PANA ACADEMY

NEPAL ENGINEERING COUNCIL
LICENSE EXAM PREPARATION COURSE

FOR

CIVIL ENGINEERS

5. Design of Structure

5.5 Steel structures

Sub topics

- Standard and built-up sections
- Design of bolted and welded connections
- Design of simple elements such as ties, struts, axially loaded columns, and column bases

Steel structures

Standard and built-up sections

IS 808:1989 Dimension of hot rolled steel beam column, channel and angle sections

IS 811:1987 Dimension of cold formed steel beam column, channel and angle sections

IS 800:2007 and NBC 111:1994

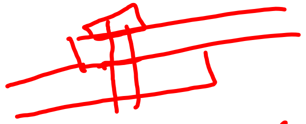
Steel sections

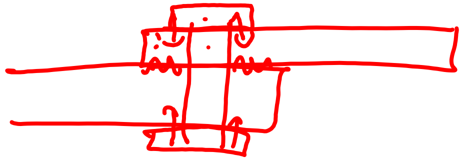
Standard section has predefined dimension and strength.

If we need different strength and dimension, then we combine steel sections by bolting, riveting or welding.

Such sections are called built-up sections

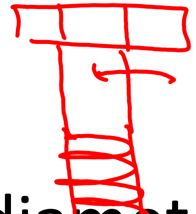
Design of Bolted connection





1. Unfinished/ Black bolts
2. Finished / Turned Bolt
3. High strength friction grip bolts (HSFG)

Grade of bolt is written as 4.6, 400 is ultimate strength of bolt and 240 is yield strength of bolt

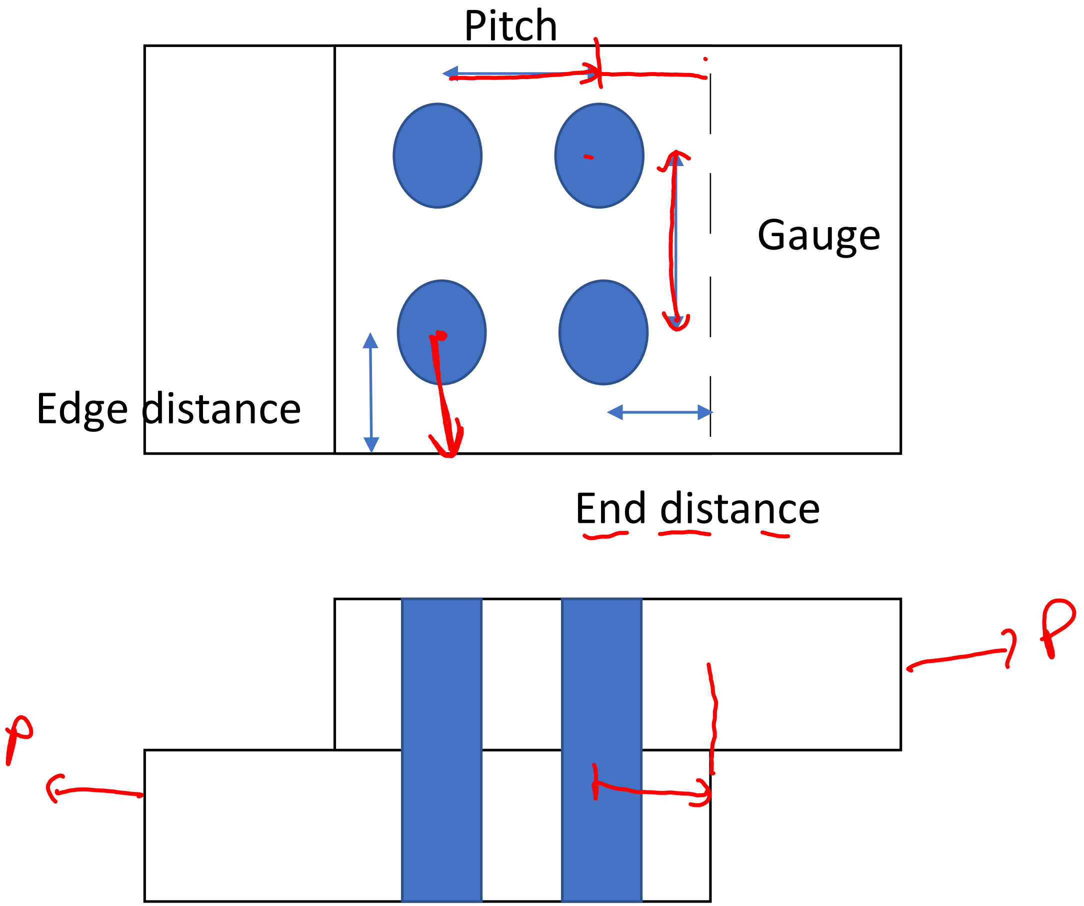


For force to be transmitted Grip length/Shank diameter should be less than or equal 8.

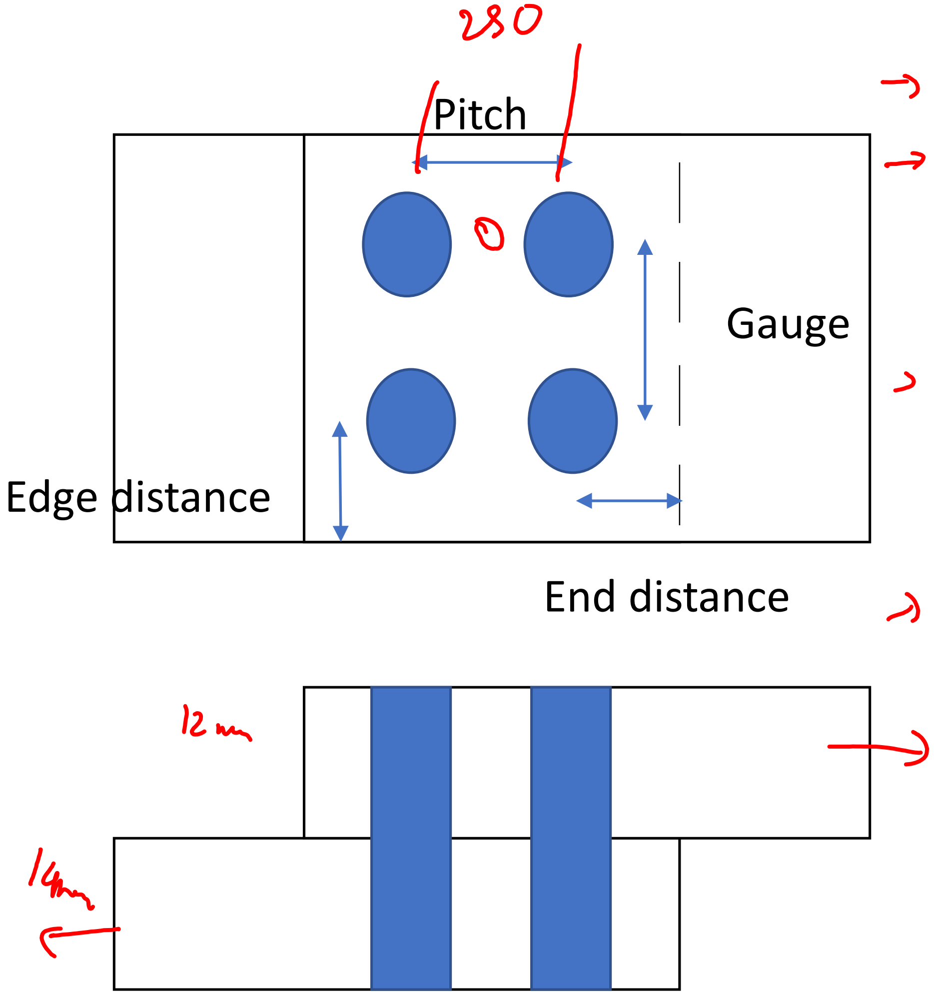
Bold should resist shear , tension or their combination.

Design of Bolted connection

Terminology in bolted connections



Design of Bolted connection



Minimum pitch=2.5d

Maximum pitch

Compression : 12t or 200mm

Tension : 16t or 200mm

Tacking bolts : 33t or 300mm

Minimum edge/end distance=

$$1.5d_o\ for\ machine\ cut$$

$$1.7d_o\ for\ hand\ cut$$

Maximum edge/end distance=

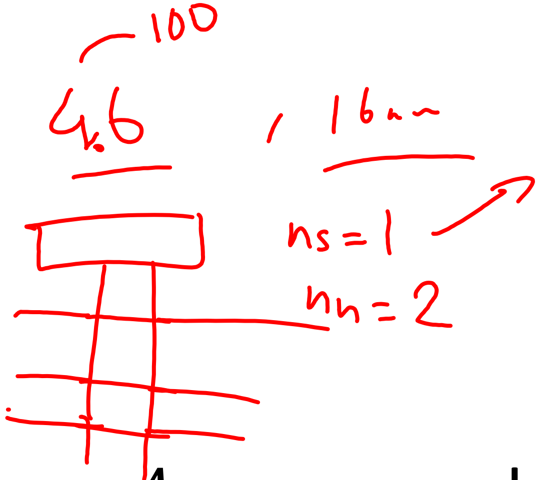
$$12t\epsilon\ where\ \epsilon = \sqrt{250/f_y}$$

d is bolt diameter, d_o is hole diameter, t is thickness of thinner plate

Bolt and hole diameter

ϕ	d_o
12 to 14 mm	$\phi + 1$
14 to 24 mm	$\phi + 2$
>24 mm	$\phi + 3$

Shear capacity

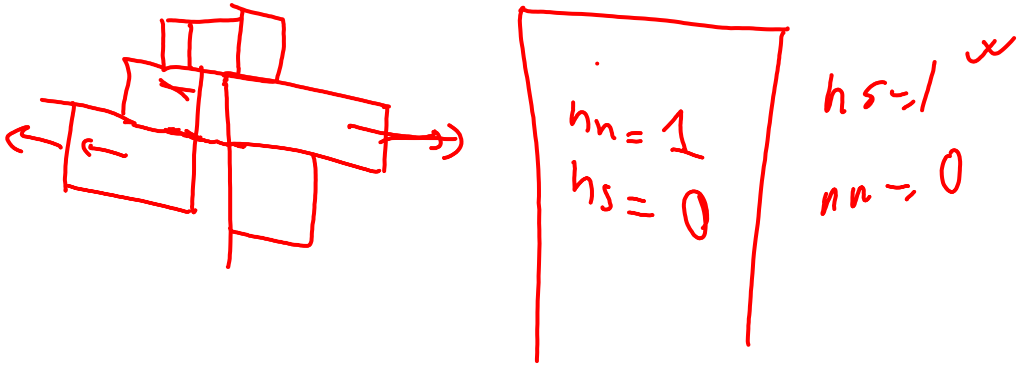


$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}}$$

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(n_n.A_{nb} + n_s.A_{sb})$$

n_s, A_{sb} are number of shear plane and area of shaft

n_n, A_{nb} are number of shear plane and area of threads



$$\gamma_{mb} = 1.25$$

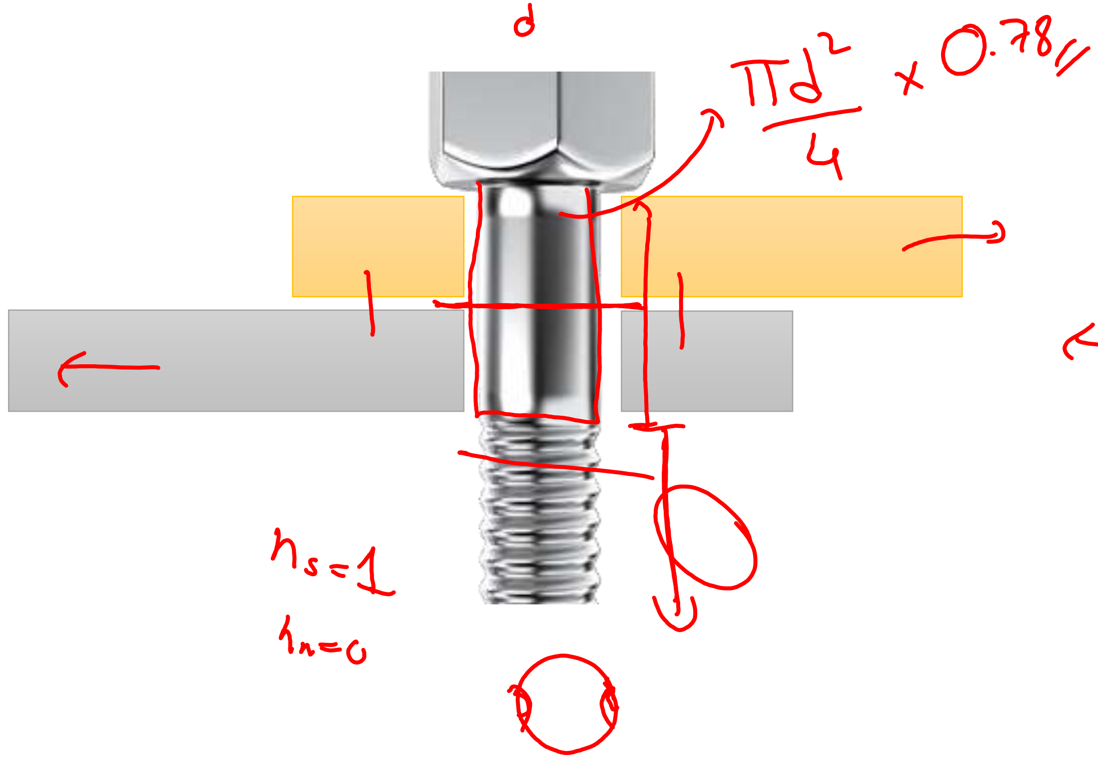
$$A_{nb} = 0.78A_{sb}$$

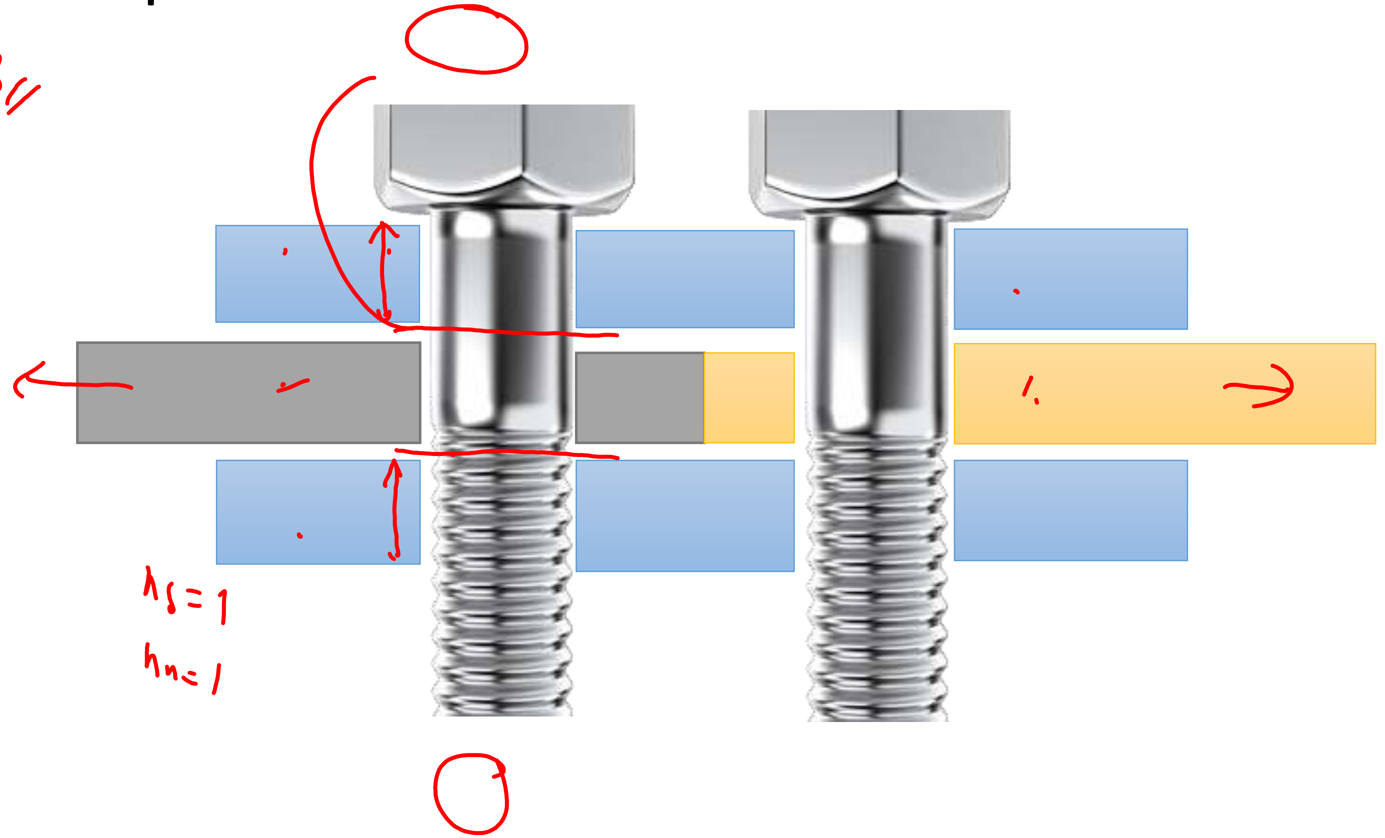
$$A_{sb} = \frac{\pi}{4}d^2$$

Shear capacity

n_s, A_{sb} are number of shear plane and area of shaft

n_n, A_{nb} are number of shear plane and area of threads





Bearing capacity

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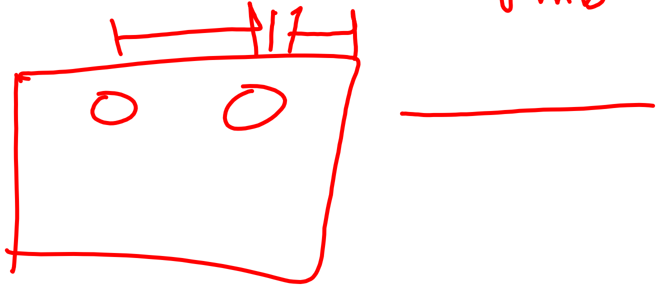
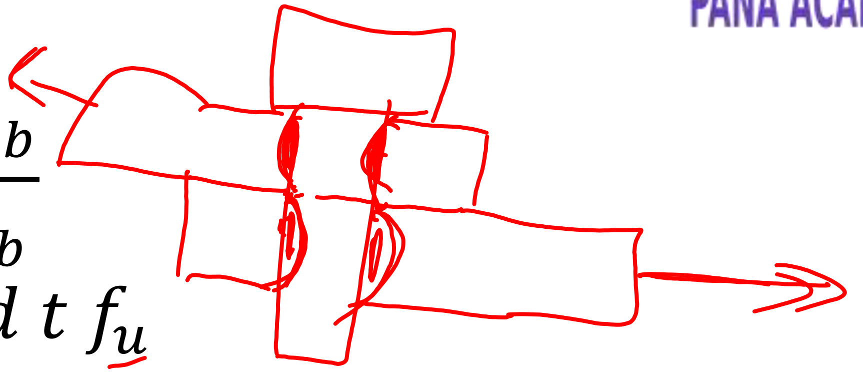


$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}}$$

$$V_{npb} = 2.5\, k_b\, d\, t\, f_u$$



k_b is smaller of $\frac{e}{3d_o}, \frac{p}{3d_o} - 0.25, \frac{f_{ub}}{f_u}, 1$

e and p are end and pitch distances of the fastners

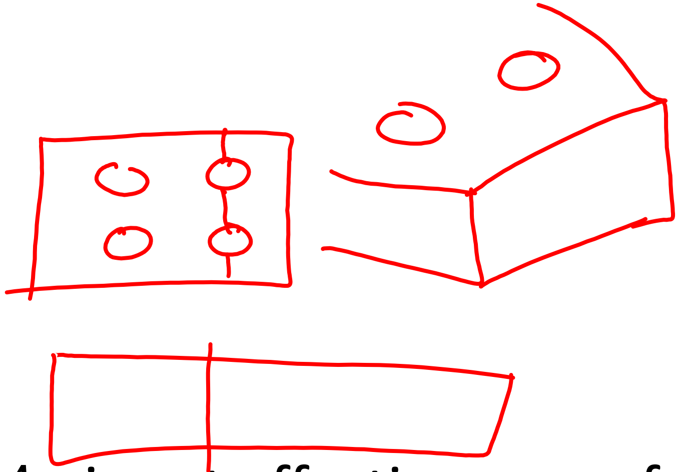
d_o is the diameter of hole

f_{ub}, f_u are ultimate tensile stress of bolt and plate

d is the diameter of bolt

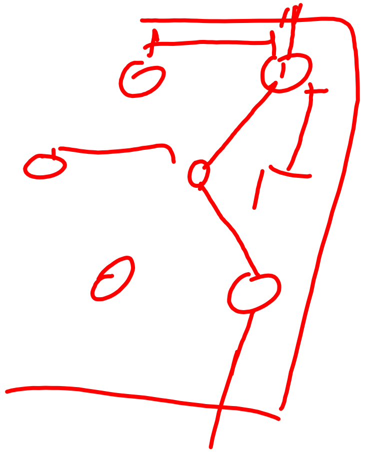
t is the sum of thickness of connecting plate

Tension capacity of plate



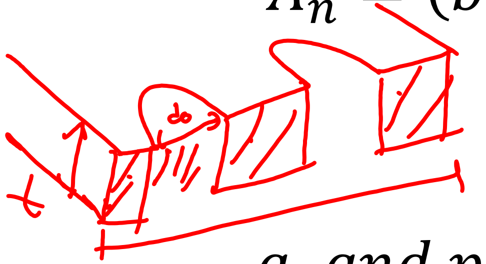
$$T_{dp} = \frac{T_{np}}{\gamma_{m1}}$$

$$T_{np} = 0.90 f_u A_n$$



A_n is net effective area of plate in tension

$$A_n = (b - nd_o)t$$



$$A_n = [b - nd_o + \Sigma\left(\frac{p_i^2}{4g_i}\right)]$$

g_i *and* p_i are gauge and pitch distances of the fastners

d_o is the diameter of hole

f_u are ultimate tensile stress of plate

γ_{m1}= 1.1

Bolt value

Minimum of shear capacity, bearing capacity is taken as bolt value of bolt.

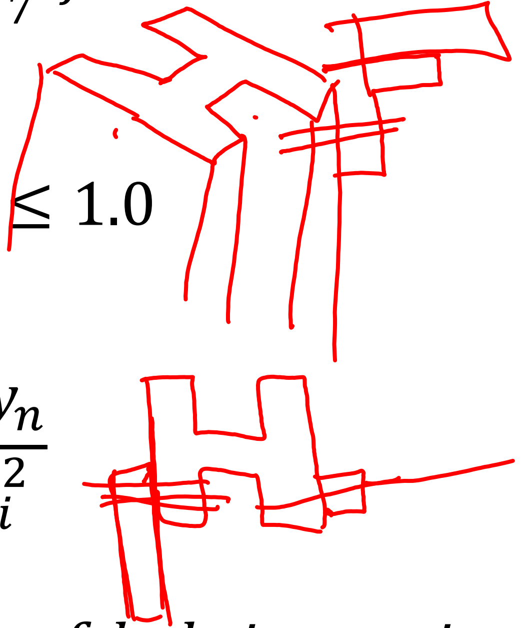
Number of bolts = Total load /Bolt value

Eccentric loading condition

Bolt experiencing shear and tension

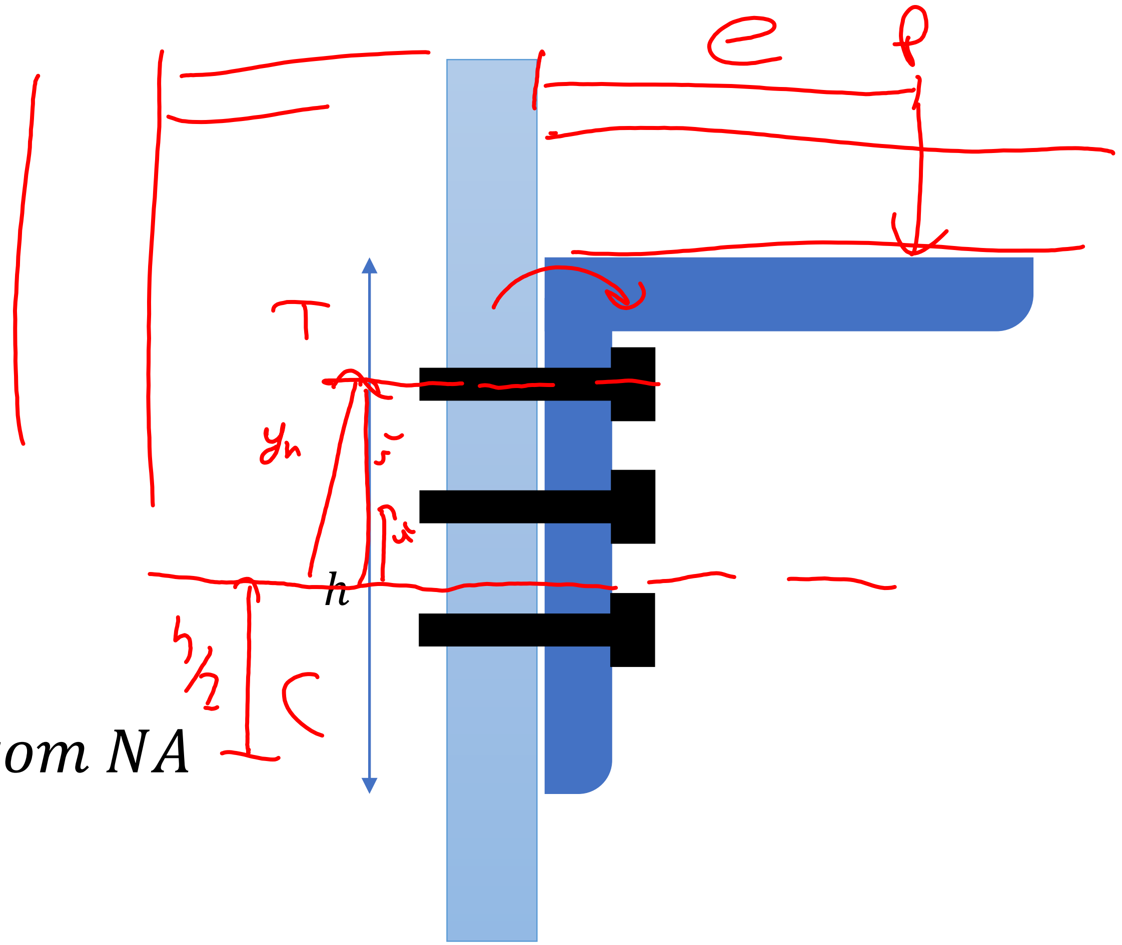
$$Height\ of\ NA = \frac{h}{7}\ from\ bottom$$

$$\left(\frac{V_{sb}}{V_{db}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \leq 1.0$$



$$V_{sb} = \frac{P}{n}, T_b = \frac{Pey_n}{\Sigma y_i^2}$$

y_i *is the distance of bolt in tension from NA*



Eccentric loading condition

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}}$$

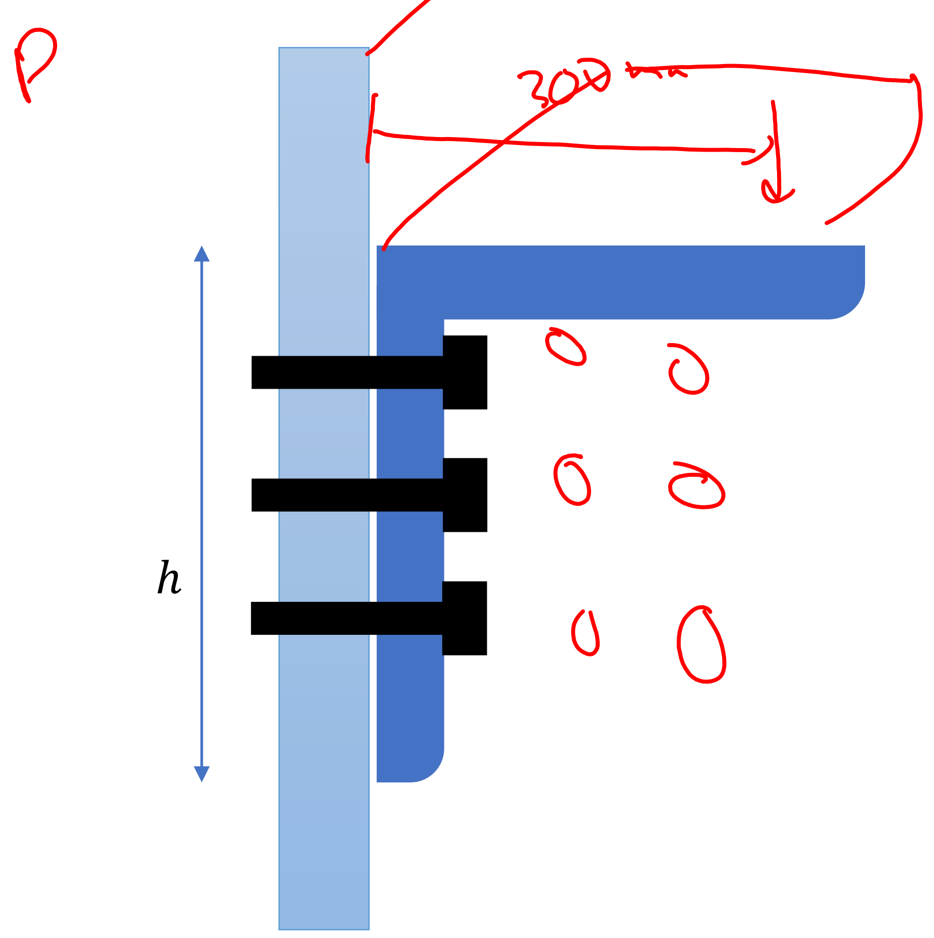
$$T_{nb} = 0.9 f_{ub} A_{n} < \frac{f_{yb} A_{sb} \gamma_{mb}}{\gamma_{mo}}$$

$$\gamma_{mo} = 1.1$$

$$\gamma_{mb} = 1.25$$

Number of bolt in a row= $\sqrt{\frac{6Pe}{mpT_{db}}}$

pitch



Eccentric loading condition

The eccentric load gives additional shear and torsion.

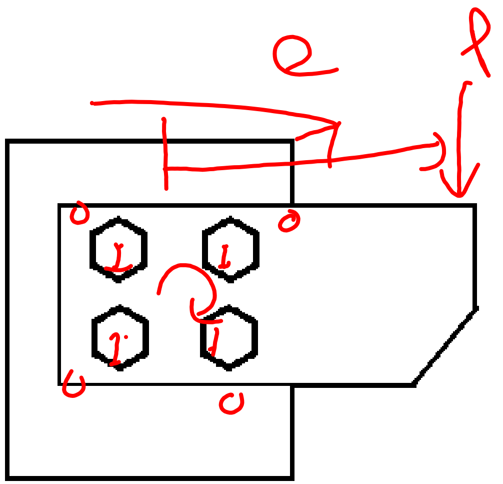
$$F_1 = \frac{P}{n}$$

$$F_2 = \frac{Per}{\Sigma r^2}$$

$$F_{2x} = \frac{Pey_i}{\Sigma r^2}, F_{2y} = \frac{Pex_i}{\Sigma r^2}$$

$$F_x = F_{2x} = \frac{Pey_i}{\Sigma r^2}, F_y = F_1 + F_{2y} = \frac{P}{n} + \frac{Pex_i}{\Sigma r^2}$$

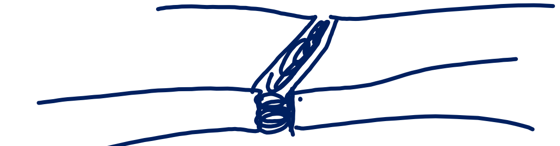
$$F_r = \sqrt{F_x^2 + F_y^2}$$



Number of bolt in a row= $\sqrt{\frac{6Pe}{mpV_{dsb}}}$

Design of welded connection

1. Butt weld
2. Fillet weld
3. Shot and plug weld



Welded connections are usually brittle.
Weld size and throat thickness and length of weld are the parameter to be designed.

Design strength of weld:

$$f_{wd} = \frac{f_{wn}}{\gamma_{mw}} \text{ and } f_{wn} = \frac{f_u}{\sqrt{3}}$$

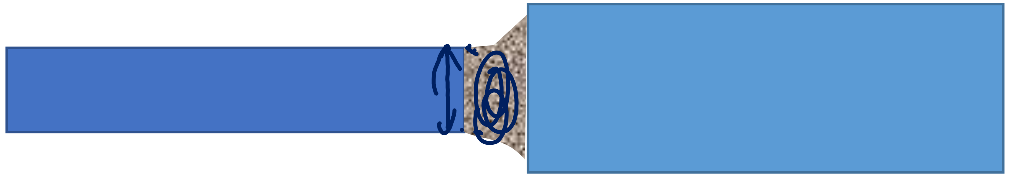
$$f_{wd} = \frac{f_u}{\sqrt{3}\ \ \gamma_{mw}}$$

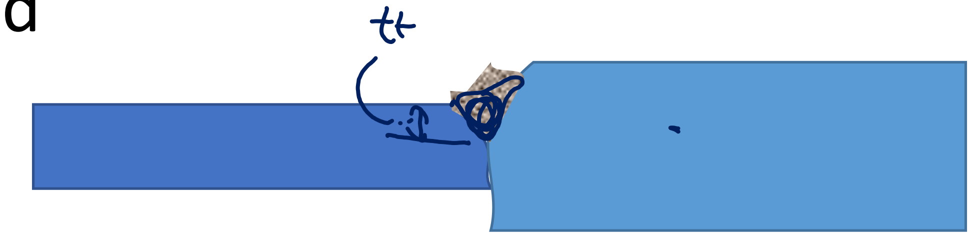
γ_{mw} = 1.25 for shop welding ,1.5 for field welding

Design of Butt weld in tension

Size of weld is the effective thickness of weld. It is taken as thickness of thinner plate for complete penetration (Double U, Double J, Double V).

In case of incomplete penetration it is taken as minimum thickness of weld metal common to two plates or in absence of data it is taken as $\frac{5}{8}^{th}$ of thickness of thinner plate.

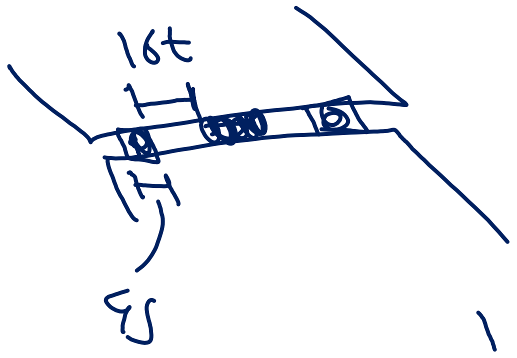




Design of Butt weld in tension

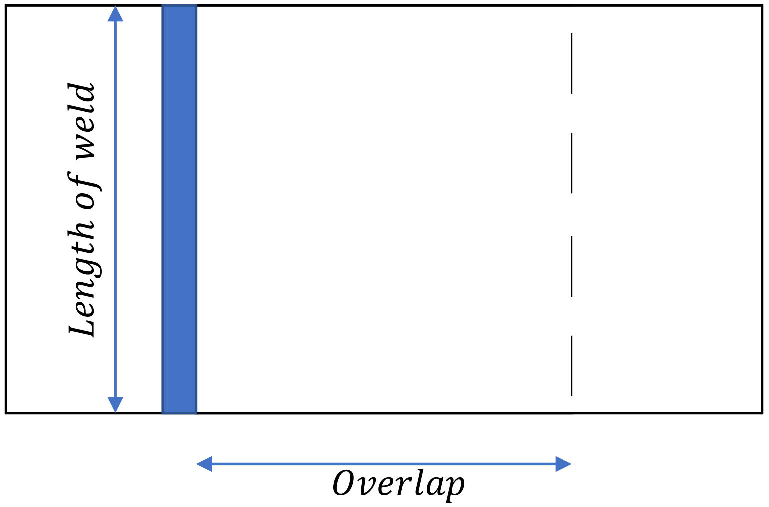
Effective length is length of welding where full size weld is done.
Minimum length ≥ 4S (size of weld)

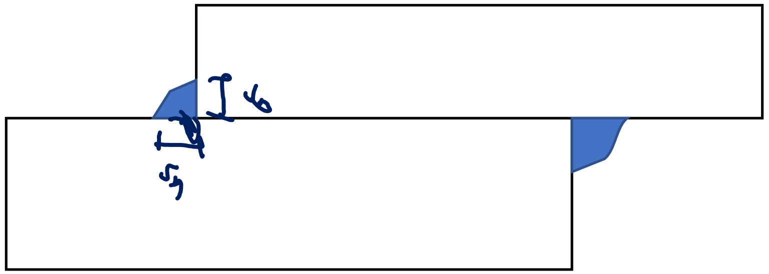
Spacing between two intermittent weld should not be more than 16 times thickness of thinner plate

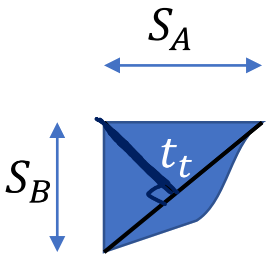


Design of Fillet weld

Terminology in welded connections



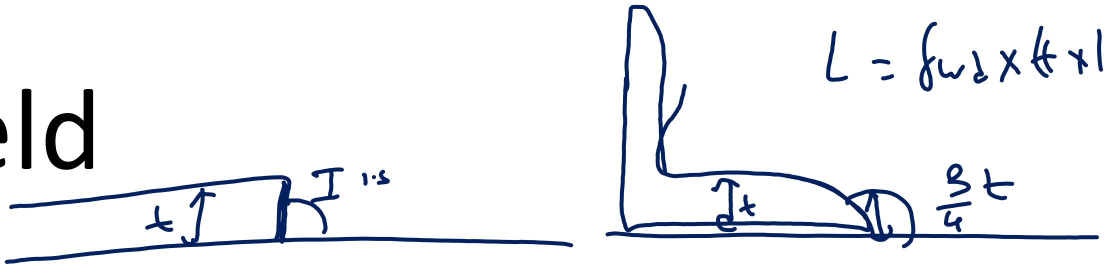




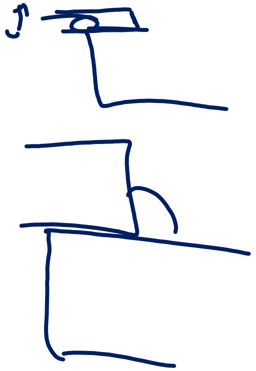
S_A, S_B *are size of weld leg*

t_t *is the throat thickeness*

Design of fillet weld



- Size of weld
  i) The size of weld is taken as minimum weld leg size
  ii) For penetration not less than 2.4 mm it is taken as minimum leg + 2.4 mm
  iii) It can be taken minimum leg size + actual penetration if penetration is done by automatic and semi automatic process



- Minimum fillet size

  It is based on thickness of thicker part
  If minimum size if greater than thickness of thinner plate, minimum size of weld is thickness of thinner part.

Thickness of thicker part	Minimum size of fillet weld
$< 10\ mm$	$3\ mm$
$10\ mm\ to\ 20\ mm$	$5\ mm$
$20\ mm\ to\ 32\ mm$	$6\ mm$
$32\ mm\ to\ 50\ mm$	$8\ mm$

- Maximum fillet size

$$S_{maximim} = t_{min} \ -1.5$$

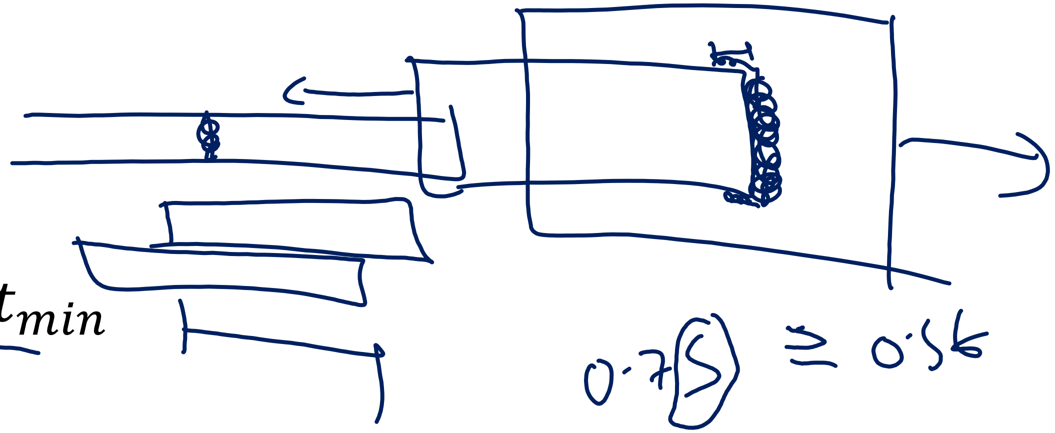
$$S_{maximim} = \frac{3}{4} t \text{ (for rounded end)}$$

Design of fillet weld

Effective throat thickness shall not be less than 3 mm and not more than 0.7t

Effective length $= l_w - 2S$

$l_e \geq 4S$



Overlap greater of 40 mm or $4t_{min}$

End return not less than 2S

End fillet weld normal to force direction can have variable thickness with throat thickness not less than 0.5t.

Design of eccentric butt weld

Subjected to shear and bending stresses.

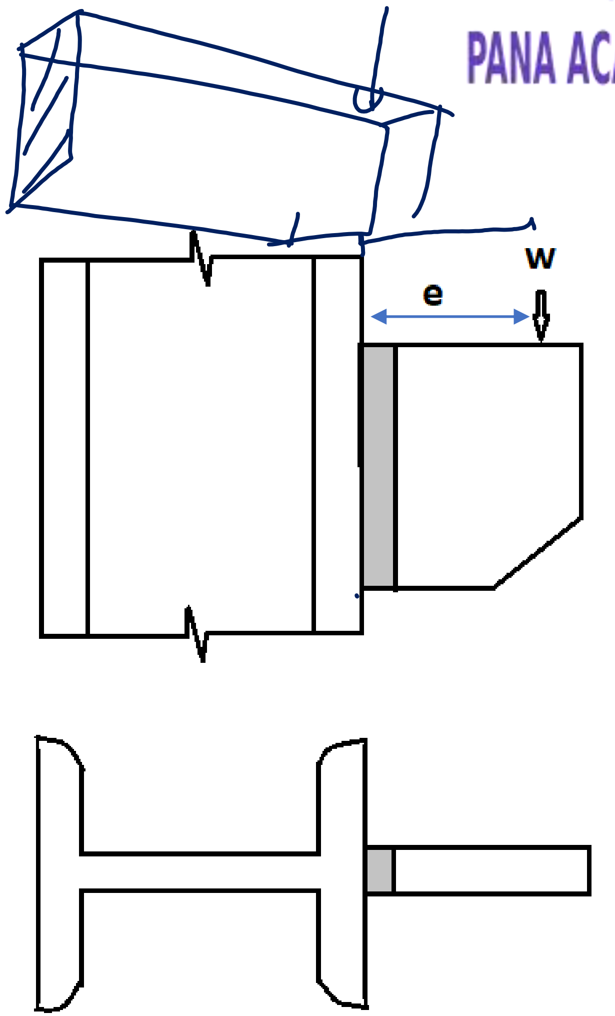
Shear stress$(\sigma_s) = \frac{w}{l_w \times t_t}$

Bending stress $(\sigma_b) = \frac{6we}{t_t \times l_w^2}$

$$\sigma_e = \sqrt{\sigma_b^2 + 3\sigma_s^2} \leq f_{wd}$$

$$f_{wd} = \frac{f_u}{\sqrt{3}\ \gamma_{mw}}$$

$\frac{M}{Z}$ $\frac{6M}{bd^2}$



Design of eccentric fillet weld

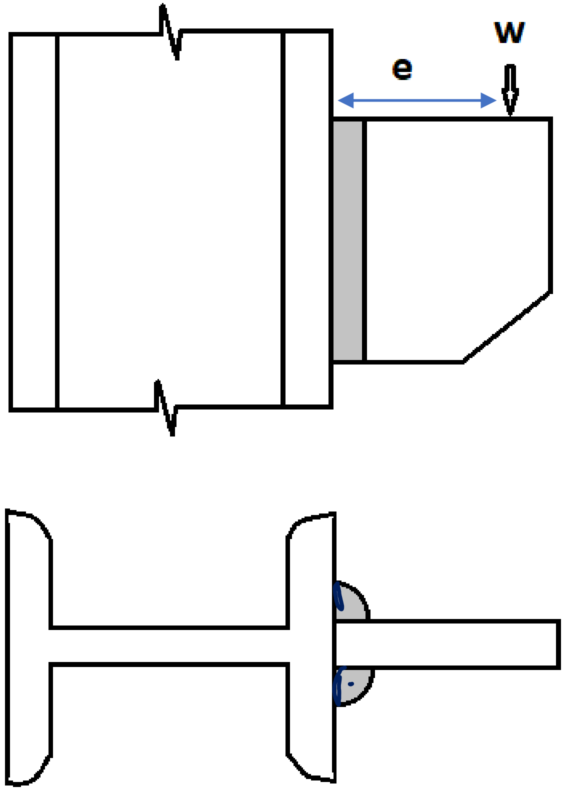
Subjected to shear and bending stresses.

Shear stress$(\sigma_s) = \frac{w}{l_w \times 2t_t}$

Bending stress $(\sigma_b) = \frac{3we}{t_t \times l_w^2}$

$$\sigma_e = \sqrt{\sigma_b^2 + \sigma_s^2} \leq f_{wd}$$

$$f_{wd} = \frac{f_u}{\sqrt{3}\ \gamma_{mw}}$$



Design of eccentric fillet weld

Subjected to shear and bending stresses.

Shear stress$(\sigma_s) = \frac{w}{l_w \times t_t}$

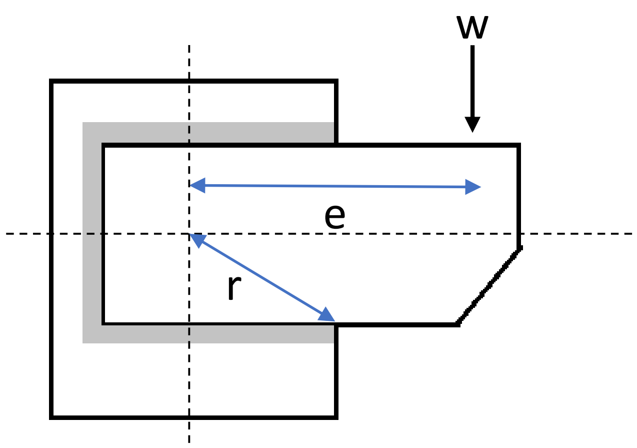
Torsional stress $(\sigma_t) = \frac{wer}{I_p}$

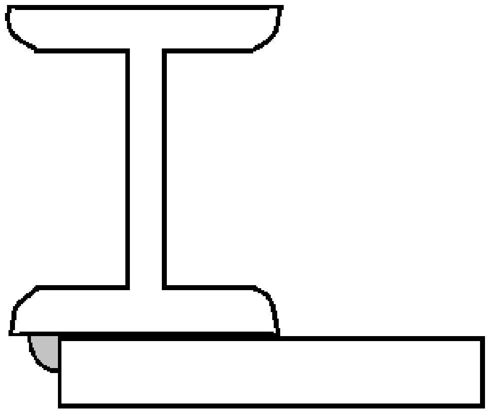
$$\sigma_{tx} = \frac{wey}{I_p}, \sigma_{ty} = \frac{wex}{I_p}$$

$$\sigma_x = \frac{wey}{I_p}, \sigma_y = \sigma_s + \sigma_{ty} = \frac{w}{l_w \times t_t} + \frac{wex}{I_p}$$

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2} \leq f_{wd}$$

$$f_{wd} = \frac{f_u}{\sqrt{3}\ \gamma_{mw}}$$





Design of ties

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Flat members and angle section are used to take tensile forces.
Angle section is preferred if there is slightest of chances of load reversal.
Types of failure:

i) Gross section yield failure (T_{dg})
ii) Net section rupture (T_{dn})
iii) Block shear failure (T_{db})

	Limiting slenderness ratio (λ)
A tension member in which a reversal 180 of direct stress occurs due to loads other than wind or seismic forces	180
A member normally acting in a tie in a roof truss or a bracing system	350

Design of ties

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Gross section yield failure (T_{dg})

$$T_{dg} = \frac{A_g f_y}{\gamma_{m0}}$$

Net section rupture (T_{dn})

$$T_{dn} = \frac{0.9 A_n f_u}{\gamma_{m1}} \qquad for\ flat\ plate$$

$$T_{dn} = \frac{0.9 A_{nc} f_u}{\gamma_{m1}} + \frac{\beta A_{go} f_y}{\gamma_{m0}} \qquad for\ angle$$

$$0.7 \le \left(\beta = 1.4 - 0.076 \frac{w}{t} \frac{f_y}{f_u} \frac{b_s}{L_c}\right) \le \frac{f_u/\gamma_{m1}}{f_y/\gamma_{m0}}$$

$A_{nc} = net\ area\ of\ connecting\ leg, A_{go} = gross\ area\ of\ outstanding\ leg$
$w = width\ of\ outstanding\ leg, t = thickness\ of\ angle$
$b_s = shear\ lag\ (distance\ from\ free\ end\ to\ attached\ part)$
$L_c = length\ of\ end\ connection\ (dist.betn\ outermost\ bolts\ or\ length\ of\ weld\ along\ load)$

$$\gamma_{m0} = 1.1,\ \gamma_{m1} = 1.25$$

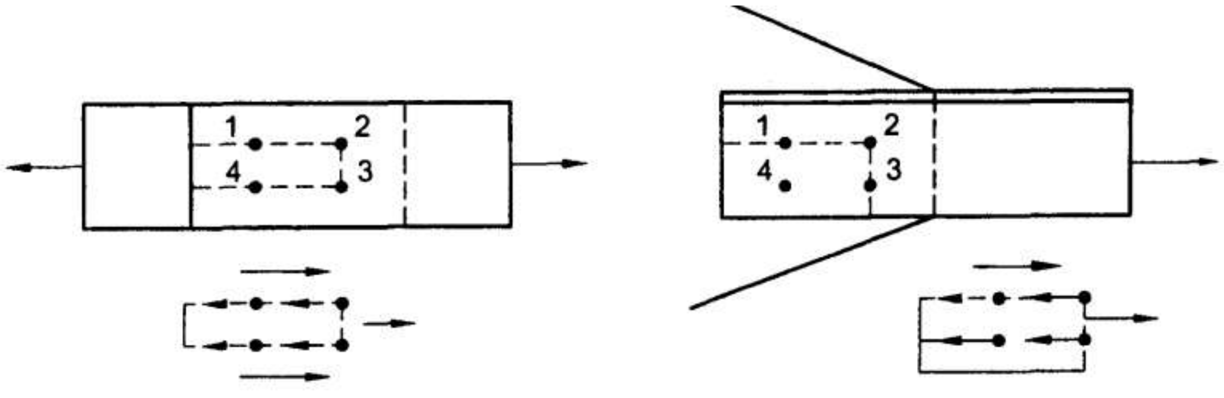
Design of ties

Block shear failure (T_{db})

$$T_{db} = \frac{A_{vg} f_y}{\sqrt{3}\ \gamma_{m0}} + \frac{0.9 A_{tc} f_u}{\gamma_{m1}}\ or\ \frac{0.9 A_{vn} f_u}{\sqrt{3}\ \gamma_{m1}} + \frac{A_{tg} f_y}{\gamma_{m0}}$$

A_{vg} , A_{vn} = minimum gross and net area in shear along bolt line parallel to external force, respectively (1-2 and 3-4 as shown in Fig. 7A and 1-2 as shown in Fig. 7B)

A_{tg} , A_{tn} = minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force, respectively (2-3 as shown in Fig. 7A,7B),



7A Plate 7B Angle

Design of struts

Flat members and angle section are used to take tensile forces.

Angle section is preferred if there is slightest of chances of load reversal.

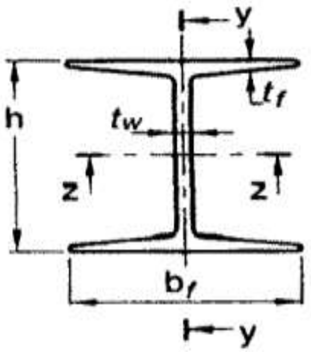
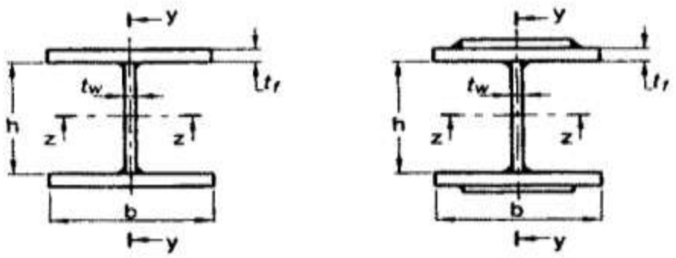
Types of failure:

i) Short column
ii) Intermediate column
iii) Long column

Buckling class of Cross section

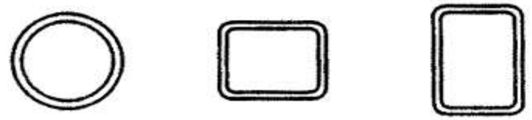
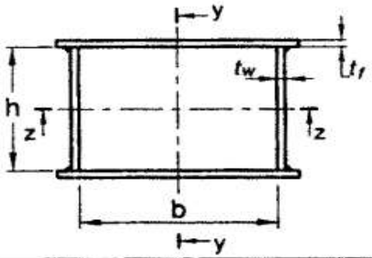
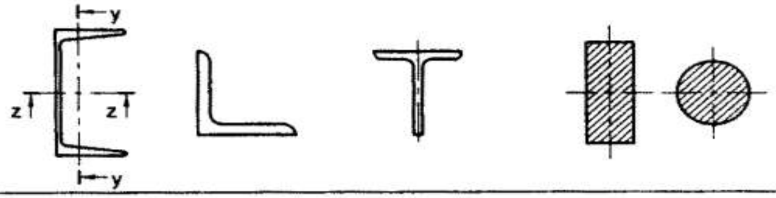
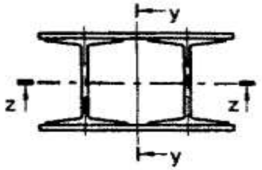
Design of struts

Buckling class

Cross-Section (1)	Limits (2)	Buckling About Axis (3)	Buckling Class (4)
Rolled I-Sections 	$h/b_f > 1.2$: $t_f \le 40$ mm	z-z y-y	a b
	$40 \le$ mm $< t_f \le 100$ mm	z-z y-y	b c
	$h/b_f \le 1.2$: $t_f \le 100$ mm	z-z y-y	b c
	$t_f > 100$ mm	z-z y-y	d d
Welded I-Section 	$t_f \le 40$ mm	z-z y-y	b c
	$t_f > 40$ mm	z-z y-y	c d

Design of struts

Buckling class

Hollow Section 	Hot rolled	Any	a
	Cold formed	Any	b
Welded Box Section 	Generally (except as below)	Any	b
	Thick welds and $b/t_f < 30$	z-z	c
	$h/t_w < 30$	y-y	c
Channel, Angle, T and Solid Sections 		Any	c
Built-up Member 		Any	c

Design of struts

$$P_d = f_{cd}.A_e$$

f_{cd} depends on yield stress of reinforcement and effective slenderness ratio(λ) and buckling class (a,b,c,d)

$$f_{cd} = \frac{f_y/\gamma_{mo}}{\phi + [\phi^2 - \lambda^2]^{0.5}} = \frac{\chi f_y}{\gamma_{mo}} \leq \frac{f_y}{\gamma_{mo}}$$

χ is stress reduction factor

$$\phi = 0.5\left[1 + \alpha(\lambda - 0.2) + \lambda^2\right]$$

α is imperfection factor

Buckling Class	a	b	c	d
α	0.21	0.34	0.49	0.76

Design of struts

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$$P_d = f_{cd} . A_e$$

f_{cd} depends on yield stress of reinforcement and effective slenderness ratio(λ) and buckling class (a,b,c,d)

$$f_{cd} = \frac{f_y/\gamma_{mo}}{\phi + [\phi^2 - \lambda^2]^{0.5}} = \frac{\chi f_y}{\gamma_{mo}} \leq \frac{f_y}{\gamma_{mo}}$$

$$\phi = 0.5\left[1 + \alpha(\lambda - 0.2) + \lambda^2\right]$$

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}} = \sqrt{\frac{f_y \left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

λ is non dimensional effective slenderness ratio from Perry Robertson's approach

f_{cc} is elastic buckling stress

Higher λ lower f_{cd} and ultimately lower strength of compression member

a, b, c, d buckling class will have compressive strength in descending order for same λ

Design of struts

Economic section will have equal radius of gyration about both axes

	Limiting slenderness ratio (λ)
Compression member subjected to dead and live load	180
Compression member subjected to wind or earthquake	250
Compression flange of a beam against lateral torsional buckling	300

Column bases

PANA ACADEMY

Column bases should have sufficient stiffness and strength to transmit axial force, bending moments and shear forces at the base of the columns to their foundation without exceeding the load carrying capacity of the supports.
Anchor bolts and shear keys should be provided wherever necessary.

The maximum bearing stress should not exceed $0.6f_{ck}$, where f_{ck} is the characteristic strength of bedding material usually it is designed for 0.45 f_{ck}

Column bases

For slab base minimum thickness is

$$t_s = \sqrt{2.5w(a^2 - 0.3b^2)\gamma_{m0}/f_y} > \mathrm{t_f}$$

w is the uniform pressure

a, b are larger and small projection of the slab base beyond the rectangle circumscribing the column;

$\mathrm{t_f}$ is the thickness of flange of compressive member

Column bases

PANA ACADEMY

For slab base minimum thickness is

$$t_s = \sqrt{2.5w(a^2 - 0.3b^2)\gamma_{m0}/f_y} > \mathrm{t_f}$$

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a, b are larger and small projection of the slab base beyond the rectangle circumscribing the column;

$\mathrm{t_f}$ is the thickness of flange of compressive member

Rivet ?

PANA ACADEMY

if the pitch is 60 mm and rivet value is 40 kN, the number of rivets required for a riveted connection carrying an eccentric load of 150 kN at a distance of 300 mm from the centre line is

10
12
6
8

MCQS

PANA ACADEMY

M 16 bolt of property class 8.8 will have an ultimate tensile strength of ……….. MPa.

a) 640
b) 800
c) 160
d) 128

Column bases

The minimum edge and end distance from the centre of any hole to the nearest edge of a plate shall not be less than __________ times the hole diameter in case of sheared or hand-flame cut edges.

a) 1.7
b) 1.6
c) 1.5
d) 1.4

Column bases

The minimum pitch for M16 bolt of grade 4.6 is?

a) 18
b) 27
c) 40
d) 50

Column bases

PANA ACADEMY

Calculate strength in shear of 16mm diameter of bolt of grade 4.6 for lap joint

a) 50 kN
b) 40 kN
c) 29 kN
d) 59 kN

Column bases

What is the efficiency of joint when strength of bolt per pitch length is 60kN and strength of plate per pitch length is 150kN?

a) 25%
b) 30%
c) 35%
d) 40%

Column bases

PANA ACADEMY

When the thickness of the thicker plate is 20 mm, the minimum size of the weld is ___________.

a) 3 mm
b) 5 mm
c) 6 mm
d) 10 mm

Column bases

PANA ACADEMY

Determine the throat thickness (in mm) of a fillet weld of size 5 mm, when the angle between fusion face is 90 degree:

a) 4.5 mm
b) 3.5 mm
c) 2.5 mm
d) 1.5 mm

Column bases

The effective length of fillet weld should not be less than

a) S
b) 2S
c) 3S
d) 4S

Column bases

Two structural steel plates of thicknesses 12 mm and 14 mm are to be welded together. What will be the maximum size of fillet weld?

a) 6.00
b) 10.50
c) 13.00
d) 12.50

Column bases

What is the value of Partial Safety Factor for Shop Fabricated Welds:

a) 1.10
b) 1.20
c) 1.25
d) 1.50

Thank YOU !!!

PANA ACADEMY