Connection and Tension Member Design

Notation:

A = area (net = with holes, bearing = in contact, etc...)

A_e = effective net area found from the product of the net area A_n by the shear lag factor U

A_b = area of a bolt

A_g = gross area, equal to the total area ignoring any holes

A_{gv} = gross area subjected to shear for block shear rupture

A_n = net area, equal to the gross area subtracting any holes, as is A_{net}

A_{nt} = net area subjected to tension for block shear rupture

A_{nv} = net area subjected to shear for block shear rupture

ASD = allowable stress design

d = diameter of a hole

f_p = bearing stress (see P)

f_t = tensile stress

f_v = shear stress

$F_{connector}$ = shear force capacity per connector

F_n = nominal tension or shear strength of a bolt

F_u = ultimate stress prior to failure

F_{EXX} = yield strength of weld material

F_y = yield strength

F_{yw} = yield strength of web material

g = gage spacing of staggered bolt holes

I = moment of inertia with respect to neutral axis bending

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

l = name for length

L = name for length

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

$LRFD$ = load and resistance factor design

n = number of connectors across a joint

N = bearing length on a wide flange steel section

= bearing type connection with threads included in shear plane

p = pitch of connector spacing

P = name for axial force vector, as is T

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

R_a = required strength (ASD)

R_n = nominal value (capacity) to be multiplied by ϕ

R_u = factored design value for LRFD design

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

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

SC = slip critical bolted connection

t = thickness of a hole or member

t_w = thickness of web of wide flange

T = throat size of a weld

V = internal shear force

$V_{longitudinal}$ = longitudinal shear force

U = shear lag factor for steel tension member design

U_{bs} = reduction coefficient for block shear rupture

X = bearing type connection with threads excluded from the shear plane

y = vertical distance

π = pi (3.1415 radians or 180°)

ϕ = resistance factor

= diameter symbol

γ = load factor in LRFD design

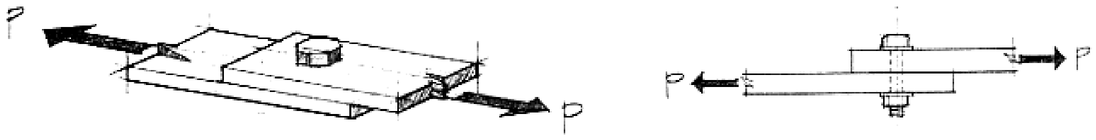
Ω = safety factor for ASD

Σ = summation symbol

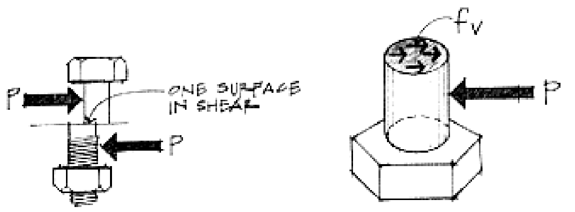
Connections

Connections must be able to transfer any axial force, shear, or moment from member to member or from beam to column. Steel construction accomplishes this with bolt and welds. Wood construction uses nails, bolts, shear plates, and split-ring connectors.

Single Shear - forces cause only one shear "drop" across the bolt.



(a) Two steel plates bolted using one bolt. *(b) Elevation showing the bolt in shear.*



f_v = Average shear stress through bolt cross section

A = Bolt cross-sectional area

$$f_v = \frac{P}{A} = \frac{P}{\pi r^2}$$

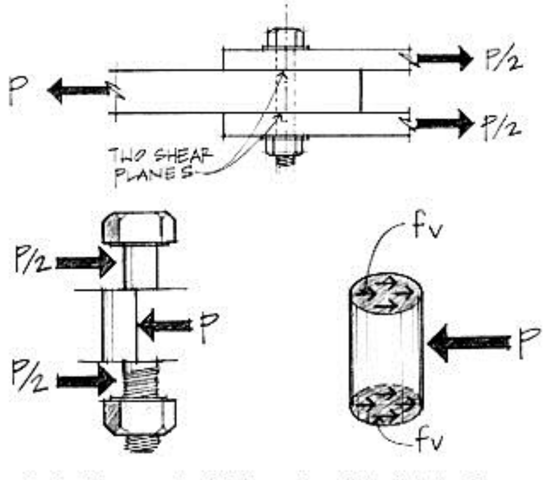
(c) *(d)*

Figure 5.11 A bolted connection—single shear.

Double Shear - forces cause two shear changes across the bolt.

$$f_v = \frac{P}{2A} = \frac{P}{2\pi r^2}$$

(two shear planes)

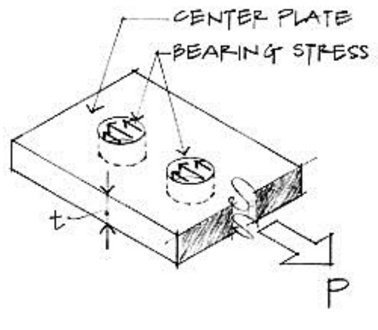


Free-body diagram of middle section of the bolt in shear.

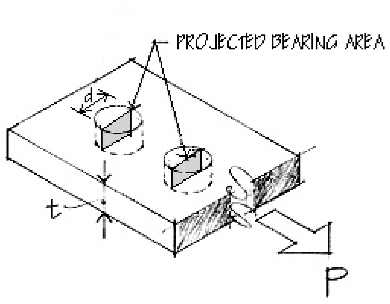
Figure 5.12 A bolted connection in double shear.

Bearing of a Bolt on a Bolt Hole – The bearing surface can be represented by *projecting* the cross section of the bolt hole on a plane (into a rectangle).

$$f_p = \frac{P}{A} = \frac{P}{td}$$



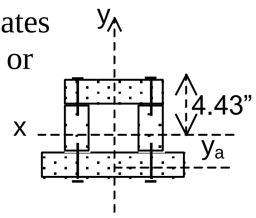
Bearing stress on plate.

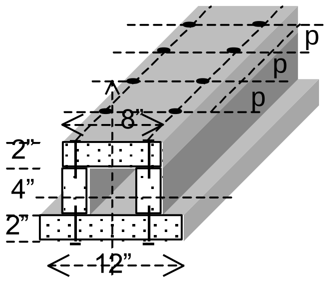


Horizontal Shear in Composite Beams

Typical connections needing to resist shear are plates with nails or rivets or bolts in composite sections or splices.

The pitch (spacing) can be determined by the capacity in shear of the connector(s) to the shear flow over the spacing interval, p.





$$\frac{V_{longitudinal}}{p} = \frac{VQ}{I} \qquad V_{longitudinal} = \frac{VQ}{I} \cdot p$$

where

$$nF_{connector} \geq \frac{VQ_{connected\,area}}{I} \cdot p$$

p = pitch length

n = number of connectors connecting the connected area to the rest of the cross section

F = force capacity in one connector

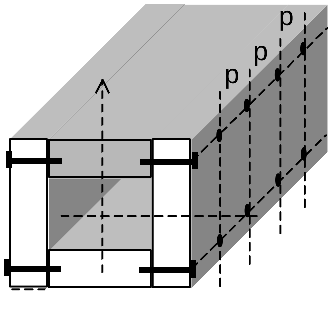
$Q_{connected\ area} = A_{connected\ area} \times y_{connected\ area}$

$y_{connected\ area}$ = distance from the centroid of the connected area to the neutral axis

Connectors to Resist Horizontal Shear in Composite Beams

Even vertical connectors have shear flow across them.

The spacing can be determined by the capacity in shear of the connector(s) to the shear flow over the spacing interval, p.



$$p \leq \frac{nF_{connector}I}{VQ_{connected\,area}}$$

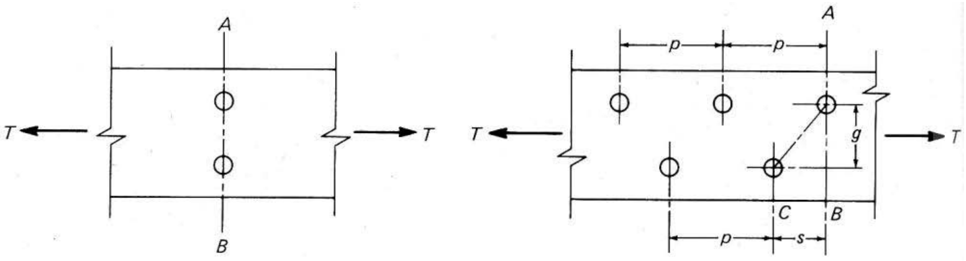
Tension Member Design

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

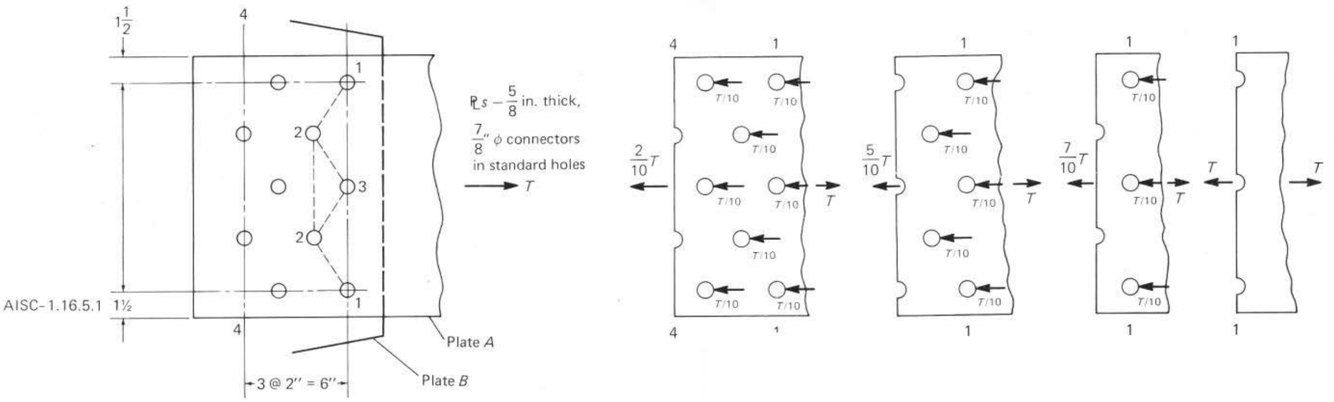
Effective Net Area:

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

$$f_t = \frac{P}{A_e} or \frac{T}{A_e}$$



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



Connections in Wood

Connections for wood are typically mechanical fasteners. Shear plates and split ring connectors are common in trusses. Bolts of metal bear on holes in wood, and nails rely on shear resistance transverse and parallel to the nail shaft.

Bolted Joints

Stress must be evaluated in the member being connected using the load being transferred and the reduced cross section area called *net area.* Bolt capacities are usually provided in tables and take into account the allowable shearing stress across the diameter for *single* and *double shear*, and the allowable bearing stress of the connected material based on the direction of the load with respect to the grain (parallel or perpendicular). Problems, such as ripping of the bolt hole at the end of the member, are avoided by following code guidelines on minimum edge distances and spacing.

Nailed Joints

Because nails rely on shear resistance, a common problem when nailing is splitting of the wood at the end of the member, which is a shear failure. Tables list the shear force capacity per unit length of embedment per nail. Jointed members used for beams will have shear stress across the connector, and the pitch spacing, *p*, can be determined from the shear stress equation when the capacity, *F*, is known.

Other Connectors

Screws - Range in sizes from #6 (0.138 in. shank diameter) to #24 (0.372 in. shank diameter) in lengths up to five inches. Like nails, they are best used laterally loaded in side grain rather than in withdrawal from side grain. Withdrawal from end is not permitted.

Lag screws (or bolts) – Similar to wood screw, but has a head like a bolt. It must have a load hole drilled and inserted along with a washer.

Split ring and shear plate connectors – Grooves are cut in each piece of the wood members to be joined so that half the ring is in each section. The members are held together with a bolt concentric with the ring. Shear plate connectors have a central plate within the ring.

Splice plates – These are common in pre-manufactured joists and consist of a sheet of metal with punched spikes.

Framing seats & anchors – for instance, joist hangers and post bases...

Connections in Steel

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

High strength bolts resist shear (primarily), while the connected part must resist yielding and rupture.

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

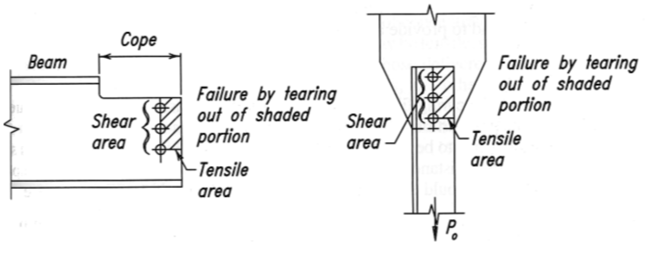


Fig. C-J4.1. Failure for block shear rupture limit state.

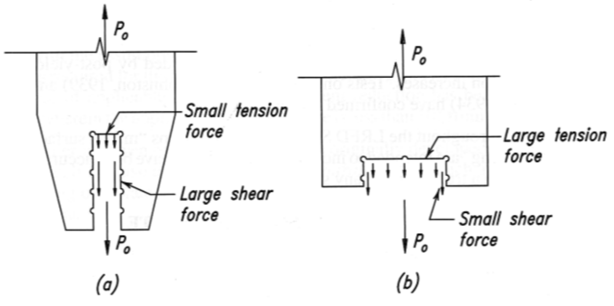
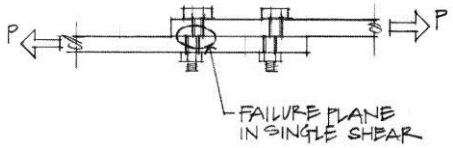
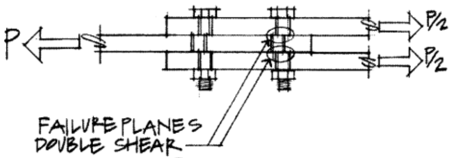
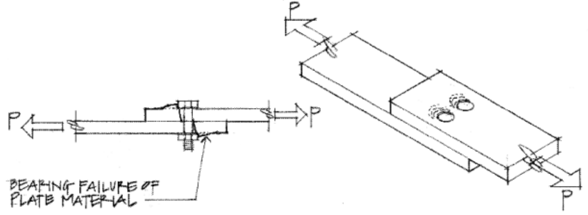


Fig. C-J4.2. Block shear rupture in tension.

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.

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 $R_u = \Sigma \gamma_i R_i$

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

where ϕ = the resistance factor
F_n = the nominal tension or shear strength of the bolt
A_b = the cross section area of the bolt

$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)

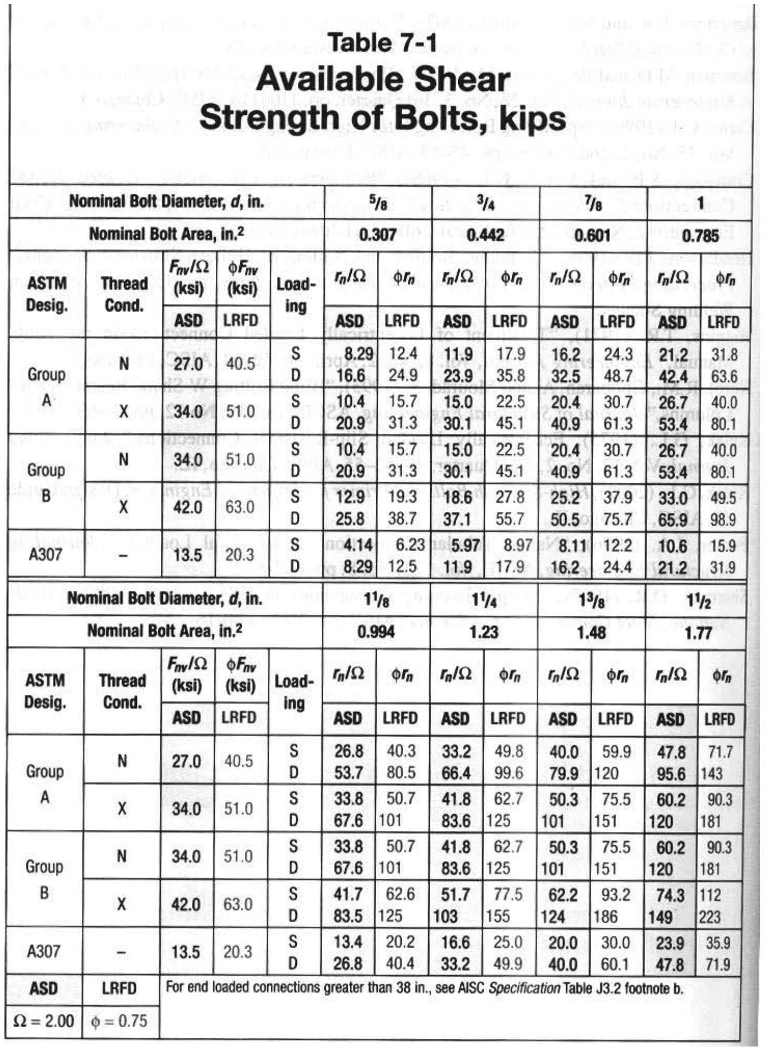


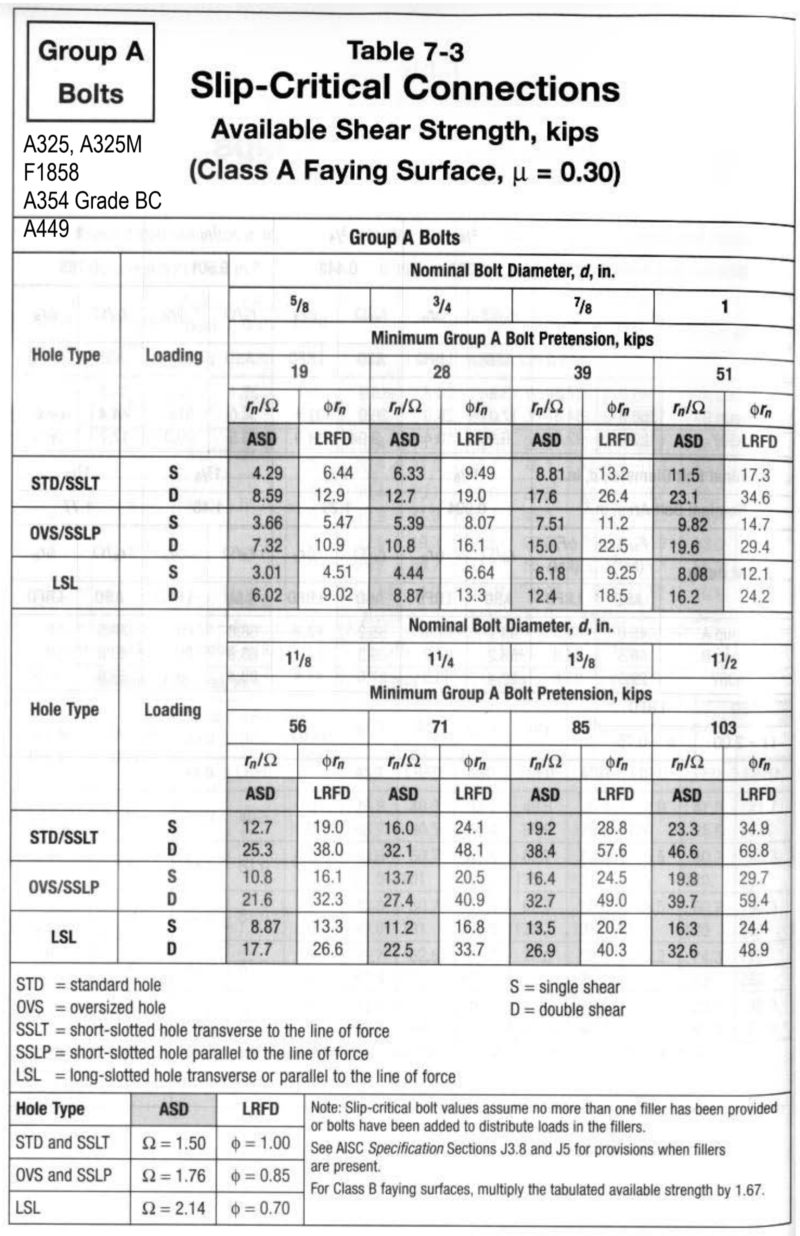
Table 7-1

Available Shear Strength of Bolts, kips

ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)	ϕF_{nv} (ksi)	Loading	$5/8$ r_n/Ω	$5/8$ ϕr_n	$3/4$ r_n/Ω	$3/4$ ϕr_n	$7/8$ r_n/Ω	$7/8$ ϕr_n	1 r_n/Ω	1 ϕr_n
Nominal Bolt Area, in.^{2}					0.307		0.442		0.601		0.785	
		ASD	LRFD		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group A	N	27.0	40.5	S	8.29	12.4	11.9	17.9	16.2	24.3	21.2	31.8
				D	16.6	24.9	23.9	35.8	32.5	48.7	42.4	63.6
	X	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
Group B	N	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
	X	42.0	63.0	S	12.9	19.3	18.6	27.8	25.2	37.9	33.0	49.5
				D	25.8	38.7	37.1	55.7	50.5	75.7	65.9	98.9
A307	–	13.5	20.3	S	4.14	6.23	5.97	8.97	8.11	12.2	10.6	15.9
				D	8.29	12.5	11.9	17.9	16.2	24.4	21.2	31.9

ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)	ϕF_{nv} (ksi)	Loading	$1\frac{1}{8}$ r_n/Ω	$1\frac{1}{8}$ ϕr_n	$1\frac{1}{4}$ r_n/Ω	$1\frac{1}{4}$ ϕr_n	$1\frac{3}{8}$ r_n/Ω	$1\frac{3}{8}$ ϕr_n	$1\frac{1}{2}$ r_n/Ω	$1\frac{1}{2}$ ϕr_n
Nominal Bolt Area, in.^{2}					0.994		1.23		1.48		1.77	
		ASD	LRFD		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group A	N	27.0	40.5	S	26.8	40.3	33.2	49.8	40.0	59.9	47.8	71.7
				D	53.7	80.5	66.4	99.6	79.9	120	95.6	143
	X	34.0	51.0	S	33.8	50.7	41.8	62.7	50.3	75.5	60.2	90.3
				D	67.6	101	83.6	125	101	151	120	181
Group B	N	34.0	51.0	S	33.8	50.7	41.8	62.7	50.3	75.5	60.2	90.3
				D	67.6	101	83.6	125	101	151	120	181
	X	42.0	63.0	S	41.7	62.6	51.7	77.5	62.2	93.2	74.3	112
				D	83.5	125	103	155	124	186	149	223
A307	–	13.5	20.3	S	13.4	20.2	16.6	25.0	20.0	30.0	23.9	35.9
				D	26.8	40.4	33.2	49.9	40.0	60.1	47.8	71.9

ASD	LRFD	For end loaded connections greater than 38 in., see AISC *Specification* Table J3.2 footnote b.
$\Omega = 2.00$	$\phi = 0.75$	



Group A Bolts

A325, A325M
F1858
A354 Grade BC
A449

Table 7-3

Slip-Critical Connections

Available Shear Strength, kips (Class A Faying Surface, $\mu = 0.30$)

Group A Bolts

Hole Type	Loading	$5/8$ r_n/Ω	$5/8$ ϕr_n	$3/4$ r_n/Ω	$3/4$ ϕr_n	$7/8$ r_n/Ω	$7/8$ ϕr_n	1 r_n/Ω	1 ϕr_n
Minimum Group A Bolt Pretension, kips		19		28		39		51	
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	4.29	6.44	6.33	9.49	8.81	13.2	11.5	17.3
	D	8.59	12.9	12.7	19.0	17.6	26.4	23.1	34.6
OVS/SSLP	S	3.66	5.47	5.39	8.07	7.51	11.2	9.82	14.7
	D	7.32	10.9	10.8	16.1	15.0	22.5	19.6	29.4
LSL	S	3.01	4.51	4.44	6.64	6.18	9.25	8.08	12.1
	D	6.02	9.02	8.87	13.3	12.4	18.5	16.2	24.2

Hole Type	Loading	$1\frac{1}{8}$ r_n/Ω	$1\frac{1}{8}$ ϕr_n	$1\frac{1}{4}$ r_n/Ω	$1\frac{1}{4}$ ϕr_n	$1\frac{3}{8}$ r_n/Ω	$1\frac{3}{8}$ ϕr_n	$1\frac{1}{2}$ r_n/Ω	$1\frac{1}{2}$ ϕr_n
Minimum Group A Bolt Pretension, kips		56		71		85		103	
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	12.7	19.0	16.0	24.1	19.2	28.8	23.3	34.9
	D	25.3	38.0	32.1	48.1	38.4	57.6	46.6	69.8
OVS/SSLP	S	10.8	16.1	13.7	20.5	16.4	24.5	19.8	29.7
	D	21.6	32.3	27.4	40.9	32.7	49.0	39.7	59.4
LSL	S	8.87	13.3	11.2	16.8	13.5	20.2	16.3	24.4
	D	17.7	26.6	22.5	33.7	26.9	40.3	32.6	48.9

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

S = single shear
D = double shear

Hole Type	ASD	LRFD	Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers. See AISC *Specification* Sections J3.8 and J5 for provisions when fillers are present. For Class B faying surfaces, multiply the tabulated available strength by 1.67.
STD and SSLT	$\Omega = 1.50$	$\phi = 1.00$	
OVS and SSLP	$\Omega = 1.76$	$\phi = 0.85$	
LSL	$\Omega = 2.14$	$\phi = 0.70$	

For bearing of plate material at bolt holes: $R_a \leq R_n / \Omega$ or $R_u \leq \phi R_n$

where $R_u = \Sigma \gamma_i R_i$

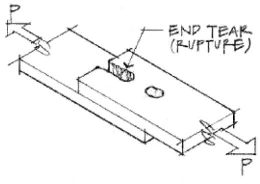


Figure 10.11 End tear-out.

- deformation at bolt hole is a concern

$$R_n = 1.2L_c tF_u \leq 2.4dtF_u$$

- deformation at bolt hole is not a concern

$$R_n = 1.5L_c tF_u \leq 3.0dtF_u$$

- long slotted holes with the slot perpendicular to the load

$$R_n = 1.0L_c tF_u \leq 2.0dtF_u$$

where R_n = the nominal bearing strength
F_u = 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

$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (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 2⅔ times the diameter of the bolt, d_b. Common edge distance from the center of last hole to the edge is 1¼ in..

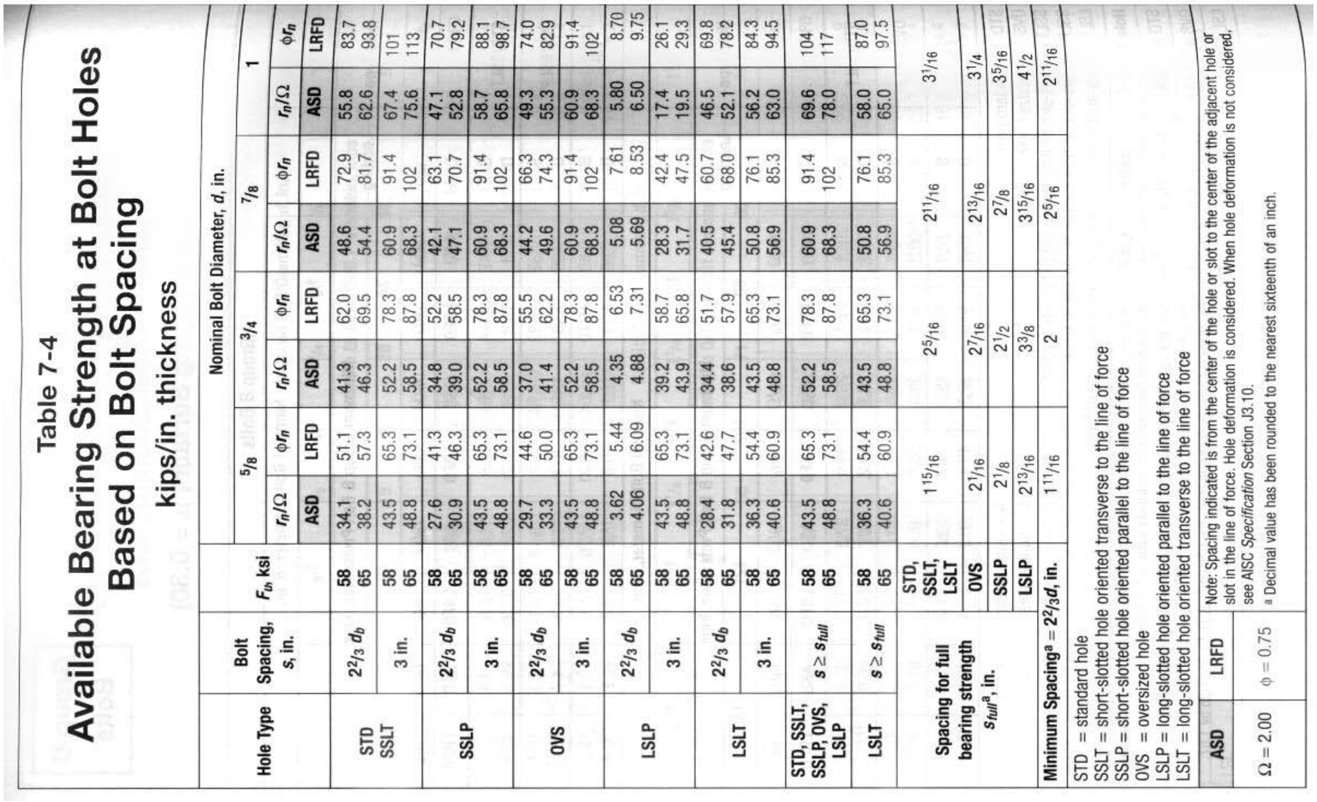


Table 7-4
Available Bearing Strength at Bolt Holes Based on Bolt Spacing
kips/in. thickness

Hole Type	Bolt Spacing, s, in.	F_u, ksi	Nominal Bolt Diameter, d, in. 5/8 r_n/Ω ASD	5/8 ϕr_n LRFD	3/4 r_n/Ω ASD	3/4 ϕr_n LRFD	7/8 r_n/Ω ASD	7/8 ϕr_n LRFD	1 r_n/Ω ASD	1 ϕr_n LRFD
STD SSLT	$2^2/_3\,d_b$	58	34.1	51.1	41.3	62.0	48.6	72.9	55.8	83.7
		65	38.2	57.3	46.3	69.5	54.4	81.7	62.6	93.8
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	67.4	101
		65	48.8	73.1	58.5	87.8	68.3	102	75.6	113
SSLP	$2^2/_3\,d_b$	58	27.6	41.3	34.8	52.2	42.1	63.1	47.1	70.7
		65	30.9	46.3	39.0	58.5	47.1	70.7	52.8	79.2
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	58.7	88.1
		65	48.8	73.1	58.5	87.8	68.3	102	65.8	98.7
OVS	$2^2/_3\,d_b$	58	29.7	44.6	37.0	55.5	44.2	66.3	49.3	74.0
		65	33.3	50.0	41.4	62.2	49.6	74.3	55.3	82.9
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	60.9	91.4
		65	48.8	73.1	58.5	87.8	68.3	102	68.3	102
LSLP	$2^2/_3\,d_b$	58	3.62	5.44	4.35	6.53	5.08	7.61	5.80	8.70
		65	4.06	6.09	4.88	7.31	5.69	8.53	6.50	9.75
	3 in.	58	43.5	65.3	39.2	58.7	28.3	42.4	17.4	26.1
		65	48.8	73.1	43.9	65.8	31.7	47.5	19.5	29.3
LSLT	$2^2/_3\,d_b$	58	28.4	42.6	34.4	51.7	40.5	60.7	46.5	69.8
		65	31.8	47.7	38.6	57.9	45.4	68.0	52.1	78.2
	3 in.	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3
		65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5
STD, SSLT, SSLP, OVS, LSLP	$s \geq s_{full}$	58	43.5	65.3	52.2	78.3	60.9	91.4	69.6	104
		65	48.8	73.1	58.5	87.8	68.3	102	78.0	117
LSLT	$s \geq s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	58.0	87.0
		65	40.6	60.9	48.8	73.1	56.9	85.3	65.0	97.5
Spacing for full bearing strength s_{full}[a], in.		STD, SSLT, LSLT	$1^{15}/_{16}$		$2^5/_{16}$		$2^{11}/_{16}$		$3^1/_{16}$	
		OVS	$2^1/_{16}$		$2^7/_{16}$		$2^{13}/_{16}$		$3^1/_4$	
		SSLP	$2^1/_8$		$2^1/_2$		$2^7/_8$		$3^5/_{16}$	
		LSLP	$2^{13}/_{16}$		$3^3/_8$		$3^{15}/_{16}$		$4^1/_2$	
Minimum Spacing[a] = $2^2/_3 d$, in.			$1^{11}/_{16}$		2		$2^5/_{16}$		$2^{11}/_{16}$	

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
LSLP = long-slotted hole oriented parallel to the line of force
LSLT = long-slotted hole oriented transverse to the line of force

ASD	LRFD
$\Omega = 2.00$	$\phi = 0.75$

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, see AISC *Specification* Section J3.10.

[a] Decimal value has been rounded to the nearest sixteenth of an inch.

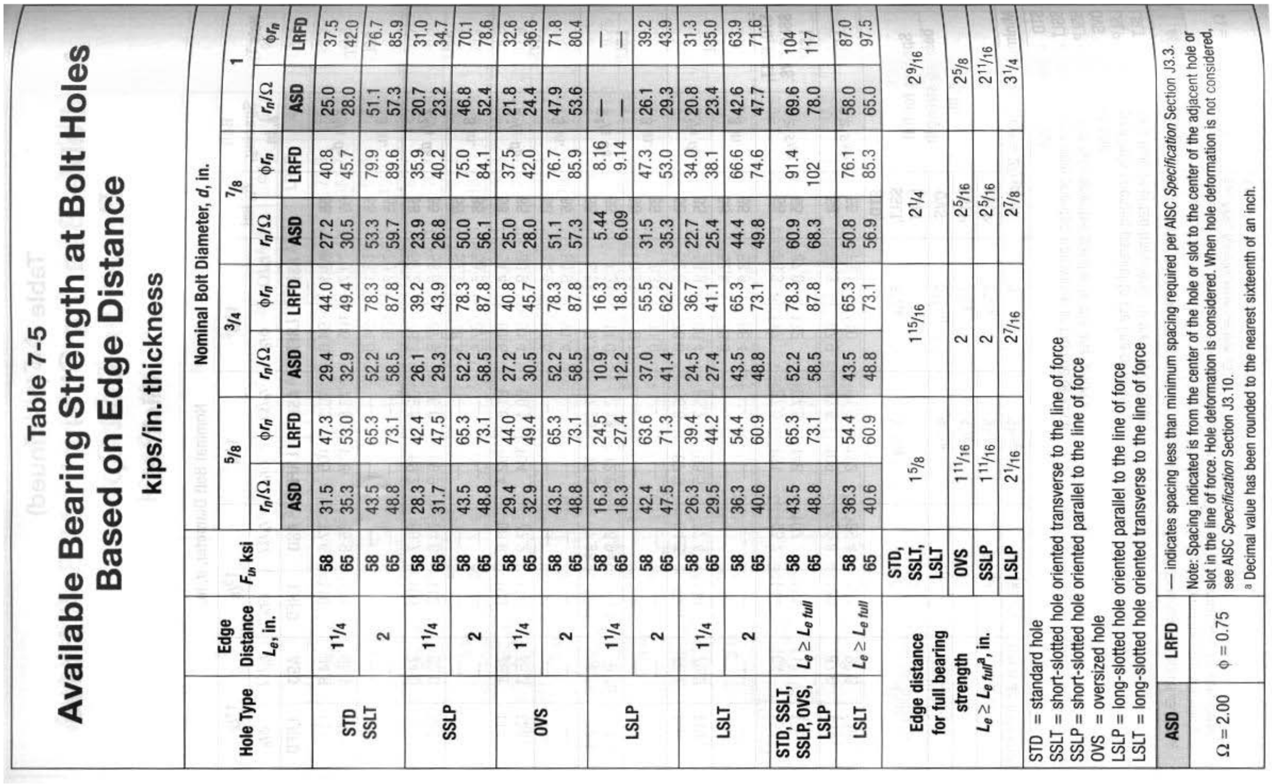


Table 7-5
Available Bearing Strength at Bolt Holes Based on Edge Distance

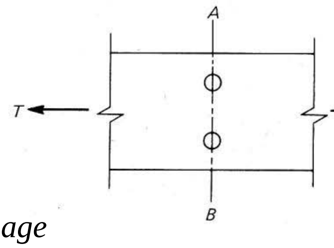
kips/in. thickness

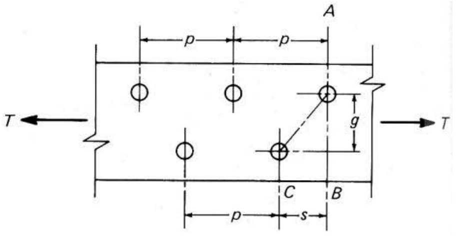
Hole Type	Edge Distance L_e, in.	F_u, ksi	Nominal Bolt Diameter, d, in.							
			5/8		3/4		7/8		1	
			r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n
			ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD SSLT	$1\frac{1}{4}$	58	31.5	47.3	29.4	44.0	27.2	40.8	25.0	37.5
		65	35.3	53.0	32.9	49.4	30.5	45.7	28.0	42.0
	2	58	43.5	65.3	52.2	78.3	53.3	79.9	51.1	76.7
		65	48.8	73.1	58.5	87.8	59.7	89.6	57.3	85.9
SSLP	$1\frac{1}{4}$	58	28.3	42.4	26.1	39.2	23.9	35.9	20.7	31.0
		65	31.7	47.5	29.3	43.9	26.8	40.2	23.2	34.7
	2	58	43.5	65.3	52.2	78.3	50.0	75.0	46.8	70.1
		65	48.8	73.1	58.5	87.8	56.1	84.1	52.4	78.6
OVS	$1\frac{1}{4}$	58	29.4	44.0	27.2	40.8	25.0	37.5	21.8	32.6
		65	32.9	49.4	30.5	45.7	28.0	42.0	24.4	36.6
	2	58	43.5	65.3	52.2	78.3	51.1	76.7	47.9	71.8
		65	48.8	73.1	58.5	87.8	57.3	85.9	53.6	80.4
LSLP	$1\frac{1}{4}$	58	16.3	24.5	10.9	16.3	5.44	8.16	—	—
		65	18.3	27.4	12.2	18.3	6.09	9.14	—	—
	2	58	42.4	63.6	37.0	55.5	31.5	47.3	26.1	39.2
		65	47.5	71.3	41.4	62.2	35.3	53.0	29.3	43.9
LSLT	$1\frac{1}{4}$	58	26.3	39.4	24.5	36.7	22.7	34.0	20.8	31.3
		65	29.5	44.2	27.4	41.1	25.4	38.1	23.4	35.0
	2	58	36.3	54.4	43.5	65.3	44.4	66.6	42.6	63.9
		65	40.6	60.9	48.8	73.1	49.8	74.6	47.7	71.6
STD, SSLT, SSLP, OVS, LSLP	$L_e \geq L_{e\,full}$	58	43.5	65.3	52.2	78.3	60.9	91.4	69.6	104
		65	48.8	73.1	58.5	87.8	68.3	102	78.0	117
LSLT	$L_e \geq L_{e\,full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	58.0	87.0
		65	40.6	60.9	48.8	73.1	56.9	85.3	65.0	97.5
Edge distance for full bearing strength $L_e \geq L_{e\,full}{}^a$, in.		STD, SSLT, LSLT	$1\frac{5}{8}$		$1\frac{15}{16}$		$2\frac{1}{4}$		$2\frac{9}{16}$	
		OVS	$1\frac{11}{16}$		2		$2\frac{5}{16}$		$2\frac{5}{8}$	
		SSLP	$1\frac{11}{16}$		2		$2\frac{5}{16}$		$2\frac{11}{16}$	
		LSLP	$2\frac{1}{16}$		$2\frac{7}{16}$		$2\frac{7}{8}$		$3\frac{1}{4}$	

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
LSLP = long-slotted hole oriented parallel to the line of force
LSLT = long-slotted hole oriented transverse to the line of force

ASD	LRFD	
$\Omega = 2.00$	$\phi = 0.75$	— indicates spacing less than minimum spacing required per AISC *Specification* Section J3.3. 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, see AISC *Specification* Section J3.10. ᵃ Decimal value has been rounded to the nearest sixteenth of an inch.

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

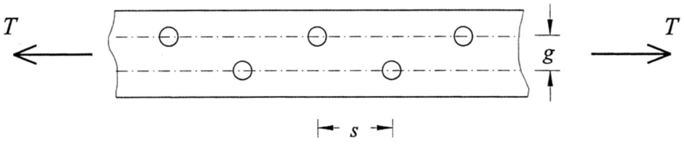
Effective Net Area:

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 from 0.6 to 1.0: $A_e = A_n U$

The staggered hole path area is determined by:



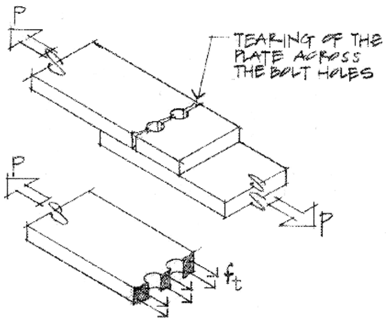
$$A_n = A_g - A_{of\ all\ holes} + t\Sigma\frac{s}{4g}$$

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 $R_u = \Sigma\gamma_i R_i$



1. yielding $R_n = F_y A_g$

   ϕ = 0.90 (LRFD) Ω = 1.67 (ASD)

2. rupture $R_n = F_u A_e$

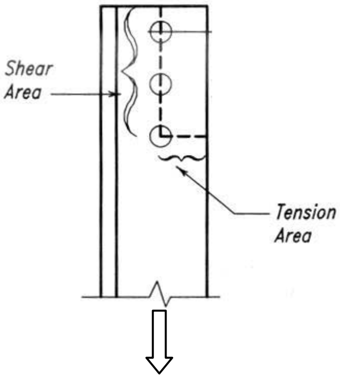
   ϕ = 0.75 (LRFD) Ω = 2.00 (ASD)

where A_g = the gross area of the member (excluding holes)
A_e = the effective net area (with holes, etc.)
F_y = the yield strength of the steel
F_u = the tensile strength of the steel (ultimate)

For shear elements:

$$R_a \le R_n / \Omega \ \ or \ \ R_u \le \phi R_n$$

where $R_u = \Sigma\gamma_i R_i$



1. yielding $R_n = 0.6 F_y A_g$

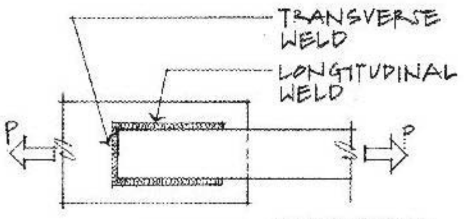
   ϕ = 1.00 (LRFD) Ω = 1.50 (ASD)

2. rupture $R_n = 0.6 F_u A_{nv}$

   ϕ = 0.75 (LRFD) Ω = 2.00 (ASD)

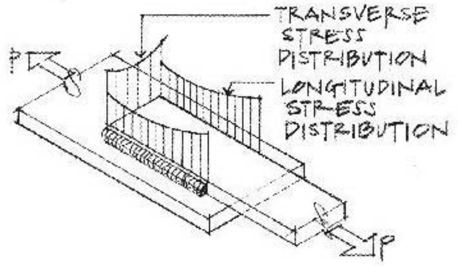
where A_g = the gross area of the member (excluding holes)
A_{nv} = the net area subject to shear (with holes, etc.)
F_y = the yield strength of the steel
F_u = the tensile strength of the steel (ultimate)

Welded Connections



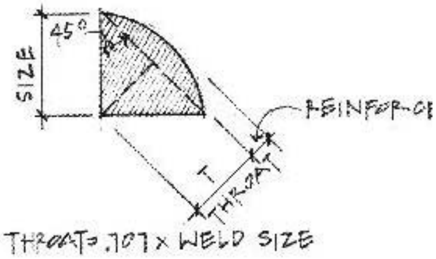
Weld designations include the strength in the name, i.e. E70XX has F_y = 70 ksi. Welds are weakest in shear and are assumed to always fail in the shear mode.

The throat size, T, of a fillet weld is determined trigonometry by: T = 0.707 ×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 permitted along edges of connected parts shall be:

- Material less than ¼ in. thick, not greater than the thickness of the material.
- Material ¼ in. or more in thickness, not greater than the thickness of the material minus 1/16 in., unless the weld is especially designated on the drawings to be built out to obtain full-throat thickness.

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 ¼ the length.

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

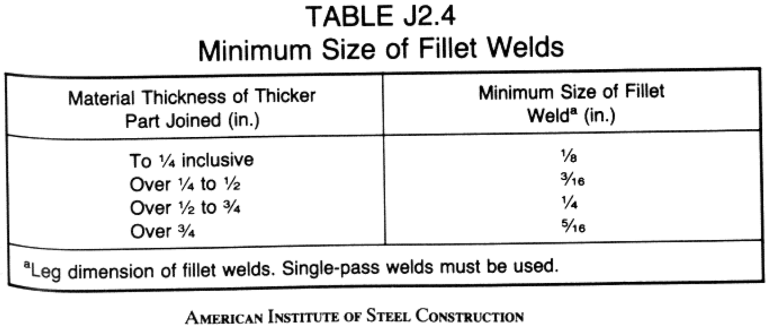


TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thicker Part Joined (in.)	Minimum Size of Fillet Weld[a] (in.)
To ¼ inclusive	⅛
Over ¼ to ½	3/16
Over ½ to ¾	¼
Over ¾	5/16

[a] Leg dimension of fillet welds. Single-pass welds must be used.

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<u>*For fillet welds:*</u> $R_a \le R_n / \Omega$ or $R_u \le \phi R_n$

where $R_u = \Sigma \gamma_i R_i$

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

$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)

where:

T is throat thickness
l is length of the weld

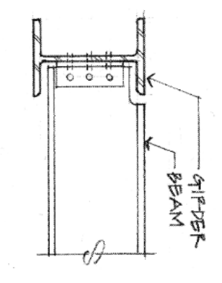
For a connected part, the other limit states for the base metal, such as tension yield, tension rupture, shear yield, or shear rupture **must** be considered.

Available Strength of Fillet Welds per inch of weld (ϕS)

Weld Size (in.)	E60XX (k/in.)	E70XX (k/in.)
3/16	3.58	4.18
¼	4.77	5.57
5/16	5.97	6.96
⅜	7.16	8.35
7/16	8.35	9.74
½	9.55	11.14
⅝	11.93	13.92
¾	14.32	16.70

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

Framed Beam Connections

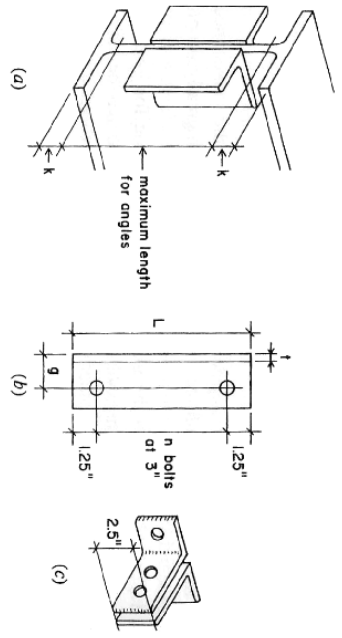


Coping is the term for cutting away part of the flange to connect a beam to another beam using welded or bolted angles.

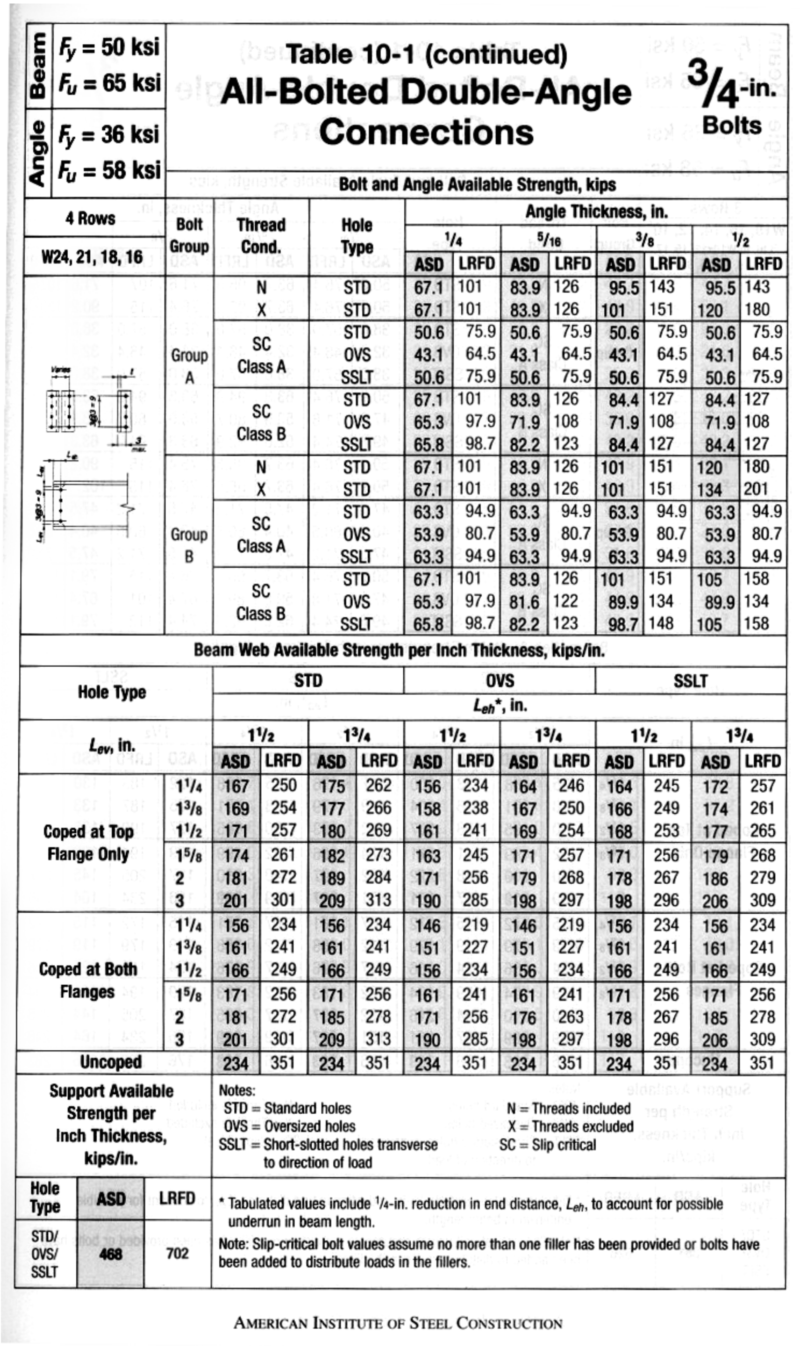
AISC provides tables that give bolt and angle available strength knowing number of bolts, bolt type, bolt diameter, angle leg thickness, hole type and coping, *and* the wide flange beam being connected. For the connections the limit-state of bolt shear, bolts bearing on the angles, shear yielding of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

here 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



Beam F_y = 50 ksi, F_u = 65 ksi
Angle F_y = 36 ksi, F_u = 58 ksi

Table 10-1 (continued)
All-Bolted Double-Angle Connections
3/4-in. Bolts

Bolt and Angle Available Strength, kips

4 Rows	Bolt Group	Thread Cond.	Hole Type	Angle Thickness, in.							
				1/4		5/16		3/8		1/2	
W24, 21, 18, 16				ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	Group A	N	STD	67.1	101	83.9	126	95.5	143	95.5	143
		X	STD	67.1	101	83.9	126	101	151	120	180
		SC Class A	STD	50.6	75.9	50.6	75.9	50.6	75.9	50.6	75.9
			OVS	43.1	64.5	43.1	64.5	43.1	64.5	43.1	64.5
			SSLT	50.6	75.9	50.6	75.9	50.6	75.9	50.6	75.9
		SC Class B	STD	67.1	101	83.9	126	84.4	127	84.4	127
			OVS	65.3	97.9	71.9	108	71.9	108	71.9	108
			SSLT	65.8	98.7	82.2	123	84.4	127	84.4	127
	Group B	N	STD	67.1	101	83.9	126	101	151	120	180
		X	STD	67.1	101	83.9	126	101	151	134	201
		SC Class A	STD	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
			OVS	53.9	80.7	53.9	80.7	53.9	80.7	53.9	80.7
			SSLT	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
		SC Class B	STD	67.1	101	83.9	126	101	151	105	158
			OVS	65.3	97.9	81.6	122	89.9	134	89.9	134
			SSLT	65.8	98.7	82.2	123	98.7	148	105	158

Beam Web Available Strength per Inch Thickness, kips/in.

Hole Type		STD				OVS				SSLT			
		L_{eh}*, in.											
L_{ev}, in.		1 1/2		1 3/4		1 1/2		1 3/4		1 1/2		1 3/4	
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Coped at Top Flange Only	1 1/4	167	250	175	262	156	234	164	246	164	245	172	257
	1 3/8	169	254	177	266	158	238	167	250	166	249	174	261
	1 1/2	171	257	180	269	161	241	169	254	168	253	177	265
	1 5/8	174	261	182	273	163	245	171	257	171	256	179	268
	2	181	272	189	284	171	256	179	268	178	267	186	279
	3	201	301	209	313	190	285	198	297	198	296	206	309
Coped at Both Flanges	1 1/4	156	234	156	234	146	219	146	219	156	234	156	234
	1 3/8	161	241	161	241	151	227	151	227	161	241	161	241
	1 1/2	166	249	166	249	156	234	156	234	166	249	166	249
	1 5/8	171	256	171	256	161	241	161	241	171	256	171	256
	2	181	272	185	278	171	256	176	263	178	267	185	278
	3	201	301	209	313	190	285	198	297	198	296	206	309
Uncoped		234	351	234	351	234	351	234	351	234	351	234	351

Support Available Strength per Inch Thickness, kips/in.

Hole Type	ASD	LRFD
STD/ OVS/ SSLT	468	702

Notes:
STD = Standard holes
OVS = Oversized holes
SSLT = Short-slotted holes transverse to direction of load
N = Threads included
X = Threads excluded
SC = Slip critical

* Tabulated values include 1/4-in. reduction in end distance, L_{eh}, to account for possible underrun in beam length.

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers.

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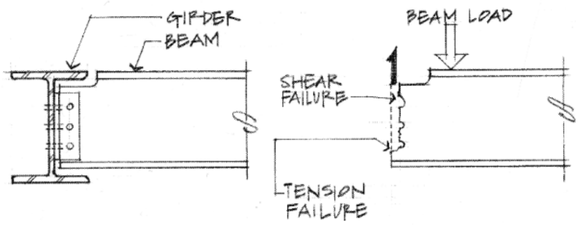
Limiting Strength or Stability States

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): $R_a \le R_n / \Omega$ or $R_u \le \phi R_n$

where $R_u = \Sigma \gamma_i R_i$

$$R_n = 0.6 F_u A_{nv} + U_{bs} F_u A_{nt} \le 0.6 F_y A_{gv} + U_{bs} F_u A_{nt}$$

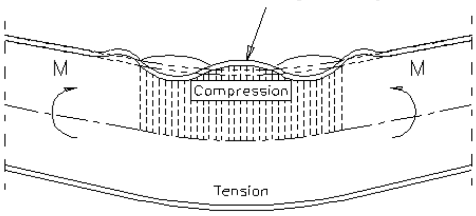
$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)

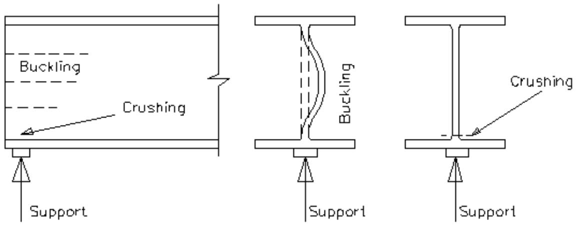
where:

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

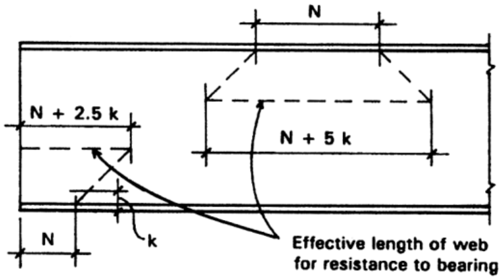
Local Buckling in Steel I Beams– Web Crippling or Flange Buckling

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:



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

$$P_{n\,(\text{interior})} = (5k + N)F_{yw}t_w$$

where t_w = thickness of the web
N = bearing length
k = dimension to fillet found in beam section tables

ϕ = 1.00 (LRFD) Ω = 1.50 (ASD)