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Research on Stability of Tower Crane based on ANSYS Software

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Abstract: In order to strengthen the safety management of tower cranes on construction sites and prevent accidents caused by the deformation of the standard section of tower cranes during the construction process, in response to the stability of the WA6013-6A tower crane operation process, the static analysis of the standard section structure and attachment method during the lifting process of tower cranes was carried out using Ansys software, and the maximum displacement and stress-strain situation of tower cranes with different tower crane heights and attachment distances were obtained. The results show that the more attached the tower crane is, the higher the standard section stress dispersion and the continuous decrease in effective stress; The smaller the distance between connecting walls, the more connecting components there are, the smaller the standard deformation rate of tower cranes, and the better the stability of tower cranes.

Keywords: Tower Crane; Ansys Analysis; Static Analysis; Attachment Spacing.

1. Introduction

Tower cranes (referred to as tower cranes) are widely used in high-rise building lifting operations, and there are still many safety accidents during use. According to the investigation and statistical analysis of tower crane accidents in recent years, it can be seen that [1-3] tower body overturning and collapse accidents account for 52% of all accidents, belonging to tower body instability and damage, which brings significant safety impacts and property losses to people's production and life activities. Currently, the factors that cause tower body instability and damage include: tower crane not being leveled and collapsed during the jacking and jointing process [4-6], tower body instability caused by overloading lifting, and tower crane collapsing under large wind loads. Currently, there is less research on attachment methods and tower body stability, and Bai Ruxuan [7-10] adopts SAP2. 000 software was used to model and calculate the structure of the tower, and the influence of attachment form and spacing on the stability of the tower crane under adverse working conditions was studied.

This article is based on the relevant parameters of the WA6013-6A tower crane of a certain project. SolidWorks software is used to model the tower crane, and ANSYS Workbench is imported to conduct static analysis on the standard section structure and wall installation height of the tower crane. Through modal analysis, its inherent characteristics are determined, and theoretical suggestions are proposed for practical operations.

2. Finite Element Analysis of Tower Cranes

2.1. Introduction to WA6013-6A Tower Crane

The WA6013-6A tower crane is divided into attached and independent types. The maximum lifting height of the attached type is 220m, the maximum working range is 60m, the minimum working range is 2.5m, the standard section height is 2.8m, the length is 1.6m, and the maximum lifting weight is 6t.

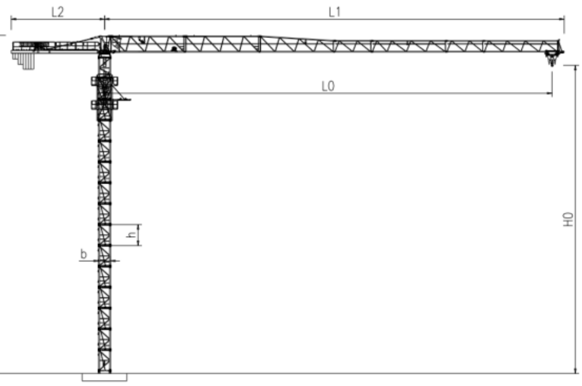

Figure 1. Outline diagram of tower crane

When building the model, simplify the main structure of the WA6013-6A tower crane, grasp the main factors, simplify the secondary factors, use shell elements to simplify the beam and rod structure, and preserve the details of the model as much as possible. The main simplification principle of the analysis model is to simplify the counterweight blocks, goods, etc. into specific loads after force analysis; Simplified bearings, bolts, and some pin shafts, and used software special functional units to replace connection relationships during the modeling process; The welding relationships such as steel plate welds are simplified as binding contact and node coupling [11-12].

In terms of load handling, the handling of loads includes the handling of lifting loads, tower crane self weight loads, dynamic loads, and wind loads. The tower crane self weight loads are set by setting material density and self weight acceleration. Due to the necessary simplification of the tower crane during modeling, the method of modifying material density was modified. In terms of constraint handling, the bottom of the tower crane body is connected to the concrete foundation with anchor bolts, and the structural stiffness is high. Fixed constraints are applied to the bottom position of the tower crane in the model[13-15].

This study simulates the operation of a tower crane with connected wall components, with a tower crane height of 150m.

2.2. Basic Assumptions

This study sets the steel properties as isotropic; The main research focuses on the deformation and stress of tower cranes, and during the research process, there will be no destructive overturning or collapse of the tower crane. The standard sections of the tower crane are connected by bolts, assuming that the bolt connections are tight, without deformation or relative displacement.

2.3. Parameter Settings and Modeling

Set the finite element material properties of the tower crane, and select Q345 as the main standard section structural material. The main parameters are as follows: Young's modulus 2e11 pa, Poisson's ratio 0.3, density 7850 kg/m3, bulk modulus 1.67 e11 pa, shear modulus 7.69 e10 pa; The standard section uses structural steel as the material, and the contact method between the standard sections is bonded. The mesh division is carried out using geometric dimension adjustment method. The grid size of the standard section is 50mm, and the grid size of the bottom base is 300mm.

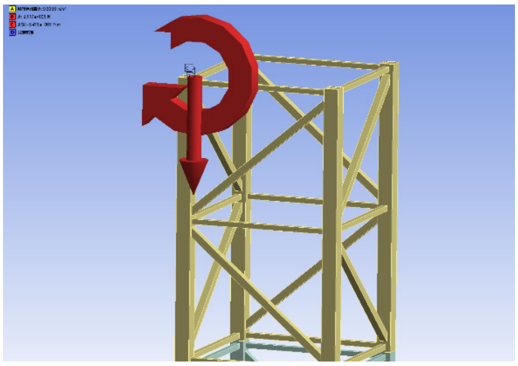

Figure 2. Simplified example diagram of mechanics

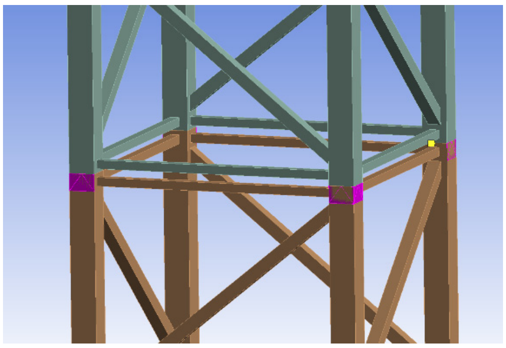

Figure 3. Grid division example diagram

Use SolidWorks software to model the tower crane, and after modeling, import the model into ANSYS for simulation calculation. After simplifying the tower crane model, it was mechanically transformed and directly applied to the top of the standard section, as shown in Figure 2. Remove and convert the connecting wall component into a fixed end that constrains the horizontal direction, as shown in Figure 3.

3. Static Analysis

In this study, three heights of 60m, 100m, and 150m were selected for simulation calculation. Each height was used to simulate three situations: no connecting wall components, maximum attachment spacing of connecting wall components (8 standard sections), and minimum attachment spacing of connecting wall components (5 standard sections), as shown in the table. Choose a maximum lifting distance of 60m, a maximum lifting mass of 1.3t, a counterweight of 17.8t, and a tower wall and other self-weight of 2.07t. After mechanical transformation, the force acting on the standard section is 211.7kN and the bending moment is 841.8kN • m.

The grid division of the tower crane is as follows, using a fixed unit division method as a whole. The standard section unit size is 20mm, and the bottom foundation unit size is 50mm.

3.1. Simulation of 60 Meter Height of Tower Crane

Table 1. Comparison of tower cranes and attachment quantities at different heights

Height/m	60m	100m	150m
Attachment quantity (no attachment)	0	0	0
Attachment quantity (maximum attachment spacing)	2	4	6
Attachment quantity (minimum attachment spacing)	3	7	10

The calculation results and analysis of the tower crane show that under this condition, the simulated height of the tower crane is 60m. Figure 4 (a) sets the condition to analyze the displacement of the tower crane without connecting wall components; The setting condition in Figure 4 (b) is that there are 5 standard sections between the connecting walls; Figure 4 (c) is set with a spacing of 5 standard sections between the connecting walls.

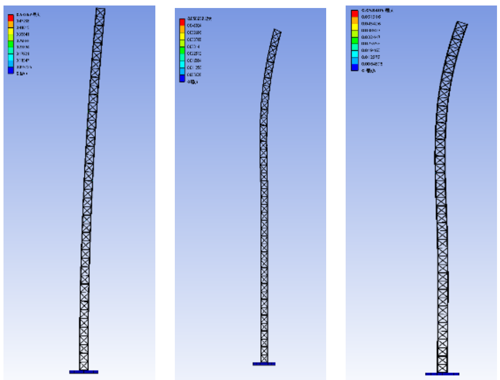

Figure 4. (a) Non connected wall components (b) Minimum attachment distance (c) Maximum attachment distance

In the absence of wall components: displacement characteristics: the maximum displacement occurs at the top of the standard section, on the side of the lifted cargo. The minimum displacement occurs at the bottom. Strain characteristics: The magnitude of strain increases with the decrease of standard section height, and the side of the lifted cargo is bent, with greater strain than the other side. The maximum strain occurs at the bottom of the lifted cargo side. Stress concentration occurs between lateral and vertical supports. Stress characteristics: The stress characteristics are consistent with the strain. The maximum stress occurs in the middle of the standard section at the bottom of the base. The minimum stress is at the top of the standard section [15-18].

Table 2. Analysis of Different Attachment Spacing for 60m Tower Crane

60m tower crane	No connecting wall components	Attachment spacing of 5 standard sections	Attachment spacing of 8 standard sections
Displacement/m	0.53762	0.050652	0.058405
Equivalent elastic strain	0.0004418	0.00048602	0.00061304
Equivalent stress/MPa	87.217	95.646	111.05

Under the condition of 5 standard sections of attachment spacing: displacement characteristics: maximum displacement at the top. Deformation characteristics: The deformation at the top is relatively large, showing a decrease first and then an increase from the top downwards. The maximum is located at the top attachment point. Stress characteristics: Consistent with strain characteristics, stress concentration occurs at the junction and attachment points.

When the attachment spacing is 8 standard sections, displacement characteristics: the maximum displacement occurs at the top and there is basically no displacement at the bottom. Strain characteristics: The deformation at the top is relatively large, showing a decrease first and then an increase from the top downwards. The maximum is located at the top attachment point. Strain characteristics: The deformation at the top is relatively large, showing a decrease and then an increase from the top down, with the maximum located at the top attachment point.

3.2. Simulation of 100-meter Height of Tower Crane

Under this condition, the height of the simulated tower crane is 100m. Figure 5 (a) sets the condition to analyze the displacement of the tower crane without connecting wall components; The setting condition in Figure 5 (b) is that there are 5 standard sections between the connecting walls; Figure 5 (c) is set with a spacing of 8 standard sections between the connecting walls.

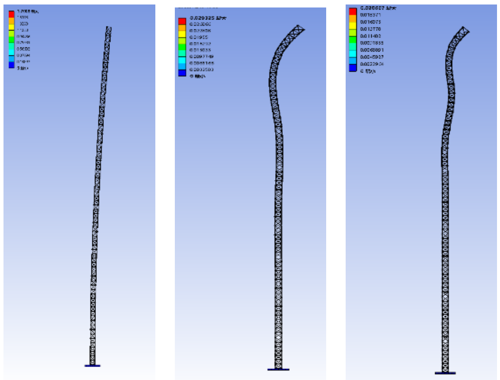

Figure 5. (a) Non connected wall components (b) Minimum attachment distance (c) Maximum attachment distance

Table 3. Analysis of Different Attachment Spacing for 100m Tower Crane

100m tower crane	No connecting wall components	Attachment spacing of 5 standard sections	Attachment spacing of 8 standard sections
Displacement/m	1.7008	0.020667	0.029325
Equivalent elastic strain	0.00060398	0.0005691	0.00081517
Equivalent stress/MPa	96.9	97.5	133

In the case of no connecting wall components: the strain characteristic is that the strain on the side of the lifted cargo is greater than that on the other side, and compared to the bottom, the difference in strain on both sides of the top is smaller than the difference in strain on both sides of the bottom. Stress characteristics, the maximum stress occurs at the bottom of the standard section and is easily concentrated at the junction with the internal diagonal bar [18-20].

When the attachment spacing is 5 standard sections, the deformation characteristics are as follows: the top deformation is relatively large, gradually decreasing downwards, but the bending side deformation is relatively large. As the weight of the bottom standard section increases, the bottom deformation tends to increase. The maximum deformation occurs at the top attachment. Stress characteristics: Consistent with strain characteristics, the maximum stress occurs at the top attachment.

In the case of 8 standard sections of attachment spacing: displacement characteristics: the maximum displacement occurs at the top, and a reverse bend occurs below the top attachment, greatly reducing displacement compared to no attachment. Strain characteristics: The maximum strain occurs at the first attachment point, and the strain changes significantly at the compression point (inside the bending). The strain decreases first from the top to the bottom and then increases. Stress characteristics: The maximum stress occurs at the highest attachment point, on the lifting side. The stress characteristics are similar to the strain characteristics, and stress concentration is prone to occur at the bolt. However, after the top attachment, the phenomenon of stress concentration decreases.

3.3. Simulation of 150 Meter Height of Tower Crane

Under this condition, the simulated height of the tower crane is 150m. Figure 6 (a) sets the condition to analyze the displacement of the tower crane without connecting wall components; The setting condition in Figure 6 (b) is that there are 5 standard sections between the connecting walls; Figure 6 (c) is set with a spacing of 8 standard sections between the connecting walls.

In the case of no connecting wall components: the maximum deformation occurs at the top of the tower crane, the maximum equivalent stress occurs near the foundation during bending testing, and the maximum equivalent elastic strain occurs in the lifting direction of the standard node vertex.

When there are 5 standard sections attached, the maximum displacement occurs at the top of the standard section. Due to the constraint of the connecting wall components, a reverse bending occurs at the top of the standard section. The maximum equivalent stress occurs at the bending point of the standard section, which is the first attachment point, then decreases and gradually increases as the standard section approaches the base.

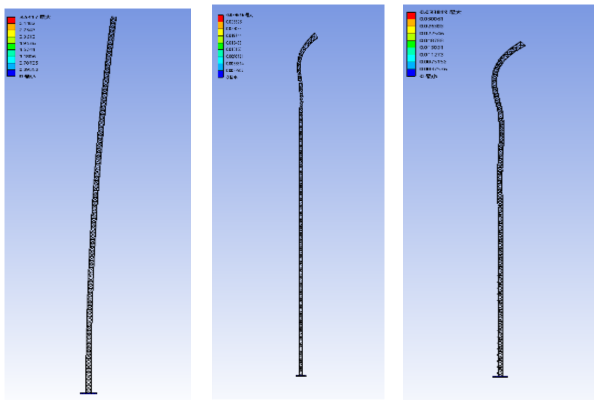

Figure 6. (a) Non connected wall components (b) Minimum attachment distance (c) Maximum attachment distance

Table 4. Analysis of Different Attachment Spacing for 150m Tower Crane

150m tower crane	No connecting wall components	Attachment spacing of 5 standard sections	Attachment spacing of 8 standard sections
Displacement/m	3.5417	0.029616	0.033819
Equivalent elastic strain	0.0009782	0.0010808	0.0010444
Equivalent stress/MPa	125.1	125.1	133.8

When the attachment spacing is 8 standard sections, the maximum displacement occurs at the top of the standard section on the side of the lifted cargo. At the first connecting wall component, there is a significant strain on the side of the lifted cargo. Strain characteristics: The deformation of the top lifting cargo side is relatively large, but as the distance from the top increases, its horizontal displacement is limited by the connecting wall components, and the standard section deformation gradually decreases. At the bottom, due to its increased gravity, the deformation at the bottom increases, mainly under compression. The stress variation characteristics are mainly affected by the self weight of the tower crane, and the bending moment of the cargo has a relatively small imp

4. Simulated Dynamic Analysis

From the calculation data in Figures 4, 5, and 6, it can be seen that under the conditions of tower crane heights of 60m, 100m, and 150m, the maximum attachment spacing is used, and compared to no attachment, it is reduced by 74.7%, 90.6%, and 94.9%, respectively. When the attachment form is the same, the displacement at each height is relatively large, which does not meet the requirement of a tower crane inclination rate of less than 4 ‰. The deformation increases with the increase of height. At the maximum attachment spacing, the perpendicularity requirement is met, and the deformation growth rates are 8.7% and 22.7%. At the minimum attachment spacing, the inclination rates are all less than 1 ‰, and the deformation growth rates are 28.9% and 40.7%. As the height increases, the deformation growth rate shows an increasing trend, which is more obvious after a height of 100m.

Figures 7 (a) and (b) show the detailed patterns of the 60m tower crane. It can be seen that the maximum x-axis deformation of the tower crane occurs at the top standard section, while the minimum x-axis deformation occurs at the bottom of the standard section. In the presence of attachment, due to its constraint on horizontal displacement, the standard section of the tower crane deforms in the x-axis direction and descends at the first attachment point.

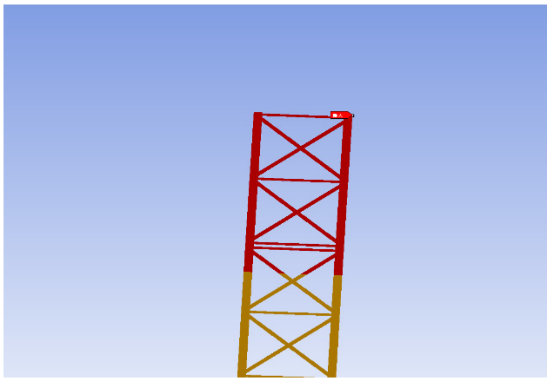

Figure 7. (a) Top displacement diagram of 60m tower crane

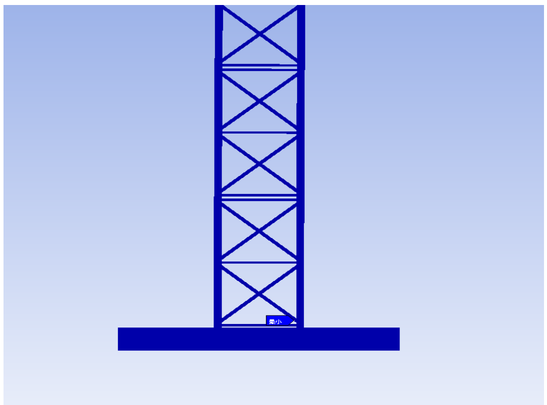

Figure 7. (b) Bottom displacement diagram of 60m tower crane

A total of 9 images in Figure 8 show the stress-strain plots of tower cranes at different heights and attachment distances; Figures 8 (a), (b), and (c) show, under the condition of a tower crane height of 60m: no attachment, 5 standard sections with attachment spacing, and 8 standard sections with attachment spacing; Figures 8 (d), (e), and (f) show, under the condition of a tower crane height of 100m: no attachment, 5 standard sections with attachment spacing, and 8 standard sections with attachment spacing; Figures 8 (g), (h), and (i) show, under the condition of a tower crane height of 150m: no attachment, 5 standard sections with attachment spacing, and 8 standard sections with attachment spacing.

Table 5. Displacement analysis of tower cranes at different heights

Displacement/mm	Tower crane height 60m	Tower crane height 100m	Tower crane height 150m
No attachment	537.3	1579	3541
Maximum attachment spacing	136.2	148.1	181.7
Minimum attachment spacing	49.9	64.3	90.5

Table 6. Analysis of verticality of tower cranes at different heights

Verticality ‰	Tower crane height 60m	Tower crane height 100m	Tower crane height 150m
No attachment	8.96	15.79	23.61
Maximum attachment spacing	2.27	1.48	1.21
Minimum attachment spacing	0.83	0.64	0.60

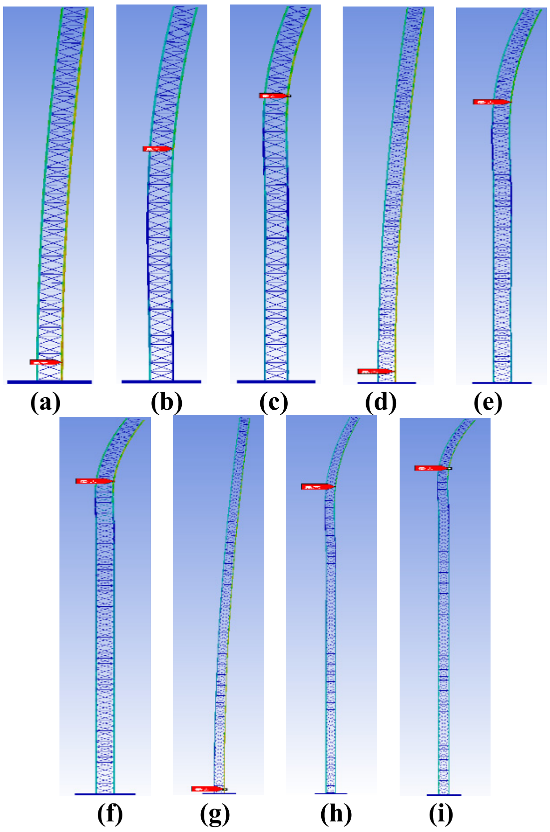

Figure 8. The stress-strain plots of tower cranes at different heights and attachment distances

Due to the consistent characteristics of stress and strain, only the tower crane stress diagram is drawn, and the location of the maximum stress is marked. In the absence of attachment constraints, the maximum stress and strain of the three heights occur in the bottom area of the tower crane standard section, and the stress and strain increase with the decrease of height, resulting in an increase in self weight stress and an increasing trend in total effective stress. In the case of attachment constraints, the maximum stress occurs on the side of the highest attachment lifted cargo, as shown in Figure 9. At this position, due to the presence of horizontal constraints, significant deformation occurs at the constraint, resulting in stress concentration.

From Figure 9, it can be seen that at the same height, the stress without attachment is the smallest. As the number of attachments increases, the stress first increases and then decreases. When the standard section of a 60m tower crane is equipped with connecting wall components according to the maximum attachment spacing, only one attachment support is needed, and the stress distribution is extremely uneven. Therefore, the effective stress is the highest under this working condition; As the number of attachments increases, stress is dispersed and distributed, and the maximum effective stress decreases. However, there is still some phenomenon of stress concentration, so the effective stress is still higher than that of the non attachment condition. In practical engineering, when using the maximum attachment spacing to install wall connectors, stress concentration should be considered and appropriate wall connectors should be added.

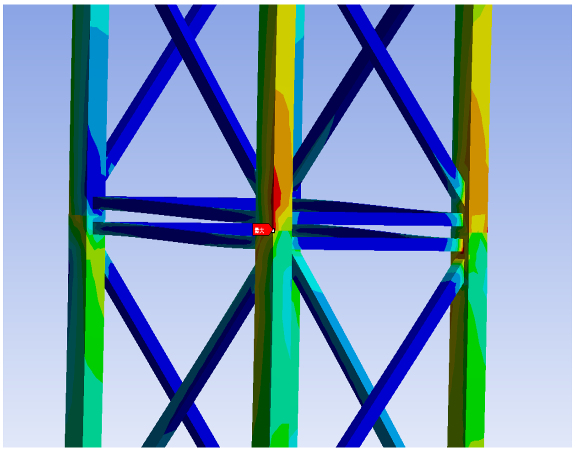

Figure 9. Schematic diagram of stress concentration area

5. Conclusion

Taking the WA6013-6A tower crane used in a certain project as an example, a static structural analysis was conducted using ANSYS simulation analysis software to study its standard section deformation and stress changes under maximum load conditions. The main conclusions are as follows:

(1) Increasing the attachment of tower cranes can effectively reduce standard section deformation and tilt rate. Therefore, it is necessary to set appropriate attachment methods for tower cranes during the construction of high-rise and super high-rise buildings.

(2) Reducing the spacing between connecting walls and increasing the number of connecting wall components can reduce standard section deformation. In the construction of super high-rise buildings with a tower height exceeding 100m, the deformation rate increases. It is recommended to reduce displacement during tower crane operation by increasing the

attachment density to ensure lifting safety.

(3) Through stress-strain cloud diagram and result analysis, it is found that the use of attachment connections in tower cranes can lead to stress concentration at the highest attachment point. However, as the number of attachments increases, the stress is dispersed and the effective stress decreases. In practical engineering, standard sections at stress concentration points should be regularly inspected to avoid bolt and pin structure failures.

References

[1] He Lianjun. Stress monitoring and numerical simulation of tower cranes for construction of super high-rise structures [D]. Harbin Institute of Technology, 2010. DOI: 10.76666/d. D265039.

[2] Wang Zhonglei, Xie Changsheng, Wang Jiyong, et al. Research on numerical simulation method for standard section connection bolts of tower cranes [J]. Mechanical Design, 2023, 40 (10): 42-49.

[3] Lv Haitao, Shi Jin, Nimazaxi. Application of numerical simulation in tower cranes [J]. China Science and Technology Press, 2018 (8).

[4] Sun Xiangyu, Zhang Mingliang, Chen Fubin. Numerical simulation study of wind load on lattice tower crane structure [J]. Building Construction, 2019, 41 (8): 4. DOI: CNKI: SUN: JZSG.0.2019-08-056.

[5] Shi Xiaoqiang. Stress monitoring and numerical simulation of hydraulic climbing formwork and tower crane systems for super high-rise structures [D]. Harbin Institute of Technology, 2015. DOI: 10.76666/d. D755190.

[6] Weng Yunhan, Wen Jie, Jiang Hongqi, et al. Numerical simulation of dynamic response of tower cranes under moving loads [J]. Science and Technology Information, 2023, 21 (11): 83-86.

[7] Jiang Jiguo, Xue Xiaohong, Yang Lei, et al. Numerical simulation of steel support reinforcement for connecting beams under the foundation of an internal climbing tower crane [J]. Construction Technology (Chinese and English), 2021, 50 (22): 5. DOI: 10.7672/sgjs2021220015.

[8] Qin Xianrong, Zhao Junlu, Wang Yulong, et al. Seismic response spectrum analysis of tower cranes based on Ansys [J]. Crane Transport Machinery, 2023 (15): 18-22.

[9] Peng Cheng, Fang Yanheng, Zhong Qilin, et al. Verification and analysis of the theoretical model for no-load weight testing of tower cranes [J]. Crane Transport Machinery, 2021.

[10] Zhou Qinqin. Research on coupled risk warning method for tower crane operation based on finite element analysis [J]. Engineering Technology Research, 2022, 7 (13): 106-108.

[11] Hu Jianfeng, Feng Jianjun, Yang Xiangfan, et al. Fatigue damage life analysis of the lifting arm of a flat head tower crane [J]. Construction Mechanization, 2012, 33 (2): 3. DOI: 10. 3969 / j.issn.1001-1366.2012.02.016.

[12] Lin Jindi, Wei Yongbin, Zhang Yunpeng. Research on the variation of attachment support reaction force during the operation of attached tower cranes [J]. Building Technology, 2012, 43 (9): 4. DOI: 10.3969/j.issn.1000-4726.2012.09.016.

[13] Wang Pingping. Dynamic response analysis of tower crane structure under random seismic excitation [D]. Southwest Jiaotong University, 2015.

[14] Song Shijun, Peng Zhenfei, Wang Zhonglei. Parameterized design of finite element model for tower crane beam elements [J]. Crane Transport Machinery, 2021, 000 (020): 39-43.

[15] Chen Wei, Qin Xianrong, Yang Zhigang, et al. Wind load characteristics analysis of tower cranes under wind field simulation [J]. Mechanical Design, 2019 (2): 8. DOI: CNKI: SUN: JXSJ.0.2019-02-003.

[16] Wen Chuanshi Analysis of safety accidents in tower cranes and exploration of preventive measures [J] Technological Innovation and Productivity, 2023, 44 (09): 66-69.

[17] Chen Yawen, Ding Keqin, Zhou Xusheng, etc Analysis and Reflection on a Tower Crane Collapse Accident [J] China Special Equipment Safety, 2015, 31 (05): 67-70.

[18] Xiong Shengping Analysis of causes and countermeasures for tower crane overturning [J] China Machinery, 2023, (06): 109-112.

[19] Huang Maoneng, Xie Guodong, Feng Tao, etc Investigation and Analysis of the Collapse of Tower Cranes during Typhoon Moranti in Xiamen [J] Building Mechanization, 2017, 38 (01): 23-28+44.

[20] White as mysterious Analysis of Stability Impact of Attachment Tower Crane under Adverse Working Conditions [D]. Anhui Jianzhu University, 2018.