PANA ACADEMY

NEPAL ENGINEERING COUNCIL
LICENSE EXAM PREPARATION COURSE

FOR

CIVIL ENGINEERS

5. Design of Structure

5.5 Steel structures

Sub topics

PANA ACADEMY

- 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

PANA ACADEMY

Standard and built-up sections

beam

Indian standard

ISJB → Beam
junior

ISLB light weight

ISMB medium

ISHB high

ISSC column section

column

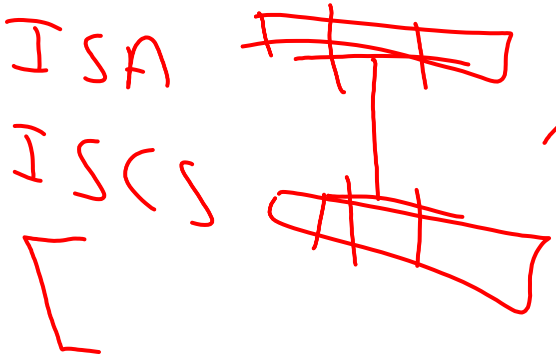
IS 808:1989 Dimension of hot rolled steel beam column, channel and angle sections

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

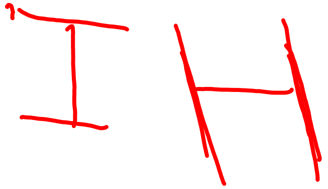
ISA

ISCS

I, Z



IS 800:2007 and NBC 111:1994



Steel sections

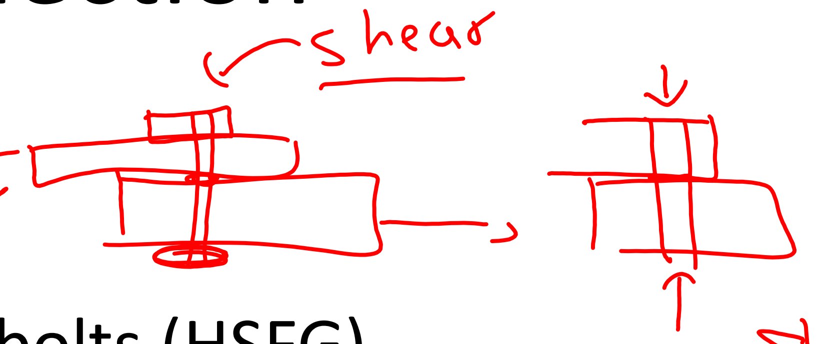
Standard section has predefined dimension and strength.

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

PANA ACADEMY



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

Shear
Tension

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

Grad 6.4

M16 grade 4.6

F_{ub} = 600 N/mm = 600 MPa

600 × 0.4 = 240

f_{yb}

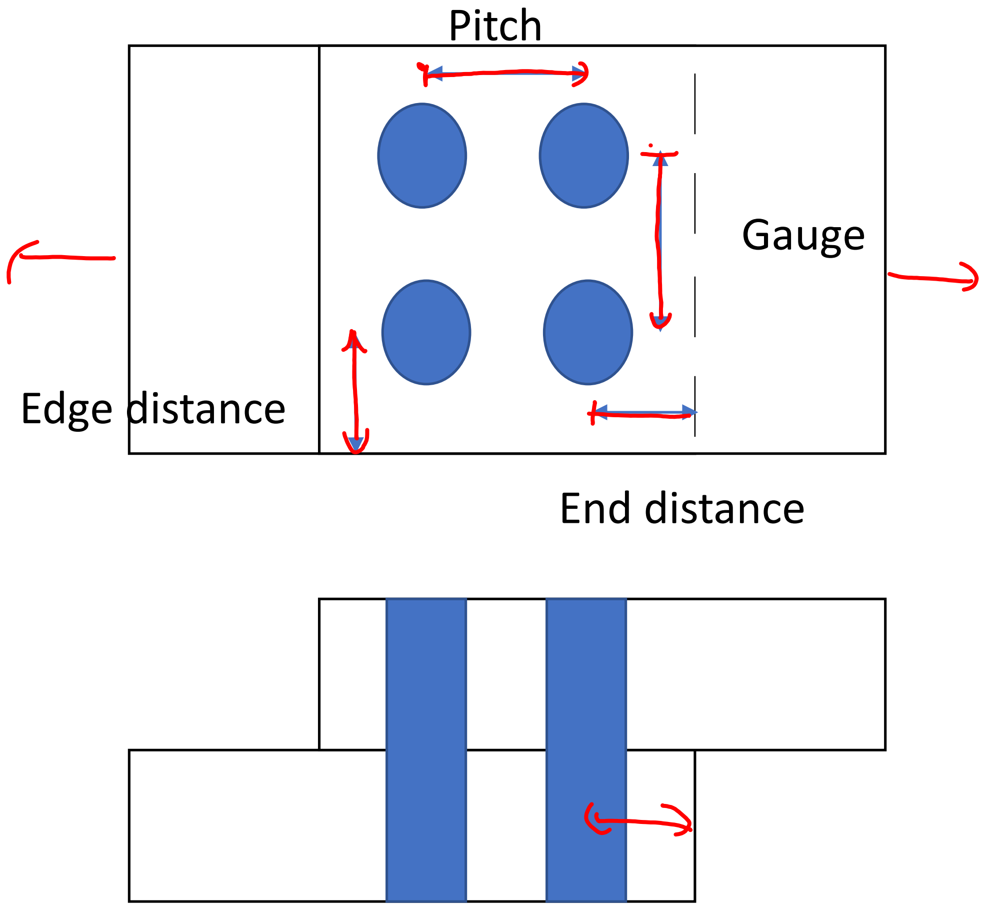
For force to be transmitted Grip length/Shank diameter should be less than or equal 8.

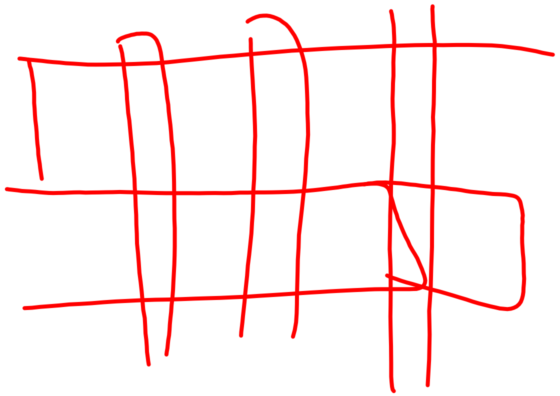
Bold should resist shear , tension or their combination.

Design of Bolted connection

PANA ACADEMY

Terminology in bolted connections





Design of Bolted connection

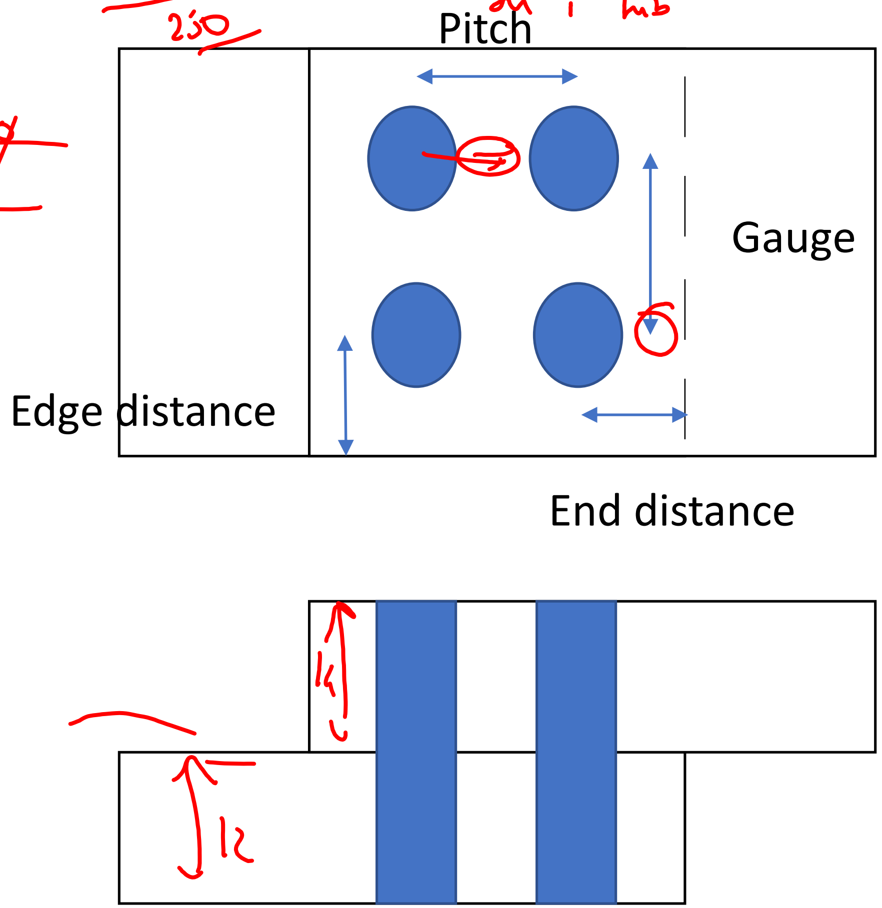
M16, grade 4.6, $d_o = 18mm$

14mm & 12mm

f_y, f_{yb}

f_u, f_{ub}

250



Minimum pitch=$2.5d$ $= 2.5 \times 16 = 40mm$

Maximum pitch $12 \times 12 = 144$

Compression : 12t or 200mm

Tension : 16t or 200mm $=192$

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=

144 $$12t\epsilon \; where \; \epsilon = \sqrt{250/f_y}$$

d is bolt diameter, d_o is hole diameter,

t is thickness of thinner plate

Bolt and hole diameter

PANA ACADEMY

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

16 $\rightarrow$ $16+2 = 18$ mm

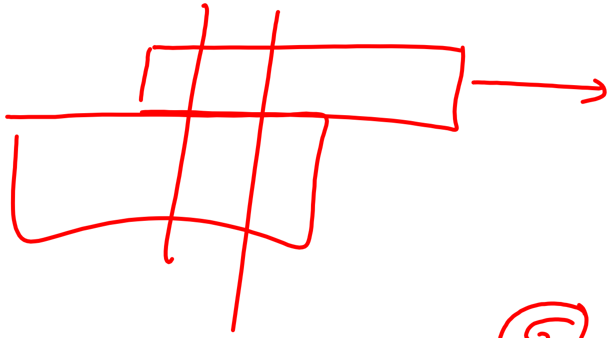
Shear capacity

PANA ACADEMY

400 fub

400x0.6 fyb

M16 Grade 4.6



100kN

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

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}(\overset{0}{n_n}.A_{nb} + \overset{1}{n_s}.A_{sb})$$

$f_{ub} = 400$

$n_n = 0$

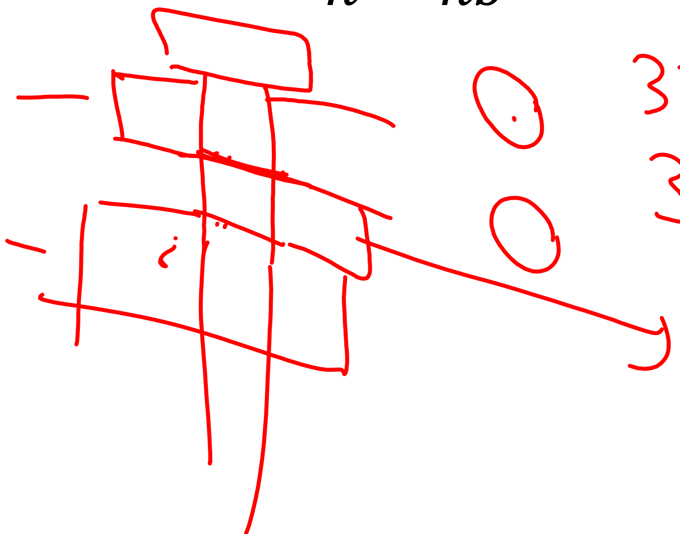
$n_s = 1$

$A_{sb} = \frac{\pi}{4} \times 16^2$

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

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



37146 N

37.148 kN

$$\gamma_{mb} = 1.25$$

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

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

Shear capacity

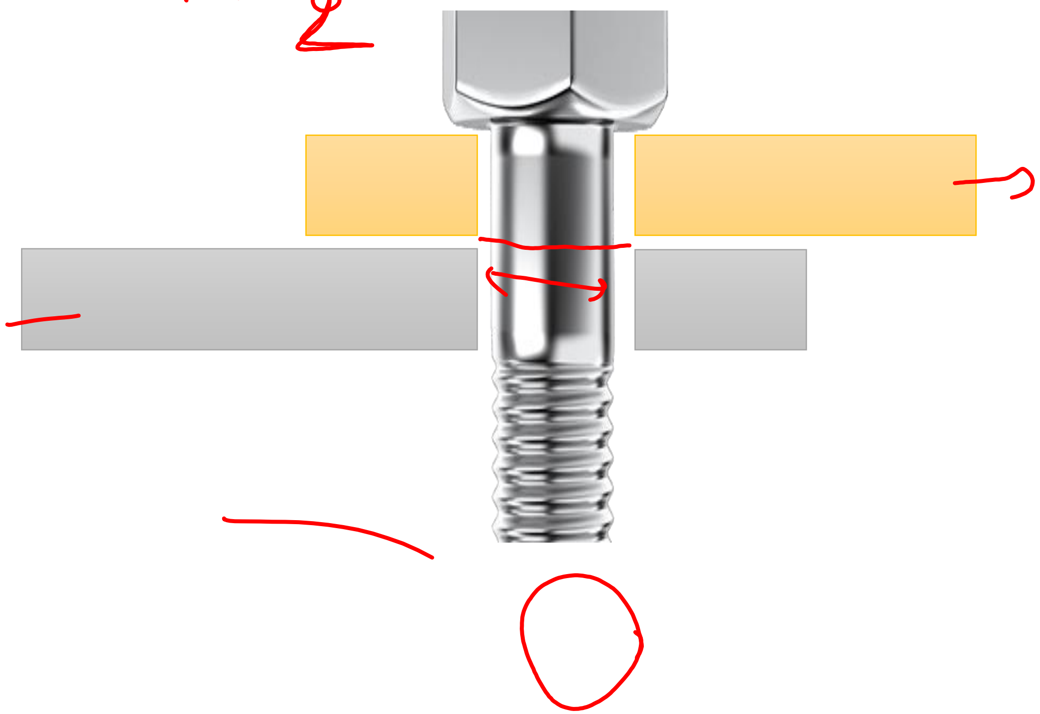
PANA ACADEMY

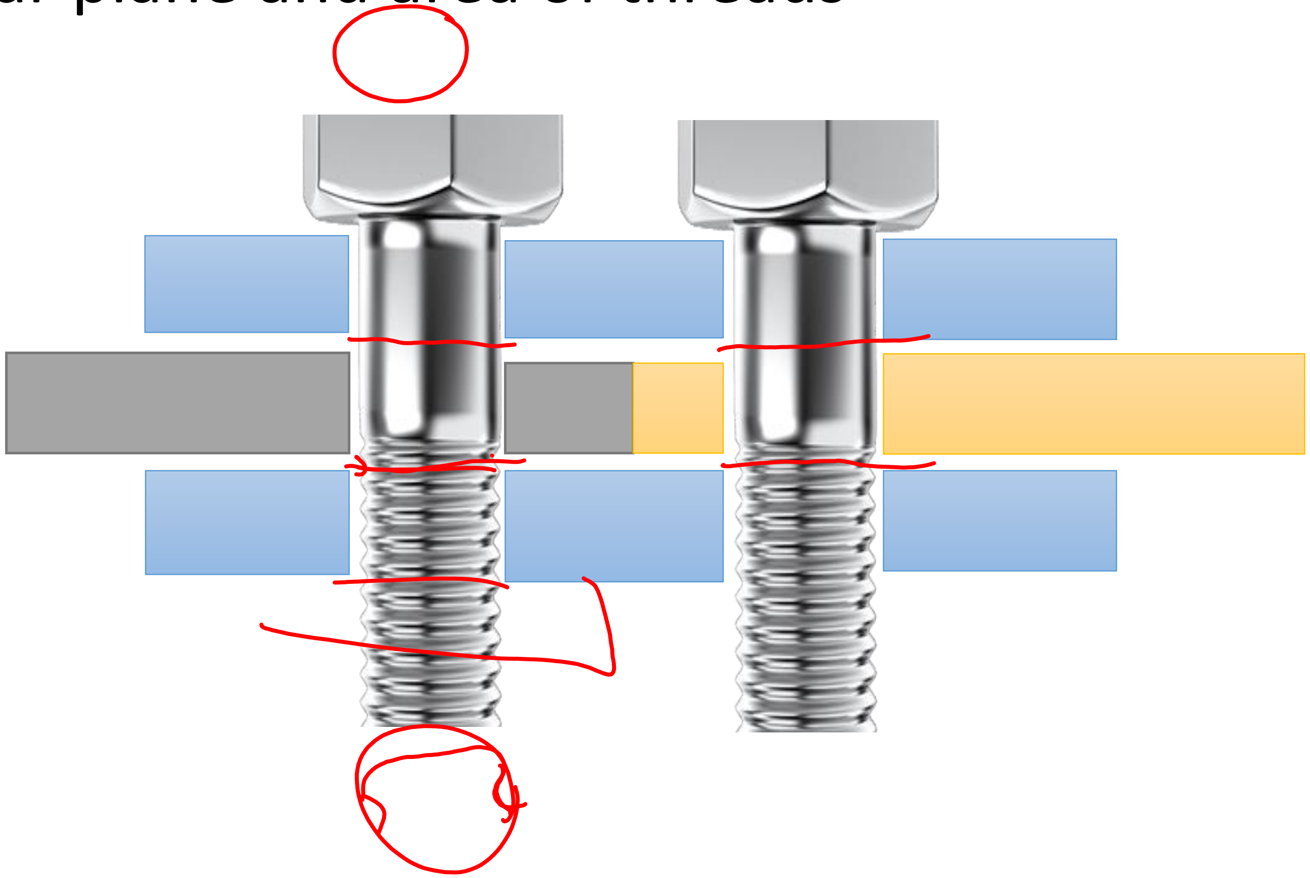
1 $\frac{\pi \times 16^2}{4}$

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

M16 2 $0.78 \times A_{sb}$





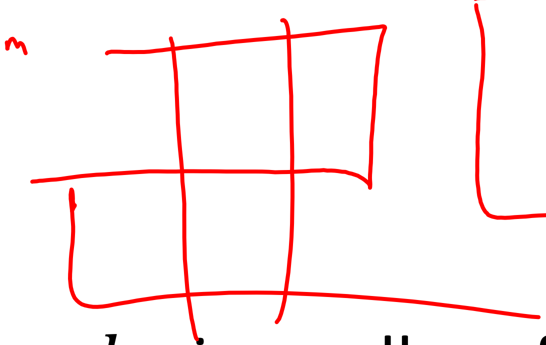
Bearing capacity

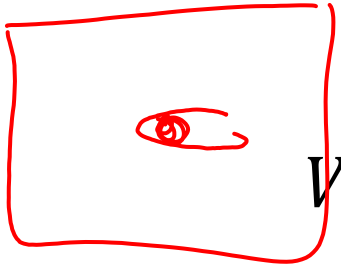
16
4.6

$f_u = 410,\ 400$
$f_y = 250$

25kN

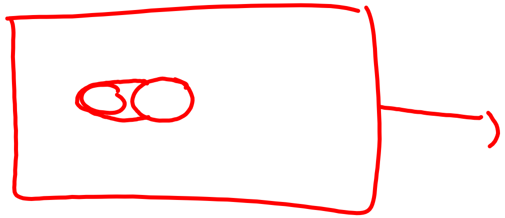
50m





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

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



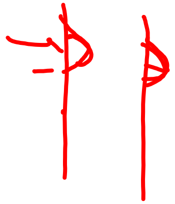
50 − 0.25

3×18

$\frac{400}{410}$

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

e *and* p are end and pitch distances of the fastners



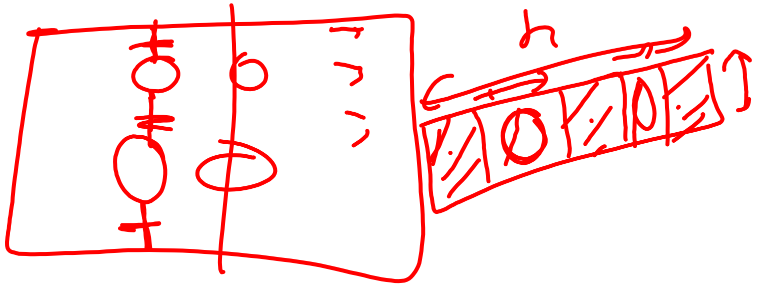
d_o is the diameter of hole

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 ~~$f_y A_g$~~

$$A_n = (b - n d_o)t$$

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

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

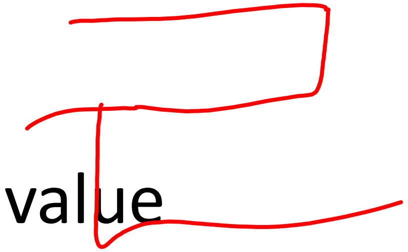
Bolt value

Minimum of shear capacity, bearing capacity is taken as bolt value of bolt. 37.1 25

$\frac{1004.0}{25} = 4$

25

Number of bolts = Total load /Bolt value



$b \times t - d_0 \times t - d_0 \times t$

$(b - n d_0)\, t$

Eccentric loading condition

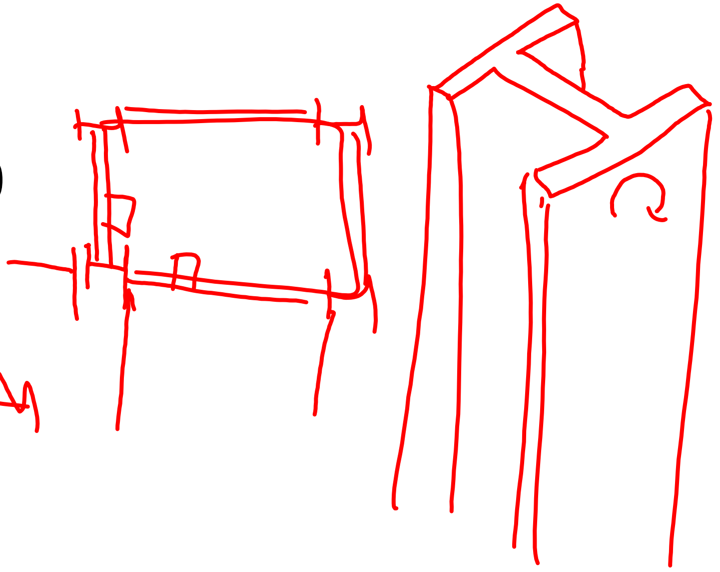
Bolt experiencing shear and tension

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

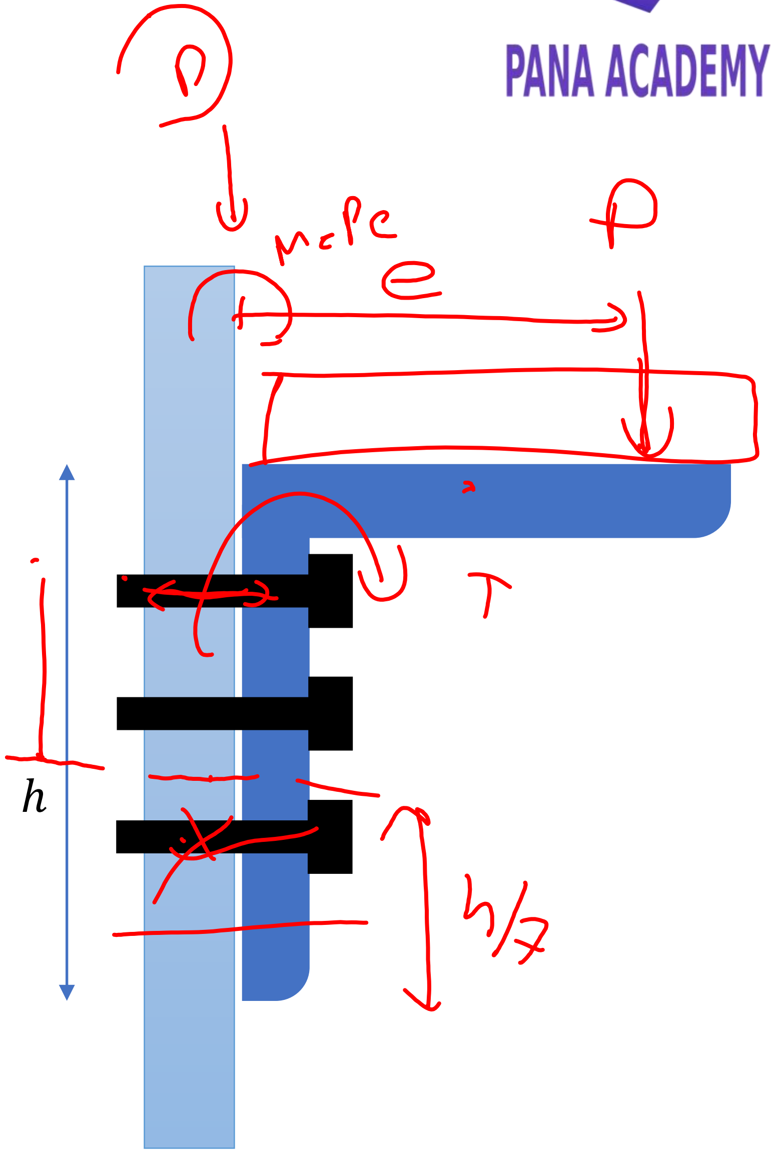
$$\frac{\sigma}{y} = \frac{M}{I} = \frac{M}{Ar^2} \qquad T = \frac{My}{\Sigma r^2}$$

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

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



y_i is the distance of bolt in tension from NA



Eccentric loading condition

PANA ACADEMY

0.78 × Asb

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

$$T_{nb} = 0.9\mathrm{f_{ub}}\mathrm{A_n} < \frac{\mathrm{f_{yb}}\mathrm{A}_{sb}\gamma_{mb}}{\gamma_{mo}}$$

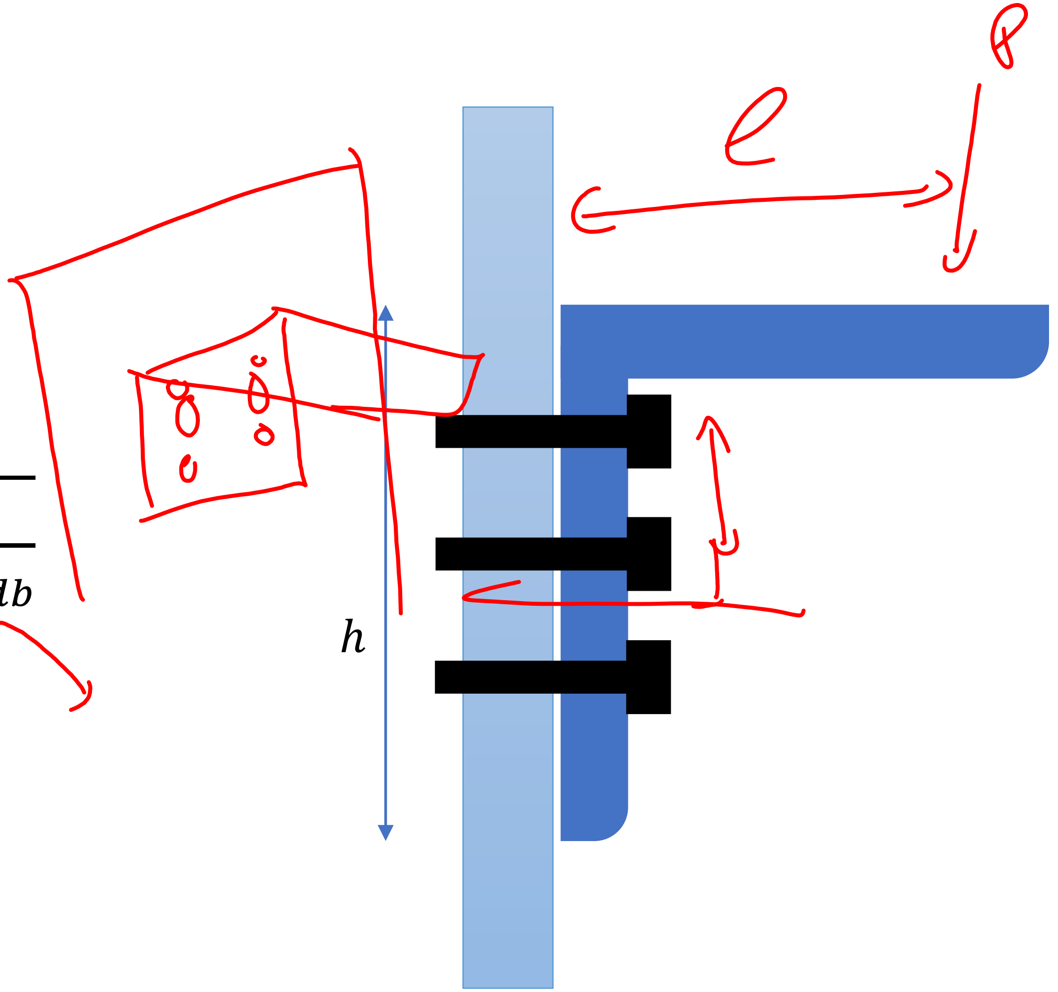
$$\gamma_{mo} = 1.1$$
$$\gamma_{mb} = 1.25$$

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

3

no of row

2



Eccentric loading condition

$\tau \propto r$

The eccentric load gives additional shear and torsion.

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

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

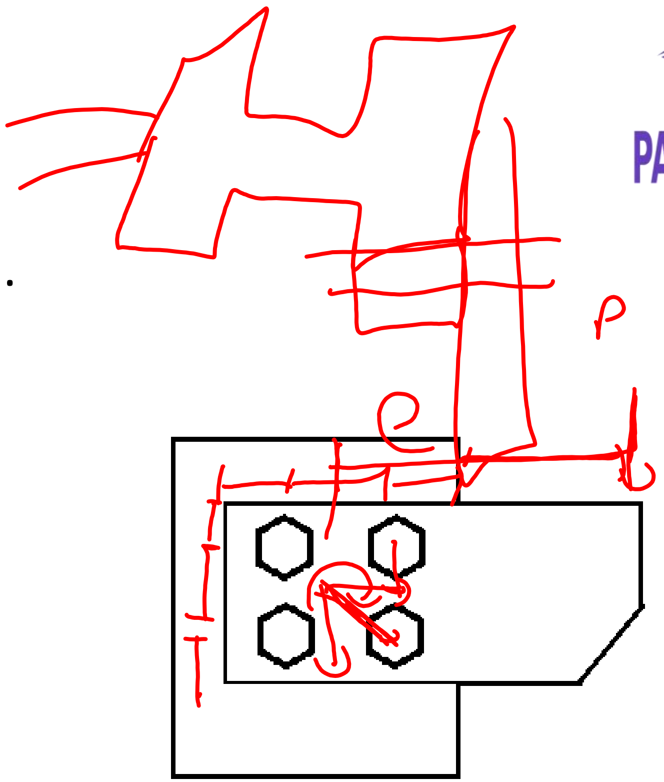
$$F_{2x} = \frac{Pey_i}{\Sigma r^2}, F_{2y} = \frac{Pex_i}{\Sigma r^2}$$

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

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

$F_r < \boxed{V_{dsb}}$

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

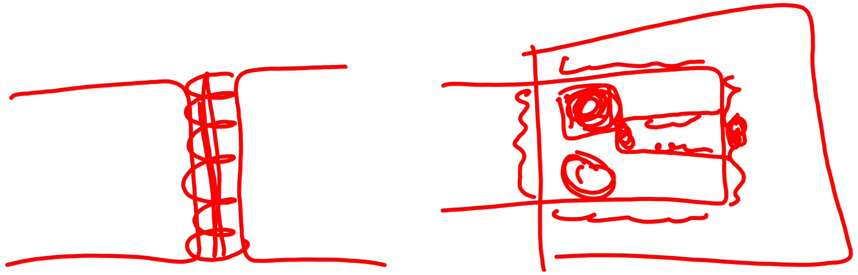


Design of welded connection

PANA ACADEMY

$P = f_{wd} \times L_w \times t_e$

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



$A_w = L_w \times t_h$

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

$P = \sigma \times A$ → Area of weld

f_{wd}

Design strength of weld:

$\frac{f_u}{\sqrt{3}\,\gamma_{mw}}$

Shop $f_{wd} = 189$ N/mm²

field $f_{wd} = 157$ N/mm²

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

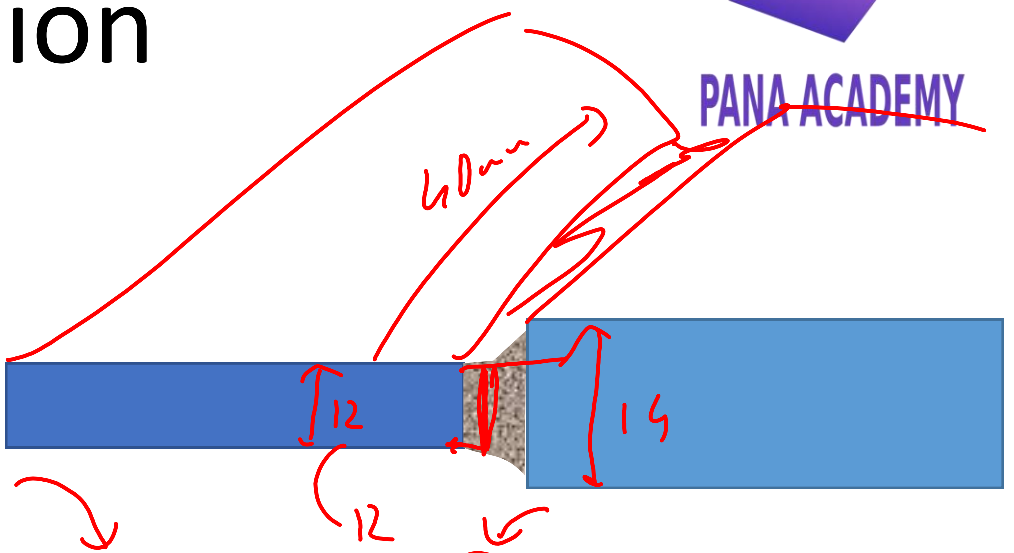
$$f_{wd} = \frac{f_u}{\sqrt{3}\ \ \gamma_{mw}}$$

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

Design of Butt weld in tension

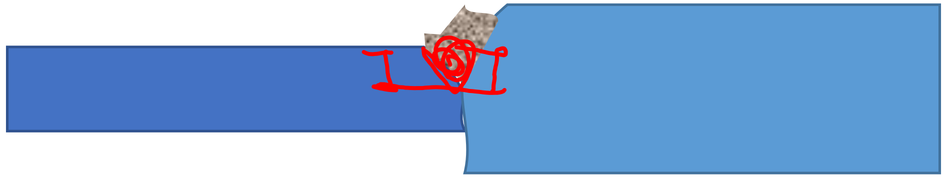
Size of weld is the effective thickness of weld. It is taken as thickness of thinner plate for complete penetration (Double U, Double J, Double V).

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.



$10000 = \sigma_w \times L_w \times 12$

σ_0



Design of Butt weld in tension

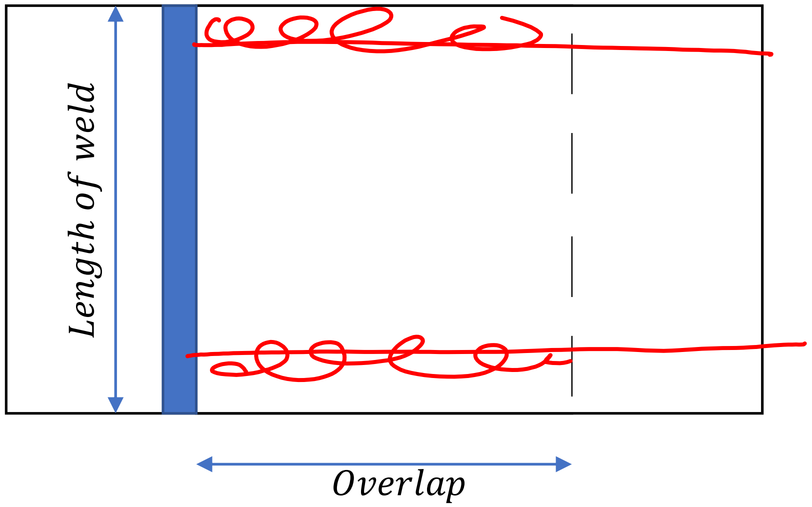
Effective length is length of welding where full size weld is done.
Minimum length $\geq 4S$

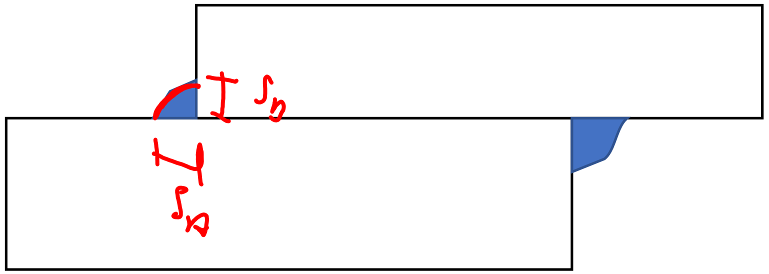
Spacing between two intermittent weld should not be more than 16 times thickness of thinner plate

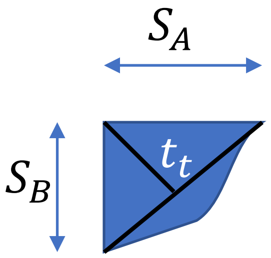
Design of Fillet weld

Terminology in welded connections

$$t_t = \frac{S_1}{\sqrt{2}} = 0.75$$







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

PANA ACADEMY

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

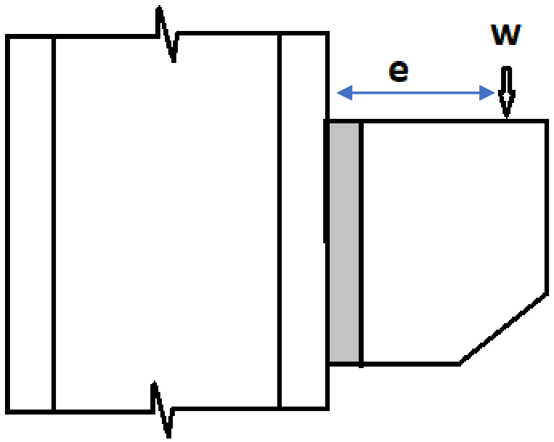
Subjected to shear and bending stresses.

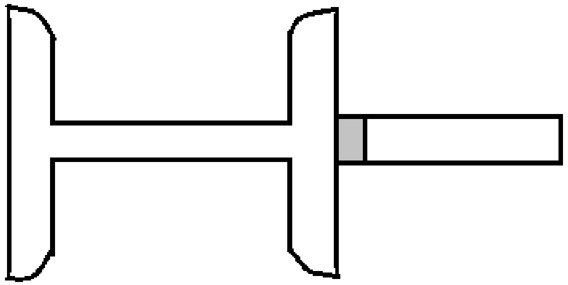
Shear stress$(\sigma_s) = \frac{w}{l_w \times t_t}$

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

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

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





Design of eccentric fillet weld

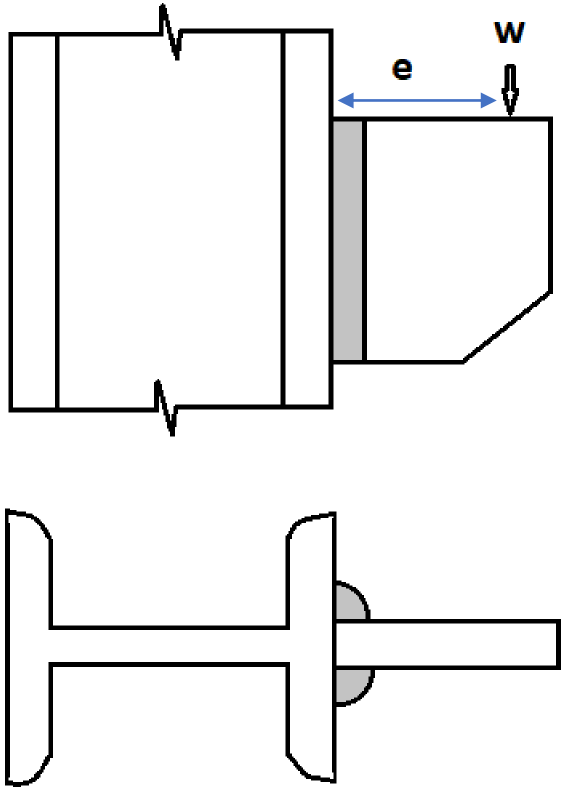
Subjected to shear and bending stresses.

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

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

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

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



Design of eccentric fillet weld

Subjected to shear and bending stresses.

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

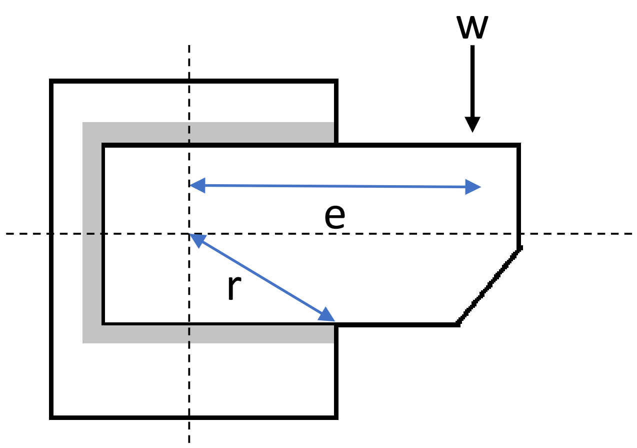
Torsional stress $(\sigma_t) = \dfrac{wer}{I_p}$

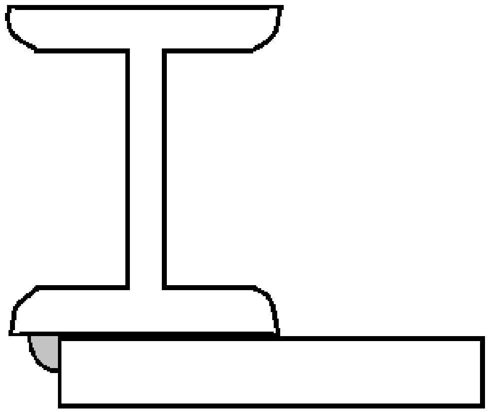
$$\sigma_{tx} = \frac{wey}{I_p}, \sigma_{ty} = \frac{wex}{I_p}$$

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

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

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





Design of ties

PANA ACADEMY

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 m a tie in a roof truss or a bracing system	350

Design of ties

PANA ACADEMY

Gross section yield failure (T_{dg})

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

Net section rupture (T_{dn})

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

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

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

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

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

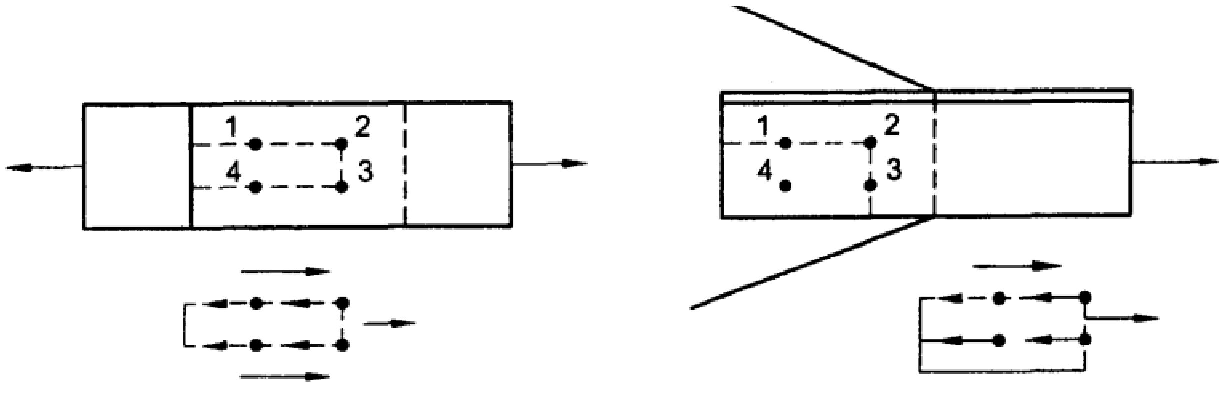
Design of ties

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

PANA ACADEMY

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

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

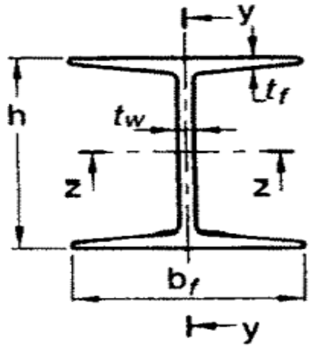
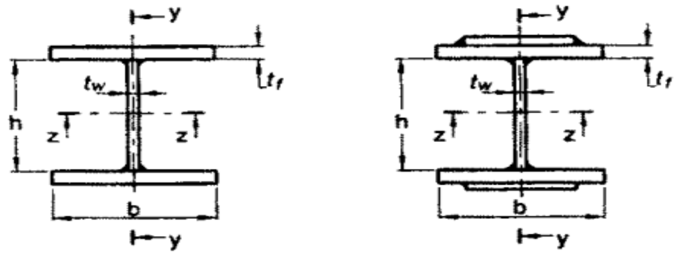
Types of failure:

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

Buckling class of Cross section

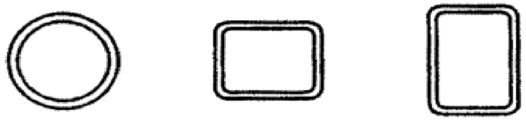
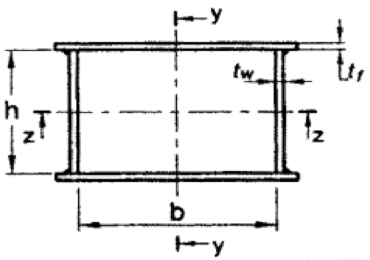
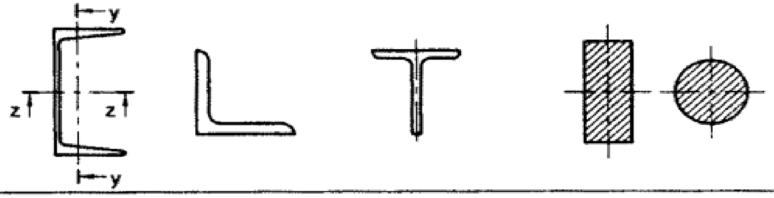
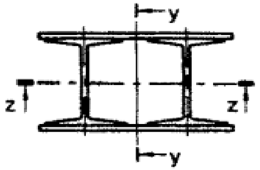
Design of struts

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

PANA ACADEMY

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

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

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

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

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

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

PANA ACADEMY

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