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Stability and reinforcement analysis of weathering steel high voltage transmission tower

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Abstract. The local instability of weathering steel transmission towers is an important reason for the collapse of transmission towers. In this paper, the wind speed is converted into wind pressure and applied to ANSYS finite element model established according to the actual equal proportion, and the influence of secondary stress and the orientation of Angle steel are considered. The stability of transmission tower is analyzed according to buckling coefficient. The results show that the buckling coefficient and the buckling position increase with the reinforcement degree of the main material of the weathering steel transmission tower. After the reinforcement of the first and second sections of the main transmission material is completed, the buckling position moves up to the web bar of the transverse arm. The buckling coefficient of T type is about 39% and 25% higher than that of the cross type and Z type respectively, which can effectively improve the safe operation ability of the line.

1. Introduction

Weathering steel transmission lines, as an important part of the power system, are widely distributed in various regions of China. They are affected by natural disasters such as freezing rain, snow and strong winds. The occurrence of severe faults such as local buckling or partial collapse of transmission lines seriously affects the safe and stable operation of power system[1]. Due to the limitations of design codes at that time, transmission towers built in the early stage failed to fully consider the influence of extreme adverse natural environment, such as maximum design wind speed, variation coefficient of wind pressure height and wind carrier shape coefficient, etc., resulting in tower collapse accidents. In fact, strength failure and buckling are the main failure modes of transmission tower collapse[2,3].

In this paper, the reinforcement scheme that is connected by a single plate and combined with various cross-section forms is adopted. ANSYS software is used to model the actual tower, and the wind pressure is converted into the node load and the eigenvalue buckling analysis is carried out, so as to select the best reinforcement scheme.

2. Wind load calculation of transmission tower

The wind load mainly depends on the wind speed. The wind speed of the transmission tower should be converted to the wind pressure load, and the basic wind pressure load should be corrected by the working condition coefficient. According to the structural characteristics of the transmission tower, the



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wind pressure load of the cross arm and the wind pressure load of the tower should be calculated separately[4].

2.1. Wind speed and wind pressure

The Bernoulli equation in fluid mechanics can transform wind speed into reference wind pressure W_0

$$W_0 = \frac{1}{2} \rho v^2 = \frac{1}{2} \frac{\gamma}{g} v^2 \quad (1)$$

Where: ρ represents the air particle density of the site environment (t/m^3); γ represents the gravitational density of a gas kN/m^3 ; v represents the wind speed (m/s). Combined with China's meteorological conditions, the design specification is usually taken $\gamma/(2g)=1600$.

2.2. Wind load standard value calculation

Transmission tower wind load is not only related to the reference wind pressure, but also takes into account the influence of tower height, component shape, fluctuating wind and icing[5]. When the wind direction is perpendicular to the structure surface, the formula for calculating the standard wind load is as follows:

$$W_s = \mu_z \mu_s \beta_z B A_t W_0 \quad (2)$$

3. Wind buckling analysis of transmission towers

When the loading test is carried out on the structure, large deformation will occur suddenly when the critical value is reached. At this time, even if the members continue to apply negligible small load, the existing equilibrium state of the structure is immediately broken, which is accompanied by a large deformation phenomenon known as structural instability or buckling[6].

3.1. Eigenvalue buckling analysis and its buckling factor

The transmission tower is a truss structure composed of a large number of components. When one component is subjected to instability deformation, the internal force characteristics of the whole structure will be affected and redistributed. Therefore, it is necessary to treat the whole structure as a whole and then conduct buckling analysis[7]. Considering the transmission tower as an ideal linear elastic structure, the theoretical buckling strength (i.e., the bifurcation point) is solved through the characteristic equation, and the calculation results are conservative, as shown in Fig. 1.

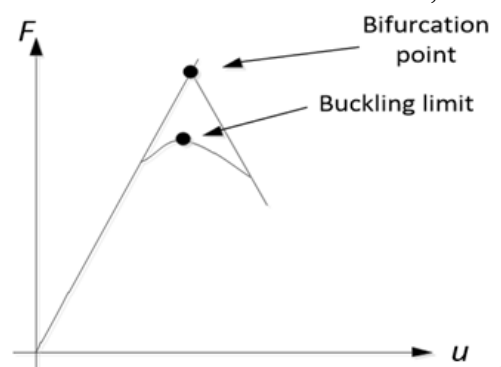


Figure 1. Eigenvalue buckling analysis

Under the condition of unit external load, let the structural stress stiffness matrix be $[K_\sigma]$, the load multiplier be λ , and the product of the two correspond to the geometric stiffness matrix of another strength. It and the usual stiffness matrix are not displacement functions. When the

load matrix $[R]$ is constant, the displacement matrix $[D]$ under the baseline condition plus the virtual displacement $[\bar{D}]$ should satisfy the equilibrium state equation:

$$\begin{aligned} ([K] + \lambda[K_\sigma])[D] &= [R] \\ ([K] + \lambda[K_\sigma])[D + \bar{D}] &= [R] \end{aligned} \quad (3)$$

We subtract this from that

$$([K] + \lambda[K_\sigma])[\bar{D}] = 0 \quad (4)$$

The above equilibrium equation becomes unstable in the presence of the singular solution, let $([K] + \lambda[K_\sigma]) = [K_{eq}]$, then:

$$[K_{eq}] < 0; \text{ Unstable equilibrium state}$$

$$[K_{eq}] = 0; \text{ Instability}$$

$$[K_{eq}] > 0; \text{ stable state}$$

The critical load at the bifurcation point is the product of λ and the applied external load. When λ is negative, it means that the buckling load should be applied in the opposite direction. The displacement feature vector $[\bar{D}]$ represents the buckling mode and can easily show the buckling shape.

4. Transmission tower reinforcement

For the transmission tower that was put into operation earlier, the operation time of some components is too long and the performance declines, which leads to the insufficient stability of the tower structure. Therefore, the reinforcement measures for the rods have lower cost and can completely improve the stability and extend the safe operation time, with remarkable effect[8].

4.1. Composite section form

The new composite section form increases the sectional area, and its reinforcement effect is not completely equivalent to the method of increasing section. The cross section forms are mainly type X, type Z and type T, as shown in figure 2. The buckling analysis is carried out to study the reinforcement effect of the composite members.

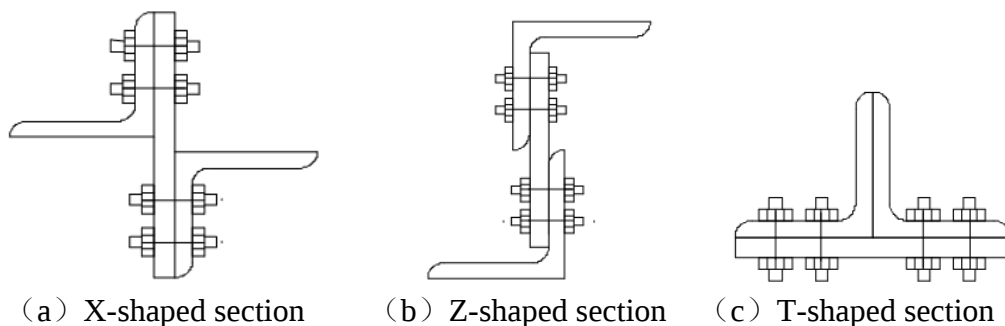


Figure 2. Composite section form of reinforced component

5. Buckling analysis of transmission tower

The eigenvalue buckling analysis of the transmission tower is completed by ANSYS, and the main steps are as follows: 1) three-dimensional modeling; 2) solve the static solution; 3) eigenvalue buckling analysis and solution; 4) expand the results; 5) result list and drawing display.

5.1. Reinforcement condition and buckling solution

In this paper, three reinforcement schemes are modeled to analyze the effect of reinforcement and compare the situation without reinforcement.

- (1) working condition 1: no reinforcement working condition.
- (2) working condition 2: reinforce the first section of the tower.
- (3) working condition 3: reinforce the first and second paragraphs of the tower.

In working condition 2 and working condition 3, cross section, z-shaped section and t-shaped section combination were adopted respectively, and the main material section was increased by 50%. According to the actual transmission tower structure modeling and applying constraints and wind loads in ANSYS software, the first 2 order buckling modes of eigenvalue buckling analysis are extracted. Figure 4 (a) and (b) are the corresponding results. The order and corresponding coefficients of buckling modes are shown in table 1.

Considering the actual situation of line operation and the situation that the wind speed continues to increase, the wind pressure of the tower increases accordingly, and the main material at the lower part of the tower body usually buckling first, causing the failure. As the weak link of the whole tower under strong wind, in order to improve its bearing capacity, this paper adopts the method of partial reinforcement of main materials and makes modeling analysis. See figure.3 for the segmentation of tower body.

5.2. Comparison of calculation results

The wind load was calculated according to the basic wind speed 30m/s and applied to the tower. The buckling modes of the tower under various working conditions were shown in figure 4. The analysis and comparison results were shown in table 1.

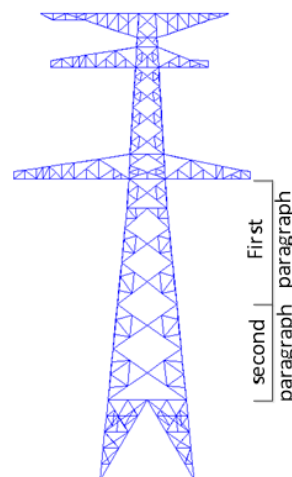


Figure 3. Schematic diagram of the body section

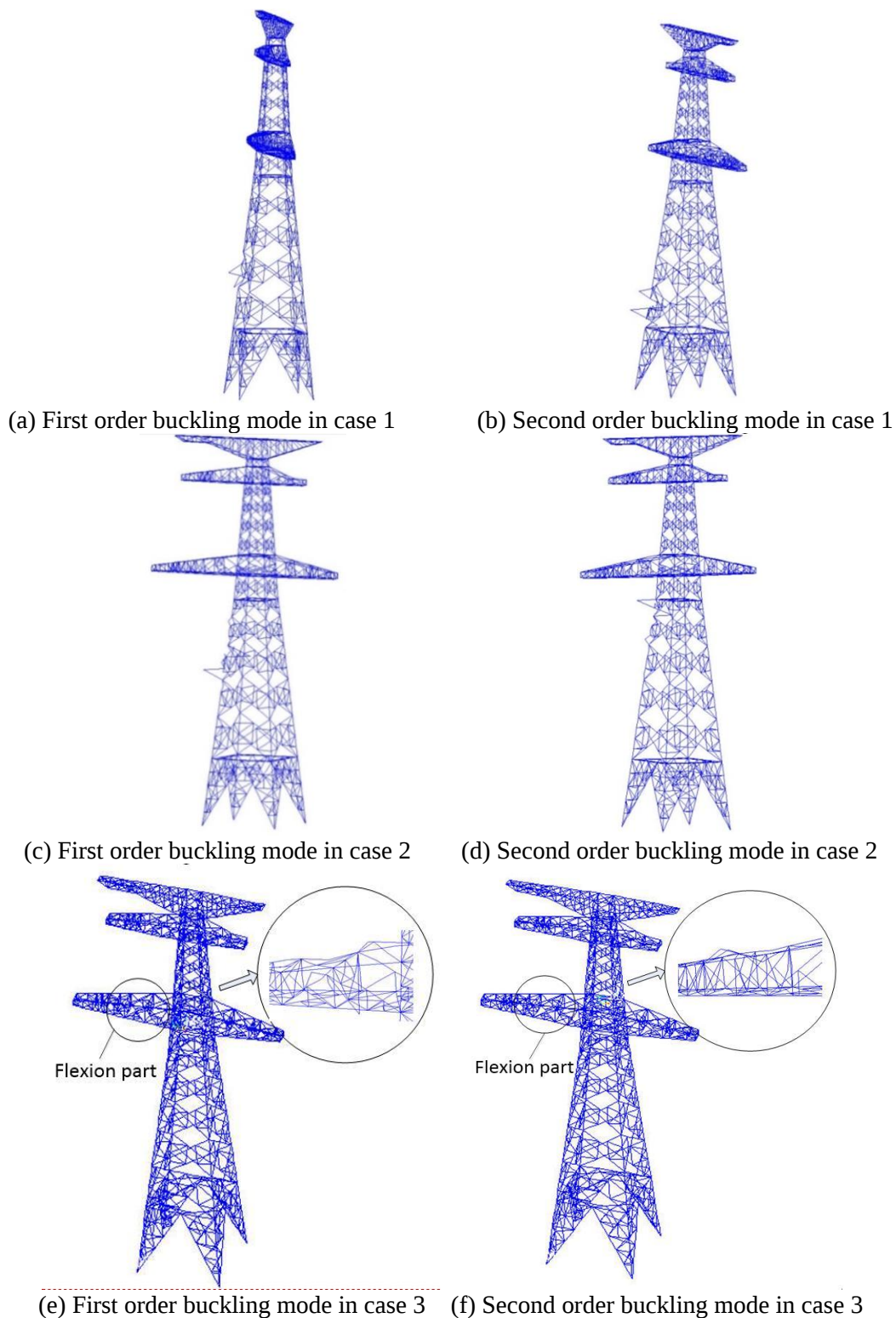


Figure 4. The first and second buckling modes under different working conditions

Table 1. Mode and coefficient of wind resistance buckling of pole and tower in various working conditions

working condition	section form	order	buckling coefficient	The buckling coefficient increases by multiple	buckling mode
1	steel angle	1	7.218	——	Section 1 tower main timber instability
		2	7.306	——	
2	X-shaped section	1	8.165	1.13	Section 2 tower main timber instability
		2	8.840	1.21	
	Z-shaped section	1	9.079	1.26	Section 2 tower main timber instability
		2	9.830	1.35	
	T-shaped section	1	11.349	1.57	Section 2 tower main timber instability
		2	12.288	1.68	
3	X-shaped section	1	32.625	4.52	The first crossarm auxiliary is unstable
		2	35.507	4.86	
	Z-shaped section	1	36.261	5.02	The first crossarm auxiliary is unstable
		2	39.554	5.41	
	T-shaped section	1	45.218	6.26	The first crossarm auxiliary is unstable
		2	49.284	6.75	

It can be seen from figure 4 that under the wind load, the instability failure of the pole occurs at the lower part of the transmission tower. The results in table 3 show that the buckling coefficients of the x-shaped, z-shaped and t-shaped columns increase by 13%, 26% and 57% respectively after the completion of the reinforcement of the first section of the tower. After the reinforcement of the first and second sections of the tower body, the increase multiples of the buckling coefficients of the cross-shaped, z-shaped and t-shaped towers are 4.52, 5.02 and 6.26, respectively. When the main material at the lower end of transmission tower is strengthened, the weak link of buckling will transfer upward gradually, and the critical buckling load of the main material will increase accordingly. With the increase of buckling coefficient, the stability of the tower is improved. With the improvement of reinforcement degree, the buckling part is transferred to the crossarm auxiliary material part, at which time the buckling factor has exceeded 30 and the safety degree is relatively high. Moreover, the bars at the crossarm where buckling occurs account for about 16% of the whole crossarm, and the scope of buckling is small and the influence is weak. On the whole, after reasonable reinforcement, the transmission tower turns from the buckling failure of the main material to the instability failure of the partial auxiliary material of the transverse arm, and the overall stability of the structure is greatly improved, which can effectively avoid the collapse accident caused by the failure of the main material. In addition, the buckling coefficients of z-shaped and t-shaped increased by about 39% and 25%, respectively, under different x-shaped reinforcement schemes. The reinforcement scheme of t-shaped has better effect.

6. Conclusions

(1) by transforming wind load into transmission tower node load and applying it to ANSYS tower model by adjusting Angle steel orientation, the buckling modal analysis finds that the weak link of transmission tower instability is located at the lower part of tower body.

(2) the secondary loading scheme takes into account the actual stress of the tower before reinforcement in the actual project. The single point restart analysis technology including the

life and death units is adopted in ANSYS. Through the locking and activation of reinforcement units, the simulation can be effectively carried out to improve the accuracy of data.

(3) after the reinforcement of the main material of the transmission tower, the main material of the reinforcement part will not lose its stability, and the unstable part will move up along the main material. After the reinforcement of the first and second sections in the main timber is completed, the main timber will not lose its stability, and the unstable part will be moved to the crossarm auxiliary.

matrix.

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