# **Connection and Tension Member Design**

## Notation:

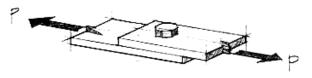
Nota	tio	n:
Α	=	area (net = with holes, bearing = in
		contact, etc)
$A_e$	=	effective net area found from the
		product of the net area $A_n$ by the
		shear lag factor U
$A_b$	=	area of a bolt
$A_g$	=	gross area, equal to the total area
		ignoring any holes
$A_{gv}$	=	gross area subjected to shear for
		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
		allowable stress design
		diameter of a hole
		bearing stress (see P)
-		tensile stress
$f_v$		shear stress
		r = shear force capacity per connector
$F_n$	=	nominal tension or shear strength of
F		a bolt
$F_u$		ultimate stress prior to failure
		yield strength of weld material
		yield strength
$F_{yw}$	=	yield strength of web material
	=	gage spacing of staggered bolt holes
Ι	=	moment of inertia with respect to
1_		neutral axis bending
k	=	distance from outer face of W
1	_	flange to the web toe of fillet
l I		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'	_	
L	_	length of an angle in a connector with staggered holes
		with staggered holes

LRF	D = load and resistance factor design
п	= number of connectors across a joint
N	= bearing length on a wide flange
1,	steel section
	= bearing type connection with
	threads included in shear plane
р	= pitch of connector spacing
P 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
1.1	multiplied by $\phi$
$R_{\mu}$	= factored design value for LRFD
$\mathbf{n}_{u}$	design
S	= longitudinal center-to-center spacing
5	of any two consecutive holes
S	= allowable strength per length of a
5	weld for a given size
SC	= slip critical bolted connection
t	= thickness of a hole or member
t $t_w$	= thickness of a hole of hielder = thickness of web of wide flange
$T_{W}$	= threat size of a weld
V	= internal shear force
	$_{gitudinal} = longitudinal shear force$
U uong	= shear lag factor for steel tension
U	member design
$U_{bs}$	= reduction coefficient for block
$O_{DS}$	shear rupture
X	= bearing type connection with
11	threads excluded from the shear
	plane
у	= vertical distance
$\pi$	= pi (3.1415 radians or 180°)
$\phi$	= resistance factor
Y	
	= diameter symbol
γ	= load factor in LRFD design
$\varOmega$	= safety factor for ASD
Σ	= summation symbol

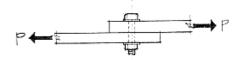
#### Connections

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.

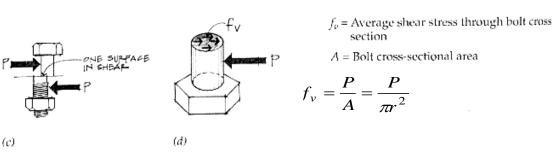
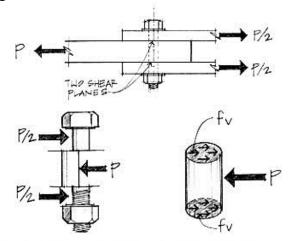


Figure 5.11 A bolted connection—single shear.

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.

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

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

$$P^{\text{CENTER-PLATE}}$$

$$P^{\text{ROJECTED DEARING AREA}}$$

$$P^{\text{ROJECTED DEARING AREA}}$$

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.

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

x

where

$$nF_{connector} \ge rac{VQ_{connected area}}{I} \cdot p$$

p = pitch length

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

F = force capacity in one connector

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

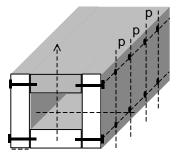
 $y_{\text{connected area}} = \text{distance from the centroid of the connected area to the neutral axis}$ 

#### 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.

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

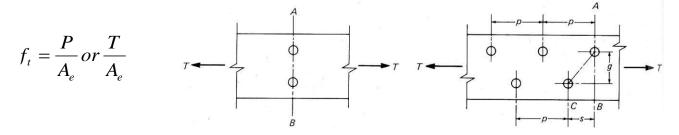


## **Tension Member Design**

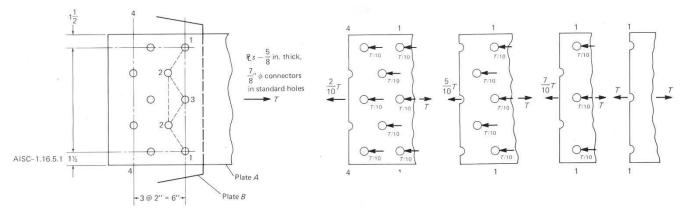
In tension members, there may be bolt holes that reduce the size of the cross section.

## 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.



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.

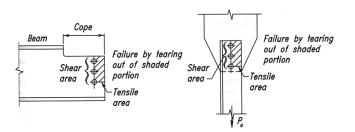


Fig. C-J4.1. Failure for block shear rupture limit state.

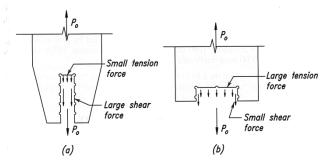


Fig. C-J4.2. Block shear rupture in tension.

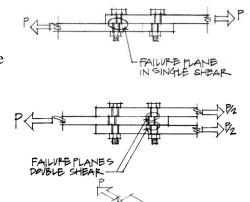
#### Note Set 17.1

S

#### 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  $R_u = \Sigma \gamma_i R_i$ 

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

where

$$\begin{split} \varphi &= & \text{the resistance factor} \\ F_n &= & \text{the nominal tension or shear strength of the bolt} \\ A_b &= & \text{the cross section area of the bolt} \end{split}$$

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

Ň	Nominal Bolt Diameter, d, in.	Diamete	er, d, in.	10.0	5	5/8	3	3/4	-	8/2	uhhas	-
	Nominal Bolt Area, in. <sup>2</sup>	olt Area,	in. <sup>2</sup>	in the	0.3	0.307	0.4	0.442	0.6	0.601	0.7	0.785
ASTM Desig.	Thread Cond.	F <sub>m</sub> /Ω (ksi)	¢F <sub>nv</sub> (ksi)	Load- ing	r <sub>n</sub> /Ω	φľn	r <sub>n</sub> /Ω	φſ'n	r <sub>n</sub> /Ω	φſ'n	r <sub>n</sub> /Ω	¢ľ,
00	1. 1. 1. 1.	ASD	LRFD	8 1	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group	N	27.0	40.5	s o	8.29 16.6	12.4 24.9	11.9 23.9	17.9 35.8	16.2 32.5	24.3 48.7	21.2 42.4	31.8 63.6
A	×	34.0	51.0	s	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				-	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
Group	z	34.0	51.0	s a	10.4 20.9	15.7 31.3	15.0 30.1	22.5 45.1	20.4 40.9	30.7 61.3	26.7	40.0
80	×	42.0	63.0	sa	12.9 25.8	19.3 38.7	18.6 37.1	27.8 55.7	25.2 50.5	37.9 75.7	33.0 65.9	49.5 98.9
A307	1	13.5	20.3	s o	4.14 8.29	6.23 12.5	5.97	8.97 17.9	8.11 16.2	12.2 24.4	10.6 21.2	15.9
No	Nominal Bolt Diameter, d, in.	Diamete	r, d, in.		=	11/8	-	11/4	13	13/8	1	11/2
	Nominal Bolt Area, in. <sup>2</sup>	olt Area,	in.2		0.994	94	12	1.23	7	1.48	1.77	E
ASTM Desig.	Thread Cond.	F <sub>m</sub> /Ω (ksi)	¢F <sub>nv</sub> (ksi)	Load- ing	ſ'nΩ	φſa	ſ'n/Ω	φĽ	r <sub>n</sub> /Ω	φĽ'n	r <sub>a</sub> /Ω	φľ <sub>n</sub>
Kî j		ASD	LRFD	,	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group	N	27.0	40.5	νD	26.8 53.7	40.3 80.5	33.2 66.4	49.8 99.6	40.0	59.9 120	47.8 95.6	71.7
A	×	34.0	51.0	s d	33.8 67.6	50.7 101	41.8 83.6	62.7 125	50.3 101	75.5 151	60.2 120	90.3 181
Group	z	34.0	51.0	sо	33.8 67.6	50.7 101	41.8 83.6	62.7 125	50.3 101	75.5 151	60.2 120	90.3
В	x	42.0	63.0	s a	41.7 83.5	62.6 125	51.7 103	77.5 155	62.2 124	93.2 186	74.3	112 223
A307	r	13.5	20.3	sο	13.4 26.8	20.2 40.4	16.6 33.2	25.0 49.9	20.0	30.0	23.9	35.9
ASD	LRFD	For end	oaded col	For end loaded connections greater than 38 in., see AISC Specification Table J3.2 footnote b.	greater th	an 38 in.,	see AISC	Specifica	tion Table	J3.2 foot	note b.	

Group A Bolts	19675	Table 7-3 Slip-Critical Connections	ritica	Table 7-3	-3 onne	ctio	su		
A325, A325M F1858 A354 Grade BC		Available Shear Strength, kips (Class A Faying Surface, $\mu$ = 0.30)	le Sh Fayir	iear S Ig Sui	trengt face,	th, kip µ = 0.	30)		
A449	ton in the	11	ß	Group A Bolts	olts				
art o.	SOLUTION NO.	1 2 4	0.WD	Non	Nominal Bolt Diameter, d, in.	Diameter,	d, in.		
200		5	5/8		3/4		/8		-
Units Trees				Minimum	Minimum Group A Bolt Pretension, kips	<b>Solt Preter</b>	nsion, kips		-
HOIE IYPE	Loading	-	19		28		39		51
A and a second		$r_n/\Omega$	øſn	$r_n/\Omega$	φľn	$r_n/\Omega$	φľn	$r_n/\Omega$	φr
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	sо	4.29 8.59	6.44 12.9	6.33	9.49 19.0	8.81 17.6	13.2 26.4	11.5 23.1	17.3 34.6
OVS/SSLP	s	3.66	5.47	5.39	8.07	7.51	11.2	9.82	14.7
All CAL	•	7.32	10.9	10.8	16.1	15.0	22.5	19.6	29.4
rsı	s D	3.01 6.02	4.51 9.02	4.44 8.87	6.64	6.18 12.4	9.25	8.08	12.1 24.2
				Non	Nominal Bolt Diameter,	Diameter,	ď, in.		1.1
		1	11/8	-	11/4	4	13/8	-	11/2
		1.44		Minimum	Minimum Group A E	solt Preter	Bolt Pretension, kips		
HOIE IYPE	Loading	លី	56		71	8	85	-	103
		$r_n/\Omega$	φľn	$r_n/\Omega$	φľn	$r_n/\Omega$	φľn	$r_n/\Omega$	0In
		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
	0	25.3	38.0	32.1	48.1	38.4	57.6	46.6	69.8
<b>JSS/SVO</b>	Ś	10.8	16.1	13.7	20.5	16.4	24.5	19.8	29.7
	-	21.0	32.3	21.4	40.9	32.1	49.0	39.7	59.4
rsı	sa	8.87 17.7	13.3 26.6	11.2 22.5	16.8 33.7	13.5 26.9	20.2 40.3	16.3 32.6	24.4
STD = standard hole OVS = oversized hole SSLT = short-slotted h SSLP = short-slotted h LSL = long-slotted hc	<ul> <li>= standard hole</li> <li>= oversized hole</li> <li>= short-slotted hole</li> <li>= short-slotted hole transverse to the line of force</li> <li>= short-slotted hole parallel to the line of force</li> <li>= long-slotted hole transverse or parallel to the line of force</li> </ul>	sverse to the allel to the lin sverse or par	e line of fo ne of force allel to the	rrce i e fo		S = single shear D = double shear	shear e shear		al e c
Hole Type	ASD	LRFD	Note: Slip	-critical bolt	Note: Slip-critical bolt values assume no more than one filler has been provided	me no more	than one fil	ler has beer	n provided
STD and SSLT	$\Omega = 1.50$	$\phi = 1.00$	See AISC	Specificatio	or poils nave been auged to discripture loads in the fillers. See AISC Specification Sections J3.8 and J5 for provisions when fillers	3.8 and J5 f	or provision:	s when fillen	ŝ
OVS and SSLP	$\Omega = 1.76$	$\phi = 0.85$	are present.	nt. B faving eu	are present. Enr Mase B faviant surfaces multiply the tobuloted musicable atreads hur 1 27	hutet oft	dolinin hoto	in chonoth b	1 67
S	$\Omega = 2.14$	$\phi = 0.70$		ne fillifel a	innini (conpi	יוא וווב ומחחו	atou availau	in annana ai	· /0-1 fr

For bearing of plate material at bolt holes:

• deformation at bolt hole is a concern

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

• deformation at bolt hole is not a concern

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

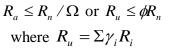
• long slotted holes with the slot perpendicular to the load

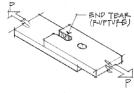
$$R_n = 1.0L_c tF_u \leq 2.0 dtF_u$$

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

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







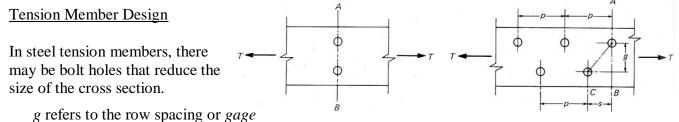
The *minimum* edge desistance from the center of the outer most bolt to the edge of a member is generally 1<sup>3</sup>/<sub>4</sub> times the bolt diameter for the sheared edge and 1<sup>1</sup>/<sub>4</sub> times the bolt diameter for the rolled or gas cut edges.

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..

Nominal Bolt Diameter, d, in. $f_{n}$ Ksi $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X) $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X)           66 $g_{12}$ $f_{11}$ (X) $\phi f_{n}$ $f_{n}$ (X) $\phi f_{n}$ $f_{n}$ (X)           66 $g_{33}$ $f_{21}$ (G) $f_{13}$ (G) $g_{13}$ (G) $g_{11}$ (G) $g_{21}$ 66 $g_{33}$ $f_{21}$ (G) $g_{21}$ (G)				0(30)	XIX	kips/in.	thickness	ness				
Bolt s, in.         Fm, state m/r, r         s/m         s/m         r/m         r/m </th <th><math display="block"> \begin{array}{ c c c c c c c c c c c c c c c c c c c</math></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>Nom</th> <th>inal Bolt (</th> <th>Diameter,</th> <th>ď, in.</th> <th></th> <th></th>	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$						Nom	inal Bolt (	Diameter,	ď, in.		
Splational solution solution solution site $r_{n} \Gamma_{n}$ $\phi r_{n}$ $r_{n} \Gamma_{n}$ $\phi r_{n}$ $r_{n} \Gamma_{n}$ $\phi r_{n}$ $r_{n} \Gamma_{n}$ 2 <sup>1</sup> /3 db         56         34.1         51.1         41.3         62.0         48.6         72.9         55.8           2 <sup>2</sup> /3 db         56         38.2         57.3         46.3         55.2         78.3         60.9         91.4         67.4         80.7         75.6           3 in.         56         38.2         57.3         46.3         55.2         78.3         60.9         91.4         77.1         55.8           2 <sup>2</sup> /3 db         56         38.2         57.3         58.5         87.8         68.3         102         55.8           3 in.         56         48.8         73.1         58.5         87.8         68.3         102         56.8           3 in.         56         48.8         73.1         58.5         87.8         68.3         102         56.8           3 in.         56         48.8         73.1         58.5         87.8         66.3         56.3         56.3         56.3         56.3         56.3         56.3         56.3         56.3	The state	Hole Tyne	Bolt	F., ksi			S. quanta	3/4		7/8		_
ASD         LRFD         ASD         LRFD         ASD         LRFD         ASD         LRFD         ASD         LRFD         ASD         C         C         ASD         C <thc< th="">         C         C         <thc< th="" tr<=""><th><math display="block"> \begin{array}{ c c c c c c c c c c c c c c c c c c c</math></th><th></th><th>s, in.</th><th>5</th><th><math>r_n/\Omega</math></th><th>¢<i>I</i>n</th><th><math>r_n/\Omega</math></th><th>¢ſn</th><th><math>r_n/\Omega</math></th><th>φſ'n</th><th><math>r_n/\Omega</math></th><th>\$r_n</th></thc<></thc<>	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		s, in.	5	$r_n/\Omega$	¢ <i>I</i> n	$r_n/\Omega$	¢ſn	$r_n/\Omega$	φſ'n	$r_n/\Omega$	\$r_n
$2^{2}/3 d_0$ 58         34.1         51.1         41.3         62.0         48.6         72.9         56.8           31n.         56         38.2         57.3         46.3         69.5         54.4         81.7         62.0           2^{1}3 d_0         56         38.2         57.3         56.3         55.2         78.3         60.9         91.4         67.4           2^{2}3 d_0         56         30.9         46.3         39.0         58.5         47.1         70.7         52.3           31n.         56         43.8         65.3         55.2         78.3         60.9         91.4         58.7           31n.         56         43.8         73.1         58.5         87.8         66.3         49.3         56.3           31n.         56         43.8         73.1         58.5         87.8         66.3         49.3         56.6           31n.         56         43.8         73.1         58.5         87.8         66.3         49.3         56.9         8.53         42.4         174           31n.         56         43.8         56.3         38.3         65.3         56.3         56.3         56.3 <t< th=""><td><math display="block"> \begin{array}{ c c c c c c c c c c c c c c c c c c c</math></td><td></td><td></td><td>1</td><td>ASD</td><td>LRFD</td><td>ASD</td><td>LRFD</td><td>ASD</td><td>LRFD</td><td>ASD</td><td>LRFD</td></t<>	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			1	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
3 in.         58         43.5         65.3         52.2         78.3         60.9         91.4         67.4           2 <sup>2</sup> /3 db         56         48.8         73.1         58.5         87.8         68.3         102         756           2 <sup>2</sup> /3 db         56         30.0         96.3         30.0         58.5         47.1         63.1         47.3           3 in.         56         43.5         56.3         30.0         58.5         77.0         7.3         58.3           2 <sup>2</sup> /3 db         56         48.8         73.1         58.5         87.8         68.3         102         56.3         55.5         44.2         56.3 </th <td>SiT 3in. 56 43.5 5.3 52.2 78.3 60.9 91.4 67.4 11 3in. 66 48.8 73.1 55.5 87.8 60.9 91.4 67.4 11 3in. 66 48.8 73.1 55.5 87.8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 60.9 9 9 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td> <td>STD</td> <td>2<sup>2/3</sup> db</td> <td><b>58</b> 65</td> <td>34.1 . 38.2</td> <td>51.1 57.3</td> <td>41.3 46.3</td> <td>62.0 69.5</td> <td>48.6 54.4</td> <td>72.9 81.7</td> <td>55.8 62.6</td> <td>83.7</td>	SiT 3in. 56 43.5 5.3 52.2 78.3 60.9 91.4 67.4 11 3in. 66 48.8 73.1 55.5 87.8 60.9 91.4 67.4 11 3in. 66 48.8 73.1 55.5 87.8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 58.7 8 60.9 91.4 60.9 9 9 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	STD	2 <sup>2/3</sup> db	<b>58</b> 65	34.1 . 38.2	51.1 57.3	41.3 46.3	62.0 69.5	48.6 54.4	72.9 81.7	55.8 62.6	83.7
2 <sup>2</sup> / <sub>3</sub> d <sub>6</sub> 56         2 <sup>10</sup> 4.1.3         3.0.6         55.2         4.7.1         70.7         52.8           3 in.         56         30.9         46.3         39.0         55.5         47.1         70.7         52.8           3 in.         56         43.5         56.3         55.2         78.3         60.9         91.4         58.6           3 in.         56         43.8         73.1         56.5         87.8         66.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3         49.3         56.3 <th< th=""><td>LP         223         db         65         27.6         41.3         34.6         52.2         42.1         63.1         47.1         70.7         52.8         42.1         70.7         52.8         52.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.3         73.3         58.5         88.3         10.2         66.3         49.1         70.7         52.8         73.3         58.5         66.3         49.3         56.3         55.3         <th5.3< th=""> <th5.3< th=""> <th5.3< th=""></th5.3<></th5.3<></th5.3<></td><td>SSLT</td><td>3 in.</td><td>58 65</td><td>43.5</td><td>65.3 73.1</td><td>52.2 58.5</td><td>78.3 87.8</td><td>60.9</td><td>91.4</td><td>67.4 75.6</td><td>101</td></th<>	LP         223         db         65         27.6         41.3         34.6         52.2         42.1         63.1         47.1         70.7         52.8         42.1         70.7         52.8         52.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.2         78.3         50.9         91.4         58.7         56.3         52.3         73.3         58.5         88.3         10.2         66.3         49.1         70.7         52.8         73.3         58.5         66.3         49.3         56.3         55.3 <th5.3< th=""> <th5.3< th=""> <th5.3< th=""></th5.3<></th5.3<></th5.3<>	SSLT	3 in.	58 65	43.5	65.3 73.1	52.2 58.5	78.3 87.8	60.9	91.4	67.4 75.6	101
3 in.         56         43.5         65.3         52.2         78.3         60.9         91.4         58.7         56.3         31.2         55.8         57.8         66.3         102.         65.8         33.3         56.3         43.4         58.5         87.8         66.3         102.         65.8         33.3         55.0         51.4         58.5         49.6         59.3         56.3         55.3         56.3 <t< th=""><td>Nut         3in.         56         43.5         65.3         52.2         78.3         60.9         91.4         58.7         58.3         58.3         102         65.8         91.4         58.7         58.3         102         65.8         91.4         58.7         56.3         122         66.3         102         65.8         91.4         58.3         102         65.8         91.4         58.3         102         65.8         91.4         58.3         113         55.5         49.6         60.9         91.4         58.3         113         113         55.5         49.6         60.9         91.4         68.3         112         55.6         53.3         55.6         53.3         55.6         53.3         55.3         55.3         55.6         55.3         55.6         55.3         55.6         55.3         55.6         55.3         55.6         55.6         55.6         55.7         56.9         85.7         113         56.9         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6</td><td></td><td>2<sup>2/3</sup> db</td><td>85 58</td><td>27.6 30.9</td><td>41.3 46.3</td><td>34.8 39.0</td><td>52.2 58.5</td><td>42.1 47.1</td><td>63.1 70.7</td><td>47.1 52.8</td><td>7.07</td></t<>	Nut         3in.         56         43.5         65.3         52.2         78.3         60.9         91.4         58.7         58.3         58.3         102         65.8         91.4         58.7         58.3         102         65.8         91.4         58.7         56.3         122         66.3         102         65.8         91.4         58.3         102         65.8         91.4         58.3         102         65.8         91.4         58.3         113         55.5         49.6         60.9         91.4         58.3         113         113         55.5         49.6         60.9         91.4         68.3         112         55.6         53.3         55.6         53.3         55.6         53.3         55.3         55.3         55.6         55.3         55.6         55.3         55.6         55.3         55.6         55.3         55.6         55.6         55.6         55.7         56.9         85.7         113         56.9         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6         55.6		2 <sup>2/3</sup> db	85 58	27.6 30.9	41.3 46.3	34.8 39.0	52.2 58.5	42.1 47.1	63.1 70.7	47.1 52.8	7.07
	VIS         22/3 db         56         29.7         44.6         37.0         55.5         44.2         66.3         49.3         55.3         8         3         5         3         5         3         5         3         5         3         5         3         5         5         44.6         37.0         5         5         4         2         5         4         5         6         3         3         5         6         7         3         5         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         5         3         1         4         5         3         1         4         5         5         3         1         4         5         5         3         1         3         1         4         5         5         3         1         4         5         3         1         4         5         3         1         4         5         3         1         1	SSLP	3 in.	58 65	43.5	65.3 73.1	52.2 58.5	78.3 87.8	60.9 68.3	91.4 102	58.7 65.8	88.1 98.7
3 in.         56         43.5         65.3         52.2         78.3         60.9         91.4         60 $2^2/3$ db         56         48.8         73.1         58.5         87.8         68.3         102         68.3 $2^2/3$ db         56         4.06         5.44         4.35         5.53         5.69         7.51         5.84 $2^2/3$ db         56         4.35         5.53         5.33         5.59         7.51         5.8 $3$ in.         56         4.35         5.13         3.92         5.83         3.17         47.5         105 $2^2/3$ db         56         31.8         47.7         38.6         5.7.9         45.4         60.7         46.5 $2^2/3$ db         56         31.8         47.7         38.6         57.9         45.4         68.0         52.1 $3$ in.         56         31.8         47.7         38.6         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         53.3         5	VD         3 in.         56         435         65.3         52.2         78.3         60.9         91.4         60.9         51.7         60.9         51.7         60.9         51.7         60.9         51.7         60.9         51.7         60.9         51.7         60.9         51.7         56.0         7.51         5.60         7.51         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.60         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.61         5.21         7.71         5.61         6.61         6.60         4.65         5.21         7.31         5.65         6.61         7.31         5.61         6.61         6.61         6.61         6.61         6.61         6.61         6.61         6.61         6.61         6.61         6.61         6		2 <sup>2/3</sup> d <sub>b</sub>	58 65	29.7 33.3	44.6 50.0	37.0 41.4	55.5 62.2	44.2 49.6	66.3 74.3	49.3 55.3	74.0 82.9
	Lin         58         3.62         5.44         4.35         6.53         5.08         7.51         5.80         8.53         6.50           BLP         31n.         58         43.5         65.3         39.2         5.87         2.83         4.25         1.74         3           BLP         31n.         56         4.06         6.09         4.88         7.31         4.39         6.53         3.17         4.75         195         3           BL         31n.         56         4.0.6         6.0.9         4.88         7.31         5.6.9         8.5.3         6.5.0         3         2.5         195         3         3         4.7.5         195         3         3         4.7.5         195         3         3         4.7.5         195         5.5         3         3         3         4.4         4.35         6.5.3         5.0.8         7.61         5.6.2         3	6	3 in.	58 65	43.5 48.8	65.3 73.1	52.2 58.5	78.3 87.8	60.9 68.3	91.4 102	60.9 68.3	91.4 102
3 in.         58         43.5         65.3         39.2         58.7         28.3         42.4         17.4 $2^{2}/3$ d <sub>6</sub> 56 $28.8$ 73.1 $43.9$ 65.8 $31.7$ $47.5$ 195.5 $2^{2}/3$ d <sub>6</sub> 56 $28.4$ $47.5$ $34.4$ $51.7$ $47.5$ $46.5$ $2^{2}/3$ d <sub>6</sub> 56 $31.8$ $47.7$ $38.6$ $57.9$ $45.4$ $68.0$ $52.1$ $31.n$ $66$ $31.8$ $42.5$ $55.3$ $53.3$ $53.3$ $53.3$ $53.3$ $53.3$ $50.9$ $52.1$ $56.3$ $52.1$ $56.3$ $52.2$ $78.3$ $50.9$ $91.4$ $69.6$ $s \geq s_{hin}$ $66.3$ $52.3$ $58.5$ $87.8$ $68.3$ $102$ $78.0$ $58.0$ $s \geq s_{hin}$ $56.3$ $52.3$ $58.5$ $87.3$ $50.9$ $91.4$ $69.6$ $s \geq s_{hin}$ $56.3$ $52.3$ $58.3$ $50.3$ $50.3$ $50.0$	ain.         56         43.5         65.3         39.2         58.7         28.3         42.4         17.4         5           11         65         48.8         73.1         43.9         65.8         31.7         47.5         19.5         2           11         56         38.4         57.1         43.9         65.8         31.7         47.5         19.5         2           11         27/3         46         56         31.8         47.7         38.6         57.1         45.4         68.0         52.1         7         45.5         60.0         52.1         7         50.8         50.1         56.1         56.3         52.1         7         8         50.8         50.1         56.1         56.3         52.1         7         8         7         1         56.9         85.3         68.3         102         78.0         10         7         10         7         66.0         91.4         69.6         10         6         3         10         7         8         7         102         78.0         10         7         10         7         10         7         10         7         10         7         10         7 <td></td> <td>2<sup>2/3</sup> d<sub>b</sub></td> <td>58 65</td> <td>3.62 4.06</td> <td>5.44 6.09</td> <td>4.35</td> <td>6.53 7.31</td> <td>5.08 5.69</td> <td>7.61 8.53</td> <td>5.80 6.50</td> <td>8.70</td>		2 <sup>2/3</sup> d <sub>b</sub>	58 65	3.62 4.06	5.44 6.09	4.35	6.53 7.31	5.08 5.69	7.61 8.53	5.80 6.50	8.70
	Line         22/3         db         58         28.4         4.2.6         34.4         51.7         40.5         60.7         46.5         22.1           3 in.         55         31.8         47.7         38.6         57.9         45.4         68.0         22.1           3 in.         55         40.5         60.9         48.8         53.3         55.0         78.0         73.1         56.9         73.1         56.9         78.1         78.0         73.1         55.9         78.1         78.1         78.6         58.0         37.4         57.6         37.4         55.9         55.3         55.0         57.6         27.1/6         27.1/6         27.1/6         27.1/6	LSLP	3 in.	58 65	43.5 48.8	65.3 73.1	39.2 43.9	58.7 65.8	28.3 31.7	42.4 47.5	17.4 19.5	26.1 29.3
3 in.         58         36.3         54.4         43.5         65.3         50.8         76.1         56.2           3 in.         65         40.6         60.9         48.8         73.1         56.9         85.3         53.0         85.3         53.0         85.3         53.0         85.3         53.0         85.3         53.0         87.1         56.9         85.3         53.0         87.3         60.9         91.4         69.6         99.6         78.0         78.	3 in.         56         36.3         54.4         43.5         65.3         50.8         76.1         56.2           SSL1,         65         40.6         60.9         48.8         73.1         56.9         85.3         83.0           SSL1,         55         8         43.5         65.3         52.2         78.3         60.9         91.4         69.6         1           \$SSL1,         5         5         40.6         60.9         48.8         73.1         58.5         87.8         68.3         102         76.0         10           \$SU1,         \$\$         5         40.6         60.9         48.8         73.1         56.9         85.3         65.0         102         76.0         10           \$SU1,         \$\$         \$\$         40.6         60.9         48.8         73.1         56.9         85.3         65.0         31/6           \$SU1,         \$\$         \$\$         40.6         60.9         48.8         73.1         56.9         85.3         65.0         31/6           \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         \$\$         31/	+10-	2 <sup>2/3</sup> d <sub>b</sub>	58 65	28.4 31.8	42.6 47.7	34.4 38.6	51.7 57.9	40.5 45.4	60.7 68.0	46.5 52.1	69.8 78.2
s ≥ sturf         58         43.5         65.3         52.2         78.3         60.9         91.4         69.6           s ≥ sturf         65         48.8         73.1         58.5         87.8         69.3         102         78.0           s ≥ sturf         66         30.3         54.4         43.5         65.3         50.8         76.1         58.0           s ≥ sturf         66         30.4         43.5         65.3         50.8         76.1         58.0           s 51.         510.         54.4         43.5         65.3         50.8         76.1         58.0           s 51.         510.         61.0         48.8         73.1         56.9         85.3         55.0           s 51.         510.         23.1         55.4         43.5         65.0         83.3         65.0           s 51.         51.6         23.1         53.1         53.1         53.6         53.6         53.6           s 51.1         115/1         23/16         23/16         213/16         213/16         213/16         23.6           in         551.P         213/16         33.8         33.6         35.16         55.16         55.16	SSLT         58         43.5         55.3         52.2         78.3         60.9         91.4         68.6         1           NOKs, $s \ge s_{nur}$ 65         48.8         73.1         58.5         87.8         68.3         102.4         68.6         1           SLT $s \ge s_{nur}$ 65         48.8         73.1         58.5         88.3         102.4         58.0         1           SLT $s \ge s_{nur}$ 65         40.6         60.9         48.8         73.1         58.0         87.3         56.0         37.6           SLT $1^{15}/16$ $2^{7}/16$ $2^{7}/16$ $2^{17}/16$ $2^{17}/16$ $3^{1/6}$ sating strength         SSLT $1^{15}/16$ $2^{7}/16$ $2^{13}/16$ $3^{1/6}$ $3^{1/6}$ sum_a, in.         SSLT $1^{15}/16$ $2^{7}/16$ $2^{13}/16$ $3^{1/6}$ $3^{1/6}$ sum_a, in.         SSLT $1^{15}/16$ $2^{7}/2$ $2^{2}/2$ $3^{1/6}$ $3^{1/6}$ sum_a, in.         SSLT $2^{1/6}/6$ $2^{1/6}/6$ $2^{1/6}/6$ $2^{1/6}/6$ $3^{1$		3 in.	58 65	36.3 40.6	54.4 60.9	43.5 48.8	65.3 73.1	50.8 56.9	76.1 85.3	56.2 63.0	84.3 94.5
7         58         36.3         54.4         43.5         65.3         50.8         76.1         58.0           STD,         STD,         73.1         56.9         85.3         55.0         85.3         55.0           STD,         STD,         73.1         56.9         85.3         55.0         85.3         55.0           SSU,         115/16 $2^{5}/16$ $2^{1}/16$ $2^{1}/16$ $2^{1}/16$ $2^{1}/16$ SSL, $1^{5}/16$ $2^{7}/16$ $2^{1}/16$ $2^{1}/16$ $2^{1}/16$ SSLP $2^{1}/16$ $2^{1}/2$ $2^{1}/2$ $2^{1}/6$ $2^{1}/6$ SSLP $2^{1}/6$ $2^{1}/2$ $2^{1}/3$ $3^{1}/6$ $3^{1}/6$ SSLP $2^{1}/3$ $3^{1}/6$ $3^{1}/6$ $3^{1}/6$ $3^{1}/6$	SLT         s > sturt         58         36.3         54.4         43.5         65.3         50.8         76.1         58.0           Pacing for full saring strength stands, in.         STD, SLT         115/16         2.5/16         2.11/16         3/14           Pacing for full stands, in.         SSLT, SLT         115/16         2.5/16         2.11/16         3/14           Pacing strength stands, in.         SSLT, Stand, in.         115/16         2.17/16         3/14           Stand, a.         SSLT, LSLP         2.13/16         2.17/16         3/14           Stand, a.         SSLT, Stand, a.         2.13/16         2.17/16         2.17/16           Stand, a.	STD, SSLT, SSLP, OVS, LSLP		58 65	43.5 48.8	65.3 73.1	52.2 58.5	78.3 87.8	60.9 68.3	91.4 102	69.6 78.0	104 117
STD, SSLT, LSLT         1 <sup>15</sup> / <sub>16</sub> 2 <sup>5</sup> / <sub>16</sub> 2 <sup>11</sup> / <sub>16</sub> LSLT         21/ <sub>16</sub> 2 <sup>17</sup> / <sub>16</sub> 2 <sup>13</sup> / <sub>16</sub> LSLT         21/ <sub>16</sub> 2 <sup>17</sup> / <sub>16</sub> 2 <sup>13</sup> / <sub>16</sub> SSLP         2 <sup>17</sup> / <sub>16</sub> 2 <sup>17</sup> / <sub>16</sub> 2 <sup>17</sup> / <sub>16</sub> SSLP         2 <sup>17</sup> / <sub>16</sub> 3 <sup>3</sup> / <sub>16</sub> 3 <sup>3</sup> / <sub>16</sub> LSLP         2 <sup>17</sup> / <sub>16</sub> 3 <sup>3</sup> / <sub>16</sub> 3 <sup>3</sup> / <sub>16</sub>	StD,         StD, <t< td=""><td>LSLT</td><td>S ≥ Stult</td><td><b>58</b> 65</td><td>36.3 40.6</td><td>54.4 60.9</td><td>43.5</td><td>65.3 73.1</td><td><b>50.8</b> 56.9</td><td>76.1 85.3</td><td><b>58.0</b> 65.0</td><td>87.0</td></t<>	LSLT	S ≥ Stult	<b>58</b> 65	36.3 40.6	54.4 60.9	43.5	65.3 73.1	<b>50.8</b> 56.9	76.1 85.3	<b>58.0</b> 65.0	87.0
OVS         21/ <sub>16</sub> 27/ <sub>16</sub> 21 <sup>3</sup> / <sub>16</sub> SSLP         21/ <sub>8</sub> 21/ <sub>2</sub> 27/ <sub>6</sub> LSLP         21 <sup>3</sup> / <sub>16</sub> 3 <sup>3</sup> / <sub>8</sub> 31 <sup>5</sup> / <sub>16</sub>	acting strength <b>OVS</b> $2^{1/_{16}}$ $2^{1/_{16}}$ $2^{1/_{16}}$ $2^{1/_{16}}$ $s_{tul^3}$ , in. <b>SSLP</b> $2^{1/_{16}}$ $2^{1/_{16}$	Spacing	for full	STD, SSLT, LSLT	115	5/16	25	/16	211	1/16	31	/16
SSLP         21/8         21/2         21/8           ISLP         213/16         33/8         315/16           Astronomy         33/8         315/16         35/16	Sturt, In.         SSLP $2^{1/8}$ $2^{1/2}$ $2^{7/8}$ $2^{7/8}$ num Spacing*         LSLP $2^{1/3}_{1.6}$ $3^{3/6}$ $3^{15/16}_{1.6}$ $3^{-5/16}_{1.6}$ num Spacing* $2^{2}_{3}g_4$ , in. $1^{11}_{1/16}$ $2$ $2^{5}_{1/6}$ $3^{-5}_{1.6}$ a standard hole $1^{11}_{1/16}$ $2$ $2^{5}_{1/6}$ $3^{-5}_{1.6}$ a standard hole $1^{-1}_{1/16}$ $2$ $2^{5}_{1/6}$ $3^{-5}_{1/6}$ a standard hole $1^{-1}_{1/16}$ $2$ $2^{5}_{1/6}$ $3^{-1}_{1/6}$ a standard hole $1^{-1}_{1/1/16}$ $2$ $2^{5}_{1/6}$ $2^{-5}_{1/6}$ a standard hole $2^{-1}_{1/2}$ $2^{-1}_{1/1/16}$ $2^{-1}_{1/2}$ $2^{-5}_{1/6}$ a standard hole $2^{-1}_{1/2}$ $2^{-1}_{1/2}$ $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ a standard hole $2^{-1}_{1/2}$ $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ a standard hole $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ $2^{-1}_{1/6}$ a standard hole $2^{-1}$	bearing :	strength	SVO	21	/16	27	/16	215	3/16	3.	/4
LSLP 2 <sup>13/16</sup> 3 <sup>3/8</sup> 3 <sup>15/16</sup> 3 <sup>15</sup> /16	LSLP $2^{13}/16$ $3^{3}/8$ $3^{15}/16$ $3^{15}/16$ num Spacing <sup>a</sup> = 2 <sup>2</sup> /3.d. in. $1^{11}/1_{16}$ 2 $2^{5}/16$ =           = standard hole           = short-slotted hole oriented transverse to the line of force         = oversized hole         = oversized hole         = long-slotted hole oriented parallel to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to the line of force         = long-slotted hole oriented transverse to tho	Sfull	÷.	SSLP	2.	1/8	2	1/2	2	7/8	35	/16
001 A In 4114 0 064	num Spacing <sup>a</sup> = 2 <sup>2</sup> / <sub>3</sub> d, in.         1 <sup>11</sup> / <sub>16</sub> 2         2 <sup>5</sup> / <sub>16</sub> = standard hole         = standard hole         = standard hole         = short-slotted hole oriented transverse to the line of force         = short-slotted hole oriented parallel to the line of force         = oversized hole           = non-slotted 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			LSLP	210	3/16	35	3/8	316	5/16	4	12
<b>z-730, III.</b> 1.1/16 Z Z/16		Minimum S	$pacing^a = 2^{2}$	<sup>2</sup> /3d, in.	11	1/16	1	2	25	/16	21.	/16
ASD LRFD Note: Spacing indicated is from the conter of the hole or slot to the center of the adjacent hole of		$\Omega = 2.00$	φ = 0.75	see AISC 5	pecification	siou in une inte or rouce, note deforma see AISC Specification Section J3.10.	rmation is c 1.10. d to the peo	orisidered.	sion in the line of force: now eventimation is considered. When now ue see AISC Specification Section J3.10. a heatman have here here here now normand to the nearest evidentith of an indu-	Jerormanon	IS HOL COUS	ing lan

Nominal Bort Diameter, 4, in.           File         3/4         7/8           5/8         3/4         7/8           5/8         3/4         7/8           5/8         3/4         7/8           5/8         3/4         7/8           31.5         6%         6%         6%         6%         6%         6%         6%         6%         6%         6%         6%         6%         6%         7/8         5%         6%         6%         6%         6%         6%         6%         6% <th colsp<="" th=""><th></th><th></th><th></th><th>kip</th><th>kips/in. thickness</th><th>thick</th><th>ness</th><th>kips/in. thickness</th><th>0</th><th></th><th></th></th>	<th></th> <th></th> <th></th> <th>kip</th> <th>kips/in. thickness</th> <th>thick</th> <th>ness</th> <th>kips/in. thickness</th> <th>0</th> <th></th> <th></th>				kip	kips/in. thickness	thick	ness	kips/in. thickness	0		
			What is a	840 Dund	Remman	Nom	inal Bolt	Diameter,	ď, in.			
Lename         T_n/12 $\phi_{fn}$ $f_n/12$ <t< th=""><th>Hole Tune</th><th>Edge</th><th>E kei</th><th></th><th>5/8</th><th></th><th>3/4</th><th></th><th>8/2</th><th>-</th><th>-</th></t<>	Hole Tune	Edge	E kei		5/8		3/4		8/2	-	-	
ASD         LRFD         ASD         ASD         LRFD         ASD         LRFD         ASD         LRFD         ASD         ASD         ASD         ASD         LRFD         ASD         ASD </th <th></th> <th>Le, in.</th> <th>102 40</th> <th><math>r_n/\Omega</math></th> <th>φLn</th> <th><math>r_n/\Omega</math></th> <th>φſ'n</th> <th><math>r_n/\Omega</math></th> <th>¢r<sub>n</sub></th> <th><math>r_n/\Omega</math></th> <th>\$r_n</th>		Le, in.	102 40	$r_n/\Omega$	φLn	$r_n/\Omega$	φſ'n	$r_n/\Omega$	¢r <sub>n</sub>	$r_n/\Omega$	\$r_n	
1/1         56         31.5         47.3         29.4         44.0         27.2         40.8         25.0         31.5         45.7         280         57.3         55.3         53.0         35.2         79.9         51.1         280         57.3         280.3         57.9         57.1         280.5         57.3         280.3         57.9         57.1         280.3         57.3         39.2         23.9         40.2         25.3         280.3         57.9         57.1         280.5         57.3         39.2         23.9         30.1         57.3         30.3         50.0         57.3         20.2         20.3         <		BA C14		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	
2         56         435         55.2         78.3         53.3         79.9         51.1           11/4         56         48.8         73.1         58.5         87.8         59.7         39.6         57.3           2         56         31.7         47.5         59.3         33.9         26.8         40.2         23.2           2         56         31.7         47.5         59.3         43.9         50.0         45.7         23.9         35.9         20.7           2         56         43.8         73.1         58.5         87.8         56.0         37.5         21.8           17/4         56         32.9         49.4         27.2         88.5         87.8         55.1         47.3         51.4           2         56         48.8         73.1         58.5         87.8         55.0         37.5         21.8           11/4         56         48.8         73.1         58.4         53.0         36.1         53.1         23.4           11/4         56         47.5         71.3         41.4         55.5         31.4         47.3         26.1           2         58         47.3 <t< th=""><td>STD</td><td>11/4</td><td>58 65</td><td>31.5 35.3</td><td>47.3 53.0</td><td>29.4 32.9</td><td>44.0 49.4</td><td>27.2 30.5</td><td>40.8</td><td>25.0</td><td>37.5</td></t<>	STD	11/4	58 65	31.5 35.3	47.3 53.0	29.4 32.9	44.0 49.4	27.2 30.5	40.8	25.0	37.5	
11/4         56         20.0         57.0         56.1         57.1         56.3         52.2         78.3         50.0         75.0         40.2         23.2         23.9         20.0         75.0         40.2         23.2         23.2         23.9         20.0         75.0         40.2         23.2         23.2         23.5         50.0         75.0         40.2         23.2         23.2         23.5         21.8         40.2         23.2         23.5         21.8         40.2         23.2         23.5         21.8         40.2         23.2         23.5         21.8         40.2         23.2         23.5         21.8         35.1         36.0         37.5         21.8         36.0         37.5         21.8         36.0         37.5         21.8         36.0         37.5         21.8         36.0         37.5         21.8         36.0         37.5         21.8         36.0         37.5         21.8         37.5         21.8         37.1         36.0         37.5         21.8         37.5         37.4         37.5         37.4         37.5         37.4         37.5         37.4         37.5         37.4         37.5         37.4         37.5         37.4         37.5	SSLT	2	58	43.5	65.3 73.1	52.2 58.5	78.3	53.3	79.9 89.6	51.1	76.7	
2         56         43.5         65.3         52.2         78.3         56.0         75.0         46.8           11/4         56         48.8         73.1         58.5         87.8         56.1         84.1         52.4           2         66         48.8         73.1         58.5         87.8         56.1         84.1         52.4           2         66         32.9         49.4         30.5         45.7         28.0         37.5         21.8           2         66         32.9         49.4         30.5         45.7         28.0         37.5         21.8           2         66         32.9         49.4         53.2         74.8         81.6            17/4         65         18.3         27.4         12.2         18.3         53.0         29.3         29.3           17/4         66         47.5         71.3         41.4         62.2         35.1         38.1         234.0         48.6           2         47.5         71.3         41.4         62.2         38.1         234.0         23.3         20.3         20.3         20.3         20.3         20.3         20.3         20.3		11/4	8 8	28.3	42.4	26.1	39.2	23.9	35.9	20.7	31.0	
1/4         58         294         44.0         27.2         40.8         25.0         37.5         21.8           2         66         32.9         49.4         30.5         45.7         28.0         37.5         21.8           2         66         32.9         49.4         30.5         45.7         28.0         37.5         21.8           2         66         48.8         73.1         58.5         87.8         57.3         85.9         35.6           1/4         66         16.3         27.4         10.2         16.3         55.5         31.5         47.4         20.9         36.1           2         66         47.5         71.3         41.4         62.2         35.3         29.3         29.3           1/4         56         29.5         34.2         27.4         41.1         25.4         38.1         27.3           2         66         49.8         63.5         37.3         48.3         66.6         42.6         47.6           2         66         43.5         57.4         41.1         25.4         38.1         23.4           4         66         43.8         73.1         48.8	SSLP	2	28	43.5	65.3 73.1	52.2	78.3 87.8	50.0	75.0 84.1	46.8	70.1	
2         58         43.5         65.3         52.2         78.3         51.1         76.7         47.3           11/4         56         48.8         73.1         58.5         87.8         57.3         85.9         53.6           11/4         56         18.3         27.4         12.2         18.3         5.09         9.14            2         56         47.5         71.3         81.6         9.14            2         56         47.5         71.3         81.4         6.09         9.14            2         56         47.5         71.3         81.4         6.09         91.4            2         56         47.5         71.3         81.7         55.5         31.5         54.7         20.8           11/4         56         29.5         44.2         27.4         41.1         25.4         38.1         23.4           2         56.3         54.4         43.5         65.3         44.4         66.6         47.5         73.0         20.8           4         58.5         87.3         60.9         91.4         66.6         47.6         47.3         56.		11/4	82 58	29.4 32.9	44.0 49.4	27.2 30.5	40.8	25.0 28.0	37.5 42.0	21.8 24.4	32.6	
1/4         58         16.3         24.5         10.9         16.3         5.44         8.16            2         56         42.4         6.3.6         37.0         55.5         31.5         47.3         26.1           2         56         47.5         71.3         41.4         62.2         35.3         53.0         29.3         28.1           2         56         29.5         34.4         85.3         36.1         28.3         28.4         88.3         102         28.4         78.1         28.4         78.1         28.4         78.1         28.4         78.1         28.4         78.1         28.4<	S	2	58 65	43.5 48.8	65.3 73.1	52.2 58.5	78.3 87.8	51.1 57.3	76.7 85.9	47.9	71.8 80.4	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		11/4	58 65	16.3 18.3	24.5 27.4	10.9	16.3	5.44 6.09	8.16 9.14	11	11	
	LSLP	2	58	42.4 47.5	63.6 71.3	37.0	55.5 62.2	31.5 35.3	47.3 53.0	26.1	39.2	
2         58         36.3         54.4         43.5         65.3         44.4         66.6         42.6           4         58         43.6         60.9         48.8         73.1         49.8         74.6         47.1 $L_e \geq L_e hult         58         43.5         65.3         52.2         78.3         60.9         91.4         69.6           L_e \geq L_e hult         65         43.8         73.1         58.5         87.8         69.3         102.2         78.0           L_e \geq L_e hult         65         36.3         54.4         43.5         65.3         50.8         76.1         58.0           26         36.3         54.4         43.5         65.3         50.8         76.1         58.0           Le> Le hult         58         36.3         54.4         43.5         65.3         50.8         75.1         58.0           Le> Le hult         58         36.3         73.1         56.0         48.8         73.1         51.4         58.0           Le> Le hult         58         36.5         53.5         56.3         50.8         57.4         58.0           Shitt         15/a         11.5/a         2.1/a  $	-101	11/4	82 82	26.3 29.5	39.4 44.2	24.5 27.4	36.7 41.1	22.7 25.4	34.0 38.1	20.8	31.3	
	P	2	63 63	36.3 40.6	54.4 60.9	43.5 48.8	65.3 73.1	44.4 49.8	66.6 74.6	42.6 47.7	63.9	
	STD, SSLT, SSLP, OVS, LSLP		58 65	43.5 48.8	65.3 73.1	52.2 58.5	78.3 87.8	60.9 68.3	91.4 102	69.6 78.0	104	
STD,         15/8         115/16         21/4           LSLT         11/16         2         25/16           OVS         111/16         2         25/16	LSLT	$L_{e} \ge L_{e}$ tull	58	36.3 40.6	54.4 60.9	43.5 48.8	65.3 73.1	50.8 56.9	76.1 85.3	58.0	87.0	
OVS         1 <sup>11</sup> / <sub>16</sub> 2         2 <sup>5</sup> / <sub>16</sub> SSLP         1 <sup>11</sup> / <sub>16</sub> 2         2 <sup>5</sup> / <sub>16</sub>	Edge di	stance	STD, SSLT, LSLT	15,		-	15/16	21/	4	29	29/16	
SSLP 111/16 2 25/16	strer	ngth	OVS	11	1/16	2		25	/16	25	8	
	$L_{\theta} \ge L_{\theta}$	tura, in.	SSLP	11	1/16	2		25	16	21	211/16	
21/16 21/16 21/8		area - 10	LSLP	21/	16	2	27/16	27	8	31/4	4	
	ASD	LRFD	- indicat	es spacing	less than m	inimum spa	acing requir	ed per AISC	Specificatio	n Section J	3.3.	
LRFD	Ω = 2.00	φ = 0.75	Note: Spacing indicated is from the center of the hole or slot to the ce slot in the line of force. Hole deformation is considered. When hole del see AISC Specification Section J3.10.	Note: Spacing indicated is from the ce slot in the line of force. Hole deformat see AISC Specification Section J3.10.	ed is from the e. Hole defo 7 Section J3	ne center of rmation is c	f the hole or considered.	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 force. Hole deformation is considered. When hole deformation is not considered, see AISC Specification Section J3.10.	center of the deformation	adjacent l is not cons	hole of idered.	



*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:  $A_e = A_n U$ 

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

*For tension elements:* 

Note Set 17.1

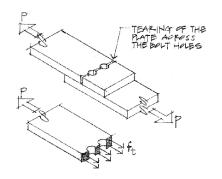
Tension

Area

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

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

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



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

For shear elements:

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

- 1. yielding  $R_n = 0.6F_y A_g$  $\phi = 1.00 (LRFD)$   $\Omega = 1.50 (ASD)$
- 2. rupture  $R_n = 0.6F_u A_{nv}$

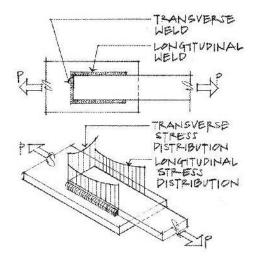
 $\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$ 

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.

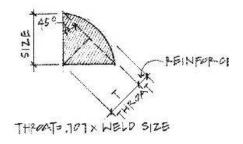
The throat size, T, of a fillet weld is determined trigonometry by:  $T = 0.707 \times weld size^*$ \* When the submerged arc weld process is used, welds over 3/8" will have a throat thickness of 0.11 in. larger than the formula.



Shear

Area

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  $\frac{1}{4}$  in. thick, not greater than the thickness of the material.
- Material <sup>1</sup>/<sub>4</sub> 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 <sup>1</sup>/<sub>4</sub> the length.

Intermittent fillet welds cannot be less than four times the weld size, not to be less than  $1 \frac{1}{2}$ ".

TABLE J2.4	
Minimum Size of Fillet W	elds

Material Thickness of Thicker	Minimum Size of Fillet
Part Joined (in.)	Weld <sup>a</sup> (in.)
To ¼ inclusive	1∕s
Over ¼ to ½	3∕16
Over ½ to ¾	1∕4
Over ¾	5∕16

American Institute of Steel Construction

<u>For fillet welds:</u>	$R_a \leq R_n / \Omega$ or $R_u \leq \phi R_n$
	where $R_{\mu} = \Sigma \gamma_i R_i$

for the weld metal:	$R_n = 0.6F_{EXX}$	Tl = Sl
$\phi = 0$	.75 (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
pei	inch of weld (	$\phi S$ )
Weld Size	E60XX	E70XX
(in.)	(k/in.)	(k/in.)
3/16	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)

#### Note Set 17.1

GIPDER BEAM

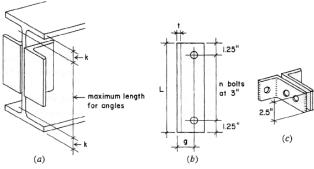
Framed Beam Connections

*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 vielding 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 doubleangle connections and all-welded doubleangle connections.



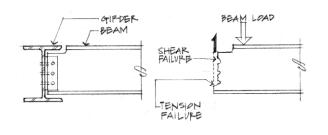
Sample AISC Table for Bolt and Angle Available Strength in All-Bolted Double-Angle Connections

	= 65 ksi	- The second se	A	ň	otto	<b>All-Bolted Double-Angle</b>	Õ	Iqn	e-1	Vng	e	e Ka	°∕4-in.	Ę.
u≿ əı6ı					ŏ	Connections	lec	tio	SU				Bolts	s
1A 15	= 58 ksi		ngtin	016-01	8	Bolt and Angle Available Strength, kips	Angle	Availab	le Strei	ngth, ki	sd	20 745 7		
4	4 Rows	tod	Ě	∩Å A	j	olou	ale		Ang	Angle Thickness, in.	kness	Ë.	S NOVO	
	40 40	Group	8	Cond.	ē 🏱	and L	-3	1/4		5/16	5 C C C	3/8	F	1/2
МС4	W24, 21, 18, 10	024	- KL -	USA .	1987	02.4	ASD		0.51.4	ASD LRFD	ASD		ASD	
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					o k			75.0	12	75.0		-	120	200
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	1	Anoup	Clas	Class A	> %	SSIT	50.6	75.9	2.100	75.9	50.6		1993	75.9
1:	÷ •		0		S	STD	67.1	101	1000	126	84.4		84.4	127
	đe		Clas	Class B	0	SVO	65.3	97.9	71.9	108	71.9		71.9	108
1					S	SSLT	65.8	98.7	82.2	123	84.4	_	84.4	121
			- ^	z>	່ທີ່		67.1	10 F	83.9	126	ē \$	151	120	180
	-^-				No lo	STD	633	94.9	63.3	94.9	633		633	04 9
ţ.		Group	s	S	00	SNO	53.9	80.7	53.9	80.7	53.9		53.9	80.7
		8	Clas	Class A	8	SSLT	63.3	94.9	63.3	94.9	63.3		63.3	94.9
			6		ŝ	STD	67.1	101	83.9	126	101	151	105	158
			o oci	JC Clace B	0	SVO	65.3	97.9	81.6	122	89.9		89.9	134
			ă		S	SSLT	65.8	98.7	82.2	123	98.7	148	105	158
		Bei	am We	b Avail	able St	Bearn Web Available Strength per Inch Thickness, kips/in.	per In	ch Thic	kness,	kips/ir	2			
	Hole Type			S	STD			6	SVO			SSLT	5	
	addi anon			1.10	64 J			Leh*	L <sub>eh</sub> *, in.					
			F	11/2	1	13/4	-	11/2	-	13/4	-	11/2	13	13/4
		03A.	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
	181	11/4	167	250	175	262	156	234	164	246	164	245	172	257
		13/8	169	254	171	266	158	238	167	250	166	249	174	261
۳ ۱	Coped at Top	11/2	171	257	180	269	161	241	169	254	168	253	177	265
Нап	Hange Only	15/8	174	261	182	273	163	245	4	257	4	256	179	268
		N 0	100	212	691	212		2007	6/1	202	8/1	107	186	500
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Ē	Flanges	15/8	171	256	171	256	161	241	161	241	171	256	171	256
	14		1at	010	195	278	14	256	176	263	170	267	105	278
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Su	Support Available	ele	Notes:								910	district A	10001	~
· • 1	Strength per		STD = 0VS =	STD = Standard holes OVS = Oversized holes	Standard holes Oversized holes				N = Threads included X = Threads excluded	reads inc reads exi	cluded			
	kips/in.	ó	SSLT =	Short-s to direc	lotted hc tion of lc	= Short-slotted holes transverse to direction of load	sverse		SC = SII	p critical				
Hole	ASD	LRFD	* Tabul	ated valu	les inclu	de <sup>1</sup> /4-in	. reducti	on in en	d distanc	e, Leh, ti	o accou	* Tabulated values include $^{1,4-in}$ . reduction in end distance, $L_{eh}$ , to account for possible	ssible	aloff Sql 7
STD/	468	702	Note: S been ad	underrun in beam lengin ote: Slip-critical bolt valu een added to distribute lo	earn ien al bolt v	gun. alues as: e loads ir	sume no	more th	an one t	iller has	been pr	undertrui in oeam lengdi. Nucle: Sito-criticato bolt values assume no more than one filler has been provided or bolts have been addrd to distribute hads in the fillers.	r bolts h	ave
2														

## 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):

 $R_a \leq R_n / \Omega$  or  $R_u \leq \phi R_n$ where  $R_u = \Sigma \gamma_i R_i$ 

$$R_{n} = 0.6F_{u}A_{nv} + U_{bs}F_{u}A_{nt} \le 0.6F_{y}A_{gv} + U_{bs}F_{u}A_{nt}$$

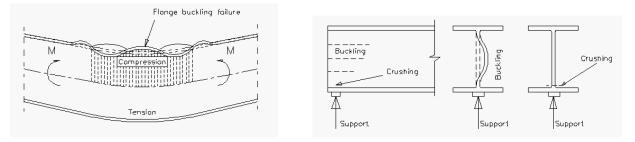
$$\phi = 0.75 (LRFD)$$
  $\Omega = 2.00 (ASD)$ 

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:

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

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

where

 $t_w$  = thickness of the web N = bearing length

k = dimension to fillet found in beam section tables

 $\phi = 1.00 \text{ (LRFD)} \qquad \Omega = 1.50 \text{ (ASD)}$ 

