Lecture # 9-10

Riveted Joints - Boiler Joints

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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.

Since a boiler is made up of number of rings, therefore the longitudinal joints are staggered for convenience of connecting rings at places where both longitudinal and circumferential joints occur.

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Assumptions in Designing Boiler Joints

The following assumptions are made while designing a joint for boilers :

1. The load on the joint is equally shared by all the rivets.

The assumption implies that the shell and plate are rigid and that all the deformation of the joint takes place in the rivets themselves.

2. The tensile stress is equally distributed over the section of metal between the rivets.

3. The shearing stress in all the rivets is uniform.

4. The crushing stress is uniform.

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Assumptions in Designing Boiler Joints

5. There is no bending stress in the rivets.

6. The holes into which the rivets are driven do not weaken the member.

7. The rivet fills the hole after it is driven.

8. The friction between the surfaces of the plate is neglected.

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Design of Longitudinal Butt Joint for a Boiler

According to Indian Boiler Regulations (I.B.R), the following procedure should be adopted for the design of longitudinal butt joint for a boiler.

1. Thickness of boiler shell

The thickness of the boiler shell is determined by using the thin cylindrical formula.

$$t = \frac{P_i D_i}{2\sigma_t \eta_l} + CA$$

where t = Thickness of the boiler shell,

P_i = Steam pressure in boiler,

D_i = Internal diameter of boiler shell, σ_t = Permissible tensile stress,

η_l = Efficiency of the longitudinal joint and CA = Corrosion Allowance varies from 1 to 2 mm

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Design of Longitudinal Butt Joint for a Boiler

The efficiencies of commercial boiler joints are given in Table below.

Type of joint	Efficiency (per cent)
Lap Joint	
Single Riveted	45 - 60
Double Riveted	63 - 70
Triple Riveted	72 - 80
Double Strap Butt Joint	
Single Riveted	55–60
Double Riveted	70–83
Triple Riveted	80–90
Quadruple Riveted	85–94

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Design of Longitudinal Butt Joint for a Boiler

The permissible tensile stress in Eq. $t = \frac{P_i D_i}{2\sigma_t \eta_l} + CA$ is obtained by,

$$\sigma_t = \frac{S_{ut}}{(fs)}$$

where,

S_{ut} = ultimate tensile strength of the plate material (N/mm^2) ,

(fs) = factor of safety

The factor of safety in boiler applications varies from 4.5 to 4.75.

It is safe practice to assume the factor of safety as 5.

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Design of Longitudinal Butt Joint for a Boiler

There are two popular grades of steel used for boiler shells and boiler rivets.

They are designated as Grade-St 37 BR and Grade - St 42 BR.

Their ultimate tensile strengths are as follows:

Grade	σ_{ut} (N/mm^2)
St 37 BR	360–440
St 42 BR	410–500

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Design of Longitudinal Butt Joint for a Boiler

2. Diameter of rivets

The diameter of the rivet hole (d) is determined by using Unwin's empirical formula. $d = 6\sqrt{t}$

But if the thickness of plate is less than 8 mm, then the diameter of the rivet hole may be calculated by equating the shearing resistance of the rivets to crushing resistance.

In no case, the diameter of rivet hole should not be less than the thickness of the plate, because there will be danger of punch crushing.

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Design of Longitudinal Butt Joint for a Boiler

2. Diameter of rivets

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

Basic Size of rivet mm	Rivet hole diameter (min) mm
12	13
14	15
16	17
18	19
20	21

R Dia	H Dia	R Dia	H Dia
22	23	39	41
24	25	42	44
27	28.5	48	50
30	31.5		
33	34.5		
36	37.5		

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

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

Note : If the pitch of rivets as obtained by equating the tearing resistance to the shearing resistance is more than p_{max}, then the value of p_{max} is taken.

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Design of Longitudinal Butt Joint for a Boiler

3. Pitch of rivets

The value of the constant C is given in Table below.

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

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4. Distance between the rows of rivets

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

(a) For equal number of rivets in more than one row for lap joint or butt joint, the distance between the rows of rivets (p_b) should not be less than 0.33 p + 0.67 d, for zig-zig riveting, and 2d, for chain riveting.

(b) 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 chain riveted, the distance between the outer rows and the next rows should not be less than 0.33 p + 0.67 or 2 d, whichever is greater.

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The distance between the rows in which there are full number of rivets shall not be less than 2d.

(c) 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.

Note : In the above discussion, p is the pitch of the rivets in the outer rows.

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Design of Longitudinal Butt Joint for a Boiler

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.

$t_1 = 1.125\, t \left(\frac{p - d}{p - 2d} \right)$ for single butt straps, every alternate rivet in outer rows being omitted.

t_1 = 0.625 t, for double butt-straps of equal width having ordinary riveting (chain riveting).

$t_1 = 1.125\, t \left(\frac{p - d}{p - 2d} \right)$, for double butt straps of equal width having every alternate rivet in the outer rows being omitted.

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Design of Longitudinal Butt Joint for a Boiler

5. Thickness of 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 1.5d

Note : The above procedure may also be applied to ordinary riveted joints.

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Design of Longitudinal Butt Joint for a Boiler

7. Permissible Stresses - According to Clause 5 of Indian Boiler Regulations, the ultimate tensile strength and shear strength of steel plates and rivets are 26 and 21 tons per square inch respectively.

Therefore, $$S_{ut} = \frac{26 \times 2240 \times 6890}{10^6} = 401.27\, N/mm^2$$

and

$$S_{us} = \frac{21 \times 2240 \times 6890}{10^6} = 324.11\, N/mm^2$$

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Design of Longitudinal Butt Joint for a Boiler

7. Permissible Stresses -

Assuming a factor of safety of 5, the permissible tensile and shear stresses are given by,

$$\sigma_t = \frac{S_{ut}}{(f_s)} = \frac{401.27}{5} = 80.25\ N/mm^2$$

$$\tau = \frac{S_{us}}{(f_s)} = \frac{324.11}{5} = 64.82\ N/mm^2$$

There is no provision for calculating permissible compressive stress in Boiler Regulations.

Assuming, $\sigma_c = 1.5\ \sigma_t$ we get, $\sigma_c = 1.5 \times 80.25 = 120.38\ N/mm^2$

Therefore, the permissible tensile, shear and compressive stresses are assumed as 80, 60 and 120 N/mm^2

Note : The above procedure may also be applied to ordinary riveted joints.

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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 is obtained by the same relations that is used in longitudinal butt joint.

$$t = \frac{P_i D_i}{2\sigma_t \eta_l} + CA$$

The diameter of the rivet hole (d) is determined by using Unwin's empirical formula. d = 6√t

But if the thickness of plate is less than 8 mm, then the diameter of the rivet hole may be calculated by equating the shearing resistance of the rivets to crushing resistance.

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Design of Circumferential Lap Joint for a Boiler

2. Number of rivets

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

∴ Shearing resistance of the rivets, $P_s = n \times \frac{\pi}{4} \times d^2 \times \tau$

where n = Total number of rivets.

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

$$W_s = \frac{\pi}{4} \times D_i^2 \times P_i$$

therefore we have

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

Total No of rivets $n = \left(\frac{D_i}{d}\right)^2 \frac{P_i}{\tau}$

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Design of Circumferential Lap Joint for a Boiler

3. Pitch of rivets

The pitch of the rivets p_l for a circumferential joint is obtained by assuming the efficiency of circumferential lap joint.

The tensile strength of plate per pitch length of rivets is given by,

$$P_t = (p_l - d)\, t\sigma_t$$

The tensile strength of the solid plate per pitch length is given by,

$$P = (p_l t\sigma_t)$$

From above two equations, the efficiency of a circumferential joint is given by,

$$\eta_c = \left(\frac{(p_l - d)t\sigma_t}{p_l t\sigma_t} \right) = \left(\frac{p_l - d}{p_l} \right)$$

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Design of Circumferential Lap Joint for a Boiler

3. Pitch of rivets

If the efficiency of the longitudinal joint is known, then the efficiency of the circumferential joint may be obtained.

It is generally taken as 50% of tearing efficiency in longitudinal joint, but if more than one circumferential joints is used, then it is 62% for the intermediate joints.

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

$$\eta_c = \left(\frac{p_l - d}{p_l} \right)$$

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Design of Circumferential Lap Joint for a Boiler

4. Number of rows

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

$$\textit{Number of rows}, \mathrm{Nr} = \frac{\textit{Total number of rivets}}{\textit{Number of rivets in one row}}$$

$$\text{Number of rivets in one row, } \mathrm{n_r} = \frac{\pi\left(D_i + t\right)}{p_l}$$

and

$$\text{Total Number of rivets} = \left(\frac{D_i}{d}\right)^2 \frac{P_i}{\tau}$$

$$\therefore \; \mathrm{N_r} = \left(\frac{n}{n_r}\right)$$

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Design of Circumferential Lap Joint for a Boiler

5. After determining the number of rows, the type of joint such as single-riveted lap joint or double riveted lap joint is decided.

The pitch is again readjusted.

The pitch p_l obtained by the above procedure has minimum and maximum limits like the pitch of longitudinal butt joint.

that is, $p_{min} = 2d$ and $p_{max} = Ct + 41.28$

The minimum limit is set from considerations of manufacturing the rivet head, while maximum limit from considerations of obtaining leakproof joint.

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Design of Circumferential Lap Joint for a Boiler

6. The distance between the rows of rivets (i.e. back pitch) is calculated by using the relations as discussed previously.

7. After knowing the distance between the rows of rivets (P_b), the overlap of the plate may be fixed by using the relation,

Overlap = (No. of rows of rivets – 1) P_b + m

where m = Margin.

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Example.4. A double riveted lap joint with zig-zag riveting is to be designed for 12 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.

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Example.5. 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 :

σ_t = 90 MPa ;

τ = 60 MPa ; and

σ_c = 120 MPa.

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Example.6. 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.

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Example.7. 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/mm^2. 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.

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Example.8. A pressure vessel has an internal diameter of 1 m and is to be subjected to an internal pressure of 2.75 N/mm^2 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. Calculate the efficiency of the joint.

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Example.9. 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.

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Example.10. A steam boiler is to be designed for a working pressure of 2.5 N/mm^2 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.

Draw the joints to a suitable scale.

References

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