Research on safety performance of jacking tower under uneven settlement

Zongming Wu1,∗ Kongliang Chen1
1Department of Civil Engineering, WuYi University, 529000
Jiangmen, Guangdong, China
∗Corresponding author’s e-mail: civil@wyu.edu.cn

Abstract. This article takes a 220KV jack-up tower as the research object. By studying the safety performance of the jacking tower under the condition of uneven foundation settlement in the mined-out area, this paper uses the finite element software Midas GTS NX to establish the jacked-up transmission tower-foundation model and the jacked-up transmission tower line-foundation model. Based on the numerical simulation analysis method, the safety of jacking towers under different working conditions is studied.

1.Introduction
With the rapid development of our country’s economy, energy has become an important engine for our country’s development. Electric energy provides the normal operation of the power system and at the same time supports the transmission lines. With the development of my country's power construction, more and more transmission lines appear in areas with poor geology. Due to the complex geological conditions in various regions of our country, the uneven settlement of the foundation is more serious [1]. Transmission tower lines pose a major threat. Scholars at home and abroad have done a lot of research on the carrying capacity and damage characteristics of transmission towers [2-8]. However, as a new type of adjustable tower, compared with ordinary electric towers, the design of jacking towers still lacks systematic research on whether there will be structural defects. The safety performance of the structure under the uneven settlement of the foundation is worthy of further investigation. Based on a 220kv transmission tower transmission project as the research background, this paper uses the finite element software Midas GTS NX to establish the jacked-up transmission tower-foundation model and the jacked-up transmission tower line-foundation model, and analyze the performance of the jacking tower under different working conditions safety.

2.Finite element model

2.1.Model parameters
This model uses MIDAS GTS to establish a three-dimensional solid model of transmission tower-line-foundation. The model consists of four parts: transmission tower, wire, soil and cap. The transmission tower is a straight tower with a height of 57.1m and a root opening of 13.5m. The tower legs are made of Q345 angle steel, the diagonal material and cross-bars are made of Q235 angle steel, and the conductors are LGJ-500/45. The length and width of the platform are both 2m. The thickness is 0.5m, it is C30 concrete, the geometric dimensions of the soil are 20m in length and width, and the thickness is 10 m. It is simulated by three-dimensional solid elements, and the yield criterion is the classic Mohr-
Coulomb criterion. The material parameters of the model are shown in Table 1. The jacking foot stand is 3m high, and the jacking model is shown in Figure 2. The three-tower two-line model of the finite element calculation model is shown in Figure 2. Among them, the No. 2 iron tower is the jacking tower.

| Materials    | Density (kg/cm³) | Elastic Modulus (N/mm²) | Poisson's ratio | Yield Strength (Mpa) |
|--------------|------------------|-------------------------|----------------|----------------------|
| Q235         | 7850             | 206000                  | 0.28           | 235                  |
| Q345         | 7850             | 206000                  | 0.28           | 345                  |
| LGJ-500      | 6742             | 65000                   | 0.3            | 92                   |

Figure 1. Transmission tower after jacking

Figure 2. Three-tower two-line model after jacking

2.2 Restrictions

When the transmission tower model of this model is established, the foundation grid group of the jacking tower is drawn according to the finite element model. According to the foundation conditions of the stress analysis, the left/right side of the model restricts the displacement in the X direction, the front/rear side restricts the displacement in the Y direction, and the bottom of the model restricts the displacement in the Z direction. The number of the foundation support of the tower is shown in Figure 3.
3. Numerical simulation method

3.1. Destruction criterion

In the transmission tower structure, the structural material is mostly angle steel. The transmission tower model is established through Midas GTS NX. The rod material is Q235. Since each rod is connected to a different number of rods, the stress on each rod is And the direction is also different, so the stress in a single direction cannot be used to explain the stress of the structure. Instead, the equivalent stress is used in material mechanics to equate the stress experienced by the material in a complex state to the stress experienced in a unidirectional state. According to the fourth strength theory of material mechanics, the calculation expression of the corresponding strength judgment condition can be obtained as Equation 1.

$$\frac{1}{\sqrt{2}}\left[ (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 \right] = \sigma_{r_4} \leq [\sigma] = \frac{\sigma_s}{n_s}$$

In the formula: $\sigma_1, \sigma_2, \sigma_3$—Three principal stresses; $\sigma_{r_4}$—Mises Relative stress of yield criterion; $[\sigma]$—Material allowable stress; $\sigma_s$—Yield stress under uniaxial tension; $n_s$—Safety factor, plastic material takes 1.5-2.2

For steel, the general design strength is 380 MPa. When a single rod is subjected to a stress of 380 MPa, it is considered that the rod will be damaged.

4. Uneven settlement conditions

- Settlement of single support A
- Settlement of double bearings A and B
- Simultaneous settlement of double bearings A and D
- Simultaneous settlement of the three supports A, B and D

4.1. Condition 1 Single support settlement

Based on the finite element model, the force and deformation of the No. 2 transmission tower under the settlement of a single support and the influence on the adjacent No. 1 and No. 3 towers are calculated and analyzed. The calculation and analysis show that only a single support will fall. When it sinks, the maximum equivalent stress of the No. 2 jacking transmission tower shows a linear relationship with the settlement value as shown in Figure 4. With the increase of the settlement value, the maximum stress of the rods at the support A also gradually increases. In the transmission tower, this When the stress on the tower body and the tower head is relatively small, the wires at the sinking part of the support are relaxed. At the same time, the wires on the other side are tightened. At this time, the stress on the wires on both
sides has not reached the failure value. In the entire power transmission tower poles, the poles on the first leg of the tower are mainly compressed, and the equivalent stress of the main material at the tower body and the cross member at the bottom of the tower body does not change significantly. When the displacement value of the tower foot A exceeds 22mm, the maximum stress value of the member at this time reaches 393MPa. As shown in Figure 5, the maximum stress has exceeded the design strength value of the steel 380MPa. At the same time, it is located in the adjacent No. 1, No. 2 and No. 3 towers. Less affected.

![Figure 4. Stress development of transmission under 22mm settlement](image)

4.2 Working condition 2 and working condition 3 under the condition of double support settlement

The double supports A and B sink at the same time. When the settlement of the transmission tower increases, the top of the transmission tower is always in maximum deformation, and the lateral deformation is much smaller than the longitudinal deformation; with the increase of the settlement, No. 2 roof The maximum equivalent stress of the power transmission tower is linear with the settlement value as shown in Figure 6. When the settlement reaches 42mm, the maximum stress of the No. 2 tower reaches 386 MPa, as shown in Figure 7. At this time, the destructive strength of the steel can be reached, while the No. 1 and No. 3 towers The stress change is less affected by the uneven settlement of the No. 2 iron tower. When the A and D supports sink by the same amount at the same time, the No. 2 tower has a stress of 375 MPa at the largest member, and the No. 1 and No. 3 towers are less affected by the uneven settlement of the No. 2 tower. At this time, the stress of the wire connecting No. 2 and No. 3 is 68MPa, which is higher than before but less than the breaking stress of the wire.

![Figure 5. Working condition 1 Stress cloud diagram tower under working condition 1](image)
4.3. Working condition 4 Settlement of A, B, D supports

After calculation and analysis, when the three tower foundations are sinking, the maximum stress of the key members of the No. 2 tower also increases with the increase of the settlement value, as shown in Figure 8. With the increase of the settlement value, the equivalent stress value on the tower leg member changes greatly, but the maximum equivalent stress of the main member of the tower body and the bottom cross member does not change very much. When the settlement value reaches 19mm, the tower leg of the tower The stress of the bar at A reaches 386MPa as shown in Figure 9, which exceeds the breaking strength of steel. At the same time, the No. 1 and No. 3 towers are less affected by the uneven settlement of the No. 2 tower, and the stress on the conductors on both sides of the No. 2 tower is also in a safe state.
5. Conclusion

Based on software analysis and comparison of results, it can be concluded.

(1) Under the settlement of single support, double support, and three support under working conditions, when the material of No. 2 jacking tower does not reach its strength, the settlement value of its rods has a linear relationship with the settlement value. Before reaching the yield strength, its uneven settlement has almost no effect on the adjacent No. 1 and No. 3 iron towers.

(2) When the three supports sink, as the settlement value increases, the deformation at the top of the transmission tower increases rapidly, and at the same time it will quickly exceed the safety range of its materials. Although the steel has not been damaged at this time, it is not suitable for continued work due to the excessive deformation of the transmission tower, and the stress of the cable may become too large during this period.

(3) In the case of uneven settlement, the location of the maximum stress change in the transmission tower is usually at the leg of the tower. At this time, the deformation at the tower leg will be greater than other parts. Therefore, protection should be carried out at the position of the legs of the transmission tower as much as possible to avoid accidents in time.

Acknowledgements

The paper supported by Guangdong Science and Technology Department Project (2016A040403125)
References
[1] Shi Zhenhua. (1997) The settlement and treatment plan of the straight-line self-supporting tower foundation of the transmission line in the mined-out area [J]. Shanxi Electric Power Technology: 19-21+36.
[2] Jia Leiliang. (2012) Analysis of the influence of goaf on overhead transmission lines and its comprehensive treatment research [D]. North China Electric Power University.
[3] Huang Xinbo, Chen Ziliang, Zhao Long, Zhu Yongcan, Xu Guanhua, Si Weijie. (2017) 110kV transmission line tower foundation settlement stress simulation analysis and test[J]. Electric Power Automation Equipment, 37(04): 153-158.
[4] Xiong Weihong, Liu Xianshan, Li Zhengliang, Tu Changgeng, Li Zhenzhu. (2015) Reliability analysis of 500kV transmission line foundation settlement iron tower[J]. Electric Power Construction, 36(02): 41-47.
[5] Wang Juanjuan. (2018) Analysis of the dynamic characteristics of transmission towers under the influence of foundation deformation[J]. Construction Technology, 47(S4): 61-64.
[6] Ji Shanhao, Li Bo. (2011) Settlement and treatment of corner tower foundation of 220kV transmission line in goaf area of coal mine[J]. Shandong Electric Power Technology, (02): 30-33.
[7] Shi Guicai, Zhou Changgen, Dai Guozhong. (2014) The combined effect of dynamic surface deformation and external load on the internal force of transmission towers[J]. China Rural Water and Hydropower:177-180.
[8] Wang Xiuge, Qiao Lan, Sun Xinshuo. (2008) Numerical simulation of the stability of power transmission tower foundation on underground goaf[J]. Metal Mine, (03): 110-113+143.
[9] Liu Hongwen. (2017) Material Mechanics (Fourth Edition) [M] Higher Education Press.