MADE EASY PUBLICATIONS

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CIVIL ENGINEERING

CONVENTIONAL Practice Sets

CONTENTS

DESIGN OF STEEL STRUCTURES

1 CHAPTER Rivets & Bolts

Rivets

Q.1 **Determine the rivet value of 18 mm diameter rivets connecting 10 mm plate and is in: (i) single shear, and (ii) double shear. The permissible stresses for rivets in shear and bearing are 80 MPa and 250 MPa respectively and for plate in bearing is 250 MPa.**

Solution:

Gross diameter of rivets, $d = 18 + 1.5 = 19.5$ mm

Strength of rivet

(i) In bearing $= \sigma_{pf} \times d \times t = 250 \times 19.5 \times 10 = 48750 \text{ N} = 48.75 \text{ kN}$

(ii) In single shear $= \tau_{vf} \times \dfrac{\pi}{4} \times d^2 = 80 \times \dfrac{\pi}{4} \times (19.5)^2 = 23891.8 \text{ N} = 23.89 \text{ kN}$

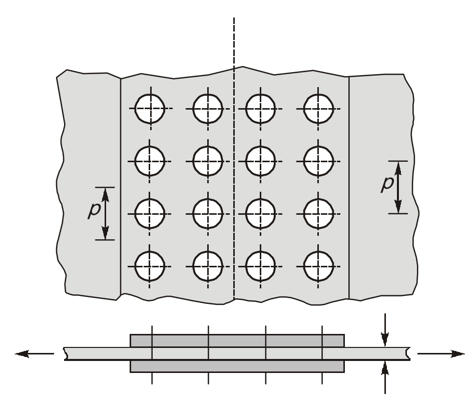
(iii) In double shear $= 2 \times \tau_{vf} \times \dfrac{\pi}{4} \times d^2 = 2 \times 23891.8 = 47783.6 \text{ N} = 47.78 \text{ kN}$

$\therefore$ Rivet value in single shear = smaller of (i) and (ii) = 23.89 kN

and Rivet value in double shear = smaller of (i) and (iii) = 47.78 kN

Q.2 **Two plates each 12 mm thick are joined by double riveted double cover butt joint as shown in figure below. Using 20 mm diameter rivets, design the pitch of the rivets. Take σ_{at} = 150 MPa. Also find the efficiency of the joint. (Consider power driver shop rivet.)**

Solution:



Gross diameter of the rivets $= 20 + 1.5 = 21.5$ mm

For power driven shop rivets $\sigma_{pf} = 300$ MPa

and $\tau_{vf} = 100$ MPa

Strength of rivets in bearing $= \dfrac{300}{1000} \times 21.5 \times 12 = 77.4$ kN

Strength of rivets in double shear $= \dfrac{2 \times 100}{1000} \times \dfrac{\pi}{4}(21.5)^2 = 72.6$ kN

Rivet value = 72.6 kN

For maximum efficiency of joint per pitch length,

Strength of plate per pitch = 2 × Rivet value

or $\sigma_{at} \times (p - d) \times t = 2 \times 72.6 \times 1000$ N

or $150 \times (p - 21.5) \times 12 = 2 \times 72.6 \times 1000$ N

or $p = 102.17$ mm (say 100 mm)

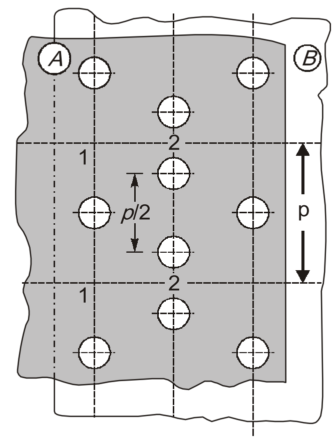
Minimum permissible pitch $= 2.5 \times d = 2.5 \times 21.5 = 53.75$ mm

$\therefore$ Adopt pitch = 100 mm

$$\text{Efficiency of joint} = \frac{150 \times (100 - 21.5) \times 12}{150 \times 100 \times 12} \times 100 = 78.5\%$$

Q.3 Two plates 10 mm and 8 mm thick are joined by a triple-riveted lap joint. Find the suitable pitch for the outer row of rivets if the pitch for central row of rivets is half of the pitch for the outer rows. Take permissible stresses for rivets in shear and bearing equal to 90 MPa and 270 MPa respectively and permissible tensile stress in plates equal to 150 MPa. Also find the efficiency of the joint.

Solution:



$$\text{Diameter of rivets} = 6.01\sqrt{t} = 6.01\sqrt{8} = 16.9 \text{ mm say } 18 \text{ mm}$$

$$\text{Gross diameter} = 18 + 1.5 = 19.5 \text{ mm}$$

Strength of rivets in single shear

$$= \frac{90}{1000} \times \frac{\pi}{4} \times (19.5)^2 = 26.88 \text{ kN}$$

$$\text{Strength of rivets in bearing on 8 mm plate} = \frac{270}{1000} \times 19.5 \times 8 = 42.12 \text{ kN}$$

$\therefore$ Rivet value = 26.88 kN

For plate *A* in figure the most critical section will be along 1-1 or 2-2

(i) Strength of plate per pitch along 1-1 $= \frac{150}{1000} \times (p - 19.5) \times 8$

$$= 1.2\,p - 23.4 \text{ kN}$$

(ii) Strength of plate per pitch along 2-2 $= \frac{150}{1000} \times (p - 2 \times 19.5) \times 8 + 26.88$

$$= 1.2\,p - 19.92 \text{ kN}$$

Comparing (i) and (ii) above, section 1-1 is weaker.

$\therefore$ Strength of plate per pitch $1.2\,p - 23.4$ kN

For maximum efficiency of joint,

Strength of plate per pitch = Strength of rivets per pitch

$\Rightarrow$ $1.2\,p - 23.4 = 4 \times 26.88$

$\Rightarrow$ $p = 109.1$ mm say 110 mm

Minimum permissible pitch = 2.5 × 21.5 = 53.75 mm

$\therefore$ Use pitch of 110 mm for outer row of rivets.

$$\text{Efficiency of joint} = \frac{4 \times 26.88 \times 1000}{150 \times 110 \times 8} \times 100 = 81.45\%$$

Q.4 Design a riveted splice for a tie of a steel bridge, 20 cm wide, 20 mm thick carrying an axial tensile force of 50,000 kg. Use 12 mm thick cover plates, 22 mm diameter rivets. Permissible stresses:
tension in plates = 1500 kg/cm^2
shear in rivets = 1000 kg/cm^2
bearing in rivets = 3000 kg/ cm^2
Give a neat sketch of the arrangement.

Solution:

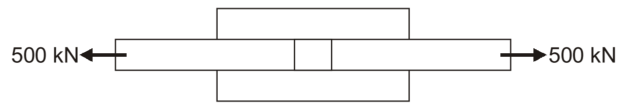
Taking $g = 10$ m/s^2 and 1 kg/cm^2 = 0.1 N/mm^2

$\therefore$ Axial tensile force, $P = \dfrac{50,000 \times 10}{1000} = 500$ kN

Nominal diameter of rivets = 22 mm

$\therefore$ Gross diameter of rivets $d' = 22 + 1.5 = 23.5$ mm

Designing the splice as a double cover butt joint as it will give maximum efficiency.



Given that thickness of cover plates = 12 mm

Width of main plate = 20 cm = 200 mm

Thickness of main plate = 20 mm

Assuming the width of cover plate = 200 mm

Strength of rivet in double shear $= \dfrac{\pi}{4}(d')^2 \times f_s \times 2 = \dfrac{\pi}{4} \times (23.5)^2 \times \dfrac{100}{1000} \times 2 = 86.75$ kN

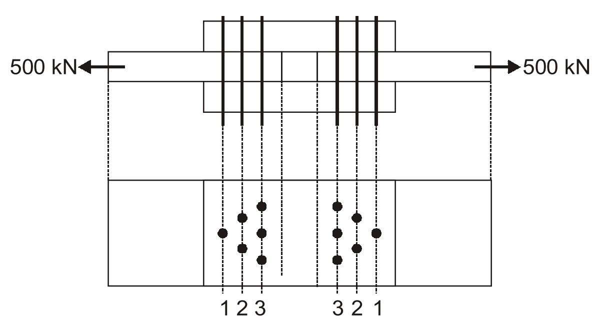
Strength of rivet in bearing $= d' t\, f_b = 23.5 \times 20 \times \dfrac{300}{1000} = 141$ kN

$\therefore$ Rivet value, $R_v = 86.75$ kN

Number of rivets, $n = \dfrac{P}{R_v} = \dfrac{500}{86.75} = 5.76 \approx 6$

The rivets can be arranged in diamond pattern

Checking the strength of cover plate and main plate in tearing



As we know that 3-3 is critical for cover plates.

$\therefore$ Strength of cover plates in tearing at 3-3 $\geq$ 500 kN

$\Rightarrow$ $(200 - 3 \times 23.5) \times 2 \times 12 \times \dfrac{150}{1000} = 466.2$ kN < 500. **Hence unsafe.**

Providing two rivets at 3-3, then

Strength of cover plats in tearing at 3-3 $= (200 - 2 \times 23.5) \times 24 \times \dfrac{150}{1000}$

$= 550.8$ kN > 500 kN (Hence safe)

Thus 2 rivets can be provided at 3-3, **Hence safe**

Thus arranging rivets in chain pattern, in 3 pairs of two rivets each.

1-1 is critical for main plate,

$\therefore$ Strength of main plate in tearing at 1-1 > 500 ≥ 500 kN

$$\Rightarrow \quad = (200 - 2 \times 23.5) \times 20 \times \frac{150}{1000} = 459 \text{ kN} < 500 \text{ kN. Hence unsafe}$$

Thus one rivet can be provided at 1-1.

We can provide three rivets at 2-2, thus checking for tearing of main plate at 2-2

$$\Rightarrow \quad = (200 - 3 \times 23.5) \times 20 \times \frac{150}{1000} + R_v > 500$$

$$\Rightarrow \quad = (200 - 3 \times 23.5) \times 20 \times \frac{150}{1000} + 86.75$$

$$= 475.25 < 500, \text{ Hence unsafe}$$

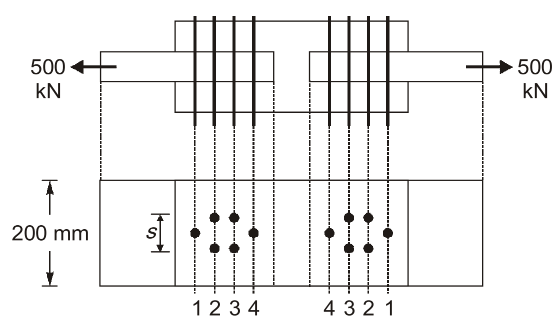
Thus, providing two rivets at 2-2

Strength of main plate in tearing at 2-2

$$= (200 - 2 \times 23.5) \times 20 \times \frac{150}{1000} + 86.75$$

$$= 545.75 > 500. \text{ Hence safe.}$$

Thus at 1-1 at the most one rivet can be provided. Two rivets can be provided at 2-2. Two rivets can be provided at 3-3. We have to create 4-4 in order to incorporate the remaining one rivet. Thus the arrangement will be as given below.



Equating the strength of rivet per pitch length to the strength of plate per pitch length in tearing.

$$R_v = (S - 23.5) \times 20 \times \frac{150}{1000}$$

$$\Rightarrow \quad 86.75 = (S - 23.5) \times 20 \times \frac{150}{1000}$$

$$\Rightarrow \quad S = 52.42 \text{ mm} = 60 \text{ mm} \not< 2.5 \times 22 = 55 \text{ mm}$$

Bolts

Q.5 Determine the strength of 20 mm diameter bolt of grade 4.6 for the following cases.

(a) Lap joint.

(b) Single cover butt joint with 10 mm thick cover plate.

(c) Double cover butt joint with 8 mm thick cover plates.
The main plates to be joined are 14 mm thick. Use Fe410 grade steel.

Solution:

For Fe410 steel, $f_u = 410$ N/mm^2, $f_y = 250$ N/mm^2

For 4.6 grade bolt, $f_{ub} = 400$ N/mm^2, $f_y = 240$ N/mm^2

Partial factor of safety for bolt material (γ_{mb}) = 1.25

Net tensile stress area for 20 mm diameter bolt (A_{nb}) = 245 mm^2 $\left(\simeq 0.78 \times \frac{\pi}{4} \times 20^2\right)$

(a) Lap joint

In lap joint, the bolts are in single shear

∴ Shear strength of bolt in single shear

$$\boxed{V_{dsb} = \frac{f_{ub} A_{nb}}{\sqrt{3}\,\gamma_{mb}}}$$

$$= \frac{400 \times 245}{\sqrt{3} \times 1.25} N = 45.26 \text{ kN}$$

Strength of bolt in bearing (V_{dpb}) = $2.5\, k_b dt \dfrac{f_u}{\gamma_{mb}}$

For 20 mm diameter bolt, diameter of bolt hole (d_0) = 22 mm

End distance (e) = 33 mm

Let pitch (p) = 50 mm

$$\therefore \quad k_b = \text{minimum of} \begin{cases} \dfrac{e}{3d_0} = \dfrac{33}{3 \times 22} = 0.5 \\ \dfrac{p}{3d_o} - 0.25 = \dfrac{50}{3 \times 22} - 0.25 = 0.508 \\ \dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.976 \\ 1.0 \end{cases}$$

$$= 0.5$$

$$\therefore \quad V_{dpb} = 2.5 k_b \frac{dt f_u}{\gamma_{mb}}$$

$$= 2.5 \times 0.5 \times 20 \times 14 \times \frac{410}{1.25} \text{N} = 114.8 \text{ kN}$$

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb} = 45.26 kN

(b) Single cover butt joint with 10 mm thick cover plate

Here also the bolt will be in single shear and bearing. The considered thickness for bearing will be the minimum of aggregate thickness of cover plate and minimum thickness of main plates to be jointed i.e.

$t = 10$ mm

As computed in part (*a*) above, strength of bolt in single shear (V_{dsb}) = 45.26 kN

Strength of the bolt in bearing (V_{dsb}) $= 2.5\,k_b\,\dfrac{dt\,f_u}{g_{mb}}$

$$= 2.5 \times 0.5 \times 20 \times \frac{10 \times 410}{1.25}\,\text{N}$$

$= 82$ kN

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb}

= 45.26 kN

(c) Double cover butt joint with 8 mm thick cover plates

Here the bolt will be in double shear and bearing. The considered thickness for bearing will be the minimum of aggregate thickness of cover plates and minimum thickness of main plates to be jointed i.e.

t = Minimum of (8 + 8, 14) mm = 14 mm

Strength of bolt in double shear (V_{dsb})

$$= 2 \times \frac{f_{ub}\,A_{nb}}{\sqrt{3}\,\gamma_{mb}} = 90.53\text{ kN}$$

Strength of bolt in bearing (V_{dpb})

$$= 2.5\,k_b\,\frac{dt\,f_u}{\sqrt{3}\,\gamma_{mb}}$$

$$= 2.5 \times 0.5 \times 20 \times 14 \times \frac{410}{1.25}\,\text{N}$$

$= 114.8$ kN

Thus strength of bolt = Minimum of V_{dsb} and V_{dpb} = 90.53 kN

Q.6 Two 10 mm thick plates are connected by lap joint to transmit a factored load of 100 kN using black bolts of 12 mm diameter and grade 4.6. What is the minimum number of bolts required for safe design? (Given f_u = 410 MPa)

Solution:

Nominal diameter of bolt, d = 12 mm

Gross diameter of bolt, d_0 = 12 + 1 = 13 mm

For grade 4.6 bolt, f_{ub} = 400 MPa

γ_{mb} = 240 MPa

(a) Shear strength of bolt (V_{dsb})

$$\boxed{V_{dsb} = \frac{f_{ab}}{\sqrt{3}\,\gamma_{mb}}\left(A_{nb}n_n + A_{sb}n_s\right)}$$

Since bolt is in single shear for lap joint

$n_s = 0,\ n_n = 1$

$$A_{nb} = 0.78\,A_{sb} = 0.78 \times \frac{\pi}{4} \times 12^2$$

$$\therefore \quad V_{dsb} = \frac{400}{\sqrt{3} \times 1.25} \times 0.78 \times \frac{\pi}{4} \times 12^2 \times 10^{-3}\,\text{kN}$$

$= 16.29$ kN

(b) Bearing strength of bolt (V_{dpb})

$$V_{dpb} = \frac{2.5 k_b d t f_u}{\gamma_{mb}}$$

$$k_b = \min\left[\frac{e}{3d_0}, \frac{p}{3d} - 0.25, \frac{f_{ub}}{f_u}, 1\right]$$

Take minimum value of e and p,

$$e = 1.5\, d_0 = 1.5 \times 13 = 19.5 \text{ mm}$$

$$p = 2.5\, d = 2.5 \times 12 = 30 \text{ mm}$$

$\therefore$ $$k_b = \min\left(\frac{19.5}{3 \times 13}, \frac{30}{3 \times 13} - 0.25, \frac{400}{410}, 1\right)$$

$$= 0.5$$

$\therefore$ $$V_{dpb} = \frac{2.5 \times 0.5 \times 12 \times 10 \times 410 \times 10^{-3}}{1.25} \text{ kN}$$

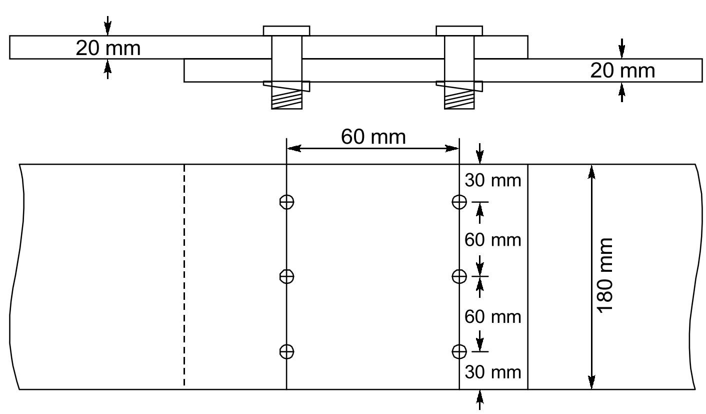
$$= 49.2 \text{ kN}$$

Therefore, bolt value, $V_{dp} = \min.(V_{dsb}, V_{dpb})$

$= 16.29$ kN

$\therefore$ No.of bolts required $= \dfrac{100}{16.29} = 6.14 \simeq 7$ bolts (say)

Q.7 Find the efficiency of the lap joint shown in the figure given below. Given M20 bolts of grade 4.6 and Fe410 (E 250) plates are used.



Solution:

For M20 bolts of grade 4.6,

Diameter of bolts, $d = 20$ mm

Diameter of bolt hole, $d_0 = 22$ mm

Ultimate strength, $f_{ub} = 400$ MPa

Partial safety factor, $\gamma_{mb} = 1.25$

For Fe 410 (E 250) plates,

Ultimate stress, $f_u = 410$ MPa

Partial safety factor, $\gamma_{ml} = 1.25$

Strength of plates in the joint:

Thickness of thinner plate, $t = 20$ mm

Width of plate, $b = 180$ mm

Number of bolts holes in the weakest section = 3

$\therefore$ Net area at weakest section, $A_u = [b - nd_0]\, t$

$= [180 - 3 \times 22] \times 20 = 2280 \text{ mm}^2$

Design strength of plates in the joint,

$$T_{dn} = \frac{0.9 f_y A_n}{\gamma_{ml}} = \frac{0.9 \times 410 \times 2280}{1.25}$$

$$= 673056 \text{ N} = 673.056 \text{ kN}$$

Strength of Bolts:

Total number of bolts = 6

(i) Design strength in shear

Number of shear planes at thread,

$$n_n = 1 \text{ per bolt}$$

$$A_{nb} = 0.78 \times \frac{\pi}{4} d^2 = 0.78 \times \frac{\pi}{4} \times 20^2 = 245 \text{ mm}^2$$

$\therefore$ Normal shear strength,

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

For single shear, $n_s = 0$ and $n_n = 1$

$$V_{dsb} = \frac{400}{\sqrt{3}}(6 \times 245) = 339482 \text{ N} = 339.482 \text{ kN}$$

$\therefore$ Design strength in shear,

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}} = \frac{339.482}{1.25} = 271.586 \text{ kN}$$

(ii) Design strength in bearing:

Nominal strength, $\boxed{V_{npb} = 2.5 K_b d t f_u}$

where K_b = least of the following:

(a) $\dfrac{e}{3d_0} = \dfrac{30}{3 \times 22} = 0.4545$

(b) $\dfrac{p}{3d_0} - 0.25 = \dfrac{60}{3 \times 22} - 0.25 = 0.6591$

(c) $\dfrac{f_{ub}}{f_u} = \dfrac{400}{410} = 0.9756$

(d) 1.0

Note: Edge distance provided is less. Hence it is critical in this case.