Research on the Relationship between Landslide of Farming Terraces and the Intensity of Rainfall and Slope Angle Based on the Indoor Rainfall Slide Slope Model

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Abstract: *Due to the increase of geographical disaster in China, it is necessary to study the formation mechanism to make a preparation for the future prevention of geological disasters and effectively reduce the unnecessary financial loss and casualties. We found there is a powerful connection between heavy rainfall and landslide slope. Thus, this article takes the accumulation of gravel soil as the research material to set up indoor rainfall and landslide model test. By comparing the rules of pore water pressure and soil pressure responding to different rainfall intensity and slope angle, we discussed over the effects of rainfall intensity and slope angle on the sliding of accumulation gravelly soil.*

Keywords: *Kinetic, Landslide model, Rainfall intensity, Slope angle, Farming terraces.*

Introduction

In recent years, the frequently paroxysmal geological disasters occurring in China have caused great damages on the local agriculture, mainly concentrated in southwest, northwest regions. Because of the influence of rainfall, soil texture, the change of water level, destruction of vegetation caused by human activity and potholing on the slope, those provides conditions for the formation of the landslide [4, 8]. The phenomenon of landslide of accumulated gravel and soil is particularly common. Therefore, it is crucial to study the impact of farming terraces and slope angle on the formation of landslide of accumulated gravel and soil. A lot of scholars have started using indoor rainfall landslide model to make research [2]. Ouyang et al. [3] made a large-scale shear test under the condition of flexible boundary, concluding that it is the stone size that most effects on the shear performance of earth-rock aggregate, the percentage of rock comes second, and the arrangement of stone last. Wang [10] made an indoor large-scale direct shear test to study the effect of moisture content and granular match on shear strength parameters of gravel and soil, setting up the relation between shear strength of gravel and soil and percentage of stone, and between shear strength of gravel and soil and moisture content. Fan et al. [1] studied the equal stress boundary loading testing machine and took the condition of flexible pedestal and indenter. Throught that, he came to the conclusion that the shear strength index of earth-rock aggregate under the condition of equal displacement boundary condition is significantly larger than the index tested under the condition he studied. Based on the scholars, we set up an indoor rainfall slope slide model, analyzed the results and finally found out the influence index, which can provide a theoretical basis and practice guidance to similar projects of slide slope prevention.

The general situation of rainfall and landslide accumulated gravel and soll

The characteristics of farming terraces

The structure of farming terraces is loose, but its water permeability is stronger, whenever material composition contains gravel, dimension stone, sand and clay, etc. The specific characteristics are shown in Table 1.

Table 1. The characteristics of sliding of farming terraces [6]

Item	Characteristics
Composition	Eluvial layer, colluvial clay, plant leaf residue, etc. Material composition mainly concludes soil, splintering rock, and mixture of soil and stone.
Sliding surface	Any connected fracture surface on the surface of subterrane or inside slope body; a plane or curved surface.
Hydrological quality	The structure of composition is loose, with wide porosity, bad intergranular binding force and strong water permeability.
Sensibility of rainfall	The stability of accumulation formation slope is influenced and controlled by rainfall.
Characteristics when happening	It has randomness, recidivity, diversity, characteristic of group and synchronism. It may be caused by rainstorm or heavy rainfall which can cause a sliding and repeated slow moving.
Displacement	It often appears discontinual shape change, the regularity of time series is bad, and displacement has the quality of late rainfall. Pull-type slide slop mainly depends on traction from bottom to the top, usually forming into multistage slide, bad globality; push-through type slide reflects as progressive sliding based on posterior extrusion.
Plane of tension fissure	Forms at the back of tensile stress, especially near the back wall of slide slope, some cracks appear. The depth and scale are decided by the stress of tensile stress and condition of displacement.
Developmental stage	Creep stage takes a long time, without obvious moving stage. The speed of sliding has great difference due to the slope angle
Being a disaster	It has large distribution areas, deep effect, and repeatability and succession, mainly happening in farming terraces, slope farmland and farming area, which is a threat to people, wealth and production.
Prevention	The methods usually are sewerage, retaining wall, soil texture improvement.

The relationship between rainfall and reason of slope sliding

Rain can induce different forms [5] of farming terraces: (1) Sliding destruction. When sliding force of soil body is greater than sliding resistance force, sliding destruction of shear occurs to the slope. (2) Flow destruction. Once the instability occurs, if the soil has strain softening behavior, sliding soil mass may be in sliding and flowing status. (3) Slide and slowing destruction. (4) Flowing or sliding damage.

Testing apparatus of indoor rainfall landslide

Indoor landslide model test device [9] as shown in Fig. 1 is mainly composed of model trough, rainfall system and intercepting drains. The frame of the model trough is made of box iron soldering with angle iron and bolt anchoring. The maximum design size of model trough is 4 m × 3 m × 2.5 m (length × width × height). To facilitate the landslide model forming and whole landslide test procedure observation, inside the framework of the model trough, there is 18 mm thick stalinite fixed which has red line mesh generation, with the size of 50 mm × 50 mm. The whole water supply pipeline consists of cast iron pipe whose inner diameter is 20 m thick, wire hose whose inner diameter is 25 mm thick, three direct links of adapter substitute, valves, sealing up clamp and waterstop. Interception pipeline consists of PVC semicircle pipe with inner diameter of 100 mm thick, steel wired hose with inner diameter of 25 mm thick sand adapter substitute.

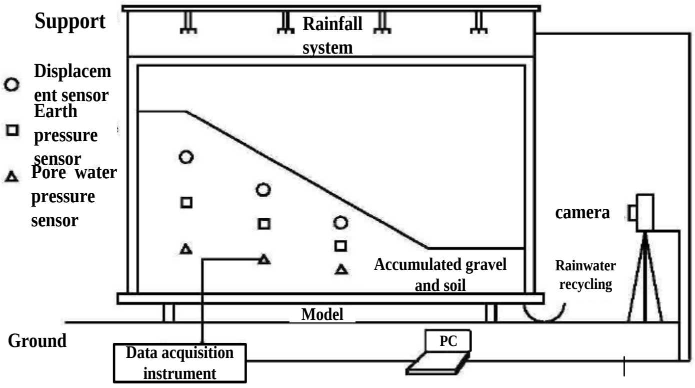


Fig. 1 Landslide model test schematic diagram

Model testing program of indoor rainfall landslide

Testing material

In accumulated gravel and soil extracted from testing, the composition of soil is silty clay with sand, and composition of mother rock is argillaceous siltstone. Some accumulated gravel and soil are selected by quartering and a test of parallel determination for moisture content in 12 groups is made, then a result that average moisture content is 8.69% is obtained. Some are selected and dried and a screen test was applied which showed that the stone content is 68.48%. Also we found that the proportion of chipping whose grain size is more than 80 mm is not exceeding 5% in all the sampling of farming terraces. Therefore, it can be ignored. Then a test was made to the sample prepared by equivalent substitution method after drying and screening the accumulated gravel and soil. We obtained the result that the optimum moisture content of farming terraces is 8%, the maximum dry density is 2.08 g/cm^3, cohesion is 97.3 kPa and internal friction angle is 26.45°.

Setting influence factors of testing

According to the existing statistical data and research results [7], long lasting light rain and short duration heavy rainfall can all easily induce the occurrence of landslides. As more than one indoor rainfall and landslide model tests needs to be carried out and sliding is hoped to happen, then continuous short-duration heavy rain is determined as the rainfall condition. Combined with the test of rainfall calibration before; we confirm that the rainfall intensity are 1.2 mm/min and 1.6 mm/min. Given the test environment and the limitation of indoor lighting, water pressure, the time of rainfall was decided to be 300 min, which means the working condition of each time will be continuous raining for 300 min.

Basic size of side slope

The sketch map of basic size of side slope is shown in Fig. 2, mainly including length, width, height, angle and shape of slope. The slope length consists of segment length of slope crest, slope surface and slope toe. The height of slope is the height of whole side slope, which means the maximum distance from the bottom to the top.

(1) The design of slope angle: Based on the analysis of geological disasters invested from all counties and cities, landslide usually grows in slope range of 25°~40°. Large and giant landslide relatively concentrated in the range of 10°~40°. With the decreasing of the landslide scale, the slope range up gradually. Small landslides grow in the range of 40°~60°. There are landslides of gravel and soil growing when slope angle is 20°~40°. When slope angle is below 20°, only special soil landslide occurs. When the slope angle is over 40°, there is more collapse and less slope landslide [11]. To sum up, the slope angle in this experiment is set as 22° (slope ratio is 1:2.5) and 31° (slope ratio is 1.5:1.5).

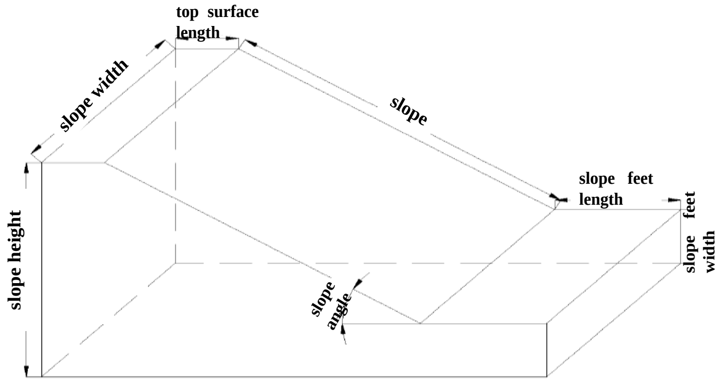


Fig. 2 Basic size for side slope

(2) The design of height: The height of slope should be confirmed by slope angle, actual size of model trough and rainfall coverage. Considering the sliding of side slope, we set the height as 150 cm when the angle is 22° and the height as 200 cm when the slope angle is 31°. In order to observe and measure the change of slope angle better, the height of slope toe is set as 50 cm.

(3) The design of width: The proper width should be in the range of 1~2 m. If the width is too small, the test will be affected by the boundary; if the width size is too big, then it greatly enhances the workload of the test model. In this experiment, the width of slope should be 150 cm, which means the slope is 150 cm wide in all working conditions.

(4) The design of length: Slope length should be based on the the slope angle, slope height, actual size of slope trough and longitudinal scope of rainfall of model. This test divides the slope length into length of top, horizontal projection length of slope surface and length of slope toe. In order to make better observation , the total length of slope is designed to be 400 cm long (it is consistent with the model trough length), the top surface designed to be 50 cm, horizontal projection length of slope surface designed to be 250 cm, length of slope toe designed to be 100 cm. These lengths and the directions are consistent.

Slide slope molding

(1) Waterproofing work: In order to ensure the accuracy and the drainage condition of the test, before filling and laying slope, two layers of transparent waterproof fabric are laid at the bottom of the model trough. On three closed sides of model trough, waterproof cloth is pasted on tempered glass surface extending 10 cm upward from the bottom; on front opening surface, waterproof fabric stretches into a semicircle interception PVC pipe extending 10 cm.

(2) Delineating: The outline of slope was delineated on the external surface of tempered glass of model tank according to the designed size of slope, thus to control the molding of slope.

(3) Placement in layers: First, the thickness of each layer was confirmed as 10 cm; then the quality of gravelly soil of every layer was calculated and prepared according to the pre-set dry density, actual measured moisture content and the volume of detritus soil; afterwards, the detritus soil is poured into the model tank, 15~20 cm for every layer; finally, the soil was compressed till reaching the height of the layer; in order to ensure the reliable bonding between layers, gravelly soil in different layers were combined into a whole; the contact surface of two adjacent layers was processed with shaping.

(4) Embedding of elements: PVC pipe was embedded into the specified location instead of element; after hierarchical compaction, the PVC pipe was pulled out and the elements were embedded. While sorting out sensor circuit, we should try to avoid the winding of connecting wires of sensor. Moreover, certain flex space needs to be reserved between the connecting wires of sensors.

(5) Adjustment of slope shape: Gravelly soil was placed layer by layer and then compacted till exceeding 3 cm beyond the preset outline; then the slope was corrected to make it smoother; finally, the surface of side slope was roughened.

Results and analysis

The process of slope's growth

Fig. 3a shows the process of landslide's development. When the rainfall duration reaches 40 min, some small runoffs appears on the slope surface, but the slope is not damaged. When rainfall duration reaches 60 min, the slope surface exhibits more runoffs, and the slope toe is observed with a small amount of water, but slope frees from damage.

Fig. 3b shows the process of the development of landslide. When the rainfall reaches to 40 min, the volume of runoff increased obviously, and we can see a small amount of fine particles flowing to slope toe with clear water. And near slope toe, there is a small amount of water. When rainfall duration reaches 60 min, local mudflow appears on the surface of slope, and a large number of fine particles and a small number of coarse particles slides towards slope toe, and the amount of water accumulating at slope toe becomes larger.

Fig. 3c shows the process of the development of landslide. When the rainfall reaches to 40 min, direct surface runoff happens, water slope foot appears near the slope toe, and local mud flows on slope surface. When rainfall lasts for 60 min, local mud flow is observed on the surface of earth and the amount of water accumulated at slope toe has a remarkable increase.

Under the same slope, rainfall intensity of Fig. 4a is 1.2 mm/min and Fig. 4b is 1.6 mm/min. The comparison between a and b shows that if the slope angle stays the same, the greater the rainfall intensity is, the earlier surface of slope will form into runoff enterclose; the greater the rainfall intensity is, the stronger the impact force of rainfall to the surface of slope will be; at the same time frame, the bigger the volume of runoff is, the earlier and more serious the erosion phenomenon of slope surface becomes. Under the same rainfall intensity, the angle of Fig. 4a is 22°, Fig. 4c is 31°. By comparing Fig. 4a and Fig. 4c, it shows that the rainfall characteristics of slope surface shows that when the rainfall intensity is constant, the greater the slope angle, the more rain in the earth's surface iapsed, the less the rain infiltrates, the earlier the runoff comes into formation, the earlier water gathers in the slope foot and the more serious the surface erodes.

a) b) c)

Fig. 3 Process of landslide's development (40 min)

a) b) c)

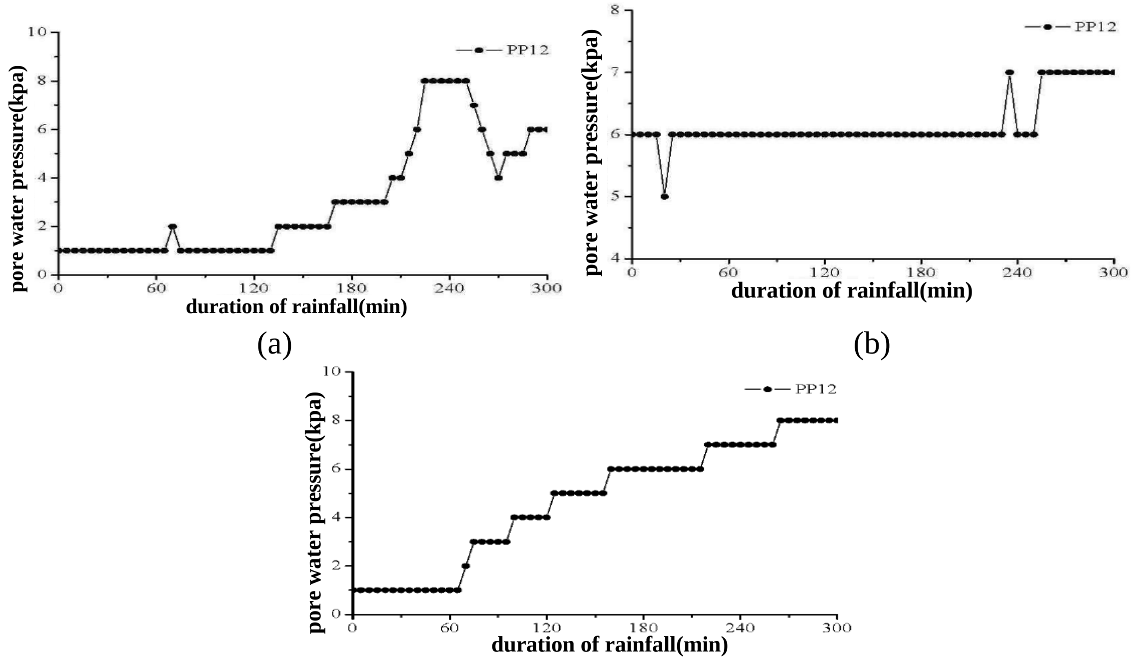
Fig. 4 Process of landslide's development (60 min)

The change of pore water pressure

Fig. 5 is the graph about the pore water pressure of slope toe change based on the rainfall. Fig. 5a and 5b are under the same rainfall intensity which is 1.2 mm/min. The slope angle of Fig. 5a is 22° and Fig. 5b is 31°. Through comparison, we found that when the rainfall intensity is constant, the smaller the slope angle is, more quickly pore water pressure responses, the faster the pore pressure increases in the early stage of rainfall and the greater the pore pressure changes. Fig. 5b and 5c are under the same slope angle of 31°. The rainfall intensity of Fig. 5c is 1.3 mm/min, inconsistent with Fig. 5b. The greater the rainfall intensity is, the more quickly pore water pressure responses and the faster the pore pressure increases in the early stage of rainfall.

The change of soil pressure

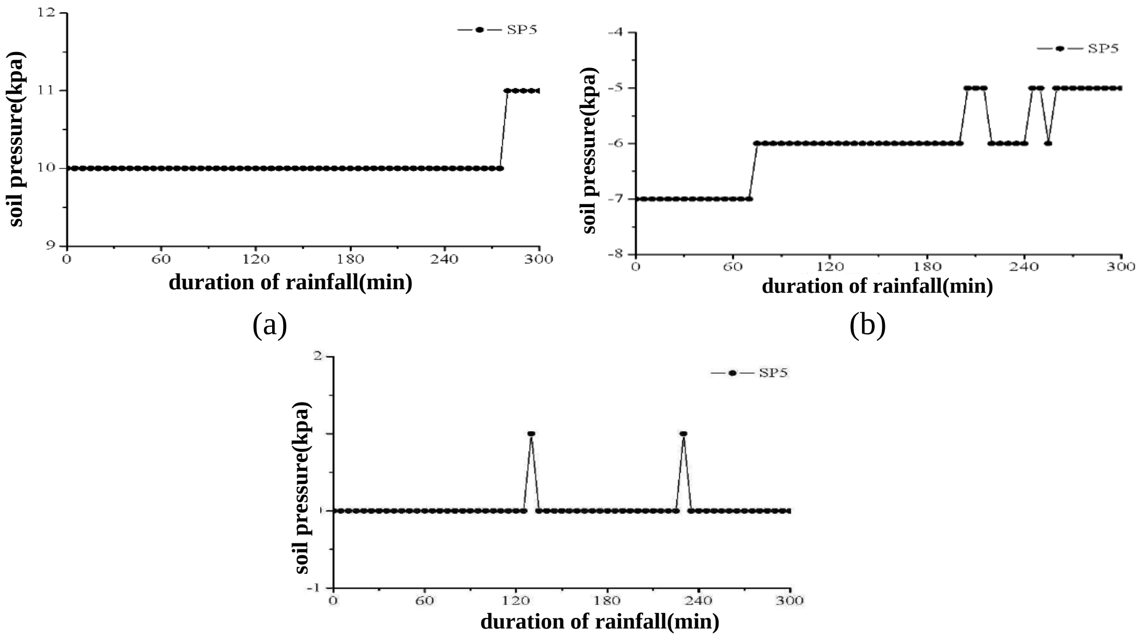
Fig. 6 is the graph of the change of soil pressure of the slope top and waist based on the rainfall. In Fig. 6a and 6b, the slope angle is 22°. The rainfall intensity of Fig. 6a is 1.2 mm/min, less than the rainfall intensity of Fig. 6b (1.6 mm/min). The comparison of characteristic curve of soil pressure of slope top and slope waist shows that, when the slope angle is fixed, the greater the rainfall intensity is, the faster the rainfall infiltrates and the more significant the increase of volume of soil on soil pressure sensor, leading to faster change of soil pressure and more remarkable increase of soil pressure. Rainfall intensity is the same in Fig. 6c and 6b. The slope angle of Fig. 6c is 31°, which is greater than Fig. 6b. Through comparison, we found that, when the rainfall intensity is fixed, the smaller the slope angle is, the deeper the rainfall infiltrates in the early stage of rainfall, the more significant the increase of volume of soil on soil pressure sensor, leading to faster change of soil pressure and more significant increase of soil pressure.



(a) (b)

(c)

Fig. 5 Changes of slope toe along with the duration of rainfall



(a) (b)

(c)

Fig. 6 Change of soil pressure of the slope top and waist based on rainfall

Conclusion

According to the experimental results and analysis, deformation and fracture of debris landslide have a great connection with rainfall intensity and slope angle and rainfall intensity is not proportional to landslide deformation. High rainfall intensity may inhibit the infiltration of rainwater and the increase of pore water pressure in slope body, thus make the sliding of slope difficult. When rainfall intensity reaches a certain value, the larger the angle is, the deeper the rainwater infiltrates, which makes the run-off channel harder to form. What is worse, the slope may lose stability. In such a condition, collapse rather than sliding may happen.

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