Numerical Analysis of The Three Piles of Facing Each Other

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Abstract. In order to study the deformation and stress characteristics of the pile under the action of landslide thrust. Taking the Suo Er Tou landslide in Gansu Province, China as the engineering background, In the paper the numerical analysis model by establishing the finite difference software FLAC3D of geotechnical engineering is analysed the displacement and bending moment of the pile. The anti-slide pile adopts pile element, soil constitutive model uses Mohr-Coulomb. The results show that the displacement of the piles at the top of the pile and the section of the pile are basically equal, but the horizontal displacement values are not equal above the sliding surface. In the sliding surface, the bending moment of the front pile is smaller than the bending moment of the back pile, but the bending moment of the front pile at the top of the pile is larger than the bending moment of the back pile.

1. Introduction

In recent years, landslide geological disasters have occurred frequently, and the anti-slide pile is widely used in landslide control. According to the combination of piles, the anti-slide pile is classified as single-row anti-slide piles, double-row anti-slide piles, and multi-row anti-slide piles. Among them, single-row anti-slide piles have the most research and application, but the landslide thrust is large and the geological conditions complex landslides, single-row anti-slide piles are sometimes difficult to meet design requirements. The double-row anti-slide pile has the characteristics of high rigidity, strong resistance to deformation and small displacement of the pile top, and can produce a good anti-sliding effect. Many scholars have made a lot of theoretical and experimental simulations for the planar combination of double-row anti-slide piles and the interaction between pile and soil.

Zhou et al. [1] studied the anti-sliding mechanism of micro anti-slide piles according to the principle of pile-soil interaction and through laboratory experiments. The anti-sliding effect is resisted by the advantages of the tensile strength of the micro-pile and the bearing capacity of the pile foundation. Landslide thrust. He et al. [2] studied the internal force, deformation and earth pressure distribution characteristics of double-row slope protection piles through laboratory tests, and based on this, the double-row piles were regarded as the rigid frame structure embedded at the bottom end, and the distribution of soil pressure between piles According to the proportion of the weight of the sliding soil, the calculation method of the double-row slope protection pile is determined. In the foundation pit engineering, [3~5] studied the earth pressure distribution of the front and back row piles, and proposed the calculation method of double-row piles under the premise of considering the spatial effect and obtained engineering application. Wan et al. [6] applied the principle of soil arching to the calculation method of double-row piles and compiled a calculation program. Zhao et al. [7] derived
the elastic analytical solution of the displacement and stress distribution in the laterally loaded piles based on the pile-soil common working mechanism and obtained the modulus of the soil on the pile side based on the approximate relationship between the deformation modulus and displacement of the soil. Distribution and weighted modulus are employed in the finite element-finite layer method to analyze the force deformation of laterally loaded piles. The characteristics of soil heterogeneity and nonliterary can be approximated, and the calculation program is compiled. Ma et al. [8] regarded the soil between the piles of double-row piles as compression springs and developed the double-row pile design software using VB.NET. Zheng et al. [9] used springs to simulate the soil between piles, and considered the influence of soil layer compression and soil reinforcement on the structure, and analyzed the finite element model of double-row pile structure.

In this paper, the numerical calculation model is established by using the geotechnical analysis software FLAC3D. In order to make the calculation results contrast, the calculation model adopts the Suo er Tou landslide in Gansu province, China and the pile element is used to simulate the force structure of the three piles of facing each other.

2. Establishment of a Calculation Model

In this paper, the geotechnical analysis software FLAC3D is used to analyze the stress and deformation characteristics of the three piles of facing each other. However, due to the weak pre-processing function of the software FLAC3D, it is very complicated to build the model in the software for this calculation model. It used ANSYS to build a calculation model and then used CivilFEM to import into FLAC3D software. There are two groups in the calculation model, namely slider and bedrock. CivilFEM is based on ANSYS, and inherits all functions of ANSYS. It provides dedicated pre-and post-processing, analysis, design and verification tools for the civil engineering.

The geometric length of the calculation model is 540m×180m, and the width varies according to the spacing of the group piles. The anti-slide pile adopts the pile element, and the constitutive calculation model of slider and bedrock uses Mohr-Coulomb, and the sliding surface is simulated by the interface element. The maximum sliding thrust is 1041kN/m, the pile length is 35m, the pile diameter is 1.8m, the connecting beam width is 1.8m, the height is 1.0m, the concrete strength grade is C25, the group pile spacing is 7.0m, the single pile spacing is 6.0m, and the sliding surface depth is 18m. The boundary condition of the model is that the bottom surfaces x, y and z are all constrained, and the front and back sides and the left and right sides both restrict the degree of freedom in the normal direction, and the top surface is not constrained. The Sketch map of the three piles of facing each other is shown in Figure 1. The physical and mechanical parameters of rock and soil is shown in Table 1. The physical and mechanical parameters of pile element and beam element is shown in Table 2. The physical and mechanical parameters of interfaces is shown in Table 3. The Model geometry is shown in Figure 2. Numerical calculation model is shown in Figure 3.

![Sketch map of three piles facing each other](image1.png)

**Figure 1.** The Sketch map of the three piles of facing each other
Table 1. The physical and mechanical parameters of soil.

| Soil class | Weight (kN/m³) | Bulk modulus (MPa) | Shear modulus (MPa) | Cohesion (kPa) | Friction angle (°) |
|------------|---------------|-------------------|--------------------|---------------|-------------------|
| Slider     | 22.0          | 83.3              | 17.9               | 20.0          | 25.0              |
| Bedrock    | 23.5          | 556.0             | 417.0              | 1800.0        | 60                |

Table 2. The physical and mechanical parameters of pile element and beam element.

| Category                                      | Pile element | beam element |
|-----------------------------------------------|--------------|--------------|
| Elastic modulus (MPa)                         | 22.6         | 22.6         |
| Poisson's ratio                               | 0.25         | 0.25         |
| Sectional area (m²)                           | 2.54         | 1.80         |
| Cohesion of shear coupling spring (kPa)       | 14.0         | ---          |
| Friction angle of shear coupling spring (°)   | 17.5         | ---          |
| Cohesion of normal coupling spring (kPa)      | 14.0         | ---          |
| Friction angle of normal coupling spring (°)  | 17.5         | ---          |

Table 3. The physical and mechanical parameters of interfaces.

| Name                                           | Shear stiffness (MPa) | Normal stiffness (MPa) | Cohesion (kPa) | Friction angle (°) |
|------------------------------------------------|-----------------------|------------------------|----------------|-------------------|
| The interfaces of slider and bedrock           | 112.5                 | 112.5                  | 12.0           | 15.0              |

Figure 2. Model geometry.

Figure 3. Numerical calculation model.
3. Analysis of Calculation Results

3.1. The horizontal displacement of the pile

Research on the horizontal displacement of the pile in the study of the structural performance of the three piles of facing each other is very important. The horizontal displacements of the front and back piles are obtained as shown in Figure 4 and Figure 5. From the figure, the following conclusions can be drawn: Firstly, the horizontal displacement of the piles in the front and back sections of the pile top and the embedded section is almost equal, the displacement of the front pile is 183mm, and the horizontal displacement of the back piles number 1 and 2 is 188mm. The horizontal displacement of the pile at the embedded section is about zero, which proves that the restraining effect of the sliding bed against the sliding pile is very good. The horizontal displacement at the top of the pile is equal because of the role of the connecting beam, although there is no assumption that the beam is rigid in the calculation model, but its cross-sectional area is large, and its axial stiffness and bending stiffness also become larger. Under the action of landslide thrust, its axial compression deformation is small, and its effect is equivalent to the translation of the rigid body. Secondly, the horizontal displacement of the front and back piles at the sliding surface upper is different, and the maximum difference between the pile with depth of -13m is 9.72mm, which is gradually reduced, indicating that the pile depth is -13m. The spatial restraint effect formed by the front and back piles is reduced. Because the top of the pile is increased by the connecting beam, the rock mass under the sliding surface has a stronger restraining effect against the pile. Finally, the spatial effect is considered in the calculation of the calculation model, but from the phenomenon that the horizontal displacement values of the back piles number 1 and 2 is almost equal, the spatial torsional deformation of the structure is small, and the main deformation of the structure is still horizontal lateral deformation with the landslide thrust. For this reason, it can be ignored the additional effect of the pile torsional deformation in the theoretical calculation model, this phenomenon can be further verified by the bending moment of the pile.

3.2. Bending moment of pile

Another indicator of the internal force analysis of the pile is the bending moment of the pile. Figure 6 and Figure 7 show the displacement moment contour and curve of the pile under the action of landslide thrust. In FLAC3D software, because the internal force of the structural element is displayed on both sides, red represents negative bending moment and black represents positive bending moment, which is not obvious in numerical value. For this reason, it is further converted into a curve by command flow, as shown in Figure 7. Shown. By comparing and analyzing the Figure 6 and 7, the
following conclusions are drawn: Firstly, the bending moment of the back piles number 1 and 2 is almost equal, which is consistent with the previous horizontal displacement analysis of the pile, that is, there is no torsional effect, but in actual engineering, the direction of application of the landslide thrust is difficult to ensure coincidence with the central axis of the anti-slide pile, which in turn produces a torsional effect. However, when the anti-slide pile is arranged, the structure will be avoided as much as possible, and the torsion effect has little effect on the internal force deformation of the pile. Secondly, the bending moment values of the front pile and the back pile at the top of the pile are quite different. The bending moment of the front pile is 14.5×10³kN·m, and the bending moment of the back pile number 1 is 10.9×10³kN·m. The bending moment of the back pile number 2 is 10.8×10³kN·m, and the bending moment of the front and back piles is about 24.8%, with the pile depth increasing, the bending moment of the front pile gradually decreases, and the bending moment of the back pile gradually increases. The value of the difference between the bending moments of the piles at the -12m depth of the pile reaches the maximum value, and the difference is 3.07×10³kN·m. When the difference value reaches the maximum value, the bending moment of the back pile gradually decreases with the increase of the embedded depth of the pile, and the bending moment of the front pile gradually increases. However, in the embedded section, the internal forces of the front and back piles tend to be zero.

4. Conclusion
(1) According to the analysis, under the action of landslide thrust of 1041kN/m, the three piles of facing each other has good resistance to deformation, large rigidity and small deformation.

(2) The lateral displacement of the front pile and the back pile of the three piles of facing each other are basically equal at the top position of the pile and below the embedded section, the displacement of the top front pile is 183mm, and the displacement of the top back pile is 188mm. The displacement of the front and back of the lower part of the embedded section is basically zero.

(3) According to the bending moment analysis of the pile, the bending moment value of the front pile at the top of the pile is 1.25 times of the bending moment value of the back pile. The main reason is that the back pile is composed of two single piles, and the front pile is only one single pile. However, the bending moment value of the front pile at the 2/3 position above the sliding surface is smaller than that of the back pile.

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