Study on the Application Technique of Vertical Pre-stressed Anchor Retaining Earth Wall in Landslide Field

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Abstract: Based on the landslide treatment project of the highway in Tai-hang mountain region, the mechanism of one particular small sliding slope has been analyzed. By using the methods of engineering geophysical prospecting and geological prospecting, it has been confirmed that the landslide is a traction-extended shallow gravel landslide. Due to the principle of minimum cost and operational, the pre-stressed anchor retaining wall has been proposed to treat this kind of land sliding. The pre-stressed anchor in the basement could have the slope sliding force been balanced, which it would significantly reduce the working amount. Also, it could cost much less than other options. The design thought has been analysed in the paper, along with the introduction of the construction key points and techniques. Affection of the treatment turned out well, which indicates that it is a good example for treating similar geological disasters.

1. Introduction
The stability of slopes in the mountainous area has been broken because of the construction of highway. Geological disasters such as landslide, collapse, crumbling and distortion have occurred. As one of the main path for transport the coal out the Shanxi province, the Fu-chang highway is pretty important. The path from Yinchaoshi to Changchengling is only 11.0 km long, but the differential altitude above sea is 575 m from 950 m to 1525 m. The geomorphic is ladder-like along with the slope ratio larger than 25°. The ridges are mostly pointed and dome-shaped, and the height difference from the top of the mountain to the slope is more than 300m. There are a total of 11 landslides within the road, where collapse and crumbling are everywhere along both side of the road. Those disasters mainly occurred in rainy season, and caused much worse damage. Due to the land-sliding and collapse, the highway has been blocked for over 20 days from June to August in 2000, and that cost millions of Yuan. Those disasters not only interfered the traffic but also been a threat to people passing through [1].

One particular landslide named No.3 has been analyzed, and the development mechanism of the landslide has been studied by comprehensive exploration methods such as engineering geophysical prospecting, geological prospecting. The vertical pre-stressed anchor retaining wall has been proposed as the treatment to the landslide. Also, the design thought and construction key points has been introduced in the following paper.

2. Landslide type and stability analysis
The mass can be divided to three different layers of materials from the top to the bottom, which are cohesion-less soil and soil aggregate, clod structure main bottom (migmatization plagiogneiss, biotite, diabase, and quartz reef and granite pegmatite), and block structure rocks, respectively.

2.1 Mechanism of landslide
Common sense has told that if the slope is covered with trees and plants and is not broken, it could remain stable for a long time not to slide. On the contrary, the rocks may lose their support on the steeper slope from the excavation. Moreover, soils and rocks may aggregate to plastic state under the rain, which could reduce the friction angle, then cause the landslide [2, 3]. However, this kind of sliding only took place on the front edge for a small movement instead of the whole part at the initial step. But the sliding on the front edge would cause the vacancy around, which could cause another round of sliding. Multiple layers of slide overlaid together could lead to a larger slide and caused chain reaction to the whole slope to slide (Fig.1). So the forming and developing procedure of landslide is a progress from minimum to maximum. Moreover, the pattern of slide is tract-extension, i.e. under the traction from the front edge, the whole part became unstable and new slide occurs to form a series of tensile fractures, which can be summed up as follows: the leading edge slides → the trailing edge and circumference free → the trailing edge and circumference die away → the trailing edge and circumference generate → the new trailing edge and circumference generated die away for the sliding → the trailing edge and circumference generate → the new trailing edge and circumference generated die away for the sliding → the trailing edge and circumference generate → …….

![Figure 1. Sketch map of mechanism of landslide.](image)

2.2 Type and stability of landslide
This landslide is a small shallow layer crushed stone slide, whose volume is about 2210 m³. And the volume is predicted to increase to the outside. This is an unstable landslide drawing from the geomorphologic guide and geological sign, and it is still enlarging and need to be monitored.

3. Design of vertical pre-stressed anchor retaining earth wall
The vertical pre-stressed anchor retaining wall is a retaining wall which anchored in the foundation and placed inside the wall, impressing the wall by elastic recovery and balancing the sliding force of slide mass. This will decrease the weight, and reduce the cost of the wall by decreasing the masonry work.

3.1 Calculation for downslide thrusting force
The downslide thrusting force is shown in Fig. 2.
Figure 2. The force of vertical pre-stressed anchor retaining wall.

\[ T = K W \sin \alpha - W \cos \tan \varphi - c L \]  

Where:
- \( T \) — the downslide thrusting force (kN);
- \( K \) — safety coefficient, make it 1.1;
- \( W \) — the weight of landslide mass (kN);
- \( \alpha \) — angle between sliding surface and horizontal;
- \( \varphi \) — internal friction angle of the slide mass;
- \( c \) — cohesion of sliding surface (kPa);
- \( L \) — length of slide surface with the upper slide mass.

Earth press of soil aggregate applied on the retaining earth wall as triangular distribution and the resultant force applied the contact surface between the earth and wall along the sliding surface [4, 5].

3.2 Calculation of vertical pre-stressed anchor retaining earth wall

3.2.1 The effective tensile force of single anchor

The effective tensile force of single anchor is this:

\[ N_b = N_i - N_e \]  

where:
- \( N_b \) — control tensile force of anchor (kN);
- \( N_e \) — lose prestress value of anchor (kN).

3.2.2 Weight of the wall

\[ G = \gamma_w V_w = \gamma_w S_w L_z \]  

3.2.3 The friction force

The effective stretching force of single anchor is checked and the anchors are set in a row, whose amount is \( n \), so the friction force of base of foundation acted by downslide thrusting force is:

\[ F = Nf = (G + nN_b) \]  

3.2.4 The stability coefficient

The stability against sliding and stability against over turning of the wall should be meet together and make the stability coefficient against sliding \( K_{s} \geq 1.3 \) and the stability coefficient against overturning \( K_{s} \geq 1.5 \), so the minimum anchor amount can be calculated: \( n_1 \) by \( K_{s} \geq 1.3 \) and \( n_2 \) by \( K_{s} \geq 1.5 \) and make \( n = \max\{n_1, n_2\} \) according to the design requirement.
3.2.5 Effective length calculate of the anchor

\[ L_e = \frac{KP}{\pi D \tau} \]  

(5)

Where:  
- \( K \)—safety coefficient of stratum and operating condition, make \( K = 3.0 \);  
- \( P \)—maximum pull-out capacity of the anchor (kN);  
- \( D \)—diameter of anchor, make \( D = 0.09 \text{m} \);  
- \( \tau \) — mean shearing strength between circumferential mortar and hole wall of anchoring section, make \( \tau = 350 \text{kPa} \).

3.2.6 Designing

The designing should be done according the calculate result. The stability against sliding and overturning meets the code together.

4. Construct technology of vertical pre-stressed anchor retaining wall

4.1 Construct Process

The construct process is shown in Fig. 3.

4.2 Construct outline of vertical pre-stressed Retaining wall

4.2.1 Setting out and excavation

Before the excavation, slope surface should be cleared and dangerous rocks should be proceeded to ensure the work is operating in a safe condition. Excavation should be done by step from the design results, the depth and width should not less than expected. Also, the bottom surface must be proceeded to be flat. The size and position of base, drilling positions should be determined based on the excavation condition.

4.2.2 Disposal and strengthening of anchor

The anchor should be made using the \( \phi 32 \text{ mm} \) hot rolled twisted steel bar, and the length should be manufactured on site. The depth should be no less than 95% of the design value. Meanwhile, a supporting system frame should be set every 2 to 4 m. No knock or other interferences is needed. For the
joints, they should be proceed by butt welding, groove welding or lap welding and antiseptic treatment should be done by cement paste.

4.2.3 Forming hole
The hole should be done by one time pneumatic impact drilling method and the diameter of the hole is 90 mm.

4.2.4 Injection
The injection material should be cement paste with the ratio of water-cement 0.4 to 0.5. The strength of 28 d should be larger than 20MPa. The time of mixing should be more than 2 min and proceed with mixing in progress and done before the initial setting. In order to improve the hardenability of the cement, slurry has been added into the mixture to accelerate the solidification and induration. The cement paste was pumped into the drilling hole, with the pressure between 0.1MPa and 1.0MPa. The pipe should be at least 1.5 m higher than the bottom and keep rising until the work is done.

4.2.5 Constructing the foundation and body of retaining wall
Before the foundation of the retaining wall is fixed, the weathered rock and gravel on the surface of the foundation should be cleaned, and then the foundation is laid with mortar. After the foundation is ready, it should be filled and tamped. After that, top drainage and seepage prevention facilities should be done in the next step. Drilling holes should be protected carefully without letting any stone chips or sediment fell into those holes. The anchor should be added by special connectors. The material of the retaining wall should be un-weathered gneiss which strength is larger than 40MPa. And thickness should be larger than 200mm; length of side should be more than 400mm; and the cement should be M12.5. The filling of backfill should be filled and compacted during construction.

4.2.6 Stretching and anchoring
The pre-stressed anchor makes use of one time stretching method. When the wall finished and mortar strength is more than 80% of design, stretching can be done.

5. Conclusions
Effective and economical sliding disposal method is adopted to prevent the infection of landslide, which is important for economic and social. On the one hand, the pre-stress can be used to resist the downslide force instead of weight. On the other hand, the holism of vertical pre-stressed retaining wall is guaranteed to prevent sliding. So the vertical pre-stressed retaining wall has a bright future.

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