                           | 29/16   | 7                 | 91/12  |
| LSLP = long<br>LSLT = long  | <ul> <li>long-slotted hole oriented parallel to the line of force</li> <li>long-slotted hole oriented transverse to the line of force</li> </ul>   | oriented proviented to | parallel to                           | the line of<br>to the line | force<br>of force |              |                               |   |                   | 100    |
| ASD   | LRFD   | Note: Spar             | sing indicate                         | ed is from the             | ne center of      | the hole or  | slot to the d                 | Note: Spacing indicated is from the center of the hole or slot to the center of the adjacent hole or slot in the line of force. Hole deformation is considered When hole deformation is not considered. | adjacent h        | ole or |
|   |  | see AISC               | see AISC Specification Section J3.10. | Section J3                 | .10.              | Olloword     | WINDLI HOLD                   | diginianon  | IO HOL USING      |        |

| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | Edge Le fin.  Le in.  ASD  LRFD  ASD  ASD  ASD  ASD  ASD  ASD  ASD  A   | Type Distance $F_{ab}$ Ksi $\frac{11/a}{L_{ab}}$ in. $\frac{11/a}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{11/a}{L_{ab}}$ $\frac{6n}{L_{ab}}$ $\frac{111}{L_{ab}}$ $11$ | Nominal Bolt Diameter, d, in. |
|--|--|--|-------------------------------|
| Les in.  Les in.  ASD LHFD ASD LHFD ASD LHFD ASD LHFD  2 65 22.8 34.3 20.7 31.0 18.5 27.7  2 65 54.8 82.3 52.4 78.6 50.0 75.0  11/4 65 20.7 31.1 25.6 14.6 66.9  2 65 43.8 65.3 17.1 25.6 14.6 21.9  2 65 43.8 65.3 17.1 25.6 14.6 21.9  2 65 43.8 65.3 17.1 25.6 14.6 21.9  2 65 20.7 31.1 18.3 24.5 14.1 21.2  11/4 65 20.7 31.1 18.3 27.4 15.8 23.8  2 65 23.2 34.7 17.1 25.6 14.1 21.2  2 65 23.2 34.7 17.1 25.6 14.1 21.2  11/4 65 20.7 31.0 15.2 22.8 9.79 14.7  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.2 34.7 17.1 25.6 11.0 16.5  2 65 23.3 32.0 19.3 28.9 17.3 28.9 17.3 25.9  2 65 23.3 37.0 19.3 28.9 17.3 25.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 25.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 28.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 28.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 25.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 28.9 17.3 25.9  2 65 21.3 32.0 19.3 28.9 17.3 28.9 17.3 25.9  2 65 21.3 32.0 19.3 32.0 18.3 12.2 89.4 13.4 13.4  2 7 8 65 3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65 73.1 11.0 81.3 12.2 89.4 13.4  2 8 65.3 97.9 72.5 10.9 79.8 12.0  2 8 65.3 97.9 72.5 10.9 79.8 12.0  3 7 7 8 7 8 8 7 8 12.0  4 7 16 1 1 1  4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  | 1796   Distance   $I_{tot}$  | 1ype   Distance   $r_{to}$  | 13/8                          |
| 4SD         LRFD         ASD         <  | $ \begin{array}{c c c c c c c c c c c c c c c c c c c $  | 11/4   58   22.8   34.3   20.7   31.0   11     1   | φĽ                            |
| 11/4         58         22.8         34.3         20.7         31.0         18.5         27.7           2         58         48.9         73.4         46.8         70.1         44.6         66.9           1/4         58         17.4         26.1         15.2         22.8         13.1         19.6           2         66         54.8         82.3         52.4         78.6         50.0         75.0           2         65         54.8         82.3         52.4         13.1         19.6           2         65         48.8         73.1         46.3         69.5         43.9         65.8           2         65         48.8         73.1         46.3         69.5         43.9         65.8           11/4         65         20.7         31.1         18.3         27.4         14.1         21.2           2         65         50.0         75.0         47.5         71.3         45.1         67.6           2         65         50.0         75.0         47.5         71.1         25.0         14.7           2         65         20.3         34.7         17.1         25.6         11.0   | Tital   See   22.8   34.3   20.7   31.0   18.5   27.7   18.5   22.7   31.1   19.6   22.5   38.4   23.2   34.7   20.7   31.1   19.6   25.6   38.4   23.2   34.7   20.7   31.1   19.6   25.6   54.8   82.3   52.4   78.6   50.0   75.0   44.6   66.9   45.6   19.5   29.3   17.1   25.6   19.5   29.3   17.1   25.6   19.5   29.3   27.4   15.8   23.8   19.6   29.7   27.7   16.3   27.4   15.8   23.8   19.6   29.7   27.7   25.6   27.3   27.3   27.3   27.4   27.8   27.3   27.4   27.8   27.3   27.3   27.4   27.8   27.3   27.4   27.8   27.3   27.3   27.4   27.8   27.3   27.3   27.4   27.8   27.3  | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | LRFD                          |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$  | 17   2   56   548   73.4   46.8   70.1   44.6   66.9   46.6   54.8   82.3   52.4   78.6   50.0   75.0   49.   73.4   46.8   70.1   44.6   66.9   75.0   49.   73.1   46.3   62.0   39.2   58.7   39.2   65.3   41.3   62.0   39.2   58.7   39.2   65.3   41.3   65.3   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   43.9   65.8   44.5   66.9   47.5   71.3   45.1   67.6   42.4   65.9   67.6   42.4   65.9   67.0   47.5   71.3   45.1   67.6   47.5   71.3   47.5   71.3   47.5   71.3   71.5   71  | 17   2   56   48.9   73.4   46.8   70.1     18   2   65   54.8   82.3   52.4   78.6   54.8   82.3   52.4   78.6   55.8     19   2   65   54.8   82.3   52.4   78.6   55.8     19   2   65   64.3   65.3   17.1   25.6   17.1     19   2   65   20.7   31.1   18.3   27.4   18.3     11/4   65   20.7   31.7   16.3   24.5   17.1     2   65   20.7   31.7   18.3   27.4   17.1     11/4   65   20.7   31.7   17.1   25.6   17.2     10   2   58   20.7   31.7   17.1   25.6   17.2     10   2   58   20.7   31.7   17.1   25.6   17.2     10   2   58   20.7   31.7   17.1   25.6   17.2     11/4   65   23.2   34.7   17.1   25.6   17.2     12   65   23.2   34.7   17.1   25.6   17.2      10   2   58   20.7   31.0   15.2   22.8   17.2      10   2   58   20.7   31.7   17.1   25.6   17.2      10   2   58   20.7   31.7   25.6   17.2      10   2   2   20.8   20.7   20.5   10.9      10   2   2   2   2   2   2      11   $L_0 \ge L_0 tuu^{\dagger}$  | 27.7                          |
| 1/4         66         54.8         82.3         52.4         78.6         50.0         75.0           11/4         58         17.4         26.1         16.2         22.8         13.1         19.6           2         68         13.5         65.3         41.3         60.5         39.2         65.8           1/4         58         48.5         65.3         41.3         60.5         43.9         65.8           2         58         44.6         66.9         42.4         63.6         43.2         65.8           2         58         44.6         66.9         42.4         63.6         40.2         60.4           2         58         20.7         31.0         15.2         22.8         14.7         67.6           11/4         65         20.0         75.0         47.5         71.3         45.1         67.6           2         68         50.0         75.0         47.5         71.3         45.1         67.6           2         68         20.7         31.0         15.2         22.8         14.7         16.1         11           2         68         20.3         17.2         25.8   | 1/4   65   54.8   82.3   52.4   78.6   50.0   75.0   4     1/4   58   17.4   26.1   15.2   22.8   13.1   19.6   1     2   65   43.5   65.3   41.3   62.0   39.2   52.8   31.1   19.6   1     2   65   48.5   73.1   46.3   69.5   43.9   65.8   43.9     1/4   65   20.7   31.1   18.3   27.4   15.8   23.8   1     1/4   65   50.0   75.0   47.5   71.3   45.1   67.6   4      1   4   65   20.7   31.0   15.2   22.8   97.9   14.7      1   4   65   23.2   34.7   17.1   25.6   11.0   16.5      1   58   20.7   31.0   15.2   22.8   97.9   14.7      1   4   65   23.2   34.7   17.1   25.6   11.0   16.5      1   5   5   5   5   5   5   5      1   4   65   23.2   34.7   17.1   25.6   11.0   16.5      1   5   5   5   5   5   5   5      1   5   5   5   5   5      1   5   6   5   3   3      1   5   6   5   3      1   6   5   5   5      1   5   6   5   5      1   5   7   7   7      1   6   7   7      1   6   7   7      1   7   6   7   7      1   7   6   7   7      2   6   5   23.2   34.7   17.1   25.6   11.0   16.5      1   7   6   7   7      1   7   6   7   7      1   8   7   8   7   8      1   8   7   8   7   8      1   8   7   8   7      1   8   7   8   7      1   8   7   8   7      1   8   7   8   7      2   6   6   7   7      3   7   7   8      4   7   7   7      5   7   8      5   8   7   8      6   7   8   7      7   8   7   8      8   7   8   7      8   7   8   7      8   8   7   8      8   7   8   7      8   7   8   7      8   8   8   7      9   8   7      1   | LP   1/4   65   54.8   82.3   52.4   78.6   5   5   5   5   5   5   5   5   5  | 6.99                          |
| 11/4         58         17.4         26.1         15.2         22.8         13.1         19.6           2         68         19.5         29.3         17.1         25.6         13.1         19.6           2         66         48.8         73.1         46.3         65.3         41.3         65.9         58.7           11/4         66         20.7         31.1         18.3         27.4         15.8         23.8           2         65         20.7         31.1         18.3         27.4         15.8         23.8           2         65         50.0         75.0         47.5         71.3         45.1         67.6           11/4         65         20.7         31.0         15.2         22.8         9.7         17.1         25.6         11.0         16.5           2         65         20.3         34.7         17.1         25.6         11.0         16.5           4.5         65         21.3         32.0         19.3         28.9         17.3         25.9           5         65         21.3         32.0         19.3         28.9         17.3         25.9           6         5 <td>  11/4   58   17.4   26.1   15.2   22.8   131   19.6   1   2   65   3   41.3   62.0   39.2   58.8   43.9   65.8   4   46.3   46.3   49.5   62.9   31.1   18.3   27.4   15.8   23.8   1   19.6   1   1   1   1   1   1   1   1   1  </td> <td>LP 2 68 17.4 26.1 15.2 22.8 1 15.1 25.6 1 15.2 22.8 1 15.2 2.8 1 15.2 25.8 1 15.2 25.8 1 15.2 25.8 1 15.2 25.6 1 15.2 25.8 1 15.2 25.6 1 15.2 25.8 1 15.2 25.8 1 15.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 27.4 1 16.3 27.4 1 16.3 27.4 1 16.3 27.4 1 17.4 66 20.7 31.0 15.2 22.8 1 17.3 25.6 1 16.3 24.7 17.1 25.6 1 16.3 24.7</td> <td>75.0</td> | 11/4   58   17.4   26.1   15.2   22.8   131   19.6   1   2   65   3   41.3   62.0   39.2   58.8   43.9   65.8   4   46.3   46.3   49.5   62.9   31.1   18.3   27.4   15.8   23.8   1   19.6   1   1   1   1   1   1   1   1   1  | LP 2 68 17.4 26.1 15.2 22.8 1 15.1 25.6 1 15.2 22.8 1 15.2 2.8 1 15.2 25.8 1 15.2 25.8 1 15.2 25.8 1 15.2 25.6 1 15.2 25.8 1 15.2 25.6 1 15.2 25.8 1 15.2 25.8 1 15.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 24.5 1 16.3 27.4 1 16.3 27.4 1 16.3 27.4 1 16.3 27.4 1 17.4 66 20.7 31.0 15.2 22.8 1 17.3 25.6 1 16.3 24.7 17.1 25.6 1 16.3 24.7   | 75.0                          |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$  | LP 2 58 43.5 65.3 41.3 62.0 39.2 58.7 3 65.8 4 65.8 4 65.8 4 8 73.1 46.3 69.5 43.9 65.8 4 8 73.1 46.3 69.5 43.9 65.8 4 8 73.1 46.3 69.5 43.9 65.8 4 8 73.1 46.3 69.5 43.9 65.8 4 8 8 73.1 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 18.3 27.4 15.8 23.8 11 19.8 20.7 31.0 15.2 22.8 9.79 14.7 17.1 2 65 23.2 34.7 17.1 25.6 11.0 16.5 21.3 32.0 19.3 28.9 17.3 25.9 14.7 2 65.5 37.2 55.9 17.3 25.9 17.3 25.9 17.3 25.9 17.3 28.5 17.3 28.9 1  | LP 2 66 48.5 73.1 46.3 62.0 3 65.5 41.3 62.0 3 65.5 48.8 73.1 46.3 69.5 48.8 73.1 46.3 69.5 48.8 73.1 46.3 69.5 48.8 73.1 46.3 69.5 48.8 73.1 18.3 27.4 11.4 65 20.7 31.0 15.2 22.8 11.4 65 20.7 31.0 15.2 22.8 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65 21.3 32.0 19.3 28.9 11.4 65.5 49.5 146 11.4 65 65.5 49.5 146 11.4 65 65.5 49.5 146 11.4 65 65.5 49.5 146 11.4 65 65.5 11.4 65  | 19.6                          |
| 11/4         58         18.5         27.7         16.3         24.5         14.1         21.2           2         58         44.6         66.9         42.4         63.6         40.2         60.4           11/4         58         —   | 11/4   58   18.5   27.7   16.3   24.5   14.1   21.2   1   2.2   2.3   2.4   2.4   2.4   2.3   2.4   2.5   2.3   2.4   2.5   2.3   2.4   2.3   2.3   2.4   2.3   2.3   2.4   2.3   2.3   2.4   2.3  | LP   11/4   665   20.7   31.1   18.3   24.5   1   18.3   27.4   1   18.3   27.4   1   18.3   27.4   1   18.3   27.4   1   18.3   27.4   1   18.3   27.4   1   1   2   65   50.0   75.0   47.5   71.3   4   2   2   2   2   2   2   2   2   2   | 58.7                          |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | LP 2 58 44.6 66.9 42.4 63.6 40.2 60.4 3 7 1.3 45.1 67.6 4 3 6.5 50.0 75.0 47.5 71.3 45.1 67.6 4 3 6.5 50.0 75.0 47.5 71.3 45.1 67.6 4 3 7 1.3 45.1 65.5 6 6.5 50.0 75.0 15.2 22.8 9.79 14.7 7 17.1 25.6 11.0 16.5 7 1.3 20.0 19.3 28.9 17.3 25.9 1 1.7 2 6.5 21.3 32.0 19.3 28.9 17.3 25.9 1 1.0 28.5 17.2 25.8 15.4 23.1 1 1 2 6.5 40.8 61.2 39.0 58.5 37.2 55.7 3 6.5 5 41.6 62.5 37.2 55.7 3 1 1.7 87.0 131 95.7 144 10 10 1 11 11 11 11 11 11 11 11 11 11 1  | LP   11/4   58   50.0   75.0   47.5   71.3   4     11/4   58   20.7   31.0   15.2   22.8     12   65   23.2   34.7   17.1   25.6   1     13   2   65   23.2   34.7   17.1   25.6   1     14   65   23.2   34.7   17.1   25.6   1     15   58   20.7   31.0   15.2   22.8   1     17   65   23.2   34.7   17.1   25.6   1     18   65   23.2   34.7   17.1   25.6   1     19   65   21.3   32.0   19.3   28.9   1     10   10   10   10   10   10     10   10   | 21.2 23.8                     |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$  | LP 2 58 20.7 31.0 15.2 22.8 9.79 14.7 2 56.5 11.0 16.5 2.2 22.8 9.79 14.7 2 56.5 23.2 34.7 17.1 25.6 11.0 16.5 2.9 11.0 16.5 23.2 34.7 17.1 25.6 11.0 16.5 2.9 11.0 16.5 2.9 28.9 14.7 17.1 25.6 11.0 16.5 2.9 11.0 28.5 17.2 25.9 1 17.3 25.9 2 25.9 1 17.3 25.9 2.9 2.9 2.9 2.9 2.9 2.9 2.9 2.9 2.9 2   | LP 2 58 20.7 31.0 15.2 22.8 15.6 23.2 34.7 17.1 25.6 17.1 25.6 17.1 25.8 19.0 28.5 17.1 25.8 19.0 28.5 17.1 25.8 19.0 28.5 17.1 25.8 19.0 28.5 17.2 25.8 19.0 28.5 17.2 25.8 19.0 28.5 17.3 25.8 19.0 28.5 17.3 20.0 19  | 60.4                          |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | 1   2   58   20.7   31.0   15.2   22.8   9.79   14.7   14.7   55.6   11.0   16.5   11.0   11.0   16.5   11.0   | LT   $t_0 = 2$   | 11                            |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | 11/4   58   19.0   28.5   17.2   25.8   15.4   23.1     2   58   40.8   61.2   39.0   58.5   37.2   55.7     2   58   40.8   61.2   39.0   58.5   37.2   55.7     3   50.85   41.6   62.5     4   5   5   5   5   5     5   5   5   5  | LT 2 58 19.0 28.5 17.2 25.8 28.9 LT 2 28.9 28.9 28.9 28.9 28.9 28.9 28.9 28  | 14.7                          |
| Le≥ Le tuti 65 45.7 68.6 43.7 65.5 37.2 55.7 55.7 66.2 65 45.7 66.5 41.6 62.5 41.6 62.5 45.7 65.8 43.7 65.5 41.6 62.5 41.6 62.5 41.6 65.8 43.7 131 95.7 144 11 140 11.2 81.3 12.2 89.4 134 120 81.3 122 89.4 134 134 134 122 82.1, $27/8$ 83.7 139.7 139.7 139.7 140 134 134 134 134 134 134 134 134 134 134   | SSLT, $L_0 \ge L_0$ full $L_0$   | SSLT,   SSL  | 23.1                          |
| $L_{e} \geq L_{e} \ \textit{full} \ \ \begin{array}{ccccccccccccccccccccccccccccccccc$   | SSLT, 108, $L_e \geq L_e  tuu$ 65 87.8 117 87.0 131 95.7 144 11 140 87.0 131 95.7 144 11 140 87.8 132 97.5 146 107 161 11 158 65.3 97.9 72.5 109 79.8 120 15.  | SSLT, Le > Le null 65 87.8 117 87.0 131 146 1 1  | 55.7<br>62.5                  |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$   | Le Le $nul$ 58         65.3         97.9         72.5         109         79.8         120           dge distance strength         SSL, strength         27/8         3 $^{3}$ /16         3 $^{3}$ /16         3 $^{1}$ /2           e ≥ Le $nul^{4}$ , in.         SSLP         3         3 $^{5}$ /16         3 $^{5}$ /16         3 $^{5}$ /16           e ≥ Le $nul^{4}$ , in.         SSLP         3         3 $^{5}$ /16         3 $^{5}$ /16         4 $^{1}$ /2           e > Le $nul^{4}$ , in.         LSLP         31 $^{1}$ /16         4 $^{1}$ /16         4 $^{1}$ /2           e standard hole         stort-slotted hole oriented parallel to the line of force         e noversized hole         e noversized hole           e noversized hole         e noversized hole         e noversized hole         e noversized hole         e noversized hole  | dge distance         SSL, sure attended by the strength         SSL, sure attended by the strength $33/16$ $33/16$ e Le und, im.         SIC, strength         31/16 $35/16$ e S Le und, im.         SSLP         3 $35/16$ e standard hole         Stort-slotted hole oriented transverse to the line of force $41/16$ e short-slotted hole oriented parallel to the line of force         e short-slotted hole   | 144                           |
| Edge distance SSLT, $2^7/8$ $3^3/16$ for full bearing LSLT $3^3/16$ $3^3/16$ strength OVS $3$ $3^5/16$ $1_e \ge L_e  \ell_{edf}^2$ , in. SSLP $3$ $3^5/16$ $1_{eff}$   | dge distance SSLT, $2^7/_{\rm R}$ $3^3/_{\rm R}$ strength OVS $3$ $3^5/_{\rm R}$ $3^5/_{\rm R}$ strength OVS $3$ $3^5/_{\rm R}$ $3^$ | dge distance SSLT, $27/8$ r full bearing LSLT $27/8$ strength OVS $3$ $e^{2} L_{e} turl^{2}$ , in. SSLP $3$ = standard hole $3$ = short-slotted hole oriented transverse to the line of force oversized hole   | 120                           |
| strength ovs 3 $3^5/16$ $L_0 \ge L_0 t \omega l^3$ , in. SSLP 3 $3^5/16$ $4^1/16$  | strength     OVS     3 $3^5/16$ $e \ge L_{\theta} tu_0 l^2$ , in.     SSLP     3 $3^5/16$ Estandard hole     311/16 $4^1/16$ = short-slotted hole oriented transverse to the line of force       = short-slotted hole oriented parallel to the line of force       = oriens/slotted hole oriented parallel to the line of force       = long-slotted hole oriented parallel to the line of force   | e $\geq$ Le tust <sup>2</sup> , in.     OVS     3       e $\geq$ Le tust <sup>2</sup> , in.     SSLP     3       LSLP     311/ $_{16}$ = standard hole     311/ $_{16}$ = short-slotted hole oriented transverse to the line of force       = short-slotted hole oriented parallel to the line of force       = oversized hole   | 31/2                          |
| $L_{\theta} \ge L_{\theta} t_{\theta} l^{\theta}$ , in. SSLP 3 35/16 47/16 47/16   | $e \ge L_{\theta}  tun^2$ , in. SSLP 3 $3^5/16$ $4^7/16$ $1$ SLP $3^{11}/16$ $4^7/16$ $4^7/16$ standard hole short-slotted hole oriented transverse to the line of force a short-slotted hole oriented parallel to the line of force = oversized hole oriented parallel to the line of force = long-slotted hole oriented parallel to the line of force = long-slotted hole oriented parallel to the line of force   | $e \ge L_{\theta}  tul^{2},  \text{in.}$ SSLP $3$ LSLP $3^{1}/\Lambda_{6}$ = standard hole = short-slotted hole oriented transverse to the line of force = short-slotted hole oriented parallel to the line of force = oversized hole  | 35/8                          |
| 13.8 GZ.8 LSLP 80.331/16 S.9 41/16   | = standard hole = short-slotted hole oriented transverse to the line of force = short-slotted hole oriented parallel to the line of force = oversized hole = long-slotted hole oriented parallel to the line of force  | = standard hole = short-slotted hole oriented transverse to the line of force = short-slotted hole oriented parallel to the line of force = oversized hole   | 35/8                          |
|  | = standard hole = short-slotted hole oriented transverse to the line of forc = short-slotted hole oriented parallel to the line of force = oversized hole = oversized hole oriented parallel to the line of force = Inon-slotted hole oriented parallels to the line of force  | = standard hole<br>= short-slotted hole oriented transverse to the line of force<br>= short-slotted hole oriented parallel to the line of force<br>= oversized hole  | 41/2                          |

| Hole Type  |  |   | 호  | s/in.  | kips/in. thickness             | ness   |   |   |                         |                    |
|--|--|---|--|--|--------------------------------|--|---|---|-------------------------|--------------------|
| Hole Type  |  | seter, o' li  | Bolf Dist                                | Isalmo#  | Nom                            | inal Bolt I  | Nominal Bolt Diameter, d, in.                         | ď, in.  |                         |                    |
| add and  | Edge   | io.   |  | 8/9  |                                | 3/4  | Control   | 8/2   | B                       | -                  |
| 1000   | $L_{\theta}$ , in.   | E NO  | Γ <sub>n</sub> /Ω                        | φr <sub>n</sub>  | ν,/Ω                           | φŁu  | Ω/u <sub>1</sub>                                      | φ <b>r</b> <sub>n</sub>   | r,/12                   | Or.                |
| DAR, L.  | SA CITY  | \$D   | ASD                                      | LRFD   | ASD                            | LRFD   | ASD   | LRFD  | ASD                     | LRFD               |
| E S  | 11/4   | 58  | 31.5                                     | 47.3   | 29.4                           | 44.0   | 27.2  | 40.8  | 25.0                    | 37.5               |
| SSLT   | 0  | 28  | 43.5                                     | 65.3   | 52.2                           | 78.3   | 53.3  | 79.9  | 51.1                    | 76.7               |
|  | 4  | 65  | 48.8                                     | 73.1   | 58.5                           | 87.8   | 29.7  | 9.68  | 57.3                    | 85.9               |
| 9133   | 11/4   | 85<br>85  | 28.3                                     | 42.4   | 29.3                           | 39.2   | 23.9  | 35.9  | 23.2                    | 34.7               |
| 395  | 2  | 58  | 43.5                                     | 65.3   | 52.2                           | 78.3   | 50.0  | 75.0  | 46.8                    | 70.1               |
|  | 11/4   | 58  | 29.4                                     | 44.0   | 27.2                           | 40.8   | 25.0  | 37.5  | 24.4                    | 32.6               |
| SAO  | 2  | 58  | 43.5                                     | 65.3   | 52.2                           | 78.3   | 51.1  | 76.7  | 47.9                    | 71.8               |
|  | 11/4   | 58  | 16.3                                     | 24.5   | 10.9                           | 16.3   | 5.44  | 8.16  | 11                      | 11                 |
| LSL  | 2  | 58  | 42.4                                     | 63.6   | 37.0                           | 55.5   | 31.5  | 47.3  | 26.1                    | 39.2               |
| - ca   | 11/4   | 58  | 26.3                                     | 39.4   | 24.5                           | 36.7   | 22.7  | 34.0  | 20.8                    | 31.3               |
| 181  | 2  | 92<br>92  | 36.3                                     | 54.4   | 43.5                           | 65.3   | 44.4  | 66.6  | 42.6                    | 63.9               |
| STD, SSLT,<br>SSLP, OVS,   | Le > Le full   | 58<br>65  | 43.5                                     | 65.3   | 52.2                           | 78.3   | 60.9  | 91.4  | 69.6                    | 104                |
| LSLT   | Le > Le full   | 58  | 36.3                                     | 54.4   | 43.5                           | 65.3   | 50.8  | 76.1  | 58.0                    | 87.0<br>97.5       |
| Edge distance  | tance  | STD,<br>SSLT,<br>LSLT   | 15/8                                     |  |                                | 115/16   | 21/4  |   | of 101 29               | 29/16              |
| strength   | ath  | OVS   | 11                                       | 111/16   | 2                              | 362  | 25  | 25/16   | 25/8                    | 8                  |
| $L_e \ge L_e tul^a$ , in.  | illa, in.  | SSLP  | -  | 111/16   | 2                              |  | 25  | 25/16   | 21                      | 211/16             |
|  | Circle 7/5   | LSLP  | 21/16                                    | 32 · 191   | 2                              | 27/16  | 27/8  | - 5519 <b>8</b>   | 31/4                    | 4                  |
| STD = stand<br>SSLT = short-<br>SSLP = short-<br>OVS = oversi<br>LSLP = long-& | e standard hole  = short-slotted hole oriented transverse to the line of force  = short-slotted hole oriented parallel to the line of force  = oversized hole = long-slotted hole oriented parallel to the line of force  = long-slotted hole oriented transverse to the line of force | oriented to oriented poriented poriented poriented poriented poriented tr | ransverse<br>parallel to<br>arallel to i | to the line<br>the line of<br>the line of<br>to the line                         | e of force<br>f force<br>force | and actions in the first of the | mest betne<br>ersq betne<br>lersq betn<br>arient betn | Sinc alort in<br>and slock the<br>stol<br>stol<br>stol afort it   |                         | JAH BING H         |
| ASD  | LRFD   | - indicate  | es spacing                               | ess than m   | inimum spa                     | icing require  | ed per AISC   | - indicates spacing less than minimum spacing required per AISC Specification Section J3.3.   | n Section J             | 3.3.               |
| 0-200  | φ=0.75   | Note: Spac  | ing indicate                             | Note: Spacing indicated is from the c<br>slot in the line of force. Hole deforma | ne center of<br>rmation is o   | the hole or<br>considered.   | slot to the<br>When hole                              | Note: Spacing indicated is from the center of the hole or slot to the center of the adjacent hole of slot in the line of stores. Hole deformation is considered. When hole deformation is not considered. | e adjacent lis not cons | nole of<br>idered, |