Stress Analysis of Tower Crane

Longxiang Chen[1,*], Hongliang Tao[2], Qiye wang[1], Ping Jiang[1]

[1] Shaoxing University, Shaoxing, China
[2] Broadvision Engineering Consultants Co. Ltd., Kunming, China
*corresponding author: Longxiang Chen

Abstract*:* In order to analyze the stress characteristics of tower crane during operation, the basic knowledge of steel structure and structural mechanics is used to analyze the stress of steel lattice tower crane and check the design of steel structure form. It is concluded that the overall stability and local stability under the combined action of wind load and maximum lifting capacity can be met when the distance between wall parts of tower crane is 7m.

Keywords*:* tower crane; stress characteristics; lattice column; overall stability; local stability

1. Introduction

With the continuous expansion of infrastructure construction scale in China, the size and weight of components increase gradually [1-3]. In order to meet the hoisting requirements of various component materials, appropriate hoisting facilities need to be selected. Tower crane is more and more widely used in the construction industry [4]. It can easily realize the vertical and horizontal transportation of materials, and greatly improve the work efficiency of construction [5]. However, in the construction process, we must consider what kind of tower crane structure or material should be selected and how to ensure its safety performance.

2. Stress Analysis and Model Simplification

By consulting the literature, we found that there have been many studies on the foundation bearing capacity, but there are few studies on the structure and materials of the tower. In this project, we believe that the tower crane foundation structure design has met the requirements of bearing capacity. We do not analyze the foundation bearing capacity, but only do structural analysis and check calculation of strength and stability for the tower body.

According to the construction requirements of the project and the tower crane model and technical parameter table, we select the crane model QTZ60, with a maximum lifting capacity of 5t, a maximum working range of 3 ~ 50m, a balance weight of 8.8t, and a triangular boom section size of 900mm high and 840mm wide. In order to meet the requirements of engineering construction, the main parameters of the crane we selected are shown in Figure 1.

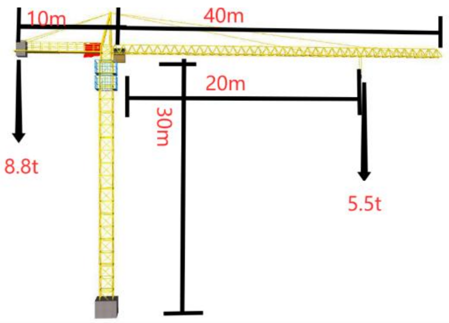

Figure 1. Mechanical calculation model of tower crane.

Considering that the dynamic characteristics of the tower crane structure are only related to the stiffness and mass of the structure, the force analysis needs to simplify the tower crane structure model. In order to simplify the calculation, the tower body, boom, balance arm and other components are replaced by equivalent elements. Each section is regarded as a homogeneous beam and rod element with uniform mass distribution. Figure 2 shows the simplified model. Among them, 1 ~ 3 are tower body, 2 ~ 3 are balance arm, 3 ~ 5 are boom and 3 ~ 6 are tower cap.

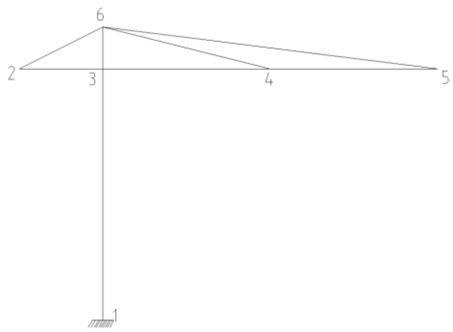

Figure 2. Composition of tower crane.

Firstly, the gravity load and bending moment are calculated, calculation diagram of vertical load as figure 3. We assume that Q235 steel is used as a whole, and the steel density is 7.85*103 kg/m3 according to the query data. We use the standard section of 1.5*1.5*3 m to roughly estimate the dead weight load of the tower:

G=G1~6+G2~3+G3~5=600kN,

The maximum lifting load is *Q1 = 55 kN, Q2 = 88kN*

Therefore, the vertical positive pressure acting on the tower body: n = G + q = 743 kN.

According to the knowledge of structural mechanics, the self weight and lifting load of each component will produce bending moments on 1 ~ 3 tower bodies.

$M=M_1+M_2+M_{2\sim3}+M_{3\sim5}=0$

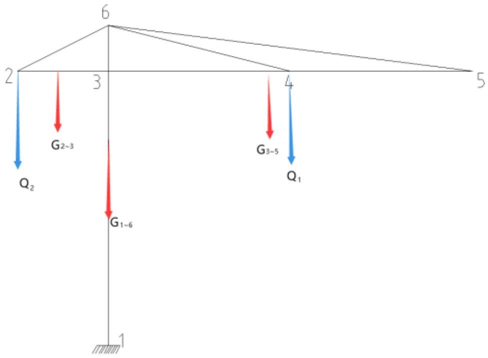

Figure 3. Calculation diagram of vertical load.

Secondly, calculate the wind load, as figure 4. According to article 4.3.4.2.2 of code for design of tower cranes (GB / T 13752-2017), calculate the wind pressure as Eq. (1).

$$P_n = 0.625 v_n^2 \quad (1)$$

Where, Pn is calculated wind pressure, vn is wind speed.

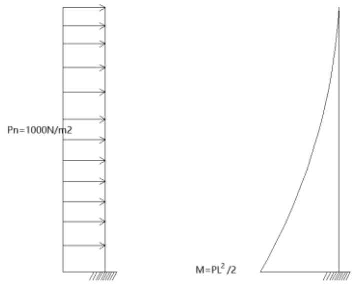

Figure 4. Wind load calculation of tower crane

Considering the most adverse impact, the average annual maximum wind speed in the middle and lower reaches of the Yangtze River is 40 m/s, and the calculated wind pressure under state is P_n = 1000 N/m^2.

The bending moment of tower crane caused by wind load can be calculated as Eq. (2).

$$M_{k\max} = \frac{P_n L^2}{2} = 450kN \cdot m \quad (2)$$

3. Stability Analysis of Compression Bending Members

Considering the influence of wall connecting parts attached to the tower body, the installation distance of wall connecting parts is L1 = 7 m according to the operation manual of tower crane. According to the above analysis, the tower body of the tower crane can be simplified as a compression bending member with two ends hinged in two directions, with a length of 7m and subjected to vertical positive pressure and bending moment. The steel of the column is Q235 angle steel L125x12. The steel for lacing is Q235 angle steel L100x10.

3.1. Geometric Characteristics of Section

The area of a single angle steel can be obtained by checking the profile steel table, as Eq. (3).

$$A_1 = 28.91cm^2 \quad (3)$$

The moment of inertia of the section as Eq. (4),

$$I_x = I_y = 426.2cm^4 \quad (4)$$

The center of gravity distance as Eq. (5),

$$Z_0 = 35.3mm \quad (5)$$

The turning radius as Eq. (6),

$$i_x = 3.83cm \quad (6)$$

According to the moving axis theorem, as Eq. (7)

$$I_{x1} = I_{y1} = [I_x + A_1 \times (\frac{150}{2} - 3.53)] \times 2 = 296188.7cm^4 \quad (7)$$

Entire section, as Eq. (8) ~Eq. (11)

$$A = 4A_1 = 115.64cm^2 \quad (8)$$

$$y_1 = y_2 = 75cm \quad (9)$$

$$I_{x2} = [I_{x1} + \frac{A}{2} \times (\frac{150}{2} - 3.53)] \times 2 = 1183062cm^4 \quad (10)$$

$$i_{x2} = \sqrt{\frac{I_{x2}}{A}} = 101.1cm \quad (11)$$

3.2. Strength Checking Calculation of Split Column and Batten

The axial force of split limb 2 as Eq. (12),

$$N_2 = N\frac{y_1}{a} + \frac{M}{a} = 671.5kN \quad (12)$$

The axial force of split limb 1 as Eq. (13),

$$N_1 = N - N_2 = 71.5kN \quad (13)$$

According to the most unfavorable section failure, the section strength of split limb 2 is checked, which can be regarded as the design of lattice column plate under axial compression. Take the maximum positive pressure N_2 = 671.5 kN. Take a standard node to check its section strength. The calculated length of the column is $l_{0x} = l_{0y}$ = 3000 mm, the steel is Q235 steel, and the design value of the compressive strength of the steel is 215N / mm^2 as Eq. (14).

$$\lambda_x = \frac{l_{0x}}{i_x} = 7.8 < [\lambda] = 150 \quad (14)$$

And the section around the x and y axes is class B. by looking up the table, it can be seen that φ_x = 0.995, as Eq. (15).

$$\frac{N}{2\varphi_x A_1 f} = 0.543 < 1 \quad (15)$$

The stability of split 2 column meets the requirements.

Batten checking calculation: take the batten as L100x10 and the angle as 45 °.

Shear force on batten, as Eq. (16)

$$V = \frac{A_1' f}{85\varepsilon_k} = 14698.6N \quad (16)$$

The axial force of an inclined batten as Eq. (17),

$$N_1^{'} = \frac{V/2}{\cos 45^\circ} = 10393.5N \quad (17)$$

The batten length and stability are calculated as Eq. (18) ~ Eq. (22).

$$l_0^{'} = \frac{a}{\cos 45^\circ} = 2021.5mm \quad (18)$$

$$\lambda^{'} = \frac{0.9l_0^{'}}{i_1} = 92.8 < [\lambda] = 150 \quad (19)$$

$$\varphi_x^{'} = 0.603 \quad (20)$$

$$\eta = 0.6 + 0.0015\lambda^{'} = 0.7392 \quad (21)$$

$$\frac{N_1}{\eta\varphi_x^{'}A_1^{'}f} = 0.056 < 1 \quad (22)$$

Therefore, the batten meets the requirements of bearing capacity.

3.3. Checking the Overall Stability in the Plane under the Action of Bending Moment

Since the pressure of split limb 2 is the largest in the above calculation process, we still take the positive pressure of split limb 2 to check the overall stability.

The stability in the plane under the action of bending moment is calculated as Eq. (23) ~ Eq. (30).

$$\lambda_{x2} = \frac{l_{x2}}{i_{x2}} = 29.7 \quad (23)$$

$$\lambda_{0x2} = \sqrt{\lambda_{x2}^2 + 27\frac{A}{A_1^{'}}} = 32.3 < [\lambda] = 150 \quad (24)$$

$$\varphi_{x2} = 0.927 \quad (25)$$

$$N_{Ex}^{'} = \frac{\pi^2 EA}{1.1\lambda_{0x2}^2} = 20487kN \quad (26)$$

$$N_{cr} = \frac{\pi^2 EI_2}{\mu l^2} = 26726kN \quad (27)$$

$$\beta_{mx} = 1 - \frac{0.18N}{N_{cr}} = 0.995 \quad (28)$$

$$W_{1x} = \frac{1183062}{75} = 15774.16cm^3 \quad (29)$$

$$\frac{N}{\varphi_{2x}Af} + \frac{\beta_{mx}M_x}{W_{1x}(1-\frac{N}{N_{Ex}^{'}})f} = 0.427 < 1 \quad (30)$$

Therefore, the overall stability meets the requirements.

3.4. Local Stability Checking Calculation

Similar to the above process, only the local stability of limb 2 is required.

Query the width thickness ratio limit of axial compression members.

When $\lambda \leqslant 80\ \varepsilon_k$, as Eq. (31),

$$\frac{\omega}{t} = 7.475 < 15\varepsilon_k = 15 \quad (31)$$

From the above checking calculation process, the above tower cranes meet the strength, stability and other design requirements according to the design standards of steel structures (GB 50017-2017), code for design of tower cranes (GB / T 13752-2017) and tower cranes (GB / T 5031-2019).

4. Conclusions

By simplifying the model of the tower crane, this paper further analyzes the stress of its components, and mainly checks the stress and stability of the tower crane. Using the relevant knowledge of steel structure, I first calculate the local stability of the tower body. When the local stability meets the requirements. Then we calculate the overall stability of the tower. Through preliminary calculation, we find that the steel selected for the tower body far meets the requirements of bearing capacity, and the steel requirements can be reduced. Secondly, in the above checking calculation process, we can replace the section form and structural form of steel to meet the requirements of different construction conditions.

There are still some problems in the above calculation process, but the relevant materials and structural forms of tower crane can be optimized by using the above checking knowledge. Therefore, it can greatly improve the installation efficiency, save the construction cost, and play a certain role in simplifying the project organization construction and optimizing the construction process.

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