Reinforcement scheme design for geotechnical slope engineering

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Abstract. With the continuous development of western mountainous areas and the deepening of infrastructure construction, geotechnical slope has become an engineering problem that cannot be ignored in the process of construction and using. Due to its universality and great harm of accidents, it has become a hot spot that engineers and researchers pay more attention to. It is of great significance to strengthen the stability of geotechnical slope. There are mature theories at home and abroad, but the actual engineering geological conditions are complex, the combination of theory and practice still needs to be explored. Combined with the slope engineering of an airport in the loess plateau area, the engineering geological conditions and the current situation of the slope were firstly introduced in this paper, then the stability checking was carried out under natural working condition and heavy rain condition respectively. The slope reinforcement was carried out for Scarp 1 and Scarp 2, respectively. This paper is of great help to further understand the principle of slope engineering reinforcement and can provide experience for slope reinforcement under similar working conditions.

1. Introduction

With the deepening of infrastructure construction and people’s increasing material and cultural needs, infrastructure construction of China is gradually moving towards the west mountainous areas, and public transportation such as bridges, tunnels and highways is continuously developed and constructed. But in the process of construction, it is inevitable to deal with geotechnical slope. Due to the complex geological landforms, harsh nature, climate and construction conditions in the western region, the projects are faced with many difficulties. If the treatment of the high slope is not appropriate, it is easy to instability and the formation of landslides and other accidents. Once there is a landslide, the economic loss and social impact caused by it are quite serious, and its later governance is also quite intractable. Successful soil and rock slope protection not only needs to pay high attention to, but also needs to learn successful cases, constantly innovates and introduces, and learns from the successful engineering technology of foreign countries. It is of great social and economic benefits and engineering theoretical value to carry out a systematic and in-depth study of slope engineering and put forward practical solutions [1-2].

Lee et al studied the slope surface erosion and shallow layer collapse that easily induced by the increase of slope angle and slope length, and proposed overall protection measures such as gentle slope angle, grass planting, lattice and drainage for soft mudstone slope [3]. Wang et al analyzed the numerical
method of strengthening effect of anti-slide pile treatment on slope, and discussed the influence of main structural parameters, such as pile position, pile length, elastic modulus of pile body and other factors on slope safety factor such as critical sliding surface, internal force and displacement response of anti-slide pile [4]. Wan summarized three main methods for geotechnical slope stability, namely traditional analysis method, numerical analysis method and new creation method [5].

At present, the research on slope engineering is more extensive and the theory is more mature. However, due to the complexity of actual engineering geological conditions and the distance between theory and practice, we need to apply practice in practical engineering. Based on the theoretical analysis of slope engineering in a loess area, this paper proposes a slope treatment scheme. At present, the slope project has been put into use and the working condition is stable. The case analysis of practical engineering in this paper will help to further strengthen the understanding of slope engineering and provide an important reference for how to carry out slope management in loess area.

2. Project overview
This project is a high excavation and deep filling project, which is located in the northern Shaanxi plateau. The glide platform is located at the southwest end of the airport runway. The overall terrain is an artificial slope formed after large-scale excavation and filling treatment at the high north and low south. The terrain fluctuates greatly and the elevation is between 1207.5m and 1165.9m. The slip platform area is divided into the original soil surface area, slope backfill area and leveling area. In the construction of pile foundation, a two-stage high and steep excavated slope is formed, which is an artificial steep ridge. The northwest steep Scarp 1 has a height difference of about 15m and a slope of about 40° – 50°. The southwest angle steep Scarp 2, elevation difference 20m, and slope about 50°-60°, as shown in Fig 1. According to the regional data and survey results, no adverse geological effects affecting the stability of the proposed site, such as collapse, slope and debris flow were found. Once the instability of the steep slope occurs, it will directly affect the safe use of the entire airport runway. Therefore, the purpose of the slope treatment design is mainly to improve the internal stress state of the slope to achieve a stable state.
According to the survey, proposed site within the scope of the depth of 64.0 m below the surface reveals the formation of top-down followed by quaternary artificial fill ($Q_4^{ml}$), quaternary on wind-blown ($Q_3^{eol}$) loess, residual pleistocene series ($Q_2^{el}$) in ancient soil, aeolian ($Q_2^{eol}$) loess, residual $Q_2^{el}$ paleosol. Site formation field characteristics and buried conditions described as shown in Tab 1.
### Tab 1. Site stratigraphic burial conditions

| Formation number | Geological age and genesis | Apparent feature | Layer thickness (m) | Bottom layer depth (m) | Bottom elevation (m) |
|------------------|---------------------------|-----------------|--------------------|------------------------|---------------------|
| ①               | Q₄<sup>ml</sup>           | **Compacted fill:** Yellowish brown, mainly silty clay, partially silty, uneven, slightly wet, medium dense, hard molded to a hard state | 10.80~ 60.00 | 10.80~ 60.00 | 1174.10~ 1146.23 |
| ①₁              | Q₄<sup>ml</sup>           | **Loose fill:** Yellowish brown, mainly composed of silty clay and silt, soil uneven, slightly wet, loose hard plastic to hard state | 0.50~ 14.30 | 0.50~ 14.30 | 1163.39~ 1200.90 |
| ②               | Q<sup>3</sup>eol         | **Loess:** Brown yellow, slightly wet, mica and a small amount of white calcareous streaks, occasionally seeing snail fragments and sporadic calcareous nodules, with large pore structure, hard plastic to hard state | 1.10~ 17.30 | 7.60~ 47.00 | 1146.09~ 1193.80 |
| ③               | Q<sup>3</sup>el           | **Ancient soil:** Brown red, slightly wet, containing a small amount of white calcium tuberculosis, calcium filament, with large pore structure, uniform soil, hard plastic state | 0.30~ 1.80 | 7.90~ 31.60 | 1145.59~ 1192.10 |
| ④               | Q<sup>2</sup>eol         | **Loess:** Brown yellow, slightly wet, mica and white calcareous streaks, wormhole structure, sporadic calcareous nodules, uniform soil, hard plastic state, difficult to sample | 2.70~ 13.30 | 16.50~ 53.00 | 1133.99~ 1187.80 |
| ⑤               | Q<sup>2</sup>el           | **Ancient soil:** Brown red, contain white calcareous stripe, calcium powder and a small amount of calcareous concretion, very small number of needle-like pores, soil even, slightly wet, hard plastic to hard state, local containing aeolian loess | 0.40~ 9.20 | 17.50~ 46.70 | 1131.69~ 1182.34 |
| ⑥               | Q<sup>2</sup>eol         | **Loess:** Yellow gray, mica and white calcareous stripes, soil uniform, slightly wet, medium and dense, difficult to sample. The layer contains 1~2 layers of eluvial paleosoil | 2.30~ 17.50 | 27.30~ 65.00 | 1129.09~ 1175.40 |
| ⑦               | Q<sup>2</sup>el           | **Ancient soil:** Brown red, containing a small amount of white calcareous tuberculosis, needle-like pore structure, uniform soil quality, hard plastic to hard state, the bottom of the layer calcareous tuberculosis is relatively rich, particle size is generally 2~4cm. The layer is interbedded between the aeolian loess and the eluvial paleosols. According to the indoor geotechnical tests, the physical and mechanical properties of the layer differ little, so it is merged into one layer | 6.50~ 17.70 | This layer is not penetrable and has a maximum exposure thickness of 17.70m |

### 3. Reinforcement design

#### 3.1. Analysis of basic characteristics of Scarp
The slope of Scarp 1 is mainly distributed below the top of the slope of sliding platform and is manually cut. Its slope is about 45° and the elevation difference before and after the slope is about 15m. The slope is mainly Q<sub>3</sub>eol loess. At present, the slope is in a stable state. According to the engineering geological survey, the slope is mainly composed of collapsible loess, and the surface water of soil layer is easy to infiltrate, soften the soil and reduce its mechanical strength index. If the engineering geological conditions change, the slope body is easy to instability and deformation, there are security risks.
The slope of Scarp 2 is mainly distributed at the bottom of the slope from the reflection network frame. It is a high and steep artificial slope excavated during the construction of the reflection network pile foundation. The slope is relatively steep, about 50-60°. At present, the slope is in a stable state. According to the engineering geological survey, the slope also has the problem of surface water infiltration, reducing the mechanical strength index, and has the hidden danger of safety.

3.2. Specific measures and effects of slope treatment
According to the comprehensive analysis of the characteristics of unstable slope, inducing factors, deformation and failure mode, damage scope and damage degree, the key point of the treatment of the potentially unstable slope body is to take the engineering measures combining retaining and anchoring, and then to consolidate the slope body with the interception and drainage project.

3.2.1. Scarp 1
Scarp 1 slopes 1:1, the vertical height is about 15m. The stability coefficient under natural working conditions is between 1.37 and 1.62, the slope is in a stable state as a whole, and the stability coefficient under heavy rain working conditions is between 1.17 and 1.41. At present, the whole slope of Scarp 1 is in a stable state, but with the passage of time or the influence of extreme weather, the slope may have the possibility of local collapse. Considering the special position of the slope, which is related to the overall stability and safety of the slide table reflection network, frame bolt retaining wall is adopted to treat the slope. The first stage is 8m high (from the top of the slope) and the slope rate is 1:0.8-1.13. The second stage is 7m high and the slope rate is 1:1.1-1.13. When 6.5m < H≤8m, set 5 rows of HRB400 Φ 25 bolt, spacing of 3 m * 4 m, anchor length L=8-14m, anchorage angle is 20°, slope stability safety factor is 1.46. It meets the requirements of the specification.

![Fig. 2 Elevation of frame anchor retaining wall](image)
3.2.2. Scarp 2

Under natural working conditions, the stability coefficient of Scarp 2 slope is between 1.13 and 1.42, and the slope is in a basic stable state. Under heavy rain working conditions, the stability coefficient is between 0.99 and 1.22, and the slope is in an unstable state. There is a risk of partial collapse and overall instability of the slope. Due to the large and concentrated rainfall in this area, the slope may be extremely unstable. Lattice anchor cable support was adopted for it, slope cutting was carried out at a vertical height of 10m, and a horse track 2m wide was reserved. Preventing the slope collapse from affecting the overall stability of the slope and the pile foundation of the reflecting net and causing new geological disasters.

The section size of lattice beam is 500×500mm, the strength of concrete is C30, and the spacing is 3.0×3.0m. The anchor cable is mechanically holed or manually shored, the aperture is not less than 150mm, the prestressed anchor cable is 16 – 25m long, and the inclination angle is 20°. Design tension is 350kN, lock load is 240kN. The frame consists of two vertical beams and three beam groups, which shall be made by pouring at one time during construction. Expansion joints of 2cm width shall be reserved between each piece, and the cracks shall be filled with asphalt boards. After adopting lattice anchor cable support, the stability coefficient of Scarp 2 is between 1.42 and 1.47, and the slope is in a stable state as a whole.

In the middle part of the slope, filling and tamping the lime soil at 3:7, which acts as a water barrier. The compacting degree should be controlled above 0.93. The slope is good for drainage, and closely connected with the intercepting ditch, drainage ditch and rapids.

4. Conclusion

Due to the complicated engineering geological conditions and serious destructiveness, the stability of geotechnical slope has become a research hotspot. This paper firstly reviews the research status of some geotechnical slope at home and abroad and summarizes the analysis methods of geotechnical slope stability. Then, the basic characteristics of the slope are analyzed and the stability of the slope is checked. Finally, according to the actual situation, the slope treatment scheme is proposed. The research results of this paper can further deepen the understanding of geotechnical slope and provide an important reference for how to carry out slope treatment and strengthen slope stability.

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