Stability Analysis and Reinforcement Management of Slope

Yi Cao¹, Huaihai Li¹, Chunyu Long¹*, Guangqing Yang¹, Chuanting Zhang¹, and Dongming Peng¹

¹ China Merchants Chongqing Communications Technology Research & Designinstitute Co.,Ltd., Chongqing, 400067, China

Abstract. The sliding damage occurred on a slope site due to rainfall and other environmental conditions, and the slope stability coefficient was calculated to be 1.05 based on the numerical analysis model of the slope based on the site investigation data, which did not meet the reinforcement requirements of the code. The slope stability coefficient after reinforcement is 1.39, which is 32.4% higher than that before reinforcement, indicating that the reinforcement scheme is feasible.

1 Introduction

Slope stability analysis and reinforcement management has been a hot issue in the field of geotechnical engineering, and experts and scholars at home and abroad have done a lot of research. Zhang Wenlian et al [1] proposed a generalized Hoek-Brown criterion strength reduction method based on the compressive strength of rock mass, and verified the feasibility of the method through slope stability analysis; Zhang Ruihuan et al [2] proposed a systematic analysis method for the stability analysis of multi-level homogeneous loess slope, and verified the feasibility of the method through engineering examples; Chen Chong et al [3] proposed a composite unit anti-slip pile model and verified the feasibility of the model with engineering examples; Zhang Bangxin et al [4-6] analyzed the sensitivity relationship between geotechnical strength parameters and slope stability and the slope reinforcement effect of different anti-slip pile spacing, pile length and pile position for a landslide; Liu Zhongshuai et al [7] analyzed the slope stability of a landslide and compared the reinforcement effect of different reinforcement schemes.

As a common technical tool in the field of geotechnical engineering, numerical analysis plays an important role in the study of slope stability and reinforcement management measures[8-10]. In this paper, a numerical analysis model is constructed for a slope, and the stability of the slope before and after reinforcement is calculated and analyzed, and the feasibility of the reinforcement scheme is verified, which can provide an important reference for similar projects.

2 Project Overview

The slope is located in Longhai City, Zhangzhou City, coastal channel Zhenhai to Guantu section, the original topography of the site is hilly and gently sloping, gentle terrain, slope 8 ~ 12 °, elevation 50 ~ 109 m; annual rainfall 1050 ~ 1300 mm, the site groundwater is assigned to the miscellaneous fill, powder clay and basalt residual sandy clay and full, strong weathering rock layer in the pore-net fissure diving and assigned to the fragmented strong The scale of landslide is about 140 m long, 125 m wide, with an average thickness of 4m and a total volume of about 70,000m³. Through the observation of cracks during the survey, the cracks are gradually expanding, and the expansion is accelerated on stormy days, and the landslide is still in an active state, and the full view of the slope is shown in Fig. 1.

Fig. 1. Overall view of the slope

3 Slope stability analysis

3.1 Parameter determination and model construction

The geological structure of the main landslide surface is shown in Fig. 2, which is obtained through site investigation. The physical and mechanical parameters of each geotechnical layer measured by indoor and outdoor tests are shown in Table 1.
A two-dimensional numerical analysis model is established for the main slip surface, as shown in Fig. 3, with horizontal and vertical displacement constraints applied to the bottom surface of the model, horizontal displacement constraints applied to the left side, and the rest are free boundaries.

### Table 1. Physical and mechanical parameters

<table>
<thead>
<tr>
<th>Category</th>
<th>Severe (kN.m$^{-3}$)</th>
<th>Cohesion (kPa)</th>
<th>Friction angle ($^\circ$)</th>
<th>Modulus of elasticity (MPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding Belt Earth</td>
<td>18.2</td>
<td>6.5</td>
<td>26.7</td>
<td>19</td>
<td>0.3</td>
</tr>
<tr>
<td>Powdery clay</td>
<td>20</td>
<td>23</td>
<td>16.4</td>
<td>15</td>
<td>0.35</td>
</tr>
<tr>
<td>Mixed fill</td>
<td>18.2</td>
<td>8</td>
<td>28</td>
<td>20</td>
<td>0.17</td>
</tr>
<tr>
<td>Strongly weathered basalt</td>
<td>22</td>
<td>24</td>
<td>25</td>
<td>300</td>
<td>0.37</td>
</tr>
<tr>
<td>Mesothelial basalt</td>
<td>24</td>
<td>40</td>
<td>72</td>
<td>1500</td>
<td>0.3</td>
</tr>
<tr>
<td>Pile</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>30000</td>
<td>0.2</td>
</tr>
<tr>
<td>Anchor rods</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>200000</td>
<td>0.35</td>
</tr>
</tbody>
</table>

#### 3.2 Stability evaluation

The average stress clouds and displacement clouds of the main sliding surface of the slope were obtained by calculation as shown in Fig. 4 and Fig. 5.
From Fig. 4 and Fig. 5, it can be seen that: the average stress of the slope is mainly concentrated in the lower left corner of the slope, and the stress value in the area of medium-weathered basalt is the largest, while the stress value on the surface of the slope is the smallest; the displacement deformation of the slope is concentrated in the area of slip zone soil and the area of miscellaneous fill above it, while the displacement deformation in other areas is basically zero. Taking the step inflection point of the slope as the tracking point, the stability coefficient change curve of the slope is calculated as shown in Fig. 6.

![Fig. 6. Stability coefficient variation curve](image)

It can be seen from Fig. 6: the stability coefficient of the main sliding surface of the slope is 1.05, while the design specification requires the stability coefficient of such slopes to be 1.2~1.3 in natural condition, which obviously does not meet the specification requirements, and the slope needs to be reinforced and managed.

4 Reinforcement treatment

4.1 Governance program

After site investigation and expert evaluation, and combined with the stability coefficient of the main sliding surface of the slope before reinforcement, the slope is reinforced by "anti-slip pile support + anchor rod + drainage cut-off". There are two types of anti-slip piles, both are round anti-slip piles, the first type of anti-slip piles with 4.8m pile spacing, 21m pile length and 1.8m pile diameter; the second type of anti-slip piles with 4.8m pile spacing, 12m pile length and 1.8m pile diameter; there are also two types of anchors, the first type of anchors is 40m long, the second type of anchors is 36m long, and the angle with the horizontal plane is 38°. Rectangular intercepting ditch is set 2m outside the top of the slope with C20 plain concrete, and rectangular intercepting ditch is set on the slope platform for slope drainage. The specific layout is shown in Fig. 7. The physical and mechanical parameters of all materials in the reinforcement scheme are shown in Table 1, and the numerical model of the constructed slope reinforcement scheme is shown in Fig. 8.

![Fig. 7. Reinforcement solution](image)

![Fig. 8. Numerical model of the reinforcement scheme](image)

4.2 Governance Evaluation

The displacement cloud of the reinforced slope is calculated as shown in Fig. 9. Taking the previous tracking point as the study point, the stability coefficient of the reinforced slope is obtained as shown in Fig. 10.
From Fig. 9, it can be seen that the displacement and deformation of the slope are significantly reduced, and the displacement and deformation of the slope before reinforcement are significantly lower than those of the slope before reinforcement in Fig. 5, and the displacement and deformation around the anti-slip piles and anchor rods are significantly smaller than those of other areas, indicating that the reinforcement measures have effectively prevented the sliding damage of the slope; from Fig. 10, it can be seen that the stability coefficient of the slope after reinforcement is 1.39, which meets the reinforcement requirements in the specification and is 32.4% higher than that of 1.05 before reinforcement. It is 32.4% higher than that of 1.05 before reinforcement, which indicates that the reinforcement solution has effectively improved the stability of the slope.

5 Conclusion

(1) The stability coefficient of the slope before reinforcement is 1.05, which does not meet the specification requirements and indicates that the slope is in an unstable state.

(2) After analysis and combined with the slope stability calculation results, the reinforcement plan of "anti-slip pile support + anchor rod + drainage cut-off" was determined.

(3) After reinforcement, the stability coefficient of the slope is 32.4% higher than that before reinforcement, which meets the requirements of the code, indicating that the reinforcement plan is feasible.

(4) The research content can provide important reference for similar projects, and in order to fit the actual project, stability analysis and reinforcement management can also be carried out for slopes under different working conditions.

Acknowledgments

This work was financially supported by Chongqing Science and Technology Bureau Project (cstc2022ycjh-bgzxm0258) fund.

References