Problem 5

Design the longitudinal joint for a 1.25 m diameter steam boiler to carry a steam pressure of 2.5 N/mm^2. The ultimate strength of the boiler plate may be assumed as 420 MPa, crushing strength as 650 MPa and shear strength as 300 MPa. Take the joint efficiency as 80%. Sketch the joint with all the dimensions. Adopt the suitable factor of safety.

Solution. Given : D = 1.25 m = 1250 mm; P = 2.5 N/mm^2 ; σ_{tu} = 420 MPa = 420 N/mm^2; σ_{cu} = 650 MPa = 650 N/mm^2 ; τ_u = 300 MPa = 300 N/mm^2 ; η_l = 80% = 0.8

Assuming a factor of safety (F.S.) as 5, the allowable stresses are as follows :

$$\sigma_t = \frac{\sigma_{tu}}{F.S.} = \frac{420}{5} = 84 \text{ N/mm}^2$$

$$\sigma_c = \frac{\sigma_{cu}}{F.S.} = \frac{650}{5} = 130 \text{ N/mm}^2$$

$$\tau = \frac{\tau_u}{F.S.} = \frac{300}{5} = 60 \text{ N/mm}^2$$

1. Thickness of plate

We know that thickness of plate,

$$t = \frac{P.D}{2\,\sigma_t \times \eta_l} + 1 \text{ mm} = \frac{2.5 \times 1250}{2 \times 84 \times 0.8} + 1 \text{ mm}$$

$$= 24.3 \text{ say } 25 \text{ mm}$$

2. Diameter of rivet

Since the thickness of the plate is more than 8 mm, therefore diameter of the rivet hole,

$$d = 6\sqrt{t} = 6\sqrt{25} = 30 \text{ mm}$$

From Table , we see that according to IS : 1928 – 1961 (Reaffirmed 1996), the standard diameter of the rivet hole is 31.5 mm and the corresponding diameter of the rivet is 30 mm.

3. *Pitch of rivets*

∴ Tearing strength of the plate per pitch length,

$$P_t = (p - d)\, t \times \sigma_t = (p - 31.5)\, 25 \times 84 = 2100\,(p - 31.5)\ \text{N}$$

Since the joint is triple riveted with two unequal cover straps, therefore there are 5 rivets per pitch length. Out of these five rivets, four rivets are in double shear and one is in single shear. Assuming the strength of the rivets in double shear as 1.875 times that of single shear, therefore

Shearing resistance of the rivets per pitch length,

$$P_s = 4 \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau + \frac{\pi}{4} \times d^2 \times \tau = 8.5 \times \frac{\pi}{4} \times d^2 \times \tau$$

$$= 8.5 \times \frac{\pi}{4} (31.5)^2\, 60 = 397\,500\ \text{N}$$

$$2100\,(p - 31.5) = 397\,500$$

∴ $p - 31.5 = 397\,500 / 2100 = 189.3$ or $p = 31.5 + 189.3 = 220.8$ mm

According to I.B.R., maximum pitch,

$$p_{max} = C \times t + 41.28\ \text{mm}$$

From Table, we find that for double strap butt joint with 5 rivets per pitch length, the value of C is 6.

∴ $p_{max} = 6 \times 25 + 41.28 = 191.28$ say 196 mm

Since p_{max} is less than p, therefore we shall adopt $p = pmax = 196$ mm

∴ Pitch of rivets in the inner row,

$$p' = 196 / 2 = 98\ \text{mm}$$

4. *Distance between the rows of rivets*

According to I.B.R., the distance between the outer row and the next row,

$$= 0.2\, p + 1.15\, d = 0.2 \times 196 + 1.15 \times 31.5\ \text{mm}$$

$$= 75.4 \text{ say } 76\ \text{mm}$$

and the distance between the inner rows for zig-zag riveting

$$= 0.165\ p + 0.67\ d = 0.165 \times 196 + 0.67 \times 31.5 \text{ mm}$$

$$= 53.4 \text{ say } 54 \text{ mm}$$

5. *Thickness of butt straps*

We know that for unequal width of butt straps, the thicknesses are as follows :

For wide butt strap, $t_1 = 0.75\ t = 0.75 \times 25 = 18.75$ say 20 mm

and for narrow butt strap, $t_2 = 0.625\ t = 0.625 \times 25 = 15.6$ say 16 mm

It may be noted that wide and narrow butt straps are placed on the inside and outside of the shell respectively.

6. *Margin*

We know that the margin,

$$m = 1.5\ d = 1.5 \times 31.5 = 47.25 \text{ say } 47.5 \text{ mm}$$

Let us now check the efficiency of the designed joint.

Tearing resistance of the plate in the outer row,

$$P_t = (p - d)\ t \times \sigma_t = (196 - 31.5)\ 25 \times 84 = 345\ 450 \text{ N}$$

Shearing resistance of the rivets,

$$P_s = 4 \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau + \frac{\pi}{4} \times d^2 \times \tau = 8.5 \times \frac{\pi}{4} \times d^2 \times \tau$$

$$= 8.5 \times \frac{\pi}{4} (31.5)^2 \times 60 = 397\ 500 \text{ N}$$

and crushing resistance of the rivets,

$$P_c = n \times d \times t \times \sigma_c = 5 \times 31.5 \times 25 \times 130 = 511\ 875 \text{ N} \quad ...(n = 5)$$

therefore combined tearing and shearing resistance

$$= (p - 2d)\, t \times \sigma_t + \frac{\pi}{4} \times d^2 \times \tau$$

$$= (196 - 2 \times 31.5)\, 25 \times 84 + \frac{\pi}{4} (31.5)^2\, 60 = 326\,065 \text{ N}$$

From above, we see that strength of the joint

$$= 326\,065 \text{ N}$$

Strength of the unriveted or solid plate,

$$P = p \times t \times \sigma_t = 196 \times 25 \times 84 = 411\,600 \text{ N}$$

∴ Efficiency of the joint,

$$\eta = 326\,065 / 411\,600 = 0.792 \text{ or } 79.2\%$$

Since the efficiency of the designed joint is nearly equal to the given efficiency, therefore the design is satisfactory.

Problem 6

A steam boiler is to be designed for a working pressure of 2.5 N/mm2 with its inside diameter 1.6 m. Give the design calculations for the longitudinal and circumferential joints for the following working stresses for steel plates and rivets : In tension = 75 MPa ; In shear = 60 MPa; In crushing = 125 MPa.

Solution. Given : P = 2.5 N/mm2 ; D = 1.6 m = 1600 mm ; σ_t = 75 MPa = 75 N/mm^2 ; τ = 60 MPa = 60 N/mm^2 ; σ_c = 125 MPa = 125 N/mm^2

Design of longitudinal joint

The longitudinal joint for a steam boiler may be designed as follows

1. *Thickness of boiler shell*

We know that the thickness of boiler shell,

$$t = \frac{P.D}{2\,\sigma_t} + 1 \text{ mm} = \frac{2.5 \times 1600}{2 \times 75} + 1 \text{ mm}$$
$$= 27.6 \text{ say } 28 \text{ mm}$$

2. *Diameter of rivet*

Since the thickness of the plate is more than 8 mm, therefore diameter of rivet hole,

$$d = 6\sqrt{t} = 6\sqrt{28} = 31.75 \text{ mm}$$

From Table, we see that according to IS : 1928 – 1961 (Reaffirmed 1996), the standard diameter of rivet hole (d) is 34.5 mm and the corresponding diameter of the rivet is 33 mm

3. *Pitch of rivets*

Assume the joint to be triple riveted double strap butt joint with unequal cover straps,

Let p = Pitch of the rivet in the outer most row.

∴Tearing resistance of the plate per pitch length,

$$P_t = (p - d)\, t \times \sigma_t = (p - 34.5)\, 28 \times 75 \text{ N}$$
$$= 2100\,(p - 34.5) \text{ N}$$

Since the joint is triple riveted with two unequal cover straps, therefore there are 5 rivets per pitch length. Out of these five rivets, four are in double shear and one is in single shear. Assuming the strength of rivets in double shear as 1.875 times that of single shear, therefore

Shearing resistance of the rivets per pitch length,

$$P_s = 4 \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau + \frac{\pi}{4} \times d^2 \times \tau$$

$$= 8.5 \times \frac{\pi}{4} \times d^2 \times \tau$$

$$= 8.5 \times \frac{\pi}{4} (34.5)^2 \, 60 = 476\,820 \text{ N}$$

$$2100 \, (p - 34.5) = 476\,820$$

$\therefore$ $p - 34.5 = 476\,820 / 2100 = 227$ or $p = 227 + 34.5 = 261.5$ mm

According to I.B.R., the maximum pitch,

$$p_{max} = C.t + 41.28 \text{ mm}$$

From Table, we find that for double strap butt joint with 5 rivets per pitch length, the value of C is 6.

$\therefore$ $p_{max} = 6 \times 28 + 41.28 = 209.28$ say 220 mm

Since p_{max} is less than p, therefore we shall adopt

$$p = p_{max} = 220 \text{ mm}$$

$\therefore$ Pitch of rivets in the inner row,

$$p' = 220 / 2 = 110 \text{ mm}$$

4. *Distance between the rows of rivets*

According to I.B.R., the distance between the outer row and the next row

$= 0.2 \, p + 1.15 \, d = 0.2 \times 220 + 1.15 \times 34.5$ mm

$= 83.7$ say 85 mm

and the distance between the inner rows for zig-zig riveting

$$= 0.165\ p + 0.67\ d = 0.165 \times 220 + 0.67 \times 34.5 \text{ mm}$$

$$= 59.4 \text{ say } 60 \text{ mm}$$

5. *Thickness of butt straps*

We know that for unequal width of butt straps, the thicknesses are :

For wide butt strap, $t_1 = 0.75\ t = 0.75 \times 28 = 21$ mm

and for narrow butt strap, $t_2 = 0.625\ t = 0.625 \times 28 = 17.5$ say 18 mm

It may be noted that the wide and narrow butt straps are placed on the inside and outside of the shell respectively.

6. *Margin*

We know that the margin,

$$m = 1.5\ d = 1.5 \times 34.5 = 51.75 \text{ say } 52 \text{ mm}$$

Let us now check the efficiency of the designed joint.

Tearing resistance of the plate in the outer row,

$$P_t = (p - d)\ t \times \sigma_t = (220 - 34.5)\ 28 \times 75 = 389\ 550 \text{ N}$$

Shearing resistance of the rivets,

$$P_s = 4 \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau + \frac{\pi}{4} \times d^2 \times \tau = 8.5 \times \frac{\pi}{4} \times d^2 \times \tau$$

$$= 8.5 \times \frac{\pi}{4} (34.5)^2\ 60 = 476\ 820 \text{ N}$$

and crushing resistance of the rivets,

$$P_c = n \times d \times t \times \sigma_c = 5 \times 34.5 \times 28 \times 125 = 603\ 750 \text{ N}$$

Combined tearing and shearing resistance

$$= (p - 2d)\, t \times \sigma_t + \frac{\pi}{4} \times d^2 \times \tau$$

$$= (220 - 2 \times 34.5)\, 28 \times 75 + \frac{\pi}{4} (34.5)^2\, 60$$

$$= 317\ 100 + 56\ 096 = 373\ 196 \text{ N}$$

From above, we see that the strength of the joint

$$= 373\ 196 \text{ N}$$

Strength of the unriveted or solid plate,

$$P = p \times t \times \sigma_t = 220 \times 28 \times 75 = 462\ 000 \text{ N}$$

∴ Efficiency of the designed joint,

$$\eta = \frac{373\ 196}{462\ 000} = 0.808 \text{ or } 80.8\%$$

Design of circumferential joint

The circumferential joint for a steam boiler may be designed as follows :

1. The thickness of the boiler shell (t) and diameter of rivet hole (d) will be same as for longitudinal joint, *i.e.*

$$t = 28 \text{ mm ; and } d = 34.5 \text{ mm}$$

2. *Number of rivets*

Let n = Number of rivets.

We know that shearing resistance of the rivets

$$= n \times \frac{\pi}{4} \times d^2 \times \tau$$

and total shearing load acting on the circumferential joint

$$= \frac{\pi}{4} \times D^2 \times P$$

From two equation

$$n \times \frac{\pi}{4} \times d^2 \times \tau = \frac{\pi}{4} \times D^2 \times P$$

$$n = \frac{D^2 \times P}{d^2 \times \tau} = \frac{(1600)^2\ 2.5}{(34.5)^2\ 60} = 89.6 \text{ say } 90$$

3. *Pitch of rivets*

Assuming the joint to be double riveted lap joint with zig-zag riveting, therefore number of rivets per row

$$= 90 / 2 = 45$$

We know that the pitch of the rivets,

$$p_1 = \frac{\pi\,(D + t)}{\text{Number of rivets per row}} = \frac{\pi\,(1600 + 28)}{45} = 113.7 \text{ mm}$$

Let us take pitch of the rivets, $p_1 = 140$ mm

4. *Efficiency of the joint*

We know that the efficiency of the circumferential joint

$$\eta_c = \frac{p_1 - d}{p_1} = \frac{140 - 34.5}{140} = 0.753 \text{ or } 75.3\%$$

5. *Distance between the rows of rivets*

We know that the distance between the rows of rivets for zig-zag riveting,

$$= 0.33\ p_1 + 0.67\ d = 0.33 \times 140 + 0.67 \times 34.5 \text{ mm}$$

$$= 69.3 \text{ say } 70 \text{ mm}$$

6. *Margin*

We know that the margin,

$$m = 1.5\ d = 1.5 \times 34.5$$

$$= 51.75 \text{ say } 52 \text{ mm}$$

Homework

1. *Two plates of 7 mm thick are connected by a triple riveted lap joint of zig-zag pattern. Calculate the rivet diameter, rivet pitch and distance between rows of rivets for the joint. Also state the mode of failure of the joint. The safe working stresses are as follows : σt = 90 MPa ; τ = 60 MPa ; and σc = 120 MPa.*
2. *Two plates of 10 mm thickness each are to be joined by means of a single riveted double strap butt joint. Determine the rivet diameter, rivet pitch, strap thickness and efficiency of the joint. Take the working stresses in tension and shearing as 80 MPa and 60 MPa respectively.*
3. *Design a double riveted butt joint with two cover plates for the longitudinal seam of a boiler shell 1.5 m in diameter subjected to a steam pressure of 0.95 N/mm2. Assume joint efficiency as 75%, allowable tensile stress in the plate 90 MPa ; compressive stress 140 MPa ; and shear stress in the rivet 56 MPa.*