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Horizontal and Vertical Eccentrically Load on the Bolt Connections Analysis

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Abstract: Bolted connections have been widely used for steel construction. Horizontal and vertical eccentric loading on different geometries bolted connections with angles are varying from any degrees. Using instantaneous center of rotation method to analysis the eccentrically loaded for bolted connections is more accurate and realistic but it involves complex and repetitive operations. Elastic method is simpler and more convenient, generally used instead of the instantaneous center of rotation method. The effect of bolted connection strength is not the same on horizontal eccentricity and vertical eccentric load distance which the strength effect is dependent on the angle of the eccentric load. This study analyzes the design strength of bolts using two methods which shows that the use of elastic methods to analyze bolt strength will underestimate nearing 30% this approach is less economical and not recommended. This study for the bolt connections strength of a certain understanding and awareness, expect the future for the safety of steel structure contribute.

Key words: Instantaneous center of rotation method, elastic method, eccentrically load, rotation, strength, steel

INTRODUCTION

There are two methods to the analysis of eccentrically loaded bolted connections which including the elastic methods and the instantaneous center of rotation method (AISC., 2010) specifications tabulated methods). The elastic methods analysis of the shear stress of each bolt according to the direct shear stress and eccentric load caused moment stress together which can be calculated the design load.

The instantaneous center of rotation method is a closed form analytical solution to the strength of the bolt connections and it is more realistic and popular in those methods. This method developed by Crawford (1969) and Crawford and Kulak (1971) tested riveted connections, its results of the tests were presented by Higgins.

Uang *et al*. (2010) indicated that the inelastic action through the bolt slip and bearing in the connection is a ductile yielding mechanism. Su and Siu (2007) found the ultimate capacity of the bolt group could be higher than elastic method.

Siu and Su (2009) predict the non-linear load-deformation response of bolt groups subjected to combined in-plane moment and shear. The bolted connections were eccentrically loaded with eccentricities. Using an instantaneous center along with the effective eccentricity was introduced to replace the elastic method. AISC specifications tabulated for eccentrically loaded bolted connections based on instantaneous center of rotation method. Engineers can simply and easily use the design in the bolt connections as long as the bolt forms, the bolt arrangement of several symmetric and eccentric loads for the common angle (Su and Siu, 2007).

Bolted connections are subjected to eccentric loads from horizontal eccentricity and vertical eccentricity. Eccentric load will cause the design strength decreased. The user may use linear interpolation which can lead to an over-estimation of bolt strength if particular bolted connections geometry is not found.

MATERIALS AND METHODS

Elastic method: This type of analysis has been commonly used since at least 1870's. Elastic method uses basic mechanics and superposition to estimate the shear stress of each bolt by the ratio of the bolt distance from the center of gravity of the bolt connections to find the maximum bolt distance to the same reference. Friction or slip resistance between the connected parts is neglected. These connected assumed to be perfectly rigid. The design eccentric load is calculated from the farthest bolt from the center which will have the highest shear stress. The required strength per bolt is r where:

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$$r = \sqrt{\left(r_{px}+r_{mx}\right)^2 + \left(r_{py}+r_{my}\right)^2}$$

Where:

$$r_{px} = \frac{P\sin\theta}{n} \text{ and } r_{py} = \frac{P\cos\theta}{n}$$

To determine the resultant force on the most highly stressed bolt, it must be resolved into horizontal component, r_{mx} and vertical component, r_{my} where:

$$r_{mx} = \frac{Md_y}{I_p};\ r_{my} = \frac{Md_x}{I_p} \quad (3)$$

Where:

d = Radial distance from CG to the center of bolt
I_p = Polar moment of inertia of the bolt group
P = The shear per bolt due to the concentric force kips
n = The number of bolts

Instantaneous center of rotation method: Eccentricity load produces both a rotation and translation of bolted connections with respect to the other. An instantaneous center is defines a rotation and translation on a structural element caused by eccentricity. The location of the instantaneous center depends upon the geometry of the bolt connections as well as the direction and point of application of the load. Crawford and Kulak (1971) and Crawford (1969) tested eccentric compression bolted connections, using a new load-deformation relationship was introduced. The load-deformation relationship for each bolt is:

$$R = R_{ult}\left(1\text{-}e^{-10\Delta}\right)^{0.55} \quad (4)$$

Where:

R = Nominal shear strength of one bolt at a deformation Δ, kips
R_{ult} = Ultimate shear strength of one bolt, kips
Δ = Total deformation including shear, bearing and bending deformation in the bolt and bearing deformation of the connection elements
e = The 2.718, ..., base of the natural logarithm

The nominal shear strength of the other bolts in the connections can be determined by applying a deformation Δ that varies linearly. If the instantaneous center location is correctly determined, then the equations of in-plane static equilibrium will be satisfied.

RESULTS AND DISCUSSION

Illustrated: This example is to demonstrate the methods specified for bolted connections as shown in Fig. 1. The procedure of calculation is not presented here due to the limited space set by the conference. Only the results based on the various methods are given are followed. In Fig. 1, S and D values are 3 inch, the e_x and e_y are the eccentricity location of the applied load (P) from the center of gravity of the bolt group as shown. Using instantaneous center of rotation methods to analyze the C values from difference angle and e_x as shown in Fig. 2-8.

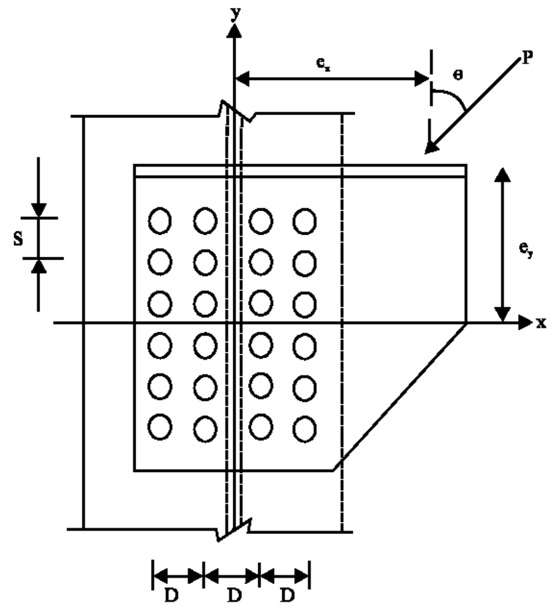

Fig. 1: Bolted connection

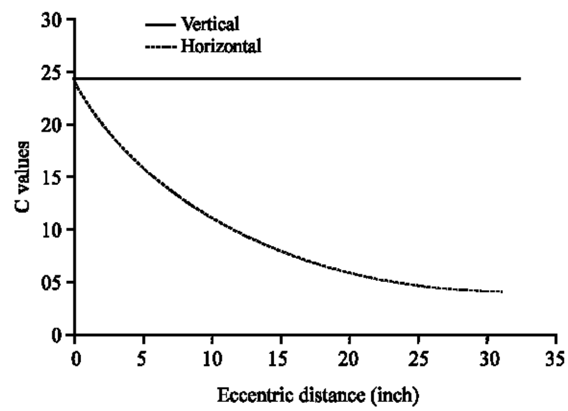

Fig. 2: Eccentricity of the C values (θ = 0°)

Figure 2-8 show the angle is increasing, only the horizontal eccentric or vertical eccentric load when the C value reflects the change in strength. The greater the distance of eccentric load, the smaller the values of C.

Figure 2 for the eccentric load angle 0°C value, when there is no horizontal eccentricity of the vertical eccentricity distance for the C value has no effect.

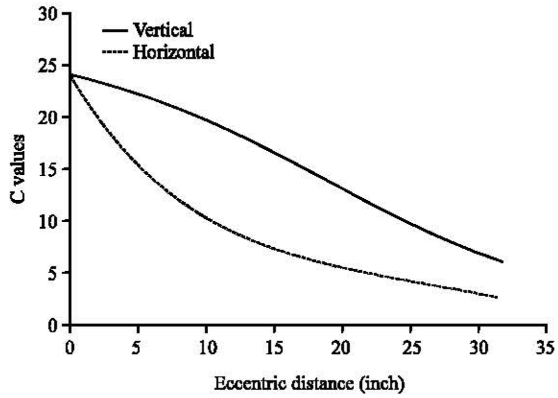

Fig. 3: Eccentricity of the C values (θ = 15°)

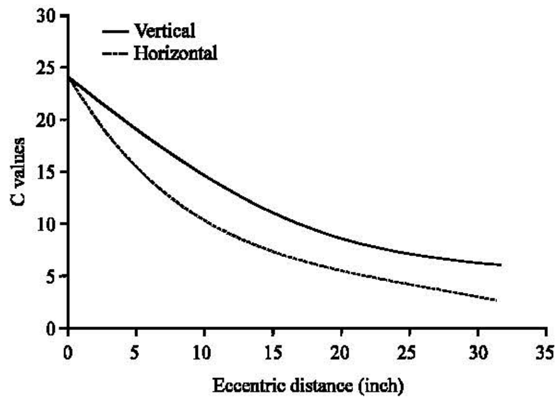

Fig. 4: Eccentricity of the C values (θ = 30°)

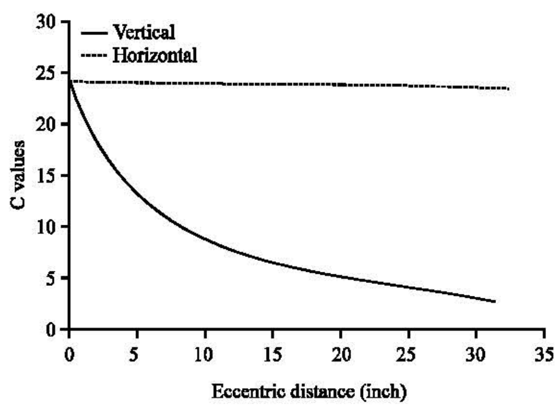

Fig. 5: Eccentricity of the C values (θ = 45°)

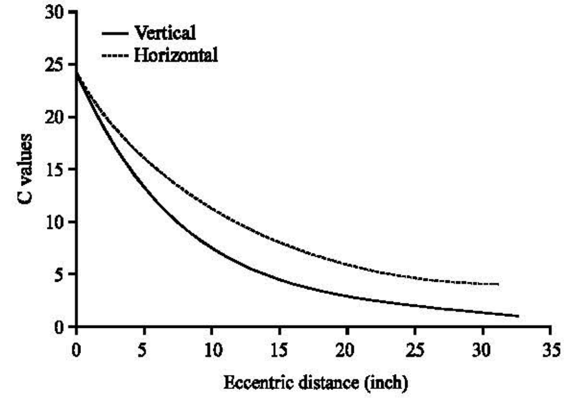

Fig. 6: Eccentricity of the C values (θ = 60°)

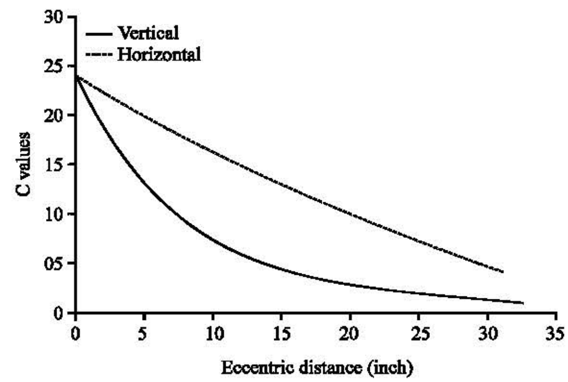

Fig. 7: Eccentricity of the C values (θ = 75°)

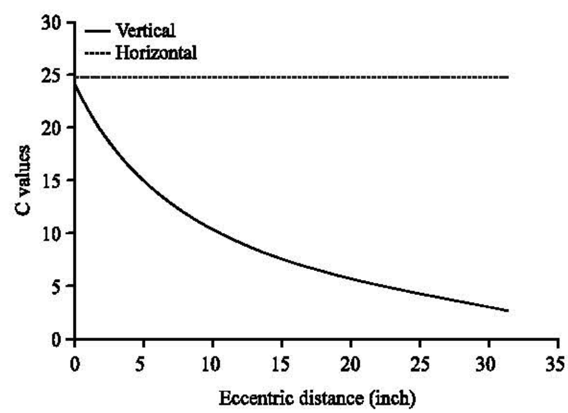

Fig. 8: Eccentricity of the C values (θ = 90°)

Figure 10 can see the same results, Fig. 5 for the eccentric load angle of 45°, the horizontal and vertical eccentricity distance will produce the same results. Figure 9 shows the effect of horizontal eccentric load distance on design strength at different angles which are 0, 15, 30, 45, 60, 75 and 90° eccentric loading. Eccentric loaded for 0-15° change is almost the same. Under th same conditions, the larger the angle, the greater the design eccentric loaded, the larger the eccentricity, the smaller the design eccentric loaded.

Figure 10 shows the effect of vertical eccentric load distance on design strength at different angles. Eccentric loaded for 75-90° change is almost the same. Under the same conditions, the larger the angle, the smaller the

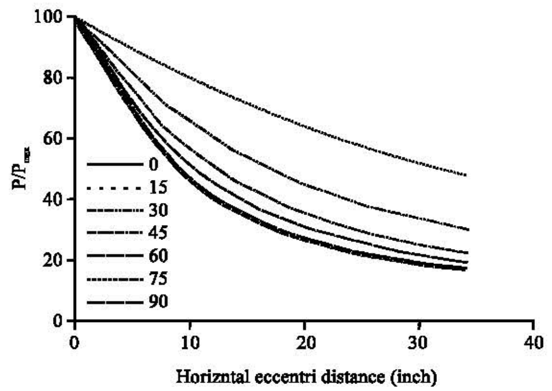

Fig. 9: Changes in horizontal eccentricity and angle

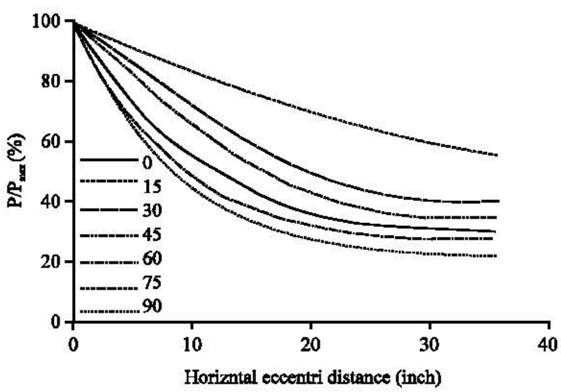

Fig. 10: Changes in vertical eccentricity and angle

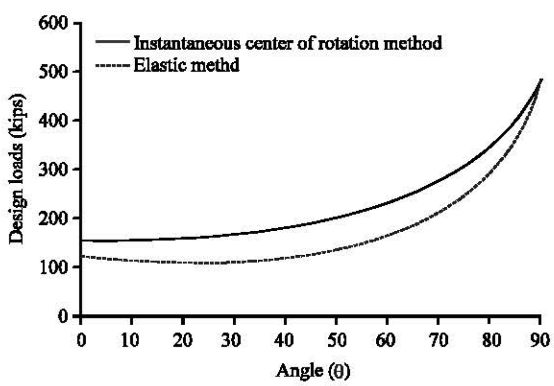

Fig. 11: Two methods analysis for design loads

design eccentric loaded. Design the eccentric force P for which the design shear strength of the bolts in the connection is adequate using the elastic and instantaneous center of rotation methods. Use 7/8 in. A325-N bolts with the load case $e_x = 16$ in; $e_y = 0$ (Fig. 11). Figure 11 shows the horizontal axis for the 0-90°, vertical axis for the design load. Instantaneous center of rotation method from 0-90° corresponds to 159.69-518.40 kips in the eccentric load design strength, elastic method is. In this case, the design eccentric load calculated from 119.67-518.40 kips. elastic method and instantaneous center of rotation method the maximum difference of 29.95%. The elastic method ismore uneconomical and accurate although relatively simple.

CONCLUSION

In this study, the eccentric load is designed to compare elastic and instantaneous center of rotation methods. The following findings can be found from this study. The results of similar design eccentric loadings are shown using the Instantaneous center of rotation method and the AISC specification, indicating the correct basis for this study.

The vertical eccentric force angle becomes larger when the impact of reduced strength will be relatively more; the horizontal eccentric load is the opposite shown in Fig. 9 and 10. Two methods are used to analyze the eccentric load design of bolts and compare the differences shown in Fig. 11.

Elastic method will underestimate the design that leads to uneconomical and irrational, instantaneous center of rotation method is the most accurate but will cause complex and lengthy operation to the user caused difficulties. Easier and simpler analysis of bolted connections of eccentric load analysis is required by the user.

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