

Design of Eccentrically Loaded Bolted/ Riveted Joints

Instructional Objectives:

At the end of this lesson, the students should be able to understand:

- Meaning of eccentricity in loading.
- Procedure for designing a screw/bolted joint in eccentric loading.
- Procedure for designing riveted joint under eccentric loading.

In many applications, a machine member is subjected to load such that a bending moment is developed in addition to direct normal or shear loading. Such type of loading is commonly known as eccentric loading. In this lesson design methodology will be discussed for three different types of joints subjected to eccentric loading

- (i) Screw joint
- (ii) Riveted joint
- (iii) Welded joint

1. Eccentrically loaded screwed joint:

Consider a bracket fixed to the wall by means of three rows of screws having two in each row as shown in [figure 11.1.1](#). An eccentric load F is applied to the extreme end of the bracket. The horizontal component, F_h , causes direct tension in the screws but the vertical component, F_v , is responsible for turning the bracket about the lowermost point in left (say point O), which in an indirect way introduces tension in the screws.

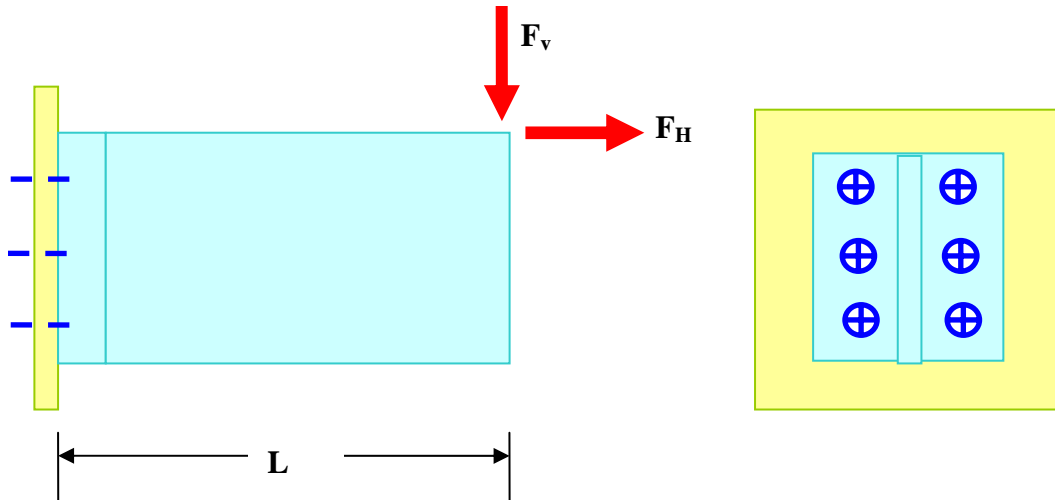


Figure 11.1.1: Eccentrically loaded bolted joint

It is easy to note that the tension in the screws cannot be obtained by equations of statics alone. Hence, additional equations must be formed to solve for the unknowns for this statically indeterminate problem. Since there is a tendency for the bracket to rotate about point O then, assuming the bracket to be rigid, the following equations are easily obtained.

$$\theta \approx \tan \theta = \frac{y_1}{l_1} = \frac{y_2}{l_2} = \frac{y_3}{l_3}$$

where y_i = elongation of the i-th bolt

l_i = distance of the axis of the i-th bolt from point O.

If the bolts are made of same material and have same dimension, then

$$f_i = ky_i$$

where f_i = force in the i-th bolt

k = stiffness of the bolts

Thus $f_i \propto l_i$ or $f_i = \alpha l_i$ (α = proportionality constant)

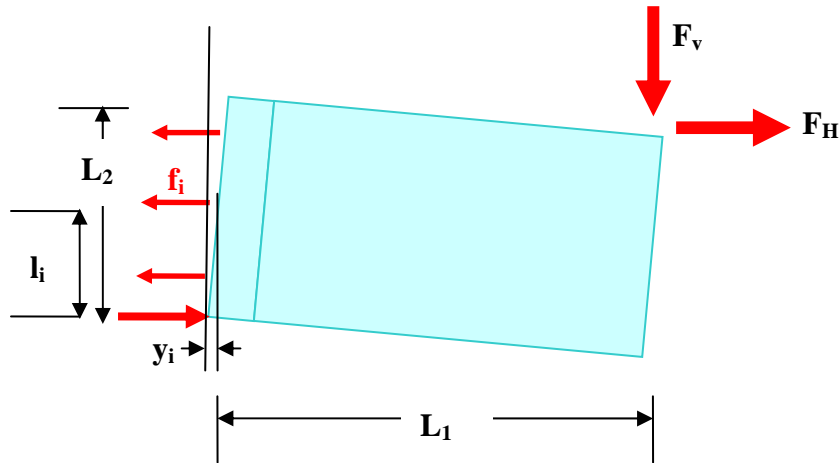


Figure 11.1.2: Determination of forces in bolts

Using the moment balance equations about O, the lowermost point in the left side, the following equation is obtained.

$$2 \sum f_i l_i = F_h L_1 + F_v L_2$$

i.e., $\alpha = \frac{F_h L_1 + F_v L_2}{2 \sum l_i^2}$. The factor 2 appears because there are two bolts

in a row.

Thus the force in the i-th screw is

$$f_i = \left[\frac{F_h L_1 + F_v L_2}{2 \sum l_i^2} \right] l_i + \frac{F_h}{n}, \text{ where } n = \text{total number of bolts.}$$

For safe design of the joint it is therefore required that

$$\sigma = \max \left\{ \frac{f_i}{A} \right\} \leq s_t$$

where s_t = allowable tensile stress of the bolt.

Note that F_v causes also direct shear in the bolt. Its effect may be ignored for a preliminary design calculation.

2. Eccentrically loaded riveted joint:

Consider, now, a bracket, which carries a vertical load F . The bracket, in this case, is connected to the wall by four rivets as shown in figure 11.1.2. The force,

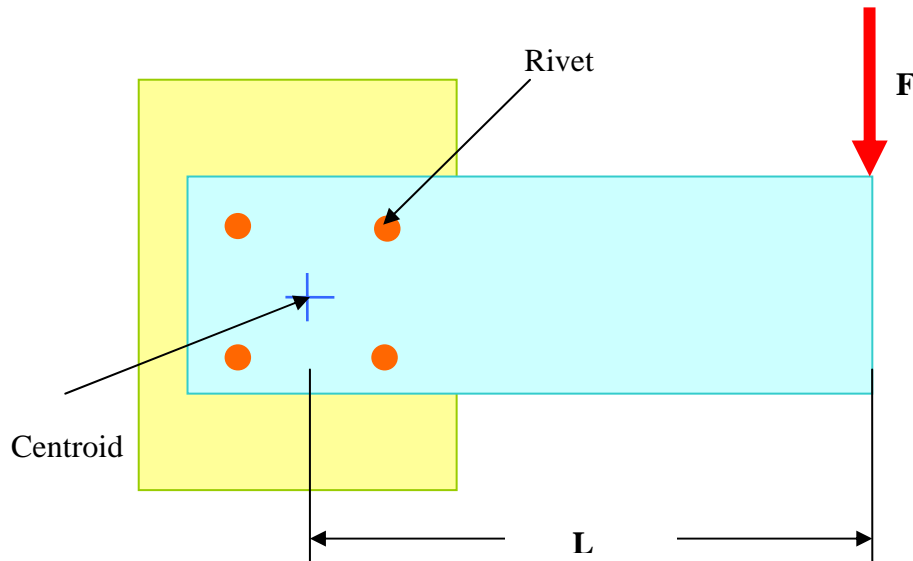


Figure 11.1.3: Eccentrically loaded rivet joint

in addition to inducing direct shear of magnitude $\frac{F}{4}$ in each rivet, causes the whole assembly to rotate. Hence additional shear forces appear in the rivets.

Once again, the problem is a statically indeterminate one and additional assumptions are required. These are as following:

- (i) magnitude of additional shear force is proportional to the distance between the rivet center and the centroid of the rivet assembly, whose coordinates are defined as

$$\bar{x} = \frac{\sum A_i x_i}{\sum A_i}, \quad \bar{y} = \frac{\sum A_i y_i}{\sum A_i}$$

(A_i = area of the cross-section of the i -th rivet)

(ii) directions of the force is perpendicular to the line joining centroid of the rivet group and the rivet center and the sense is governed by the rotation of the bracket.

Noting that for identical rivets the centroid is the geometric center of the rectangle, the force in the i-th rivet is

$$f_i = \alpha l_i$$

where α =proportional constant

l_i =distance of the i-th rivet from centroid.

Taking moment about the centroid

$$\sum_i f_i l_i = FL$$

$$\text{or } \alpha = \frac{FL}{\sum_i l_i^2}$$

Thus, the additional force is $f_i = \frac{FL}{\sum l_i^2} l_i$.

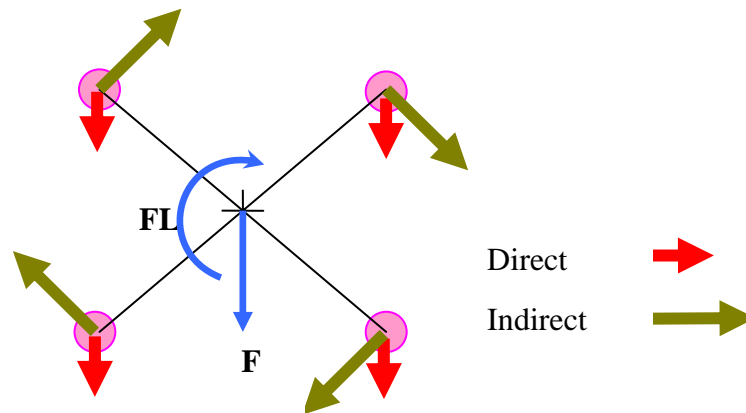


Figure 11.1.4: Forces on rivets due to

The net force in the i-th rivet is obtained by parallelogram law of vector addition as

$$f_i' = \sqrt{f_i^2 + \left(\frac{F}{4}\right)^2 + 2 \cdot \frac{F}{4} \cdot f_i \cos \theta_i}$$

where θ_i =angle between the lines of action of the forces shown in the figure.

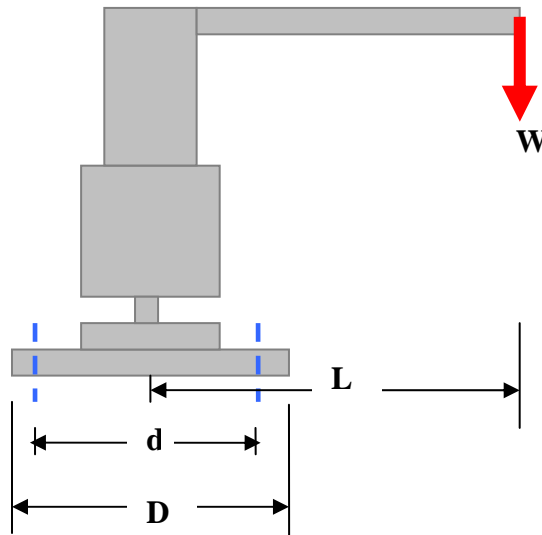
For safe designing we must have

$$\tau = \max\left(\frac{f_i'}{A}\right) \leq s_s$$

where s_s = allowable shear stress of the rivet.

Model questions and answers:

Q. 1. The base of a pillar crane is fastened to the foundation by n bolts equally placed on a bolt circle of diameter d . The diameter of the pillar is D . Determine the maximum load carried by any bolt when the crane carries a load W at a distance L from the center of the base.



Ans. In this case the pillar have a tendency to topple about the point on the outer diameter lying closest to the point of application of the load.

Choose the line joining the center of the base and the point of application of the load as the reference line. In this case

y_i = distance of the i -th bolt from the tilting point

$$= \left(\frac{D}{2}\right) - \left(\frac{d}{2}\right) \cos \theta_i$$

where θ_i = angular position of the i -th bolt. Since there are n equally spaced bolts so

$$\theta_{i+1} - \theta_i = \frac{2\pi}{n}$$

Using the same considerations as done in section-1, the force in the i-th bolt is

$$f_i = \frac{W(L-D/2)}{\sum y_i^2} \left(\frac{D}{2} - \frac{d}{2} \cos \theta_i \right)$$

It is easy to see that $\sum y_i^2 = \frac{n}{2} \left(2 \left(\frac{D}{2} \right)^2 + \left(\frac{d}{2} \right)^2 \right)$.

Hence the maximum load occurs when $\theta_i = \pm\pi$ whereby

$$f_{\max} = \frac{W \left(L - \frac{D}{2} \right) \left(\frac{D}{2} + \frac{d}{2} \right)}{\frac{n}{2} \left(2 \left(\frac{D}{2} \right)^2 + \left(\frac{d}{2} \right)^2 \right)}$$

Q. 2. A bracket is supported by means of 4 rivets of same size as shown in **figure 6**. Determine the diameter of the rivet if the maximum shear stress is 140 MPa.

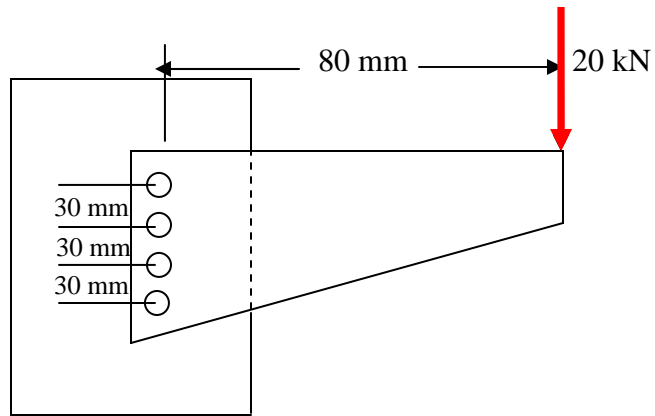
Ans. F_1 = The direct shear force = 5 kN per rivet. The maximum indirect shear force occurs in the topmost or bottommost rivet and its magnitude is

$$F_2 = \frac{20 \times 80}{2 \times 15^2 + 2 \times 45^2} \times 45 \text{ kN and the direction is horizontal.}$$

Therefore the maximum shear force on the rivet assembly is $F = \sqrt{F_1^2 + F_2^2}$.

Hence

$$\frac{\pi}{4}d^2 \times s_s = F \quad \text{which yields } d \approx 16 \text{ mm.}$$



Source:

<http://nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Machine%20design1/pdf/mod11les1.pdf>