Structure Design and Calculation of Support Frame of Repair Tower

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Abstract. Take the support frame of reversal lift system with pulley block as research object, complete the stress analysis and structure design of support frame, then make the finite element simulation calculation by using ABAQUS, the results conform to the requirements of the strength.

Introduction

Repair tower is composed of 23 lattice standard sections, flange connection are used between any two standard section. The size of standard section is 1000mm×1000mm and 1200mm×1200mm, the length is 3m, because the repair tower's material is aluminum, each of standard section's weight is 275kg, The parameters are shown in table 1.

Table 1 Parameters of standard section

No.	Category	Value
1	Size	1000mm×1000mm/1200mm×1200mm
2	Length	3m
3	Quantity	22
4	Weight	275kg
5	Material	Aluminum
6	Structure	Lattice type

Reversal lift system

Considering the Repair tower's material is aluminum, and the weight is light, Repair tower assembly using reversal lift system with pulley block, which includes the support frame, bracing wire of support frame, lift rope, pulley block, bracing wire of repair tower, traction equipment etc.as shown in Figure 1.

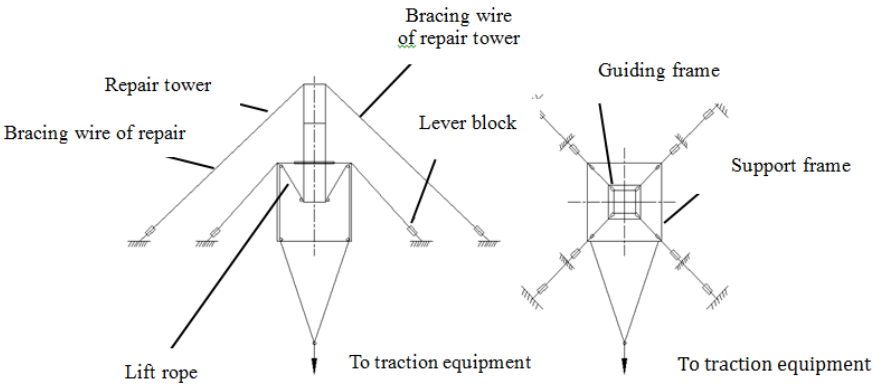

Fig.1 Reversal lift system with pulley block

The analysis model of support frame

The analysis model of support frame is simplified as shown in Figure 2, The four pillars of support frame have force form lift rope, the tension of rope is indicated by the arrows in Figure 2.

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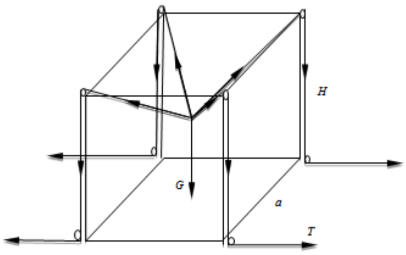

Fig.2 The analysis model of support frame

Because the support frame of repair tower is symmetric structure, the four lift rope use isometric design, in the process of assembling of repair tower, the four lift rope are synchronous, so an analysis of one pillar of support frame is given. The stress analysis of one pillar is shown in Figure 3.

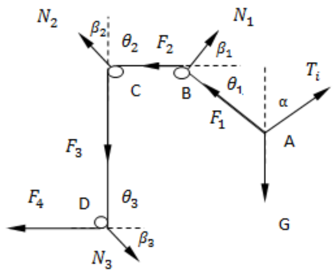

Fig.3 The stress analysis of one pillar

The first step is to establish the model based on point A:

$$\sum F_x = F_1 \cdot \sin\alpha - T_{ix} \qquad (1)$$

$$\sum F_y = F_1 \cdot \cos\alpha - T_{iy} - G \qquad (2)$$

Thus:

$$F_1 = \frac{G}{4\cos\alpha} \qquad (3)$$

Take the analysis based on point B, because there is friction between the rope and pulley, when the rope through the first pulley , the tension F_1 will increase to be F_2, angle of Force N_1 and F_2 is β_1, the friction coefficient of the pulley is K_1, According to force equilibrium equations:

$$\sum F_x = F_1\cos\theta_1 + N_1\cos\beta_1 - F_2 = 0 \qquad (4)$$

$$\sum F_y = N_1\sin\beta_1 - F_1\sin\theta_1 = 0 \qquad (5)$$

$$F_2 - F_1 = N_1K_1 \qquad (6)$$

We can calculate:

$$N_1 = \frac{\sin\theta_1}{\sin\beta_1}F_1 \qquad (7)$$

$$N_1 = \frac{F_1(1-\cos\theta_1)}{\cos\beta_1 - K_1} \qquad (8)$$

Combine eq. (7) and eq. (8):

$$\frac{(1-\cos\theta_1)}{\cos\beta_1 - K_1} = \frac{\sin\theta_1}{\sin\beta_1} \qquad (9)$$

Square calculation of eq.(9):

$$\sin^2\beta_1 + K_1 \cdot \sin\theta_1 \cdot \sin\beta_1 + \frac{1}{2}(1+\cos\theta_1)({K_1}^2 - 1) = 0 \qquad (10)$$

Under the condition of $F_2 \geq F_1$ and $0 \leq \beta_1 \leq 90^\circ$:

$$\sin\beta_1 = \frac{1}{2}\sqrt{{K_1}^2 \cdot \sin^2\theta_1 - 2(1+\cos\theta_1)({K_1}^2 - 1)} - \frac{1}{2}K_1 \cdot \sin\theta_1 \qquad (11)$$

$$F_2 = F_1 \cdot (1 + K_1 \cdot \frac{1}{\sin\beta_1}) \qquad (12)$$

Take the analysis based on point C:

$$\sum F_x = N_2\sin\beta_2 - F_2 = 0 \qquad (13)$$

$$\sum F_y = N_2\cos\beta_2 - F_3 = 0 \qquad (14)$$

$$F_3 - F_2 = N_1K_1 \qquad (15)$$

According to the eq.(13), eq.(14) and eq.(15), We can calculate:

$$F_3 = F_2(1 + K_2\frac{1}{\sin\beta_2}) \qquad (16)$$

According to the eq.(12) and eq.(15), We can calculate:

$$F_{i+1} = F_1\left(1 + K_1\frac{\sin\theta_1}{\sin\beta_1}\right)\left(1 + K_2\frac{\sin\theta_2}{\sin\beta_2}\right)\cdots\left(1 + K_i\frac{\sin\theta_i}{\sin\beta_i}\right) \quad (17)$$

$$N_i = F_i\frac{\sin\theta_i}{\sin\beta_i} \quad (18)$$

$K_1, K_2, \cdots\cdots, K_i$—The friction coefficient of each pulley.

$\alpha_1, \alpha_2, \cdots\cdots, \alpha_i$—The angle of input force and vertical line .

$\beta_1, \beta_2, \cdots\cdots, \beta_i$—The angle of output force and resultant force.

The vertical force of pillar is:

$$P_{TC} = F_1[\left(1 + K_1\frac{\sin\theta_1}{\sin\beta_1}\right)\left(1 + K_2\frac{\sin\theta_2}{\sin\beta_2}\right)\sin\theta_2 + \sin\theta_1] \quad (19)$$

The horizontal force of pillar is:

$$P_{Ts} = F_1[\left(1 + K_1\frac{\sin\theta_1}{\sin\beta_1}\right)\left(1 + K_2\frac{\sin\theta_2}{\sin\beta_2}\right)\cos\theta_2 - \sin\theta_1] \quad (20)$$

The support frame is symmetry to the center of repair tower, the side length of support frame' section is a=3.2m, the side length of repair tower' section is b=1.2m, the diagonal distance of a and b is x, as shown in Figure 4.

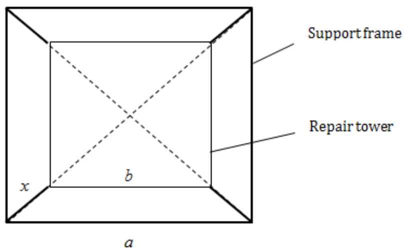

Fig.4 Top viewport of support frame and repair tower

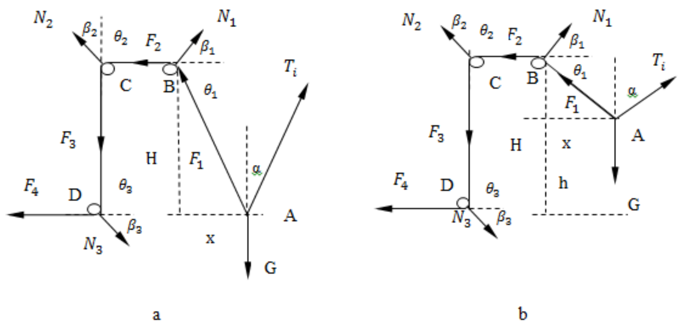

Fig.5 The stress analysis of one pillar in the process of ascension

As shown in figure 5a, the angle θ is :

$$\theta_1 = \arctan\frac{H}{x} \quad (21)$$

When the hoisting height of repair tower is h, the angle θ is :

$$\theta_1 = \arctan\frac{H-h}{x} \quad (22)$$

In order to guarantee the installation space, the support frame' height H is 6m. the largest lifting weight G is 60t, so we can calculate:

$$P_{TC} = 2.9677 \times 10^5 \quad (23)$$

The pillar of support frame use normal seamless steel tube, D=140mm, t=15mm, the area of cross section of pillar A is:

$$A = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}(114^2 - 80^2)\text{=}5177.86mm^2 \quad (24)$$

The working stress σ is

$$\sigma = \frac{P_{TC}}{A}\text{=}\frac{296770}{5177.86} = 57.32\text{MPa} \quad (25)$$

By using ABAQUS software package, the maximum stress of support is 58.01MPa. as shown in Figure 6, the results conform to the requirements of the strength.

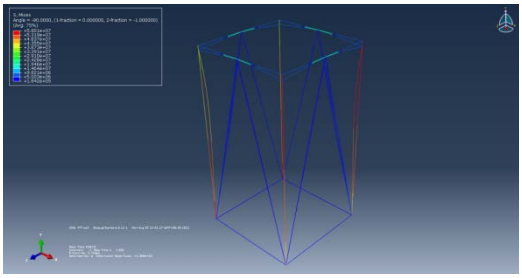
Fig. 6 Stress distribution of support frame

Conclusions

Theory analysis and simulation results indicate the high accuracy of our calculation, the support frame, which can meet the requirement of repair tower to Reversal lift.

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