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MOMENT CAPACITY OF ECCENTRICALLY-LOADED BOLTED CONNECTIONS

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Introduction

Normally, for eccentrically-loaded connections with the load applied in the plane of the bolt group, the applied load eccentricity is assumed to act through the bolt group centroid. However, since vertical translational displacement of the bolt group may take place, the point of rotation may not be the centroid. Instead, the method used here uses the concept of an *instantaneous center*, first proposed by Crawford and Kulak[1]. The resultant of the rotational movement about the bolt group centroid and translational vertical movement is assumed to be represented by a single rotation about a point called the instantaneous center. Unlike the centroid, as the load increases, the instantaneous center moves, until ultimate strength of the group is reached. The objective of this study is to determine what effect the increment of number of lines of bolt columns and/or rows have on the moment capacity of a bolt group.

Equations of Equilibrium

For a particular bolt n in a group consisting of m number of bolts, the vertical component of the resultant force on the bolt is given by,

$$(R_v)_n = \frac{x_n}{\sqrt{x_n^2 + y_n^2}} \cdot (R_t)_n + R_s \qquad (1)$$

$(R_t)_n$ is the shear force due to torsion on the bolt from the applied load, R_s is the direct shear force shared equally by each bolt, x_n and y_n are the horizontal and vertical distances of the bolt from the instantaneous center, i.c. (Fig. 1). From equilibrium of vertical forces, we obtain

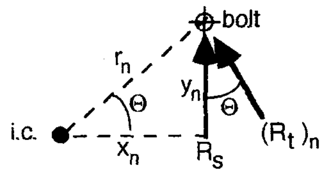

Fig. 1 Shear forces on a bolt

$$P - \sum_{n=1}^{m} (R_v)_n = 0 \qquad (2)$$

where m is the total no. of bolts and P in this case is the ultimate load for the bolt group and is currently the variable to be determined. Taking the sum of moments about the instantaneous center, we obtain

$$P.e_i - \sum_{n=1}^{m} r_n.(R_t)_n = 0 \qquad (3)$$

where e_i and r_n are the perpendicular distances from the instantaneous center, of the applied load and bolt n respectively (Figures 1 and 2).

Both equations (2) and (3) must be satisfied in order that the bolt group remains in equilibrium. As the location of the instantaneous center is not directly known, the value of $(R_t)_n$ can be obtained from,

$$(R_t)_n = R_{ult}(1 - e^{-\mu\Delta_n})^{\lambda} \qquad (4a)$$

$$\text{and } \Delta_n = \frac{r_n}{r_{max}}.\Delta_{ult} \qquad (4b)$$

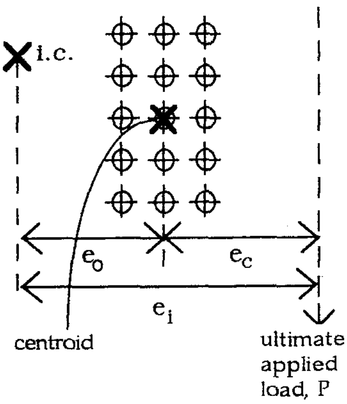

Fig. 2 Instantaneous center of a bolt group

developed by Fisher[2], that describes the load-deformation relationship of single bolts under direct shear. r_{max} is the maximum value of r_n and depends on e_i . e in equation (4a) is the base of natural logarithm. Table of values of the ultimate strength, R_{ult} , the ultimate deflection, Δ_{ult} , and the regression coefficients, μ and λ , for various types of bolts and plates are available[2].

Computer Analysis

The value of P obtained from equation (2) and (3) must be equivalent. A program was developed to determine the bending moment capacity of various bolt groups from 1x2 to 15x15 (rows x lines) numbers of bolts. It uses an iterative method and ultimately narrows down a value of e_i that will converge the difference between equation (2) and (3) to a predefined tolerance.

In this analysis, the pitch (horizontal distance between bolts) and the gauge (vertical distance between bolts) was maintained at 40 mm throughout. It was assumed that 22.23 mm A325 bolts were used with ASTM 440 steel for plates. Fisher's table[2] gives values of $R_{ult} = 440$ kN, $\Delta_{ult} = 4.7$ mm, $\mu = 23$ and $\lambda = 1$. The load acts 30 mm from the bolt group centroid in a vertical direction. Some results are shown in Figures 3 and 4.

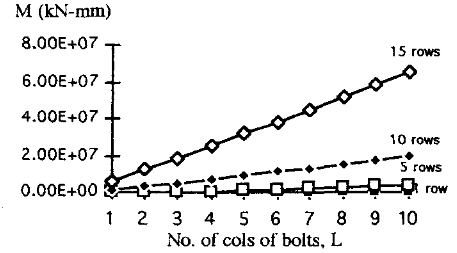

Fig. 3 Moment Capacity, M vs. no. of columns of bolts

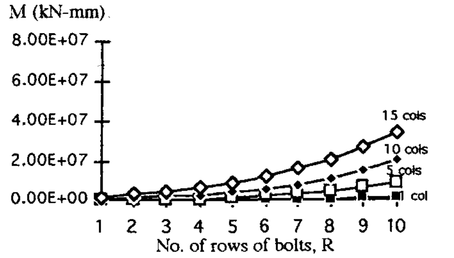

Fig. 4 Moment Capacity, M vs. no. of rows of bolts

In a second analysis, the pitch was increased to 80mm. Some of the results are summarized in the table below.

Table 1. Comparison of sample results of connections with p=40mm and p=80mm

Pitch, p(mm)	*No. of rows, R*	*No. of lines, L*	*Total no. of bolts*	*Moment capacity (kN-mm)*
40	5	10	50	4.37×10^6
80	5	10	50	8.29×10^6
40	10	5	50	9.41×10^6

Observations

(1) Increasing L while keeping R constant increases the moment capacity significantly for larger values of R (Fig. 3). The rate of change of moment capacity with respect to the number of lines increases substantially at higher numbers of rows. At lower numbers of rows (5 or less), it would seem that adding more lines of bolts does not increase the moment capacity substantially.

(2) Increasing R while keeping L constant increases the moment capacity (Fig. 4). The rate of change of M with respect to R is greater for higher R values. For lower numbers of lines (5 or less), the rate of change of M with respect to R does not change substantially.

(3) If pitch can be changed, increasing pitch for a certain number of lines and rows of bolts, increases the moment capacity. This is illustrated in the table above.

Conclusions

The following conclusions were reached:

(1) If pitch and gauge of bolts are maintained, the increase in number of rows of bolts has a more significant effect than the increase in the number of lines of bolts on the moment capacity of eccentrically-loaded bolted connections.

(2) Increasing the pitch of connection while maintaining the number of lines and rows, increases its moment capacity . It is possible to obtain a particular value of moment capacity when reducing the number of rows of bolts by increasing both the number of lines of bolts and the pitch.

References

1. *Eccentrically Loaded Bolted Connections*, Crawford, S.F., Kulak, G.L., ASCE Proc., Vol. 97, ST3, March 1971, pp. 765-783

2. *Behavior of Fasteners and Plates with Holes*, Fisher, J.W., ASCE Proc., Vol. 91, ST6, Dec. 1965, pp. 265-286