APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS

ARCH 631

DR. ANNE NICHOLS

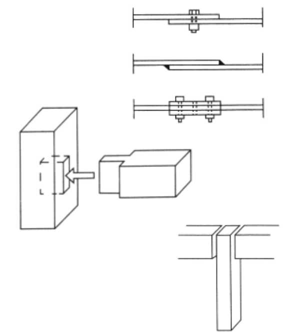
FALL 2012

lecture
seventeen

connections

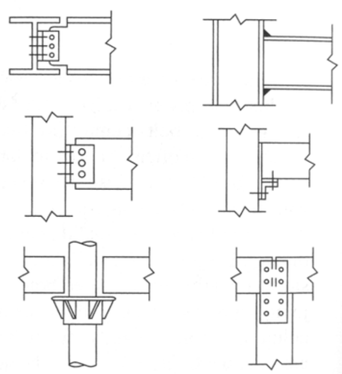
Connection Design Considerations

- joints often critical in design
  - can influence choice of structural system
- types used influenced by:
  - member behavior
  - member geometry
- basic types join by:
  - lapping
  - deforming and interlocking
  - butting



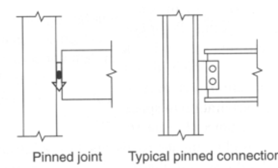
Connectors

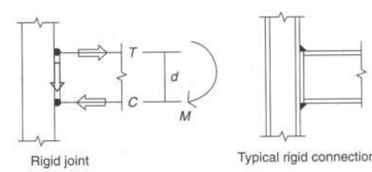
- "third-elements"
  - bolts
  - nails
  - welds
  - splice plates
- transfer load at a point, line or surface
  - generally more than a point due to stresses



Connector Rigidity

- pinned joints
  - point type
- rigid joints
  - line and surface types
  - multiple "points" separated by distance resist moment





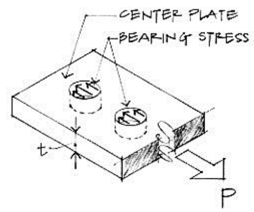
$$T = C \qquad M = Td = Cd$$

Point Connectors

- connected members in tension cause shear stress

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

- connected members in compression cause bearing stress

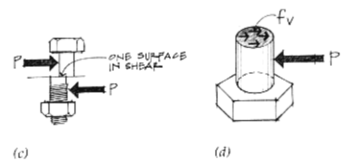


Bearing stress on plate.

Single Shear

- seen when 2 members are connected

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



(c) (d)

Figure 5.11 A bolted connection—single shear.

f_v = Average shear stress through bolt cross section

A = Bolt cross-sectional area

$f_v = \frac{P}{A}$

$$f_v = \frac{P}{A} = \frac{P}{\pi \, d^2/4}$$

Double Shear

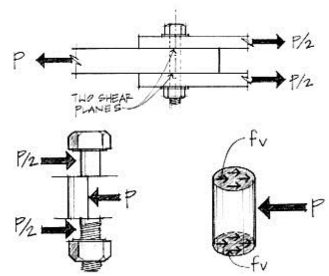
- seen when 3 members are connected

$$\Sigma F = 0 = -P + 2(P/2)$$

$f_v = \frac{P}{2A}$

(two shear planes)

$$f_v = \frac{P}{2A} = \frac{P/2}{A} = \frac{P/2}{\pi \, d^2/4}$$

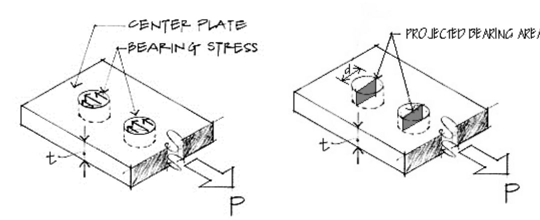


Free-body diagram of middle section of the bolt in shear.

Figure 5.12 A bolted connection in double shear.

Bearing Stress

- compression & contact
- projected area

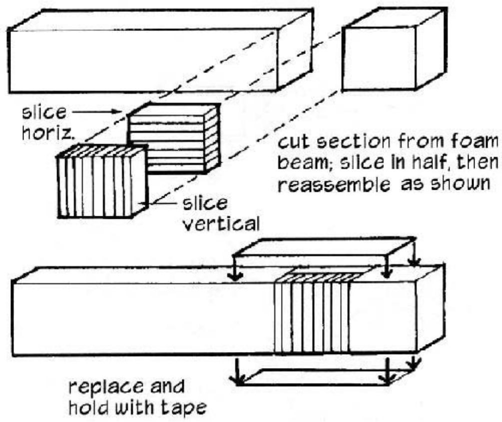


Bearing stress on plate.

$$f_p = \frac{P}{A_{projected}} = \frac{P}{td}$$

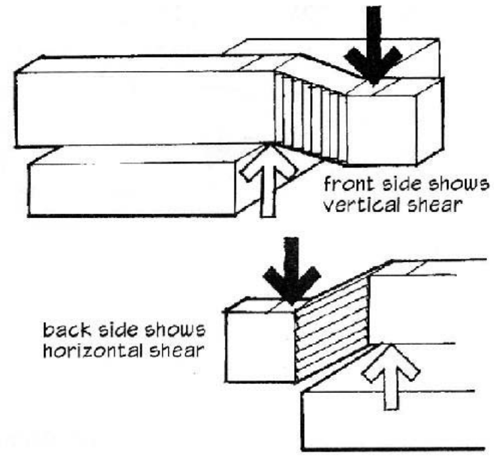
Beam Stresses

- *shear – horizontal & vertical*



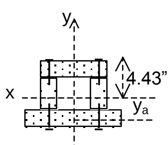
Beam Stresses

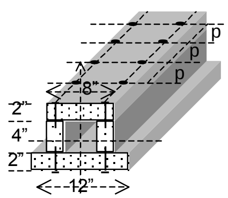
- *shear – horizontal & vertical*



Connectors Resisting Beam Shear

- *plates with*
  - *nails*
  - *rivets*
  - *bolts*
- *splices*
- *V from beam load related to $V_{longitudinal}$*





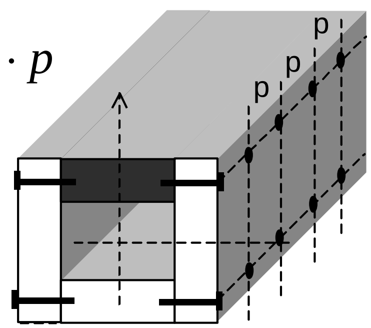
$$\frac{V_{longitudinal}}{p} = \frac{VQ}{I}$$

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

Vertical Connectors

- *isolate an area with vertical interfaces*

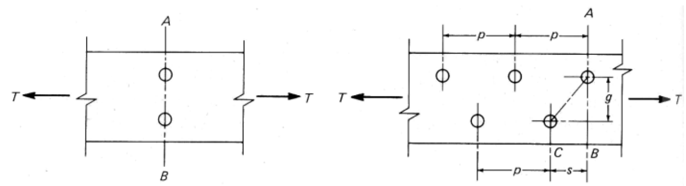
$$nF_{connector} \geq \frac{VQ_{connected\ area}}{I} \cdot p$$



Tension Members

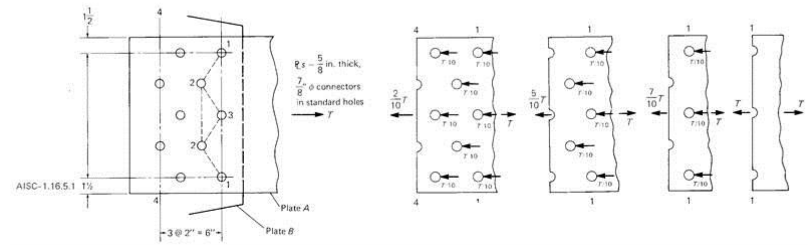
- members with <u>holes</u> have reduced area
- increased tension stress
- A_e is effective net area

$$f_t = \frac{P}{A_e}\left(or\ \frac{T}{A_e}\right)$$



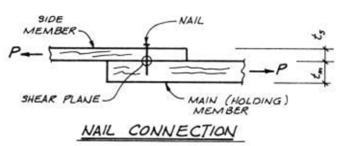
Effective Net Area

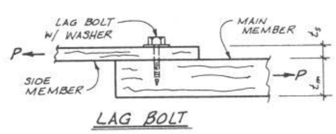
- likely path to "rip" across
- bolts divide transferred force too



Wood Connectors

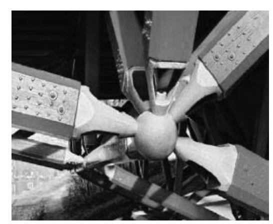
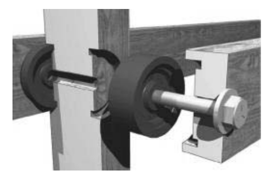
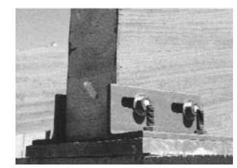
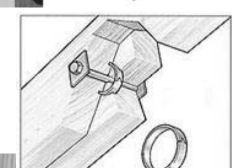
- adhesives
  - used in a controlled environment
  - can be used with nails
- mechanical
  - nails
  - bolts
  - lag bolts or lag screws
  - split ring and shear plate connectors
  - timber rivets



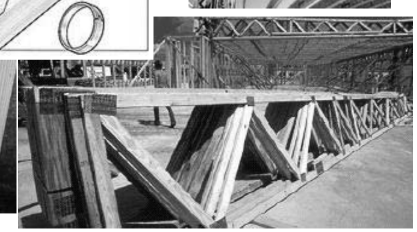


Wood Connections

- mechanical

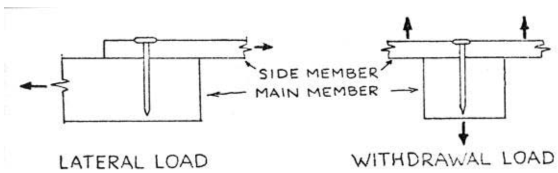









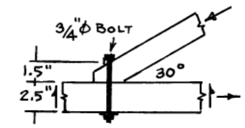
Nails

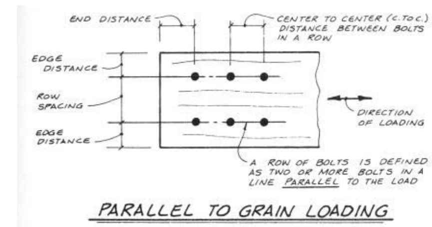
- *tension stress (pullout)*
- *shear stress*
- *nails presumed to share load by distance from centroid of nail pattern*



Bolts

- *bearing stress*
  - *parallel to grain*
  - *perpendicular to grain*
- *shear stress*
- *tension stress in member*
- *concerned with end shear rupture*





Lag Screws

- *tension stress (pullout)*
  - *avoid parallel to grain*
- *shear stress*

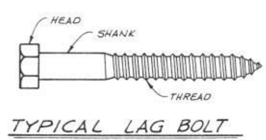
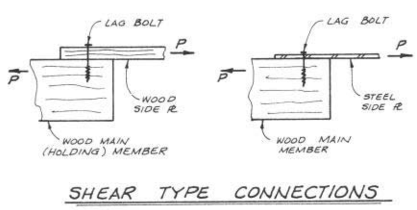
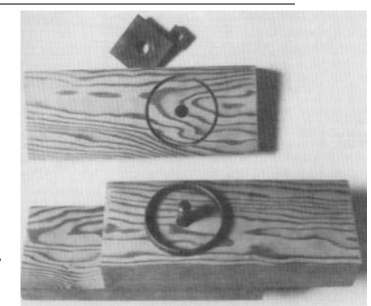


Figure 13.16a Lag bolt. Large-diameter fastener with wood screw thread and bolt head. Also known as lag screw.



Split Ring Connectors

- *bearing stress*
  - *parallel to grain*
  - *perpendicular to grain*
- *shear stress*
- *tension stress in member*
- *concerned with end shear rupture*
- *(like bolts)*



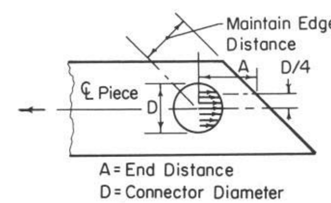


Plate Connections

- *rigid*
  - *bolts or nails*
  - *plate*
  - *continuous at top & bottom*
- *shear*
  - *metal plate with teeth*

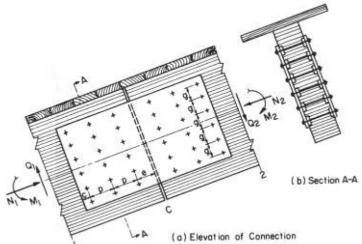
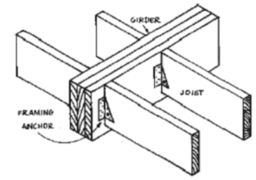
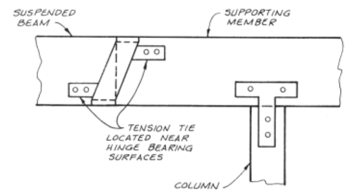


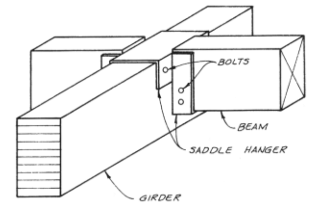
Figure 6.24—Typical Rigid-Plate Connection Between Prefabricated Glued-Laminated Members.

Miscellaneous Connectors

- *beam hangers*
- *frame anchors*
- *seats*
- *etc…*

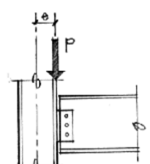




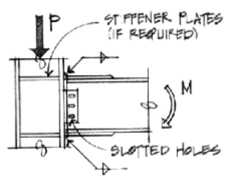


Steel Connections

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



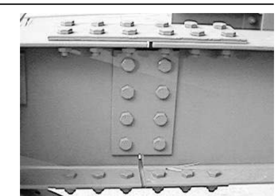
(a) Framed beam (shear) connection.
e = Eccentricity; M = P × e

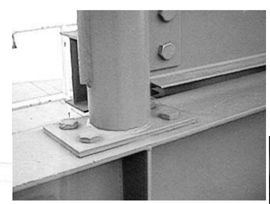


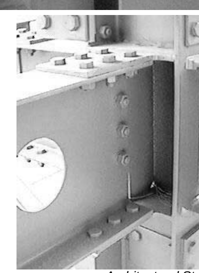
(b) Moment connection (rigid frame).
M = Moment due to beam bending

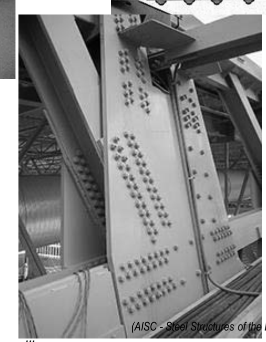
Bolts

- *bolted steel connections*







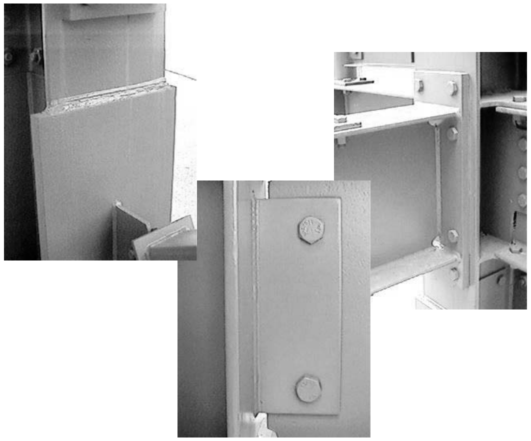


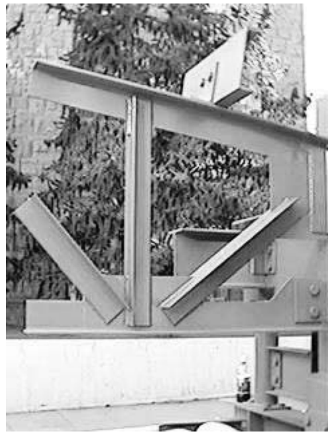
http://courses.civil.ualberta.ca

(AISC - Steel Structures of the Everyday)

Welds

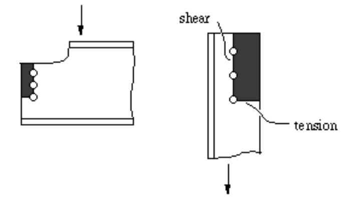
- *welded steel connections*

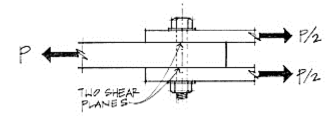


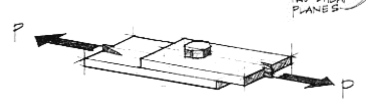


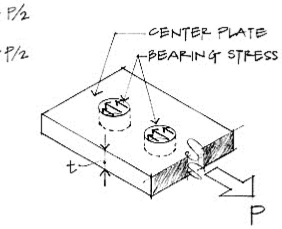
Bolted Connection Design

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



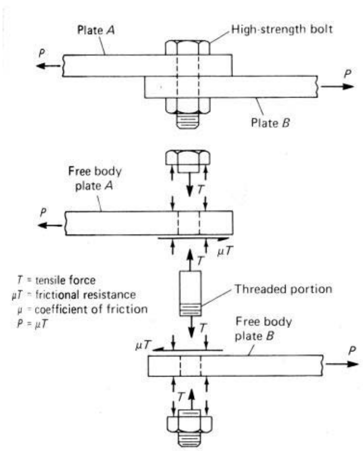






Bolts

- *types*
  - *materials*
    - *high strength*
  - *location of threads*
    - *included*
    - *excluded*
  - *friction or bearing*
    - *always tightened*



Bolted Connection Design

- *Unified steel*
  - *shear:*

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

$$\Omega = 2.00 \qquad \phi_v = 0.75$$

    - *bolt strengths*
  - *bolt types*
    - *A325-SC, A490-SC*
    - *A325-N, A490-N*
    - *A325-X, A490-X*

Table 7-1
Available Shear Strength of Bolts, kips

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
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	
Group A	N	27.0	40.5	S	8.29	12.4	11.9	17.9	16.2	24.3	21.2	31.8
				D	16.6	24.9	23.9	35.8	32.5	48.7	42.4	63.6
	X	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
Group B	N	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
	X	42.0	63.0	S	12.9	19.3	18.6	27.8	25.2	37.9	33.0	49.5
				D	25.8	38.7	37.1	55.7	50.5	75.7	65.9	98.9
A307	–	13.5	20.3	S	4.14	6.23	5.97	8.97	8.11	12.2	10.6	15.9
				D	8.29	12.5	11.9	17.9	16.2	24.4	21.2	31.9

ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi) 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
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	
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.
$\Omega = 2.00$	$\phi = 0.75$	

Bolted Connection Design

- *Unified steel*
  - *bearing:*
    - *bolts rarely fail by bearing*
    - *other part fails first*
  - *slip critical*
    - *tightened down*
  - *holes are 1/16" larger*
  - *effective hole widths are 1/8" more*

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 $L_e \geq L_{e\,full}$[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

Bolted Connection Design

- *single shear or tension*

$$R_u \leq \phi R_n$$
$$\phi = 0.75$$

$$R_n = F_n A_b$$

- *double shear*

$$R_n = F_n 2A_b$$

- *bolt area*
  - *threads excluded*
  - *threads included*

Bolted Connection Design

- *bearing at bolt holes*

$$R_u \leq \phi R_n$$
$$\phi = 0.75$$

  - *deformation is concern*

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

  - *deformation isn't concern*

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

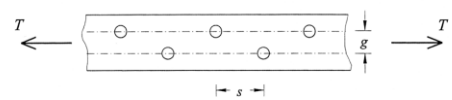
  - *long slotted holes*

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

L_c – clear length to edge or next hole

Tension Members

- *$A_e = A_n U$*
  - *A_n is actual net area*
  - *U is shear lag factor by element type*



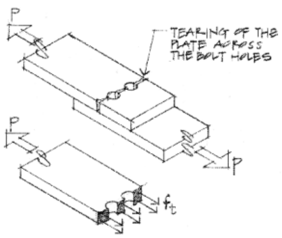
$$A_n = A_g - A_{of\ all\ holes} + t\Sigma \frac{s}{4g}$$

Tension Members

- limit states for failure $R_u \le \phi R_n$

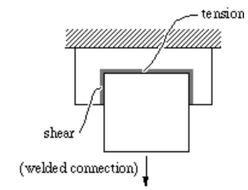
1. yielding $\phi = 0.9 \quad R_n = F_y A_g$
2. rupture* $\phi = 0.75 \quad R_n = F_u A_e$

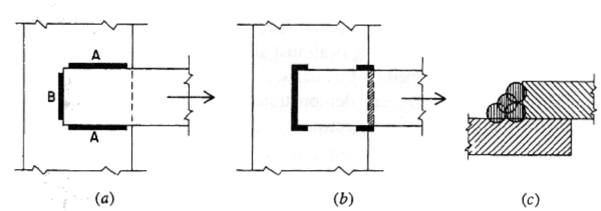
A_g - gross area
A_e - effective net area
F_u = the tensile strength of the steel (ultimate)



Welded Connection Design

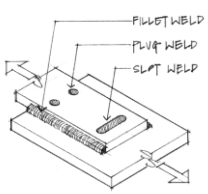
- considerations
  - shear stress
  - yielding
  - rupture

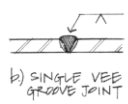




Welded Connection Design

- weld terms
  - butt weld
  - fillet weld
  - plug weld
  - throat
- weld materials
  - E60XX
  - E70XX
    F_{EXX} = 70 ksi





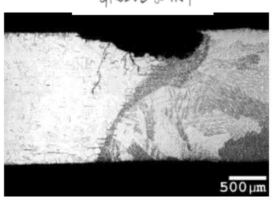


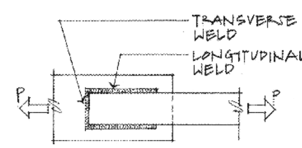
TABLE J2.4
Minimum Size of Fillet Welds

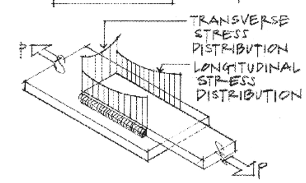
Material Thickness of Thicker Part Joined, in. (mm)	Minimum Size of Fillet Weld[a] in. (mm)
To 1/4 (6) inclusive	1/8 (3)
Over 1/4 (6) to 1/2 (13)	3/16 (5)
Over 1/2 (13) to 3/4 (19)	1/4 (6)
Over 3/4 (19)	5/16 (8)

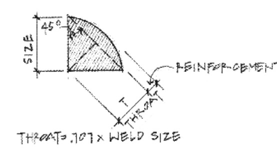
[a] Leg dimension of fillet welds. Single pass welds must be used.
[b] See Section J2.2b for maximum size of fillet welds.

Welded Connection Design

- shear 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”*

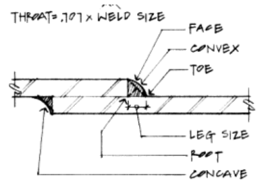


TABLE J2.4 Minimum Size of Fillet Welds	
Material Thickness of Thicker Part Joined, in. (mm)	**Minimum Size of Fillet Weld[a] in. (mm)**
To ¼ (6) inclusive	⅛ (3)
Over ¼ (6) to ½ (13)	3/16 (5)
Over ½ (13) to ¾ (19)	¼ (6)
Over ¾ (19)	5/16 (8)

[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*

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

$$\phi = 0.75$$

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

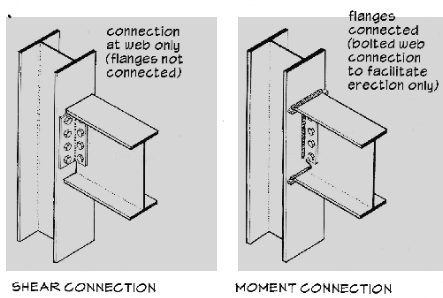
  - *table for ϕS*

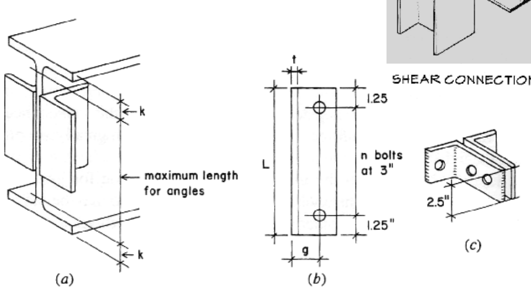
Available Strength of Fillet Welds per inch of weld (ϕS)		
Weld Size (in.)	E60XX (k/in.)	E70XX (k/in.)
3/16	2.39	4.18
¼	4.77	5.57
5/16	5.97	6.96
⅜	7.16	8.35
7/16	5.57	9.74
½	8.35	11.14
⅝	11.93	13.92
¾	14.32	16.70

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

Framed Beam Connections

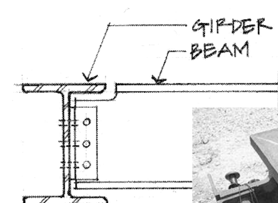
- *angles*
  - *bolted*
  - *welded*

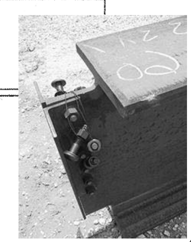


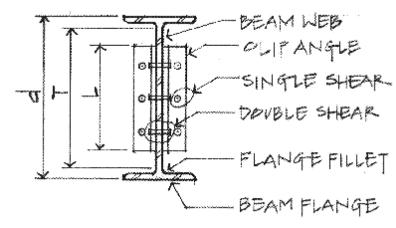


Framed Beam Connections

- *terms*
  - *coping*



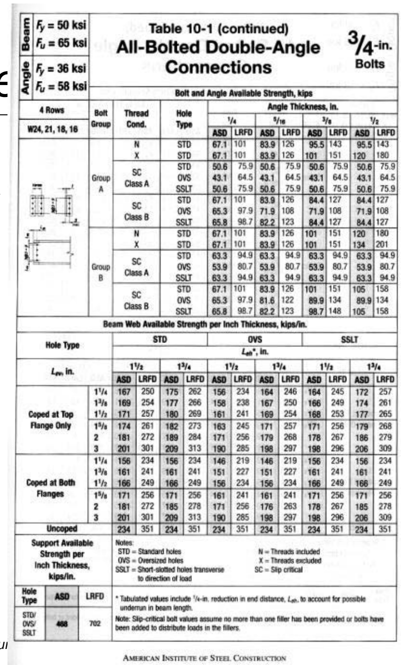




(AISC - Steel Structures of the Everyday)

Framed Beam Connections

- tables for standard bolt holes & spacings
- n = # 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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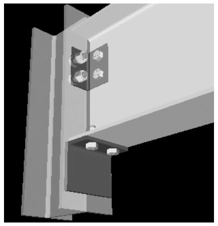
Other Beam Connections

- seated beam
  - unstiffened
  - stiffened
- continuous
  - beam to column
  - beam to beam



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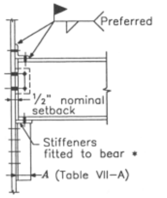

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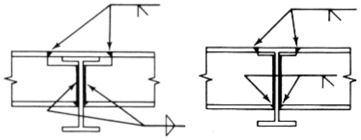
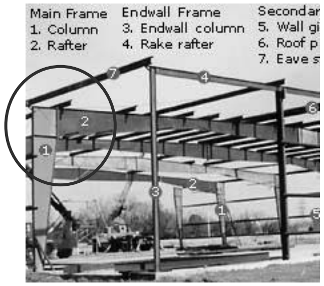
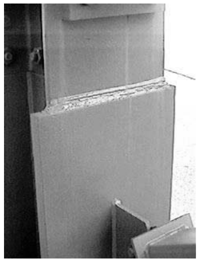
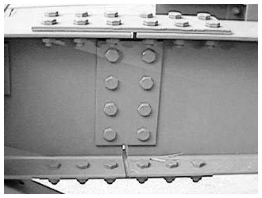


Other Connections

- rigid frame knees
- beam splice
- column splice







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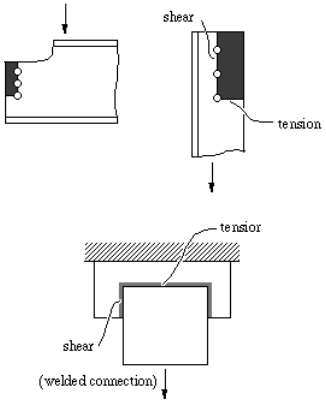
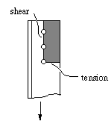
Beam Connections

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



Beam Connections

- *LRFD design of connected elements*
  - *shear yielding* $\phi = 1.00 \quad R_n = 0.60 F_y A_g$
  - *shear rupture* $\phi = 0.75 \quad R_n = 0.60 F_u A_{nv}$
  - *block shear rupture* $\phi = 0.75$

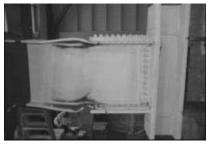


$$R_n = 0.6 F_u A_{nv} + U_{bs} F_u A_{nt} \le 0.6 F_y A_{gv} + U_{bs} F_u A_{nt}$$

where U_{bs} is 1 for uniform tensile stress

Beam Connections

- *tension yielding* $\phi = 0.90 \quad R_n = F_y A_g$
- *tension rupture* $\phi = 0.75 \quad R_n = F_u A_e$
- *flexural yielding* $\phi_b = 0.90 \quad M_n = F_y S_{net}$
- *local web buckling*
- *lateral torsional buckling*



Beam Connections

- *block shear rupture*
- *tension rupture*

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

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

Beam Bearing

- *design considerations*
  - *web crippling*
  - *base plate bending*
  - *bearing on concrete, etc.*
- *load distributed*

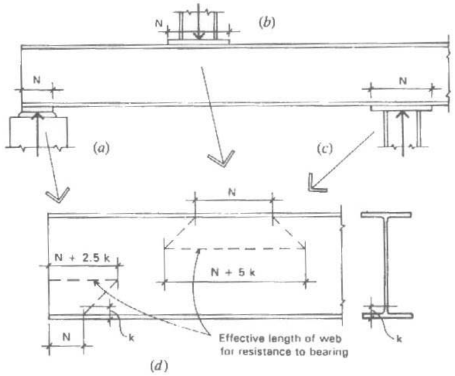
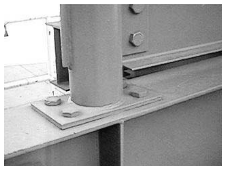


Figure 9.10 Considerations for bearing in beams with thin webs, as related to web crippling (buckling of the thin web in compression).

Column Base Plates

- attached by anchor bolts
  - usually 4
  - 2 if no moment
- plate level
  - by shims & grout
  - leveling nuts
- considers
  - bearing on steel
  - bending of plate



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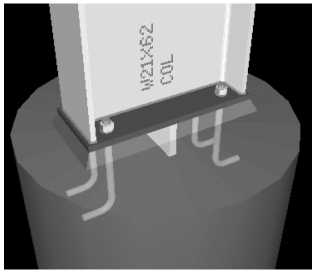

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