Slope Stabilization Using Back-analysis Method

Guozhou Chen¹, Chuanjin Li² and Qingjun Fang¹

¹ College of Civil Engineering, Fujian University of Technology, Fuzhou, Fujian, 350118, China;
² Fujian-Taiwan Cooperative Institute of Civil Engineering Technology in Universities of Fujian Province, Fujian University of Technology, Fuzhou, Fujian, 350118, China;
*Corresponding author’s e-mail: blackchenzhou@163.com

Abstract. This paper presents a case study of slope stabilization in a constructing highway through Henan Province in China. The geology and stability back-analysis of the landslide are introduced. The more representative values of regional shear strength parameters are received from back-analysis. A solution is recommended to stabilize a 45 m high slope. This solution is to use the retaining system combining compression anchor and reinforced concrete beam. The lengths of anchors vary from 20 m to 33 m. The stability analysis of this reinforced slope is also presented. 12 monitors are installed in order to record the axial load change. Based on record data, the effect of the anchors is analyzed.

1. Introduction
Ground anchors, also referred to tiebacks have become increasingly popular choices for permanent slope reinforcement because of less cost and shorter construction period (e.g., Weatherby 1982, Moerman 2005). Azm (1997) made back-analysis for a highway embankment landslide and evaluated the stability of the adjacent slope in Jordan. Zhu Weishen (2001) analyzed the effects of bolt reinforcement on the character of jointed rock masses in the high slope of the Three Gorges flight lock in China by modeling tests. Akgun (2004) introduced the design of anchorage and assessment of the stability of openings in Turkey. In Johnson’s report (2003), four recent case histories in which anchor loads were monitored for 1 to 5 years after construction were reviewed and analyzed to assess the influence of various design parameters on system performance. Many new types of anchors have been applied in practical projects worldwide such as compression anchor (e.g., A D BARLEY 1995, Cheng 2001 and Chen 2018).

This paper presents a case study of rock slope reinforcement in K40+280-K40+420 of WanPing Highway through the southern Henan Province in China. The slope is 45 m in height and 140 m in length. The solution to stabilize the slope is to use the retaining system combining compression anchor and concrete beam. 12 monitors are installed in order to record the anchor load versus time.

2. Geology
The top 2-5 m soil layer is consisted of loose sand or medium sand silt, followed by decomposed shales and sandstones. The angle between rock strike and road direction is 14°. The rock dip angle is 25°. These rocks are weak to moderately weak. The shear strength parameters of the rock in the area has been determined by sampling analysis as follows: internal friction angle $\varphi$=18°, cohesion $c$=22.5 kPa. However this determination method is associated with uncertainties due to the problems related to sampling technique and laboratory testing.
Four landslides occur on this highway during cutting slope. The field picture of a representative landslide is shown in Figure 1.

Analysis shows that the main causes of these landslides include excessive excavation of the slope, lack of reinforcements in time, the ingress of water into the slope, and the underlying shale material, resulting in its softening.

3. Stability back-analysis

Determining soil strength by back analysis in connection with landslide can avoid many of the problems associated with sampling and laboratory testing, so a parametric slope stability back analysis is carried out in order to determine the more representative values of regional shear strength parameters.

The landslide occupied the northern slope from K40+880 to K40+980 is taken to be the back-analysis model. This landslide runs approximately north-south. The ground movement may be defined as two-planar landslide, where the higher parts have moved outwards about 6 m. The precise location of the failure face cannot be absolutely identified, but the available site picture of the landslide presents the approximate position of the failure face (see Figure 2). In two-dimensional analysis model, failure surface of the landslide could be simplified as a sliding "Block".

The computer program Geo-slope is utilized to perform back analysis. In the back analysis, Modified Janbu limiting state equilibrium method is used to calculate the stability factor of slope. The analysis model is shown as Figure 3.
Figure 3. Analysis model of landslide

Shear strength parameters are divided by a number in order to bring the slope to the point of failure. This number means the reduction magnitude of shear strength due to rain infiltration. When the stability factor is equal to 1, it is assumed that shear strength parameters could assess the condition at the time of failure.

The factored shear strength parameters are therefore given by:

\[ c_f = c \times f_d \]  \hspace{1cm} (1)

\[ \phi_f = \arctan\left(\tan\phi \times \frac{f_d}{c} \right) \] \hspace{1cm} (2)

Where \( c \) is cohesion determined by sampling analysis, \( \phi \) is internal friction angle determined by sampling analysis, \( f_d \) is reduction factor, \( c_f \) is factored cohesion, \( \phi_f \) is factored internal friction angle.

| Cohesion (kPa) | Internal Friction Angle (°) | Stability Factor |
|---------------|----------------------------|-----------------|
| 22.5          | 18                         | 1.245           |
| 20.0          | 16                         | 1.078           |
| 18.5          | 15                         | 1.002           |
| 18.0          | 15                         | 0.988           |

The calculated result is shown in table 1. The result shows that the shear strength parameters of rock considering the effect of rainfall should be as follows: internal friction angle \( \phi = 15^\circ \), cohesion \( c = 18.5 \) kPa, density \( \gamma = 23 \) kN/m³.

4. Reinforced stability analysis

A 45 m high slope at K40+280-K40+420 of highway is required to be reinforced in order to ensure the safety of the road. Figure 4 shows a plan view of the site. For purposes of analyzing the anchor forces required for stabilizing this slope, the computer program Geo-slope was utilized to evaluate the stabilities of both the non-reinforced and reinforced slope.

Figure 4. Plan view of K40+280-K40+420
Based on the subsurface borings and slope inclinometer measurements, it could be assumed that the geology condition and potential failure surface of this slope are similar to landslide at K80+880-K80+980. So the shear strength parameters from back-analysis of landslide at K80+880-K80+980 are used in the stability analysis of this slope. The stability analysis model is shown in Figure 5. The stability factor of the slope without reinforced steps is 0.841, which shows that the cutting slope is unstable.

This slope is designed to be reinforced by a retaining system combines compression anchor and concrete beam. Anchor system includes 244 anchors with 4.0 m vertical spacing and 4.0 m horizontal spacing.

![Figure 5. Stability analysis model of slope](image)

The highest section is 45 m high including 11 rows of anchors. For each eight meters in height, a working bench is excavated on slope surface. In this model, each anchor is modeled as a centralized force while the concrete beams are not taken into account. The calculation result shows that the stability factor of the reinforced slope is 1.356 which satisfies the request in Chinese code.

![Figure 6. Field picture of reinforced slope](image)

The steel tendons are fully free and unbonded with the grout along the total tendon length. Bearing bodies are installed at the end of the steel tendons. So when the anchor is loaded, the load can be transferred to the bearing bodies through the steel tendons. Then the bearing bodies transfer load to soil through the grout. The stress in the grout is compression, so this type anchor is called compression anchor. Figure 6 shows the field picture of reinforced slope.

### 5. Anchor load monitor

Twelve anchors are instrumented with load cells. Load cells are placed between the anchor reaction panel (wedge plate) and bearing plate at the anchor head. Figure 7 shows a finished anchor instrumented with a load cell.
Data from load cells is recorded once daily after lock-off. It is more than 120 days from the first day to record to the present. Table 2 presents the load changes of the anchors at 40, 80 and 120 days.

Table 2. Summary of anchor Loads

| Anchor ID | Design Load (kN) | Lock-off Load (kN) | Load at Day 40 (kN) | % of DL at 40 days | Load at Day 80 (kN) | % of DL at 80 days | Load at Day 120 (kN) | % of DL at 120 days |
|-----------|------------------|--------------------|---------------------|-------------------|---------------------|-------------------|---------------------|---------------------|
| 01        | 1060             | 795                | 839                 | 79%               | 856                 | 81%               | 892                 | 84%                 |
| 02        | 1060             | 784                | 788                 | 74%               | 801                 | 76%               | 852                 | 80%                 |
| 03        | 1060             | 776                | 803                 | 76%               | 822                 | 78%               | 845                 | 80%                 |
| 04        | 1060             | 789                | 827                 | 78%               | 855                 | 81%               | 921                 | 87%                 |
| 05        | 1060             | 733                | 777                 | 73%               | 1054                | 99%               | 1086                | 102%                |
| 06        | 1060             | 802                | 778                 | 73%               | 796                 | 75%               | 674                 | 64%                 |
| 07        | 1060             | 800                | 914                 | 86%               | 939                 | 89%               | 1072                | 101%                |
| 08        | 1060             | 779                | 804                 | 76%               | 825                 | 78%               | 847                 | 80%                 |
| 09        | 1060             | 741                | 847                 | 80%               | 871                 | 82%               | 1034                | 98%                 |
| 10        | 1060             | 837                | 882                 | 83%               | 914                 | 86%               | 970                 | 92%                 |
| 11        | 1060             | 772                | 816                 | 77%               | 836                 | 79%               | 877                 | 83%                 |
| 12        | 1060             | 775                | 809                 | 76%               | 826                 | 78%               | 857                 | 81%                 |

As shown in Table 2, load of No.06 anchor decreases from 802 kN to 674 kN, but others all increases. Loads of two anchors (No.05 and No.07) exceed the design load. However, anchors are joined with reinforced concrete beams, so they could provide resistance to the landslide driving force as a whole system.

The average anchor load over the first 120 days is 86% of the design load and no anchor failure is found, which shows that the retaining system is effective for stabilizing the slope.

6. Conclusion

The conclusions of this paper can be summarized as follows:

(1) Soil strength determined by back analysis in connection with landslide is suitable for stability analysis of adjacent slope especially considering the effect of rainfall.

(2) The reinforcement system combining compression anchor and reinforced concrete beam is used to stabilize a 45 m high slope. The monitoring data show that The reinforcement system is effective.

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