DR. ANNE NICHOLS
SPRING 2013

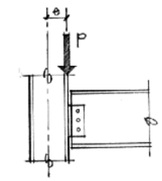
lecture
nineteen

steel construction: bolts & tension members

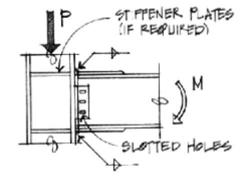
http://courses.civil.ualberta.ca

Connections

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



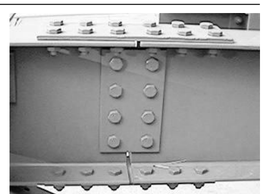
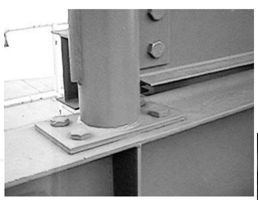
(a) Framed beam (shear) connection.
e = Eccentricity; M = P × e



(b) Moment connection (rigid frame).
M = Moment due to beam bending

Bolts

- bolted steel connections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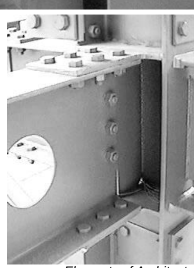
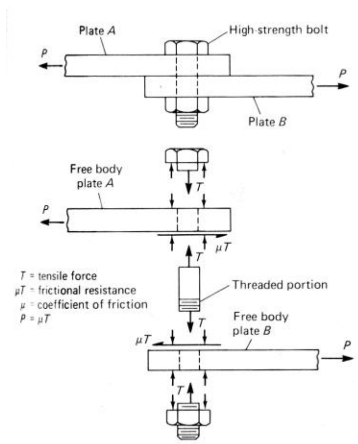



(AISC - Steel Structures of the Everyday)

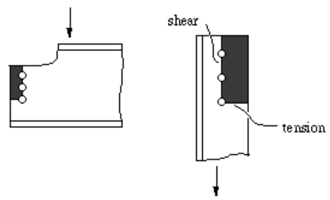
Bolts

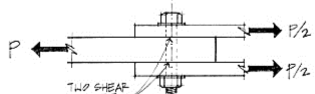
- types
  - materials
    - high strength
    - A307, A325, A492
  - location of threads
    - included
    - excluded
  - friction or bearing
    - always tightened

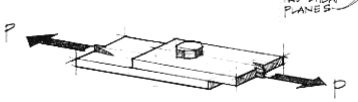


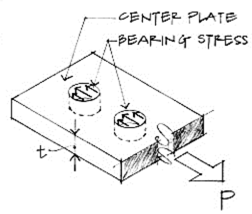
Bolted Connection Design

- considerations
  - – bearing stress
    - yielding
  - – shear stress
    - single & double
  - – member
    - rupture









Bolts

- rarely fail in bearing
- holes considered 1/8" larger
- shear & tension $R_a \le R_n / \Omega$ $\quad R_u \le \phi_v R_n$
  $\phi_v = 0.75$
  - – single shear or tension
    $$R_n = F_n A_b$$
  - – double shear
    $$R_n = F_n 2A_b$$

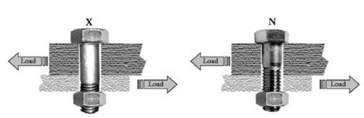
Bolts

Table 7-1
Available Shear Strength of Bolts, kips

Nominal Bolt Diameter, d, in.					5/8		3/4		7/8		1	
Nominal Bolt Area, in.²					0.307		0.442		0.601		0.785	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi) ASD	ϕF_{nv} (ksi) LRFD	Loading	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n 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
Nominal Bolt Diameter, d, in.					1 1/8		1 1/4		1 3/8		1 1/2	
Nominal Bolt Area, in.²					0.994		1.23		1.48		1.77	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi) ASD	ϕF_{nv} (ksi) LRFD	Loading	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n 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.										
$\Omega = 2.00$	$\phi = 0.75$											

Table 7-2
Available Tensile Strength of Bolts, kips

Nominal Bolt Diameter, d, in.			5/8		3/4		7/8		1	
Nominal Bolt Area, in.²			0.307		0.442		0.601		0.785	
ASTM Desig.	F_{nt}/Ω (ksi) ASD	ϕF_{nt} (ksi) LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD
Group A	45.0	67.5	13.8	20.7	19.9	29.8	27.1	40.6	35.3	53.0
Group B	56.5	84.8	17.3	26.0	25.0	37.4	34.0	51.0	44.4	66.6
A307	22.5	33.8	6.90	10.4	9.94	14.9	13.5	20.3	17.7	26.5
Nominal Bolt Diameter, d, in.			1 1/8		1 1/4		1 3/8		1 1/2	
Nominal Bolt Area, in.²			0.994		1.23		1.48		1.77	
ASTM Desig.	F_{nt}/Ω (ksi) ASD	ϕF_{nt} (ksi) LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD	r_n/Ω ASD	ϕr_n LRFD
Group A	45.0	67.5	44.7	67.1	55.2	82.8	66.8	100	79.5	119
Group B	56.5	84.8	56.2	84.2	69.3	104	83.9	126	99.8	150
A307	22.5	33.8	22.4	33.5	27.6	41.4	33.4	50.1	39.8	59.6
ASD	LRFD									
$\Omega = 2.00$	$\phi = 0.75$									



www.fastenal.com

Bolts

- bearing $(\phi_{\not{v}})$ $\quad R_a \le R_n / \Omega$ $\quad R_u \le \phi R_n$
  $\phi = 0.75$
  - – deformation is concern
    $$R_n = 1.2 L_c t F_u \le 2.4 d t F_u$$
  - – deformation isn't concern
    $$R_n = 1.5 L_c t F_u \le 3.0 d t F_u$$
  - – long slotted holes
    $$R_n = 1.0 L_c t F_u \le 2.0 d t F_u$$

  L_c – clear length to edge or next hole (ex. 1¼", 3")

Bolts

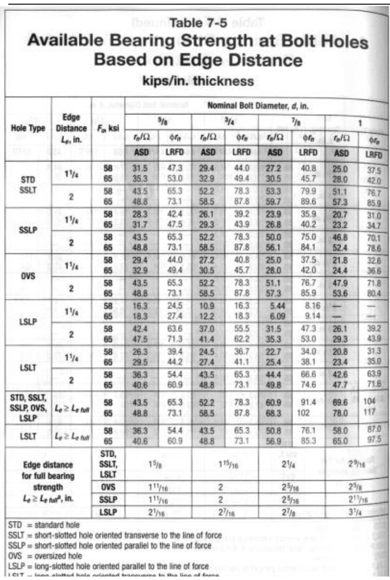


Table 7-5
Available Bearing Strength at Bolt Holes Based on Edge Distance
kips/in. thickness

Hole Type	Edge Distance L_e, in.	F_u, ksi	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	1 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 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 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 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 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 $L_e \geq L_{e\,full}$, in.	Hole type	5/8	3/4	7/8	1
	STD, SSLT, LSLT	1 5/8	1 15/16	2 1/4	2 9/16
	OVS	1 11/16	2	2 5/16	2 5/8
	SSLP	1 11/16	2	2 5/16	2 11/16
	LSLP	2 1/16	2 7/16	2 7/8	3 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

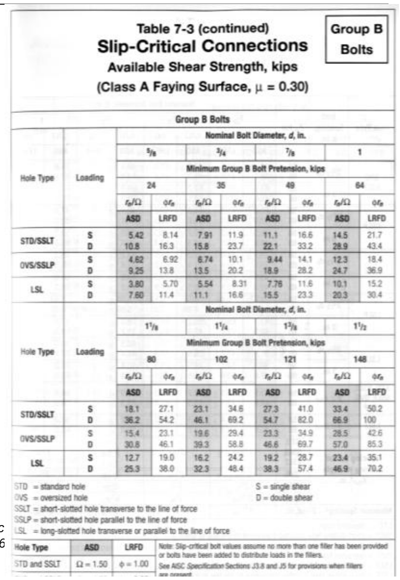


Table 7-3 (continued)
Slip-Critical Connections
Available Shear Strength, kips
(Class A Faying Surface, μ = 0.30)

Group B Bolts

Hole Type	Loading	5/8 (24) r_n/Ω ASD	5/8 (24) ϕr_n LRFD	3/4 (35) r_n/Ω ASD	3/4 (35) ϕr_n LRFD	7/8 (49) r_n/Ω ASD	7/8 (49) ϕr_n LRFD	1 (64) r_n/Ω ASD	1 (64) ϕr_n LRFD
STD/SSLT	S	5.42	8.14	7.91	11.9	11.1	16.6	14.5	21.7
	D	10.8	16.3	15.8	23.7	22.1	33.2	28.9	43.4
OVS/SSLP	S	4.62	6.92	6.74	10.1	9.44	14.1	12.3	18.4
	D	9.25	13.8	13.5	20.2	18.9	28.2	24.7	36.9
LSL	S	3.80	5.70	5.54	8.31	7.76	11.6	10.1	15.2
	D	7.60	11.4	11.1	16.6	15.5	23.3	20.3	30.4

(Nominal Bolt Diameter, d, in.; Minimum Group B Bolt Pretension, kips, in parentheses)

Hole Type	Loading	1 1/8 (80) r_n/Ω ASD	1 1/8 (80) ϕr_n LRFD	1 1/4 (102) r_n/Ω ASD	1 1/4 (102) ϕr_n LRFD	1 3/8 (121) r_n/Ω ASD	1 3/8 (121) ϕr_n LRFD	1 1/2 (148) r_n/Ω ASD	1 1/2 (148) ϕr_n LRFD
STD/SSLT	S	18.1	27.1	23.1	34.6	27.3	41.0	33.4	50.2
	D	36.2	54.2	46.1	69.2	54.7	82.0	66.9	100
OVS/SSLP	S	15.4	23.1	19.6	29.4	23.3	34.9	28.5	42.6
	D	30.8	46.1	39.3	58.8	46.6	69.7	57.0	85.3
LSL	S	12.7	19.0	16.2	24.2	19.2	28.7	23.4	35.1
	D	25.3	38.0	32.3	48.4	38.3	57.4	46.9	70.2

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
STD and SSLT	Ω = 1.50	ϕ = 1.00

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.

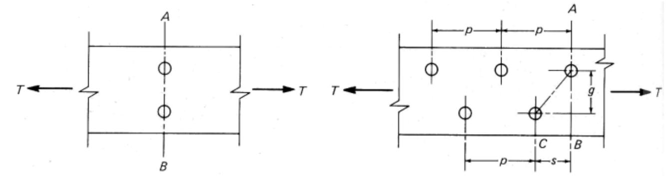
Tension Members

- steel members can have <u>holes</u>
- reduced area

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

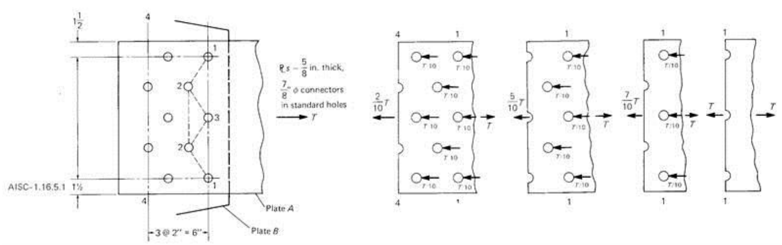
- increased stress

(AISC - Steel Structures of the Everyday)



Effective Net Area

- likely path to "rip" across
- bolts divide transferred force too
- shear lag $A_e \leq A_n U$

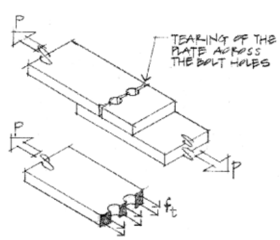


Tension Members

- limit states for failure $\quad P_a \leq P_n/\Omega \quad P_u \leq \phi_t P_n$

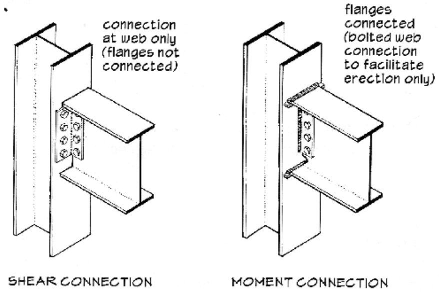
1. yielding $\phi_t = 0.9 \quad P_n = F_y A_g$
2. rupture* $\phi_t = 0.75 \quad P_n = F_u A_e$

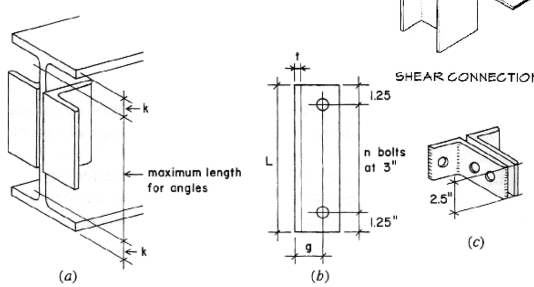
A_g - gross area
A_e - effective net area (holes 3/16" + d)
F_u = the tensile strength of the steel (ultimate)



Framed Beam Connections

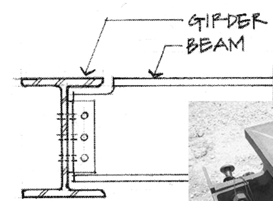
- *angles*
  - *bolted*
  - *welded*

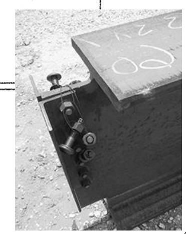


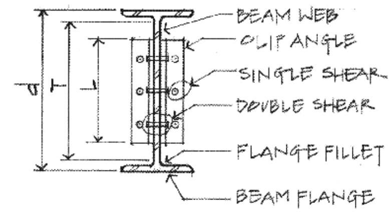


Framed Beam Connections

- *terms*
  - *coping*







(AISC - Steel Structures of the Everyday)

Framed Beam Connections

- *tables for standard bolt sizes & spacings*
- *# bolts*
- *bolt diameter, angle leg thickness*
- *bearing on beam web*

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 W24, 21, 18, 16	Bolt Group	Thread Cond.	Hole Type	1/4 ASD	1/4 LRFD	5/16 ASD	5/16 LRFD	3/8 ASD	3/8 LRFD	1/2 ASD	1/2 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 / L_{ev}, in.		STD L_{eh}* 1 1/2 ASD	STD 1 1/2 LRFD	STD 1 3/4 ASD	STD 1 3/4 LRFD	OVS 1 1/2 ASD	OVS 1 1/2 LRFD	OVS 1 3/4 ASD	OVS 1 3/4 LRFD	SSLT 1 1/2 ASD	SSLT 1 1/2 LRFD	SSLT 1 3/4 ASD	SSLT 1 3/4 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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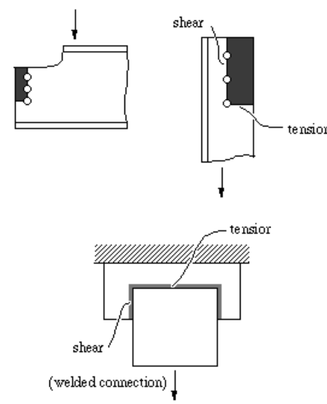
Beam Connections

- *LRFD provisions*
  - *shear yielding*
  - *shear rupture*
  - *block shear rupture*
  - *tension yielding*
  - *tension rupture*
  - *local web buckling*
  - *lateral torsional buckling*



Beam Connections

$\phi = 0.75$

$$R_n = 0.6F_uA_{nv} + U_{bs}F_uA_{nt} \leq 0.6F_yA_{gv} + U_{bs}F_uA_{nt}$$

– where U_{bs} is 1 for uniform tensile stress

Figure 2-1. Block Shear Rupture Limit State (Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

block shear rupture

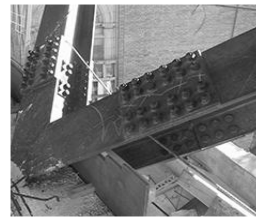
Figure 2-14. Tension Fracture Limit State (Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

tension rupture

Other Bolted Connections

- truss gussets
- base plates
- splices

(AISC - Steel Structures of the Everyday)



The Royal Ontario Museum Toronto . Canada
Daniel Libeskind
(AISC - Steel Structures of the Everyday)