



Safety assessment and design of a new type of exoskeleton reinforcement scheme for a 110kV iron tower in a coastal area

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Abstract. By analyzing the influencing factors of wind load, taking the 110kV transmission tower in Zhongshan area as an example, a new wind resistance reinforcement scheme is designed for the tower. Taking the steel structure reinforcement scheme as an example, the reinforcement effect of the new "exoskeleton" reinforcement scheme is analyzed, and different material wind resistance reinforcement schemes are comprehensively analyzed to improve the safety of the tower.

Keywords: Wind load, tower safety, exoskeleton reinforcement.

1 Introduction

Wind load is one of the important loads on transmission lines, and strong wind load has become a significant cause of tower collapse in transmission lines. Typhoons are frequent in the southeastern coastal areas of China, and Zhongshan City in Guangdong Province is a key area affected by typhoons. There are a total of 152 110kV transmission lines in the region, with approximately 3500 iron towers distributed in 24 townships. The distribution of 110kV transmission lines in the region is extensive, with many lines and outdated ones. Under the influence of strong typhoons, there is a risk of collapse. At present, when analyzing the typhoon resistance of transmission towers, a single design wind speed is mainly used, without considering the influence of micro terrain and micro meteorological conditions on the actual wind speed. In the research of tower reinforcement technology, the usual methods are to increase the cross-section and change the transmission path, which have two drawbacks. Firstly, it is necessary to drill a large number of holes on the original tower material, which will weaken the cross-section of the original components. Secondly, only individual components can be reinforced, making it difficult to improve the overall structural load-bearing capacity. Therefore, it is necessary to evaluate the risk of tower collapse under strong typhoons for the 110kV transmission line towers in Zhongshan City, and develop new reinforcement methods to address the high risk.

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A. M. Zende et al. (eds.), *Proceedings of the 2024 3rd International Conference on Structural Seismic Resistance, Monitoring and Detection (SSRMD 2024)*, Atlantis Highlights in Engineering 27,

https://doi.org/10.2991/978-94-6463-404-4_24

2 Analysis of wind load influencing factors

The basic situation of strong typhoons that have caused significant disasters in the Guangdong Hong Kong Macao region in the past 10 years, including three major impacts on Zhongshan, namely Typhoon Nida, Typhoon Tiange, and Typhoon Shanzhu. Especially in 2018, Typhoon "Shanzhu" landed near Jiangmen with a wind speed of 50m/s. It had a significant impact on the power transmission lines in the Zhongshan area. By analyzing the wind speed, direction, and path of strong typhoons that have landed in the Guangdong Hong Kong Macao region in the past 10 years, the results show that the main typhoon winds that can cause disasters in the Zhongshan region are southeast and north winds.

According to the "30 year return period transmission line basic wind speed zoning map" of China Southern Power Grid Corporation, it can be seen that the areas in Zhongshan area with a basic wind speed of 31m/s include Nantou Town, Dongfeng Town, Xiaolan Town, Guzhen Town, Huangpu Town, Fusha Town, and Henglan Town; The areas with a basic wind speed of 33m/s include Triangle Town, Port Town, Shaxi Town, Dayong Town, South District, Banfu Town, Shiqi District, North of Minzhong Town, and North of East District; The areas with a basic wind speed of 35m/s include the central and western regions of the Torch, the southern part of the Eastern District, the southern part of Minzhong Town, Wuguishan Town, San Township, Shenwan Town, and Tanzhou Town; The areas with a basic wind speed of 37m/s include the eastern part of the Torch Development Zone, Nanlang Town, and the eastern part of Minzhong Town.

In fact, within the same basic wind speed range, terrain conditions, building height, and density have a certain degree of impact on wind loads. For example, facing the wind in mountainous areas has an acceleration effect on wind loads, and existing buildings can have a certain obstruction effect on airflow. In order to more reasonably consider the wind load calculation value, this project introduces terrain condition correction coefficients and building density adjustment coefficients on the basis of basic wind speed.

The average wind speed in mountainous areas is the same as on flat ground at the foot of the windward side, with the maximum acceleration at the mountaintop and the maximum deceleration at the foot of the leeward side. It basically recovers to the same level of wind field 5 hours after the foot of the leeward side; The increase in average wind speed near the mountaintop surface increases with the increase of mountain slope and height; The decrease in average wind speed near the ground on the leeward side and the height of the mountain's influence both increase with the increase of mountain slope and height; The root mean square values of the fluctuating wind speed at the foot, waist, and mountaintop of the windward side are the same as those on flat ground, reaching their maximum at the foot of the leeward side of the mountain, and basically restoring to the same level wind field 5 hours later. Therefore, a calculation method for wind speed terrain correction coefficient can be proposed to calculate the regional wind speed terrain correction coefficient in Zhongshan City. The calculation results are shown in the figure 1.

$$\eta_B = \left[1 + \kappa \tan \alpha \left(1 - \frac{z}{2.5H} \right) \right]^2 \tag{1}$$

In the formula, $\tan \alpha$ The slope of a mountain peak or slope on the windward side;
 κ The coefficient is taken as 2.2 for peaks and 1.4 for slopes;
 H is the total height of the mountain peak or slope;
 z is the height of the calculated position of the structure above the ground.

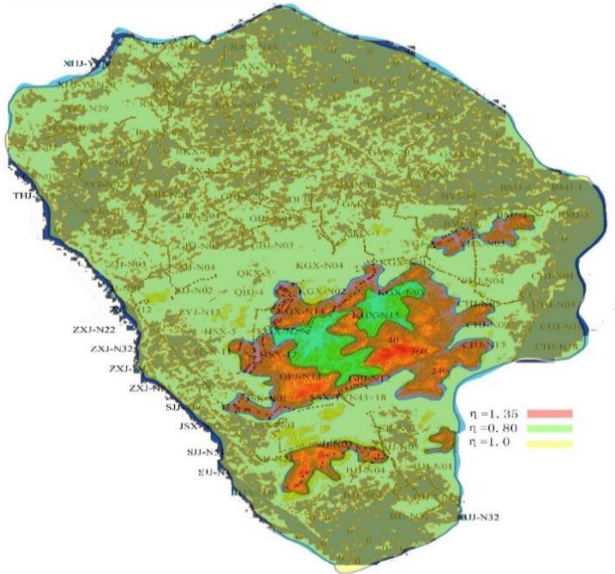


Fig. 1. Distribution map of wind speed terrain correction coefficient

3 Safety assessment of 110kV transmission towers in Zhongshan area and design of new wind resistant reinforcement schemes for towers

Based on the above analysis, taking into account the impact of terrain and building density on airflow, the basic wind speed used for safety assessment of iron towers under strong typhoons can be calculated using the following formula:

$$v = \eta \zeta v_0 \tag{2}$$

In the formula, v is the basic wind speed used for structural safety assessment;
 η is the topographic terrain adjustment factor;
 ζ is the building density adjustment factor;
 v_0 is the recommended 30 year return period basic wind speed for Southern Power Grid Company.
 definition λ To consider the comprehensive adjustment coefficient of terrain and building density, there are:

$$\lambda = \eta\zeta \tag{3}$$

Based on the terrain, topography, and urban construction situation of Zhongshan City, the comprehensive adjustment coefficient of each region can be calculated and a comprehensive adjustment coefficient map can be drawn. By overlapping the comprehensive adjustment coefficient with the 30 year return period basic wind speed recommended by Southern Power Grid Company, the evaluation wind speed for each region can be intuitively calculated.

The safety of the 110kV transmission tower in Zhongshan City was evaluated using this principle. The evaluation results showed that a total of 802 towers in the 100kV transmission line tower had typhoon safety risks and needed to be reinforced.

Most of the 110kV transmission lines in Zhongshan area are double circuit lines on the same tower, and their iron towers are mostly drum shaped. Due to the weak wind resistance and high risk of collapse of the straight tower, the reinforcement design of this project takes the straight tower of the 110kV double circuit line on the same tower as an example. The traditional reinforcement methods include increasing the section of the component and adding a stay wire. For some old lines, the section of the components is small, and the method of increasing the section generally requires opening holes in the original structure, greatly reducing the bearing capacity of the original structure and making construction extremely inconvenient [1-3]. The wire drawing method is simple to construct, but its improvement in structural bearing capacity is limited, and it requires re land acquisition and is greatly affected by site conditions. This project designs a new type of wind resistance reinforcement scheme for iron towers based on the characteristics of wind load action - exoskeleton reinforcement.

The overall structure diagram of the exoskeleton reinforcement scheme is shown in Figure 2:

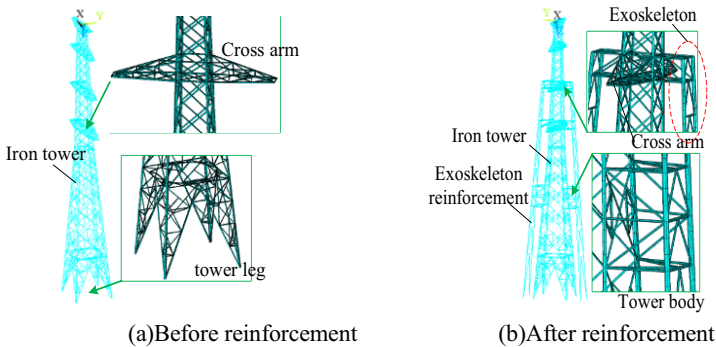


Fig. 2. Exoskeleton reinforcement design scheme

3.1 Materials and Comparison

The reinforcement plan of this project can use aluminum alloy structure or steel structure, and different materials have a significant impact on the mechanical properties of the structure and the overall engineering cost.

In order to ensure the reinforcement effect and facilitate maintenance, this project plans to use pipe reinforcement.

3.2 Basic design scheme

The construction period of the transmission line foundation project accounts for about 50% of the entire construction period, the transportation engineering quantity accounts for about 80% of the entire project, and the cost accounts for about 30% of the project cost. Therefore, the selection and design of transmission line tower foundation schemes are very important for the entire project's construction period, quality, and safety.

The area where this project is located is a coastal area with good construction conditions and convenient transportation. Some areas have thick weak layers, so the selection of foundation forms is mainly based on expanded foundations and pile foundations, and straight column rigid step foundations can be used[4-5], as shown in Figure 3.

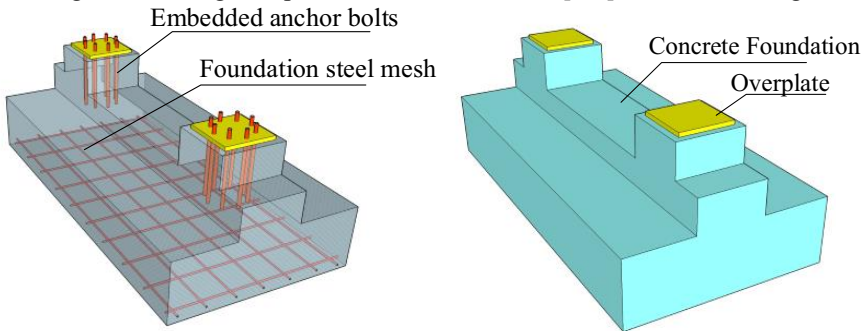


Fig. 3. Basic design scheme

3.3 Column base design scheme

The column base is connected by anchor bolts. The specific structure is shown in Figure 4. The reinforcement component - the end of the vertical rod is equipped with an end plate, with 8 bolt holes on the end plate. The position of the end plate is the same as that of the embedded anchor bolt, and the hole diameter is 2mm larger than the diameter of the embedded anchor bolt. During installation, align the components in place, tighten the upper and lower bolts of the end plate, and then use new high-strength grouting materials to pour and compact in the gaps.

The reinforcement component - the vertical rod has a certain angle with the plumb surface, which is achieved through the connection between the column base end plate and the vertical rod, that is, the end plate, transition plate, and foundation surface are all located in the horizontal plan [6].

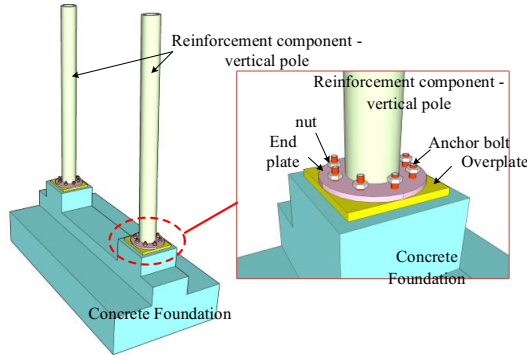


Fig. 4. Column base design scheme

3.4 Rod connection design scheme

Due to limitations in construction site conditions, steel pipe components cannot be assembled using welding or other connection methods after transportation to the site. Flange connection is an ideal connection method for steel pipe structures. As an important connection form of steel pipe structures, flange connection has many advantages, such as good load-bearing performance, convenient support and installation, simple appearance, and aesthetics. The reinforcement plan for the exoskeleton of this project adopts fully assembled construction, and the connection of pipe fittings adopts flange connection, which is divided into two forms: pipe fitting docking and T-shaped connection, as shown in Figure 5.

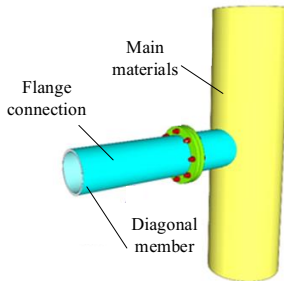


Fig. 5. Rod connection design scheme

4 Analysis of reinforcement effect

This section takes the steel structure reinforcement scheme as an example to analyze the reinforcement effect of the new "exoskeleton" reinforcement scheme. as shown in Figure 6.

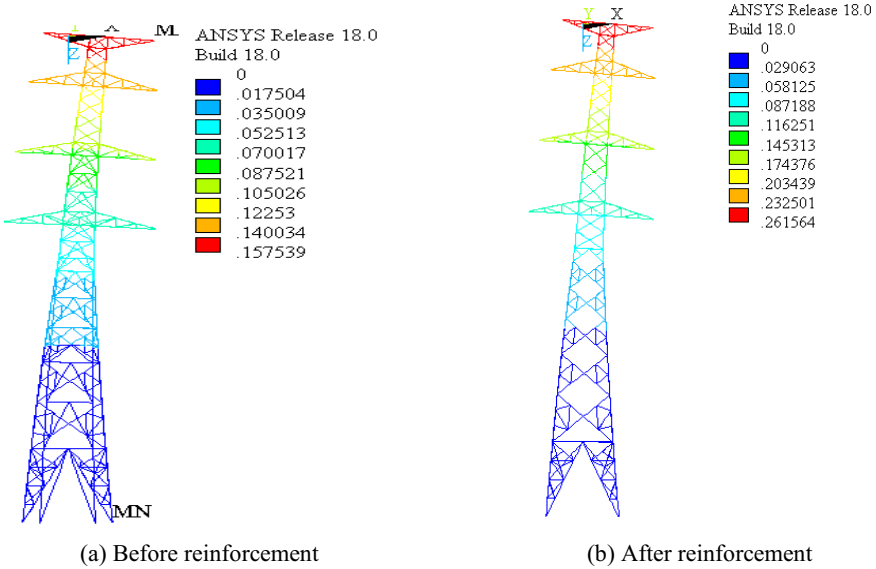


Fig. 6. Displacement nephogram

After finite element analysis, the maximum displacement of the structure reached 0.262m before reinforcement. The maximum stress reaches 331MPa, exceeding the yield strength of the material. After reinforcement, under the same load conditions, the maximum displacement decreased to 0.157m and the maximum stress decreased to 211MPa. The stiffness has increased by 40% and the bearing capacity has increased by 36%. The above calculations indicate that the new tower reinforcement scheme has a significant improvement effect on the stiffness and bearing capacity of the tower.

After calculation and analysis, it is shown that the displacement of the reinforced tower under a strong wind load of 48m/s is equivalent to the maximum displacement and maximum equivalent stress of the tower before reinforcement at a wind speed of 37m/s. Under this design condition, the reinforcement plan can increase the wind resistance of the modified iron tower from 37m/s to 48m/s. That is, the corresponding Pufu wind power level can be increased from "level 13" to "level 15".

5 Comprehensive analysis of wind resistance reinforcement schemes using different materials

In order to facilitate comparative analysis and ensure consistent cross-sectional dimensions, a mechanical model for the reinforcement scheme of Q235B steel structure and 6061 aluminum alloy structure was established, with a design wind speed of 37m/s considered and mechanical performance analysis conducted. As is shown in Table 1.

Table 1. Comparison of mechanical properties

	maximum displacement		maximum stress	
	absolute value	Performance improvement	absolute value	Performance improvement
Before reinforcement	262mm	—	331MPa	—
Q235BSteel structure reinforcement	158mm	39%	211MPa	36%
6061 Aluminum alloy reinforcement	212mm	19%	275MPa	17%

From Table 1, it can be seen that both material components can improve the bearing capacity of the original structure. Under the same design cross-section and structural size, the mechanical performance of the steel structure reinforcement scheme is better than that of the aluminum alloy structure reinforcement scheme.

In order to compare the cost and performance of different material reinforcement schemes, the structural mechanical indicators under a wind speed of 37m/s were calculated and analyzed, and the section of the components was changed to maintain consistent mechanical performance. The comparison of material usage and cost is shown in Table 2.

Table 2. Comparison of comprehensive parameters

Scheme category	Rod type	Section specifications	Total length/m	Weight per meter kg	Total weight Kg	price index	Price indicators
Steel structure scheme	montant	Φ140×5	92.12	16.65	1533.798	5	12193
	cross bar	Φ70×3	47.74	4.96	236.7904		
	diagonal	Φ45×3	214.83	3.11	668.1213		
Aluminum alloy solution	montant	Φ170×10	92.12	14.43	1329.292	24	46344
	cross bar	Φ90×5	47.74	3.74	178.5476		
	diagonal	Φ60×4	214.83	1.97	423.2151		

In summary, the comprehensive price index of the aluminum alloy scheme is about 4 times that of the steel structure scheme[7]. The recommended scheme for wind resistant exoskeleton reinforcement of iron towers is the steel structure scheme.

6 Conclusion

Under the same conditions, the mechanical performance of the steel structure reinforcement scheme is superior to that of the aluminum alloy structure reinforcement scheme.

The comprehensive price index of the aluminum alloy scheme is higher than that of the steel structure scheme. Recommended steel structure scheme for engineering.

The reinforcement scheme of wind resistant exoskeleton for iron towers can improve their lateral wind resistance and has broad application prospects in coastal transmission line reinforcement projects.

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