Research on Application of Lattice Anchor System Design and Construction Monitoring in Slope Protection

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Abstract. This article focuses on the application of lattice anchor system in high slope protection. According to the engineering geological characteristics of the slope of the site, combined with the requirements of the layout of the slope of the site, the slope is permanently supported by the combined support system of lattice anchor rods, nets, and soil spray. The example takes the slope under the arc failure mode as the research object to carry out the parameter design calculation, and conducts real-time monitoring during and after the construction. Calculation and monitoring analysis show that it is feasible for concrete lattice anchor system to be used in slope reinforcement projects, and the stable bearing capacity of lattice anchor system is higher, which has higher construction safety and better effect.

Keywords: Slope, Lattice anchor, Design calculation, Construction monitoring.

1. Introduction
In the construction of modern cities and towns, whether it is construction engineering, municipal engineering, or road and bridge engineering, high slope protection is often involved. The effect of the protection construction is related to the construction quality and safety. If the high slope protection technology is not properly applied, it will increase the probability of landslides and collapses of large and high slopes. The economic and property losses caused by landslide disasters are no less than earthquakes and other natural disasters. According to literature surveys, landslide disasters occur every year and seriously affect people’s lives and property safety [1]. Therefore, in the construction of engineering projects, technicians need to carry out scientific design and construction monitoring of slope support technology according to the actual situation of the project, to improve the effect of slope protection and ensure the stability of the slope. However, the engineering and technical issues and geological issues involved in landslides are more complex, especially the prevention and treatment of high and steep slopes that have received extensive attention from the engineering community [2]. Han Dongdong etal, studied the anti-sliding effect of lattice prestressed anchor rods on landslides and the force and deformation laws of anchor rods through large-scale physical model tests [3].
To ensure the safety of the slope and its environment, appropriate support, reinforcement and protection measures shall be taken for the slope. With the development of times and continuous improvement and innovation, the slope support technology is changing with each passing day. At present, the commonly used support structure types in the engineering community are: gravity retaining wall, buttress retaining wall, cantilever support, lattice beam anchor retaining wall support, row pile anchor retaining wall support, anchor shotcrete support, slope rate method, etc. Among them, the reinforcement technology of the lattice beam anchor rod retaining wall has the advantages of flexible layout, various forms, easy adjustment of the cross-sectional structure, and the lattice structure can be used for hanging nets, spraying concrete, planting grass, and beautifying the environment [4]. At the same time, the reinforcement technology has low cost, short construction period, small slope deformation, safety and reliability, and it is widely used in the reinforcement of high slope [5]. This article mainly introduces the successful application of lattice beam anchor retaining wall in the industrial and civil construction industry, and analyzes the parameter selection and construction monitoring of lattice beam anchor support.

2. Project Overview
The project is a relocation and construction project for the management and living quarters of the urban solid waste treatment plant in Changsha City, covering an area of more than 6.9 hectares. According to the survey results, the stratum distributed in the site mainly includes artificial fill layer and Quaternary residual slope accumulation layer, and the underlying bedrock is late Yanshanian granite. Analyze the topographic and geological conditions of the site. The slope area is narrow and the height is large. The design is designed to excavate according to the graded grading method. The standard graded height is 10m. Individual sections are restricted by land use, and the single-stage slope height can exceed 10m, the slope ratio should be treated differently and reasonably set according to different land use ranges. According to the survey data, the slope stratum is generally fully to strongly weathered granite, and the overburden and fully weathered layer are thinner. The geological conditions are conducive to the stability of the slope. However, due to the large slope height, the slope stability is carried out on typical sections. Analysis shows that the bare slope is basically stable without protection, so the slope needs to be protected and reinforced. Through comparative analysis of the slope reinforcement scheme, the lattice bolt support scheme is finally used to deal with the slope.

3. Slope design calculation
Traditional slope stability analysis methods mostly use safety factor methods, such as Fellenius method, Bishop Method, Jan-bu method, Mideastern-Price method, and Spencer method. These methods are widely used in side slope due to their simple and intuitive calculation Evaluation of slope stability. However, the safety factor method does not consider many uncertain factors that actually exist in the rock and soil mass, so that slopes with the same safety factor have different failure risk levels due to the variability of the calculated parameterst [6].

The slope protection project is based on the principle of "safety and economy" to ensure that the proposed structure meets the slope stability requirements under certain conditions, while at the same time achieving the objectives of economy and reasonableness and strong construction operability. Due to the limitation of the scope of land acquisition for this project, there are basically no conditions for gentle slope excavation near the ground line, and only the slope surface can be reinforced. According to the relevant parameters such as the site stratum conditions, slope excavation and backfill height, rock and soil physical and mechanical indicators, the design calculation of this project selects a typical profile, and after excavation is in place according to the designed slope, the exposed slope is analyzed without protective measures. Stable conditions, and judge whether protective measures need to be taken according to the stable conditions, and provide a basis for engineering design. The slope stability calculation uses Beijing Lizheng Geotechnical Software, the calculation module selects the complex soil slope stability calculation, and the calculation method uses the Arc Slip method.
3.1. Geotechnical engineering characteristic index

According to the survey results, the stratum distributed in the site mainly includes artificial fill layer and Quaternary residual slope accumulation layer, and the underlying bedrock is late Yanshanian granite. The engineering characteristic indexes of the geotechnical layer are shown in the table.

| Stratum         | Characteristic value of bearing capacity fak (kPa) | Compression modulus Es (MPa) | Shear strength Natural severity γ (kN/m³) | Standard value of ultimate bond strength between soil and anchor frbk (kPa) |
|-----------------|--------------------------------------------------|-------------------------------|------------------------------------------|-------------------------------------------------|
| Artificial fill | 60                                               | 2.5                           | 10                                       | 18.5                                            |
| Planting soil   | 60                                               | 2.5                           | 10                                       | 18.5                                            |
| Silty sandy clay| 80                                               | 3.0                           | 10                                       | 18.0                                            |
| Sandy clay      | 180                                              | 6.5                           | 18                                       | 19.0                                            |
| Fully weathered granite | 350 | 9.0 | 22 | 20.1 | 80 |
| Strongly weathered granite | 600 | 50 | 26 | 23.0 | 300 |
| Moderately Weathered Granite  | 3600 | / | 33 | 24.0 | 1200 |

3.2. Lattice anchor

The lattice anchor rod is composed of lattice beams and anchor rods. The lattice size of the lattice beams in this design is 3m × 3m (middle to middle), the beam section size is 0.4m × 0.3m (width × height), and C30 concrete is used for pouring. A bolt is set at the intersection, and the bolt parameters need to be determined according to calculation.

1) Calculation of the standard value of the remaining sliding force of the slope and the horizontal tension of the anchor rod

The stability and remaining sliding force of the slope after excavation are calculated as the design load parameters of the anchor structure. In this calculation, the left side slope of road K0+160 is selected for calculation, and the calculated remaining sliding force is 155KN/m. Considering the average inclination of the most dangerous sliding surface at the anchor rod at 33°, the anchor rod level can be obtained. The standard value of tensile force is H_α=155×cos33°=130KN/m.

2) Calculation of axial tension of anchor rod

The axial tension of the anchor rod, that is, the anchoring force of the anchor rod, is calculated to distribute the remaining sliding force to the tension value that each anchor rod must bear. The magnitude of the axial tension determines the diameter of the anchor rod reinforcement. The axial tension of a single anchor rod can be determined according to the following formula:
\[ N_{ak} = \frac{H_{ak}}{\cos \alpha} \]

In the formula: \( N_{ak} \) — corresponding to the axial tension of the anchor rod when the standard combination of action (KN); 
\( H_{ak} \) — standard value of anchor rod horizontal tension (KN); 
\( \alpha \) — Anchor rod inclination angle (°).

This calculation is based on the arrangement of anchor rods on the left side slope of road K0+160 and the most dangerous sliding surface determined by the slope stability analysis of this section. It can be known that the most dangerous sliding surface and the slope are included. Total 5 rows of anchor rods are designed vertically, and the lateral spacing is 4.24m. The standard value of the horizontal tension distributed to each anchor rod is \( 130 \times 4.24/5 = 110.24 \) KN, and then the axial tension of each bolt is \( N_{ak} = 110.24 / \cos 15^\circ = 113.65 \) KN.

3) Calculation of the cross-sectional area of anchor rod reinforcement

The cross-sectional area of anchor rod steel bars is calculated as follows:

\[ A_S \geq \frac{K_b N_{ak}}{f_y} \]

In the formula: 
\( A_S \) — Anchor bar cross-sectional area (m²); 
\( K_b \) — the tensile safety factor of the anchor rod body, take \( K_b = 2.2 \); 
\( f_y \) — the design value of the tensile strength of the bolt, grade three steel \( f_y = 360 \) MPa.

Calculated: \( A_S = 694.53 \) mm², converted into a steel bar diameter of 29.7mm, considering the corrosion of the steel bar, the final diameter of the anchor rod is 32mm.

4) Calculation of anchorage length and stratum anchorage length

The borehole diameter of the full-length bonded non-prestressed bolt is generally larger than the diameter of the rod body by 50mm. In order to enhance the bonding force between the anchor solid and the ground, the planned borehole diameter for this project is 110mm, and the rod body is filled with M30 cement mortar. The length of the anchoring section of the anchor rod can be calculated as follows:

\[ l_a \geq \frac{KN_{ak}}{\pi D f_{b,k}} \]

In the formula: 
\( l_a \) — the length of anchor rod anchoring section (m); 
\( K \) — safety factor, take \( K = 2.6 \); 
\( N_{ak} \) — Axial tension of single anchor rod (KN); 
\( \pi \) — 3.14; 
\( D \) — Anchor solid diameter (m); 
\( f_{b,k} \) — standard value of bond strength between anchor solid and rock-soil layer (kPa), take the strongly weathered layer \( f_{b,k} = 300 \) kPa.

Calculate: \( l_a = 2.85 \) m, take \( l_a = 3 \) m. That is, the length of the anchoring section of the bolt should pass through the sliding surface and enter the strongly weathered layer not less than 3m.

The total length of anchor rod = free section + anchored section + outer anchor section. Due to the different scales of the most dangerous sliding surface of different sections, the length of the free section of the anchor rod is different. In order to facilitate the design and calculation of the engineering quantity, this design finally determines the anchor rod parameters as follows:

1) Anchor rod for soil and fully weathered rock: The length of the anchor rod is 15m, the rod body is made of HRB400 steel bar, and the diameter of the steel bar is 32mm. When the length of the anchor rod is set to 15m, the rod bodies have passed through the most dangerous sliding surface and entered the strongly weathered layer not less than 3m.

2) Anchor rod in strong and moderately weathered rock: The length of the anchor rod is 10m, the rod body is made of HRB400 steel bar, and the steel bar diameter is 32mm.
In order to minimize the damage to the environment due to excavation, and reduce the erosion and erosion of rainwater on the slope, the slope protection is carried out in the lattice structure by the method of spraying with the net and the soil.

![Lattice bolt support design drawing](image)

**Figure 2.** Lattice bolt support design drawing

4. Slope construction monitoring
In order to ensure the safety of a certain slope during the construction period and determine its stable state, while verifying the design, the deformation monitoring during the construction process and the deformation monitoring are carried out to achieve information construction to reduce unnecessary losses. There are many monitoring methods for slopes. Non-contact measurement technology can achieve high efficiency, automation, and dynamic detection, but its monitoring accuracy is low. In traditional monitoring methods, GPS measurement, total station measurement, leveling measurement, tilt measurement, and displacement meter measurement have low efficiency, but high accuracy [7-10]. According to the characteristics of this project, traditional monitoring methods are selected. Slope monitoring mainly includes displacement monitoring, manual patrol, and crack observation. Through the monitoring of slope deformation, the depth of the sliding surface, the sliding range and its deformation development trend of the slope are judged, and the stability of the slope itself and the surrounding area of the excavation construction are evaluated. Provide early warning information on the impact of structures.

4.1. Measuring point layout
The slope safety level of this project is level 1, and the slope safety monitoring shall be carried out according to relevant regulations. Set up monitoring sections and monitoring points for slopes according to sections. At least 3 monitoring sections are arranged for the first-level slopes. The main monitoring content of each monitoring section is displacement monitoring. Displacement monitoring points are set up on the top of the slope, and each monitoring section is no less than 1 Monitoring points. This time, the safety monitoring of K0+000~K0+195 slopes was mainly carried out. A total of 4 reference points and 18 displacement monitoring points were arranged. The measuring point layout is shown in the figure.
4.2. Monitoring results

(1) Horizontal and vertical displacement monitoring of slope: The change curve of displacement with time is shown in Figure 4～Figure 7

![Figure 3](image)

**Figure 3.** Schematic diagram of the position of K0+000～K0+195 slope monitoring points

![Figure 4](image)

**Figure 4.** K0+044～K0+141 Slope monitoring point free surface direction displacement $\Delta s$ change curve with time

![Figure 5](image)

**Figure 5.** K0+141～K0+195 Slope monitoring point free surface direction displacement $\Delta s$ change curve with time
According to the Technical Code for Building Slope Engineering [11], the horizontal displacement limit warning value is 20mm. From the first observation to the last observation, the maximum cumulative displacement of the free surface at K0+000~K0+195 slope monitoring point is -17mm at the 10th measuring point, that is, the slope is forward tilted 17mm, not exceeding the warning value. The maximum cumulative vertical displacement is -18mm at the No. 4 measuring point, that is, the slope sinks 18mm, which does not exceed the warning value.

It can be seen from the cumulative displacement-time curve of each monitoring point of the slope of K0+000~K0+195 that: the cumulative displacement-time curve of the monitoring point is in a sawtooth shape, and the fluctuation of individual measuring points is large because of the influence of rainy weather. Instrument observation accuracy. The change of the displacement in the direction of the empty surface is generally forward, and the change of the displacement has no obvious increasing trend and is gradually stable; the change of the vertical displacement is gentle, and there is no obvious increasing trend, and it is basically stable.

(2) The results of manual patrol and crack observation during the monitoring and measurement process show that there is no obvious cracking on the slope surface, there is no heavy load and debris around the slope, and the protection of the measuring points is good. The slope is in a safe state during construction.

5. Summary
Based on the characteristics of both deep reinforcement of the concrete lattice anchor system and shallow protection of the slope, the slope reliability analysis under the arc failure mode is used to design and calculate the force of the lattice anchor and the selection of anchor system parameters. On-site inspection and instrument monitoring are used to monitor the three indicators of horizontal displacement, vertical displacement and surface cracks. Practice has proved that the concrete lattice anchoring system is feasible and has achieved good results in slope reinforcement projects. The research results can
provide a basis for the selection of slope design and construction monitoring projects, and provide reference and reference for future similar engineering research.

Acknowledgments
Foundation items: Natural Science Foundation of Hunan (No. 2019JJ50030); Science and Technology Innovation Project of Yiyang City (No. 2019YR02)

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