Disaster Mechanism and Safety Evaluation of Sihong Landslide

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Abstract: In order to analyze the causes and mechanism of rainfall induced landslide, Taking sihong landslide in guangxi as an example, finite element method (FEM) and the theoretical calculation were adopted, it respectively analyzes the stability of the landslide in the natural state and rainfall conditions, the influence factors of landslide are analyzed and evaluated the landslide stability. The research results show that the disaster mechanism of Sihong landslide is due to the strong permeability of clay layer, and the weathering layer is into water easily soften, and the rainfall infiltration is easy to form a weak interlayer, which induces local deformation and finally slides. Sihong landslide is in a stable state under natural conditions. However, landslide was in the unstable state under the saturated condition. According to the plastic cloud map of the sliding surface, dangerous area of stress was concentrated in the front edge of the landslide, so it is suggested to take prevention measures of double-row anti-slide piles and the masonry slope. The formation mechanism of the landslide can provide engineering reference for similar project.

1. Introduction
Geological disasters always occur in southern China due to rainfall-induced landslides. Relevant research results show that 90% of geological disasters are induced by rainfall. Landslides are the most common disasters induced by rainfall, with high frequency and wide distribution [1-4].

Scholars have carried out a large number of studies on the mechanism of landslide instability at present. Huang Runqiu et al [5] combined with systematic investigation of engineering geological conditions and adopted FLAC3D numerical simulation to deeply discuss the deformation and failure mechanism of bedding slope. Cai Yue et al. [6] discussed various factors affecting the stability of antidipping layered rock slope based on discontinuum theory and discrete element technology. Liu Zhongyu et al. [7] studied the stability of loess slope under earthquake conditions. Xu Zhangjian et al. [8] deeply studied the characteristics and mechanism of various loess landslides in China.

The influence of rainfall on slope stability is mainly depended on two factors. Considered the increase of dead weight in the transient saturated zone in the shallow surface of slope was caused by rainfall, and the decrease of negative pore water pressure in soil was caused by rainwater infiltration [9-10]. However, long-term rainfall leads to the decrease of soil strength softening and further deteriorates the stability of the soil slope [11-12]. In the paper, Sihong landslide is taken as a case study, 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 guiding for engineering practice.
2. Geological background of landslide area

2.1 Topography
Landslide area is in the middle and low mountain area, and the location of the landslide is the foreland ridge. The elevation of the mountain peak is 230m, the elevation of the slope toe is 120m, and the relative elevation difference is 110m. The landslide is distributed in the middle and upper part of the mountain, and the distribution elevation is 140 ~ 160m. The slope of the landslide is 70°. The slope of the area where the landslide is located is 25° 35°. The vegetation on the slope is mostly pine trees, and the vegetation coverage rate on the slope reaches 80%. Residents cut the slope at the foot of the slope to build houses with a height of 3~8m.

2.2 Strata lithology
The strata in the exploration area are Quaternary residual slope (Qel+ dl) clay, and the underlying bedrock is Cambrian Huangkou Formation (∈ H) mudstone and silty mudstone, with continuous distribution of bedrock. The basic characteristics of engineering geology in each stratum are described from top to bottom as follows.

(1) Quaternary Pleistocene residual slope deposit (Qel+ dl) clay bed
This layer is the Quaternary residual slope stratification, distributed in the surface layer of slope body, with a single layer structure, the thickness is generally 1 ~ 4m, the lithology is yellow clay, yellow brown, hard plastic ~ plastic shape, as shown in Fig 1.

(2) Silty mudstone of Cambrian Huangkou Formation (∈ H)
The rock mass is yellow brown, medium thick stratified, the lower part is strongly weathered, most of the rock structure has been destroyed, the rock weathering strength is not uniform, local rock can be ground into sand, the core is fragmenting, sand, block diameter 3 ~ 10cm. According to the exploration, three undisturbed samples were tested in strong weathering. The strong weathering silty mudstone is soft rock, and weakness expansion contraction property, as shown in Fig 2 ~ Fig 3.
2.3. Geological structure
According to the regional geological and field investigation, the survey area is located at the southern end of the Wumaling compound anticline, with a length of 50km and a width of 8km, with an axial dip angle of 75°, and the two wings symmetric to the NE direction. The general dip angle is from 50° to 75°. The axial part is Huangkou Formation (H), and the wing part is Xiaoneichong Formation (X).

2.4. Hydrogeological conditions
According to the characteristics of rock lithology, groundwater was crevice water of clastic rock structure in exploration area. Groundwater occurrence mainly in structural fissure, rainfall water, the mountain drainage, river on both sides of the gully have springs scattered, exposed position above the water surface, flow rate changes with the seasons, decline in spring, the underground in the aqueous medium, surface residual diluvial layer permeability medium to weak. Through borehole exploration, it is inferred that in the absence of rainfall, the buried depth of the groundwater level in the exploration area is relatively shallow. According to the borehole series water level measurement, the buried depth is 0 ~ 15.2m, which is mostly exposed in the bedrock. However, in the case of heavy rain, the rainfall penetrates into the slope body and then flows above the soil-rock interface. Therefore, it is has a great influence on the groundwater level, and the rock-soil interface is in the state of full water during the rainstorm.

3. Developmental characteristics of landslide geological hazards

3.1. Landslide characteristics
Sihong landslide is developed in the soft surface between rock and soil, and the soft structural plane in the eluvium is the sliding zone.

The landslide is distributed in the middle of the mountain with an elevation of 140 ~ 160m. The landslide is slow at the beginning and steep at the end. The slanting length of the landslide body is about 35m, the width of the trailing edge is about 50m, and the width of the leading edge is about 110m. The slippage is silty clay, and the sliding surface is roughly located in the interface between the eluvial layer and the strongly weathered mudstone. The arc-shaped crack is about 6m in length at the back edge of the landslide, with a maximum width of over 0.2m and a strike of 155°. New fractures were unfound in the upward extension of the crack from the trailing edge, so the crack was identified as the trailing edge of the landslide.

The landslide is still in the creep stage at present. According to the field survey and the composition of landslide deposits, the landslide body is mainly composed of silty clay deposited on the residual slope. Drilling during the survey revealed a 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. If a heavy rainfall was happened and surface water flows down along the potential sliding face into the ground, the landslide is highly to collapse and destabilize on a larger scale.

3.2. Characteristics of landslide deformation and failure

According to the investigation, the main surface deformation characteristics of the landslide are collapse zone in the leading edge, multiple transverse and longitudinal tensile cracks and scattered small crams in the middle and front surface of the landslide body, and perforative tensile cracks and sliding walls in the back edge. The landslide exploration profile can be seen in Fig. 4.

![Fig 4 Profile of sihong landslide in 1-1 section](image)

(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 surface slope 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 slope is mostly a series of small remaining steep slopes with a gradient of 50° ~ 60°, and the steep slopes are generally 0.3 ~ 0.5m high. Most of the steep slopes retain the characteristics of the fracture, and some of them are not obvious due to surface rainwater scouring and cultivation.

(2) Sliding deformation characteristics of the middle and upper part of the landslide

Vegetation on the hillside is developed, mainly pine trees planted were coverd 80% of the vegetation, which makes the exposed soil loose and increases the infiltration of rainfall. Field investigation showed that cracks about 10m long could be seen on the slope. At present, there are several small collapses in the middle of the slope surface, showing a number of steep cramps. The height of the steep cramps is generally 0.5-1m. In the case of rainfall, water seepage can be seen at the local foot of the cut slope, showing a planar flow with small flow and slightly muddy, which generally lasts for several days after the rain.

(3) Landslide front deformation

The leading edge is artificial slope cutting with a height of 1.5 ~ 2.0m, and a slope greater than 40°. The artificial cutting changes redistributes the slope stress. The retaining wall has been built, but the
retaining wall is uncontinuous, and the whole slope foot is difficult to control, the drainage hole of the retaining wall has been blocked, and cracks have appeared in the retaining wall.

(4) Sliding surface

The exploration groove revealed that there was an obvious wet and soft soil zone near the contact surface of rock and soil in the landslide body through drilling, with a thickness of 5 ~ 10cm. The soil was in the shape of soft plastic, which could be rolled into thin strips by hand. The surface of the soil could be seen in the extruding part, so it was inferred to be a sliding zone. The soil structure disturbance above the belt is not obvious. Combined with drilling exposure and ground investigation, it is considered that the sliding surface of landslide is the contact surface of rock and soil mass.

(5) Characteristics of sliding bed

Strongly weathered mudstone is mainly consisted of the slide bed. It is distributed in the landslide area, and its color is mainly gray-yellow, muddy. The bedding is difficult to see, and the weathering cracks are densely developed. The material is accompanied by fragments of mudstone or sandstone. Dry drilling is difficult to drill, impact drilling is difficult to core, the core can be crushed by hand, easy to soften in water, the strength is significantly reduced. The thickness of the layer is generally 5 ~ 10.0m. Comprehensive drilling core and experience in engineering investigation concludes that the layer of rock is a soft rock, the rock mass basic quality grade for IV level.

4. Cause analysis of landslide

According to the landslide of deformation of, the main causes of Sihong landslide include topographic conditions of slope body, material composition (stratigraphic lithology), strongly rainfall and human engineering activities

4.1. Topographic conditions

The landform of the landslide is the landform of ridges and valleys of middle and low mountains. The relative height difference of the mountain is more than 100m, and the slope where the landslide body is located is range from 25° to 35°. The upper part of the trailing edge of the landslide is steep, the middle and lower part is slightly slow, and it is a "concave" catchment terrain, which is easy to form landslides.

4.2. Strata lithology

The landslide is located is covered with the Quaternary residual sloping soil, which is composed of gravel silty clay and silty clay. Due to the planting of pine trees and destroyed vegetation on the slope, and the surface soil directly exposed with good water 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 easily to slip under the action of gravity.

4.3. Rainfall

Rainfall is closely related to the landslide, which is the main triggering factor of the landslide activity. In the working area, the rainfall is concentrated, and the annual rainfall is up to 1600mm. Extreme rainfall occurs frequently in the rainy season. The characteristics of short-term heavy 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 heavy rainfall, the slope stability decreased, especially the local slope body, which triggered the instability of rock and soil mass on the slope and formed the landslide.

There are human activities such as farming on the landslide, which destroy the slope vegetation and facilitate the infiltration of surface water. And fruit trees and vegetables in the middle of the slope. Irrigation also has a certain effect on groundwater.
5. Landslide stability analysis and evaluation

5.1. Qualitative analysis of stability

According to the topographic and geological conditions, the typical and unstable slope stability section was selected. The upper layer is a clay, followed by strongly weathered mudstone. The calculation model is shown in Figure 5. M-C constitutive model was used for soil. The left and right sides of the model are constrained, the bottom is constrained, and the top is free. The physical and mechanical parameters of soil layer are shown in Table 1.

Table 1 Soil physical parameter in landslide

| Parameter | Lithology               | γ(kN/m³) | Dry   | Saturated | c (kPa) | φ (°)  | c (kPa) | φ (°)  |
|-----------|-------------------------|---------|-------|-----------|---------|--------|---------|--------|
|           | Silty clay (①)          |         | Dry   | Saturated |         |        |         |        |
|           |                         | 18.90   | 19.14 | 24.40     | 20.30   | 16.70  | 16.50   |
|           | Strongly weathered mudstone (②) | 19.5 | 19.64 | 20.00     | 14.00   | 11.00  | 12.70   |

5.2. Comprehensive evaluation of landslide stability

Finite element method (FEM) and the theoretical calculation were adopted, it respectively analyzes the stability of the landslide in the natural state and rainfall working conditions, the influence factors of landslide are analyzed and evaluated the landslide stability, seen shown in Figure 6.

Through qualitative evaluation and quantitative calculation, it can be seen that the landslide is in a stable state as a whole under natural conditions. Under saturated condition, the whole landslide should be in a basic stable state. Therefore, in order to ensure that the landslide has enough safety reserve and the safety of Sihong residential area, it is suggested to take engineering treatment measures as soon as possible. In the natural working condition, the safety factor is 1.2, which is basically stable, while in the rainstorm working condition, the safety factor of the slope is only 0.984, which is unstable.

6. Conclusion and suggestions

According to the investigation and survey and the stability calculation, the landslide is under an unstable state during the rainstorm. The main development trend is as follows that the clay layer has strong permeability, and the weathered layer is easy to soften when it meets with water. The landslide area is also in an area with frequent extreme rainfall weather, and the rainwater infiltration is easy to form a weak interlayer, which may induce local deformation or even large-scale sliding of the landslide. According to the comprehensive analysis of the deformation and failure characteristics of
the landslide, the stability of the landslide and the distribution range of the hazard objects, it is suggested to adopt the scheme of retaining and surface drainage:

1. Groundwater and rainwater on the slope have a great influence on the landslide, which is one of the important reasons for the sliding deformation of the landslide. Therefore, the water should be intercepted and discharged as far as possible. The erosion of rainfall on the slope and the softening effect of rainwater were need reduced. Drainage ditches was built on the periphery of the landslide body to intercept surface water.

2. According to the characteristics of the landslide and the topographic and geomorphic features, the slope cracks are used for pointing and filling, and the stone masonry slope protection is carried out.

3. In order to ensure safety of the landslides, deformation monitoring shall be carried out during the construction period and in the next hydrological year.

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