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Experimental study of laterite soil slope influenced by water level fluctuation

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ABSTRACT

Failure of slopes is often caused by seasonal water level fluctuation of reservoirs. To examine the impacts of water level fluctuation in water rising and drawdown stage, a slope model test is presented using the laterite soil. The controlling of rising and drawdown of water level is implemented in the test, and a series of test data such as pore water pressure, water content and displacement are obtained during the simulation process. The results indicate that the pore water pressure responses delay with the rising and drawdown water level. The water content gradually increases from the trailing edge. The mechanism of deformation and instability are revealed by the experiment under water level fluctuation. The results indicate that the displacement in the vertical direction is much larger than that in the horizontal direction under the condition of water level fluctuation, especially in water rising stage. The water rise and drawdown gradually softening will lead to the strength reduction and therein induce larger deformation.

Keywords: Slope; Physical model test; Water level fluctuation; Pore water pressure; Water content; Deformation

1. Introduction

A significant feature of the slope of the reservoir is that it is influenced by the fluctuation of water level for a long time [1–3]. The Stability problems of the slope during the water level fluctuation are also commonly encountered, especially for the rapid drawdown of the water level [4]. The dynamic changes in the water level of the reservoir are very frequent due to the operation of reservoir operation. The stability of slope relates the variation in the reservoir water level [5]. Water level fluctuation changes the soil between dry and humid states [6,7]. The pore water pressure and surface forces are internal and external forces on the slope. As a result of the water level fluctuation, the pore water pressure field in the slope is also in constant change, which will affect the stability of the slope. The change of the water level dominates the transient flow response. Thus, water level fluctuation causes the slope instability and ground subsidence. And the change seepage field leads to periodic loading of pore water pressure and effective stress [8,9].

The water level fluctuations will affect the slope stability [10–12]. Many researches have been made to explore the effect of water level fluctuation on slope. Gao [13] adopted a 3D rotational failure mechanism to investigate the influence of water level change on slope stability. Viratjandr [14] assessed the safety factor of slopes under different drawdown conditions. Huang [15] studied the stability coefficients of hydrodynamic pressure landslides with different permeability coefficients affected by reservoir water level fluctuations. Paronuzzi [16] examine the influence of filling-drawdown on Mt. Toc slope stability. Song [17] investigated effect of the parameters of SWCC on the stability of slope for reservoir water level fluctuation. Li [18] and Miao [19] evaluated the slope stability and displacement by cen-

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trifugal test. Physical model test is an effectively method to improve insight into the mechanisms associated the water level change [20].

In this paper, a physical slope model test is made using the laterite soil, and the model test is performed for rising water level and lowering water level. The influence of water level fluctuation on the pore water pressure, water content and deformation is studied.

2. Methodology

2.1. Physical model

The testing water channel as shown in Fig. 1 is made using steel frame and glass wall with 80 cm in width, 80 cm in height and 400 cm in length. The height and thickness of the slope model are 70 cm and 80 cm, respectively. And the top width is 100 cm. The grading angle and base length of the slope model are designed with 45° and 170 cm, respectively. In order to ensure that the water level changes uniformly during the test, the sealing glass on the other side of the channel is parallel to the slope surface, which is 45° between the sealing glass and the bottom plate as shown in Fig. 1.

A water level control method is present to simulate the rise and drawdown of the water level. The water level control system consists of a water storage tank, a tube, a flow control meter and water pump. The changes of water level are controlled by injecting water or drawing water out. The water pump and a valve are used to control the rate of the rising and drawdown process of the water level.

2.2. Tested soil and construction of physical model

Laterite soil is used in the model experiments, which was excavated from a slope of reservoir in Nanchang of China. The specific gravity is 2.71. The maximum dry density is the 1.877 g/cm^3. The dry density of the slope model in this paper is 1.6 g/cm^3. The saturated hydraulic permeability coefficient is 6.59×10^{-5} cm/s. The initial water content of laterite soil in model is 15%. The tested soil layer is filled by four layers according the dry density 1.6 g/cm^3. The first layer is 10 cm, and other three layers are 20 cm. The soil remained covered for 24 h before the filling program is started. The experiment is started immediately after constructing the slope model to avoid unintended changes of water content. The sides of testing channel are coated with vaseline to reduce friction. The overview of the slope model after construction is shown in Fig. 2. The slope behaviour is observed when the water level is changed. The pore water pressure, water content and deformation are recorded during the rising and the drawdown process of the water level.

2.3. Measure method

Controlling the rising and drawdown of water level is implemented in the test, a series of test data are obtained, such as pore water pressure, water content and displacement. Three types of instrumentation are installed to monitor the behaviour of the slope model. The instruments are piezometers, soil moisture probes and white balls. All the instruments located inside the slope are installed.

The deformation in the model slope is measured using the white ball. The white balls are buried along the side of slope. The movement of the white ball can be observed in the test process through glass. Vaseline is used as an interface around the white ball to reduce friction to a minimum.

Fig. 2. Overview of the slope model after construction.

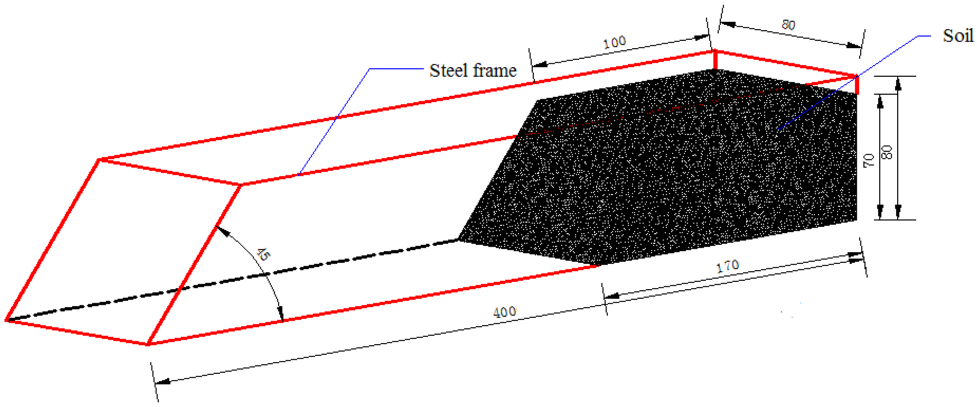


Fig. 1. Slope model (dimensions are in cm).

A total of 17 white balls were installed at elevations of 10 cm, 30 cm, 50 cm and 60 cm. The arrangement of the white ball in the slope is shown in Fig. 3. The horizontal and vertical deformations are measured.

Five piezometers are installed at 10 cm, 30 cm and 50 cm elevations of the slope model. When the slope model is constructed to 10 cm elevation, 3 piezometers are installed. And the other two piezometers are buried at 30 cm and 50 cm, respectively. The intent is to measure the pore water pressure changes generated during the water level fluctuation. When the slope model is constructed target elevation for the piezometers, the piezometers are installed. Soil moisture probes are placed at the different elevations to measure the water content in the soil. The location of the soil moisture probes is the same as the location of the piezometers. A total of 5 soil moisture probes are buried in slope model. The layout and location of piezometer and soil moisture probe are schematically shown is Fig. 4. The piezometers and soil moisture probes are calibrated prior to installation.

2.4. Test scheme

The model test is divided into 4 stages. The first stage is rising water level stage with water level rising from 0 to 60 cm, the rate of rising water level is 0.6 cm/h (rising the water level for 10 h). The second stage is holding water level stage with water level at an elevation of 60 cm (holding the water level for 12 h). The third stage is drawdown stage of water level from 60 cm to 0, and the rate of lowering water level is 3 cm/h (during 2 h). The fourth stage is static stage for 12 h. The total time of the test is 34 h. The test scheme is listed in Table 1.

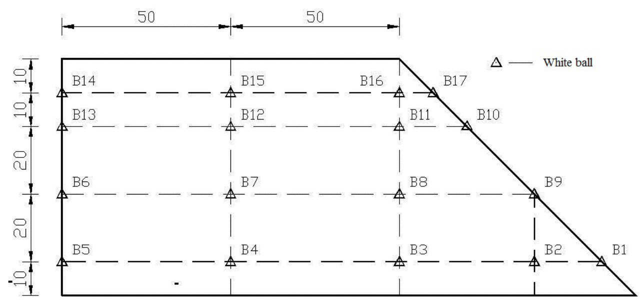


Fig. 3. Layout of white ball in slope model (dimensions are in cm).

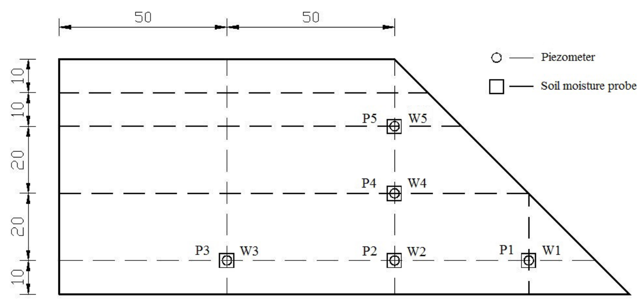


Fig. 4. Layout of piezometer and soil moisture probe in slope model (dimensions are in cm).

3. Results and discussion

3.1 Pore water pressure

During the rising water level stage as shown in Fig. 5, the water table and pore water pressure in the interior slope rise gradually. The most amplitude is 60 cm in this case. The variation of the pore water pressure with time of each test stage from 5 piezometers is shown in Fig. 6. It is clear from the Fig. 6 that, while the water level is rising, the pore water pressure is rising with increasing time. When water level rises to the highest water level 60 cm, the pore pres-

Table 1
Test schemes

Stage No.	Scheme type	Water level change (cm)	Fluctuation rate(cm/h)	Duration (h)
No. 1	Rising	0 ⟶ 60	6	10
No. 2	Holding	60 ⟶ 60	0	12
No. 3	Drawdown	60 ⟶ 0	3	2
No. 4	Static	0 ⟶ 0	0	10

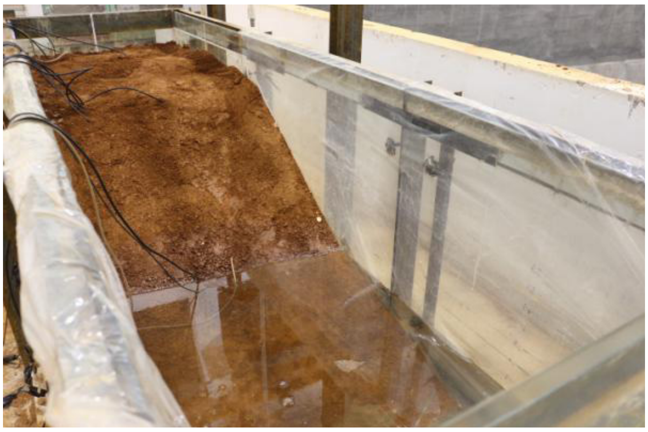


Fig. 5. The water level rising.

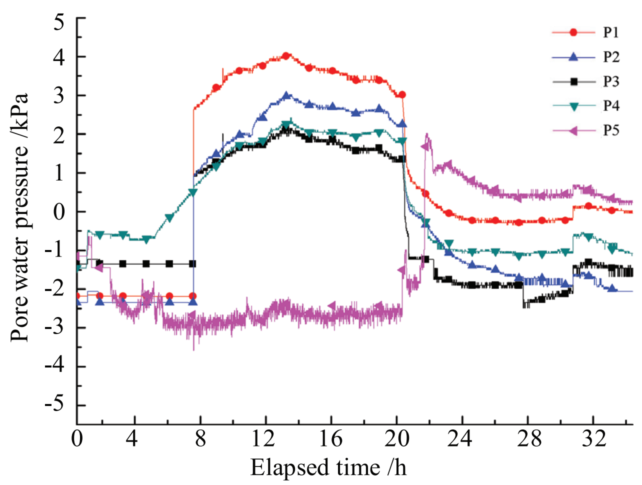


Fig. 6. Variation of the pore water pressure with elapsed time.

sure does not reach the maximum. The pore pressure will continue to rise during holding water level stage with water level 60 cm.

Water level fluctuation induces the change of pore water pressure, especially in waterfront of the slope. The pore water pressure recorded increases rapidly. When the water level rises to 60 cm, the pore water pressure at all points reaches a relatively high value. However, the maximum pore water pressure appears at the holding water level stage. A delay is observed for the pore water pressure response. This is due to the influence of the hydrophilicity and permeability in clay medium. After a water level of 60 cm is maintained for 10 h, the sudden drawdown of the water level began. The rate of drawdown is approximately 3 cm/h. During the water level drawdown stage, the water table and pore water pressure in the interior embankment rapidly decrease. The pore water pressure is a key factor which results the slope failure.

3.2. Water content

The water content measure from 5 soil moisture probes is shown in Fig. 7. The water allows to flow into the slope, the soil moisture probes start to respond. The water content measured in the soil moisture probes at the different elevations increased with time in response to increases water levels. The soil moisture probes show a similar general trend during the water level rising. The water content increases significantly and reaches a peak value. It is clear that the rising rate of the water content in different position is also different. The smaller the horizontal distance from the water content measurement position to the intersection of the slope surface, the larger the rising rate of the water content. The water content is rising linearly with time in the rising stage. The water content expresses a significant delay relative to the drawdown of the water level. The change process of water content is similar to the change trend of pore water pressure.

The change rate of water content is the fastest in the process of rising water level and drawdown water level, especially for the measurement points in the high level (No.5 soil moisture probe). And the rate of water content change is slow at the stage of water level holding and the stage of water static setting. The soil is saturated or near saturated.

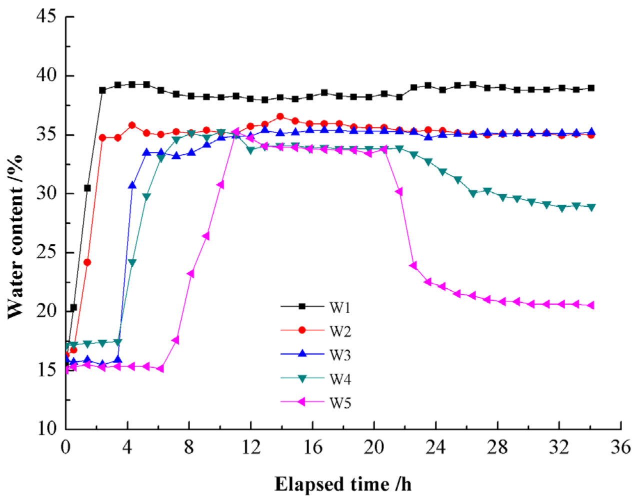


Fig. 7. Variation of the water content with elapsed time.

3.3. Deformation

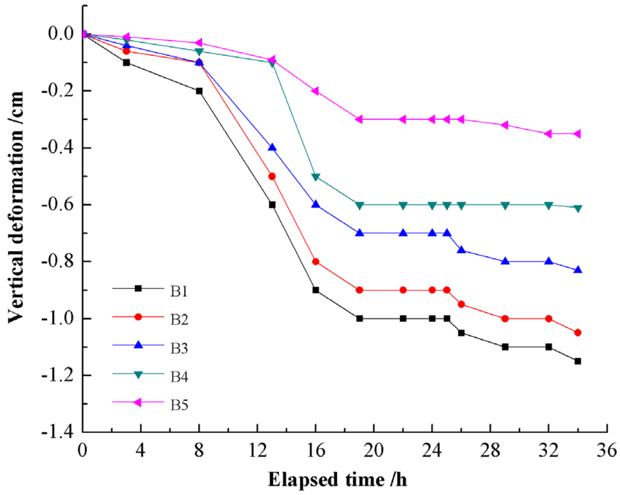
3.3.1. Vertical deformation

The distances from the first level, second level, third level to the base of the slope model is 10 cm, 30 cm and 50 cm, respectively. The Fig. 8 shows the variations of vertical deformation in the different levels and the time. Fig. 8a, Fig. 8b and Fig. 8c are vertical deformation of the first level, second level and third level, respectively. The testing results of three levels are very similar. The only difference among three levels is value of the deformation. The deformation increases steadily with the rise of the water level during the rising water level stage, which is similar to the proportional relationship. The settlements range from 3 mm to 12 mm. As the water level rises, the water is permeated from the surface of the slope to the interior, the pore water pressure in the slope increases and the corresponding effective stress decreases, which leads to the softening of the front soil. The settlements are likely due to the wetting-induced collapse. The larger the horizontal distance from white ball to the intersection of the slope surface, the smaller the vertical deformation.

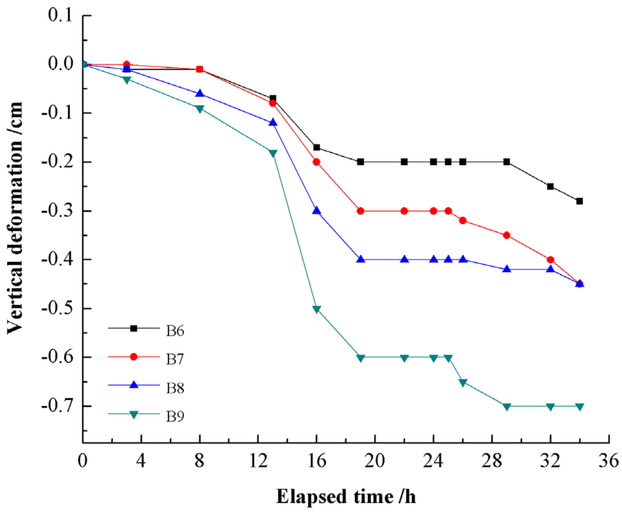
3.3.2. Horizontal deformation

The horizontal deformations recorded by all white balls are shown in Fig. 9. Fig. 9a, Fig. 9b and Fig. 9c are horizontal deformation of the first level, second level and third level, respectively. The horizontal displacement of each measurement point is positive outside the slope and negative to the slope. When the water level reaches 60 cm, the deformations of the measurement points increase sharply. In the case of the horizontal deformation of the first level as shown in Fig. 9a, No. 1, No. 2 and No. 3 measurement points move into the slope when the water level begins to rise, while the No. 4 and No. 5 measurement points move out of the slope. This is due to the humidification of the soil near the surface of the slope and the compression to the seepage direction. As the water level rises to the highest level 60 cm and holding the water level stable for a period of time, the displacement of each measurement point gradually increases and reaches steady state. The moving direction of the point away from the slope surface changes from outward to inward due to the infiltration. As the drawdown of water level, the horizontal deformation point to the slope surface due to the drop of phreatic line. The horizontal deformations of second level and third level are similar to the first level.

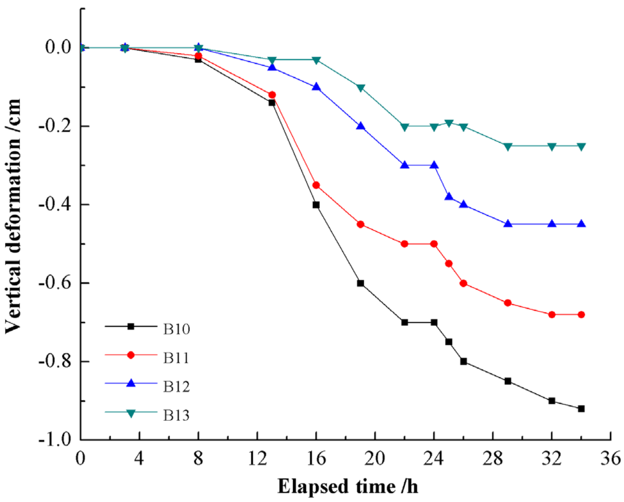
Comparing the deformation in the process of rising and drawdown water level, the deformation in water level rising stage is larger than when water level drawdown stage. The reason is that the unsaturated state is changed into saturated state by seepage and the soil has softened. The mechanical properties, such as cohesion and the internal friction angle, have changed greatly. The rise and drawdown of the water level has a great influence on deformation of slope.



(a) First level

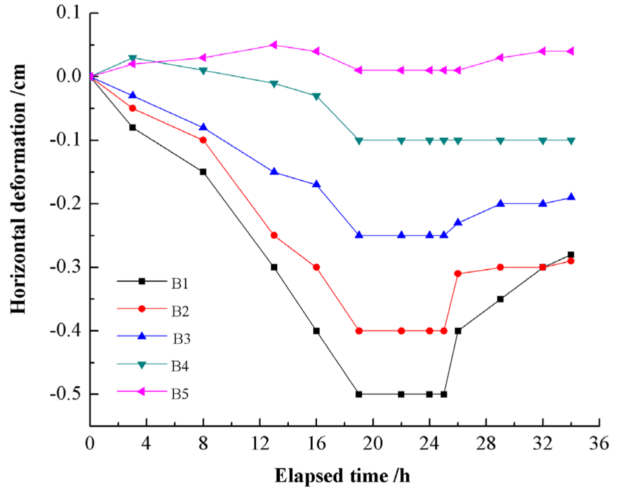


(b) Second level

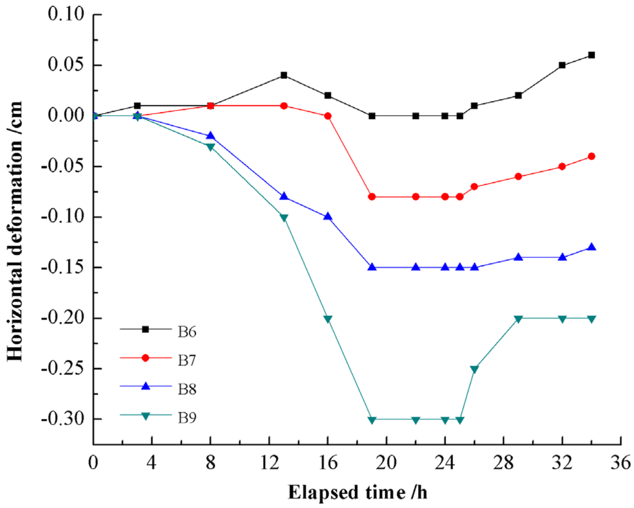


(c) Third level

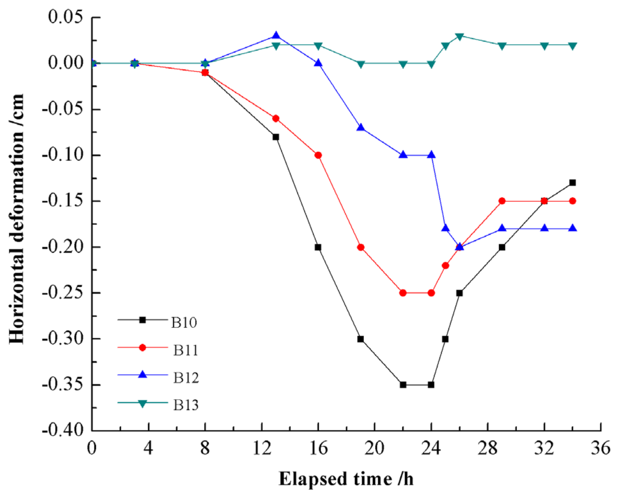
Fig. 8. Variation of the vertical deformation with elapsed time.



(a) First level



(b) Second level



(c) Third level

Fig. 9. Variation of the horizontal deformation with elapsed time.

4. Conclusion

In order to investigate the influence of the water level fluctuation on the pore water pressure, water content and deformation in the slope, a physical model is made of laterial soil. The experiment improves the understanding of the physical behavior of the slope subjected to water level fluctuation. As the water level rises, the pore water pressure increases. When the water level rises to the highest level, the pore pressure does not reach the maximum. The pore pressure will continue to rise during the water holding stage and achieve stability. When the water level falls, the pore pressure decreases rapidly. The pore water pressure in soil exhibits the significant delay relative to the water level fluctuation. The whole change process of water content is the same as the change trend of pore water pressure. The vertical displacement of the soil has been moving downward during the whole test process. Horizontal deformation will occur in the direction of slope or outside slope with the different stages and measurement positions. The soil has strong water softening characteristics by the water level fluctuation.

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