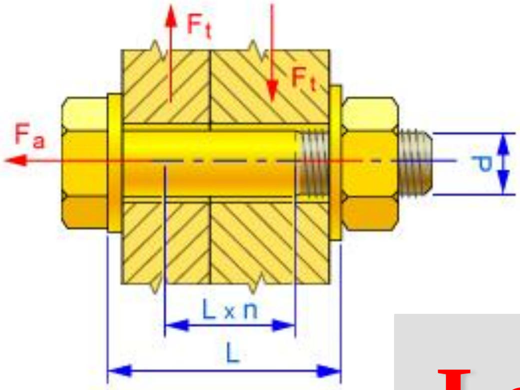


Timber and Steel Design

Lecture 13 Bolted Connections 1

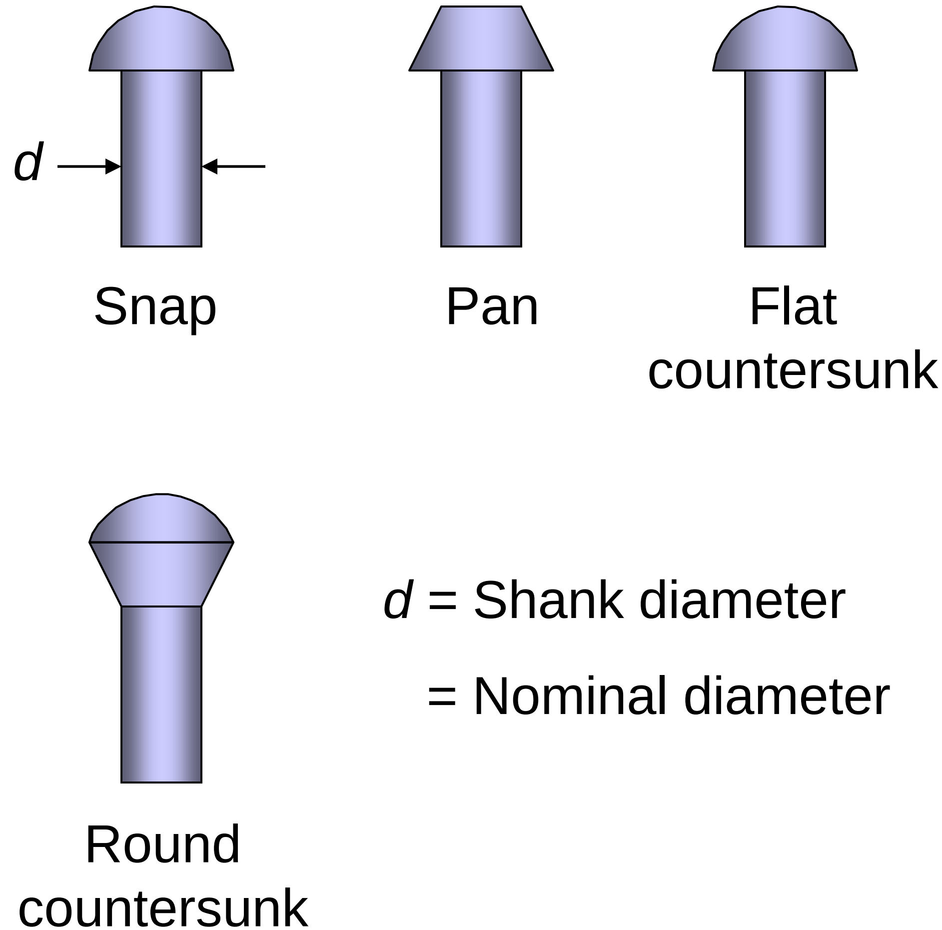
- Types of Joints
- Failure of Joints
- Types of Bolts
- AISC Bolt Strengths
- Truss Joints

Mongkol JIRAVACHARADET

S U R A N A R E E INSTITUTE OF ENGINEERING
UNIVERSITY OF TECHNOLOGY SCHOOL OF CIVIL ENGINEERING

Riveted Connections

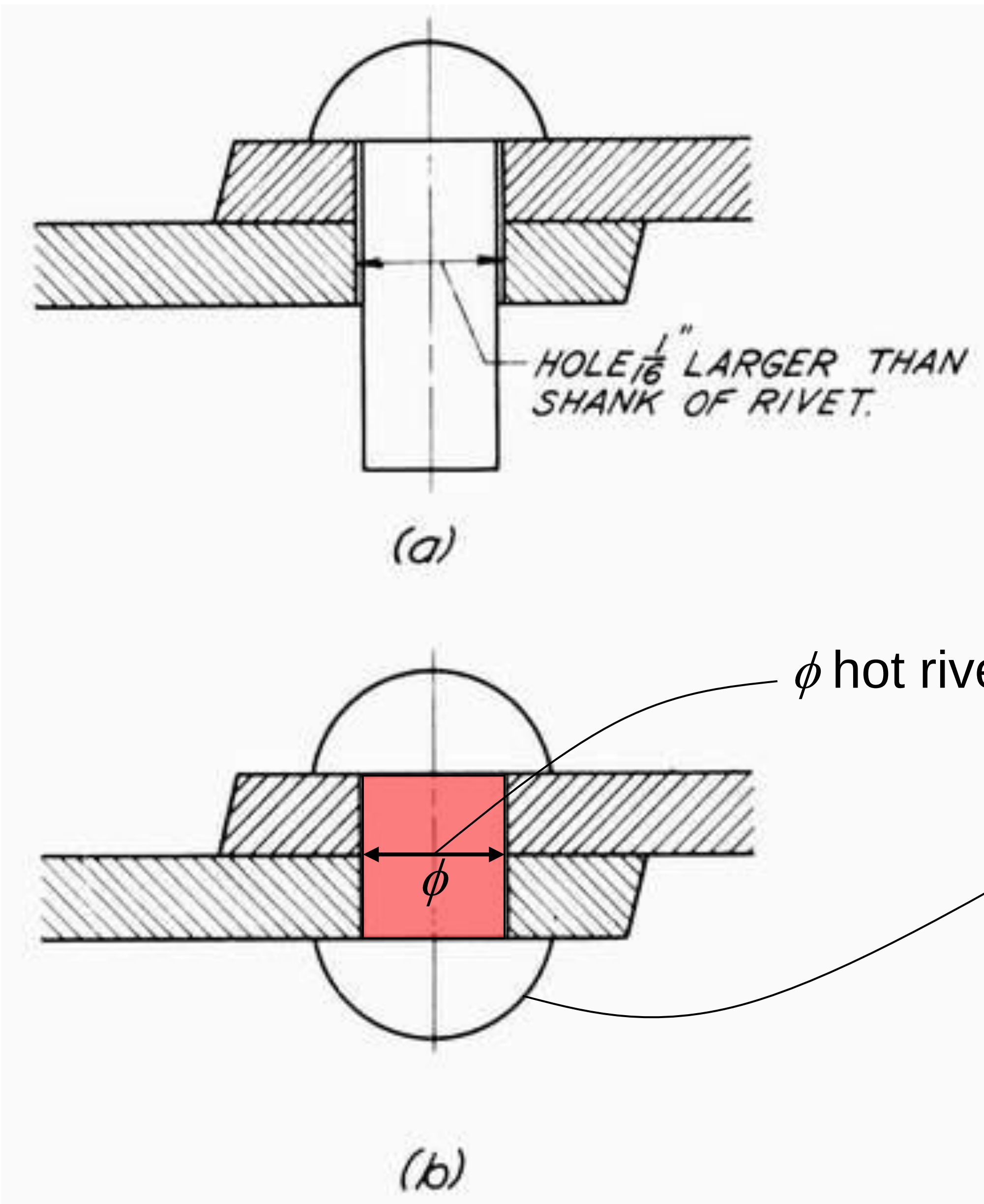
rivet = round ductile steel bar (shank) with a head at one end



d = Shank diameter

= Nominal diameter

Riveting Procedure



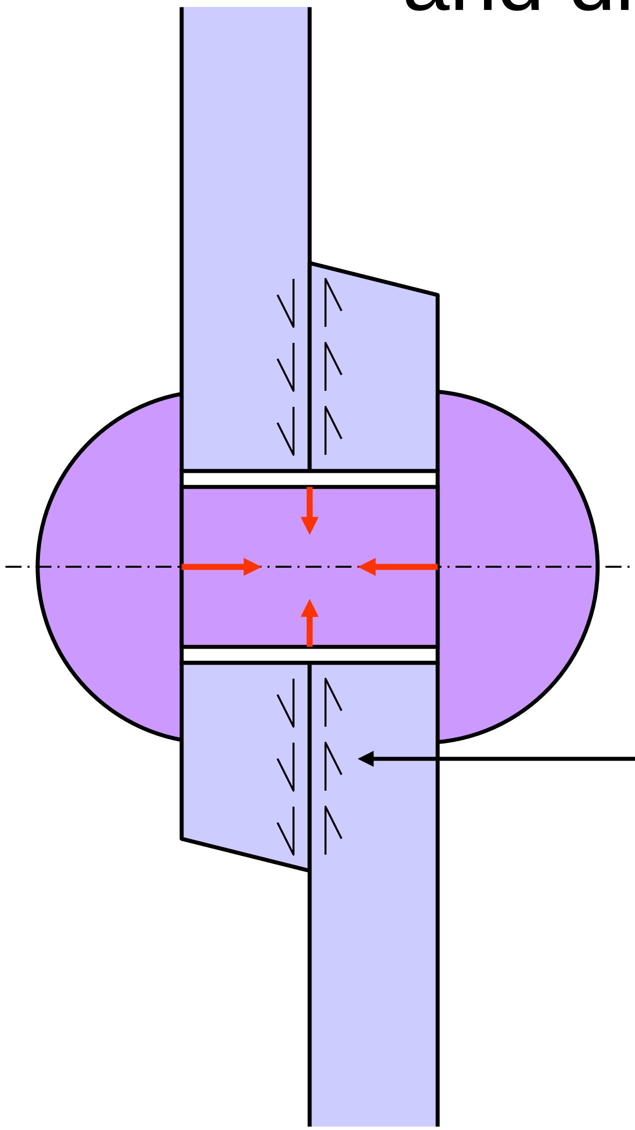
ϕ hot rivet = ϕ hole

Rivets are heated before driving

Head is formed by

- Hand hammer
- Hydraulic pressure
- Pneumatic pressure

On cooling, the rivet shrinks both length and diameter



Connected parts become tighter:

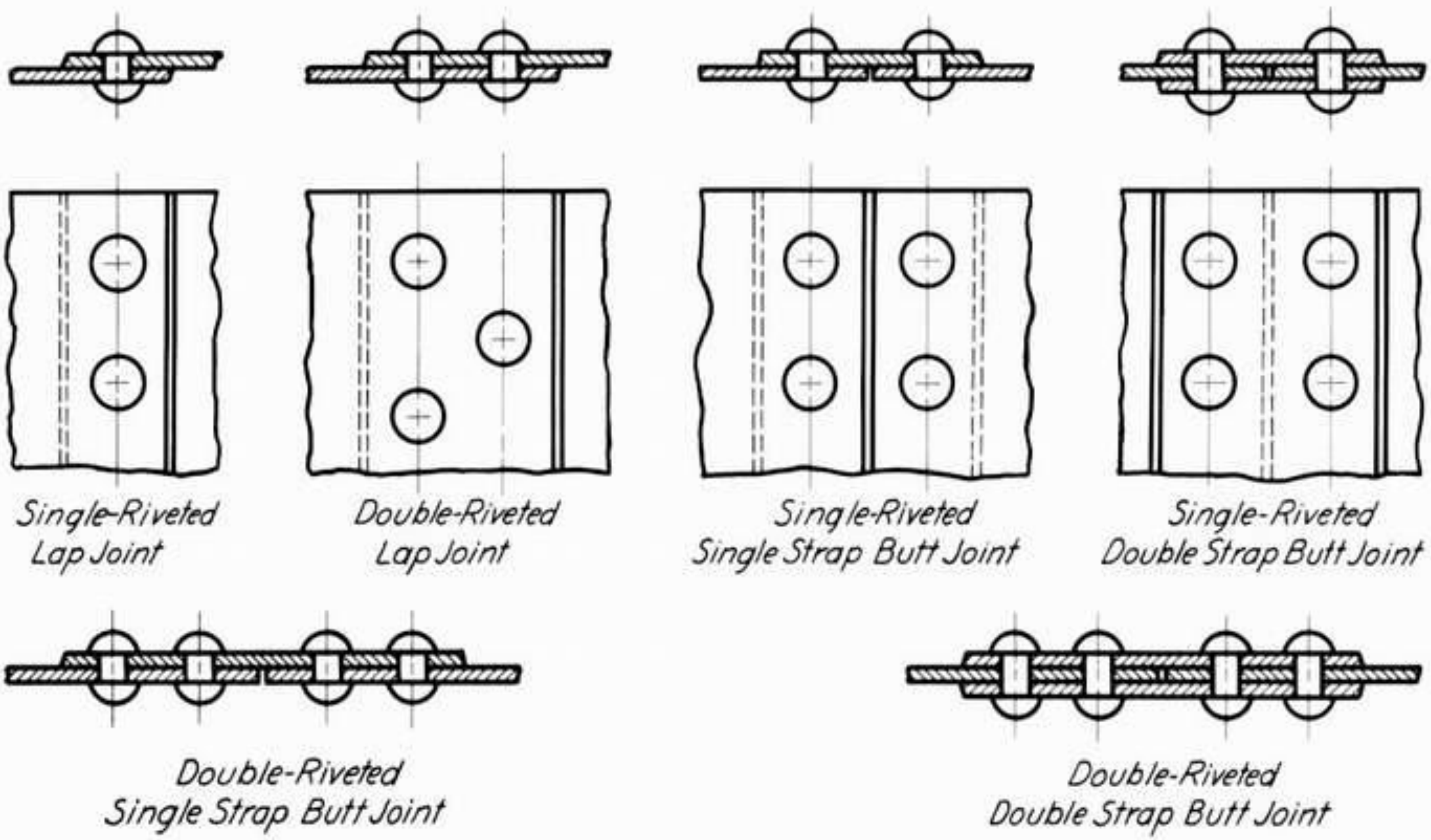
- Tension in rivet

- Compression in plates

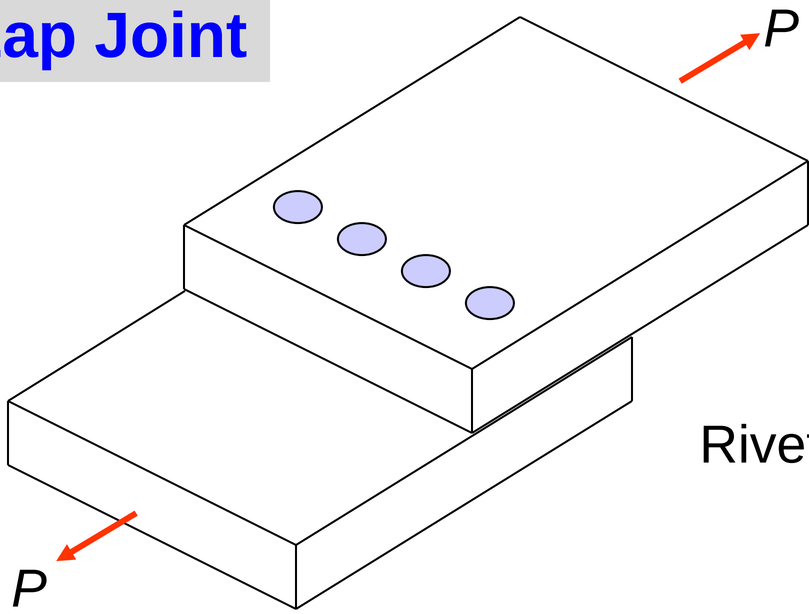
Friction between plates called

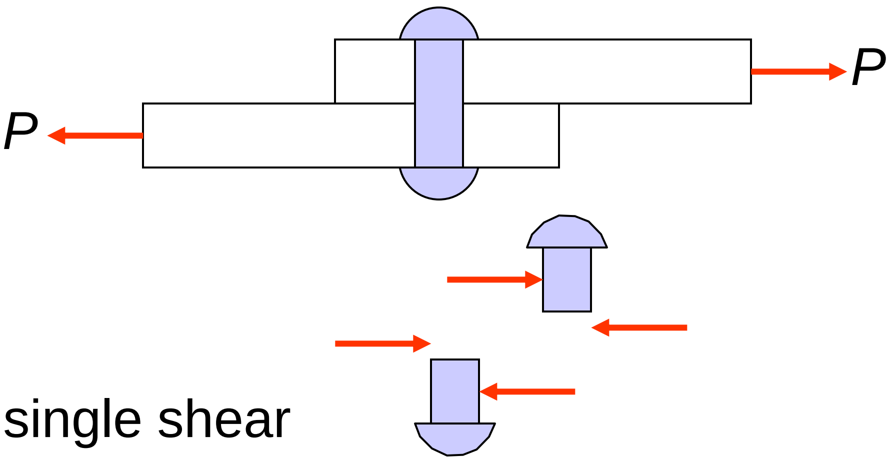
"clamping action"

Forms of riveted joints



Lap Joint

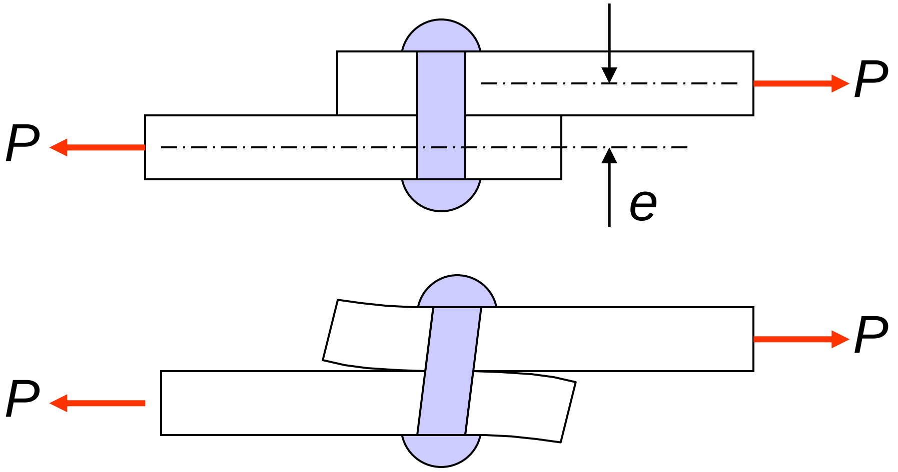


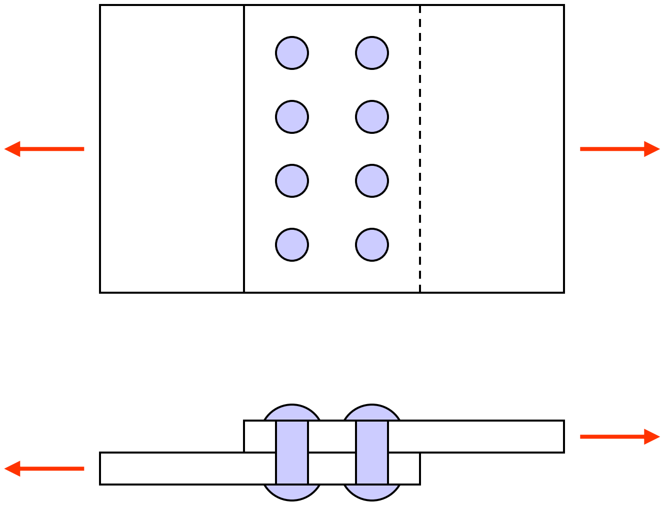


Rivet in single shear

$f_v = P / A$

Eccentricity in lap joint

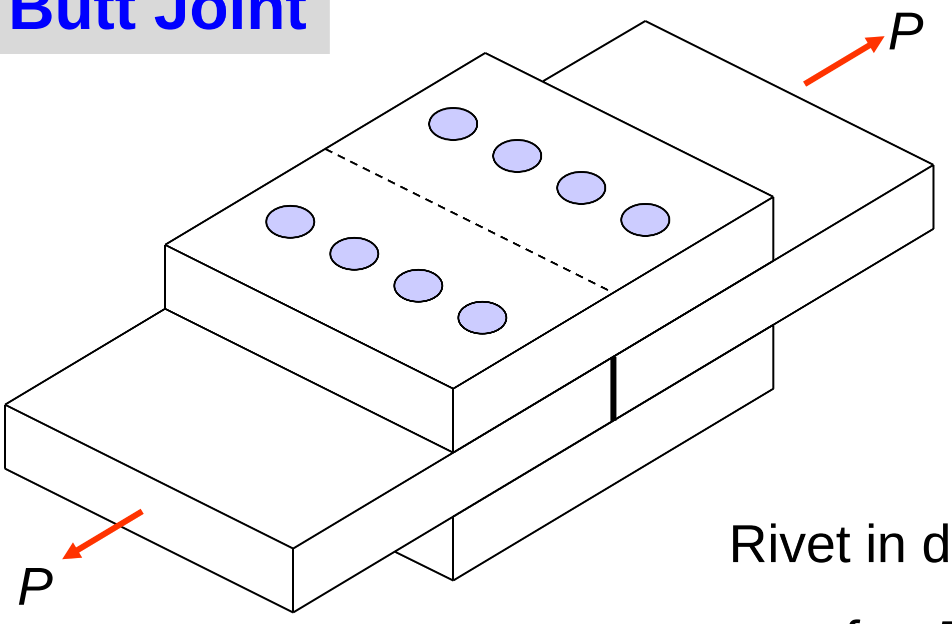


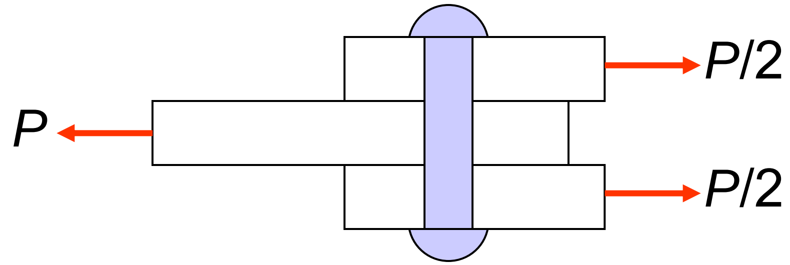


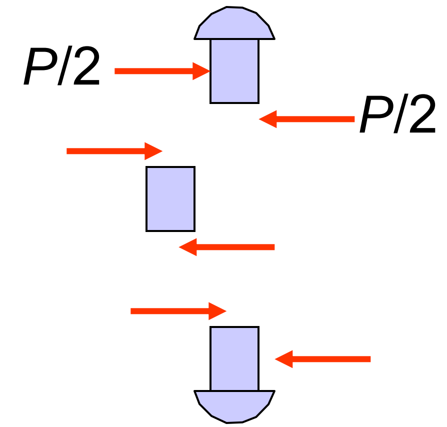
Double riveted lap joint

Undesired bending causes tension in rivets

Butt Joint







Rivet in double shear

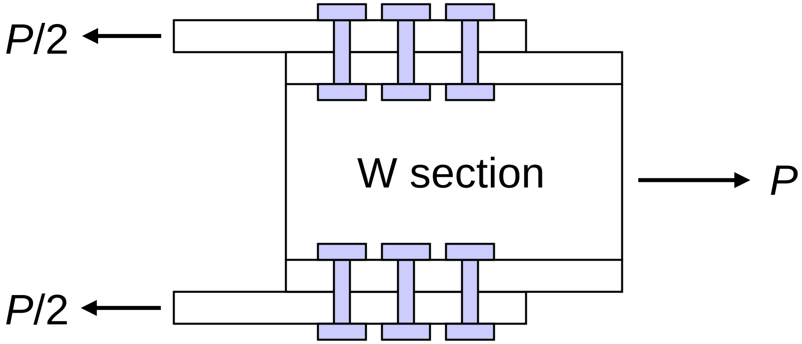
$f_v = P/2A$

Butt joint v.s. Lap joint:

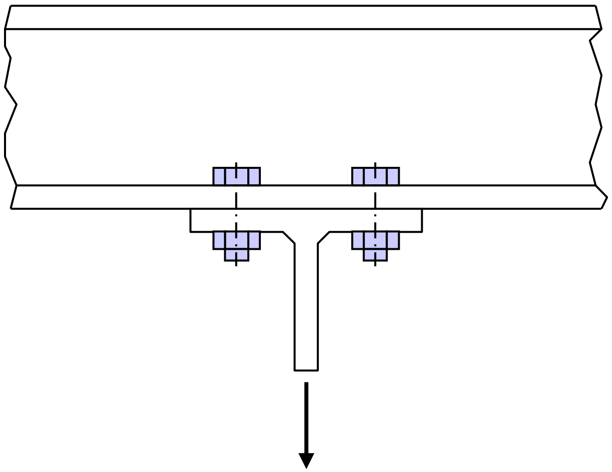
- แรงเฉือนในสลักเกลียวลดลงครึ่งหนึ่งของการต่อแบบทาบ
- จุดต่อรับแรงตรงแนวไม่เกิดโมเมนต์ดัด
- จุดต่อราคาเพิ่มขึ้น มักใช้ในจุดต่อที่รับแรงมาก

Bolted Connections

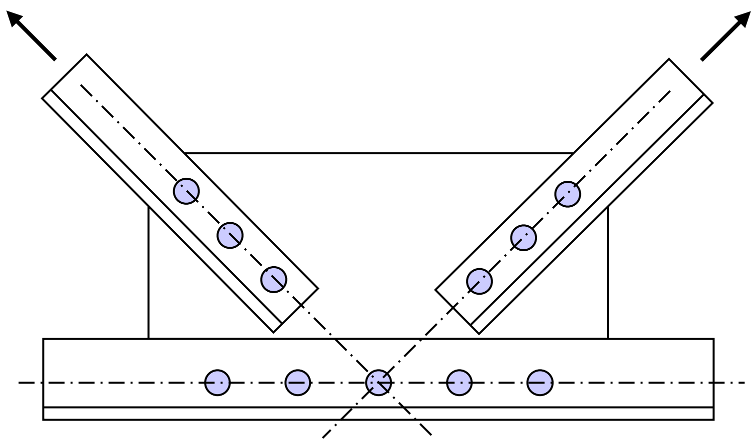
การต่อสลักเกลียวในลักษณะต่าง ๆ



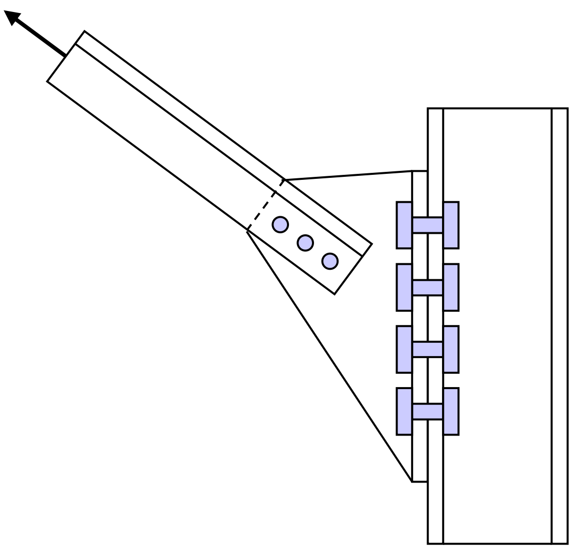
(a) จุดต่อปีกคาน



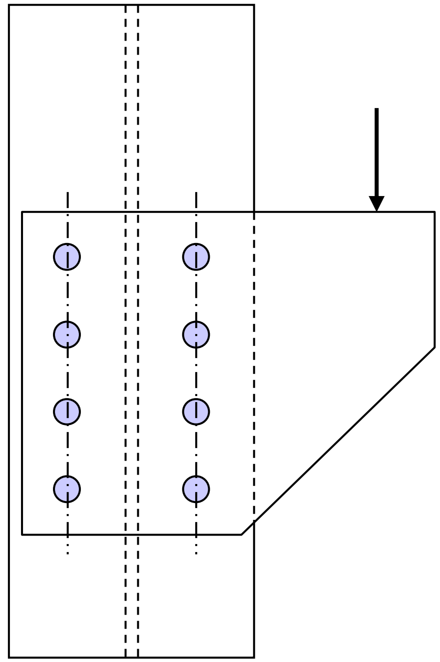
(b) จุดต่อแบบแขวน



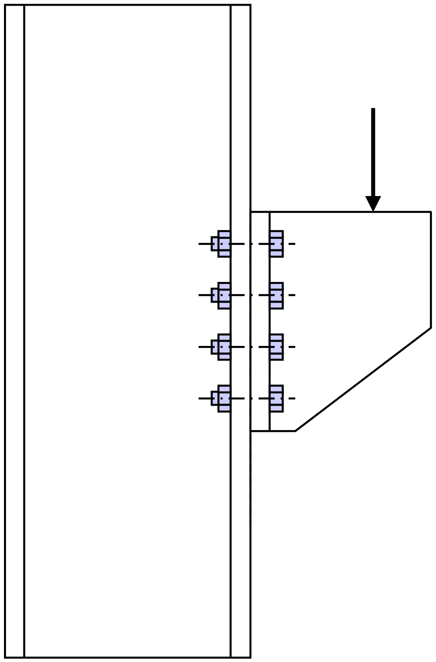
(c) จุดต่อโครงถัก



(d) จุดต่อการยึดโยง



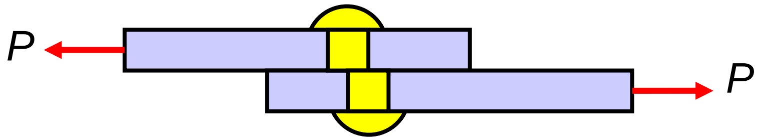
(e) จุดต่อเยื้องศูนย์แป้นหูช้าง



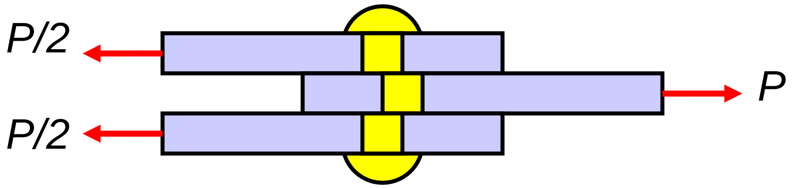
(f) จุดต่อเยื้องศูนย์

Failure of Joints

Case 1: Shear failure of rivets



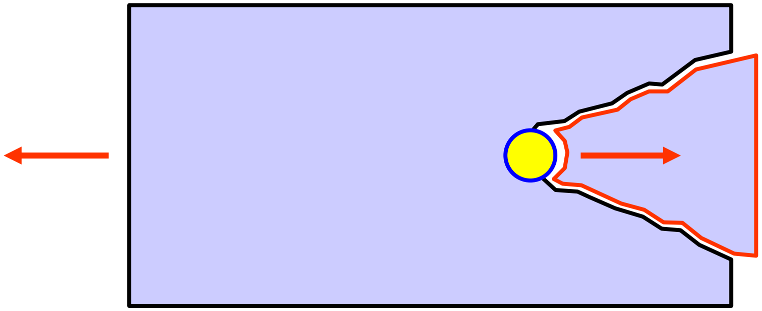
Single shear in lap joint



Double-shear in butt joint

Shear stress in rivet exceed the limit

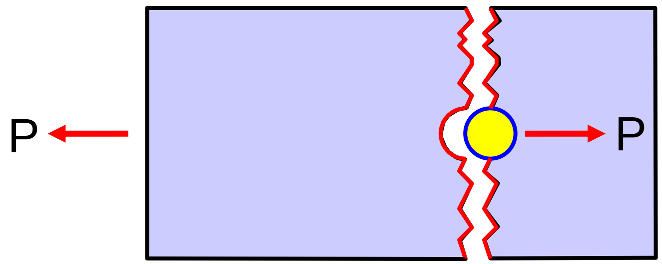
Case 2: Shear failure of plates



Shearing out

Insufficient edge distance

Case 3 : Tension or Tearing failure of plates



Tensile stress at net cross section exceeds tensile strength

Case 4 : Bearing failure of plate

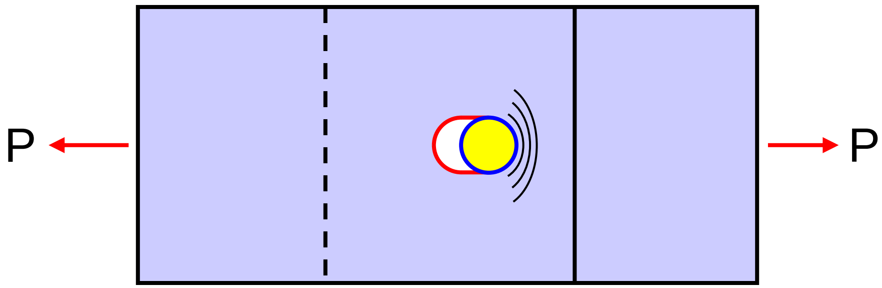
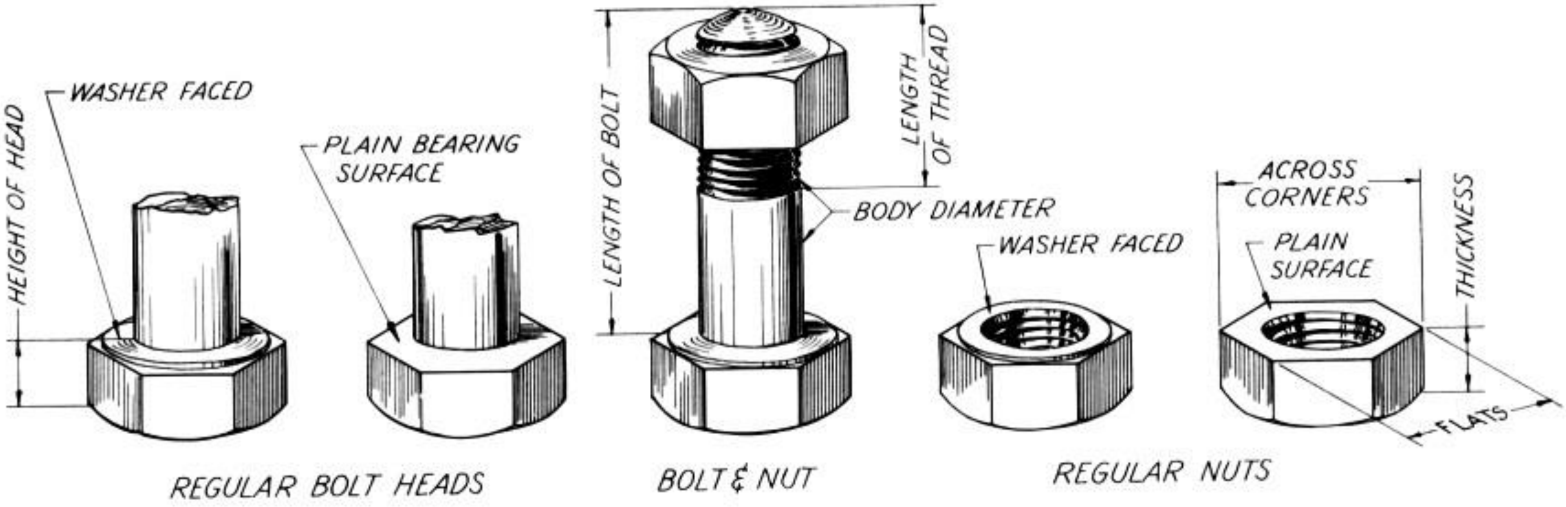
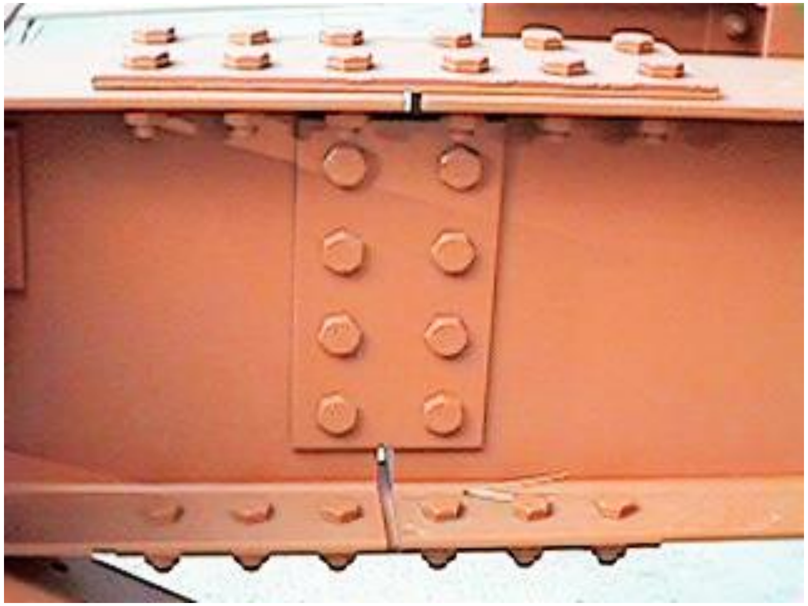


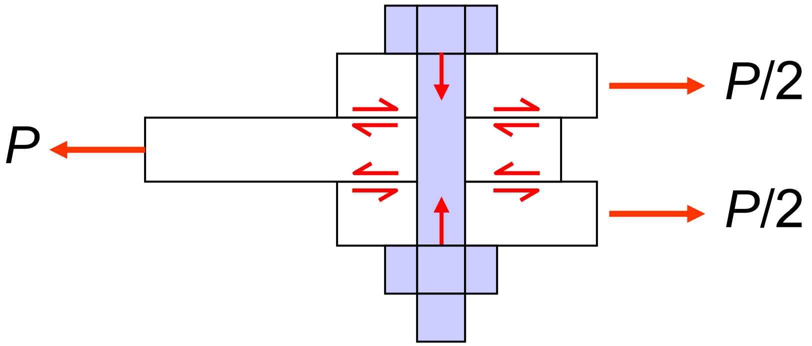
Plate may be crushed when bearing stress in plate exceeds the limit

Bolted Connections





Beam splice moment connection

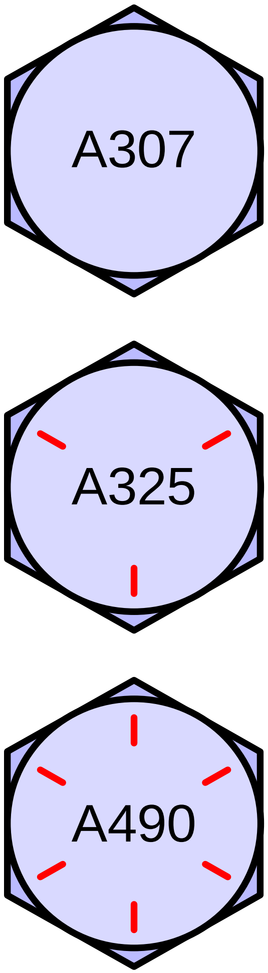


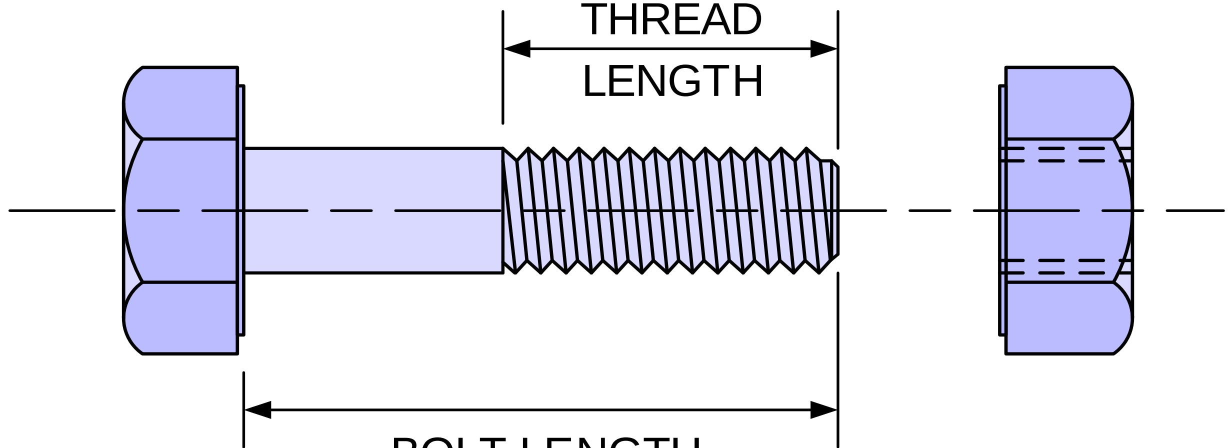
Friction from clamping pressure using high strength bolt

BOLT & NUT

BOLT = น๊อตตัวผู้ = สลักเกลียว

NUT = น๊อตตัวเมีย = แป้นเกลียว

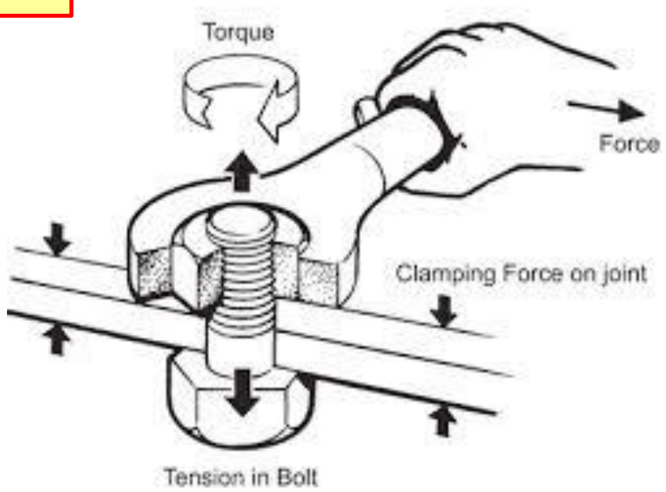




BOLT **NUT**

Snug-tight bolts → Bearing joints

For most connection, bolts are tightened by full effort of a human using a spud wrench.



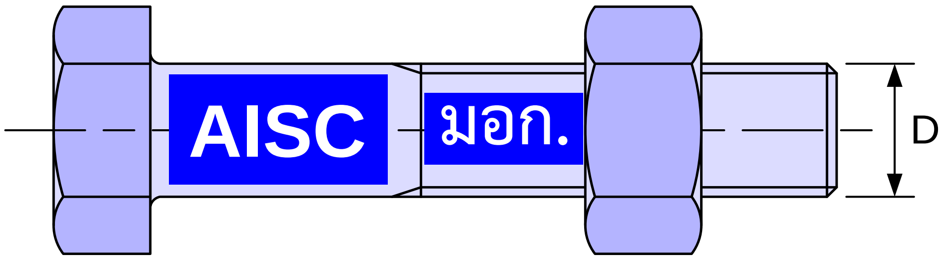
Pretensioned joints

Required under seismic load or fatique

For A325 and A490 bolts, min. pretension equal to 70% min. tensile stress.

Slip-critical Joints

Same as pretensioned joint except treatment of the contact surface.



BOLT SIZES

(1 in. = 25.4 mm)

มอก. 2450-2552
ISO 888 : 1976

US Custom

Bolt Size, in.
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2

→ Multiplied by 25.4 mm

13 mm
16 mm
19 mm
22 mm
25 mm
29 mm
32 mm
35 mm
38 mm

Metric Size

Bolt Size, mm
M16
M20
M22
M24
M27
M30
M36

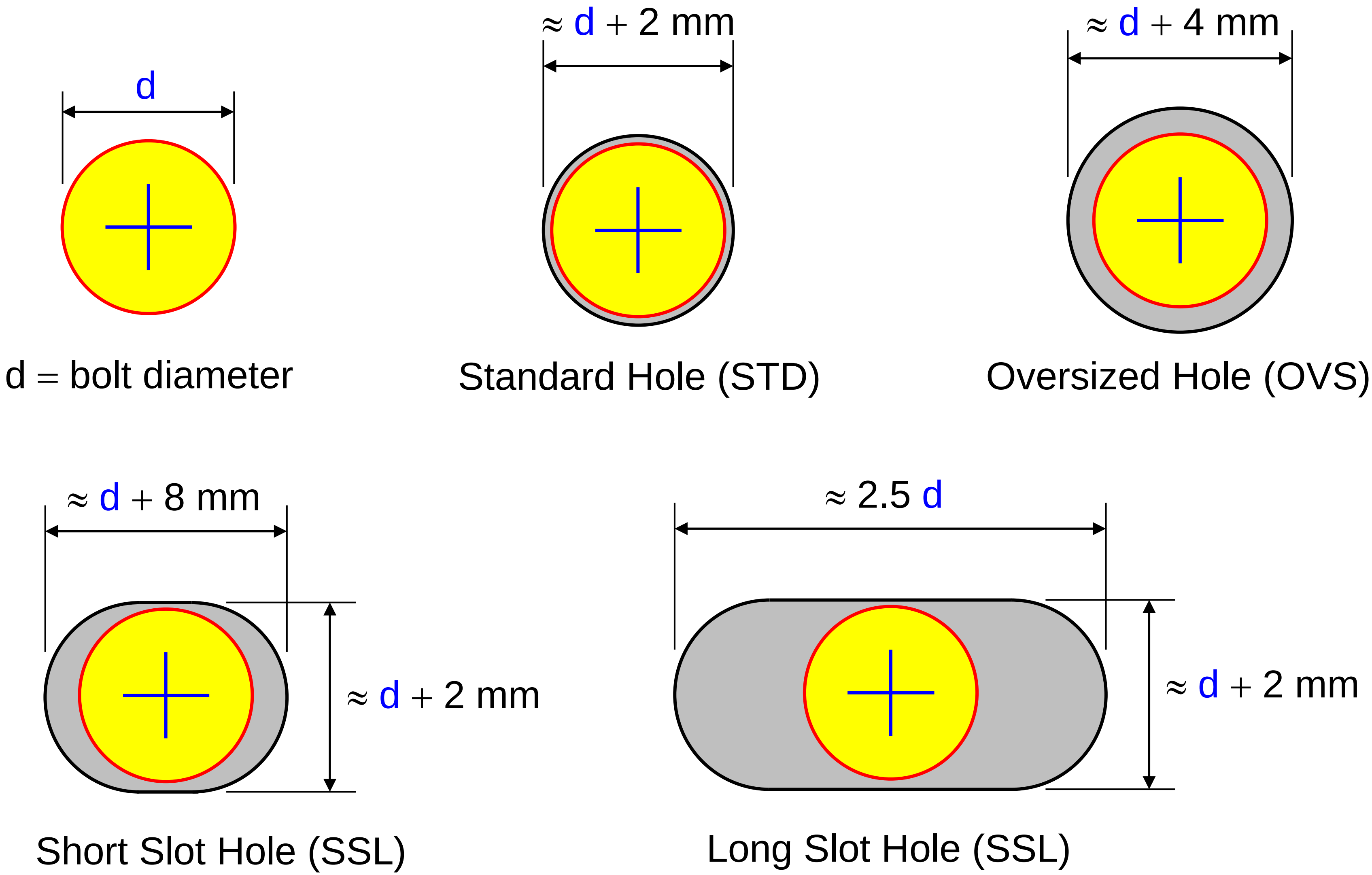
12 mm
14 mm
16 mm
18 mm
20 mm
22 mm
24 mm
27 mm
30 mm
33 mm
36 mm

TABLE J3.3M
Nominal Hole Dimensions, mm

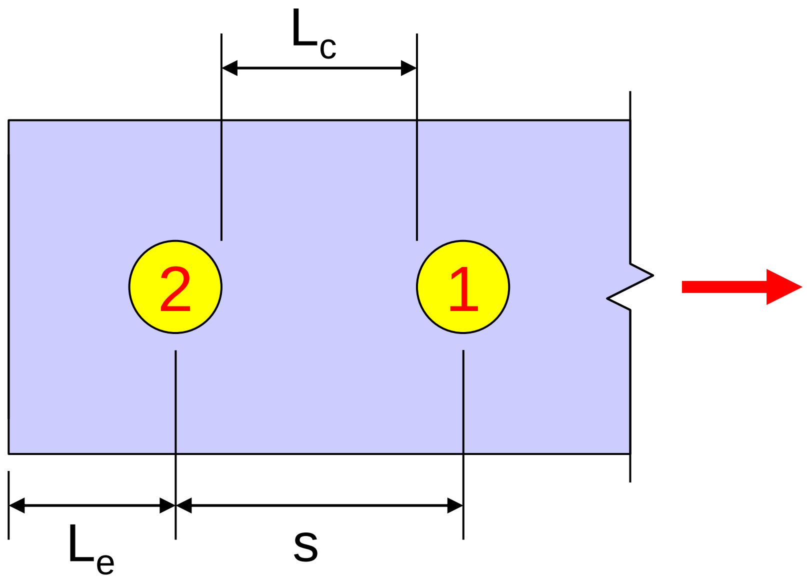
Bolt Diameter, mm	Hole Dimensions			
	Standard (Dia.)	Oversize (Dia.)	Short-Slot (Width × Length)	Long-Slot (Width × Length)
M16	18	20	18×22	18×40
M20	22	24	22×26	22×50
M22	24	28	24×30	24×55
M24	27[a]	30	27×32	27×60
M27	30	35	30×37	30×67
M30	33	38	33×40	33×75
≥ M36	$d + 3$	$d + 8$	$(d + 3) \times (d + 10)$	$(d + 3) \times 2.5d$

[a] Clearance provided allows the use of a 1-in.-diameter bolt.

Type of Holes



3. Minimum Spacing & Edge Distance **AISC J3**



L_c = clear distance, in the direction parallel to the applied load.

L_e = edge-distance to center of the hole

s = center-to-center spacing of holes

d = diameter of fastener

h = diameter of hole from Table J3.3M

Minimum Spacing

$s \geq 2\tfrac{2}{3}d$ (prefer 3d)

$L_c \geq d$

Minimum Edge Distance

For standard holes

$L_e \geq$ value from AISC Table J3.4 ($\approx 1.5d$)

For oversized holes or slotted holes

$L_e \geq$ value of standard hole + C_2 from Table J3.5

TABLE J3.4M
Minimum Edge Distance,[a] mm, from Center of Standard Hole[b] to Edge of Connected Part

Bolt Diameter (mm)	At Sheared Edges	At Rolled Edges of Plates, Shapes or Bars, or Thermally Cut Edges [c]
16	28	22
20	34	26
22	38 [d]	28
24	42 [d]	30
27	48	34
30	52	38
36	64	46
Over 36	1.75d	1.25d

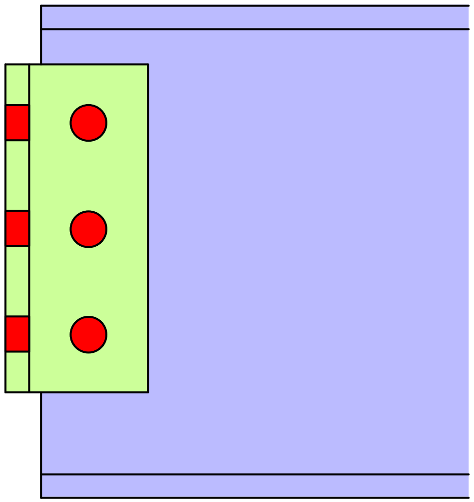
[a] Lesser edge distances are permitted to be used provided provisions of Section J3.10, as appropriate, are satisfied.
[b] For oversized or slotted holes, see Table J3.5M.
[c] All edge distances in this column are permitted to be reduced 3 mm when the hole is at a point where required strength does not exceed 25 percent of the maximum strength in the element.
[d] These are permitted to be 32 mm at the ends of beam connection angles and shear end plates.

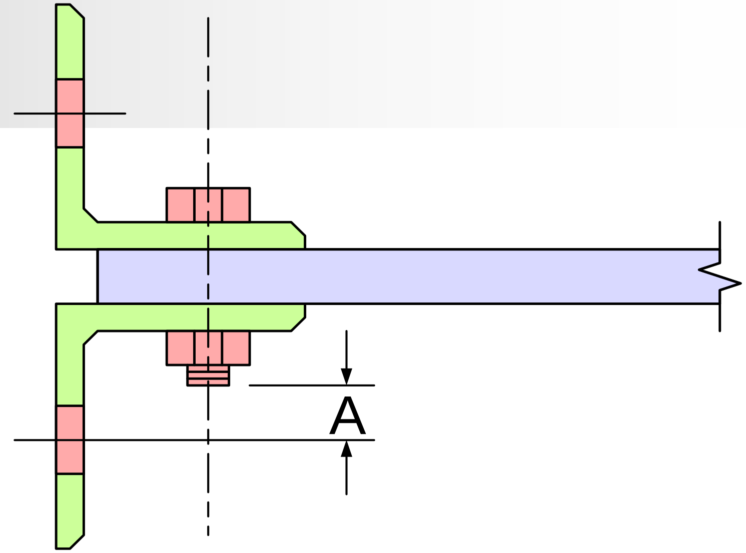
TABLE J3.5M
Values of Edge Distance Increment C_2, mm

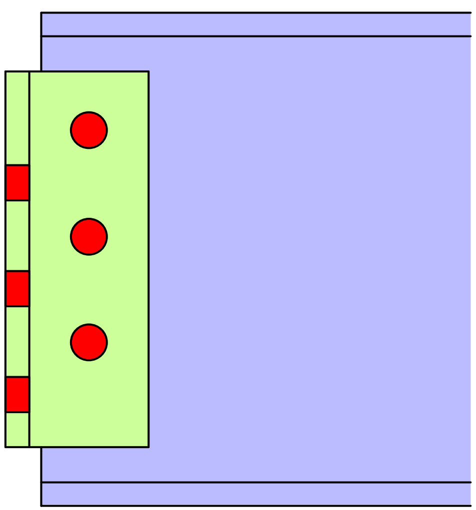
Nominal Diameter of Fastener (mm)	Oversized Holes	Slotted Holes		
		Long Axis Perpendicular to Edge		Long Axis Parallel to Edge
		Short Slots	Long Slots[a]	
≤ 22	2	3	$0.75d$	0
24	3	3		
≥ 27	3	5		

[a]When length of slot is less than maximum allowable (see Table J3.3M), C_2 is permitted to be reduced by one-half the difference between the maximum and actual slot lengths.

Minimum Clearance







สลักเกลียว เส้นผ่าศูนย์กลาง	แป้นเกลียว ความสูง	ระยะช่องว่าง น้อยที่สุด, A
12	12	22
16	16	25
19	19	32
22	22	35
25	25	38
28	28	40
32	32	43

6. Bolt Tensile & Shear Strength

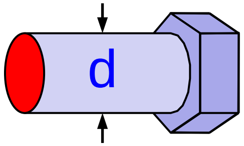
AISC J3

The nominal tensile and shear strength :

$$R_n = F_n A_b \qquad \text{(J3-1)}$$

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

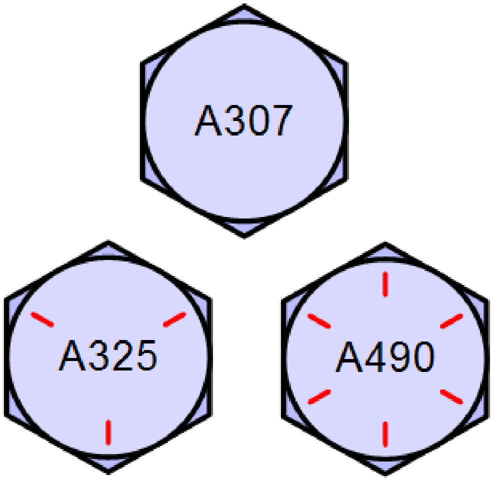
where A_b = bolt area $= \frac{\pi}{4} d^2$



$F_n = F_{nt}$ = nominal tensile stress or

$= F_{nv}$ = nominal shear stress

Table J3.2



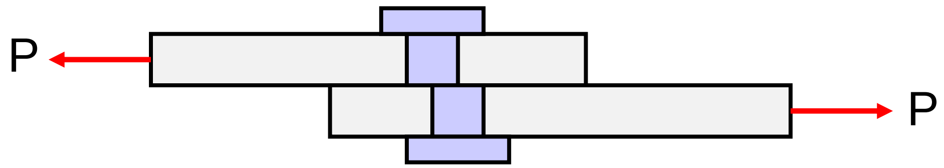
A307 : Unfinished bolts or Ordinary or Common bolts

A307 bolts are mode from carbon steel similar to A36.

A325 : High-strength bolts made from a heat-treated medium carbon steel

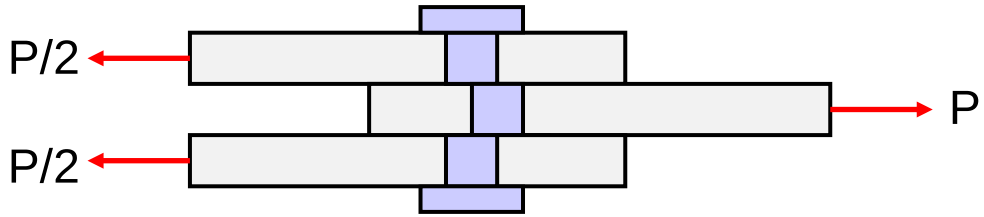
A490 : High-strength bolts made from a heat-treated alloy steel

Single & Double Shear



Single shear

$$R_n = F_{nv} A_b$$



Double shear

$$R_n = F_{nv} (2A_b)$$

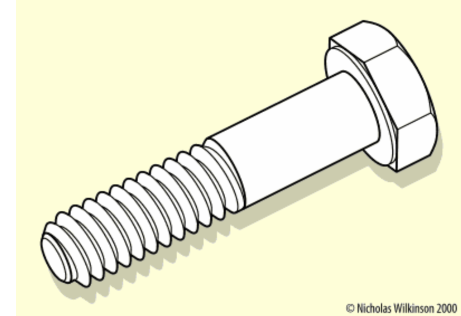
AISC TABLE J3.2
Nominal strength of Fasteners and Threaded Parts

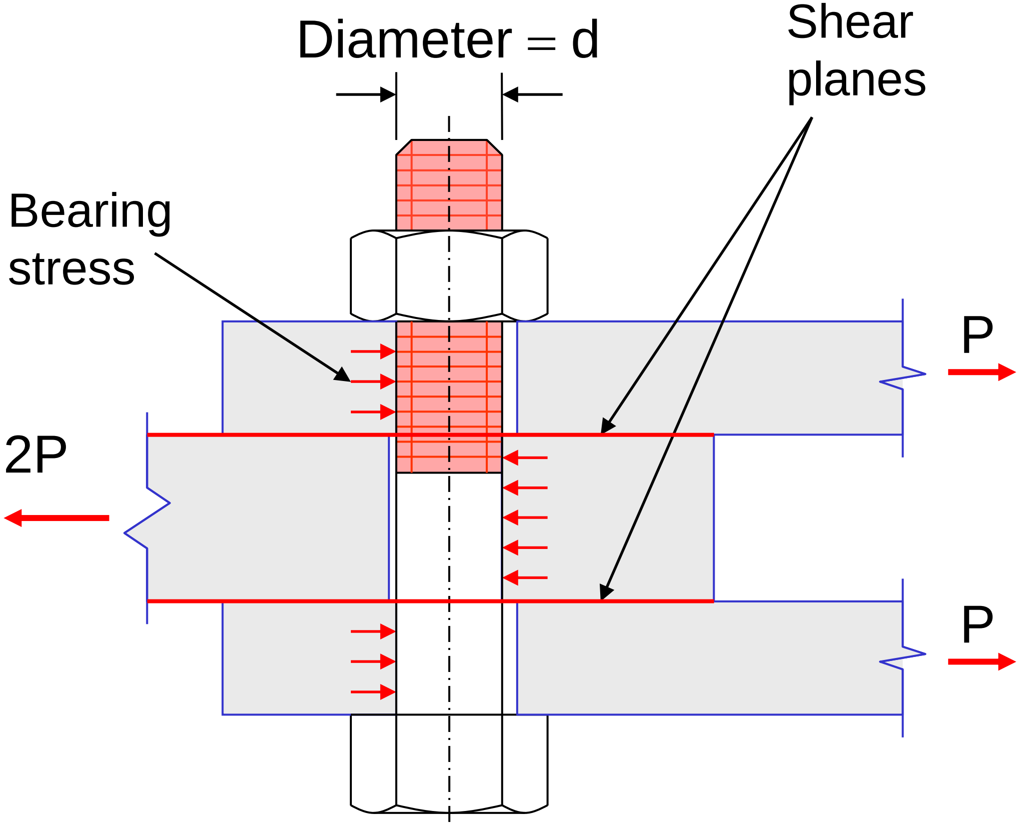
Fasteners	Nominal Tensile Strength, F_{nt}			Nominal Shear Strength in Bearing-Type Connections, F_{nv}		
	ksi	MPa	ksc	ksi	MPa	ksc
A307 bolts	45	310	3,100	27	186	1,900
A325 threads are included in shear plane (A325-N)	90	620	6,300	54	372	3,800
A325 threads are excluded from shear plane (A325-X)	90	620	6,300	68	469	4,700
A490 threads are included in shear plane (A490-N)	113	780	7,900	68	469	4,700
A490 threads are excluded from shear plane (A490-X)	113	780	7,900	84	579	5,900

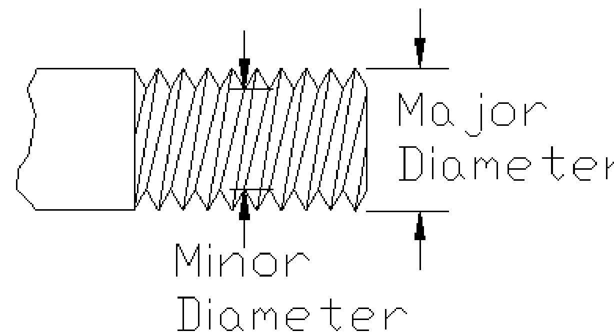
Table D-1 Nominal Tensile Strength of Bolt, $F_{nt} A_b$ (tons)

ASTM Desig.	F_{nt} (ksc)	Bolt Diameter, d (mm)						
		16	19	20	22	24	25	27
		Bolt Area (cm^2)						
		2.01	2.84	3.14	3.80	4.52	4.91	5.73
A307	3,100	6.23	8.79	9.74	11.78	14.02	15.22	17.75
A325	6,300	12.67	17.86	19.79	23.95	28.50	30.93	36.07
A490	7,900	15.88	22.40	24.82	30.03	35.74	38.78	45.23

Threads Excluded from Shear Plane or not ?







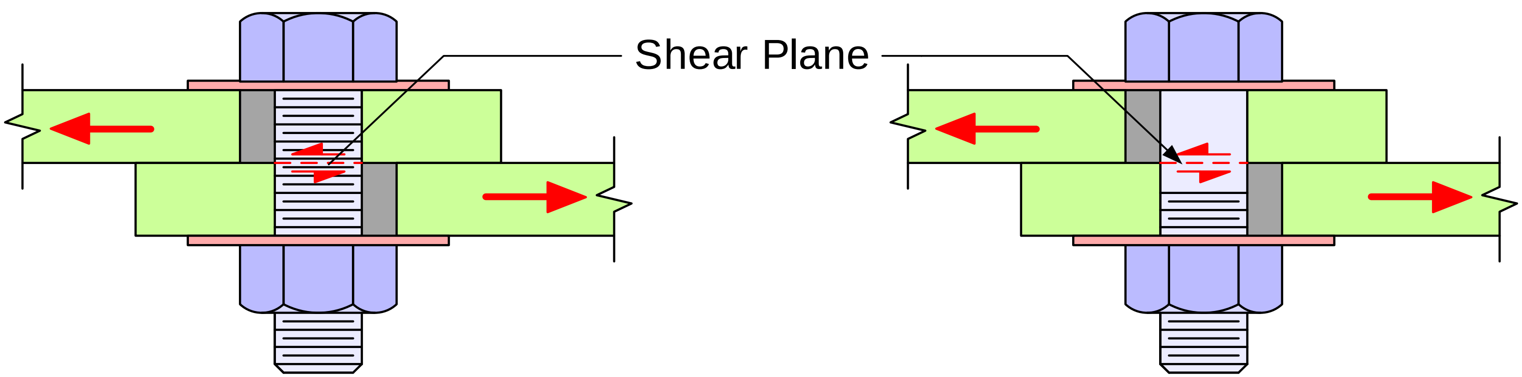


Table D-2 Nominal Shear Strength of Bolt, $F_{nv} A_b$ (tons)

ASTM Desig.	Thread Cond.	F_{nv} (ksc)	Load-ing	Bolt Diameter, d (mm)						
				16	19	20	22	24	25	27
				Bolt Area (cm^2)						
				2.01	2.84	3.14	3.80	4.52	4.91	5.73
A307	-	1,900	S	3.82	5.39	5.97	7.22	8.60	9.33	10.88
			D	7.64	10.77	11.94	14.45	17.19	18.65	21.76
A325	N	3,800	S	7.64	10.77	11.94	14.45	17.19	18.65	21.76
			D	15.28	21.55	23.88	28.89	34.38	37.31	43.51
	X	4,700	S	9.45	13.33	14.77	17.87	21.26	23.07	26.91
			D	18.90	26.65	29.53	35.73	42.52	46.14	53.82
A490	N	4,700	S	9.45	13.33	14.77	17.87	21.26	23.07	26.91
			D	18.90	26.65	29.53	35.73	42.52	46.14	53.82
	X	5,900	S	11.86	16.73	18.54	22.43	26.69	28.96	33.78
			D	23.73	33.46	37.07	44.86	53.38	57.92	67.56

N : Bearing-Type connection with threads *include* in shear plane
X : Bearing-Type connection with threads *exclude* in shear plane
S : Single shear D : Double shear

10. Bearing and Tearout Strength at Bolt Holes AISC J3

The available bearing strength ϕR_n and R_n/Ω for bearing at bolt holes:

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

The nominal bearing strength R_n is determined as follows :

a) For standard, oversized and short-slotted holes or long slot hole with slot parallel to the direction of force

When deformation at bolt hole at service load is a design consideration

$$R_n = 1.2 L_c t F_u \leq 2.4 d t F_u \qquad \text{(J3-6a,c)}$$

When deformation at bolt hole at service load is not a design consideration

$$R_n = 1.5 L_c t F_u \leq 3.0 d t F_u \qquad \text{(J3-6b,d)}$$

b) For long slot hole with slot perpendicular to the direction of force

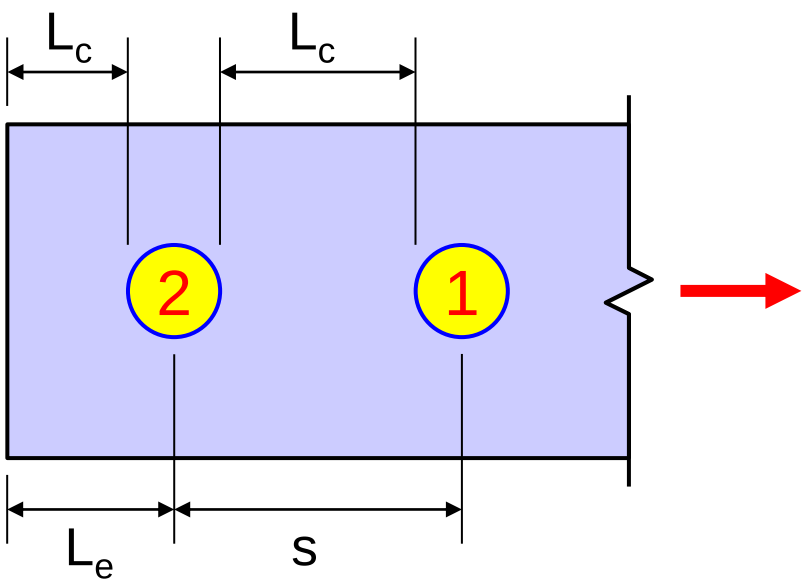
$$R_n = 1.0 L_c t F_u \leq 2.0 d t F_u \qquad \text{(J3-6e,f)}$$

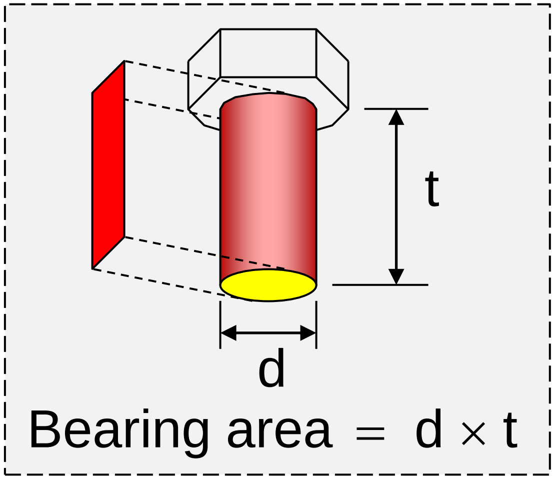
where F_u = specified minimum tensile strength of connected material

d = nominal fastener diameter

t = thickness of connected material

L_c = clear distance in the direction of force, between the edge of the hole and adjacent hole or edge of the material





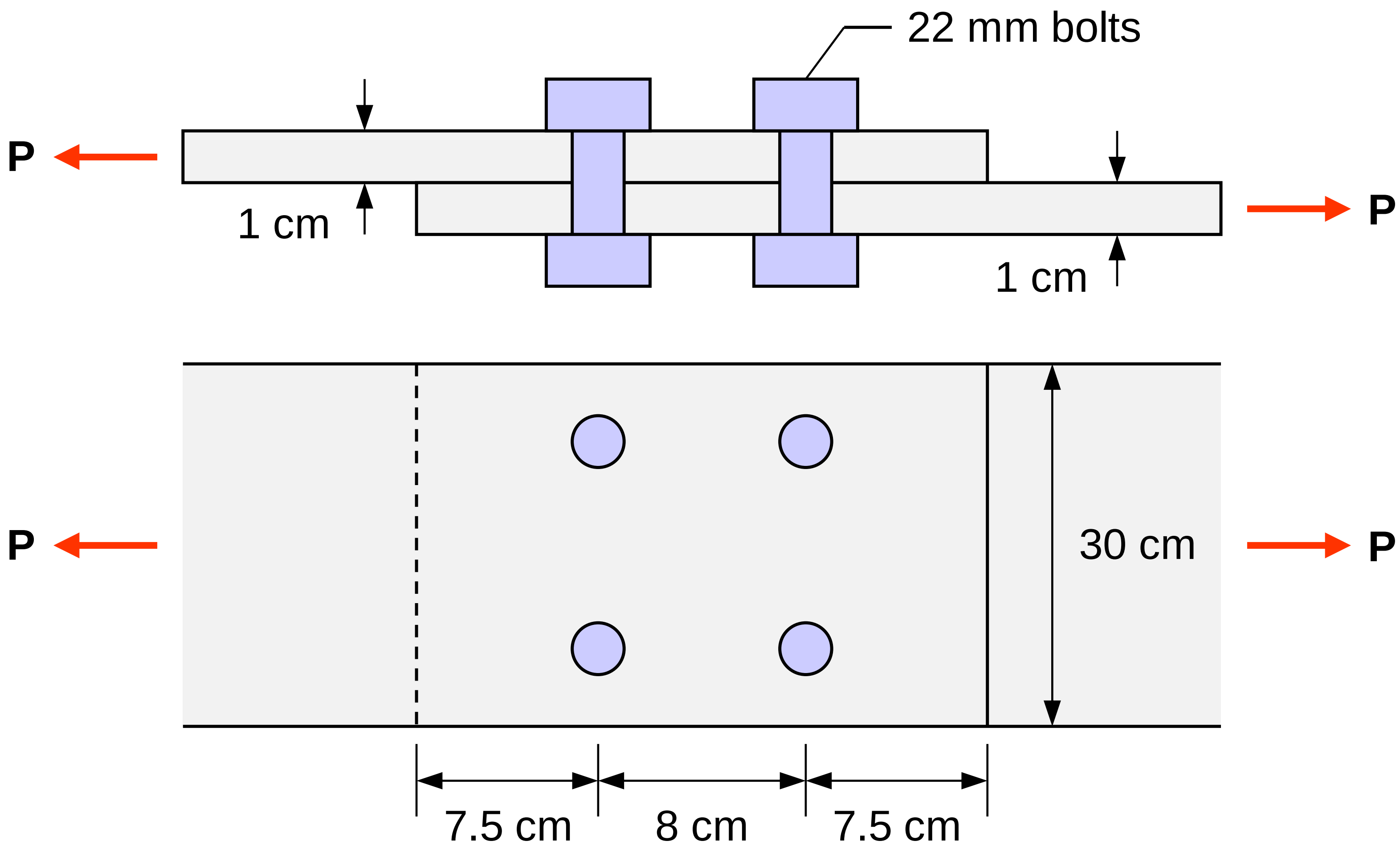
For bolt (1) $L_c = s - h$

For bolt (2) $L_c = L_e - h/2$

Table D-3 Nominal Bearing Strength for $L_c > 2d$, **$2.4dF_u$** (tons/cm thickness)

TIS Desig.	F_u (ksc)	Bolt Diameter, d (mm)						
		16	19	20	22	24	25	27
		Bolt Area (cm^2)						
		2.01	2.84	3.14	3.80	4.52	4.91	5.73
SM400	4,000	15.36	18.24	19.20	21.12	23.04	24.00	25.92
SM490	5,000	19.20	22.80	24.00	26.40	28.80	30.00	32.40
SM520	5,300	20.35	24.17	25.44	27.98	30.53	31.80	34.34
SM570	5,800	22.27	26.45	27.84	30.62	33.41	34.80	37.58

Example 13-1 : Determine the design strength and allowable strength for the bearing-type connection shown. The steel is A36 (F_y = 2,500 ksc and F_u = 4,000 ksc), the bolts are 22-mm A325, the holes are standard sizes, and the treads are excluded from the shear plane.



Solution

(a) Gross section yielding

$$P_n = F_y A_g = (2.5)(1 \times 30) = 75 \text{ tons}$$

LRFD $\phi_t = 0.9$	ASD $\Omega_t = 1.67$
$\phi_t P_n = 0.9(75) = 67.5 \text{ tons}$	$\dfrac{P_n}{\Omega_t} = \dfrac{75}{1.67} = 44.9 \text{ tons}$

(b) Tensile rupture strength

$$A_n = 30 - 2(2.4)(1) = 25.2 \text{ cm}^2$$

$$U = 1.0 \text{ as all parts connected}$$

$$A_e = U A_n = (1.0)(25.2) = 25.2 \text{ cm}^2 < 0.85 A_g$$

$$= (0.85)(30) = 25.5 \text{ cm}^2 \text{ as per AISC Spec. J4.1}$$

$$P_n = F_u A_e = (4.0)(25.2) = 101 \text{ tons}$$

LRFD $\phi_t = 0.75$	ASD $\Omega_t = 2.00$
$\phi_t P_n = 0.75(101) = 75.8 \text{ tons}$	$\dfrac{P_n}{\Omega_t} = \dfrac{101}{2.00} = 50.5 \text{ tons}$

(c) Bolt shear strength A325-X : $F_{nv} = 4{,}700$ ksc

$$R_n = F_{nv} A_b (\text{No. of bolts}) = (4.7)(\pi \times 2.2^2 / 4)(4) = 71.5 \text{ tons}$$

or from Table D-2 : $R_n = 17.87(4) = 71.5$ tons

LRFD $\phi = 0.75$	ASD $\Omega = 2.00$
$\phi R_n = 0.75(71.5) = 53.6$ tons	$\dfrac{P_n}{\Omega} = \dfrac{71.5}{2.00} = 35.8$ tons

(d) Bolt bearing strength

$$L_c = \text{lesser of } 7.5 - \frac{2.4}{2} \text{ or } 8 - 2.4 = 5.6 \text{ cm} > [\,2d = 2(2.2) = 4.4 \text{ cm}]$$

$$R_n = 1.2 L_c t F_u (\text{No. of bolts}) \le 2.4 d t F_u (\text{No. of bolts})$$

$$= 1.2(5.6)(1.0)(4.0)(4) = 108 \text{ tons}$$

$$> 2.4(2.2)(1.0)(4.0)(4) = 84.5 \text{ tons}$$

$\therefore$ **$R_n = 84.5$ tons**

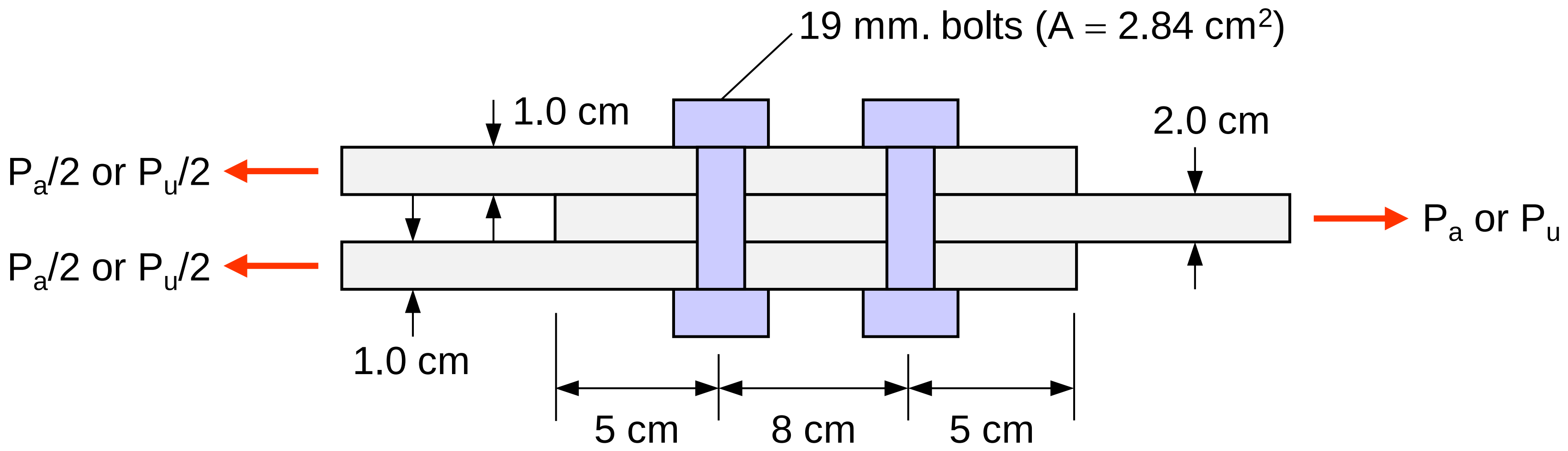
or from Table D-3 : $R_n = 21.12(1.0)(4) = 84.5$ tons

LRFD $\phi = 0.75$	ASD $\Omega = 2.00$
$\phi P_n = 0.75(84.5) = 63.4$ tons	$\frac{P_n}{\Omega} = \frac{84.5}{2.00} = 42.3$ tons

Ans. LRFD $=$ 53.6 tons (Bolt shearing)

ASD $=$ 35.8 tons (Bolt shearing)

Example 13-2 : How many 20-mm A325 bolts in standard holes with threads excluded from the shear plane are required for the bearing-type connection shown. Use F_u = 4,000 ksc and assume edge distances to be 5 cm and the distance center-to-center of holes to be 7.5 cm. P_u = 150 tons (LRFD), P_a = 100 tons (ASD).



Solution. Bolts in double shear and bearing on 2 cm

Bearing strength of 1 bolt

$$L_c = \text{lesser of } 5 - 2.2/2 = 3.9 \text{ cm or } 7.5 - 2.2 = 3.9 \text{ cm}$$

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

$$= 1.2(3.9)(2.0)(4.0) = 37.4 \text{ tons} < 2.4(2.0)(2.0)(4.0) = 38.4 \text{ tons}$$

Shearing strength of 1 bolt A325-X : $F_{nv} = 4{,}700$ ksc

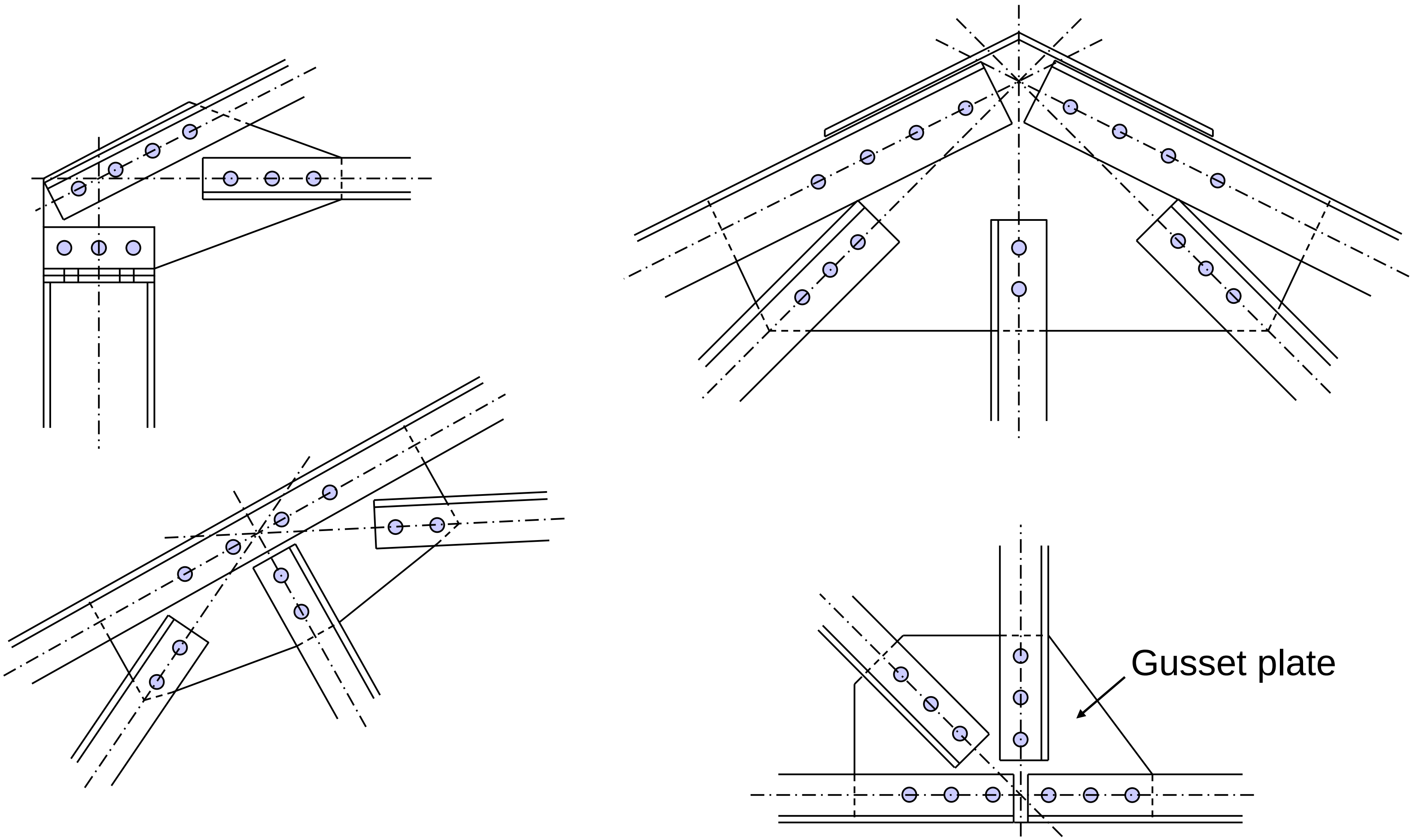
$$R_n = (2A_b)F_{nv} = 2(\pi \times 2.0^2 / 4)(4.7) = 29.5 \text{ tons}$$ ← **Control**

LRFD $\phi = 0.75$	ASD $\Omega = 2.00$
$\phi_t P_n = 0.75(29.5) = 22.1 \text{ tons}$	$\dfrac{P_n}{\Omega_t} = \dfrac{29.5}{2.00} = 14.8 \text{ tons}$
No. bolts reqd. $= \dfrac{P_u}{\phi R_n} = \dfrac{150}{22.1} = 6.79$	No. bolts reqd. $= \dfrac{P_a}{R_n / \Omega} = \dfrac{100}{14.8} = 6.75$

Use eight 20-mm bearing type A325 bolts.

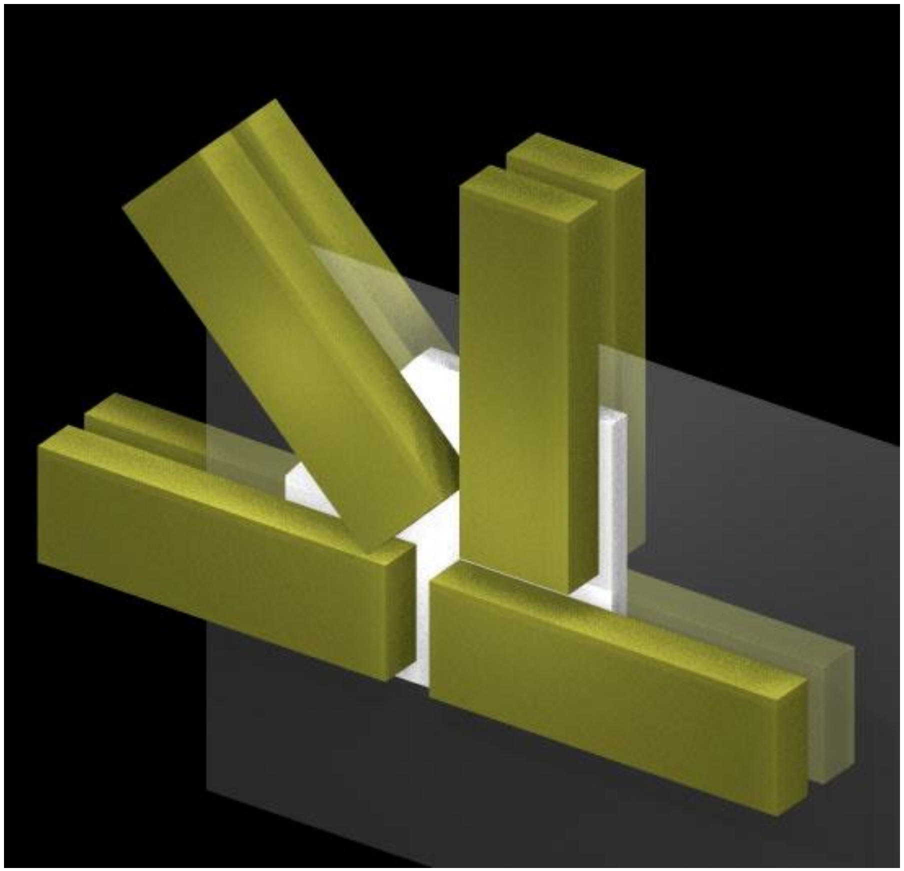
จุดต่อสลักเกลียวในโครงถัก

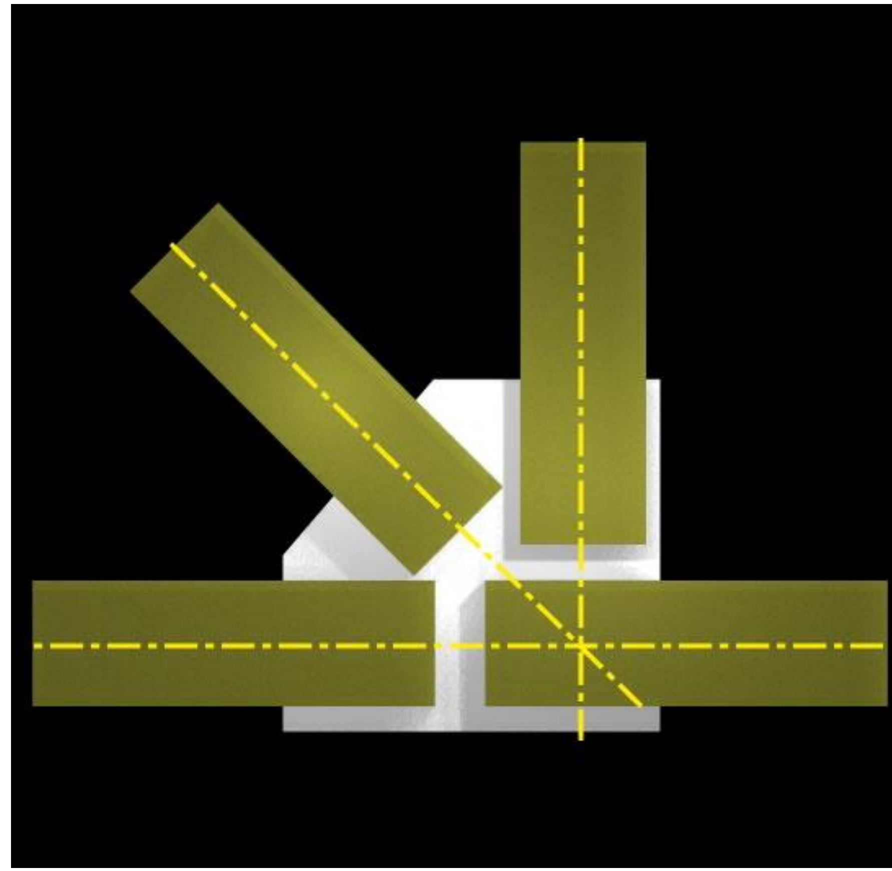
- แรงในองค์อาคารจะต้องมาตัดกันที่จุดต่อโดยไม่มีการเยื้องศูนย์
- พื้นที่ในการต่ออาจไม่เพียงพอจะใช้ *Gusset plate* ช่วย



Truss Joint

Double member with a single connector piece, called a **gusset plate**.





Members must have sufficient "bite" into the plate for bolts or weld contact.

Converging centerlines enable equilibrium without member moments.


End of Lecture