Design of Boiler Joints

The boiler has a longitudinal joint as well as circumferential joint. The ***longitudinal joint*** is used to join the ends of the plate to get the required diameter of a boiler. For this purpose, a butt joint with two cover plates is used. The ***circumferential joint*** is used to get the required length of the boiler. For this purpose, a lap joint with one ring overlapping the other alternately is used.

Design of Longitudinal Butt Joint for a Boiler

1. ***Thickness of boiler shell.*** First of all, the thickness of the boiler shell is determined by using the thin cylindrical formula,

$$t = \frac{P.D}{2\,\sigma_t \times \eta_l} + 1 \text{ mm as corrosion allowance}$$

t = Thickness of the boiler shell,

P = Steam pressure in boiler,

D = Internal diameter of boiler shell,

σ_t = Permissible tensile stress, and

η_l = Efficiency of the longitudinal joint.

The following points may be noted :

(*a*) The thickness of the boiler shell should not be less than 7 mm.

(*b*) The efficiency of the joint may be taken from the following table

Efficiencies of commercial boiler joints.

Lap joints	*Efficiency (%)*	**Maximum efficiency*	*Butt joints (Double strap)*	*Efficiency (%)*	**Maximum efficiency*
Single riveted	45 to 60	63.3	Single riveted	55 to 60	63.3
Double riveted	63 to 70	77.5	Double riveted	70 to 83	86.6
Triple riveted	72 to 80	86.6	Triple riveted (5 rivets per pitch with unequal width of straps)	80 to 90	95.0
			Quadruple riveted	85 to 94	98.1

* The maximum efficiencies are valid for ideal equistrength joints with tensile stress = 77 MPa, shear stress = 62 MPa and crushing stress = 133 MPa.

2. *Diameter of rivets.* After finding out the thickness of the boiler shell (t), the diameter of the rivet hole (d) may be determined by using Unwin's empirical formula,

$$d = 6\sqrt{t} \qquad \text{(when } t \text{ is greater than 8 mm)}$$

The following table gives the rivet diameter corresponding to the diameter of rivet hole as per IS : 1928 – 1961 (Reaffirmed 1996).

Size of rivet diameters for rivet hole diameter as per IS : 1928 – 1961 (Reaffirmed 1996).

Basic size of rivet mm	12	14	16	18	20	22	24	27	30	33	36	39	42	48
Rivet hole diameter (min) mm	13	15	17	19	21	23	25	28.5	31.5	34.5	37.5	41	44	50

3. Pitch of rivets. The pitch of the rivets is obtained by equating the tearing resistance of the plate to the shearing resistance of the rivets. It may noted that

(a) The pitch of the rivets should not be less than 2d, which is necessary for the formation of head.

(b) The maximum value of the pitch of rivets for a longitudinal joint of a boiler as per I.B.R. is

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

where t = Thickness of the shell plate in mm, and

C = Constant.

The value of the constant C is given in Table

Values of constant C.

Number of rivets per pitch length	Lap joint	Butt joint (single strap)	Butt joint (double strap)
1	1.31	1.53	1.75
2	2.62	3.06	3.50
3	3.47	4.05	4.63
4	4.17	–	5.52
5	–	–	6.00

4. *Distance between the rows of rivets.* The distance between the rows of rivets as specified by Indian Boiler Regulations is as follows :

0.33 p + 0.67 d, for zig-zig riveting, and

2 d, for chain riveting.

For joints in which the number of rivets in outer rows is half the number of rivets in inner rows and if the inner rows are zig-zig riveted, the distance between the outer rows and the next rows shall not be less than 0.2 p + 1.15 d. The distance between the rows in which there are full number of rivets (zig-zag) shall not be less than 0.165 p + 0.67 d.

5. Thickness of butt strap. According to I.B.R., the thicknesses for butt strap (t_1) are as given

below :

(a) The thickness of butt strap, in no case, shall be less than 10 mm.

(b) t_1 = 1.125 t, for ordinary (chain riveting) single butt strap.

(c) For unequal width of butt straps, the thicknesses of butt strap are

t_1 = 0.75 t, for wide strap on the inside, and

t_2 = 0.625 t, for narrow strap on the outside.

6. Margin. The margin (m) is taken as 1.5 d.

Design of Circumferential Lap Joint for a Boiler

1. *Thickness of the shell and diameter of rivets.* The thickness of the boiler shell and the diameter of the rivet will be same as for longitudinal joint.

2. *Number of rivets.* Since it is a lap joint, therefore the rivets will be in single shear.

∴ Shearing resistance of the rivets,

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

n = Total number of rivets.

Knowing the inner diameter of the boiler shell (D), and the pressure of steam (P), the total shearing load acting on the circumferential joint,

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

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

$$n = \left(\frac{D}{d}\right)^2 \frac{P}{\tau}$$

Knowing the efficiency of the circumferential lap joint (η_c), the pitch of the rivets for the lap joint (p_1) may be obtained by using the relation :

$$\eta_c = \frac{p_1 - d}{p_1}$$

4. *Number of rows.* The number of rows of rivets for the circumferential joint may be obtained from the following relation :

$$\text{Number of rows} = \frac{\text{Total number of rivets}}{\text{Number of rivets in one row}}$$

and the number of rivets in one row

$$= \frac{\pi (D + t)}{p_1}$$

D = Inner diameter of shell.

Problem 3

A double riveted lap joint with zig-zag riveting is to be designed for 13 mm thick plates. Assume σ_t = 80 MPa ; τ = 60 MPa ; and σ_c = 120 MPa State how the joint will fail and find the efficiency of the joint.

Solution. *Given : t = 13 mm ; σt = 80 MPa = 80 N/mm^2 ; τ = 60 MPa = 60 N/mm^2 ; σ_c = 120 MPa = 120 N/mm^2*

1. Diameter of rivet

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

$$d = 6\sqrt{t} = 6\sqrt{13} = 21.6 \text{ mm}$$

From Table , we find that according to IS : 1928 – 1961 (Reaffirmed 1996), the standard size of the rivet hole (d) is 23 mm and the corresponding diameter of the rivet is 22 mm

2. Pitch of rivets

We know that tearing resistance of the plate,

$$P_t = (p - d)t \times \sigma_t = (p - 23)\, 13 \times 80 = (p - 23)\, 1040 \text{ N}$$

and shearing resistance of the rivets,

$$P_s = n \times \frac{\pi}{4} \times d^2 \times \tau = 2 \times \frac{\pi}{4} (23)^2\, 60 = 49\,864 \text{ N}$$

...(∵ There are two rivets in single shear)

$$p - 23 = 49864 / 1040 = 48 \text{ or } p = 48 + 23 = 71 \text{ mm}$$

The maximum pitch is given by,

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

From Table , we find that for 2 rivets per pitch length, the value of C is 2.62.

$$\therefore \quad p_{max} = 2.62 \times 13 + 41.28 = 75.28 \text{ mm}$$

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

$$p = 71 \text{ mm}$$

3. ***Distance between the rows of rivets***

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

$$p_b = 0.33\,p + 0.67\,d = 0.33 \times 71 + 0.67 \times 23 \text{ mm}$$

$$= 38.8 \text{ say } 40 \text{ mm}$$

4. ***Margin***

We know that the margin,

$$m = 1.5\,d = 1.5 \times 23 = 34.5 \text{ say } 35 \text{ mm}$$

Failure of the joint

Now let us find the tearing resistance of the plate, shearing resistance and crushing resistance of the rivets.

We know that tearing resistance of the plate,

$$P_t = (p - d)\,t \times \sigma_t = (71 - 23)13 \times 80 = 49\,920 \text{ N}$$

Shearing resistance of the rivets,

$$P_s = n \times \frac{\pi}{4} \times d^2 \times \tau = 2 \times \frac{\pi}{4}\,(23)^2\,60 = 49\,864 \text{ N}$$

and crushing resistance of the rivets,

$$P_c = n \times d \times t \times \sigma_c = 2 \times 23 \times 13 \times 120 = 71\,760 \text{ N}$$

The least of P_t, P_s and Pc is P_s = 49 864 N. Hence the joint will fail due to shearing of the rivets.

Efficiency of the joint

We know that strength of the unriveted or solid plate,

$$P = p \times t \times \sigma_t = 71 \times 13 \times 80 = 73\,840 \text{ N}$$

∴ Efficiency of the joint,

$$\eta = \frac{P_s}{P} = \frac{49\,864}{73\,840} = 0.675 \text{ or } 67.5\%$$

Problem 4

A pressure vessel has an internal diameter of 1 m and is to be subjected to an internal pressure of 2.75 N/mm2 above the atmospheric pressure. Considering it as a thin cylinder and assuming efficiency of its riveted joint to be 79%, calculate the plate thickness if the tensile stress in the material is not to exceed 88 MPa.

Design a longitudinal double riveted double strap butt joint with equal straps for this vessel. The pitch of the rivets in the outer row is to be double the pitch in the inner row and zig-zag riveting is proposed. The maximum allowable shear stress in the rivets is 64 MPa. You may assume that the rivets in double shear are 1.8 times stronger than in single shear and the joint does not fail by crushing. Make a sketch of the joint showing all calculated values. Calculate the efficiency of the joint.

Solution. Given : D = 1 m = 1000 mm ; P = 2.75 N/mm^2 ; η_l = 79% = 0.79 ; σ_t = 88 MPa = 88 N/mm^2; τ = 64 MPa = 64 N/mm^2

1. Thickness of plate

We know that the thickness of plate,

$$t = \frac{P.D}{2\,\sigma_t \times \eta_l} + 1\text{ mm} = \frac{2.75 \times 1000}{2 \times 88 \times 0.79} + 1\text{ mm}$$
$$= 20.8 \text{ say } 21 \text{ mm}$$

2. *Diameter of rivet*

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

$$d = 6\sqrt{t} = 6\sqrt{21} = 27.5\text{ mm}$$

From Table , we see that according to IS : 1928 – 1961 (Reaffirmed 1996), the standard diameter of the rivet hole (*d*) is 28.5 mm and the corresponding diameter of the rivet is 27 mm.

3. *Pitch of rivets*

Let *p* = Pitch in the outer row.

We know that the tearing resistance of the plate per pitch length,

$$P_t = (p - d)\, t \times \sigma_t = (p - 28.5)\, 21 \times 88 = 1848\, (p - 28.5) \text{ N}$$

Since the pitch in the outer row is twice the pitch of the inner row and the joint is double riveted, therefore for one pitch length there will be three rivets in double shear (*i.e.* $n = 3$). It is given that the strength of rivets in double shear is 1.8 times that of single shear, therefore

Shearing strength of the rivets per pitch length,

$$P_s = n \times 1.8 \times \frac{\pi}{4} \times d^2 \times \tau = 3 \times 1.8 \times \frac{\pi}{4} (28.5)^2\, 64 \text{ N}$$
$$= 220\,500 \text{ N}$$

$$1848\, (p - 28.5) = 220\,500$$

$$\therefore \quad p - 28.5 = 220\,500 / 1848 = 119.3$$

$$\text{Or} \quad p = 119.3 + 28.5 = 147.8 \text{ mm}$$

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

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

From Table, we find that for 3 rivets per pitch length and for double strap butt joint, the value of C is 4.63.

$$\therefore \quad p_{max} = 4.63 \times 21 + 41.28 = 138.5 \text{ say } 140 \text{ mm}$$

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

$$p = p_{max} = 140 \text{ mm}$$

∴ Pitch in the inner row

$$= 140 / 2 = 70 \text{ mm}$$

4. *Distance between the rows of rivets*

According to I.B.R., the distance between the rows of rivets,

$p_b = 0.2\,p + 1.15\,d = 0.2 \times 140 + 1.15 \times 28.5 = 61$ mm

5. ***Thickness of butt strap***

According to I.B.R., the thickness of double butt straps of equal width

$$t_1 = 0.625\,t\left(\frac{p-d}{p-2d}\right) = 0.625 \times 21\left(\frac{140-28.5}{140-2\times 28.5}\right)\text{ mm}$$
$$= 17.6 \text{ say } 18 \text{ mm}$$

6. ***Margin***

We know that the margin,

$m = 1.5\,d = 1.5 \times 28.5 = 43$ mm

Efficiency of the joint

We know that tearing resistance of the plate,

$P_t = (p - d)\,t \times \sigma_t = (140 - 28.5)\,21 \times 88 = 206\,050$ N

Shearing resistance of the rivets,

$$P_s = n \times 1.8 \times \frac{\pi}{4} \times d^2 \times \tau = 3 \times 1.8 \times \frac{\pi}{4}\,(28.5)^2\,64 = 220\,500 \text{ N}$$

Strength of the solid plate,

$= p \times t \times \sigma_t = 140 \times 21 \times 88 = 258\,720$ N

∴ Efficiency of the joint

$$= \frac{\text{Least of } P_t \text{ and } P_s}{\text{Strength of solid plate}} = \frac{206\,050}{258\,720} = 0.796 \text{ or } 79.6\%$$

Since the efficiency of the designed joint is more than the given efficiency, therefore the design is satisfactory.