Theoretical and Finite Element Analysis of Steel Corbel Columns under Eccentric Compression

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Abstract: In order to study the stress characteristics of steel corbel column under eccentric pressure, the corbel column is regarded as a cantilever column for theoretical analysis based on engineering mechanics, and the analytical solution of structural stress of corbel column is obtained. The three-dimensional finite element models of three kinds of corbels are established by using ABAQUS software. The static analysis under eccentric load is carried out, and the stress distribution of corbel columns is obtained. The results show that changing the loading position will have a great impact on the stress state of the structure, and finding out the reasonable loading position can make the component better exert its mechanical performance. Finally, the reasonable loading position and structural measures of the single corbel column in this project are proposed, which can provide reference for similar projects.

1. Introduction
Corbel columns are often used in industrial buildings as load-bearing components. With the continuous improvement of China's industrialization, there is an increasing demand for large-span space workshops. The commonly used prefabricated reinforced concrete corbel columns can not meet the construction requirements of new industrial buildings[1]. A new industrial workshop is to be built in an economic and Technological Development Zone of a city in Northeast China, which requires large operation space and installation of crane beam with large tonnage. According to experts' demonstration, if the conventional RC corbel column is used, the column section size will be greatly increased. In order to place the crane beam in a reasonable position, the clear distance between the crane beams must be reduced, and the crane cannot be installed normally. Therefore, in order to meet these requirements, the corbel is redesigned. The theoretical research on corbel is less. From the stress characteristics of corbel, the corbel is mainly affected by pressure and bending moment. P Z Guo [2] analyzed the overall corbel column as a cantilever deep beam, and checked the overall bearing capacity of the structure. For the concrete corbel column, many experts and scholars based on truss theory and shear friction theory to analyze the bearing capacity of corbel part[3], combined with a large number of experimental research results, obtained some semi empirical formula, although the theoretical basis is not enough, but enough to meet the actual engineering use. It is difficult to analyze the local force of corbel column from the theoretical point of view, only through the experimental method and statistical data analysis to get some empirical results[4,5].
In this paper, based on engineering mechanics, the corbel column is regarded as a cantilever column, and the analytical solution of the structural stress is obtained. The stress analysis of the corbel column is carried out by using the finite element software ABAQUS, and the stress conditions under different loading positions are obtained, and the reasonable loading position of the new type of corbel is determined. Finally, suggestions for determining the reasonable loading position of the single corbel are given.

2. Theoretical analysis of corbel stress
Corbels are all eccentrically compressed members. In normal use, corbels are mainly subjected to the joint action of bending moment and pressure. Under the action of bending moment, the inner and outer fibers of the corbel column are in compression and tension respectively. The pressure will make the whole column in compression state. The stress state of each part of the corbel column needs to be superimposed. After calculation, the most unfavorable load on the top of the column is 100kN, and that of the crane beam is 100 kN.

3. Finite element model of corbel

3.1. Corbel design
In this study, three different structural forms of corbel columns are established. The specific dimensions of corbel columns are shown in Figure 1, and the thickness of columns is taken as 0.2m.

3.2. Establishment of finite element model
In this paper, the finite element model of steel corbel column is established by using the finite element software ABAQUS [6]. In the construction process, the corbel part is generally welded, and it is regarded as the whole structure in the modeling, and the calculation and Simulation of the weld is not done. The material selection of this model is only steel, and the specific parameters are shown in Table 1. The bottom of the finite element model of corbel column is completely fixed, that is, the linear displacement (U1, U2, U3) in x, y and z directions and the angular displacement (UR1, UR2, UR3) along the x, y and z directions are fixed. A reference point is set up in the corbel part of the column and the top of the column, which is coupled to the top of the column, and then the load is applied on the reference point to simulate the crane beam load and roof load. The mapping method is used for mesh generation. The eight node three-dimensional solid element (C3D8R) is used in the mesh generation. A larger mesh is drawn up for calculation, and then the mesh is reduced to half of the original one. Comparing the results of two calculations, if the error is less than 5%, the result is considered to be accurate. Otherwise, the mesh should be subdivided and recalculated. The established finite element calculation model is shown in figure 2.
Table 1. Material parameters

| Material type | Modulus of elasticity (MPa) | Poisson's ratio | Density (Kgm⁻³) | Yield strength (MPa) |
|---------------|-----------------------------|-----------------|------------------|---------------------|
| Steel         | $2.0 \times 10^5$           | 0.3             | 7800             | 300                 |

4. The influence of different parameters on the mechanical properties of corbel

4.1. Different forms of corbel

According to the results of the finite element calculation, the maximum stress of the three types of corbel column designed in this paper will appear at the place where the corbel part and the main body of the column are connected, and the corbel of different structural forms will have an impact on the maximum stress as shown figure 3. The maximum stress values are shown in Table 2.

Table 2. The maximum stress of three kinds of Corbels

| Form of corbel columns | Right angle | Obtuse angle | Arc shape   |
|------------------------|-------------|--------------|-------------|
| $\sigma_{\text{max}}$ (Mpa) | 17.60       | 16.82        | 15.67       |

4.2. Different loading positions

According to table 3, we can see that the absolute values of stress at points A, B and C (figure 4) gradually decrease with the gradual backward movement of action position. The displacement value is the displacement value of the top of the bracket under the load. Due to the eccentric compression of the corbel column, the top of the column has a certain forward displacement. The loading position is gradually moved backward along the central axis of the column, and it is calculated once every 0.02m of movement. The load is recorded as a, b, c, d, e, f, g from the center of column top. With the action point moving backward gradually, the horizontal displacement value of the top of the corbel part of the corbel column also gradually decreased [7].
Figure 4. Schematic diagram of stress extraction point

Table 3. Stress of each point when loading position changes

| Abscissa (m) | \(\sigma_A\) (Mpa) | \(\sigma_B\) (Mpa) | \(\sigma_C\) (Mpa) | Displacement (mm) |
|-------------|-------------------|-------------------|-------------------|-------------------|
| a           | 11.32             | -4.76             | 15.67             | 3.36              |
| b           | 10.78             | -4.23             | 14.88             | 3.14              |
| c           | 10.25             | -3.69             | 14.09             | 2.91              |
| d           | 9.71              | -3.16             | 13.30             | 2.69              |
| e           | 9.18              | -2.63             | 12.50             | 2.46              |
| f           | 8.64              | -2.10             | 11.71             | 2.24              |
| g           | 8.11              | -1.57             | 10.92             | 2.02              |

5. Comparison of calculated and theoretical values

Figure 5. Comparison of theoretical value and numerical solution
The comparison between the theoretical calculation and the numerical solution is shown in figure 5. From the figure 5, it can be found that the theoretical calculation value and the numerical solution are more and more similar with the gradual backward displacement of load, and the error gradually decreases. This is due to the forward displacement of eccentric compression member, which leads to the p-Δ effect. With the gradual backward displacement of load, the displacement value of the structure gradually decreases, so the p-Δ effect is weakened, which makes the theoretical calculation results more and more consistent with the actual stress situation.

6. Construction measures and design suggestions
In the actual design part of the corbel column, the shape of the corbel needs to be specially designed. The reasonable shape can reduce the maximum stress value in the structure, so that the stress can be more reasonable distributed in the structure, and give full play to the mechanical properties of the material. In view of the three types of corbel column proposed in this paper, the arc-shaped corbel has more reasonable stress distribution than the other two. The circular corbel can not only bear the load of crane beam, but also play the role of rib, which changes the distribution of local stress and effectively relieves the local stress concentration [8,9].

In the process of normal structure construction, the load is always arranged in the center of the structure. For this kind of column with single corbel under eccentric compression, the transverse displacement of the structure can be reduced by adjusting the position of load. With the backward displacement of loading position, the absolute value of stress at A and B points gradually decreases. It can be seen that under the condition of ensuring other construction requirements, the roof load of single corbel column is under construction, the loading position can be moved back to weaken the p-Δ effect and give full play to the bearing capacity of the structure[10].

7. Conclusions
The single corbel structure column is designed. Through theoretical calculation and finite element structural model calculation, the following conclusions are obtained.

(1) Compared with the three forms of corbel, the arc-shaped corbel has better stress distribution performance and should be widely used in the design of corbel structure.

(2) The p-Δ effect of single corbel column can be effectively weakened by adjusting the loading position of roof load at the top of column, so that the actual stress state of structure can be estimated by simple structural mechanics and material mechanics, which should be fully considered in the design and construction of corbel column.

(3) In engineering practice, the loading position of such single corbel column should not only be arranged in the center of the structure, but also determined by calculation according to the concrete form of the corbel column and the relationship between the loads.

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