Study on Treatment Technology of Rock Slope Landslide of an Expressway in Guizhou

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Abstract. A highway deep cutting slope is in Guizhou province, with a total length of about 258m and a maximum excavation height of 49.96m. After continuous heavy rainfall, groundwater seeped out on the slope, and cracks appeared. Based on calculation and engineering experience, the slope was reinforced by anchor ropes and anti-slide piles. After the treatment, the deformation of the slope was monitored by GNSS displacement monitors, and the results of displacement monitoring show that the three monitoring points No.1, No.2 and No.3 are relatively stable, and the daily accumulated horizontal displacement of monitoring point No.4 is relatively large, reaching 400mm on March 17th, but the change rate of displacement tends to slow down gradually.

1. Project Overview

The deep cutting slope is located in an expressway in Guizhou Province, with a total length of about 258m and a maximum excavation height of 49.96m. The original design scheme of the slope in this section is five-stage grading, and the slope ratios are 1: 0.5 for the first grade, 1: 0.75 for the second to fourth grades, and 1: 1 for the fifth grade respectively. A 2m wide platform is set between each grade, and shrubs are used for slope protection and greening. The slope began to be excavated in October 2018, and reached the first grade slope in May 2019. On June 12th, 2019, cracks began to appear at the top of the slope, and the slope was stable after being cleared. After the rainy season in June 2019, it often rains in the survey area; On September 11, 2019, continuous heavy rainfall began, groundwater seeped out on the slope, and cracks appeared on September 17, 2019, with a width of about 20cm; On September 21st, cracks appeared, with a width of about 1m, extending obliquely from the first grade to the fourth grade slope. On October 12th, the slope began to collapse along the crack. Using anti-slide piles to treat rock slope landslides is a relatively mature technology [1-5]. The pile number of the section where the landslide collapsed is ZK214+435 ~ ZK214+641, which is about 206 meters long. The area of the landslide body is about 7663m², and the volume is about 104024 m³. See Figure 1 for its location.
According to the field geological survey, the site is located in the northeast wing of Jingshan Park anticline, and the underlying bedrock is mainly dolomitic limestone mixed with mudstone and marl in the second member of Middle Triassic Guanling Formation (T2g2). According to the outcrop measurement of nearby bedrock, the occurrence of rock strata in the site is $63^\circ \sim 92^\circ \angle 9^\circ \sim 16^\circ$, the dominant occurrence is $71^\circ \angle 14^\circ$, and two groups of joints and fissures are mainly developed, and the dominant occurrence is $J1: 332^\circ \angle 84^\circ, J2: 40^\circ \angle 86^\circ$ respectively. The weak interlayer of moderately weathered mudstone is exposed from the foot of the slope to the platform of the first grade slope, and the exposed thickness of drilling is $0.4 \sim 0.9$ m (Figure 2). Under the action of groundwater, mudstone is under the alternating action of water saturation and drying for a long time, and its quality is soft and near-soil (Figure 3).

![Figure 1. Overall view of deep cutting.](image1)

![Figure 2. Landslide range (red line) and distribution of mudstone weak interlayer (blue line).](image2)

![Figure 3. Weak mudstone interlayer.](image3)
The left side slope of ZK 214+360 ~ ZK 214+690 is bedding slope, but the dip angle of strata is 14°, which is generally slow. Mudstone weak interlayer is distributed in the lower part of the slope, which has poor water permeability and water-proof property. Groundwater is easy to collect runoff in the contact zone between mudstone and dolomitic limestone, which makes mudstone saturated and softened, and it is the material basis of landslide. The lithology of this area is dolomitic limestone, and karst depressions, pipelines and vertical cracks on the surface are extremely developed, which creates favorable conditions for surface water infiltration. Continuous heavy rainfall occurred locally before the slope landslide, and rainfall infiltration was the direct cause of the landslide. The site is located in the northeast wing of Jingshan Park anticline, which is monoclinic in general. However, local small structures are well developed and there are many vertical cracks. To some extent, the excavation and construction disturbance of the slope objectively aggravate the cracking of the vertical cracks of the slope, leading to the gradual deformation and failure mode of the slope from bottom to top.

2. Treatment Plan
According to the field survey and geological mapping, the potential sliding area is in a stable state in the natural state after the landslide is cleared, and it is basically stable in the case of heavy rain or continuous heavy rain, so it is necessary to reinforce the slope. See the following Table 1 for calculation parameters.

| Location                              | Natural         | Saturation       |
|---------------------------------------|-----------------|------------------|
|                                       | c (kPa) | φ (°) | c (kPa) | φ (°) |
| Landslide zone                        | 18.10   | 9.30  | 15.20   | 10.50 |
| Weak interlayer in potential sliding zone | 17.50   | 12.40 | 15.20   | 10.50 |
| Fracture surface                      | 50      | 18    | 40      | 16    |

According to the calculation results, analyze and evaluate the stability of the slope (without considering the landslide). Referring to the relevant specifications, the classification criteria of the slope stability state are as follows (Table 2): the stability factor \( F \geq F_{st} \) is stable, \( F_{st} > F \geq 1.05 \) is basically stable, \( 1.05 > F > 1.0 \) is under stable and \( F < 1.0 \) is unstable, among which \( F_{st} \) is the safety factor of slope stability, which is 1.25 under normal working conditions (working conditions 1) and 1.25 under abnormal working conditions (working conditions 2).

| Stake         | Part number | Stability factor | Safety factor | Stability         | Remaining sliding force (kN) |
|---------------|-------------|-----------------|---------------|-------------------|-----------------------------|
| K214+480      | 1           | 1.293           | 1.25          | Stable            | 0                           |
|               | 2           | 1.094           | 1.15          | Basically stable  | 2016                        |
| K214+540      | 1           | 1.310           | 1.25          | Stable            | 0                           |
|               | 2           | 1.108           | 1.15          | Basically stable  | 1297                        |
| K214+590      | 1           | 1.347           | 1.25          | Stable            | 0                           |
|               | 2           | 1.139           | 1.15          | Basically stable  | 621                         |

According to the sliding force of each typical section, the treatment scheme of each section is determined as follows.

ZK214+480 calculated section: the designed residual sliding force is 2016 KN/m. According to the checking calculation, the anti-slide pile with a pile diameter of 2×3m provides a resistance of 1600KN/m, and the pile spacing is 6m. The anchor cable beam provides the remaining resistance of
416 KN/m, and is designed with 7 bundles of anchor cables. The anti-sliding force of anchor cables for each hole is 750KN/m, and the anti-sliding force of anchor cables along the layer is 636 kN/m. Two rows of anchor cables are arranged on the second grade slope at the top of the anti-sliding pile, with a longitudinal spacing of 3m. Because the rock mass in this section is relatively complete, only the anchor cable longitudinal beam is set.

ZK214+540 calculated section: the designed residual sliding force is 1,297 KN/m. According to the checking calculation, the anti-slide pile with a pile diameter of 1.8×2.4m provides a resistance of 1,000 KN/m, and the pile spacing is 6 m. The anchor cable beam provides the remaining resistance of 297 KN/m, and is designed with 7 bundles of anchor cables. The anti-sliding force of anchor cables for each hole is 750KN/m, and the anti-sliding force of anchor cables along the layer is 636 KN/m. Two rows of anchor cables are arranged on the first grade slope of the anti-sliding pile top, with a longitudinal spacing of 4m. Because the rock mass in this section is relatively complete, only the anchor cable longitudinal beam is set.

ZK214+590 calculated section: the designed residual sliding force is 621 KN/m. According to the checking calculation, the anti-slide pile with a pile diameter of 1.8×2.4m provides a resistance of 1,000 KN/m, and the pile spacing is 6 m. From ZK214+590-ZK214+690 section, the anchor cable frame beam is used for protection, and the design of 7 bundles of anchor cables is adopted. The anti-sliding force of anchor cables for each hole is 750KN/m, and the anti-sliding force of anchor cables along the layer is 636KN/m. Three rows of anchor cables are arranged on the slope, with a longitudinal spacing of 3.5m.

According to the sliding force, the diameter of anti-slide pile, the number of anchor cables and the longitudinal spacing should be properly transitioned between sections.

ZK214+420-590: Clear the landslide body and part of the rear edge mountain body, and set up anti-slide piles along the cracks in the rear edge of the landslide body. The 2nd or 1st grade slope of the anti-slide pile top is protected by anchor cable, the 2nd grade slope platform of the pile top is 10m wide, the 3rd grade slope of the pile top is protected by anchor frame beam, and the boulder at the rear edge of the slope is protected by point anchor, the slope in front of the anti-slide pile is protected by shrub slope protection greening (hanging net), and other slopes (between anti-slide piles) are protected by SNS active protection net. In order to ensure the effect of slope greening, vines are planted along all levels of slope platforms for greening. Inclined drainage holes are arranged along individual sections where weak interlayer is exposed.

3. Stability Monitoring
To ensure the safety early warning in the front yard of landslide treatment and the construction safety in the process of landslide treatment, the slope deformation and anchor stress are monitored, and the scheme is as follows (Figure 4):

1) Surface deformation monitoring. According to the stability analysis of the slope behind the landslide, four Beidou GNSS monitoring points are arranged on the surface to monitor the horizontal and vertical deformation of the surface water, which has been monitored all the time.

2) Deep displacement monitoring. Combined with geological prospecting borehole, inclinometer pipe is installed in SLZK442 borehole to monitor the deep displacement, which has been completed and monitored at present.

3) Anchor cable stress monitoring. Anchor cable protection is an important slope protection measure, and anchor cable stress monitoring should be carried out during construction to ensure the actual protection effect of anchor cable.
Figure 4. Location of surface displacement monitoring points.

Figure 5. Horizontal displacement of Beidou GNSS monitoring point on the surface.
The results of displacement monitoring show that the three monitoring points No.1, No.2 and No.3 are relatively stable, and the daily accumulated horizontal displacement of monitoring point No.4 is relatively large, reaching 400mm on March 17th, but the change rate of displacement tends to slow down gradually (Figure 5, Figure 6).

**References**

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