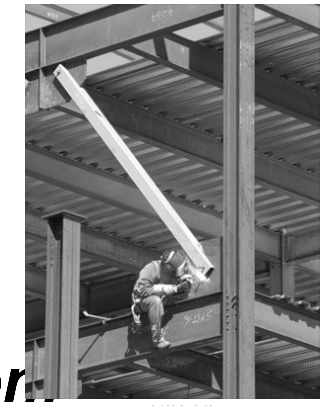
ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 331
DR. ANNE NICHOLS
SUMMER 2014

lecture
eighteen

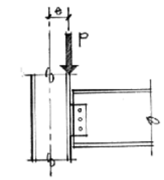


nrmc.org

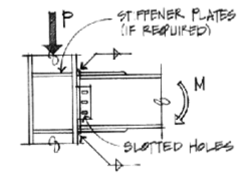
steel construction: bolts, welds & light gages

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

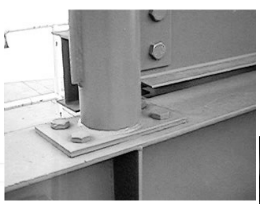


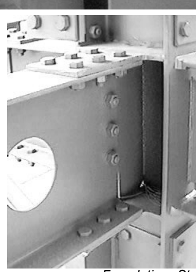
(b) Moment connection (rigid frame).
M = Moment due to beam bending

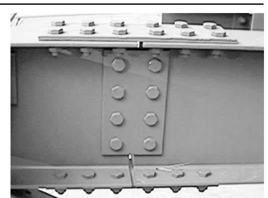
Bolts

- bolted steel connections

http://courses.civil.ualberta.ca







(AISC - Steel Structures of the Everyday)

Welds

- welded steel connections

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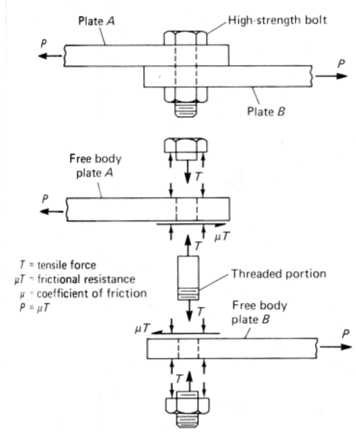
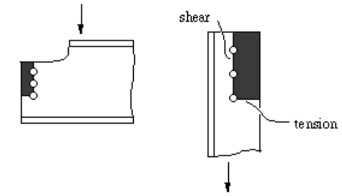
Bolts

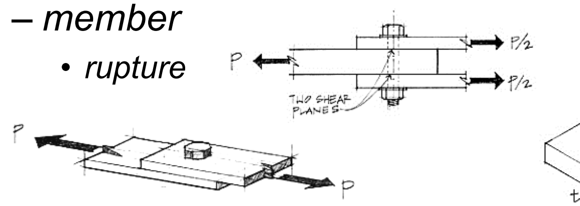
- *types*
  - *materials*
    - *high strength*
    - *A307, A325, A490*
  - *location of threads*
    - *included - N*
    - *excluded - X*
  - *friction or bearing (SC)*
    - *always tightened*

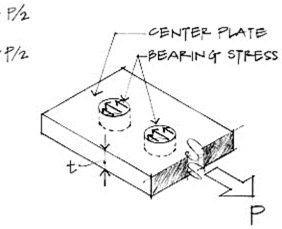


Bolted Connection Design

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







Bolts

- *rarely fail in bearing*
- *holes considered 1/8" larger*
- *shear & tension*

$$R_a \leq R_n / \Omega \qquad R_u \leq \phi_v R_n$$

$$\phi_v = 0.75$$

  - *single shear or tension*

$$R_n = F_n A_b$$

  - *double shear*

$$R_n = F_n 2 A_b$$

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)	ϕF_{nv} (ksi)	Loading	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	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

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)	ϕF_{nv} (ksi)	Loading	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	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

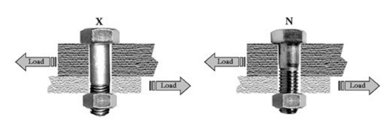
ASD	LRFD	For end loaded connections greater than 38 in., see AISC *Specification* Table J3.2 footnote b.
$\Omega = 2.00$	$\phi = 0.75$	

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)	ϕF_{nt} (ksi)	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	ASD	LRFD
Group A	45.0	67.5	13.8	20.7	19.9	29.8	27.1	40.6	35.3	53.0
Group B	56.5	84.8	17.3	26.0	25.0	37.4	34.0	51.0	44.4	66.6
A307	22.5	33.8	6.90	10.4	9.94	14.9	13.5	20.3	17.7	26.5

Nominal 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)	ϕF_{nt} (ksi)	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	ASD	LRFD
Group A	45.0	67.5	44.7	67.1	55.2	82.8	66.8	100	79.5	119
Group B	56.5	84.8	56.2	84.2	69.3	104	83.9	126	99.8	150
A307	22.5	33.8	22.4	33.5	27.6	41.4	33.4	50.1	39.8	59.6

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



Bolts

- *bearing* $R_a \le R_n / \Omega \qquad R_u \le \phi R_n$

$$\phi = 0.75$$

- – *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	1¼	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	1¼	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	1¼	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	1¼	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	1¼	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	$L_e \ge L_{e\,full}$	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	$L_e \ge L_{e\,full}$	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 $L_e \ge L_{e\,full}$[a], 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 kips) r_n/Ω ASD	5/8 (24 kips) ϕr_n LRFD	3/4 (35 kips) r_n/Ω ASD	3/4 (35 kips) ϕr_n LRFD	7/8 (49 kips) r_n/Ω ASD	7/8 (49 kips) ϕr_n LRFD	1 (64 kips) r_n/Ω ASD	1 (64 kips) 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 kips) r_n/Ω ASD	1 1/8 (80 kips) ϕr_n LRFD	1 1/4 (102 kips) r_n/Ω ASD	1 1/4 (102 kips) ϕr_n LRFD	1 3/8 (121 kips) r_n/Ω ASD	1 3/8 (121 kips) ϕr_n LRFD	1 1/2 (148 kips) r_n/Ω ASD	1 1/2 (148 kips) 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

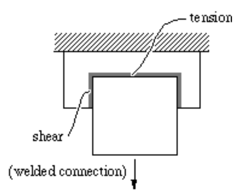
STD = standard hole
OVS = oversized hole
SSLT = short-slotted hole transverse to the line of force
SSLP = short-slotted hole parallel to the line of force
LSL = long-slotted hole transverse or parallel to the line of force
S = single shear
D = double shear

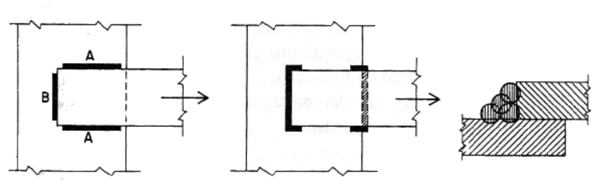
Hole Type	ASD	LRFD
STD and SSLT	Ω = 1.50	ϕ = 1.00

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.

Welded Connection Design

- *considerations*
  - – *shear stress*
  - – *yielding*
  - – *rupture*

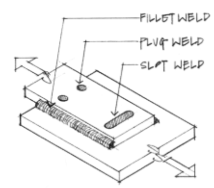




(a) (b) (c)

Welded Connection Design

- *weld terms*
  - – *butt weld*
  - – *fillet weld*
  - – *plug weld*
  - – *throat*
- *field welding*
- *shop welding*



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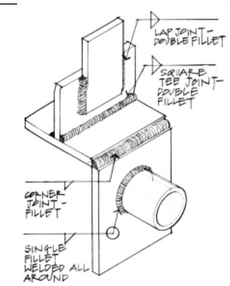
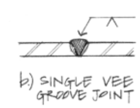
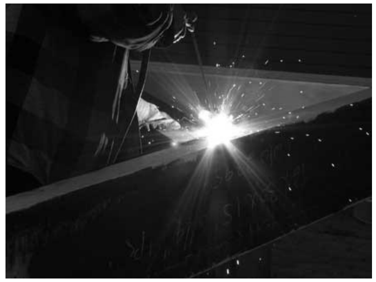


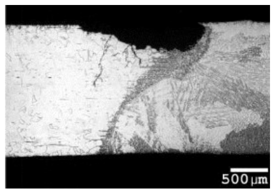


Welded Connection Design

- *weld process*
  - *melting of material*
  - *melted filler - electrode*
  - *shielding gas / flux*
  - *potential defects*

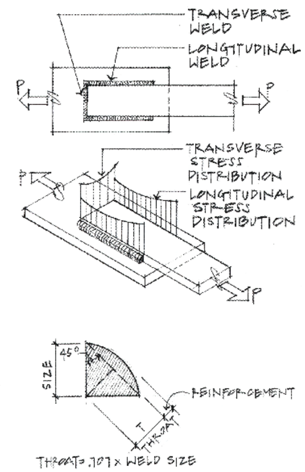


- *weld materials*
  - *E60XX*
  - *E70XX*
    F_{EXX} = 70 ksi



Welded Connection Design

- *shear failure assumed*
- *throat*
  - *T = 0.707 x weld size*
- *area*
  - *A = T x length of weld*
- *weld metal generally stronger than base metal (ex. F_y = 50 ksi)*



Welded Connection Design

- *minimum*
  - *table*
- *maximum*
  - *material thickness (to ¼")*
  - *1/16" less*
- *min. length*
  - *4 x size min.*
  - *≥ 1 ½"*

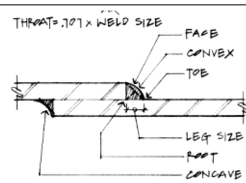


TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thicker Part Joined, in. (mm)	Minimum Size of Fillet Weld[a] in. (mm)
To ¼ (6) inclusive	⅛ (3)
Over ¼ (6) to ½ (13)	3/16 (5)
Over ½ (13) to ¾ (19)	¼ (6)
Over ¾ (19)	5/16 (8)

[a] Leg dimension of fillet welds. Single pass welds must be used.
[b] See Section J2.2b for maximum size of fillet welds.

Welded Connection Design

- *shear*

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

$$\phi = 0.75$$

$$R_n = 0.6 F_{EXX} \underbrace{Tl}_{\text{area}} = Sl$$

  - *table for ϕS*

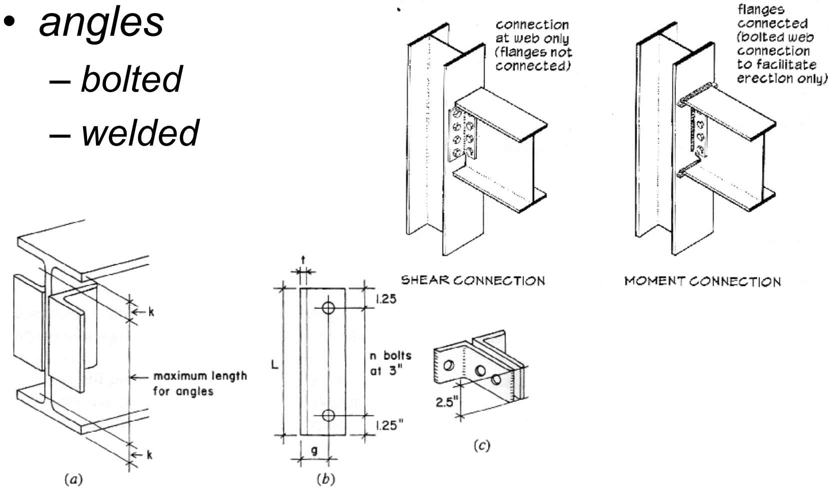
Available Strength of Fillet Welds per inch of weld (ϕS)

Weld Size (in.)	E60XX (k/in.)	E70XX (k/in.)
3/16	2.39	4.18
¼	4.77	5.57
5/16	5.97	6.96
⅜	7.16	8.35
7/16	5.57	9.74
½	8.35	11.14
⅝	11.93	13.92
¾	14.32	16.70

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

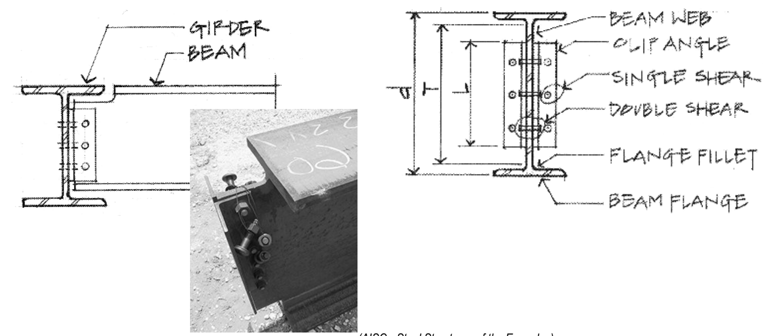
Framed Beam Connections

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



Framed Beam Connections

- *terms*
  - *coping*



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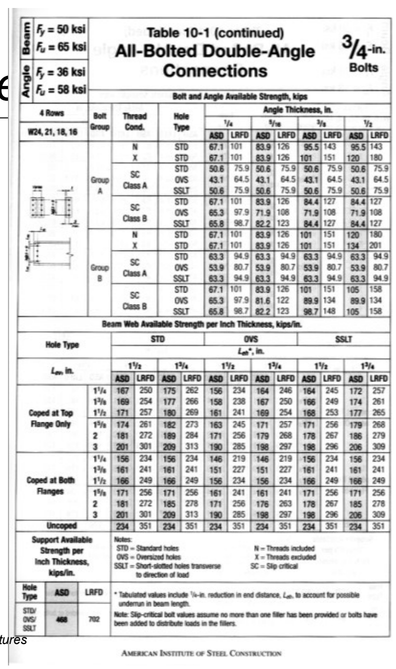
Framed Beam Connections

- *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		STD				OVS				SSLT			
	L_{eh}*, in.	1 1/2		1 3/4		1 1/2		1 3/4		1 1/2		1 3/4	
	L_{ev}, in.	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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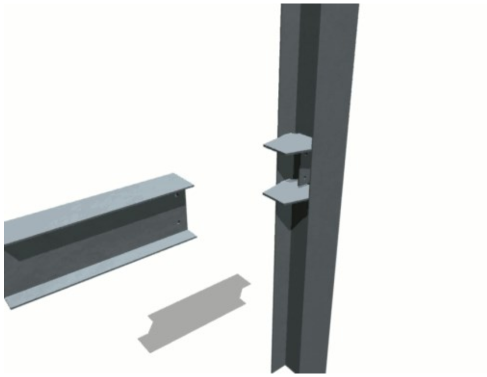
Framed Beam Connections

- *welded example (shear)*

(AISC - Steel Structures of the Everyday)

Framed Beam Connections

- *welded moment example*



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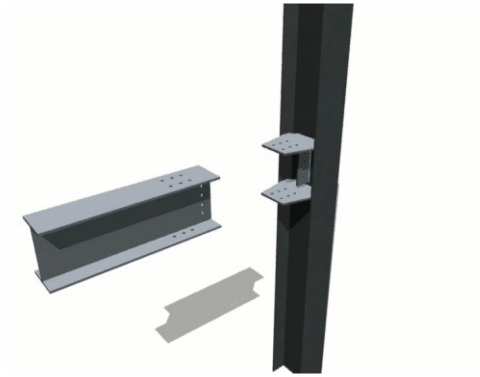
Framed Beam Connections

- *welded/bolted moment example*



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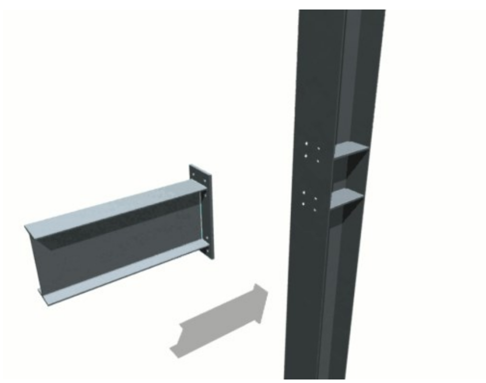
Framed Beam Connections

- *welded/bolted moment example*



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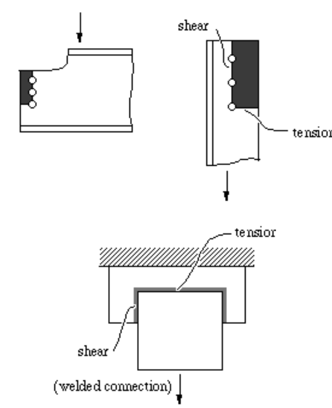
Beam Connections

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



Beam Connections $\phi = 0.75$

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

- 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)

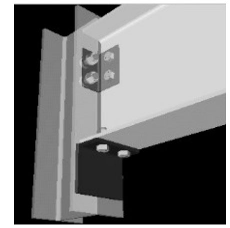
block shear rupture

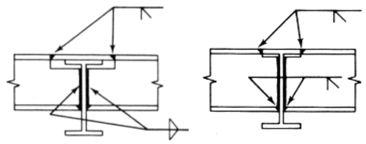
Figure 2-14. Tension Fracture Limit State (Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

tension rupture

Other Connections

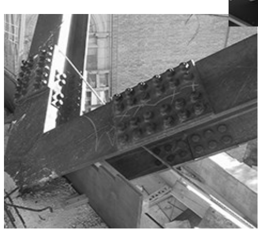
- seated beam
- continuous
  - beam to column
  - beam to beam





Other Connections

- splices



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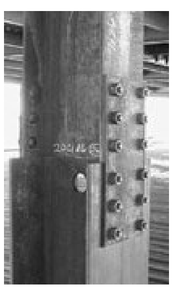

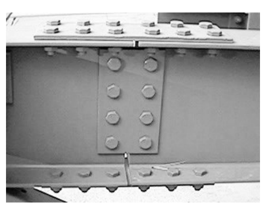

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Other Connections

- rigid frame knees
- gussets & joints

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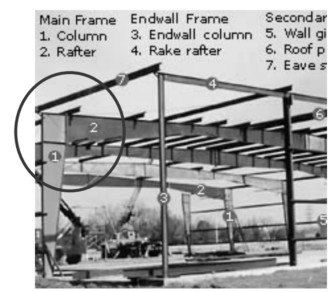
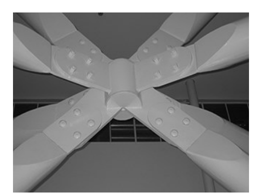
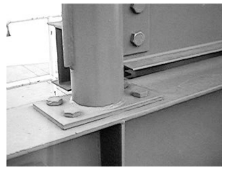




Other Connections

- base plates
  - anchor bolts
  - bearing on steel
  - bending of plate



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