



# Force Analysis of Flat-top Tower Crane Under Typhoon Action

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**Abstract.** In order to understand the effect of wind load on the force state of tower crane, the finite element model of tower crane was established by using Midas Gen software, and the stress and deformation analyses of tower crane were carried out. The results show that the dangerous parts of the tower crane are the connection between the tower body and the lifting arm and the connection between the attachment wall and the standard section; under the action of the typhoon, when the free height of the tower crane decreases, the stress in the connection part between the attachment wall and the standard section and the deformation of the lifting arm decrease, and the higher the attachment wall is, the more obvious is the role of the attachment wall; under the action of the typhoon, the stress and deformation of the tower crane rods are in a safe range, and the tower crane is Safety. The research results provide a basis for the optimisation of the wind protection scheme of tower crane in the dependent project, which is of reference significance for the optimisation of the wind protection scheme of tower crane in other projects.

**Keywords:** Tower crane, Typhoon, Finite element analysis.

## 1 Introduction

With the increase in building height and scale, tower crane is an indispensable vertical transport equipment in all kinds of construction projects, which plays an important role in the construction site, and the service environment of tower crane is also increasingly complex <sup>[1]</sup>. Tower cranes have a high centre of gravity, are more dangerous, and are highly susceptible to safety accidents in harsh environments such as high winds <sup>[2]</sup>. Its towering structure makes it subject to complex and variable wind loads in the working process, and the extreme wind may cause the crane structure to produce large displacements and vibrations, and even trigger structural instability, collapse and other serious consequences <sup>[3]</sup>, which will not only cause great damage to the crane itself, but also may threaten the safety of surrounding personnel and buildings.

Numerous engineering cases both at home and abroad have shown that tower crane accidents caused by wind disasters have brought significant losses to the construction industry, including casualties, property damage, and project delays, etc. <sup>[4]</sup>. It is of great

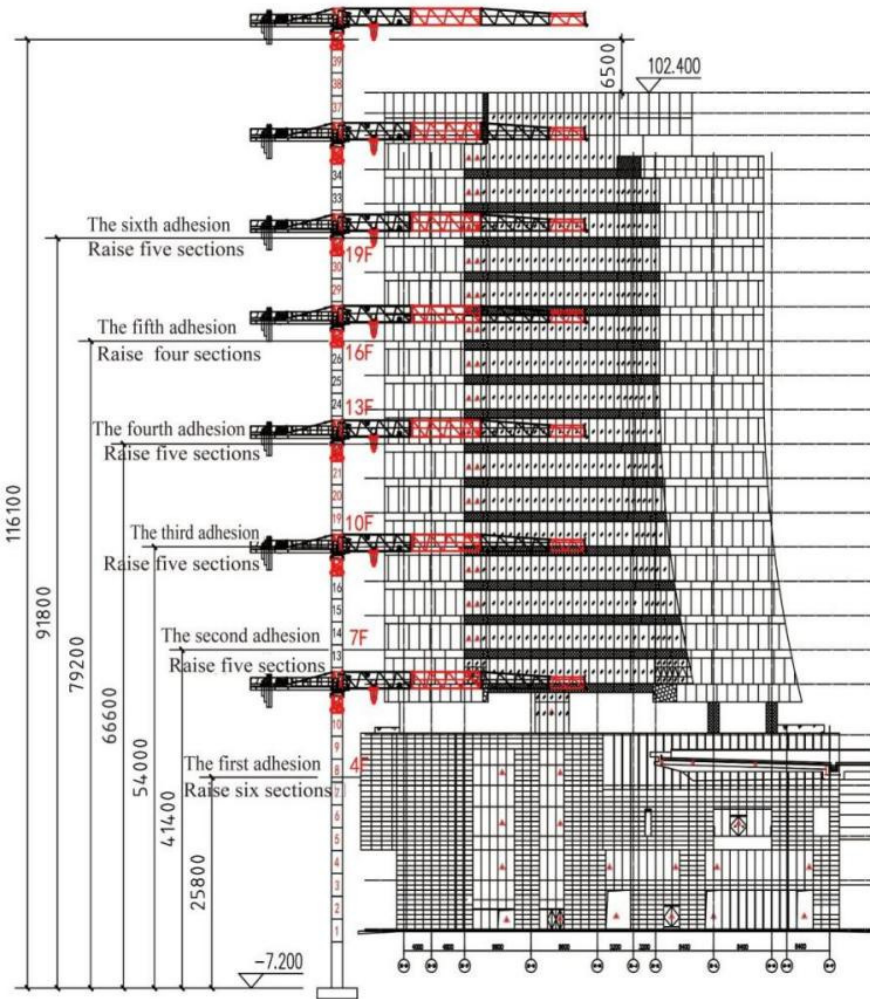
significance to carry out research on the wind resistance of tower cranes. Zheng Shou et al. [5] discussed the safety control of tower crane equipment in high-rise buildings against typhoons. Through the analysis of the typhoon resistance capacity, damage types and causes of tower cranes, they proposed targeted typhoon prevention technical measures, providing a reference for the safety control of tower cranes in high-rise buildings under typhoon conditions to ensure the safety of the construction site. Sun Xiangyu et al. [6] employed the Computational Fluid Dynamics (CFD) numerical simulation method and utilized the RNG  $k-\varepsilon$  and SST  $k-\omega$  turbulence models to deeply analyze the force conditions of tower cranes under a wind speed of 28 m/s at different wind direction angles. They proposed that when designing tower cranes, it is necessary to ensure a reliable connection between the tower body and the main structure to prevent bending and torsional damage. Lu Yi [7] focused on the safety problems of super high-rise construction ancillary facilities in the tornado environment, and used a variety of research methods to propose numerical simulation methods, clarify the wind load type coefficient, analyze the wind vibration effect, and achieve safety assessment and early warning, so as to provide a basis for the construction safety of super high-rise buildings. Yang Yigui [8] used wind tunnel tests, finite element analysis, and probability statistics methods to study the characteristics and wind-induced vulnerability of tower cranes under wind loads ranging from 0 to 30 m/s. He clarified the influence of factors such as Reynolds number, turbulence intensity, model length, wind attack angle, and interference between adjacent sections on the wind load characteristics of tower cranes and provided a standardized resistance calculation method for oblique wind directions. Liu Yun et al. [9] took the tower crane of the Yangtze River Bridge of Ma'anshan Highway Railway as the research object, used the dimensionality reduction spectral notation (DR-SRM) to simulate the random wind field, and constructed a fuzzy comfort evaluation method for the ultra-high tower crane under the maximum operating wind speed of 20m/s by introducing the membership function into the probability density evolution theory (PDEM). Zhang Kai [10] studied the operation stability of tower cranes under strong winds such as typhoons and proposed a set of comprehensive solutions. Through the collaborative application of non-locking rotating mechanism, wall attachment fixing technology and intelligent safety monitoring system, the wind resistance and safety of the tower crane are improved. At present, there are relatively few studies on the wind resistance of tower cranes under extreme wind conditions such as typhoons, and there is a lack of special wind resistance design methods and safety evaluation standards for tower cranes.

In this study, the finite element simulation method was used to examine the mechanical performance of tower cranes under typhoon action, in order to provide a basis for the wind safety of tower cranes.

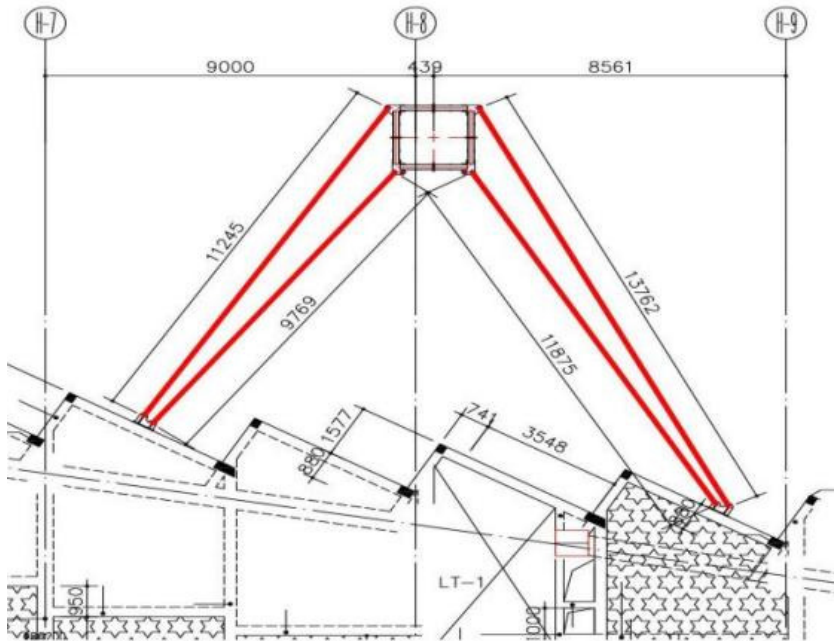
## 2 Finite Element Model

Located in Chenghai District, Shantou City, Guangdong Province, the supporting hotel project of the exhibition and exhibition centre in Tagangwei Area, Shantou East Coast

New Town, Guangdong Province, is a tropical storm-prone area, with an average annual wind speed of more than 2.40m/s and an average wind speed of 35.79m/s when the typhoon makes landfall. The construction site installed a flat-top tower crane, the installation height is 116.10 metres, a total of six attachments (the first attachment height is 25.80m; the second attachment height is 41.40m; the third attachment height is 54.00m; the fourth attachment height is 66.60m; the fifth attachment height is 79.20m; the sixth attachment height is 91.80m), and the length of the first to sixth four tie rods is 11.24m, 9.76m, 11.87m, 13.76m. Figure 1 shows the layout of the tower crane.



(a) Tower crane elevation layout drawing



(b) Attachment plan of the 1st to 6th lanes

**Fig. 1.** Tower crane layout drawing

The size and rod materials of the tower crane are: the standard section size is  $1.80\text{m} \times 1.80\text{m} \times 2.80\text{m}$ , the main chord is made of  $160\text{mm} \times 16\text{mm}$  angle steel, and the cable-stayed rod is made of  $40\text{mm} \times 4\text{mm}$  square steel; The main chord on the crane arm is made of  $\Phi 159\text{mm} \times 7\text{mm}$  tube steel, the lower chord is made of  $120\text{mm} \times 80\text{mm} \times 6\text{mm}$  rectangular steel, and the web rod is made of  $\Phi 76\text{mm} \times 3\text{mm}$  tube steel; The main chord of the balance arm is made of  $\Phi 10\text{mm}$  steel pipe; The cable is made of  $\Phi 8\text{mm}$  steel pipe; The attachment rods are all made of two channel steel 30A buckle buckles, and the structure is a two-limb plate type. The attachment rod material is Q235, and the standard section, crane arm, balance arm and other component materials are Q345B.

The finite element analysis software Midas Gen is used to establish a finite element analysis model, the software was chosen for its advanced capabilities in nonlinear structural analysis, dynamic load simulation, and more. The beam and truss elements of the software effectively simulate the standard part and rod system of the crane, and the boundary conditions of the foundation and attachment points can also be truly constrained. The top cable of the tower crane is simulated by the tension truss element only, the beam element is used to simulate the structure of the standard section, the boundary condition of the fixed constraint is adopted at the bottom of the tower crane, and the tower crane is set up with six attachments, in which the attachment brace between the tower body and the building is simulated with the beam element, and the attachment point adopts the boundary condition of the fixed constraint. Figure 2 shows the finite element analysis model of a tower crane.

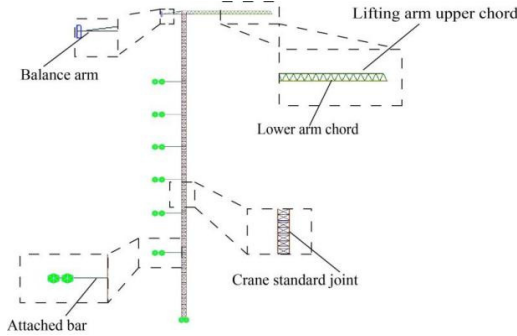


Fig. 2. Finite element analysis model of tower crane

### 3 Force Analysis of Tower Cranes

#### 3.1 Force Analysis Under the Action of Self-Weight

Fig. 3 shows the stress and deformation of the tower crane under its own weight. The maximum tensile stress produced by the tower crane boom is 132.76MPa, and its position is at the junction of the tower crane boom and the tower body, and the maximum deformation of the crane arm is located at the end of the boom, and the maximum vertical displacement is 10.50cm; the maximum compressive stress produced by the balance arm is 138.51MPa, and the maximum deformation is 9.76cm, and its position is all located at the end of the balance arm; the stress peak of the attachment rod appears at the uppermost attached wall, and its value is 15.29MPa, and the displacement of the attached wall is very small, almost close to 0; the maximum deformation of the tower body is located at the connection part with the crane arm, and the maximum vertical displacement is 7.22cm.

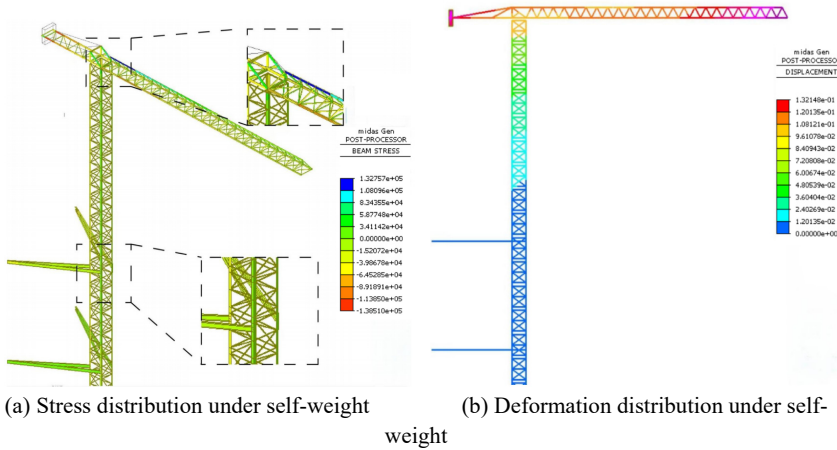


Fig. 3. Stress and deformation of tower crane under its own weight

### 3.2 Force Analysis Under the Combined Action of Self-Weight and Wind Load

According to the Code for Loading of Building Structures, the load combination is 1.2 self-weight + 1.4 wind load. Fig. 4 shows the stress and deformation of the tower crane under the action of load combination. The maximum tensile stress produced by the tower crane boom is 152.23MPa, and its position is at the junction of the tower crane boom and the tower body; the maximum deformation is located at the end of the boom, the maximum vertical displacement is 21.28cm, and the maximum horizontal displacement is 1.92m; the maximum compressive stress produced by the balance arm is 158.65MPa, the maximum deformation is 11.36cm, and its position is at the end of the balance arm; the higher the attached wall, the greater the stress, the stress peak of the attachment rod appears at the uppermost attached wall, its value is 69.78MPa, the deformation of the attached wall is very small, and the maximum deformation is located in the part where the sixth attachment is connected with the tower body, and its value is 1.15cm; the maximum compressive stress of the tower body is 247.52MPa, and the maximum compressive stress is 241.26MPa, all of which are located at the junction of the sixth attachment standard section and the attachment rod, and the maximum deformation is located at the junction with the crane arm, and its value is 10.27cm. The stress of the components is within the yield limit of the material (Q345B: 345 MPa), and the structure is safe.

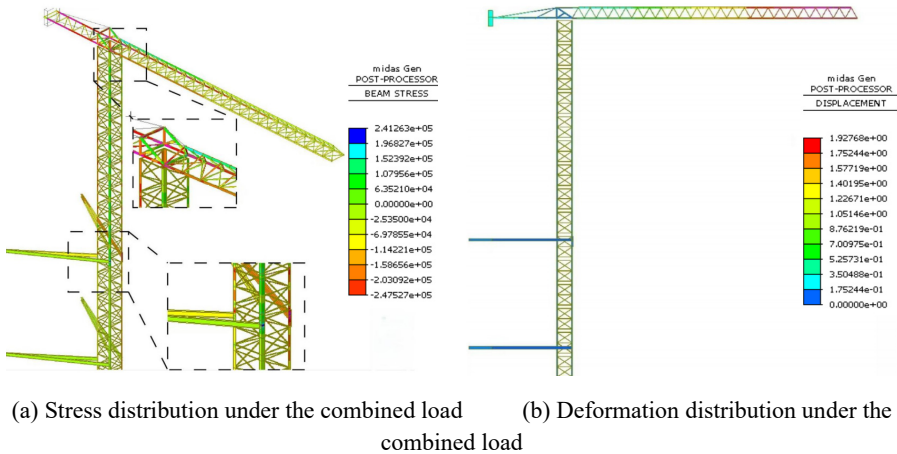
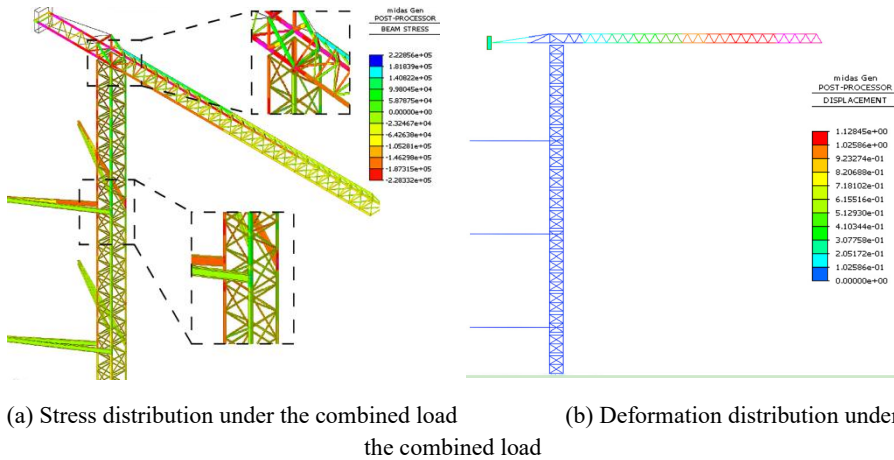


Fig. 4. Stress and deformation of tower crane under load combination

## 4 Increase the Force Analysis of the Tower Crane After Attachment

Because the free height of the tower crane is relatively large, it is unstable under the action of a typhoon. An attachment is added to the sixth attachment of the tower crane, and the stress of the tower crane under the load is analysed. Figure 5 shows the stress

and deformation of the tower crane under the action of load combination after increasing the attachment. The maximum tensile stress produced by the tower crane boom is 140.82MPa, its position is at the junction of the tower crane boom and the tower body. The maximum deformation is located at the end of the boom, the maximum vertical displacement is 19.77cm, the maximum horizontal displacement is 1.11m, the maximum compressive stress produced by the balance arm is 146.29MPa, the maximum deformation is 11.37cm, and its position is all located at the end of the balance arm. The stress peak of the attachment rod appears at the uppermost attached wall, its value is 64.26MPa; the higher the attached wall, the greater the stress. The maximum deformation of the attached wall is located in the part where the seventh attachment is connected with the tower body, and its value is 0.95cm. The maximum tensile stress of the tower body is 99.80MPa, and the maximum compressive stress is 105.28MPa, all of which are located at the connection between the seventh attachment standard section and the attachment rod, and the maximum deformation of the tower body is located at the connection part with the crane arm, and its value is 9.72cm. The stress of the components is within the yield limit of the material (Q345B: 345 MPa), and the structure is safe. The maximum vertical displacement of the tower crane is less than  $1.34H/100$  in the relevant specifications, ( $H$  is the height of the tower crane).



**Fig. 5.** The stress and deformation of the tower crane under the action of load combination after increasing the attachment.

The results indicate that with the addition of attachments, the stress at the connection points between the tower body and the attachments is significantly reduced, remaining within the material's yield limit (Q345B: 345 MPa), ensuring structural safety. Furthermore, under typhoon conditions, the horizontal displacement of the crane's jib is substantially decreased, effectively reducing swaying caused by strong winds. This demonstrates that enhancing stability by adding attachments to reduce the free height can significantly improve the overall stability of tower cranes.

## 5 Conclusion and Significance

### 5.1 Conclusion

In this paper, the finite element model of the flat-top tower crane is established by using the software Midas Gen, the stress and deformation of the tower crane under the combined action of self-weight and wind load are analysed, and the influence of increased attachment on the stress state of the tower crane is studied, and the following conclusions are drawn:

- 1) The dangerous part of the tower body is the connection between the tower body and the crane arm and the connection part of the attached wall and the standard section;
- 2) Under the action of a typhoon, the stress of the tower crane itself and the attached wall components are less than the allowable stress, and the deformation of the tower crane is within the safety range, and the tower crane is safe;
- 3) Under the action of a typhoon, when the free height of the tower crane is reduced, the stress of the connection between the attached wall and the standard section and the shaking of the crane arm are reduced, and the higher the attached wall, the greater the stress of the attached rod, the more obvious the force, and the greater the role.

### 5.2 Practical Application Significance

- 1) Reducing the free height by attaching accessories can significantly alleviate stress concentration and deformation, and it is recommended to design more wall attachment members reasonably in the initial design stage.
- 2) During typhoons, the crane boom - tower joints and wall - standard section joints require priority reinforcement, and monitoring systems can be installed at these joints to provide early warning of potential overloading.

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