Influence of finite element structural modification on dynamic characteristics of transmission tower

Mingjian Jian¹ ² *, Jidong Li², Hualing Deng¹ ², Huakai Zhang¹, Tangqing Yuan², Yang Chen²

¹ State Grid Shandong Electric Power Research Institute, Jinan, 250002, PR China
² Shandong Electric Power Industrial Boiler and Pressure Vessel Inspection Center Co., Ltd, Jinan, 250002, PR China

*Corresponding author e-mail: jianmingjian@yjy.sd.sgcc.com.cn

Abstract. Taking a 500kV dry type single circuit angle tower as the research object, the computational modal analysis of the established finite element calculation model is carried out. It is found that local vibration occurs at the bottom of the transmission tower. The weakness of the original structure lies in the intersection of the longest web, the deformation displacement of the joint is the largest, so the structure needs to be strengthened. There are two corresponding strengthening methods: Diamond reinforcement and positive cross reinforcement. Further analysis results show that the regular cross structure has a certain strengthening effect on the original structure.

Keywords: Transmission tower; finite element; dynamic characteristics; structural modification.

1. Introduction

A large number of tower collapse accidents show that with the development of high-voltage and ultra-high-voltage technology, the increase of tower height and tower spacing, especially for the river crossing tower and typhoon and tornado prone areas, it is necessary to carry out dynamic optimization design on the basis of static design [1-4]. The modal analysis of transmission tower is the basis of dynamic optimization design [5-8]. Based on the benchmark dynamic model, sensitivity calculation can be carried out to analyze the influence of member changes on structural modal frequency changes, thus providing a basis for design optimization.

Taking a 500kV dry type single circuit angle tower as the research object, the structure is shown in Fig. 1. The tower is 30m in height, 45m in total height, 12.876m in root opening and 400m in horizontal span. The main limb of the tower is connected by Q420 and Q345 angle steel of different specifications, and the inclined material is connected by Q235 angle steel of different specifications. The structural type is shown in the figure, the size is shown in the design drawing, and the material mechanical properties of each part of the structure are shown in table 1.
Fig. 1 Structure of transmission tower

Table 1 The first five natural frequencies of GIS pipeline shell structure

| Structure       | Material | Yield limit [MPa] | Elastic modulus [MPa] | Density [kg/m³] | Poisson's ratio | Strength design value [MPa] |
|-----------------|----------|-------------------|-----------------------|-----------------|----------------|-----------------------------|
| Main limb       | Q420     | 420               | 2.06×10⁵              | 7860            | 0.3            | 378                         |
| Main limb       | Q345     | 345               | 2.06×10⁵              | 7860            | 0.3            | 310                         |
| Web Member      | Q235     | 235               | 2.06×10⁵              | 7860            | 0.3            | 215                         |

2. Modal analysis of transmission tower
A preliminary computational modal experiment is carried out on the established finite element model. The first eight order frequencies and modes of the tower are calculated and the results are shown in Table 2. The first-order vibration mode of the tower shows that the overall Z-direction dominant first-order bending, accompanied by X-direction bending, the node displacement increases with the increase of height, and the maximum offset point occurs at the end point of the bottom line bracket inside the corner tower, as shown in Fig. 2. The second-order vibration mode shows that the overall X-direction dominant first-order bending, accompanied by Z-direction bending, the node displacement increases with the increase of height, and the maximum offset point occurs at the end of the bottom line bracket inside the corner tower, as shown in Fig. 3. The local mode shapes are shown in Fig. 4.

Table 2 Modal analysis results of corner tower

| Order number | Simulated mode shapes                     | Analog frequency[Hz] |
|--------------|------------------------------------------|----------------------|
| 1            | First order bending in Z direction        | 2.20                 |
| 2            | First order bending in X direction        | 2.58                 |
| 3            | Global first order torsion               | 3.34                 |
| 4            | Second order bending in X direction      | 4.19                 |
| 5            | Second order bending in Z direction      | 4.14                 |
| 6            | Global second order torsion              | 4.73                 |
| 7            | X-direction first-order bending and local mode shapes | 5.17       |
| 8            | Local mode shapes                        | 5.99                 |
Through the above modal analysis, it is found that the transverse plane between the tower body and the tower leg is relatively stable, and the inclined material of the tower body may lose stability. Therefore, the rigidity of the tower can be enhanced to enhance the overall safety of the tower. In order to avoid the local vibration hazard, the modal parameters can be changed by adding some components, that is, changing the structural parameters.

3. Modal analysis and optimization of local structures

3.1. Local modal analysis of original structure of tower bottom section.

The original structure of the tower bottom section is shown in Fig. 5, and the analysis results of the first 10 local modes are shown in Table 3. According to the modal analysis results of the original structure, it can be found that the weak link of the original structure lies in the intersection of the longest web members, and the joint deformation displacement is the largest. Therefore, the corresponding setting of the following two ways of strengthening: Rhombic reinforcement, Positive cross reinforcement.
Fig.5 Original structure model of tower bottom section

Table.3 Local modal analysis results of original structure at the bottom of tower body

| Order number | frequency [Hz] | Mode shapes               |
|--------------|----------------|---------------------------|
| 1            | 6.50           | Local mode shapes         |
| 2            | 10.13          | Bending in X direction    |
| 3            | 10.17          | First order torsion       |
| 4            | 15.74          | Contraction in Y direction|
| 5            | 19.90          | Second order torsion      |
| 6            | 25.45          | Second order local modes  |
| 7            | 25.59          | Second order bending in X direction |
| 8            | 25.99          | Bending in Z direction    |
| 9            | 29.51          | Local mode shapes         |
| 10           | 29.89          | Local mode shapes         |

3.2. Reinforced by rhombic structure.

The reinforcement model of rhombic structure is shown in Fig. 6, and the modal frequency variation is shown in Table 4. After strengthening with rhombic structure, the frequency of each order is generally increased, the vibration mode changes greatly and is more complex, and there are four local vibration modes in the first six orders. Therefore, this method has little effect on strengthening the original structure or weakening the effect, and increases the material consumption.

Fig.6 Rhombic reinforcement structure model
**Table 4** Modal frequency changes of rhombic reinforced structure after modification

| Order number | frequency [Hz] | Frequency after enhancement [Hz] | Rate of change | Mode shapes                          |
|--------------|----------------|----------------------------------|----------------|--------------------------------------|
| 1            | 6.50           | 6.51                             | 0.00094        | Local mode shapes                    |
| 2            | 10.13          | 20.31                            | 1.00583        | First order torsion                  |
| 3            | 10.17          | 22.07                            | 1.17057        | Local mode shapes                    |
| 4            | 15.74          | 22.31                            | 0.41764        | Local mode shapes                    |
| 5            | 19.90          | 25.84                            | 0.29866        | Second order torsion                 |
| 6            | 25.45          | 29.60                            | 0.16314        | Local mode shapes                    |
| 7            | 25.59          | 29.79                            | 0.16451        | Local mode shapes                    |
| 8            | 25.99          | 30.46                            | 0.17224        | Bending coupled torsion in X direction |
| 9            | 29.51          | 31.74                            | 0.07560        | Coupled bending in X and Z directions |
| 10           | 29.89          | 31.95                            | 0.06878        | Coupled bending in X and Z directions |

3.3. Reinforced with positive cross.

The change of modal frequency after using positive cross reinforcement (as shown in Fig. 7) is shown in Table 5. The frequency of each order is generally reduced, the frequency change rate is stable, the frequency range is narrow, and the local vibration mode appears in the high order. Therefore, this kind of structure has a certain strengthening effect on the original structure, and whether it should be determined by combining the working environment and economy.

![Model of reinforced structure with positive cross](image-url)
Table 5: Modal frequency changes of positive cross structure after strengthening and modifying

| Order number | Frequency [Hz] | Frequency after enhancement [Hz] | Rate of change | Mode shapes               | Figure number |
|--------------|----------------|----------------------------------|----------------|---------------------------|---------------|
| 1            | 6.50           | 6.66                             | 0.02448        | First order X-direction bending | 4.31          |
| 2            | 10.13          | 6.69                             | -0.33918       | First order Z-direction bending | 4.32          |
| 3            | 10.17          | 7.92                             | -0.22140       | Local mode shapes         | 4.33          |
| 4            | 15.74          | 13.22                            | -0.16002       | First order torsion       | 4.34          |
| 5            | 19.90          | 16.06                            | -0.19298       | Local mode shapes         | 4.35          |
| 6            | 25.45          | 16.89                            | -0.33623       | First order torsion coupled bending | 4.36          |
| 7            | 25.59          | 17.02                            | -0.33469       | First order torsion coupled bending | 4.37          |
| 8            | 25.99          | 19.52                            | -0.24870       | Diagonal tension coupled local modes | 4.38          |
| 9            | 29.51          | 19.84                            | -0.32784       | Diagonal tension coupled local modes | 4.39          |
| 10           | 29.89          | 20.12                            | -0.32675       | Diagonal tension coupled local modes | 4.40          |

4. Summary
The results of modal analysis show that local vibration occurs at the bottom of transmission tower. The weak link of the original structure lies in the intersection of the longest web members, and the deformation displacement of the joint is the largest.

There are two corresponding strengthening methods: Rhombic reinforcement and positive cross reinforcement. The results show that the rhombic structure has little effect on strengthening or weakening the original structure, and increases the material consumption. The results show that the frequency of each order is generally reduced, and the frequency change rate is stable and the range of frequency variation is narrow. There are two local vibration modes in the first six modes, which have little change, which can strengthen the original structure.

References
[1] Hongnan Li, Haifeng Bai. Current situation and development trend of research on disaster resistance of high voltage transmission tower line system[J]. Journal of Civil Engineering, 2007, 40(2): 39-46.
[2] Qiang Huang, Jiahong Wang, Mingyong Ou. Analysis of ice disaster in Hunan power grid in 2005 and corresponding measures [J]. Power grid technology, 2005, 29 (24): 16-19.
[3] Zheng Li, Jingbo Yang, Junke Han, et al. Analysis of tower collapse caused by ice disaster in 2008 [J]. Power grid technology, 2009, 33 (2): 31-35.
[4] Jianguo Xu, Huajun Shi, Yong Guo, et al. Finite element modeling of long span transmission tower line system [J]. Electric power construction, 2011, 32 (3): 15-19.
[5] Yiping Luo, Mingzheng Zeng, Xiaoliang Zhou, et al. Study on static wind load response of transmission tower [J]. Science and Technology Bulletin, 2017, 33 (11): 52-55.
[6] Mingxi Zhao, Bo He, Wentao Feng, et al. Influence and analysis of tower line coupling factors on mechanical properties of high voltage transmission tower line structure under icing load [J]. Chinese Journal of electrical engineering, 2018, 38 (24): 7141-7148.
[7] Wenjuan Lou, Gang Luo, Xiaohui Yang, et al. Dynamic wind deflection response characteristics and frequency domain calculation method of transmission lines [J]. High voltage technology, 2017, 43 (5): 1493-1499.
[8] KELESOGLU O. Fuzzy multiobjective optimization of trussstructures using genetic algorithm[J]. Advances in Engineering Software, 2007, 38(10): 717-721.