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Study on the Simulation of Shear Strength Decrease of Soil in Sliding Zone of Old Landslides When Submerged by Reservoir Water in Landslide Physical Model Test

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ABSTRACT: Reservoir water is the main factor to make shear strength of soil in sliding zone of old landslides on reservoir banks decrease. To simulate the decrease of shear strength of sliding zone when submerged by reservoir water in landslide physical model test, a new method was put forward. The new method is numerical method that used to simulate the changes of plastic zone of sliding zone at different uplifting angles of physical model flume and different decreasing cohesion values of the sliding zone, and then a corresponding relationship between the uplifting angle of the model flume and the decrease of cohesion of the sliding zone of the landslide model is established. The new method was applied to Shiliushubao landslide physical model test, and the test result shows that the new method is effective on the simulation of shear strength decrease of soil in sliding zone of old landslides when submerged by reservoir water in landslide and gives a way by raising uplifting angle of physical model flume in a short time to simulate the shear strength decrease of soil in sliding zone in old landslide when submerged by reservoir water for a long time.

KEYWORDS: Physical model test, Sliding zone, Shear strength parameter, Decrease, Submerge

1 PREFACE

Landslide is an important geological disaster and it will probably threaten to human life (Chen Zuyu 2003). Landslide hazards, as a kind of natural disaster, are defined as that the geotechnical substance on a slope slides downward along a certain weak zone in the slope. The movement of slide mass of landslides will make the roads, the villages and towns, the buildings etc. damaged, block the watercourses and navigable, induce flood and submerge farmland, which gives great loss to property and lives of human being (Yang Dayuan et al. 1993).

Reservoir impoundment will make some bank slopes which are stable before reservoir impoundment slide. When the reservoir water level rises, phreatic surface will go up because of reservoir water permeating in the slope, which will bring about a decrease of the effective stress and sliding resistance of bank slopes. When the reservoir water level drops, phreatic surface will go down and lag behind water level drop, the hysteresis effect will make the excess pore water pressure increase and then weaken the stability of landslide (Zheng Yingren et al. 2007). Therefore, the study on the deformation and failure of the bank slope in reservoir is a prerequisite to give direct to reservoir landslide control.

Currently, there are many ways to study on characteristics of deformation and failure of landslides, in which the principal ways which used most frequently are numerical simulation and physical model test. To physical model test, it often takes a long time to simulate the deformation and failure of landslide models when exposed to reservoir water level fluctuation. In order to shorten the period of physical model test to improve physical model test efficiency, raise the angle of physical model flume to speed up the simulation of deformation and failure of the landslide models. To simulate reasonably the characteristics of mechanical parameters of sliding zone is the key to success in the physical model test (Zhang Zhenhua et al. 2009, Liu Bo et al. 2007, Luo Xianqi et al. 2005, Headquarter of the Three Gorges Reservoir Geological Hazards Control in the Ministry of Land and Resources 2003, Wang Zhiwang et al. 2004, Luo Xianqi et al. 2001).

The cohesion of sliding zone is the most distinct in decrease of mechanical parameters of sliding zone of bank slopes when exposed to reservoir water level fluctuation. Many indoor geotechnical tests indicate that the value of soil cohesion has more change than that of internal friction angle when water content of the soil changes (Cheng Yumei et al. 2003), so cohesion of soil is much more sensitive to the changes of water content of the soil, which has great influence on the stability of bank slopes when the bank slope exposed to reservoir water level fluctuation (Wang Yuanxun 2003). The shear test of the gypsum by Patton also indicated that the peak strengthen and residual strengthen of the internal friction of the gypsum are almost the same, which proved that the internal friction angle of soil in sliding zone are nearly consistent with the variation of plastic strain of that (Sun Jun 1999).

In view of the context mention above, the numerical simulation method is taken to find the relationship between

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the lifting-up angle of the model flume and the decrease of cohesion value of the sliding zone in the landslide when exposed to reservoir water level fluctuation, which gives a way by raising lifting-up angle of physical model flume of the landslide in a short time to simulate the decrease of shear strength parameters of soil in sliding zone when exposed to reservoir water level fluctuation for a long time.

2 INTRODUCTION OF THE SHILIUSHUBAO LANDSLIDE

The Shiliushubao landslide locates in the Badong County, Hubei Province. It is approximately 65km away from the Three Gorges Dam, is the main part of the Huanglashi landslide group and is a large-scale landslide. The photograph of the landslide is shown as Figure 1. The elevation of the front edge and the back edge of the landslide is respectively 62m and 320m and the thickness of sliding mass of the landside is usually 60m. The length of the landside is 50 meters long, and the width is from 350 meters to 470 meters wide. The area is about 250 000 square meters, and the volume is approximately 11 800 000 cubic meters. The materials of the sliding mass are mainly of the greenishness marlstone rock and the purple-red mudstone, and the structure of sliding mass is spallation and disintegrated structure. The geohydrologic unit of the landslide is shown in Figure 2. The landslide was stable before the Three Gorges Reservoir impoundment, but the landside will most likely to be unstable after the reservoir impoundment from 135 meter water level to 175 meter water level (Li XG 2003, Luo XY et al. 2007, Yangtze River Water Resource Commission 1992).

According to the suggested values of physical and mechanical parameters from geological exploration and that from back analysis (Luo Xianqi et al. 2005, Sun Jun 1999), the physical and mechanical parameters of physical model are obtained as Table 1. The similitude ratio between model and prototype is 1:100.

Table 1 Value of physical and mechanical parameters of physical model of Shiliushubao landslide

Item	Natural volume weight $\gamma(kN \cdot m^{-3})$	Saturated volume weight $\gamma(kN \cdot m^{-3})$	Permeability coefficient $k(m \cdot s^{-1})$	Consolidated quick shear value		Deformation modulus E/MPa
				c/kPa	$\varphi/(°)$	
Sliding mass	20.1	22.3	2.10×10^{-3}	10.0	38.5	2.0
Sliding zone	20.0	22.0	1.20×10^{-4}	5.0	17.6	0.6

3 NUMERICAL SIMULATION

3.1 Computational domain

A plane strain model is chosen as mechanical model for the physical model test of Shiliushubao landslide. According to the similitude ratio (1:100) between model and prototype of the landslide and the geometry size of the landslide, the length in horizontal direction of the physical model is 7.55m, the height in vertical direction at the landslide front edge is 1.53m and the height in vertical direction at the landslide back edge is 5.7m. The average thickness of the sliding mass is 0.6m and the longitudinal length is 5.5m.

3.2 Numerical mesh model and boundary conditions

Based on the engineering geological generalized of the landslide, the computational cross section is composed of four kind of materials. Quadrilateral element is selected as the element type to mesh the computational domain, which is divided into 2 592 elements and 5 406 nodes. The bottom boundary of the computational domain is fixed in three orthogonal directions, the side boundary of the computational domain is fixed in normal direction. The numerical mesh model is shown as Figure 3.

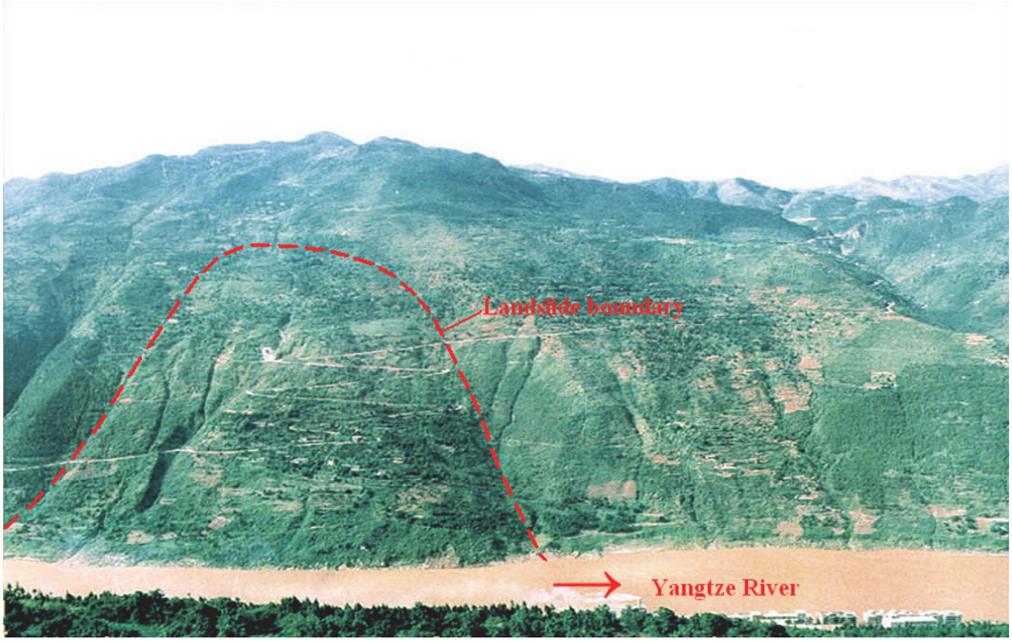

Figure 1 Photograph of Shiliushubao landslide

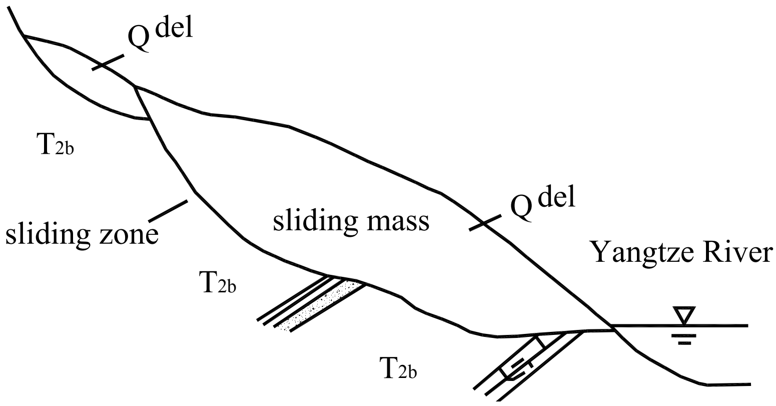

Figure 2 The geohydrologic unit of the Shiliushubao landslide

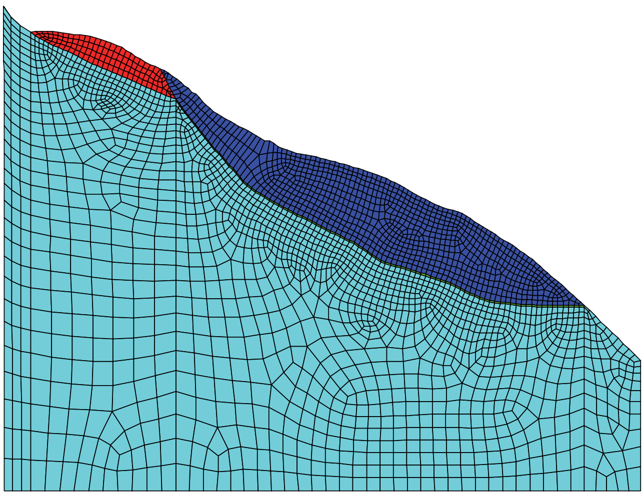

Figure 3 Numerical mesh model

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3.3 The constitutive model and yield criteria of the materials

The constitutive model of the materials in the physical model is ideal elastoplastic model and the yield criteria of that is compound criteria with Mohr-Coulomb and tension yield which can judge whether the yield of the sliding zone in the physical model is failure or not when to raise lifting-up angle of physical model flume or decrease the shear strength of sliding zone. The yield criteria described on the stress space formed by σ_1 and σ_3 is shown as Figure 4.

The curve corresponding to the formula of Mohr-Columb yied criteria (f^s=0) described in Figure 3 is from point A to B and f^s can be expressed as the following formula:

$$f^s = \sigma_1 - \sigma_3 N_\phi + 2c\sqrt{N_\phi} \quad (1)$$

Where φ = internal friction angle of the materials; c = cohesion of the materials; and

$N_\phi = (1 + \sin(\phi)) / (1 - \sin(\phi))$;

The curve corresponding to the formula of tension yield criteria (f^t=0) described in Figure 3 is from point B to C, and f^t can be expressed as the following formula:

$$f^t = \sigma_3 - \sigma^t \quad (2)$$

Where σ^t is the strength of tension;

Plastic potential function can be expressed as shear plastic flow function (g^s) and tension plastic flow function (g^t), and they can be expressed as following formulas:

$$g^s = \sigma_1 - \sigma_3 N_\psi \quad (3)$$

Where $N_\psi = (1+\sin(\psi))/(1-\sin(\psi))$; and ψ is dilatation angle.

$$g^t = \sigma_3 \quad (4)$$

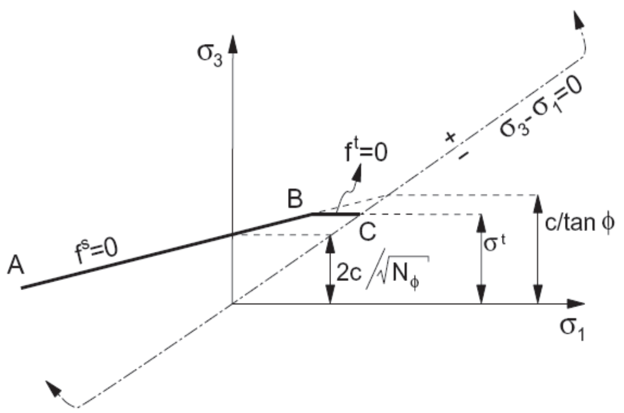

Figure 4 Compound criteria with Mohr-Coulomb and tension yield criteria

4 ANALYSIS OF COMPUTATIONAL RESULT

4.1 The relationship between the decrease of shear strength and percentage of plastic zone in sliding zone

Fast Lagrangian Analysis of Continua (hereinafter referred as FLAC) method was taken to compute the plastic zone in sliding zone of a series of schemes with decrease of cohesion value of sliding zone. According to the computational results of a series of schemes, the percentages of the length of plastic zone in sliding zone to the total length of sliding zone can be calculated. Based on the computational results mentioned above, the curve of the percentage of plastic zone vs. cohesion of sliding zone can be obtained and it is shown as Figure 5. The Figure 5 indicates that with the decrease of cohesion value of sliding zone, the percentage of plastic zone in sliding zone increase. When the cohesion value of sliding zone was reduced to 1.8kPa, the percentage of plastic zone in sliding zone is 100%. The fit curve and formula to express the relationship between the decrease of shear strength and percentages of plastic zone in sliding zone is shown as Figure 5.

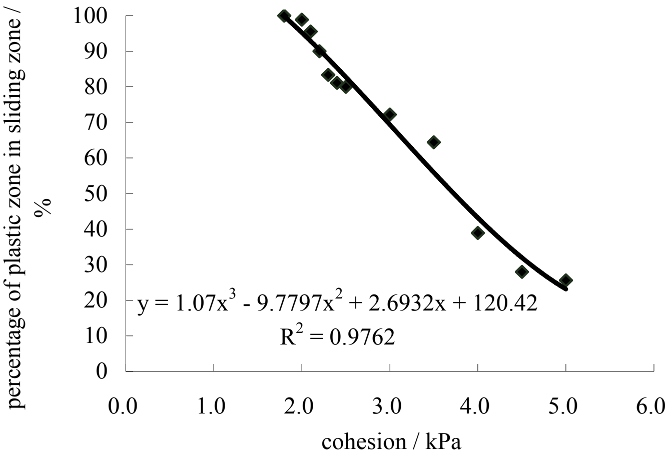

Figure 5 The curve of the percentage of plastic zone vs. cohesion of sliding zone

4.2 The relationship between uplifting angles of physical model flume and the percentages of plastic zone in sliding zone

On condition that the value of physical and mechanical parameters of physical model keeps invariable, uplift the physical model (which mesh model shown as Figure 1) 18° gradually (the mesh model of physical model after lifting 18° is shown as Figure 6). Flac method is taken to compute the plastic zone in sliding zone of a series of schemes with different uplifting angles of physical model flume. According to the computational results of a series of schemes, the percentage of the length of plastic zone in sliding zone to the total length of sliding zone can be calculated. Based on the computational results mentioned above, the curve of the percentage of plastic zone vs. uplifting angle can be obtained and it is shown as Figure 7. The Figure 7 indicates that with the increase of uplifting angle, the percentage of plastic zone in sliding zone increase. When the uplifting angle increases to 18°, the percentage of plastic zone in sliding zone is 100%. The fit curve and formula to express the relationship between the uplifting angles and percentages of plastic zone in sliding zone is shown as Figure 7.

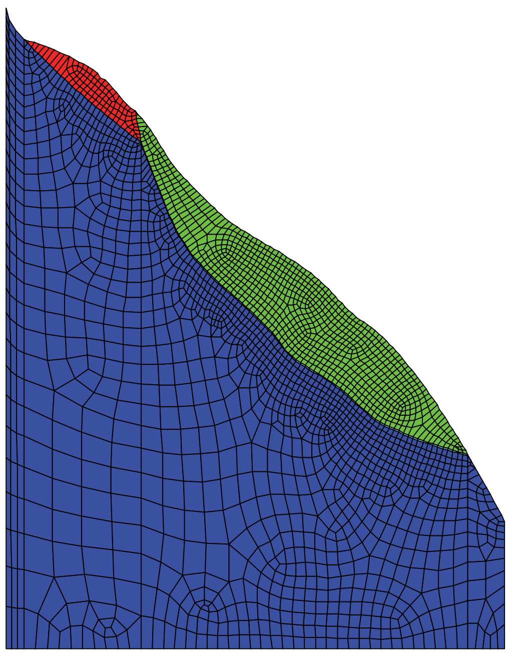

Figure 6 The mesh model of physical model after uplifting angle to 18°

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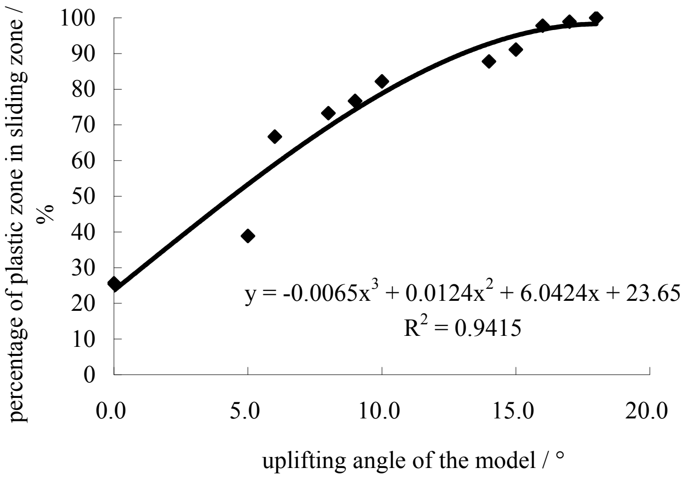

Figure 7 The curve of the percentage of plastic zone vs. uplifting angle

4.3 The relation between uplifting angle of the physical model and the decrease of shear strength of sliding zone

According to the relationship between the decrease of shear strength and percentage of plastic zone in sliding zone and the relationship between uplifting angles of physical model flume and the percentages of plastic zone in sliding zone, the relation between uplifting angle of the model and the decrease of shear strength of sliding zone can be established, which is expressed as the following curve and formula shown in Figure 8. The Figure 8 indicates that with the increase of uplifting angle of the physical model, the cohesion of sliding zone decrease. When the cohesion value of sliding zone was reduced to 1.8kPa, the uplifting angle increases to 18° and the percentage of plastic zone in sliding zone is 100%, that is to say, in order to accelerate simulating the effect that caused by the reservoir water level fluctuation on stability of the physical model of Shiliushubao landslide, we can uplift the model angle gradually to realize it. The fit curve and formula to express the relationship between uplifting angle of the physical model of the landslide and the decrease of cohesion of sliding zone is shown as figure 8. The uplifting angle of the model in the test was 17.8° that was very approaching to the angle 18°, which indicates that raising uplifting angle of physical model flume in a short time to simulate the shear strength decrease of soil in sliding zone in old landslide when submerged by reservoir water for a long time is effective.

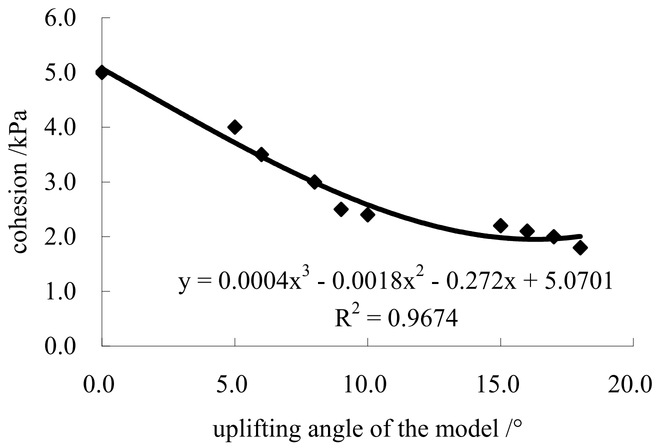

Figure 8 The curve of cohesion of sliding zone vs. uplifting angle of the physical model

5 CONCLUSION

The relation between uplifting angle of the physical model of Shiliushubao landslide and the decrease of shear strength of sliding zone is obtained by numerical simulation. Deformation and failure of the sliding zone is identical between the cohesion value of sliding zone reduced to 1.8kPa and the uplifting angle increasing to 18°, which indicates that the simulation of decreased of shear strength of sliding zone when exposed to reservoir water level fluctuation can be realized by uplifting the angle of physical model flume in landslide physical model test. So it is a way by raising lifting-up angle of physical model flume of a landslide in a short time to simulate the decrease of shear strength of sliding zone of the landslide when exposed to reservoir water level fluctuation for a long time, which gives references to other physical model tests of old landslides when exposed to reservoir water level fluctuation.

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