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Type of Slope Failure Identified from Pore water Pressure and Moisture content Measurements

Muhammad Rehan Hakro[1, a], Indra Sati Hamonangan Harahap[2,b]

[1,2] Department of Civil Engineering Universiti Teknologi PETRONAS, Malaysia

[a]rehanhakro@yahoo.com, [b]indrasati@petronas.com.my

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Abstract. Rainfall-induced landslides occur in many parts of the world and causing a lot of the damages. For effective prediction of rainfall-induced landslides the comprehensive understanding of the failure process is necessary. Under different soil and hydrological conditions experiments were conducted to investigate and clarify the mechanism of slope failure. The failure in model slope was induced by sprinkling the rainfall on slope composed of sandy soil in small flume. Series of tests were conducted in small scale flume to better understand the failure process in sandy slopes. The moisture content was measured with advanced Imko TDR (Time Domain Reflectrometry) moisture sensors in addition to measurements of pore pressure with piezometers. The moisture content increase rapidly to reach the maximum possible water content in case of higher intensity of rainfall, and higher intensity of the rainfall causes higher erosion as compared to smaller intensity of the rainfall. The controlling factor for rainfall-induced flowslides was density of the slope, rather than intensity of the rainfall and during the flowslide the sudden increase in pore pressure was observed. Higher pore pressure was observed at the toe of the slope as compared to upper part of the slope.

Introduction

Slope may be defined as surface of ground that makes an angle to the horizontal place. Slope can be man-made or natural. We can broadly describe the slope failure as landslide in which large mass surges down slope in response to gravity. Landslide is complex process that can occur in natural as well as in engineered or man-made slope. Slope may resist gravity or collapse because each slope possesses unique characteristics of soil and geometric features. The flowslide is the rapid type of the slope failure having long runout distance and occured mostly becuase of rainfall. Slopes slide often begins from hairline tension cracks, which propagates through layers of soil.

Soils in dry and rainy season experiences drying and wetting processes at shallow depth, and the soil moisture content significantly affected by drying and wetting process. Rainfall induces the slope failure because in dry or partially dry slope the part of rainfall infiltrated in to the slopes and alters the existing moisture equilibrium. Slope failure occurs due to development of excess moisture. This moisture disturbs the interparticle friction and cohesion in the saturated soil. The soil moisture content particularly at the shallow depth may go through the unsaturated and saturated conditions, and in the stability of soil slope the mechanics of unsaturated soil plays an important role. The matric suction provides the shear strength to unsaturated soils, when matric suction reduced due to infiltration of rainfall, ultimately the shear strength of soil reduced. The change in soil matric suction plays an important role in the stability of slope. Because of rainfall descending of wetting front changes the unsaturated zone into saturated zone, increase the shear stress from increase the unit weight of the soil and decrease the shear resistance due to loss of capillary suction. When steady state or equilibrium conditions achieved the movement of wetting front stopped. The slope may be in danger long after termination of rainfall because low negative pressure and high degree of saturation remain in the slope for longer time. Pore pressure increase may be related to infiltration of rainfall or because of build-up of perched or ground water table [1]. Due to rainfall events the slope failure occurs based on individual geometry, strength of soil and infiltration parameters [2]. To understand the occurrence of landslide and the process acting within mass movements due to rainfall many methodological approaches has been developed, however the actual process of failure initiation is still not clear.

Due to infiltration of the rainfall many slope failure occurs because of increase in pore pressure and seepage force in the soil. As the soil becomes gradually saturated with infiltration of rainfall, the stability of the unsaturated soil slope can be dramatically altered and even resulting in slope failure. If there is plenty of water the in the soil with favourable geological conditions the collapsed soil may take the form of the flow. The flowslide is the type of the slope failure that mostly developed from shallow slips and having long run-out distances, and occurs without any warnings. For study the rainfall-induced slope failure few model studies have been conducted and valuable information has been revealed. [3] investigated the effect of grain size and different initial dry densities on generation of pore pressure and failure behaviour by laboratory flume experiments. Laboratory experiments have been conducted by [4] to investigate the hydrological trigger and failure mode of landslides in clay and sandy soil. They observed that failure occurs in sand without visible precursor and occurs suddenly, while failure in clay soil takes about weeks to fail. Monitoring of pore pressure is considered as useful tool to predict the landslides in sandy soil instead of monitoring the displacement.

[5] conducted the experiments in flume to investigate the effect of initial sample thickness and initial dry density on the development of the pore pressure and flowslide motion under artificial rainfall in laboratory. Experiments conducted by [6] in large flume to understand the behaviour of landslide under different hydrological triggers such as exfiltration from bedrock, prolonged rainfall, overhead sprinkling and combination of these methods. [7] performed the experiments in laboratory on homogenous soil slopes with inclination of 30^{O} to 40^{O} on slity sand. They observed from the results that failure occurred at the toe of the slope when the soil in that region nearly saturated.

Although great efforts are devoted to initiation, fluidization of landslide with emphasis on pore water pressure generation [8, 9], but the slope failure with measurement of moisture content is limited. Hence, the present research attempts to investigate the effect of moisture content during heavy rainfall events on the initiation of slope failure with different soil and hydrological conditions.

This research is based on investigation of rainfall-induced slope failure by monitoring the hydrological response of sandy slope by measurements of moisture content and pore pressure by Imko TDRs and piezometer respectively.

Methodology

The experiments were performed in a model flume as shown in Figure 1. The flume has dimensions of 2m x 2m x 1m with constant inclination of 45^{0}. The model flume made of Plexis glass except the frame, which is made from steel, glass was used to observe the changes during the failure. Before the conducting the experiment the soil was placed in model flume layer by layer, and each layer was compacted in case of dense slope, while slight compaction given in case of loose slope. The slope thickness, density and initial moisture content and rainfall intensity were varied to investigate the rainfall-induced slope failure. The rainfall intensity was controlled by flow meter and valves were attached with the body of sprinklers fitting. The compaction was given to slope with 2 kg manual fabricated hammer. The soil was placed parallel to flume bed and compacted. After the preparation of model slope, the sensor such as moisture sensor Imko TDRs and piezometers were installed in soil slope by drilling the holes in soil slope, after that holes were backfilled with moist soil. The pore pressure was measured with electrical piezometer model Sisgeo P235S, with range of measurements from 0 to 100 kPa. The failure in model slope was induced by artificial rainfall through sprinkler. The grain size distribution of soil sample is shown in Figure 2. Based on the results of gradation curve the coefficient of uniformity C_u and coefficient of curvature C_v was calculated as 3.3 and 0.83 respectively. The basic properties of sand were, soil particle density 2.6 kg/m^3 x 10^3 and from this dry density was calculated as 1.6×10^3 kg/m^3, and the void ratio of 0.58. The hydraulic conductivity was 3×10^{-4} m/s. The data acquisition system was consisting of personal computer and Unilog datalogger of Seba Hydrometry, and data were logged at the interval of 2 minutes.

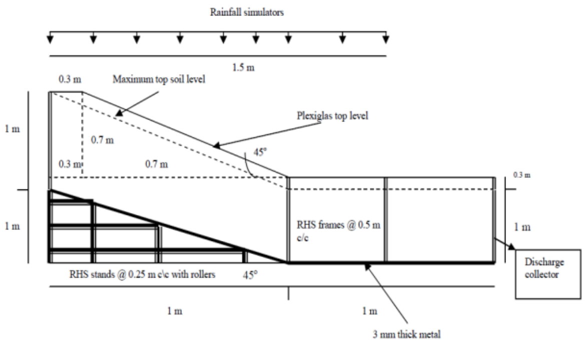

Figure. 1. Side view of model flume

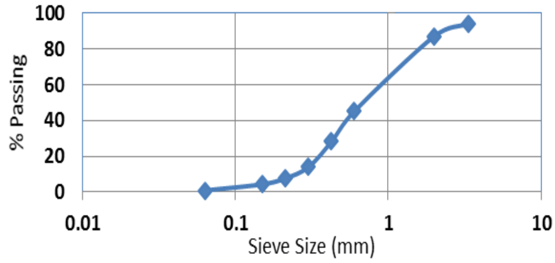

Figure. 2. Particle Size distribution curve

The moisture content was measured with Imko TDR, the TDR consist of 2 rods with 10cm of the depth, and these TDRs were connected to another Globelog datalogger for data acquisition and same this was logged after 2 minutes.

Results and Discussion

The current research was mainly focus on the mode of slope failure by changing the soil and hydrological parameters. The shape and slope inclination was made fixed and then failure was induced in soil slope by artificial rainfall. The slope failure induced when the moisture at the toe of the slope attains the full saturation [7, 10]. According to most literature it was believed that slope failure initiated at the toe of the slope, but it is not true in all cases. Although the toe of the slope is sensitive to rainfall, but the failure can be initiated at upper parts of the slope as well, this was due to reduction of shear strength with increasing of moisture content. This was because after the formation of cracks higher infiltration increase the water content at that part of the slope and trigger the slope failure. After the formation of cracks the large failure occurred with couple of minutes. Even if the flowslide occurs due lower soil density of soil slope, in the case higher thickness of soil slope only shallow soil depth was suffer flowslide. In most of the experiments no sudden sliding was observed, this was due to higher density and thickness of slope, because density turns depends upon the thickness of slope. The soil particles washed at the toe of the slope due rainfall infiltration and became fluidized; this progressed upwards once this started at toe of the slope. The failure surface continues to deepen after shallow slip surface. The experiments were conducted under higher intensity of the rainfall with flow rate was 8 litres/minutes with dense slope conditions. The piezometer P1 was placed at base near to toe of the slope, the piezometer P2 was placed middle of the slope base. The variation in pore pressure with time is given Figure 3. The moisture sensor M1, M2 and M3 was placed at 15, 18, 20 cm of depth respectively. The moisture sensor M1 and M2 shows two steps to reach the maximum saturation and the M3 showed only one step to reach to saturation. The depth of the slope was 30 cm and all the sensors were placed near the toe of the slope. When the pressure increases, it pushes the soil particles and making the soil attraction weaker and slope failure more probable. During the experiments the sharp increase in pore was measured by piezometers during the flowslide failure shown in Figure 5.

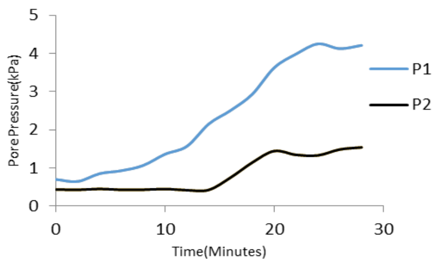

Figure 3. Variation in pore pressure

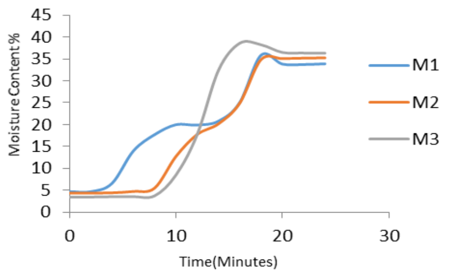

Figure 4. Variation in moisture content

The toe of the slope is critical during rainfall infiltration and maximum changes take place at the vicinity of the toe because higher pore pressure and moisture content observed from toe of the slope, this was also stated by finite element and laboratory experiments of [11] and stated that the most significant and instrumental measurements of changes at the toe of the slope because of high hydraulic gradient, this high hydraulic gradient is the indication of pressure ridges, seepage and surface erosion. Prior to failure formation of tension cracks, appearance of seepage observed in many natural landslide, this was also observed in the present laboratory experiments prior to failure. However the failure time to landslide will be higher in case of natural slope as compared to laboratory experiments. In the case of failure at the toe of the slope, results lateral removal of support results retrogressive failure shown in Figure 6. According to [12] the retrogressive failure is the parts of debris flow, and in our extensive experiments in sandy soil the most of failure modes was retrogressive type in case of slope having higher density. After the saturation runoff occurs at the toe of the slope, which gradually erodes the toe of the slope and induces the instability.

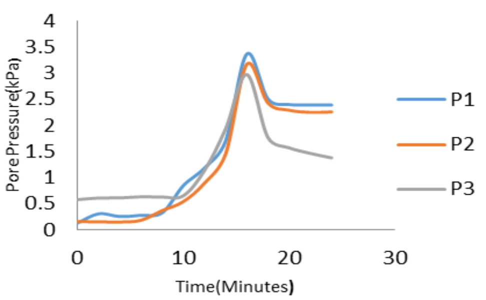

Figure 5. Variation in pore pressure

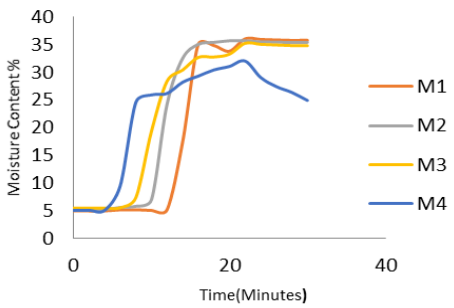

Figure. 6. Variation in moisture content

Conclusion

Experiments were conducted in model flume in sandy slopes to investigate the rainfall-induced slope failures. The slope failed due to infiltration of rainfall. After the saturation the prolonged rainfall generates the runoff at the toe of the slope. The runoff gradually erodes the toe of the slope and induces the instability at upper parts of the slope. The toe of the slope is critical to rainfall because of higher seepage and hydraulic gradient that erode the soil mass, and in the presence of higher moisture content the soil mass moves downwards. Due to removal of lateral support at the toe of the slope the larger collapse occurred in the form of retrogressive sliding. The soil moisture reaches the saturation by two step process, the first indicate the arrival of wetting front and second the rise of water table. The flow type of the failure i.e., flowslide was not due to higher rainfall intensity, however due to lower density of soil slope. The flowslide type of the failure was rapid and occurs suddenly after the formation of cracks at the critical locations of the slope. The variations in pore pressure in slope influenced by density of slope and mode of slope failure; steady failure steady rise in pore pressure, while unsteady failure results unsteady rise in pore pressure. The failure mode affected by density of soil slope more significantly than intensity of rainfall. By increasing the density of slope the dangerous type of slope failure likes flowslide can be controlled. The experiments can be conducted in laboratory under controlled conditions unlike field studies.

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Refernces

[1] M. T. J. Terlien, "The determination of statistical and deterministic hydrological landslide-triggering thresholds," *Environmental Geology,* vol. 35, pp. 124-130, 1998/08/01 1998.

[2] B. Collins and D. Znidarcic, "Stability Analyses of Rainfall Induced Landslides," *Journal of Geotechnical and Geoenvironmental Engineering,* vol. 130, pp. 362-372, 2004.

[3] G. Wang and K. Sassa, "Pore-pressure Generation and Movement of Rainfall-induced Landslides: Effects of Grain Size and Fine-particle Content," *Engineering Geology,* vol. 69, pp. 109-125, 2003.

[4] A. Spickermann*, et al.*, "Water Infiltration Characteristics of Unsaturated Soil Slope and its Effects on Suction and Stability " *Geophysical Research Abstracts,* vol. 11, 2009.

[5] G. Wang and K. Sassa. (2001, Factors Affecting Rainfall-induced Flowslides in Laboratory Flume Tests. *Geotechnique 51,* 587-599. Available: http://www.icevirtuallibrary.com/content/article/10.1680/geot.2001.51.7.587

[6] M. E. Reid*, et al.*, "Deciphering Landslide Behavior Using Large-Scale Flume Experiments," Tokyo, Japan, 2008, pp. 497-500.

[7] R. P. Orense*, et al.*, "Instrumented Model Slope Failure due to Water Seepage," *Journal of Natural Disaster Science,* vol. 26, pp. 15-26, 2004/00/00 2004.

[8] Y. Okura*, et al.*, "Landslide Fluidization Process by Flume Experiments," *Engineering Geology,* vol. 66, pp. 65-78, 2002.

[9] G. Wang and K. Sassa, "An Experimental Study on the Rainfall-Induced-Flowslides," in *Environmental Forest Science*. vol. 54, K. Sassa, Ed., ed: Springer Netherlands, 1998, pp. 591-598.

[10] A. Tohari*, et al.*, "Laboratory Rainfall-Induced Slope Failure with Moisture Content Measurement," *Journal of Geotechnical and Geoenvironmental Engineering Geology,* vol. 133, pp. 575-587, 2007.

[11] S. G. Catane*, et al.*, *Laboratory Experiments on Steady State Seepage-Induced Landslides Using Slope Models and Sensors*, 2011.

[12] G. B. Crosta*, et al.*, "Forecasting hazard scenarios and implications for the evaluation of countermeasure efficiency for large debris avalanches," *Engineering Geology,* vol. 83, pp. 236-253, 2006.

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