Effect of Power Line Type on The Safety of Transmission Tower

Xiaokun Xu¹ and Chuqi Hu²,*
¹College of Mechanical Engineering, Tianjin University, P.R. China
²College of Mechanical Engineering, Tiangong University, P.R. China
*Email: 1481872646@qq.com
Xu and Hu contribute equally to this work.

Abstract. The supply of electricity is directly affected by the structural safety of transmission tower. The unsuitable power line type can impose extra forces on transmission tower. The failure within transmission tower results in power outage because the designed power transmission tower cannot bear the extra force loading. In this paper, the mechanical responses in transmission tower with different power line types were calculated by means of finite element software. Commercial software Abaqus was employed for analyzing the structural safety of transmission tower. Ten kinds of power line were chosen to impose static forces on transmission tower. Based on the finite element results, the maximum stress and displacement were obtained. When the dimension of power line is less than a certain value, the transmission tower is safe; otherwise, the transmission tower may collapse.

1. Introduction
With the continuous development of China's high voltage power grid, the transmission tower has become an important lifeline project. The high voltage power grids are very sensitive to loads caused by power line type. The unsuitable power line could lead to the collapse of transmission tower. Therefore, accurate analysis on the matching of transmission tower and power line type is very important. Many researchers have studied and analysed the state of quilted structure such as high voltage tower under different loads. Some researchers found that the wind loads would cause structural displacement of the quilted structure and also affect the stiffness of the transmission line tower [1]. Zhang gave out the time history of response, damaged parts and strengthening measures [2]. In addition, the wind loads in different regions also have different effects on the high voltage tower. Bao et al. described the influence of micro-topography on the loads of transmission lines [3]. Literatures introduce the effect of typhoons on transmission lines in coastal areas [4-6]. The failure mode of transmission tower was discussed [7]. The static loads can lead to the local plastic deformation by conducting the experimental study of transmission tower [8]. Manis et al. discussed the extreme bearing capacity of power transmission tower [9]. Recently, finite element models on transmission tower have been widely used to assess the structural safety [10, 11]. Here, we research the effect of power line dimension on the mechanical response of transmission tower. The finite element model for 3D transmission tower was built. The ten static loads were calculated and then imposed on the transmission tower. The safety of transmission tower was calculated based on the simulated results.
2. Finite Element Model
Abaqus/CAE was used to establish the object model of power transmission tower. Before establishing the 3D model, we firstly sketch the component module according to the size in Fig 1a, and then connect the spatial lines between the nodes. The finished 3D model is shown in Fig 1b. The bottom of the tower is shown in Fig. 1b and hinged connection was adopted. The hinge mode is to limit all displacement degrees of freedom of the bottom four points, namely, U1, U2 and U3 are zero. Because the model is a non-independent entity, the mesh module is first structured in the assembly of the model tree. First set the approximate global size to 1.7, as shown in Fig. 1a. The grid cell type was selected here as beam. The material properties of the truss structure are set as steel. Therefore, its Young's modulus, Poisson's ratio and density were set as 210 GPa, 0.3 and 7800 kg/m³. The annular section is selected as the truss beam in truss structure. Therefore, an annular section with a radius of 50 mm and a thickness of 10 mm was created in the model tree, and the section type was selected as beam. The influence of wire load on frame structure is calculated. The length of wire is 500 m, and the hanging position and direction are shown in Fig. 1c. The static forces were calculated based on the length of 500m power line. The static forces of 10 kinds of power line are shown in Table 1. The angle between force direction and horizontal line is 5 °. After submitting the job and checking the boundary column of cloud map, the mechanical responses on the target query position could be displayed.

![Figure 1. Finite element model (FEM) for transmission tower: (a) Dimension for FEM; (b) 3D FEM model; (c) Loading force position and direction.](image)

| No. | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Type| 210/35| 300/40| 400/65| 500/65| 630/80| 710/90| 800/100| 900/75| 1120/50| 1250/50|
| Force (N) | 4760  | 5660  | 8040  | 9440  | 11830 | 13330 | 15020 | 15370 | 17320 | 19330 |

3. Mechanical Response
Fig. 2 shows the mechanical response distribution in transmission tower with the 630/80 power line type. The transmission tower was stressed and slightly deformed under the static loading of power line. There is maximal stress at the bottom of the power transmission tower; however, there is minimal stress at the top of the transmission tower. As for displacement, the tendency is different. The maximum displacement appears on the top of transmission tower and the minimal displacement appears at the bottom. The calculated results for different power line types are shown in Table 2. Based on Table 2, both the maximal stress and the overall displacement present a upward trend with the increasing dimension of power line.
Figure 2. (a) Stress distribution in transmission tower; (b) Displacement distribution in transmission tower.

Table 2. Calculated results from finite element model for different power line types.

| Number | Power line type | Maximum stress (MPa) | Maximum displacement (mm) |
|--------|----------------|----------------------|---------------------------|
| 1      | 210/35         | 92.3                 | 2.6                       |
| 2      | 300/40         | 117.6                | 3.3                       |
| 3      | 400/65         | 167.2                | 4.7                       |
| 4      | 500/65         | 196.3                | 5.6                       |
| 5      | 630/80         | 246.1                | 7.1                       |
| 6      | 710/90         | 277.3                | 7.9                       |
| 7      | 800/100        | 312.4                | 8.9                       |
| 8      | 900/75         | 319.6                | 9.1                       |
| 9      | 1120/50        | 360.3                | 10.2                      |
| 10     | 1250/50        | 402.1                | 11.4                      |

Figs. 3-4 reflect directly the mechanical responses of the transmission tower. The variation trend of the maximal stress is similar to that of the maximal displacement. The maximal stress increases linearly with the increasing power line dimension. The material used for transmission tower is Q345 steel. The yield strength of Q345 steel is 345 MPa. The 345 MPa yield strength is added into Fig. 3 in order to assess the safety of transmission tower. If the dimension of power line is larger than a certain value, the maximal stress can exceed the strength limit of transmission tower design. In that case, the transmission tower is not safe. As for displacement requirement, the displacement limit is near 10 mm during transmission tower design. In the case of large size power line, the plastic deformation can appear at the bottom of transmission tower. Therefore, the safety risk may exist during the application of the transmission tower. For a given transmission tower, there is a certain power line size. If the power line size is larger than the certain value, the transmission tower may be in the risk of structural safety.
4. Concluding Remarks
In this work, a 3D finite element model for transmission tower was built. The maximal stress and displacement of the power transmission tower were simulated under power line static force loading. The tendency of mechanical response was discussed for power line with different dimensions. The following conclusions are achieved:

(1) The maximal stress appears at the bottom of transmission tower; however, the maximal displacement is at the top.

(2) Both the maximal stress and maximal displacement increase with the increasing dimension of power line.

(3) For a given transmission tower, there is a certain power line size. The transmission tower may be in the risk of structural safety if the power line size is larger than the certain value.
5. Acknowledgments
This research was financially supported by Fundamental Research Funds for undergraduates.

6. References
[1] Wu Jing-yu 2013 Wind load analysis of transmission line tower structure China New Technology & New Products 15 29-30
[2] Zhang Nai-long, Jia Yong-yong, Li Hong-ze, et al 2019 Time history analysis and strengthening technique of transmission tower-line system under typhoon load Science Technology and Engineering 19 193-200
[3] Bao Bo, Cheng Ren-li, Xiong Xiao-fu, et al 2014 A typhoon risk early warning method for power transmission line considering micro-terrain correction Power System Protection and Control 42 79-86
[4] Zhou Hong-bo and Huang Yu 2014 Study on construction safety risk control of high-rise buildings in the extreme typhoon condition China Civil Engineering Journal 47 126-135
[5] Xiao Fei 2015 Analysis on impact of typhoon “rammasun” on power grid in coastal areas of Guangxi Hongshui River 34 79-81
[6] Zhao Yuan-qiang 2015 Transposition design of 500 kV transmission line in coastal strong-typhoon area Hongshui River 34 10-12
[7] F. Yang, J. Yang and J. Han 2010 Study on the limited values of foundation deformation for a typical UHV transmission tower, IEEE Trans Power Deliv 25 2752-58
[8] Q. Xie, L. Sun, H. Lin and Q. Chen 2017 Experimental study on wind-resistant ultimate load-carrying capacity of 500 kV transmission tower, High Volt. Eng 38 712-719
[9] P. Manis and A. G. Bloodworth 2017 Climate change and extreme wind effects on transmission towers, Proc Inst. Civil. Eng., Struct. Build. 170 81-97
[10] B. Li, M. Jian and D. Zhang 2012 Finite element analysis of foundation settlement of 220 kV transmission towers Appl. Mech. Mater. 201-202, 602-607
[11] Y. Xu, J. Lin, S. Zhan and F. Wang 2019 Multistage damage detection of a transmission tower: Numerical investigation and experimental validation Structure Control Health Monitoring 26 1-33