3.4 Analysis of bolt groups

In general, any group of bolts resisting a moment can be classified into either of two cases depending on whether the moment is acting in the shear plane or in a plane perpendicular to it. Both cases are described in this section.

3.4.1 Combined shear and moment in plane

Consider an eccentric connection carrying a load of P as shown in Fig. 3.29. The basic assumptions in the analysis are (1) deformations of plate elements are negligible, (2) the total shear is assumed to be shared equally by all bolts and (3) the equivalent moment at the geometric centre (point *O* in Fig. 3.29) of the bolt group, causes shear in any bolt proportional to the distance of the bolt from the point *O* acting perpendicular to the line joining the bolt centre to point *O* (radius vector).

Resolving the applied force *P* into its components P_x and P_y in *x* and *y*-directions respectively and denoting the corresponding force on any bolt *i* to these shear components by R_{xi} and R_{yi} and applying the equilibrium conditions we get the following:

$$R_{xi} = P_x/n \text{ and } R_{yi} = P_y/n \qquad \textbf{(3.16)}$$

Where *n* is the total number of bolts in the bolt group and R_{xi} and R_{yi} act in directions opposite to P_x and P_y respectively.

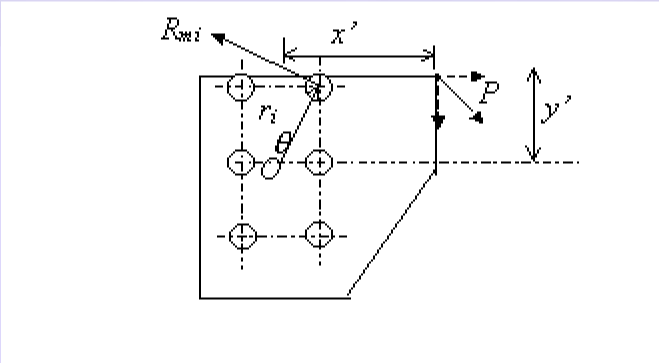

Fig. 29 Bolt group eccentrically loaded in shear

The moment of force *P* about the centre of the bolt group (point O) is given by

$$M = P_x\, y' + P_y\, x' \qquad \textbf{(3.17)}$$

where x' and y' denote the coordinates of the point of application of the force P with respect to the point *O*. The force in bolt *i,* denoted by R_{mi}, due to the moment *M* is proportional to its distance from point *O*, r_i, and perpendicular to

$$R_{mi} = k\, r_i \qquad \textbf{(3.18)}$$

Where, k is the constant of proportionality. The moment of R_{mi} about point *O* is

$$M_i = k\, r_i^2 \qquad \textbf{(3.19)}$$

Therefore the total moment of resistance of the bolt group is given by

$$MR = \Sigma\, k\, r_i^2 = k\, \Sigma\, r_i^2 \qquad \textbf{(3.20)}$$

For moment equilibrium, the moment of resistance should equal the applied moment and so *k* can be obtained as $k = M/\Sigma r_i^2$, which gives R_{mi} as

$$R_{mi} = M\, r_i/\Sigma\, r_i^2 \qquad \textbf{(3.21)}$$

Total shear force in the bolt R_i is the vector sum of R_{xi}, R_{yi} and R_{mi}

$$R2 = \sqrt{\left[\left(R_{xi} + R_{mi}\cos\theta_i\right)^2 + \left(R_{yi} + R_{mi}\sin\theta_i\right)^2\right]} \qquad \textbf{(3.22)}$$

After substituting for R_{xi}, R_{yi} and R_{mi} from equations (3.16) and (3.21) in (3.22), using $\cos\theta_i = x_i/r_i$ and $\sin\theta_i = y_i/r_i$ and simplifying we get

$$R_i = \sqrt{\left\{\left[\frac{P_x}{n} + \frac{My_i}{\sum\left(x_i^2 + y_i^2\right)}\right]^2 + \left[\frac{P_y}{n} + \frac{Mx_i}{\sum\left(x_i^2 + y_i^2\right)}\right]^2\right\}} \qquad \textbf{(3.23)}$$

The x_i and y_i co-ordinates should reflect the positive and negative values of the bolt location as appropriate.

3.4.2 Combined shear and moment out-of-plane

In the connection shown in Fig. 3.30, the bolts are subjected to combined shear and tension. The neutral axis may be assumed to be at a distance of one-sixth of the depth *d* above the bottom flange of the beam so as to account for the greater area in the compressed portions of the connection per unit depth.

The nominal tensile force in the bolts can be calculated assuming it to be proportional to the distance of the bolt from the neutral axis l_i in Fig. 3.30. If there exists a hard spot on the compressive load path such as a column web stiffener on the other side of the lower beam flange, the compressive force may be assumed to be acting at the mid-depth of the hard spot as shown in Fig. 3.30c. In such a case, the nominal tensile force in the bolts can be calculated in proportion to the distance of the bolt from the compressive force $(l_i = L_i)$.

$$T_i = k l_i \quad \text{where } k = \text{constant} \qquad \textbf{(3.24)}$$

$$M = \Sigma T_i L_i = k \Sigma l_i L_i \qquad \textbf{(3.25)}$$

$$T_i = M l_i / \Sigma l_i L_i \qquad \textbf{(3.26)}$$

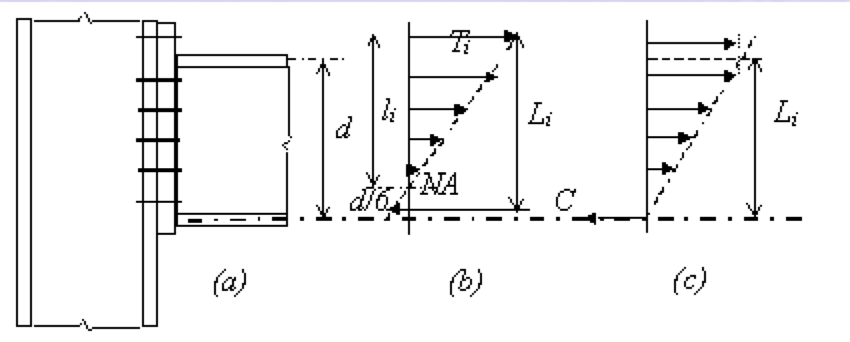

Fig. 30 Bolt group resisting out-of-plane moment

In the case of extended end plate connections, the top portion of the plate behaves as a T-stub symmetric about the tension flange. For calculating the bolt tensions in the rows immediately above and below the tension flange, l_i can be taken as the distance of the tension flange from the neutral axis to the line of action of the compressive force, as the case may be. If the end plate is thin, prying tension is likely to arise in addition to the nominal bolt tension calculated as above.

The shear can be assumed to share equally by all the bolts in the connection. Therefore, the top bolts will have to be checked for combined shear and tension as explained before.