Confirmation of Reasonable Position of iron tower for Gravel Soil in Transmission Line Project in South Part of Gansu

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Abstract: Based on the example of a power transmission line project in South part of Gansu, using the limit equilibrium analysis method, by Lizheng software, the safety coefficient of gravel slope under the tower load was calculated. The calculation results show that under the condition of safety coefficient of 1.25, the safe slope gradient is 39.3° in natural condition. The height of slope added from 9m to 11m, the safe slope gradient decreased from 31.1°to 29.2°, and the height of slope added from 11m to 18m, the safe slope gradient added from 29.2°to 39.2°. When the height of slope reached 20m, the iron tower has no effect on slope, the stability of iron tower was determined by stability of slope itself. After vertical load was applied, the safe slope gradient and shear stress inside of the slope changed seriously. Under 200kPa load, from the foot to top of the slope, the shear stress increased 35.27% ~ 93.1%, and on the top, 122.2%, maximumly, comparing with natural condition. This paper can provide a scientific basis for the later project in the same area.

1. Introduction

At present, the study on the gravel soil slope in Longnan area is mainly focused on the geological disaster of gravel soil landslide[1-2], the influence of groundwater or soil permeability in gravel soil slope on slope stability[3-4]; the research on transmission line mainly focuses on the influence of icing and wind load on the design and operation of the tower, and the systematic research on the selection of the reasonable location of the tower built on gravel soil slope is less. The superposition of the stability of the gravel soil slope and the load of the tower will have different effects on the stability of the gravel soil slope, and then affect the stability of the tower. The transmission line tower built on the gravel soil slope should not only consider the stability of the slope itself, but also consider the possibility of slope shear failure under the load of the tower. Under the superposition of the slope itself and the tower load, with the increase of the slope, the sliding force of the slope increases and the friction force decreases, so the safety factor also decreases.

Based on the slope engineering of a transmission line project near Linjiang Township, Longnan City, through laboratory tests, the basic mechanical index of soil mass is obtained. Using the principle of limit equilibrium method, the safe slope of gravelly soil slope is analyzed with straightening slope calculation software, and the influence of different slope, slope height and tower load on the reasonable position of the tower is summarized, which is the basis of the transmission line project in this area. The determination of tower location provides reference.

2. Factors affecting the reasonable location of tower

2.1 Slope grade
The slope gradient has great influence on the reasonable position of the tower. When the slope gradient is small, the component force of tower load along the slope direction is small, so that the tower has little impact on the gravelly soil slope; with the increase of slope, the component force of tower load along the slope direction is increasing, and its impact on the gravelly soil slope is increasing, when the slope increases to the limit value of slope stability, this slope is the safe slope; if the slope is greater than this slope, the tower is in an unstable state. In a steady state, it is necessary to avoid selecting tower location on such slope.

2.2 Slope height
The position of the tower on the slope also has a great influence on the slope stability. When the slope height is small, the tower load produces stress diffusion near the slope toe, resulting in slope instability; When the slope height is large, the tower load stress diffused to the whole slope, having little impact on slope stability.

2.3 Drainage conditions
Rainfall, especially heavy rainfall, is the main trigger factor of the slope instability. Because of the low saturation of the shallow surface soil layer of the gravel soil slope, there are many bubbles in the pores, and the resistance is large, and the content of the fine-grained soil mainly composed of silt and clay particles is high in the shallow surface soil layer, and the soil has large viscous resistance. Therefore, only when the hydraulic gradient reaches a certain value, the air bubble resistance in the pore and the viscous resistance in the soil are overcome, will the seepage occur. It can be seen that only when the hydraulic gradient is large enough to overcome the resistance of bubbles in the pores and the viscous resistance in the soil, the infiltration will occur. For the middle and deep gravel soil slope, it generally needs a long time and certain intensity of continuous rainfall or heavy rainfall to make the surface soil reach the saturation state and have infiltration, so as to make rainwater infiltration.

The effect of rainfall on gravelly soil landslide is mainly to increase the pore water pressure of the landslide mass, increase the sliding force of the landslide mass and reduce the normal stress acting on the sliding surface, so as to reduce the equivalent shear strength of the rock and soil mass at the sliding surface, and finally promote the gravelly soil slope to slide and form a landslide.

2.4 Excavation, slope cutting and top loading
Unreasonable excavation of slope toe will result in too large free face of slope, reduce gravity of slope toe, reduce anti sliding force of sliding surface, and cause slope instability. The influence of excavation on the deformation is not only due to the instantaneous deformation caused by the change of stress, but also due to the resulting creep. Moreover, the excavation does not end in an instant, but also has an impact on the later creep. Improper slope cutting tends to thin or cut through the structural surface or weak interlayer at the slope toe, reducing the anti sliding force of the sliding surface of the slope body, while the sliding force of the slope does not decrease, so the stability of the slope is reduced. When the overburden of structural plane or weak interlayer is cut through, the structural plane and side slope form an unfavorable combination, which leads to structural plane controlled instability of the slope.

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3. Stability requirements for tower location

In the stage of construction drawing design of transmission line, it is an important work to select safe and stable tower location. The stability of the tower needs to meet two conditions: (1) the slope distance at the tower site meets the requirements for the overall slope stability; (2) the internal and external slope stability requirements.

3.1 Slope distance requirements of tower location

According to the requirements of relevant specifications[5], for the buildings located on the top of stable soil slope, the slope top is less than or equal to 3m, the horizontal distance between the outer edge of the foundation bottom and the slope top shall meet the requirements of formula (1) and formula (2), but not less than 2.5m:

\[ a \geq 3.5b - \frac{d}{\tan\beta} \]  
\[ a \geq 2.5b - \frac{d}{\tan\beta} \]  

Where: \( a \) is the horizontal distance from the outer edge line of the foundation bottom to the top of the slope (m); \( b \) is the side length of the foundation bottom perpendicular to the edge line of the top of the slope (m); \( d \) is the buried depth of the foundation (m); \( \beta \) is the slope angle (°).

3.2 Slope stability

Limit equilibrium method is the most widely used and mature method in engineering design. The purpose of slope stability analysis is to determine the reasonable section size (i.e. allowable slope and slope height) according to the engineering geological conditions, or check whether the proposed size is stable. Rational slope stability analysis should follow the principle of comprehensive evaluation based on qualitative analysis and quantitative calculation. Therefore, according to the engineering geological conditions, possible failure modes and the signs of deformation and failure, the stability of the slope is determined qualitatively, and the stability trend is estimated. For the gravel soil slope, the circular sliding method should be used to calculate the slope stability coefficient[6-7], according to formula (3), (4) and (5):

\[ F_s = \frac{\sum R_i}{\sum T_i} \]  
\[ N_i = (G_i + G_{bi}) \cos \theta_i + P_{wi} \sin (a_i - \theta_i) \]  
\[ T_i = (G_i + G_{bi}) \sin \theta_i + P_{wi} \cos (a_i - \theta_i) \]  
\[ R_i = N_i \tan \phi_i + c_i \]  

Where: \( F_s \) is the slope stability coefficient; \( C_i \) is the standard value of bond strength of rock and soil mass on the sliding surface of calculation strip \( i \), kPa; \( \phi_i \) is the standard value of internal friction angle of rock and soil mass on the sliding surface of calculation strip \( i \), (°); \( l \) is the length of sliding surface of calculation strip \( i \), m; \( \theta_i \) and \( a_i \) are the bottom angle of calculation strip \( i \) and the ground water level surface angle, (°); \( G_i \) is the dead weight of rock and soil mass per unit width under calculation strip \( i \) (kN / m); \( G_{bi} \) is the dead weight of surface buildings per unit width of calculation strip \( i \) (kN / m); \( P_{wi} \) is the hydrodynamic pressure per unit width of calculation strip \( I \) (kN/m); \( N_i \) is the force of calculation strip \( I \) on the normal line of sliding surface (kN/m); \( T_i \) is the force of calculation strip \( I \) on the tangent line of sliding surface, (kN/m); \( R_i \) is the anti-sliding force on the sliding surface of calculation strip \( i \) (kN / m).

Straightening engineering software is a two-dimensional limit equilibrium analysis software suitable for the stability analysis of soil and rock slope, which can be used to calculate the safety factor of slope and evaluate the stability of slope. In this paper, the Janbu method is used to analyze the slope stability, and the circular sliding surface is selected as the sliding surface, and the dangerous sliding surface is searched by the given range of the circular entrance and exit. The width of the soil strip in the strip method is 1 m, and the step length of the center is 1 m when searching. The safety factor of slope stability is calculated when the tower is in the same position of the gravel soil slope and the slope gradient is different. In the transmission line project in Longnan, the minimum slope distance of
2.5m is taken when the buried depth of tower foundation is certain; according to the technical code for building slope engineering (GB50330-2013) requires that the safety grade of tower slope engineering is grade II slope. When the minimum safety factor calculated by arc method is 1.25-1.30\(^6\), the corresponding angle is the slope safety angle, and the tower is in a stable state.

4. Engineering example

4.1 Brief introduction of engineering examples
The study area is located near Linjiang Township, Longnan City, Gansu Province, which is a typical gravel soil slope. The slope height is 15m and the slope is about 39°. The tower is located in the middle of the slope. The single foundation load of the tower is 200KPa, the foundation width is 3M, the foundation buried depth is 6m, and the underground water buried depth is more than 30m.

4.2 Physical and mechanical parameters of gravelly soil
According to the field drilling data, the component of gravelly soil slope is residual Deluvial gravelly soil, dark soil yellow, slightly wet, loose ~ slightly dense, gravel content is 50%~60%, general particle size is 10~100mm, a small amount is more than 200mm, with poor psephicity, the rest is filled with silt and breccia, with layer thickness of 10m, surface layer covering thickness of 1.0~1.5m silt, and groundwater buried depth of more than 10m.

According to the indoor geotechnical test, the relevant physical and mechanical indexes of gravelly soil are shown in Table 1, and the shear strength indexes are shown in Table 2.

### Table 1 Physical and mechanical indexes of gravelly soil

| No. | Depth (m) | No. of samples | composition (%) | \( \rho \) (g/cm\(^3\)) | e | Gs | \( \alpha \) \( \cdot \) \( \psi \) (MPa\(^{-1}\)) | Quick Shear |
|-----|-----------|----------------|----------------|------------------|----|-----|-----------------|-------------|
| 1   | 20        | 2              | 2~20mm 283     | 0.89             | 1.84 | 0.72 | 2.74            | 0.01        |
| 2   | 30        | 3              | 2~20mm 74      | 0.63             | 2.13 | 0.75 | 2.73            | 0.09        |
| 3   | 40        | 4              | 1<2mm 39      | 0.14             | 1.98 | 0.69 | 2.73            | 0.04        |
| 4   | 50        | 4              | 0.5<2mm 107   | 0.13             | 2.07 | 0.63 | 2.77            | 0.02        |
| 5   | 60        | 4              | 2<4mm 176     | 0.10             | 1.81 | 0.62 | 2.75            | 0.03        |
| 6   | 70        | 4              | 4<8mm 88      | 0.19             | 1.58 | 0.59 | 2.74            | 0.02        |
| 7   | 80        | 4              | >8mm 195      | 0.18             | 1.58 | 0.59 | 2.74            | 0.02        |

### Table 2 Shear strength index

| Shear strength index | Number of samples | Average value | Standard deviation | variation coefficient | correct coefficient | Standard value |
|----------------------|-------------------|---------------|--------------------|----------------------|---------------------|----------------|
| C/kPa                | 24                | 14.66         | 3.668              | 0.267                | 0.779               | 10.69          |
| \( \varphi \) (°)   | 24                | 29.90         | 4.322              | 0.145                | 0.893               | 26.70          |

4.3 Limit equilibrium analysis based on righting software
According to the calculation model, the slope height in the calculation is the slope height in the model minus the buried depth of the foundation, the cohesion \( c \) is 10kPa, the internal friction angle \( \varphi \) is 26°, and the corresponding safety factors of different slopes under natural state and 200kPa load are shown in Table 3; the internal failure surface of different slopes is shown in Figure 1.

![Figure 1](image-url)
4.4 Analysis of calculation results

According to the results of test, when the safety factor of 1.25 is met, the stable slope of the natural slope is 39.3°. It can also be seen when the slope height increases from 9m to 11m, the failure surface in the slope gradually turns straight from the downward arc shape (Figure 1), reducing the anti-sliding force of some slope bodies, reducing the safety slope from 31.1° to 29.2°; when the slope height increases from 11m to 18m, although the slope angle of the failure surface increases, due to the diffusion of stress, the shear stress generated by the tower load changes with the increase of the slope angle The slope height decreases significantly, so the safety slope increases from 29.2° to 39.2°; when the slope height reaches 19m, the tower has no impact on the stability of the slope, and the safety slope reaches 39.3° of the natural state; when the slope height is greater than 20m, the impact of the tower on the stability of the slope can be ignored.

It can be seen from Figure 2 that under the load of 200kPa tower, the shear stress in the slope increases gradually from the toe to the slope top, which can be increased by 35.27% - 60.9% compared with that under the natural state; the growth rate of 13, 14 and 15 soil strips near the slope top increases by 67.4%-93.1% compared with that under the natural state; the shear stress of 15 soil strips near the slope top increases significantly, which can be increased by 122.2% at most compared with that under the natural state If the tangential force at the top of the slope is greater than the shear strength of the soil, the shear failure of the slope will occur from the top of the slope.

5. Conclusion

(1) When the safety factor is 1.25, the stable slope of the natural slope is 39.3°; when the slope height increases from 9m to 11m, the safe slope decreases from 31.1°to 29.2°; when the slope height increases from 11m to 18m, the safe slope increases from 29.2°to 39.2°; when the slope height reaches 19m, the tower has no impact on the stability of the slope, and the safe slope reaches 39.3°of the natural state; when the slope height is greater than 20m The influence of tower on slope stability can be ignored.

(2) With the increase of the height of the slope, the tangential force inside the slope also changes. Under the load of 200kPa, the shear stress in the slope can be increased by 35.27% - 93.1% from the toe to the top of the slope, and 122.2% at the top of the slope.

(3) In addition to the safe slope, the drainage conditions of the slope, excavation and slope cutting, and the loading on the top of the slope are also critical to the selection of the reasonable location of the tower. Heavy rainfall will increase the pore water pressure of the slope, reduce the equivalent shear strength of the slope, and easily cause slope instability. Therefore, it is also one of the key factors for...
the stability of the tower position to take good measures of water prevention and drainage around the tower base during the construction.

(4) It should be noted that the calculation in this paper is also based on the intact shape of the gravel soil slope, and there is no significant free face at the slope toe. If the gravel soil slope has a significant free face, the above calculation results are not applicable. The calculation of the stability of the tower is the next research focus.

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