ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN

ARCH 331
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FALL 2013

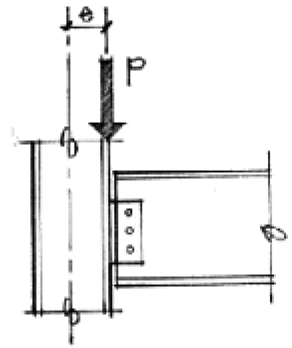
lecture
twenty one

nrmc.org

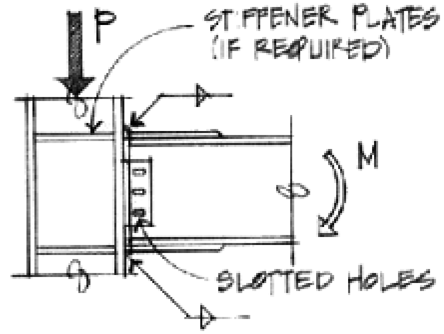
steel construction: bolted & welded connections

Connections

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



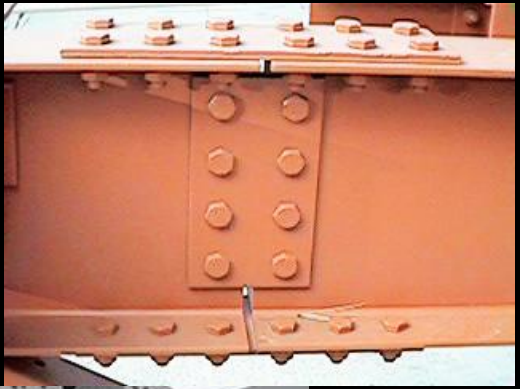
(a) Framed beam (shear) connection.
e = *Eccentricity;* M = P × e



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

Bolts

- *bolted steel connections*



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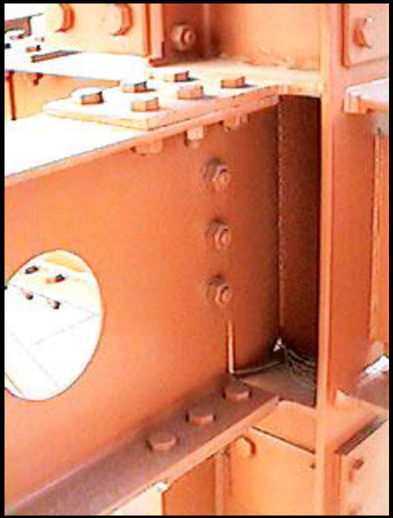
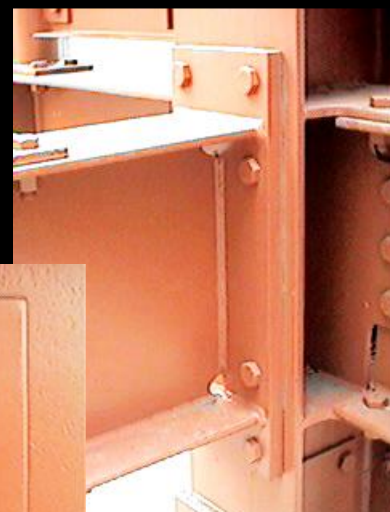


(AISC - Steel Structures of the Everyday)

Welds

- *welded steel connections*



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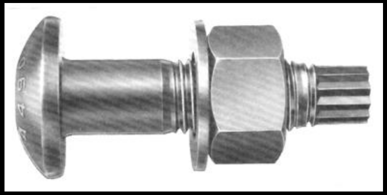
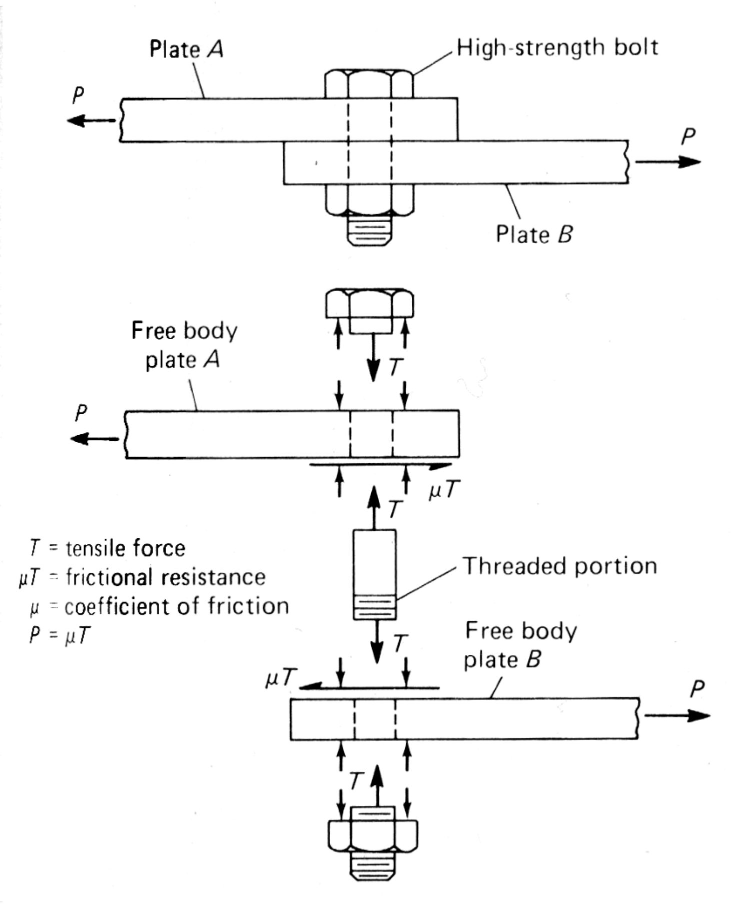
Bolts

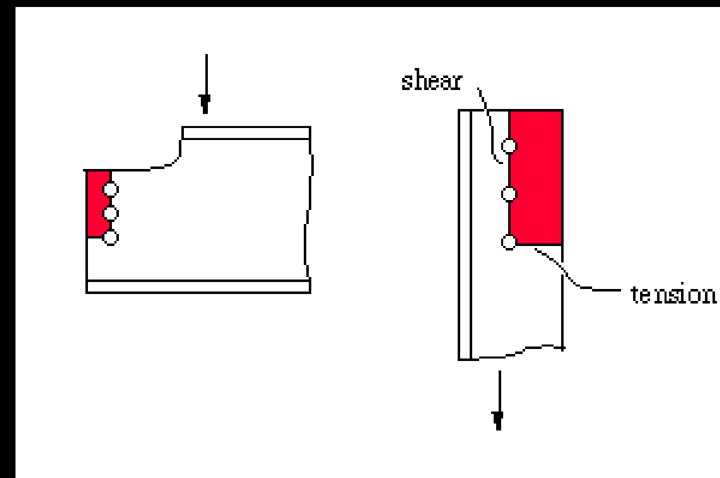
- *types*
  - *materials*
    - *high strength*
    - *A307, A325, A490*
  - *location of threads*
    - *included - N*
    - *excluded - X*
  - *friction or bearing (SC)*
    - *always tightened*

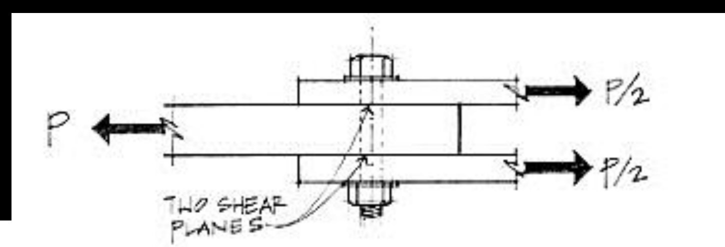


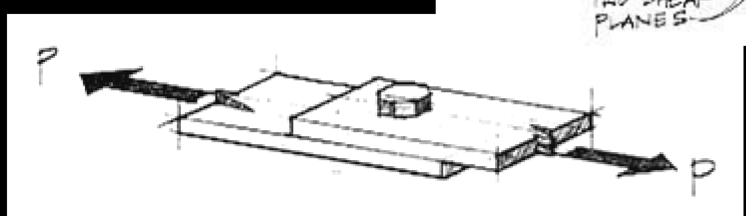


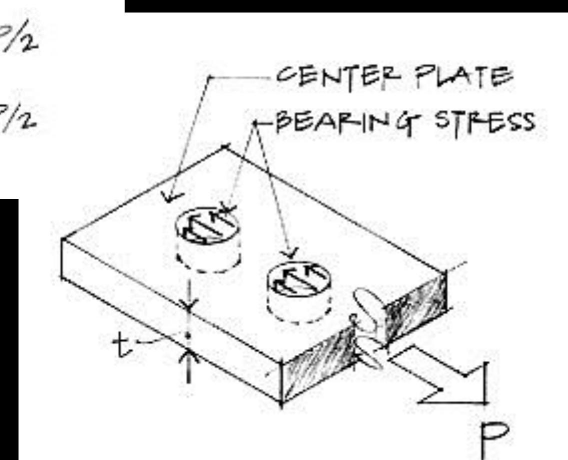
Bolted Connection Design

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









Bolts

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

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

$$\phi_v = 0.75$$

  - *single shear or tension*

$$R_n = F_n A_b$$

  - *double shear*

$$R_n = F_n 2 A_b$$

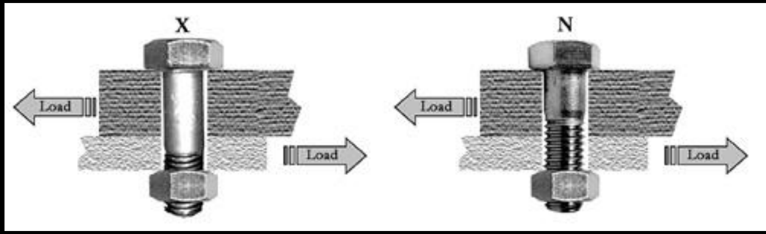
Bolts

Table 7-1
Available Shear Strength of Bolts, kips

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
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	
		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

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
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	
	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									
$\Omega = 2.00$	$\phi = 0.75$									



http://www.fastenal.com

Bolts

- *bearing*

$$R_a \leq {}^{R_n}\!/_{\Omega} \qquad R_u \leq \phi R_n$$

$$\phi = 0.75$$

  – *deformation is concern*

$$R_n = 1.2 L_c t F_u \leq 2.4 d t F_u$$

  – *deformation isn't concern*

$$R_n = 1.5 L_c t F_u \leq 3.0 d t F_u$$

  – *long slotted holes*

$$R_n = 1.0 L_c t F_u \leq 2.0 d t F_u$$

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	Nominal Bolt Diameter, d, in. 5/8 r_n/Ω ASD	5/8 ϕr_n LRFD	3/4 r_n/Ω ASD	3/4 ϕr_n LRFD	7/8 r_n/Ω ASD	7/8 ϕr_n LRFD	1 r_n/Ω ASD	1 ϕr_n LRFD
STD SSLT	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 $L_e \geq L_{e\ full}$[a], in.		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
LSLT = long-slotted hole oriented transverse 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	Nominal Bolt Diameter, d, in. 5/8 (Min. Pretension 24 kips) r_n/Ω ASD	5/8 ϕr_n LRFD	3/4 (35) r_n/Ω ASD	3/4 ϕr_n LRFD	7/8 (49) r_n/Ω ASD	7/8 ϕr_n LRFD	1 (64) r_n/Ω ASD	1 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

Hole Type	Loading	Nominal Bolt Diameter, d, in. 1 1/8 (Min. Pretension 80 kips) r_n/Ω ASD	1 1/8 ϕr_n LRFD	1 1/4 (102) r_n/Ω ASD	1 1/4 ϕr_n LRFD	1 3/8 (121) r_n/Ω ASD	1 3/8 ϕr_n LRFD	1 1/2 (148) r_n/Ω ASD	1 1/2 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

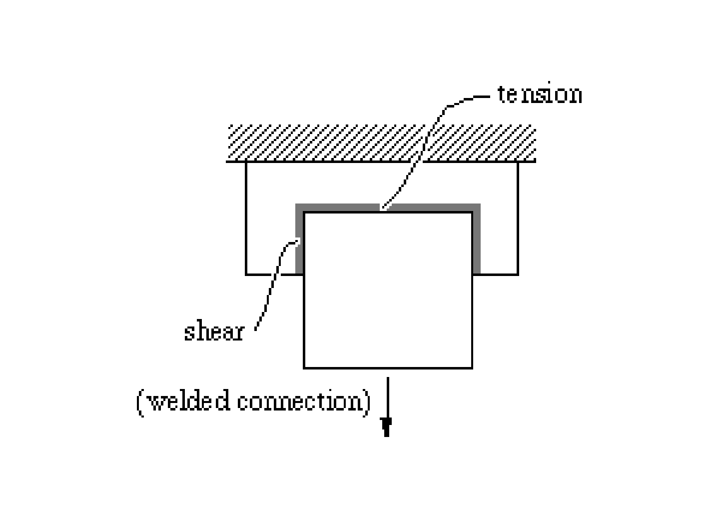
STD = standard hole
OVS = oversized hole
SSLT = short-slotted hole transverse to the line of force
SSLP = short-slotted hole parallel to the line of force
LSL = long-slotted hole transverse or parallel to the line of force
S = single shear
D = double shear

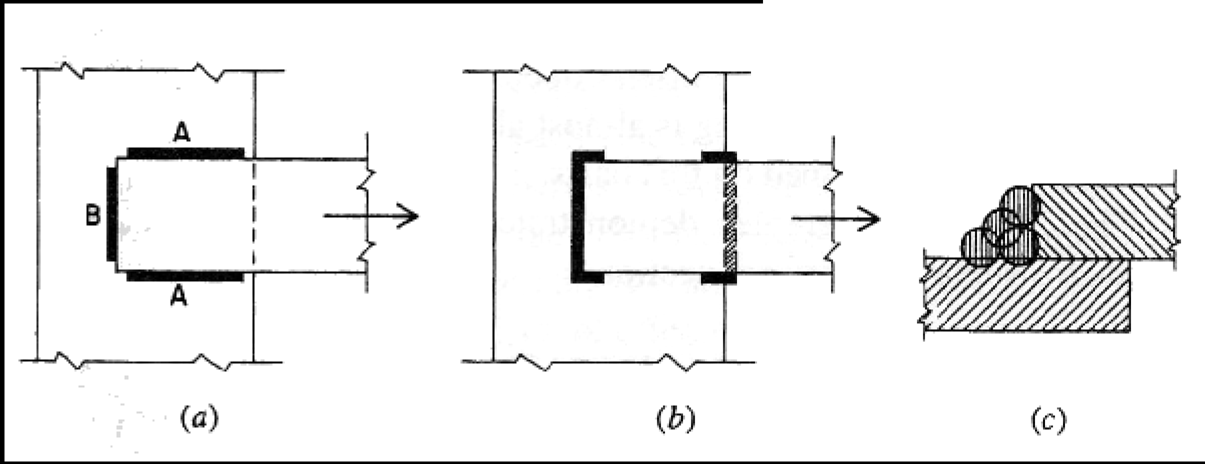
Hole Type	ASD	LRFD
STD and SSLT	Ω = 1.50	ϕ = 1.00

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

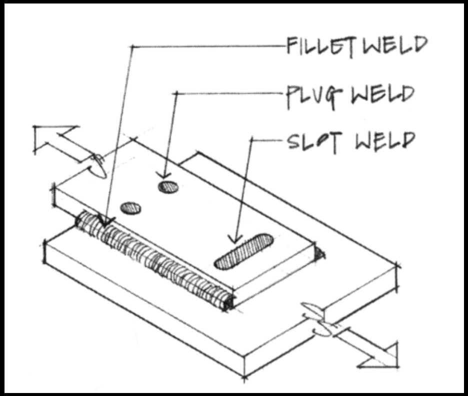
- considerations
  - shear stress
  - yielding
  - rupture

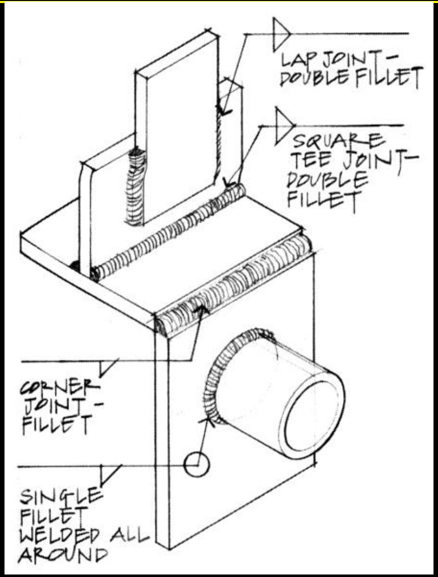




Welded Connection Design

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





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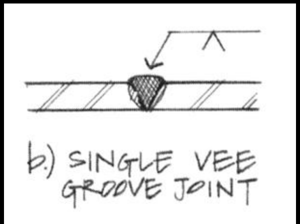
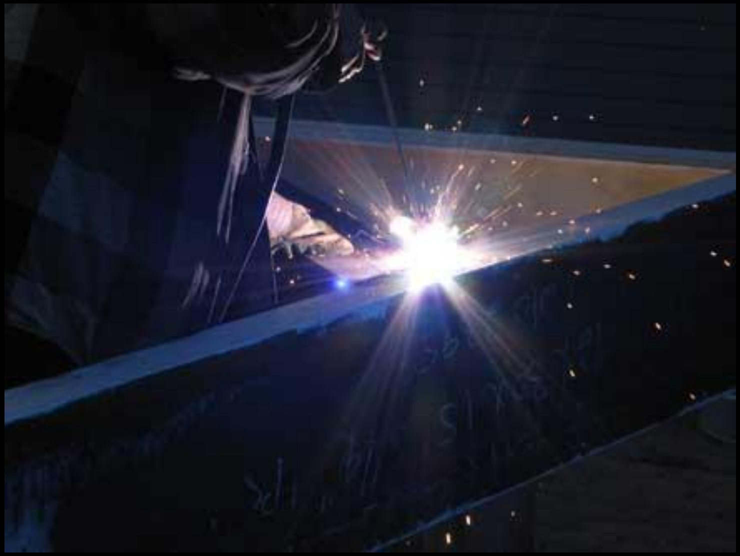
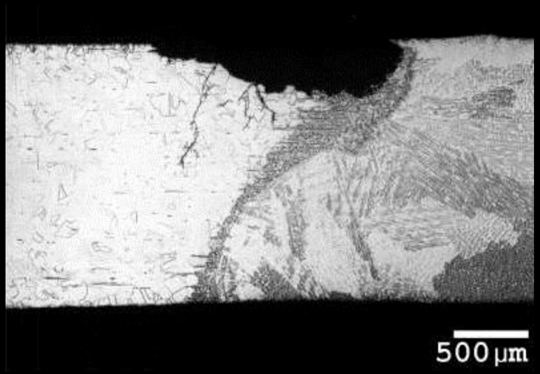


Welded Connection Design

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

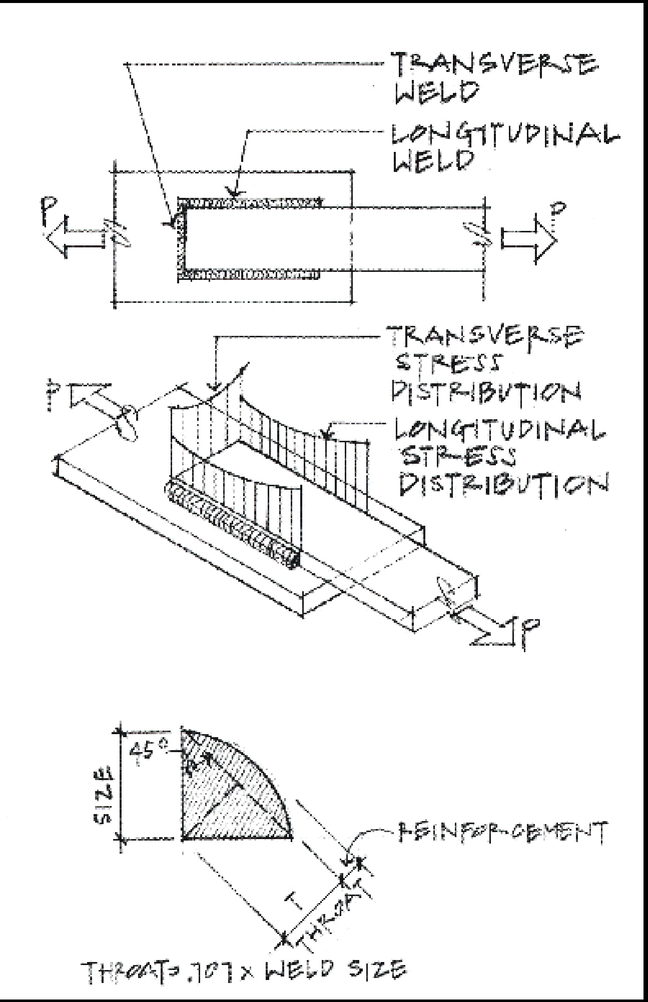


- weld materials
  - E60XX
  - E70XX
    F_{EXX} = 70 ksi



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”*

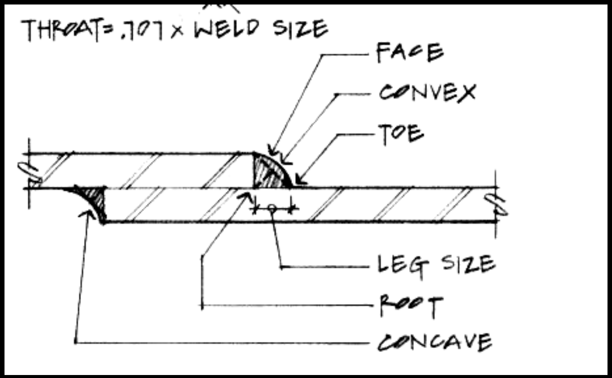


TABLE J2.4
Minimum Size of Fillet Welds

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*

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

$$\phi = 0.75$$

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

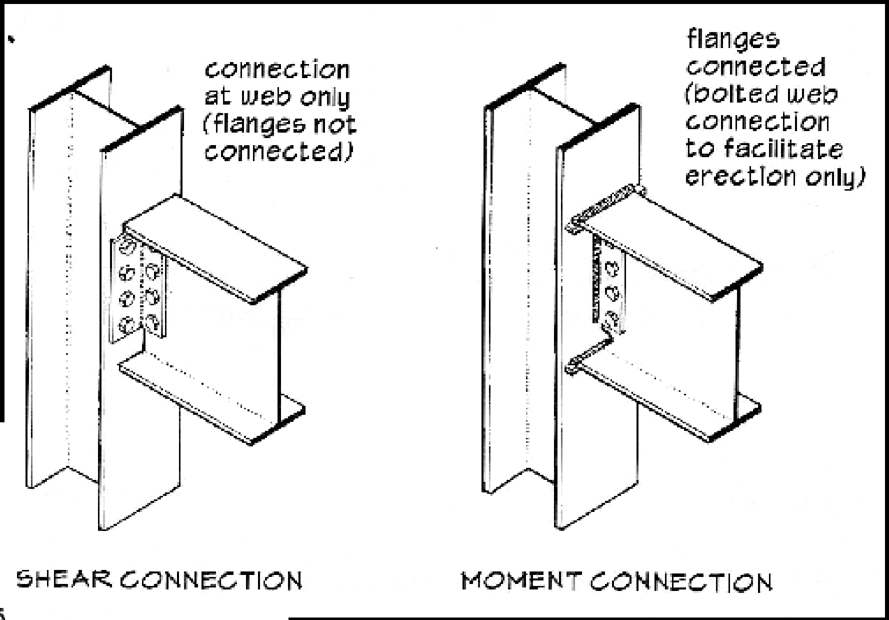
  - *table for ϕS*

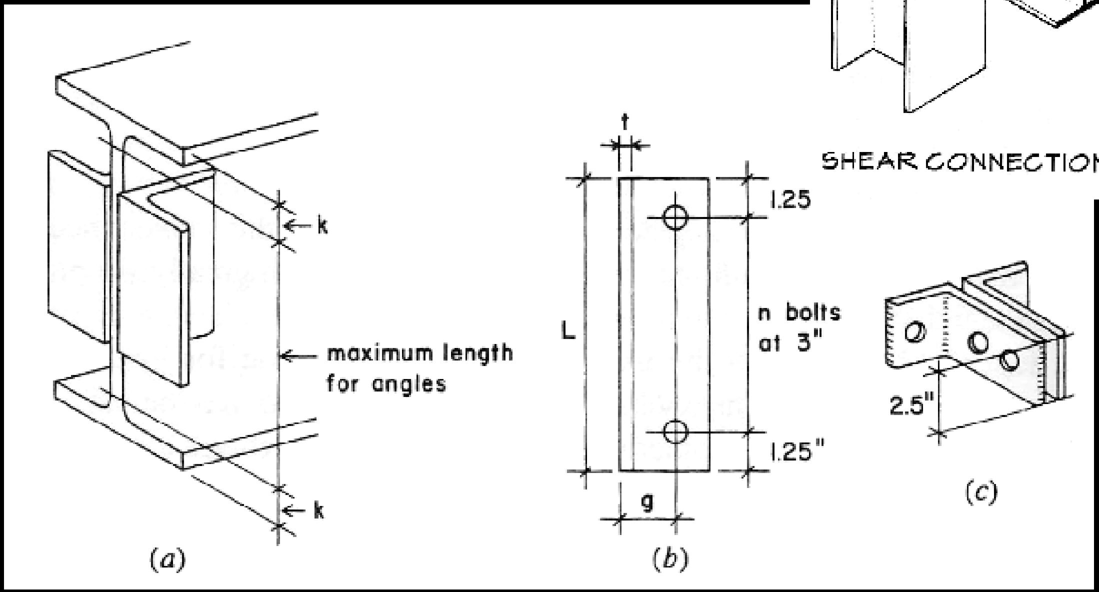
Available Strength of Fillet Welds per inch of weld (ϕS)		
Weld Size (in.)	E60XX (k/in.)	E70XX (k/in.)
3⁄16	3.58	4.18
¼	4.77	5.57
5⁄16	5.97	6.96
⅜	7.16	8.35
7⁄16	8.35	9.74
½	9.55	11.14
⅝	11.93	13.92
¾	14.32	16.70

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

Framed Beam Connections

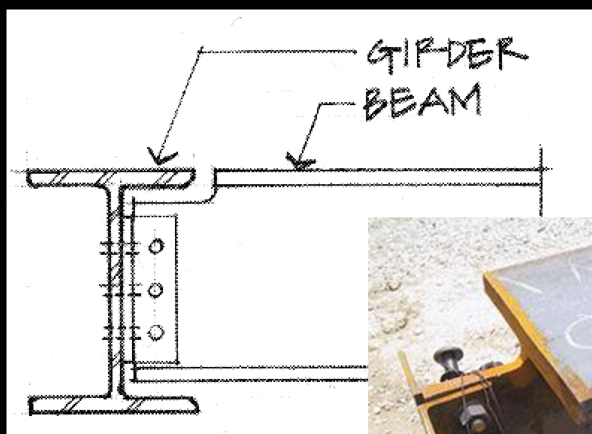
- *angles*
  - *bolted*
  - *welded*

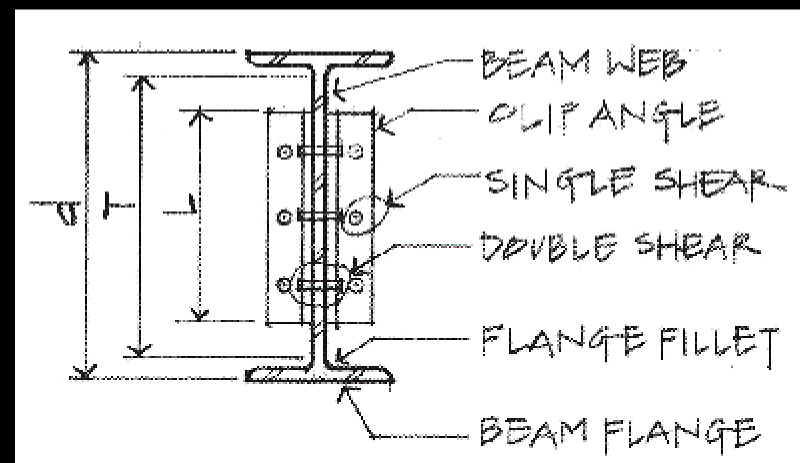




Framed Beam Connections

- *terms*
  - *coping*





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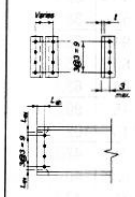
Framed Beam Conne

- *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	Table 10-1 (continued) All-Bolted Double-Angle Connections	3/4-in. Bolts
Angle	F_y = 36 ksi F_u = 58 ksi		

Bolt and Angle Available Strength, kips

4 Rows W24, 21, 18, 16	Bolt Group	Thread Cond.	Hole Type	Angle Thickness, in. 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)*

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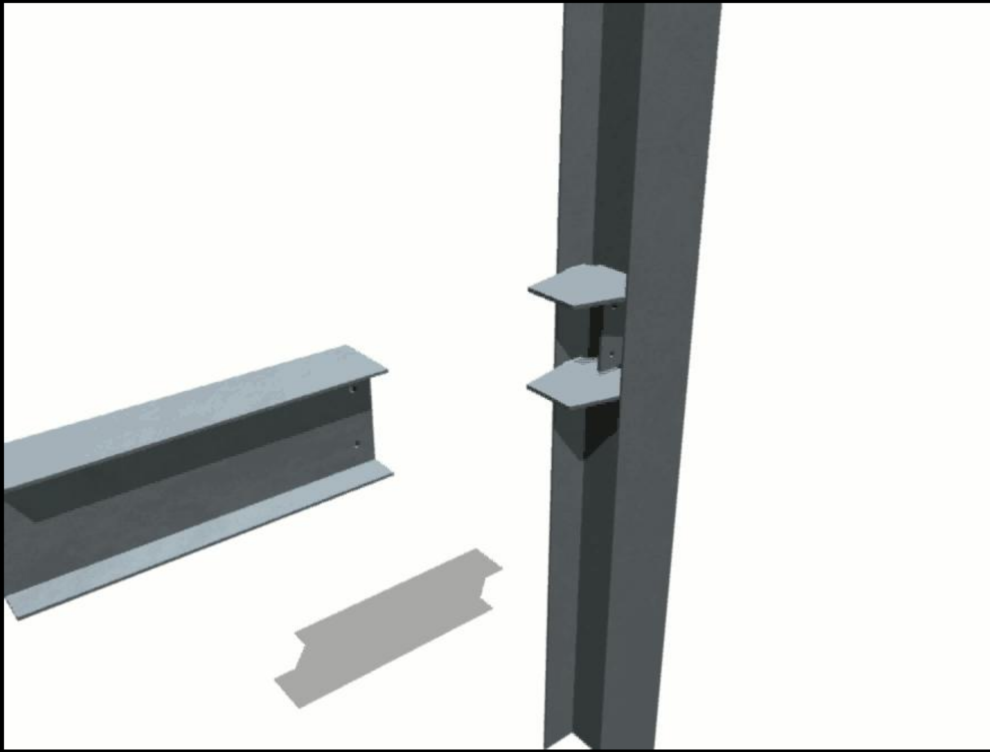
Framed Beam Connections

- *welded moment example*



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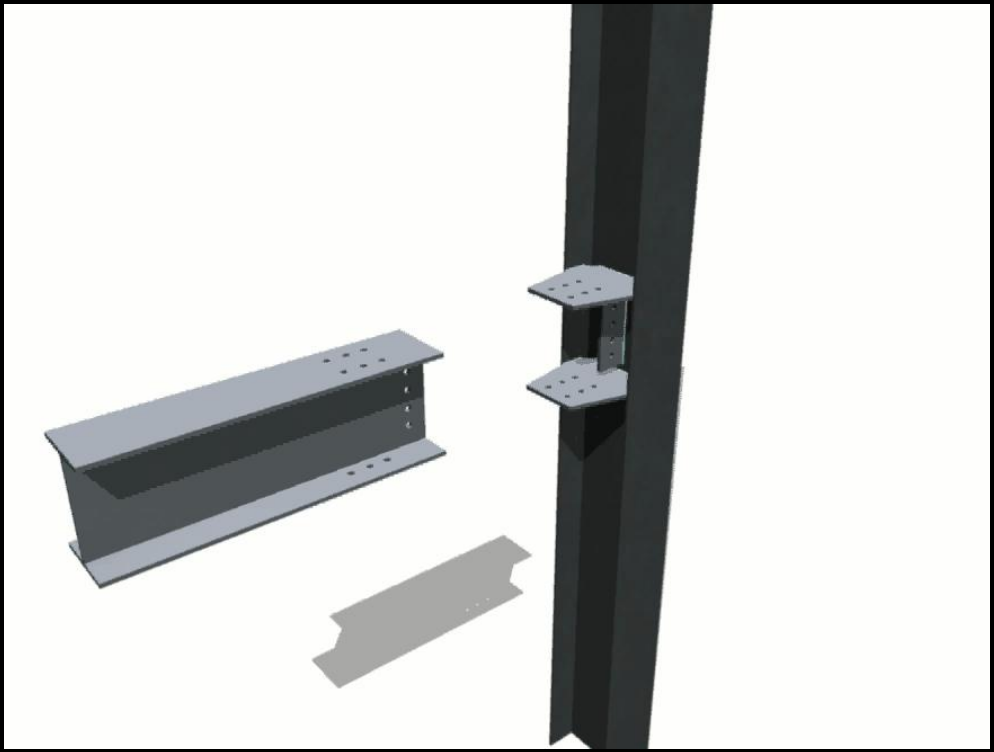
Framed Beam Connections

- *welded/bolted moment example*



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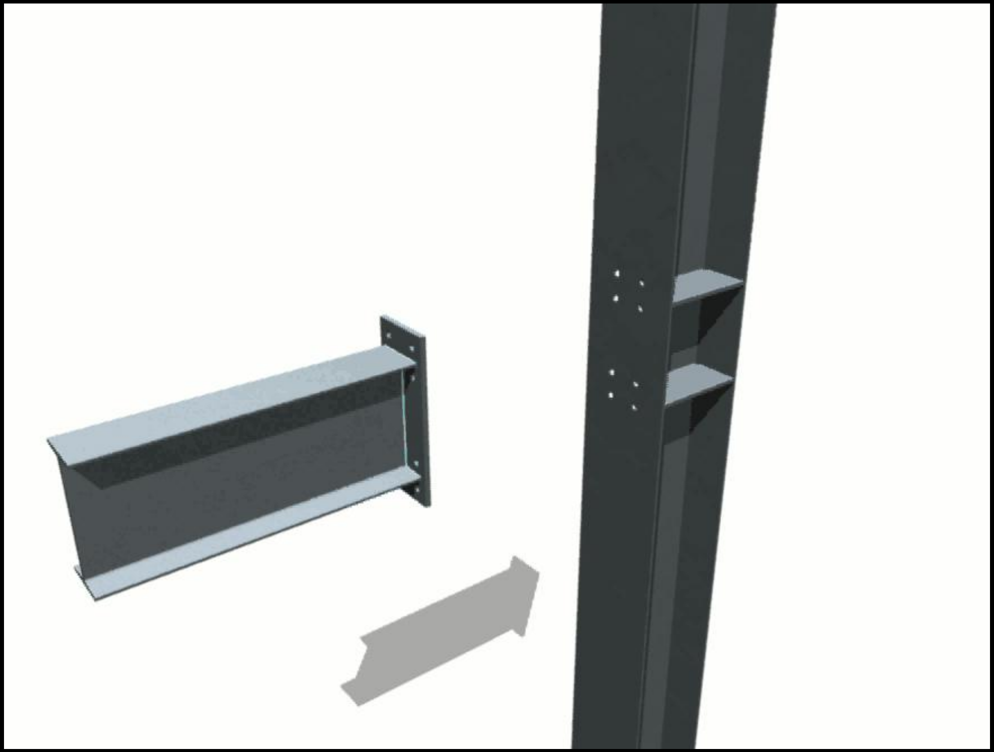
Framed Beam Connections

- *welded/bolted moment example*



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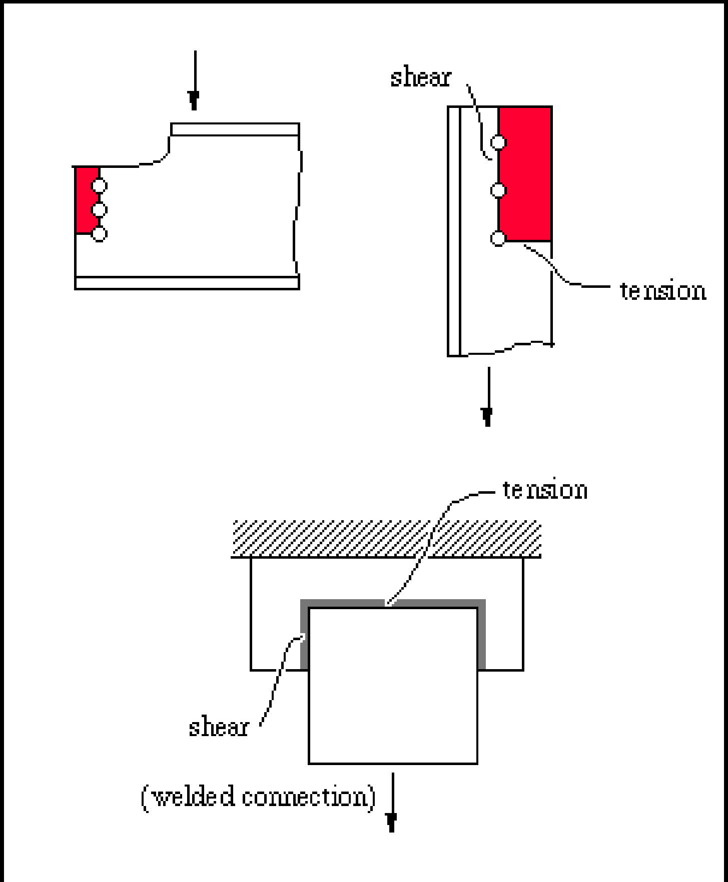
Beam Connections

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



Beam Connections

$$\phi = 0.75$$

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

– 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)

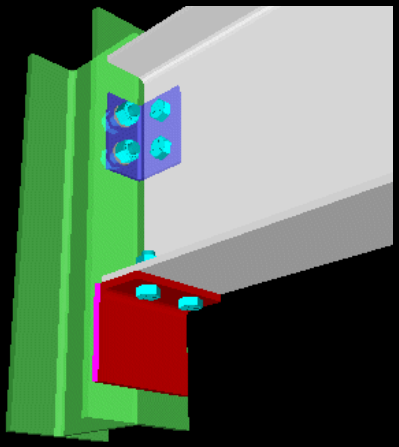
block shear rupture

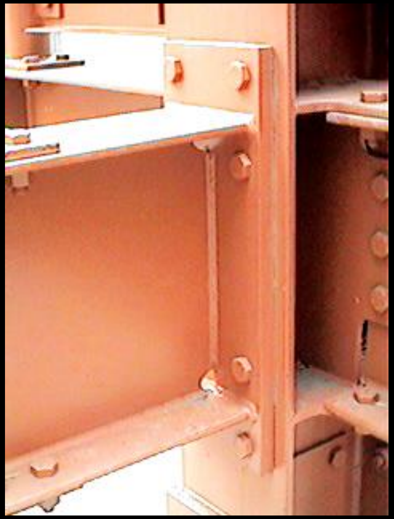
Figure 2-14. Tension Fracture Limit State (Photo by J.A. Swanson and R. Leon, courtesy of Georgia Institute of Technology)

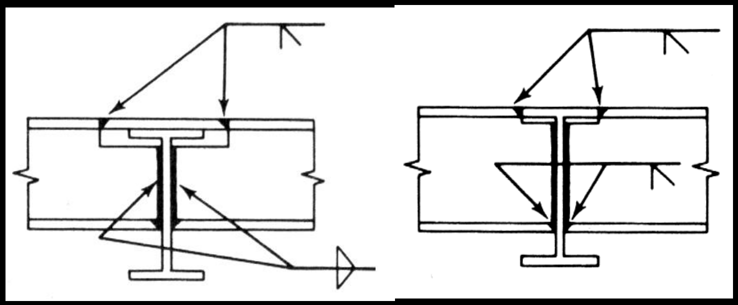
tension rupture

Other Connections

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







Other Connections

- *splices*

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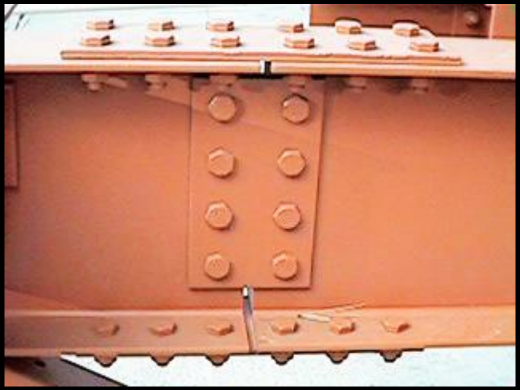

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Other Connections

- *rigid frame knees*
- *gussets & joints*

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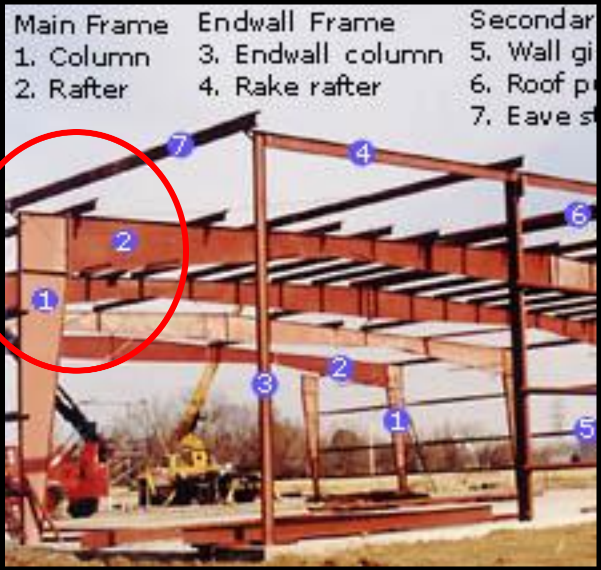

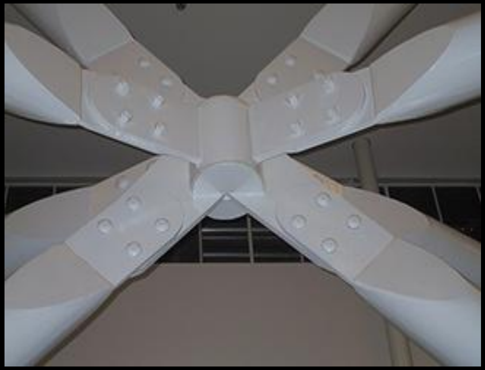

Other Connections

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

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