Stability Analysis of Slope in Lijiagou Village, Xingtai County, and Design of Support scheme

Zhifei Zhang a,b, Minghui Gao a,b, Xinyou Wang a,b, Guoqin Yan a, Yulong Li a,b, Yang Cui a,b, Qizhi Wang c

aHebei Key Laboratory of Geologic al Resources and Environment Monitoring and Protection, 58 Xingyuan Street, Shijiazhuang, 050021, Hebei, P.R., CHINA
bHebei Geo-Environment Monitoring, 58 Xingyuan Street, Shijiazhuang, 050021, Hebei, P.R., CHINA
cHebei University of Science and Technology, 26 Yuxiang Street, Shijiazhuang, 050018, Hebei, P.R., CHINA

Abstract: The typical part of the slope was modeled and calculated using Midas-GTS finite element analysis software based on the landslide control project in Lijiagou Village, Xingtai County. According to the results, the horizontal displacement, effective plastic zone, and safety factor of the slope under natural and rainfall conditions were analyzed respectively, to master the potential sliding surface of the landslide. Carry on the support scheme design and carry on the feasibility analysis evaluation, and finally, select the optimal scheme according to the governance effect. The findings demonstrate that the current plan can successfully increase the side support plan's design slope stability and serve as a model for projects of a similar nature.

1. INTRODUCTION

The frequency and severity of geological catastrophes have been on the rise in China in recent years, creating a significant challenge for their prevention and management [1]. The landslide, a frequent geological catastrophe, has developed into a significant issue that obstructs geological environment management and urban construction. To ensure urban safety and contain landslide disasters, it is therefore of major theoretical and practical value to research landslide stability analyses and support schemes. Correct slope stability analysis and effective landslide control measures can secure the safety of people and their property, ensure the orderly functioning of society, and foster the growth of the natural environment and the national economy. Long-term landslide hazard exists at Lijiagou Village, Xingtai County, due to poor topographic and geological conditions for stratigraphic stability. The elevation of this landslide, which ranges from 617 m at the back edge to 582 m at the front edge with a relative elevation difference of 35 m, is on the west side of the slope of Lijiagou village. The landslide's back margin is bordered by a crack at the ridge, while the front edge has a steep bedrock that has been manually excavated. The landslide is rocky and is situated next to a tiny natural ditch on the right and a ridge on the left. The slope has a stepped and changeable morphology with a lateral width of 61.67 m and a longitudinal length of 69.97 m. The slope is 96 degrees in direction and has slopes varying from 30 to 45 degrees. The slope's top portion has a thickness of 0 to 0.5 m covering Quaternary sediments, while the slope's lower portion is heavily weathered bedrock with a thickness of around 4-6 m. The landslide has a volume of roughly 21,600 m³ and is regarded as a minor landslide.

This paper focuses on the management of landslides in Lijiagou Village, Xingtai County. By reviewing various data about landslides to understand the formation mechanism and damage mode of landslide, the key parameters of the model are selected based on the indoor and outdoor geotechnical test results, and the stability of landslide in Lijiagou Village, Xingtai County is calculated, and analyzed from multiple angles by strength reduction method [2] with the help of MIDAS GTS software, and the optimal support plan is proposed.

2. CALCULATION MODEL

The key to determining the stability of a landslide in landslide stability analysis is how to select the physical parameters of geotechnical soil. The stability of the slope is influenced by the elastic modulus E, cohesive force C, and internal friction angle of the soil in the area. The specific parameters were determined based on a combination of indoor tests of slip soils taken in the borehole and the parameter inversion method (see Table 1).

The physical and mechanical parameters of each layer of soil in their natural state are displayed in Table 1 below based on the exploration report of Lijiagou village in Xingtai County and the empirical values of the study feasibility program:

* Corresponding author: 1054598806@qq.com
### Table 1. Table of soil material property parameters (kN/m/sec)

<table>
<thead>
<tr>
<th>Soil mass</th>
<th>Unit type</th>
<th>Constitutive model</th>
<th>Elastic modulus</th>
<th>Poisson’s ratio</th>
<th>Bulk density</th>
<th>Saturated bulk density</th>
<th>Void ratio</th>
<th>Cohesion</th>
<th>Internal friction angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravelly soil layer</td>
<td>2D plane strain</td>
<td>Mohr-Coulomb</td>
<td>10000</td>
<td>0.2</td>
<td>20</td>
<td>23.5</td>
<td>0.40</td>
<td>13</td>
<td>15.62</td>
</tr>
<tr>
<td>Plagioclase gneiss</td>
<td>2D plane strain</td>
<td>Mohr-Coulomb</td>
<td>200000</td>
<td>0.3</td>
<td>24.2</td>
<td>26</td>
<td>0.68</td>
<td>15</td>
<td>36.58</td>
</tr>
<tr>
<td>Bedrock</td>
<td>2D plane strain</td>
<td>Mohr-Coulomb</td>
<td>138000</td>
<td>0.37</td>
<td>26.3</td>
<td>27.5</td>
<td>0.40</td>
<td>12500</td>
<td>35.00</td>
</tr>
</tbody>
</table>

Three representative profiles (Figure 1) were chosen to create the two-dimensional landslide model in this paper, which was based on the survey report of the landslide in Lijiagou Village, Xingtai County. The safety coefficients of the landslide in various states were calculated and compared. It should be mentioned that the accuracy of the finite element software's calculation output is highly related to the suitable settings of the model parameters. As a result, the Moore-Coulomb model is utilized to explain the soil parameters in this work, whereas the elastic model is employed to describe the support structure.

Three typical profiles are selected to model the landslide, as shown in Figure 2:

![Figure 1. Engineering geological section](image)

(a)Ⅰ-Ⅰ section  (b)Ⅱ-Ⅱ section  (c) Ⅲ-Ⅲ section

![Figure 2. Profile model](image)

(a)Ⅰ-Ⅰ section  (b)Ⅱ-Ⅱ section  (c) Ⅲ-Ⅲ section

3. ANALYSIS RESULT

3.1. Results without support

The I-I profile's horizontal displacement is shown in Figures 3 and 4, respectively, for the natural state and the rainy state. The research reveals that the landslide has a distinct deformation trend along the boundary between the two layers of diagonal gneiss and gravel soil and that the displacement value near the slope's base is substantially higher and less stable. In addition, when it rains, the level of the groundwater rises, the soil becomes more saturated, and the soil materializes. These three factors increase slope displacement and diminish stability. The stability analysis under the natural state and rainfall state are carried out separately using the strength reduction method, and the horizontal displacement, effective plastic zone, and safety factor of each profile are analyzed by the results of the model, and finally a suitable support scheme is designed and selected [3].

![Figure 3. Natural state I-I profile horizontal displacement map](image)
3.2. Support scheme

3.2.1. Anchor rods support

To accomplish the anticipated reinforcement effect, the length requirements of anchor rods should be calculated and established with greater accuracy during the design of anchor support [4]. By choosing an appropriate anchor length, you may boost the slope's stability while simultaneously enhancing the tensile strength of the slope and the interaction between the anchors. According to the actual circumstances surrounding the landslide in Lijiagou Village, Xingtai County, the anchor lengths were designed as 11 m and 5 m for profiles I-I, 11 m and 6 m for profiles II-II, and 15 m and 18 m for profiles III-III. These lengths were anchored in the hard soil layer with a borehole diameter of 120 mm and an inclination angle of 145°, with HRB400 steel reinforcement of 25 mm diameter and 42.5 R cement mortar used in pouring.

Anchor rods: For each profile, the intended anchor rod lengths are 11 m and 5 m for I-I, 11 m and 6 m for II-II, and 15 m and 18 m for III-III. The borehole is 130 mm in diameter, the inclination angle is 145°, 25 mm HRB400 reinforcement is chosen, and 42.5 R cement mortar is used in pouring.

Anti-slide piles: At the bottom and middle of the slope, 23 anti-slide piles with a diameter of 0.5 m and a length of 15 m were installed, with C35 concrete and HRB400 main reinforcement and HPB300 hoop reinforcement, respectively.

3.2.2. Anti-slide pile support

Anti-slide pile support is a type of slope support technique in which prefabricated steel or concrete piles are buried at varying depths in the soil retaining layer and fixed to the slope soil body with the aid of beam sets, tie bars, and other elements to jointly withstand the slope instability brought on by the horizontal displacement of the deep soil body [5-10]. By carrying the horizontal displacement force, countering the anti-slide resistance, and supporting the slope soil body, the anti-slide pile assures the stability of the slope. By the actual circumstances surrounding the landslide in Lijiagou Village in Xingtai County, 2~3 anti-slide piles with a diameter of 0.5 m and a length of 15 m were installed, with C35 concrete, HRB400 main reinforcement, and HPB300 hoop reinforcement.

3.2.3. Mixed support of anchor rods and anti-slide piles

The combination of the above two support methods, anchor rods and anti-slide piles, proposes a combination scheme that can not only prevent sliding support but also prevent sliding support.

3.3. Safety factor analysis

The slope supported by a combination of anchor and anti-slide pile has the best stability, and at the same time, no landslide will occur under the rainfall condition, and it can still retain the stable state, according to analysis and comparison. Table 2 displays the analysis' findings:

<table>
<thead>
<tr>
<th>Section</th>
<th>Working conditions</th>
<th>Factor of safety</th>
<th>Slope stability state</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-I</td>
<td>Mixed support</td>
<td>2.790</td>
<td>stabilize</td>
</tr>
<tr>
<td></td>
<td>Mixed support+rainfall</td>
<td>2.000</td>
<td>stabilize</td>
</tr>
<tr>
<td>II-II</td>
<td>Mixed support</td>
<td>2.500</td>
<td>stabilize</td>
</tr>
<tr>
<td></td>
<td>Mixed support+rainfall</td>
<td>1.862</td>
<td>stabilize</td>
</tr>
<tr>
<td>III-III</td>
<td>Mixed support</td>
<td>2.225</td>
<td>stabilize</td>
</tr>
<tr>
<td></td>
<td>Mixed support+rainfall</td>
<td>1.426</td>
<td>stabilize</td>
</tr>
</tbody>
</table>

3.4. Result analysis under support conditions

3.4.1. Displacement field analysis

When the mixed support scheme of anchor rod and anti-slide pile is chosen, the slope's horizontal displacement is decreased and the slope's stability is increased under the natural condition. Rainfall conditions cause the slope's horizontal displacement to reduce, notably the displacement at the slope's foot, yet the stability of the slope still declines in comparison to that under the natural condition with mixed support. The horizontal displacements of the I-I profile under the natural state and the state of rainfall are shown in Figure 5.
3.4.2. Analysis of axial force and a bending moment of the anti-slide pile

Figures 6 and 7 show that the anchor shaft force in the rainstorm situation is much higher than the anchor shaft force in the natural state, which was previously mentioned.

4. CONCLUSION

The analysis in this paper demonstrates that a variety of factors, including the physical and mechanical characteristics of the soil layer, external environmental factors like rainfall, and the design and placement of support structures like antiskid piles and anchors, all affect the stability of the slope of Lijiagou village in Xingtai County. Three options of anchor rod support, anti-slide pile support, and mixed anchor rod and anti-slide pile support were designed using the deformation and horizontal displacement of the slope before and after the rainfall. The mixed anchor rod and anti-slide pile support were ultimately chosen as a more reasonable support measure by evaluating the stability and safety coefficient. Following the implementation of the mixed anchor and anti-slide pile support scheme, the effective plastic zone of the landslide slope was greatly reduced, and the safety factor was significantly increased. This demonstrates how the support system's design can significantly increase the landslide's stability. In addition, this project serves as a helpful resource for other geological disaster studies.

REFERENCES

1. Luo W, Huang Y. Exploration of landslide geological hazard survey and prevention and


