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Research on the Force of Steel Column in Tower Crane High Pile Cap System

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Abstract: Due to the special working condition of the tower crane, the high pile bearing system installed in the middle of the foundation pit should bear relatively large vertical load, horizontal force, bending moment and torque. The force situation is very complex. The research results show that the steel column is a compressive bending force member, and the most unfavorable working condition occurs in the stage, when the installation tower crane is put into use and the foundation pit has not been excavated.

1. Introduction

In the midst of towering buildings in the urban areas of large cities, due to the restrictions of the surrounding narrow environment, the tower crane can only be installed in the middle of the foundation pit to achieve 360 degree free rotation. More and more projects use tower crane high pile caps, and install tower cranes before the excavation of the foundation pit in advance. Due to the special working condition of tower crane, its high pile cap system has to bear relatively large vertical load, horizontal force, bending moment and torque, and the stress situation is very complicated[1]. At present, the research and accumulated experience in this area is still relatively little, so the study of the load condition of the tower crane high pile cap system has important theoretical and practical significance.

2. The stress analysis of tower crane high pile cap system

The load analysis of tower crane pile cap system is shown in Figure 1. The foundation load of tower crane is composed of bending moment, vertical force, horizontal force and torque. Due to the size requirements of the embedded parts of tower crane foundation, the dimensions of the foundation cap are relatively large, which can be regarded as rigid region compared with pile foundation. Since tower crane pile cap system is mostly used in basement foundation pit, in order to facilitate the construction of basement structure, the pile foundation is usually designed in two sections, with lattice steel column or steel pipe column above the bottom of basement floor and normal concrete solid pile below the bottom of basement floor. Generally, the geological conditions below the bottom of basement floor are relatively good, and most of them have entered different degrees of rock formation. Under such strong constraints, the mechanical model of the concrete pile can be simplified to bear only the pressure and tension of the rod, and the steel column because it is embedded in the concrete solid pile, its section size must be smaller than the concrete pile, so after the pile is formed, the steel column is essentially separated from the surrounding geological environment, in the surrounding unconstrained state, the upper end is embedded with the cap, the lower end is embedded with the concrete pile,which is a rod to bear the bending moment, vertical force, horizontal force and torque, the force of which is complex.

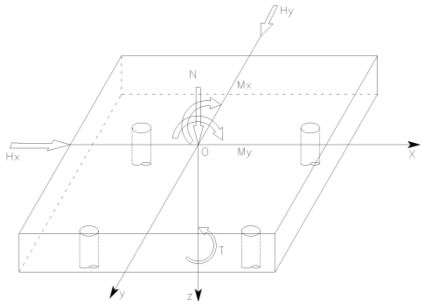

Figure 1: Stress analysis diagram of tower crane high pile cap system

2.1. The force analysis on the high pile platform System of Tower Crane in the Current Tower Crane Foundation Specification

According to the current JGJT 187-2019 tower crane concrete foundation engineering technical standard[2] Article 6.3.2 Point 2 eccentric vertical force effect of pile top action should be calculated according to the following formula.

$$Q_{\max} = \frac{F_v + G}{n} + \frac{M_v + F_h h}{L} \tag{1}$$

Where: Q_{max}-The maximum vertical force of angular pile under eccentric vertical force when corresponding to the standard combination of action (kN).

F_v-Vertical force acting on the top surface of pile cap when corresponding to the standard combination of action (kN).

G-The standard value of the self-weight of the pile cap and the soil on it (kN). The underwater part is calculated according to the floating weight.

n- The number of piles in pile foundation.

M_v- The moment applied longitudinally to the top surface of the bearing, along the diagonal direction of the rectangular or square bearing, or along any strip bearing in the cross-shaped bearing, corresponding to the standard combination of the action (kN ·m).

F_h- The horizontal force exerted on the top surface of the bearing table, when the tower crane is in line with the standard combination of action (kN).

h- The height of the cap, the calculation of the load effect of the foundation pile top of the combined foundation should include the length from the lattice steel column to the top of pile (m).

L- The axial distance of the piles at both ends of any strip bearing table in the diagonal or cross bearing table of the rectangular bearing table (m).

Article 7.3.2 The 1 point lattice steel column should be designed according to the axial compression member, and the overall stability of the compression should meet the following requirements.

$$\frac{N_{\max}}{\varphi A f} \leq 1 \tag{2}$$

Where: N_{max}-The maximum axial compression design value (N) of the N-steel column should be calculated according to the basic combination specified in section 6.3 of this standard and taken;

A - The gross section area of the member (mm^2), the sum of the gross section area of the limb;

f - Steel tensile, compressive and bending strength design value (N/mm^2);

φ - The stability coefficient of the axial compression member, according to the converted slenderness ratioλ_{0max} of the member and the yield strength of steel, according to the current national standard "Steel structure design Standard" GB50017.

2.2. Analysis of bending force of steel column

The steel column is actually a compression, bending and torsion bearing member. When the cap is twisted, the cap drives the steel column to deform, and the top of the steel column has the linear displacement perpendicular to the diagonal of the cap and the angular displacement[3] of the central axis of the steel column itself, as shown in Figure 2, resulting in the bending moment and torque of the steel column. As the angular displacement is relatively small, the torque generated is relatively less, corresponding to the height of the larger rod, bending is the main form of instability, so the torque can be ignored, the main research on the bending force of the steel column.

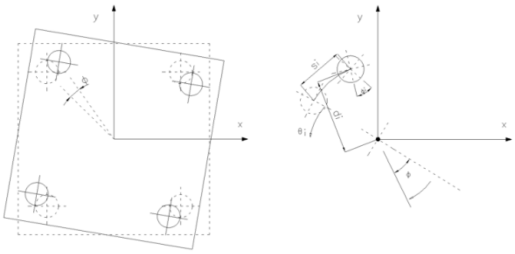

Figure 2: Deformation diagram of twisted pile group

Since the distance between each pile of the four pile caps and the torsion center of the cap is equal, the horizontal force exerted by the torque on the top of the steel column by the cap is 2/L:

$$F_{Ti} = \frac{T}{2L} \tag{3}$$

The horizontal force distributed by the horizontal force of the tower crane to the top of the steel column is:

$$F_{hi} = \frac{F_{\text{h}}}{4} \tag{4}$$

Due to the maximum horizontal force at the diagonal of the tower crane, the maximum horizontal force at the top of the steel column is:

$$F_{\text{himax}} = F_{Ti} + F_{hi} = \frac{T}{2L} + \frac{F_{\text{h}}}{4} \tag{5}$$

In non-working state, the tower crane does not work, release the rotary brake, no torque is generated on the cap, and the maximum horizontal force of the top of the steel column is:

$$F_{\text{himax}} = F_{hi} = \frac{F_{\text{h}}}{4} \tag{6}$$

The maximum bending moment produced by the top and bottom of the steel column is:

$$M_{\text{imax}} = \frac{F_{\text{himax}} l_{\text{i}}}{2} \tag{7}$$

l_i-isteel column actual height (m)

The bending moment produced by the top and bottom of the steel column is equal in size and opposite in direction. The bending moment of the column body is linearly distributed, and the reverse bending point is in the middle.

2.3. Analysis of bending stability of steel column

Take tubular steel column as an example, according to the current GB 50017-2017 steel structure design standard[4] Article 8.2.4 and its provisions:

$$\frac{N}{\varphi A f} + \frac{\beta M}{\gamma_{\text{m}} W (1 - 0.8 \frac{N}{N'_{Ex}}) f} \leq 1.0 \tag{8}$$

$$N'_{Ex} = \pi^2 EA / (1.1 \lambda_x^2) \tag{9}$$

Where: N, φ, A, f are the same as equation (2); β - Equivalent bending moment coefficient;

M - The maximum bending moment design value within the calculated component segment range; γ_{m} - The plastic development coefficient of the cross-section of m-circular components

W - Gross cross-sectional modulus of the maximum compressed fiber in the plane of bending moment action (mm^3) E - Elastic modulus (N/mm^2); λ_x - component slenderness ratio.

3. Engineering Applications

3.1. Introduction to Computational models

A large project in Guangzhou plans to use high pile cap system to install tower crane, tower crane independent free height of 62m, mechanical parameters are as follows:

Working state: M_v=5513.0 kN ·m, F_h=48.3 kN, F_v=1237.8 kN, T=942.6 kN ·m

Non-working state: M_v=5980.0 kN ·m, F_h=200.3 kN, F_v=1048.8 kN, T=0 kN ·m

The size of the cap section is ($L \times W \times H$) 5000 mm×5000 mm×1400 mm

Weight of cap G=5×5×1.4×25=875 kN

The Φ630×15mmsteel column is made of Q235 steel with a calculated length of 20.25m. It is supported in the grouting pile with a diameter of Φ1200mm. The grouting pile enters not less than 2.5 m into the breezed rock formation or the weathered rock formation. The center distance of 4 steel columns on 4 sides is 3200 mm and the diagonal center distance is 4525mm.

3.2. Calculation conclusion

According to GB50068-2018 Unified Standard[5] for the Reliability design of building structures, Article 8.2.9 Function factor of building structures, there are three load combinations:(1)γG=1.0,γQ=1.0;(2)γG=1.3,γQ=1.5;(3)γG=1.0,γQ=1.5, taking the steel column as the main calculation object, substituting the relevant parameters into the formula (1)~(9), the calculation results are shown in Table 1.

Table 1: Stability calculation results of steel column

	Working state			Non-working state			
	Axial force part $\frac{N}{\varphi A f}$	Moment part $\frac{\beta M}{\gamma_m W(1-0.8\frac{N}{N'_{Ex}})f}$	Total	Axial force part $\frac{N}{\varphi A f}$	Moment part $\frac{\beta M}{\gamma_m W(1-0.8\frac{N}{N'_{Ex}})f}$	Total	Conclusion
(1)γ_G=1.0,γ_Q=1.0	0.470	0.586	1.056	0.498	0.391	0.889	Not safe
(2)γ_G=1.3,γ_Q=1.5	0.679	0.758	1.437	0.721	0.340	1.061	Not safe
(3)γ_G=1.0,γ_Q=1.5	0.637	0.809	1.446	0.683	0.363	1.046	Not safe

From Table 1, no matter the load standard value combination or the normal use limit state standard combination, the steel column stability calculation value is greater than 1. It will occur instability failure, and the axial force part of the calculation value is less than 1. It is very easy to misjudge as safety. Fortunately, in the program review stage timely was found and the design scheme was adjusted. The occurrence of safety accidents was avoided.

Simplifying the mechanical model of the steel column to the axial compression rod for design calculation is acceptable for shallow foundation pits, high pile caps that are not too high, and small and medium-sized tower cranes. The installation of a tower crane on a high pile cap is in use while the foundation pit has not yet been excavated. The maximum calculated length of the steel column is the most unfavorable working condition. With the deepening of the foundation pit, the high pile cap becomes higher and the specifications of the tower crane become larger. If the design and calculation of the steel column do not consider the influence of the horizontal force and torque of the tower crane on the bending moment of the steel column, it will cause serious safety hazards.

4. Conclusion

The stress state of the steel column of the tower crane high pile cap system is relatively complicated. The result of simply applying the calculation formula of the low pile cap and the axial load member cannot reflect the real stress of the steel column, which is not safe. Moreover, the most unfavorable working condition occurs in the working state of the tower crane rather than the non-working state, and the consequences of safety accidents will be very serious. We must pay enough attention to the technical personnel.

Acknowledgements

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