Study on deformation law of slope foundation under different external loads

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Abstract: The external load has a great influence on the stability of the transmission tower foundation. Considering that the external load on the foundation is more complicated, the external load is simplified to the basic center. The analysis of the deformation law under the external load is helpful to grasp the dangerous part of the foundation after being subjected to external force. In order to highlight the variability in the direction of the external load, the external load is set to a certain size, and the load direction is regularly changed. Using the finite element difference software FLAC3D to analyze the internal deformation law of the model under nine working conditions. The results show that the deformation of the foundation in the horizontal and vertical directions will change regularly with the direction of the concentrated force. When the direction of the concentrated force is within a certain range, it will play a positive role in the stability of the foundation.

1. Introduction
Long-distance continuous transmission of high-voltage power is one of the important guarantees for the vigorous development of mountainous economy. This also puts higher requirements on the quality of high-voltage electric long-distance transportation engineering. The stability of the transmission tower base directly affects the quality of the transmission project. Therefore, it is particularly important to fully grasp the deformation of the foundation of the electric tower and its foundation slope.

To study the deformation law of slope, the deformation can be observed through model experiments. Tang Ya-nan and others used pressure sensors and close-range measurement photography to study the deformation and failure characteristics of high-steep slopes. Through the model experiment, Wang Entrepreneur and others used the total station to observe the deformation of the model slope and study the deformation law of the open pit slope. In addition, it is a more common method to study the slope deformation law in combination with numerical analysis software. Hou Zhifeng et al. used the combination of numerical analysis and on-site monitoring to analyze the deformation law of subgrade settlement and lateral displacement of the slope during road paving. Wang Zhaolong et al. used the MIDAS/GTS finite element analysis software to study the deformation of the high slope of the red layer, and obtained the conclusions about the deformation characteristics and structural characteristics, bedrock shape and dip angle. Based on the finite element model, Li Jian uses nonlinear dynamic time history to analyze the influence of groundwater seepage on the slope. It is believed that groundwater can change the size of the slope and the maximum displacement level, and can change the potential sliding scale of the slope. In the above analysis of the slope deformation, the influence of the external load on the slope deformation is not taken into account.

In the transmission project, the transmission tower foundation is affected by the external structure load, and due to the influence of the climatic environment, it will also be affected by the external load
without fixed direction and size. In areas where the strength of the rock mass near the slope is low, these external loads are liable to cause slope instability. In this paper, the load on the foundation is simplified, and the FLAC3D numerical simulation software is used for quantitative analysis to study the horizontal and vertical deformation laws of the foundation slope under different external loads.

2. The deformation law of horizontal and vertical directions of foundation slope

2.1 Calculation conditions

According to the external forces in different directions that the high-voltage transmission tower may be subjected to, this paper proposes nine kinds of working conditions to simulate and analyze the influence of concentrated forces in different directions on the deformation of the slope foundation. The concentrated force under all working conditions is 200kN. The positive direction of the concentrated force rotates counterclockwise in the negative direction of the x-axis to positive. Figure 1 shows the geometry of the analytical model. The specific working conditions are shown in Table 1.

![Figure 1 Schematic diagram of the external force direction under nine working conditions](image1)

![Figure 2 Schematic diagram of the geometric model](image2)

| Working condition | size/kN | angle/° | Working condition | size/kN | angle/° |
|-------------------|---------|---------|-------------------|---------|---------|
| 1                 | 200     | 0       | 6                 | 200     | 120     |
| 2                 | 200     | 30      | 7                 | 200     | 135     |
| 3                 | 200     | 45      | 8                 | 200     | 150     |
| 4                 | 200     | 60      | 9                 | 200     | 180     |
| 5                 | 200     | 90      |                   |         |         |

2.2 Calculation model

For simplification, the slope slopes are treated as straight lines. The rock mass of the actual slope body which is perpendicular to the ground 0.5m thick and the foundation near the slope inner side is 8 times the width of the foundation foundation is modeled. The foundation depth is 15m. The specific geometric model is shown below.

The model boundary condition is that, in the horizontal direction, the left and right side boundaries of the model are fixed, thereby limiting the horizontal displacement in the x direction of the boundary. At the same time, the displacement of the model in the X, Y, and Z directions is limited. And to limit the displacement of the entire model in the y direction, thus constructing a planar model. The physical and mechanical parameters of the material are selected as follows:

| Elastic Modulus (MPa) | Poisson's ratio | Cohesion (kPa) | Internal friction angle (°) |
|-----------------------|----------------|----------------|-----------------------------|
| 90                    | 0.35           | 35             | 25                          |

![Table 2 Physical and mechanical parameters of the material](image3)
3. Research on the deformation law of foundation under external load.

The deformation of the foundation changes with the direction of the external load. A full understanding of the changing laws in the process is a prerequisite for ensuring the normal construction and normal use of the project. This chapter mainly studies the degenerative laws of foundation under the action of concentrated force from both horizontal and vertical directions. In order to facilitate analysis according to uniform standards, take 2mm as the critical value of horizontal displacement.

3.1 Study on the horizontal deformation of slope foundation under external load

![Figure 3](image1.png) Displacement of the horizontal displacement of the foundation under the working condition 1 (force direction 0°)

![Figure 4](image2.png) Horiztonal displacement of the ground under the working condition 2 (force direction 30°)

![Figure 5](image3.png) Horizontal displacement of the ground under the working condition 4 (forced direction 60°)

![Figure 6](image4.png) Horizontal displacement of the ground under the working condition 5 (forced direction 90°)
The nine working conditions in the above FIG. 3 to FIG. 8 are divided into two stages to analyze the displacement in the horizontal direction.

(1) The condition of the horizontal force component in the negative direction of the x-axis
Under the conditions of the horizontal force component in the negative direction of the x-axis, the analysis shows that:
①Figure 3 is a displacement cloud diagram based on the horizontal concentrated force in the negative direction of the x-axis. Since the foundation is only subjected to horizontal forces, a large horizontal deformation occurs on the left side of the foundation during the calculation, and local damage occurs, and the model cannot be balanced. Under this condition, the horizontal force threatens the stability of the transmission tower.
②After the foundation is affected by the horizontal force component, the range of horizontal displacement is mainly concentrated in a certain range close to the slope.
③During the process of reducing the horizontal force component, the soil range in which the horizontal displacement occurs is reduced. The figure shows that the displacement cloud map gradually shrinks toward the slope.
④The horizontal displacement around the foundation and foundation decreases as the horizontal force decreases. When the horizontal force is zero, the horizontal displacement produced in the foundation is small.
⑤Due to the different directions of concentration, the horizontal displacement cloud map has a certain directionality. That is, the tilt direction of the cloud image is substantially the same as the direction of the concentrated force.

(2) The horizontal force component is in the positive direction of the x-axis
Under the condition of the horizontal force component in the positive direction of the x-axis, it can be seen that after the horizontal direction force changes direction, the horizontal displacement changes from a negative value to a positive value. Analysis shows that:
①Due to the constraints inside the slope foundation, the range of influence of the horizontal force on the slope is reduced.
②With the gradual increase of the horizontal force component, the range of horizontal displacement on the slope gradually increases, and the horizontal displacement value increases.
③With the gradual increase of the horizontal force component, the tilting direction of the horizontal displacement cloud map gradually becomes horizontal, that is, it is consistent with the direction of the concentrated force.
3.2 The deformation law of the slope foundation in the vertical direction under external load

For the working conditions presented in Figures 9 to 14, the deformation law in the vertical direction is analyzed in two stages.

1) Vertical force component increase phase

The vertical force component is analyzed during the increase process.

Figure 9 is a displacement cloud diagram based on the horizontal concentrated force only to the
left. It can be seen from the analysis in 2.1 that under this condition, the foundation slope may be un
stable.
② Since the direction of concentration is directed to the direction of the slope, the extent of vertical deformation occurs within a certain range close to the slope. The tilt direction of the cloud image is approximately the same as the direction of concentration.
③ In the process of increasing the vertical force component, the range of vertical deformation on the slope gradually decreases, and the vertical displacement value increases. The figure shows that the displacement cloud map gradually shrinks toward the foundation.
④ The basic vertical displacement is proportional to the magnitude of the force. The vertical force component increases and the vertical displacement increases, but the range of vertical deformation on the slope decreases.

(2) Vertical force component reduction phase
① As the vertical component decreases, the vertical displacement occurring in the foundation decreases. Figure 14 is a vertical deformation cloud diagram of the foundation under the horizontal force of the x-axis positive direction. It can be seen that the vertical deformation in the foundation is small, but mainly horizontal deformation.
② The tilting direction of the vertical displacement cloud image is approximately the same as the direction of the concentrated force. In this stage, the tilting direction of the cloud image gradually changes from vertical to horizontal.
③ As the direction of the concentrated force changes from vertical to horizontal, the range of vertical deformation on the slope gradually decreases.

4. Conclusion
1. Under the action of concentrated force, the deformation cloud diagram of the foundation has a certain inclination, and its inclination direction is the same as the direction of the concentrated force.
2. The direction of the concentrated force gradually changes from pointing to the outward direction of the slope to the inside of the slope. The effect on the slope is gradually changed from being unfavorable to the stability of the slope to reinforcing the slope.
3. In the actual project, the slope should be reinforced, especially the key slope of the slope on the side of the slope to improve the stability of the slope as a whole.

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