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12 Riveted Joints

12.1 Classification

Riveted joins are commonly classified as

- **Strong joints**, used in structures such as bridges, beams and trusses.
- **Tight joints**, used in tanks and containers where leakage must be prevented.
- **Strong and tight joints**, used in boilers and pressure vessels where the joint must both resist load and remain steam- and water-tight.

12.2 Installation

A rivet consists of a cylindrical shank with a factory head formed at one end. Before installation, the rivet length is chosen so that enough material projects beyond the plates to form the second, or field, head after upsetting.

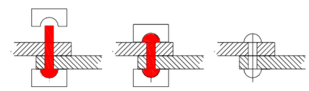

Fig. 1 Installation

The rivet is heated and inserted into the prepared hole. The factory head is supported by a bucking bar while the projecting end is upset using a hammer and rivet set. The displaced metal forms the field head and clamps the plates together.

As the hot rivet cools it contracts. Because the rivet heads prevent shortening, the rivet is placed in tension while the plates are compressed together.

This produces a clamping force that helps prevent leakage and causes part of the load to be transferred by friction between the plates.

12.3 Caulking

Even a well-made riveted joint may contain minute gaps between adjoining plates. To make the joint steam- and water-tight, the exposed plate edge can be caulked.

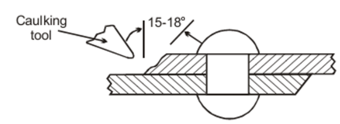

Fig. 2 Single Rivet

A blunt caulking tool is driven along the edge of the plate at an angle of approximately 15° to 18°. The metal at the edge is displaced slightly, forcing it tightly against the adjoining plate and closing any leakage path.

Caulking improves the tightness of the seam but contributes little to its strength. A seam may therefore contain more rivets than required for strength alone in order to achieve satisfactory tightness.

12.4 Riveted joint types

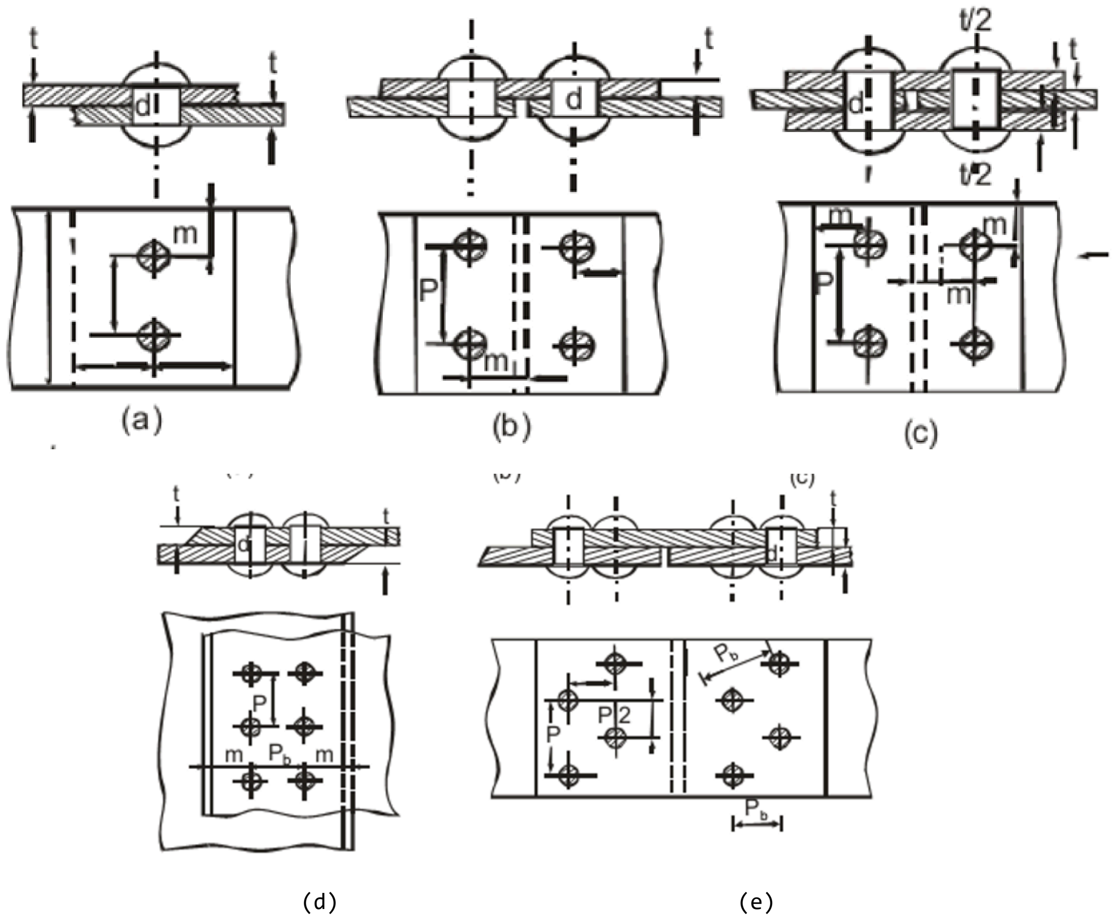

Fig. 3 Riveted joint types

The most common forms of riveted joints used in boilers and pressure vessels are shown in Fig. 3.

The simplest joint is the **lap joint**, in which one plate overlaps another. The rivets pass through both plates and transfer load by shear. Lap joints require fewer parts and are easy to manufacture, but the load path is offset, which tends to bend the plates when the joint is loaded.

A **butt joint** places the edges of the plates together and joins them using one or more cover plates, called **straps**. Because the plates remain in the same plane, butt joints provide a more direct load path than lap joints and are commonly used for important boiler seams.

The illustrated joints are:

a. **Lap joint**

The plates overlap and are connected by a single row of rivets.

b. **Single-cover butt joint**

The plate edges meet and are joined by a single cover strap on one side.

c. **Double-cover butt joint**

The plate edges meet and are joined by cover straps on both sides. The load is transmitted symmetrically through the joint, making this arrangement stronger and more efficient than the single-cover butt joint.

d. **Double-riveted lap joint**

A lap joint using two rows of rivets. The additional rivets increase the strength and tightness of the seam.

e. **Double-riveted butt joint**

A butt joint using two rows of rivets arranged in a staggered pattern. Staggering improves the efficiency of the joint by reducing the weakening effect of the rivet holes.

The dimensions shown in the figures are commonly used in riveted-joint calculations:

Symbol	Meaning
p	rivet pitch, the distance between adjacent rivets in the same row
m	margin, the distance from the centre of a rivet to the edge of the plate
d	rivet diameter
p_b	back pitch, the distance between adjacent rows of rivets
p_d	diagonal pitch, the centre-to-centre spacing of staggered rivets measured diagonally

The selection of rivet diameter, pitch, and row spacing is a compromise between strength, tightness, manufacturing cost, and ease of inspection. Additional rows of rivets generally increase the strength of a joint, but they also require more holes to be drilled, which removes metal from the plates and increases construction time.

12.5 Analysis of Riveted Joints

Riveted joints can fail in several different ways. These are known as **failure modes**.

The principal failure modes are:

- Tearing of the plate along a section weakened by rivet holes
- Shearing of the rivets
- Crushing of the rivets
- Crushing of the plate at the rivet holes or margin

Each failure mode can be analysed separately to determine the load required to produce failure.

The strength of the joint is governed by the weakest failure mode. In other words, the maximum load that can be carried safely is limited by the failure mode requiring the smallest load to produce failure.

Good riveted-joint design aims to proportion the rivets, pitch, and plate thickness so that no single failure mode is excessively weaker than the others.

12.5.1 Tearing of plate

A line of rivet holes weakens a plate in much the same way that perforations weaken a sheet of paper.

A familiar example is a spiral-bound notebook. When the paper is pulled, it usually tears between adjacent holes because only a narrow strip of material remains to resist the load.

The same effect occurs in riveted joints. In Fig. 5, the pulling force acts across a section containing rivet holes. The holes remove part of the metal, leaving only the material between the holes to resist tearing.

The width of metal available to resist tearing is

$(p - d)$

where

p	=	rivet pitch
d	=	rivet-hole diameter

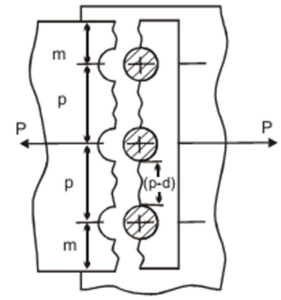

Fig. 4 Tearing

Multiplying by the plate thickness gives the net tearing area:

$A_{t(d,p,t)} \to (p - d) \cdot t$

The force required to tear the plate is therefore

$P = \sigma_t \cdot A_t(d, p, t)$

where

P	=	tearing force
A_t	=	net area resisting tearing
σ_t	=	tensile strength of the plate material

For example,

$$\begin{aligned} P_t &= \sigma_t \cdot A_t(d, p, t) \text{ where } \begin{cases} \sigma_t \to 60000 \\ p \to 3.500 \\ d \to 0.750 \\ t \to 0.375 \end{cases} \\ &= 61875 \end{aligned}$$

Notice that the rivet hole removes part of the plate section.

For comparison, the tearing force of an identical plate with no hole is

$$\begin{aligned} P &= \sigma_t \cdot A_t(d, p, t) \text{ where } \begin{cases} \sigma_t \to 60000 \\ p \to 3.500 \\ d \to 0 \\ t \to 0.375 \end{cases} \\ &= 78750 \end{aligned}$$

The reduction in strength is due entirely to the metal removed to make the rivet hole.

A larger rivet is not always stronger. Increasing rivet diameter increases the rivet's shear strength, but it also removes more metal from the plate and reduces the tearing strength.

12.5.2 Shearing of Rivet

A rivet transfers load from one plate to another. If the load becomes large enough, the rivet may fail by shearing across its cross-sectional area.

In a lap joint or single-cover butt joint, the rivet is usually in single shear, as shown on the left side of Fig. 5. The load attempts to cut the rivet along one shear plane.

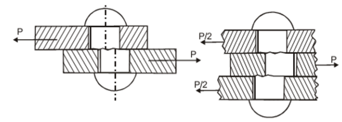

Fig. 5 Shearing

The area resisting shear is the cross-sectional area of the rivet:

$$A_{s(d)} \rightarrow \pi\left(\frac{d}{2}\right)^2$$

where

A_s	=	area resisting shear
d	=	rivet diameter

The load-carrying capacity in single shear is

Shearing stress in single shear is thus:

$$P_s = \sigma_r \cdot \pi \cdot \left(\frac{d}{2}\right)^2$$

where σ_r is the allowable shear stress of the rivet material.

For example,

$$\begin{aligned} P_s &= \sigma_r \cdot \pi \cdot \left(\tfrac{d}{2}\right)^2 \text{ where } \begin{cases} \sigma_r \rightarrow 44000 \\ d \rightarrow 0.750 \end{cases} \\ &= 19438.605 \end{aligned}$$

In **double shear**, as shown on the right side of Fig. 5, two shear planes must fail before the rivet is severed.

The load-carrying capacity in double shear is therefore approximately twice that of single shear:

$$P_d \approx 2P_s$$

Some authorities use a factor of 1.75 rather than 2.0 to account for unequal loading of the two shear planes. The NBIC uses a factor of 2 when evaluating riveted joints.

12.5.3 Crushing of Rivet

As load is applied to a riveted joint, the rivet bears against the wall of the hole. If the bearing pressure becomes excessive, the rivet material may be crushed.

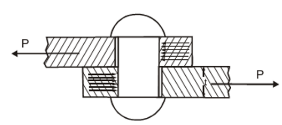

Fig. 6 Crushing

This failure mode differs from shearing. In shearing, the rivet is cut across its cross-section. In crushing, the rivet is compressed where it bears against the plate.

The area resisting crushing is the projected contact area of the rivet:

$$A_{c(d,t)} \rightarrow d \cdot t$$

where

A_c	=	area resisting crushing

d	=	rivet diameter
t	=	plate thickness

The crushing strength is therefore

$P_c = \sigma_c \cdot d \cdot t$

where

P_c	=	crushing load
σ_c	=	allowable crushing stress of the rivet material

For example,

$$\begin{aligned} P_c &= \sigma_c \cdot d \cdot t \text{ where } \begin{cases} \sigma_c \to 95000 \\ d \to 0.750 \\ t \to 0.375 \end{cases} \\ &= 26718.750 \end{aligned}$$

Increasing either the rivet diameter or plate thickness increases the resistance to crushing.

12.5.4 Tearing of Plate Margin

A rivet placed too close to the edge of a plate may tear out the material between the hole and the edge.

The resisting area consists of two sections of metal, one on each side of the rivet hole. The total area resisting failure is

$A_{ms} = 2mt$

where

m	=	margin
t	=	plate thickness

The load required to tear out the plate margin is

$P_{ms} = 2mt\sigma_t$

where σ_t is the tensile strength of the plate material.

For example,

$$\begin{aligned} P_{ms} &= 2mt\sigma_t \text{ where } \begin{cases} m \to 2 \\ t \to 0.375 \\ \sigma_t \to 60000 \end{cases} \\ &= 90000 \end{aligned}$$

To prevent this type of failure, rivets must be located sufficiently far from the edge of the plate.

12.5.5 Summary of Failures

A riveted joint may fail in several different ways:

Tearing of plate:	P_t	61875
Shearing of rivet:	P_s	19438.605
Crushing of rivet:	P_c	26718.750
Crushing of plate margin:	P_{ms}	90000

The strength of a riveted joint is determined by calculating the load required for each failure mode.

The safe load of the joint is governed by the weakest failure mode; that is, the failure mode requiring the smallest load to produce failure.

A well-designed joint proportions the rivets, pitch, margin, and plate thickness so that no single failure mode is excessively weaker than the others.

In practice, however, the theoretically optimum design cannot always be achieved. Plate thicknesses and rivet diameters are available only in standard sizes, traditionally in increments of one sixteenth of an inch. Rivet spacing is likewise limited by practical measurement and manufacturing considerations.

The designer must therefore select dimensions from available materials and proportions, then verify that the resulting joint is safe and suitable for service. Riveted-joint design is consequently a compromise between theoretical efficiency, manufacturing practicality, and economy.

12.5.6 Assumptions Used in Riveted-Joint Analysis

The equations developed in this chapter are based on several simplifying assumptions. Real riveted joints do not satisfy all of these assumptions exactly.

In practice, loads are not perfectly distributed, rivets may bend slightly, stress concentrations exist around holes, and friction between plates may carry part of the load. Nevertheless, the assumptions provide calculations that are sufficiently accurate for practical boiler design and form the basis of most traditional riveted-joint analysis.

12.6 Efficiency of Riveted Joints

The load carrying capacity of a solid plate is $P_l = p \cdot t \cdot \sigma_t$ where

p	=	pitch
t	=	thickness
σ_t	=	tensile strength

A solid plate is stronger than a riveted plate because rivet holes remove material.

The ratio of the strength of a riveted joint to the strength of the unperforated plate is called the joint efficiency.

Ideally, the strength of all modes will be equal.

In practice, equal strengths cannot usually be achieved because rivet diameters, plate thicknesses, and pitches are limited to standard sizes.

$E = \frac{\lfloor P_t, P_s, P_c, P_{ms} \rfloor}{P_l}$

Joint efficiency is the ratio of the strength of the joint to the strength of the corresponding unperforated plate.

Since the joint can only carry the load associated with its weakest failure mode, the minimum of the calculated strengths is used.

Joint efficiencies are usually stated on boiler blue prints.

When detailed calculations or original drawings are unavailable, the following typical efficiencies may be used.

12.6.1 Typical Riveted Joint Efficiencies

Type of Joint	Efficiency (%)
Lap Seam, Single Riveted	58
Lap Seam, Double Riveted	74
Lap Seam, Triple Riveted	78
Butt Strap, Double Riveted	82
Butt Strap, Triple Riveted	88
Butt Strap, Quadruple Riveted	94

Source: NBIC 2007

The shell plate between seams has full strength. The seams do not. Joint efficiency is therefore used when determining the strength and maximum allowable working pressure of riveted boilers.