Effect of Cross-Section Dimension on the Safety of Transmission Tower

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Abstract. The safety of power transmission tower directly affects the supply of electricity. If the designed power transmission tower could not bear the strong wind, the collapse of transmission tower would lead to the power outage. In this paper, we analyzed the safety of transmission tower subjected to the strong wind of level 10 by using a finite element method. Commercial software Abaqus was used for simulating the mechanical response of transmission tower. Finite element model was introduced to complete the static analysis of truss structure. Ten kinds of cross-sections were chosen to assess the safety of transmission tower. According to the simulated results, both the maximum stress and the maximum displacement decrease with the increasing cross-section dimension. When the cross-section dimension is less than a certain value, the designed power transmission tower could not safe under the strong wind of level 10.

1. Introduction
Truss as a kind of steel structure has been widely used in the design of modern engineering structure [1]. As for power transmission tower, truss is further employed to facilitate the construction [2, 3]. The wind loading is the primary loading during the usage of transmission tower [4]. Under the strong wind loading, the collapse accidents of transmission tower could result in the power outage, which affect the normal life and economics. Therefore, the safety of power transmission tower should be ensured. Yang et al. analyzed the failure mode of transmission tower subjected to strong wind loading [5]. Shu et al. considered the non-uniform wind loading during the design of power transmission tower [6]. By means of the experimental study, it is found that the static wind loads result in the local plastic deformation in transmission tower, which is the cause of the failure mechanism of transmission tower [7]. Manis et al. further analyzed the extreme bearing capacity of power transmission tower under strong wind loading [8]. Recently, because of the development of finite element method, finite element model can be used in the design process of transmission tower [9]. Xu et al. proposed a multiscale finite element model to research the effect of joint type on the damage of transmission tower [10]. Besides the joint type, the dimension of cross-section is a main parameter to determine the safety of transmission tower. Here, we research the effect of cross-section dimension on the damage of transmission tower subjected to the strong wind loading. The wind loads of level 10 were first calculated using the experienced equations. The wind loads were imposed as static loads in finite element model. Finite element models for the transmission tower with different cross-section dimensions were established. Then, the safety of the transmission tower was calculated.
2. Finite Element Model

A finite element model (FEM) on power transmission tower was set up using ABAQUS 6.12. The model quantitatively reflects the characteristics of geometry, material, load, constraint and other aspects of the analysis object. The main parts of FEM are geometric model building, element selection, element characteristic definition, mesh generation, model checking and processing. In building geometry, wire was selected at the approximate size of 200 m. Then lines with specific dimensions were created to form the 3-dimensional diagram of the truss structure. The boundary condition in the simulation is hinge connection. The mesh size is an approximate global size of 0.2 m. The lateral wind load is loaded on the completed model for simulation analysis.

The calculations of wind speed and wind pressure at different heights are as follows. The measured results show that the wind speed changes exponentially along the height. The expression for the wind speed at the height of is the following form:

\[ v(h) = \left( \frac{h}{10} \right)^{a} \cdot v_{10} \]  

In the equation (1), \( v_{10} \) is the wind speed at the height of 10 m, the ground roughness \( a \) is 0.15, and the wind speed at 10-meter height is 25 m/s. Therefore, the wind speed at different heights is calculated. If the area of the windward surface in the object and the local wind speed \( V \) (the unit of velocity is m / s) are known, the wind force imposed on the object can be calculated (the force unit is N):

\[ F = \frac{v^2 S}{1.63} N \]  

where \( v \) is the local wind speed and \( S \) is the area of windward surface.

Based on ABAQUS 6.12, a finite element model is established to simulate the influence of cross-section size on the mechanical responses of truss structure under different wind forces. The truss is made of L-shaped angle steel. Figure 1 shows the FEM of the power transmission tower used in this work. When the cross-section of the tower is changed into L-shape with different dimensions, the corresponding wind force is assigned to the FEM in figure 1. After the assignment, the simulation analysis is carried out to obtain the maximum stress and displacement value. The simulation processes were repeated if the cross-section size is changed into another dimension. The calculation results under different section sizes were recorded and saved.

![Figure 1. Finite element model for transmission tower subjected to wind loading.](image)
3. Mechanical Response

Figure 2 shows the stress distribution of FEM with cross-section dimension of 75×6. It can be seen from figure 2 that the tower will be stressed and slightly deformed when subjected to wind load. The maximal stress appears at the bottom of the power transmission tower. The minimal stress is at the top of the transmission tower. The calculated results at different cross-sections are illustrated in table 1. According to the data from table 1, it can be found that: with the increasing dimension of the cross-section, the stress acting on the tower also decreases, and the overall displacement of the tower presents a downward trend.

| Number | Dimension (mm) | Maximum stress (MPa) | Maximum displacement (m) |
|--------|----------------|----------------------|--------------------------|
| 1      | 20×4           | 439.9                | 1.8330                   |
| 2      | 25×4           | 339.2                | 0.8792                   |
| 3      | 30×4           | 291.4                | 0.9549                   |
| 4      | 36×5           | 184.2                | 0.4172                   |
| 5      | 40×5           | 163.5                | 0.3622                   |
| 6      | 46×5           | 139.7                | 0.3087                   |
| 7      | 50×6           | 108.1                | 0.2408                   |
| 8      | 63×6           | 88.80                | 0.1983                   |
| 9      | 70×6           | 88.32                | 0.1849                   |
| 10     | 75×6           | 88.03                | 0.1776                   |

In order to reflect directly the mechanical responses of the transmission tower under wind loading, the variations of the maximal stress and displacement are further shown in figures 3-4. The variation trends of the stress and displacement are similar to each other. The stress decreases rapidly with the increasing cross-section dimension for small dimension. If the dimension of cross-section exceeds a certain value, the stress decreases gradually. In this work, the stress or displacement will have no change if the dimension of cross-section is larger than 63×6. This means that much larger dimension cross-section is useless under the certain wind loading. For assessing the safety of the transmission tower, the yield strength of steel was added into figure 3 and the displacement limit to ensure the safety of transmission tower was plotted into figure 4. As shown in figures 3-4, for the cross-section with small dimension, the maximal stress is larger than the yield strength and the maximal displacement is also larger than the displacement limit. In this case, the plastic deformation could
happen in the local zone of the transmission tower. This leads to a safety risk during the application of the transmission tower. When the dimension of cross-section is larger than 36×4, the maximal stress is less than yield strength and the maximal displacement is less than the displacement limit. The safety can be ensured during the application of the transmission tower.

Figure 3. The relationship between Mises stress and cross-section dimension.

Figure 4. Variation of maximum displacement with the increasing cross-section dimension.

4. Concluding Remarks
In this work, a 3-D finite element model for transmission tower was set up. The mechanical responses of the power transmission tower were simulated under the wind loading. The variations of maximal stress and displacement were analyzed in the power transmission tower with different cross-section dimensions. The following conclusions are obtained:
1) The maximal stress and the maximal displacement appear at the bottom and top of the power transmission tower, respectively.
2) The variation trend of the maximal stress is similar to that of the maximal displacement. With the increasing dimension of cross-section, the mechanical responses decrease rapidly for small dimension but decreases gradually for large dimension.

3) To ensure the safety of the transmission tower in engineering application, the dimension of cross-section should be larger than 36×4.

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