Study on Stability Analysis and Prevention Technology of Traction Landslide

Jiang Si-yi*, Li Hai-liang

The Guangxi Zhuang Autonomous Region geological environment monitoring station, Guilin, Guangxi 541004, P.R. China

*Corresponding author’s e-mail: 370333108@qq.com

Abstract: Landslides are affected by engineering geological conditions, precipitation and rainfall. It is of greatly significance to study the causes and treatment methods of landslides to prevent and ensure the safety of people's lives and property. Base on a case of Songmu landslide, the causes and mechanism of rainfall-induced landslide are analyzed. The stability of landslide under natural and rainfall conditions is analyzed respectively by using finite element strength reduction method and standard calculation method. The influencing factors of landslide are analyzed and the safety and stability of landslide are evaluated. The research results show that the disaster mechanism of Songmu landslide is that rainwater penetrates the clay layer, and the weathered layer is easily softened when rain seepage into landslide. The low strength of the soil induces local deformation and finally occurs sliding. In natural condition, the whole landslide is basically stable, but in saturated condition, the whole landslide should be in unstable state. The formation mechanism of the landslide can provide guidance for the prediction of the landslide deformation and treatment in the future.

1. Introductions

Landslide geological disasters occur frequently in Southwest China, among which large landslides, due to the huge amount of high potential energy and strong impact and destructive power, and cause devastating damage to nearby civil buildings, rivers, highways, railways and other important transportation routes, greatly threatening the safety of people's lives and property [1-3].

Researchers have carried out a large number of studies on the mechanism of landslide instability. The development of landslide is affected by the difference of geological conditions and external disturbance factors, resulting in different failure modes [4]. The common failure modes of landslide are traction landslide and thrust-type landslide. Traction landslide is usually disturbed by artificial excavation at the foot of slope or the rise and fall of reservoir water level, showing the feature of backward and backward deformation [5-6], while thrust-type landslide shows the feature of backward and forward deformation due to the influence of backing-edge loading or rainfall-filling cracks [7-8].

The influence of rainfall on slope stability is mainly considered as the increase of weight caused by rainfall, and the decrease of negative pore water pressure in soil caused by rainwater infiltration [9-10]. However, for the soil slope, long-term rainfall infiltration leads to the decrease of soil strength softening [11-12]. In the paper, Sihong landslide is taken as a case, and the stability of high soil slope is analyzed by standard theory analysis and finite element strength reduction method. On this basis, the process of landslide deformation evolution is considered to provide a basis for guiding engineering practice.
2. Geological background of landslide area

2.1. Terrain and landform
The landform of the landslide area is the ridge valley of middle and low mountains, and the location of the landslide is the foreconvex ridge. The elevation of the mountain from top to toe is 360~570m. The slope direction of the landslide is 170°. At present, the slope of the area where the landslide is located is 25° ~ 35°. The vegetation in the slope is mostly pine trees, and coverage rate of the vegetation in the slope reaches 80%.

2.2. Strata lithology and engineering geological properties
The stratum in the exploration area is the Quaternary residual slope deposit (Qel+ dl) gravel cohesive soil, and the underlying bedrock is the Devonian Tangjiawan Formation (D2t) mudstone and silty mudstone, and continuously distributed bedrock.

The basic characteristics of engineering geology in each stratum are described as follows from new to old.

(1) Quaternary Pleistocene residual slope deposit (Qel+ dl) gravel cohesive soil
The layer is the Quaternary residual slope stratification, distributed in the surface of slope body. Which the thickness is generally 3.8-11.5m, lithology is gravel clay, hard plastic to plastic shape, gravel composition is 5 ~ 25% argillaceous sandstone or mudstone, particle size is 1 ~ 10cm. The images of the residual slope exposed by the probing trough are shown in Fig 1.

Figure 1 Residual soil in groove

(2) Devonian Tangjiawan Formation (D2t) mudstone, silty mudstone
Rock is gray yellow, strong weather thick layer, argillaceous structure. Among of most structure has been destroyed, the rock weathering strength is not uniform. According to the previous work results, the strongly weathered mudstone is relatively soft, fewly expansion and contraction property. Rock cores were shown in Figure 2 and Figure 3.
2.3. Geological structure
According field investigation, the area is located on Wanggao-fengshutou compression-torsion fault zone. The fault is located in the line from Wanggao to Fengmu Mountain with the total length of 65km, extending in a north-south direction. Parallel cutting of the west wing of Xiwan subaxial syncline in Yanshanian period, oblique cutting of Indosinian syncline. It is partly covered by the Paleogene. The fracture surface dips westward with a dip 40° and the western hanging wall rises. The strata on the west side of the fault are obviously missing, and the rock strata in the fault zone are squeezed into breccia, which is silicified and invaded by diorite porphyrite dikes.

2.4. Hydrogeological conditions
Groundwater type of clastic rock structure was crevice water in exploration area. It occurrence and migration mainly in structural fissure, and supplies by rainfall water. Through borehole exploration, it is inferred that in the absence of rainfall, the depth of the groundwater level in the exploration area is relatively shallow. According to the borehole water level measurement, the depth of water level is 0 ~ 15.2m. However, in the case of heavy rainfall, the rainfall penetrates into the slope body and then flows above the soil-rock interface. Therefore, it is considered that rainfall has a great influence on the groundwater level, and the rock-soil surface is full of water during the rainstorm.
3. Developmental characteristics of landslide geological disasters

3.1. Landslide characteristics
Songmu landslide is developed in the inner dislocation zone of the residual laminated strata. The landslide is distributed in the middle of the mountain with the elevation of 220 ~ 240m. It is slow in the front and steep in the back. The slanting length of the landslide body is about 40m, the width of the trailing edge is about 10m, the width of the leading edge is about 30m, the main sliding direction is 85°, and the area is about 1200m². The sliding body is the residual silty clay, and the sliding surface is roughly located in the intra-layer dislocation zone of the residual silty clay. The arc-shaped crack at the back edge of the landslide is about 4m in length with a maximum width 0.2m and a strike of 165°.

The landslide is still in the creep stage. The slipped landslide body is mainly composed of the silty clay, and the sliding surface is located in the dislocation zone within the residual layers. The potential sliding surface with a thickness of 0.05 to 0.10m. In the natural state, the landslide is basically stable at the present stage. However, heavy rainfall and surface water seeps into the potential sliding face, the landslide is highly likely to collapse and destabilize on a larger scale.

3.2. Characteristics of landslide deformation
Deformation characteristics of the surface in Songmu Landslide are mainly manifested as collapse zone, longitudinal tensile cracks and scattered small ridges were found in the middle and front surface in the landslide body. Tensile cracks and sliding walls in the back edge, the landslide geological profile is shown in Fig. 4.

(1) Landslide trailing edge characteristics
① The landslide was caused by a series of dislocation cramps and tensile fractures, the height of the cramps was about 0.2 ~ 0.6m, the slope dip was about 30° ~ 35°, there was a local collapse in the front edge, and the vegetation on the slope was seriously tilted.

② The main fracture and tensile fracture are relatively developed, and the slopes mostly show a series of residual small steep slopes with a gradient of 50° ~ 60°. The height of steep slopes are generally 0.3 ~ 0.5m. Most of the steep slopes retain the characteristics of the fracture, and some of them are unobvious due to surface rainfall scouring.
(2) Deformation characteristics in the middle and upper part of the landslide
The vegetation on the hillside is developed, contained mainly pine trees, the coverage rate of vegetation is 80%. The bare soil is loose, and the infiltration of rainfall increases. Field investigation showed that a crack of about 5m was visible on the slope. Several steep cramps warein the middle of the slope, the height is generally 0.5~1m.

(3) Deformation in the front of the landslide
The leading edge is artificially cut slope, with a cut height of 1.5 ~ 2m and a slope greater than 40°, which redistributes the slope stress and changes the balance conditions to some extent.

(4) Sliding zone
The exploration and drilling revealed that there was an obvious wet and soft soil zone in the debris stratum of the landslide body, with a thickness of 5 ~ 10cm. The soil was a loose body with a slimy feeling. The surface of the soil could be seen in the part of the extruded body, and it was inferred to be a sliding zone.

(5) Slide bed characteristics
The slide bed is mainly gravel bearing soil on residual slope. The lower part is mostly clay, with strong water resistance and high water content, and the groundwater level is mostly concentrated in this part.

4. Cause analysis of landslide
According to the deformation of songmu landslide, the causes of the landslide mainly include slope topographic conditions, material composition, strong rainfall, and human engineering activities.

4.1. Topographic conditions and strata lithology
The landform of the landslide is ridges and valleys of middle and low mountains. The relative height of the mountain is more than 100m.

The slope is covered with the Quaternary residual slope soil layer, whose lithology is silty clay containing gravel. Due to the planting of pine trees on the slope and destroyed vegetation, soil is good permeability. The strong weathered mudstone in the lower part is water-proof, and the soil of the slope is easy to reach saturation after rainfall penetrates into the interior of the slope body, which further reduces the strength of the soil and makes it easy to slip under the action of gravity.

4.2. Rainfall
Rainfall is closely related to the landslide, and is the main triggering factor of the landslide. the rainfall is concentrated, and the annual rainfall reaches 1560mm. Especially in the rainy season, the characteristics of short-term rainfall and continuous heavy rainfall for several days reduce the shear strength of the soil layer, which is not conducive to the stability of the soil. On the one hand, the weight of saturated soil and water increased, and on the other hand, the slope soil softened. Under strong rainfall, the slope stability decreased, especially the local slope body, which triggered the instability of the slope, and evenformed the landslide. According to the survey, the landslide occurred during heavy rainfall.

4.3. Human engineering activity
Vegetation in slope was destroyed by human, which is conducive to the infiltration of surface water. The main cause of this landslide is excavation of the slope toe, and accumulated creep deformation of the soil behind the retaining wall after was about 3m.

5. Landslide stability analysis and evaluation

5.1. Model establish
Based on topographic and geological conditions, the most typical section was selected as the calculation research. The upper soil layer is clay, followed by fully weathered mudstone, strongly weathered
mudstone, and moderately weathered mudstone. The calculation model is shown in Figure 5. The soil body adopts the M-C constitutive model. The left and right sides of the model are constrained, the bottom is constrained, and the upper part is free. The physical and mechanical parameters of the soil layer are shown in Table 1.

Table 1 Parameter table of landslide stability calculation

| Parameter Lithology       | C (kPa) | Dry Shear strength | Saturated Shear strength |
|---------------------------|--------|-------------------|-------------------------|
| Silty clay (①)           | 19.10  | 19.42             | 22.00 19.00 15.00 12.40 |
| Slippery soil            | 19.10  | 19.42             | 24.96 14.89 18.75 11.50 |
| Strongly weathered mudstone (②) | 19.60  | 19.85             | 23.40 11.60 8.40 11.90 |

5.2. Stability analysis

Finite element method (FEM) and theoretical calculation were used to analyze the stability of the landslide under natural state and rainfall condition, and the influencing factors of the landslide were analyzed and evaluated, as shown in Fig. 6.

As shown in Fig 6, it can be seen that the safety factor is 1.23 under the natural working condition, which is basically stable. While the safety factor of the slope is only 0.645 under the rainstorm working condition. As can be seen from the displacement cloud diagram in Fig. 7, the leading edge of the landslide has an obvious displacement and sliding trend under rainfall conditions and is prone to instability. Therefore, in order to ensure that the landslide has enough safety reserves and pine landslide safety, it is suggested to take engineering treatment measures as soon as possible.
6. Prevention treatment and suggestions

According to the deformation and failure characteristics of the landslide, the stability of the landslide and the comprehensive analysis of the damage objects, it is suggested to adopt the scheme of retaining and surface drainage.

1. The continuous strong rainfall was the main cause of the landslide. The infiltration of rain water increased the dead weight of the slope and increased the sliding force, while the softening of mudstone formed a soft layer, which significantly reduced the shear strength of the slope and reduced the sliding force provided by the leading edge of the landslide.

2. Groundwater and rainwater on the slope have a great impact on the landslide, which is one of the important reasons for triggering the sliding deformation of the landslide. Therefore, water should be intercepted as far as possible and discharged from the landslide body. Erosion of the slope by rainfall and the softening of rainwater infiltration were reduced, so as to protect the overall stability of the slope.

3. According to the characteristics of the landslide and the topographic and geomorphic features, double-row anti-slide piles are settled in the landslide.

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