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Stability Analysis and Application of Two-Stage Support on The High Fill Slope

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Abstract: This paper relies on the two-stage slope project, which is in Sanmenxia. The first grade slope is reinforced by soil nailing, multi-row piles and buttress retaining wall support scheme are adopted for the second stage subsequent fill slope, finite element simulation software is used, a numerical analysis model for multi-stage support slope is established, the development and change of soil nail axial force, pile axial force, pile shear force and bending moment as well as slope displacement and overall stability safety coefficient of multi-grade slope during layered construction process are simulated and analyzed. The results show that the horizontal load formed by the layered filling soil of the second grade slope makes the pile produce bending moment and shear force and the soil nail produce axial force. The vertical load formed by the filling soil makes the plastic area of the slope develop into the deep part of the soil, slip surface is formed around the soil nailing and multi-row pile supporting area, finally. It is proved that it is reasonable and feasible to adopt soil nail reinforcement and multi-row pile and supporting wall joint support scheme for multi-grade slope respectively, slope is stable as a whole.

1. Introduction
In recent years, a large number of scholars have adopted various methods to study and analyze the stability of natural slope, artificial slope, slope excavation and structural support slope. However, in the analysis and calculation of the stability of the artificial slope and the slope with structural support, the classification of the support is usually less, and most of them are the analysis of the single-stage slope support structure. With the widespread rise of high slope and the limitation of construction conditions, more and more people adopt multi-level support to ensure the stability of slope. Therefore, it is of great theoretical and practical significance to study the stability of multi-level support for high fill slope.

The research and application of slope support structure in China started relatively late, however, with the development of economy and construction industry, the slope support structure has developed in China. Support, soil reinforcement of composite structure and anchorage technology and other new light support technology has been gradually developed. Such as cantilever, anchor bolt, support wall, anchor plate and other new types of retaining wall, as well as anti-slide pile, prestressed anchor cable, soil nail wall, pile plate wall and other new supporting structures. These new support structures have been widely used in geotechnical engineering in recent years.

Peng Mingxiang deeply studied the stability of soil nailing excavation, and gave the critical excavation height of slope working face, the stability and safety factor analysis and calculation method of the stability and safety factor against collapse, and the measures to prevent the working face from collapse.
Using the method of circular arc sliding slippage, Li Zhong [3] established the searching model for the most dangerous sliding surface of slope and gave the function relation between center position and stability coefficient of slope slip surface, based on the limit equilibrium theory and the failure mode of slope sliding surface. Zhang Mingju [4] also made a series of corresponding research.

Soil nailing wall is a common form of support for slope reinforcement and deep foundation pit support; in recent years, the multi-row pile support structure has been applied successfully in the high slope support engineering. This paper is based on the geological conditions of the high fill slope project on the west side of Hong Run City in Sanmenxia. According to the requirements of engineering construction sequence, soil nailing wall is used to reinforce the original grade slope; the technique of multi-row pile support is applied to fill slope support engineering, forming the secondary slope support form of soil nailing wall and multi-row pile. The stability of multi-stage support for high fill slope is simulated by fast Lagrange finite difference method.

2. Modeling

2.1 Project Profile

The west slope area of Hon Run city is located in south of Shan state avenue, east of Cang Longjian River. The slope is mainly soil slope, mingled with the construction waste; the slope is about 140 m long and 10 ~ 12 m high, slope toe angle is about 45° ~ 65°, the slope is covered with grassland, local part of the gully formed due to the rains washed out. 12 buildings are planned to be built on the top of the slope, with a height of 18 to 30 storeys. The overall safety grade of the project is grade 1, and the geological environment of the slope is of medium complexity.

According to the slope engineering geological conditions of evaluation and analysis of stability, this slope is in unstable condition, at the top of the fill the slope range is larger, the thickness is about 0.9 ~ 8.2 m, the soil is loose and unstable, and the loess-like silt is below it. Since the slope is a permanent slope, the service life should be greater than or equal to the service life of the buildings on both sides of the slope. Under the influence of adverse factors such as water erosion, it is possible to produce collapse and landslide. The corresponding slope support measures are suggested.

2.2 Calculation Model

2.2.1 Geometry Model

Figure 1 shows the basic dimensions of the model. In this calculation model, the distance from the slope foot to the left boundary is 14 m, the distance from the top to the right boundary is 42.5 m, and the downward boundary of the slope foot is 17.9 m. The total height of the model is 30.8 m, the total length is 62.8 m, and the width is 5 m. The bottom of the calculation model is fixed and fixed with fixed hinge support. The slope surface and the top of the side slope are free boundary. The left and right sides of the boundary adopt sliding hinge support, the horizontal direction is restrained, the vertical direction is not constrained, and there can be vertical displacement. The overall 3d numerical analysis model is shown in figure 2.
In the simulation, the secondary slope with the method of layered filling, filling each layer height is 1.2 m, which is divided into 6 layer for filling, every fill layer for a condition, after the completion of the filling on 30 kpa road load, as a condition of 7, a total of seven conditions.

### 2.2.2 Selection of Parameters

The soil layer is simulated by solid element, and the soil layer parameters are given according to the survey report. The soil structure adopts mohr-coulomb model. The solid element simulation is adopted for the buttress wall. The geometric parameters are shown in figure 3, and the calculated model parameters are shown in table 1. Unit anchor cable (cable) are adopted to simulate the soil nail and soil nailing material is steel wrapped slurry, using cable element simulation, a total of five rows, the former three rows of soil nail length is 12 m, the length of the two rows of soil nail behind is 9 m, all soil nail diameter is 150 mm, angle is 12°, every 1 m arrangement in a row, specific parameters are shown in table 2. The surface layer is shotcrete, and the calculation model is simulated by shell element, and the model parameters are shown in table 3. Multi-row piles are concrete cast-in-place piles with 5 rows and 5 columns in total, with a pile length of 11.5 m, a pile diameter of 0.5 m, a horizontal spacing of 1.5 m and a vertical spacing of 1 m. Pile unit is adopted for simulation, and other model parameters are shown in table 4.

### Table 1: Parameters of retaining wall retaining wall

| solid element density (kg/m³) | Modulus of elasticity (GPa) | Poisson's ratio |
|-------------------------------|----------------------------|----------------|
| Retaining wall                | 2500                       | 20             | 0.2             |

### Table 2: Parameters of the soil nailing

| Row of soil nail | Length of soil nail (m) | Horizontal Spacing (m) | Steel Area (cm³) | Modulus of elasticity (GPa) | Cement friction Angle (°) |
|------------------|--------------------------|------------------------|------------------|----------------------------|----------------------------|
| 1                | 12                       | 1                      | 4.91             | 210                        | 26                         |
| 2                | 12                       | 1                      | 4.91             | 210                        | 26                         |
| 3                | 12                       | 1                      | 4.91             | 210                        | 26                         |
| 4                | 9                        | 1                      | 4.91             | 210                        | 26                         |
| 5                | 9                        | 1                      | 4.91             | 210                        | 26                         |
3. Simulation and Analysis

3.1 Deformation analysis of soil nail and multi-row pile

3.1.1 Analysis of displacement of slope with combined support

The horizontal displacement and vertical settlement of the two-grade slope are shown in figure 4 and figure 5. As the two-grade layered fill slope gradually increased, the maximum horizontal displacement value point moves gradually from the inside to the lower part of the retaining wall and slope surface. The maximum horizontal displacement after the completion of soil filling occurs at the bottom of the retaining wall, with a value of about 3mm. At the 7th working condition, the horizontal displacement distribution law did not change much, but the displacement value changed greatly, and the maximum horizontal displacement value increased to about 9mm.

With the increase of filling layer by layer, the vertical settlement law of slope is consistent, and the change is only reflected in the increase of value. From about 6.5mm in working condition 1 to about 12mm in working condition 6, the vertical settlement diagram also showed no significant change in working condition 7, but the maximum increase was about 32mm.

3.1.2 Analysis of soil nail axial force

The axial force evolution process under each working condition of soil nailing in each row is shown in figure 6. It can be seen that the axial force distribution of soil nails in the same row is generally consistent under different working conditions, which is only reflected in the increase in value. Compared with the first 6 working conditions, under the working condition 7, the axial force in the first half of the area near the nail head increases significantly, and the increment decreases gradually along the length of the nail body, with little change near the nail tail.

The axial diagram of each row of soil nail formed after layered filling is shown in figure 7. It can be seen from the figure that the axial force distribution of soil nailing in each row is roughly similar. The first four rows show the distribution rule of "bow shape" on the large and small sides of the middle, while the fifth row shows the trend of first decreasing, then increasing and then decreasing. Compared with the soil nailing support system formed by the top-down layered excavation, there are significant differences.
3.1.3 Deformation analysis of pile

Figure 8 shows the axial force comparison diagram of each pile in various working conditions in multi-row piles. With the increase of the number of soil filling layers, the axial force of each pile increases steadily. Pile not only bears the vertical load, but also the vertical and horizontal effects of the upper soil filling. As a whole, the five columns of piles have different positions, different soil displacement and bearing different axial forces. The axial forces from the outside to the inside
gradually increase.

As shown in figure.9 and figure.10, the shear strength comparison diagram of each pile row under various working conditions in multi-row piles is shown. From the graph, with the number of filled soil can increase step by step, the columns of pile cap on shear value from negative to positive, from small to large. In other words, the direction of shear force has changed. The external force of slope decreases gradually, the internal force of slope increases gradually, and the force gradually changes from outside slope to inside slope. In the fifth column, the shear force gradually decreases from the outside to the inside, and the shear distribution of pile body is quite different from that of the first four columns, which is caused by the different position and the different displacement of soil body on the slope.

![Graphs showing axial force of each pile under various working conditions](image-url)

Fig. 8 The axial force of each pile under various working conditions
(a) The shearing force of the first column pile under all working conditions

(b) The shearing force of the second column pile under all working conditions

(c) The shearing force of the third column pile under all working conditions

(d) The shearing force of the fourth column pile under all working conditions

(e) The shearing force of the fifth column pile under all working conditions

Fig. 9 The shearing force of each pile under various working conditions
3.2 Slope stability analysis

The strength reduction method was used to simulate and analyze the overall stability of soil nailing and multi-row pile supporting slope. The step length of each working condition was set to 0.05. The shear strain increment and displacement evolution of each working condition from working condition 1 to working condition 7 were calculated respectively to judge the sliding trend and stability of slope.

The large displacement point was taken as the characteristic point to calculate the slope stability safety coefficient under various working conditions, it is concluded that the slope safety coefficient under the working condition as shown in figure 11, as the filling soil increase in the number, the slope safety factor decreases gradually, the working condition of $F_s = 1.35 > 1.3$, which meets the technical specification for building slope engineering (GB50330-2013) [15] ($F_s \geq 1.3$).

4. Conclusion

Based on the specific project cases as the background. In this paper, the stability of high slope, where the soil nailing and filling pile combined support are used and its working mechanism are analyzed in numerical simulation. The deformation behavior and variation characteristics of soil nailing and multi-row pile in the joint support of soil nailing and multi-row pile are studied. Through the successful application of engineering examples, the results show that:

1. The first grade undisturbed soil slope is reinforced by soil nails, the secondary fill slope is supported by multi-row piles and buttress retaining wall, the horizontal soil pressure caused by the layered filling of the secondary slope in the construction process is borne by the multi-row pile and soil nail. The soil nail produces axial force, which decreases from top to bottom. The horizontal shear force produced by multi-row piles decreases gradually from the outside to the inside.

2. During the construction of the joint support, the vertical soil pressure caused by the layered filling of the secondary slope is mainly borne by multi-row piles. The axial force of pile body increases gradually from outside to inside.

3. Under the combined vertical load and horizontal soil pressure caused by the filling soil, the plastic zone of the slope develops into the deep soil. Finally, slip surface is formed around the soil.
nailing and multi-row pile supporting area. The safety factor $F_s$ of the overall stability of slope can meet the requirements of the technical specification for construction slope engineering (GB50330-2013).

Secondary slope is verified in practical engineering applications, that soil nailing reinforcement scheme and multi-row pile + supporting wall joint support scheme are adopted for the second grade slope respectively, is reasonable and feasible. Both of them play their respective roles well, making the whole slope stable.

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