Analysis of Behaviour for Bolt Joint of Corrugated Plate Subjected to Bending Moment

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Abstract. In this paper, the stress distribution of corrugated plate and bolt is obtained by numerical simulation of single row screw connection of corrugated plate with different side distance. The position of rotation axis and suitable side distance of single row bolt under the action of moment are determined, and the calculation formula of single row bolt connection of corrugated plate under the action of moment is given by referring to the calculation formula of steel structure bolt connection.

1. Numerical simulation of single row screw connection of corrugated plate
Since this test only studies the position of the center axis of rotation under different margins, the specimens have the same parameters except for the margins. The bolt prestress is based on the 8.8 M20 bolt prestress in Steel Structure Design (GB50017-2017) 125kN to add.

Considering the convergence of the finite element software Abaqus, displacement loading is used when loading, and the loading displacement is 15 cm. The loading point is taken at the crest of the three-point point of the corrugated board, and the boundary conditions are determined by simple supports at both ends. The loading mode is shown in Figure 1.

2. Analysis of simulation results
The figure 2 below shows the numerical model simulation results. It can be seen from the figure that the part with large stress is bolt and base plate. The stress of corrugated plate is relatively small, which is mainly due to the different material properties of them. The yield strength of Q235 steel is lower than that of grade 8.8 bolt.
2.1. Tension distribution of each bolt

Number the bolts according to the direction of the coordinate system. The one near the origin of the coordinate is No. 1 bolt, the middle is No. 2 bolt, and the last is No. 3 bolt. The figure 3 shows the bolt tension under different margins. When the margin is 20mm, the edge of the bolt pad and the edge of the corrugated board coincide, and the tension of No. 1 and No. 3 bolts at the edge is about 76% greater than that of No. 2 bolt.

When the edge distance is more than 20 mm, the tensile force of No.1 and No.3 bolts on the transverse edge of corrugated plate is greatly reduced and less than that of No.2 bolt in the middle, while the tensile force of No.2 bolt is greatly increased to about 65 kn. And with the increase of the margin, the tension of No.1 and No.3 bolts decreased after a short increase, while the tension of No.2 bolts remained at the original level basically unchanged, resulting in the tension gap between bolts gradually increased. And the tension value of No. 2 bolt at the wave crest is more than 20% - 30% of that of No. 1 and No. 3 bolt. When the edge distance is more than 70mm, the difference between them is greater.

2.2. Analysis of bolt tension variation with margin

Taking the average value of the three bolt tensions as the reference value, the change in the tension of each bolt is unstable when the margin just appears, and will change greatly. When the margin is 40mm, the average value starts to stabilize gradually, and gradually decreases when the margin increases to 50mm.

Although the increase of edge distance will reduce the bolt tension to a certain extent, considering the tension difference between bolts and the utilization rate of corrugated steel, it is not significant to increase the edge distance blindly. Considering all factors, when using M20 bolt connection, the edge distance of corrugated plate is in the range of 40-60mm.
3. Calculation of single row bolt tension of corrugated board

The biggest difference between the corrugated plate and the flat plate is that there is corrugation in the cross section. When subjected to bending, it can resist part of the bending moment to a certain extent, so the calculation process is different from that of the flat plate.

3.1. Derivation of calculation formula for bolt tension

The above model is simplified as a mechanical model for calculation. The maximum bending moment at the corrugated plate connection is , because the section characteristics of the corrugated plate can resist part of the bending moment, this part of the bending moment is defined as , and the bending moment borne by the bolt is defined as , so the total bending moment can be expressed as equation (1)

\[ M_1 = M_S + M_B \]  

Where
- \( I_z \) —— Moment of inertia of cross section to neutral axis z
- \( y_{\text{max}} \) —— The ordinate of the section at the farthest point from the neutral axis

According to the calculation formula of bolt group under the action of torque in "Code for Design of Steel Structures" (GB50017-2017), the calculation formula of single bolt tension is as equation (2)

\[ N = \frac{M}{ny_1} \sum_{i=1}^{n} y_i^2 \]  

Where
- \( N \) —— Tension of single bolt
- \( n \) —— Number of bolt rows
- \( y_1 \) —— Maximum value in A
- \( y_i \) —— The distance from each bolt to the centroid of bolt group
- \( M \) —— Moment at joint

When the bolt has only a single row, equation (3) becomes

\[ N = \frac{M_B}{ny_1} \]  

3.2. Contrast analysis of average value of bolt tension calculation

According to the above formula, the back calculation is carried out for the neutral axis under the single row of bolt connection, and Figure 4 is obtained. It can be seen from Figure 4 that the distance between the neutral axle and the nearest bolt row is about 20 mm. The main reason is that the stiffness of the edge with the edge distance of 20 mm is larger than that of other parts due to the existence of the base plate, so the rotation axis is basically at the edge of the base plate (i.e. 20 mm). Even if the edge distance increases more, the position of the rotation axis does not change much. It can be seen that blindly increasing the edge distance will only cause waste of resources, which will not play a big role in improving the stress situation of the bolt, so it is very important to select the appropriate edge distance under the condition of ensuring that the edge will not be torn.
In summary, when the corrugated plate is subjected to bending moments and the connection part only depends on the single-row bolt connection, when calculating according to the "Steel Structure Design Code" (GB50017-2017), the selection of the rotation axis is recommended to be determined according to the edge distance of the pad. However, considering the safety factors, reducing the distance properly can improve the safety, so reducing the distance of the rotating shaft by 25% to 15 mm. For example, the size of the base plate in this example is that the distance between the rotating shaft and the nearest row of bolts is 20 mm, which should be taken as 15 mm in calculation. Distance of 15 mm is selected as $Y_1$ to calculate the average value of bolt tension under each side distance, and compare with the single bolt tension value as shown in the figure 5. It can be seen from the figure that the calculated average value is about 19% higher than the maximum value of the average tension. Considering that the bolt tension at the wave crest is smaller than that at the wave trough, the calculated average value can be increased by about 10% - 20% when calculating the bolt tension at the wave crest.

4. Conclusions

- When the margin is 20mm, the pulling force of the No. 1 and No. 3 bolts at the edge is about 76% greater than that of the No. 2 bolt at the peak.
- With the increase of the edge distance, the tension of No.1 and No.3 bolts decreased rapidly and maintained at a certain plateau then began to decline slowly, while the tension of No.2 bolts increased rapidly and maintained at the plateau about 65 kN.
- The rotation axis of the bolt is on the edge of the backing plate. In order to improve safety during calculation, the distance between the rotation axis and the nearest bolt can be shortened.
- Taking all aspects into consideration, when the corrugated board is connected with M20 bolts, the margin is more suitable in the range of 40-60mm.

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