International Journal of the Physical Sciences Vol. 6(13), pp. 3126-3133, 4 July, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.549
ISSN 1992 - 1950 ©2011 Academic Journals

*Full Length Research Paper*

# Soil slope deformation behavior in relation of soil water interaction based on centrifuge physical modeling

**Muhammad Mukhlisin[1,2]*, Ilyias Idris[1], Wan Zuhairi Wan Yaacob[3], Ahmed ElShafie[1] and Mohd Raihan Taha[1]**

[1]Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia.
[2]Department of Civil Engineering, Polytechnic Negeri Semarang, Indonesia.
[3]School of Environmental Sciences and Natural Resources, Faculty of Science and Technology, Universiti Kebangsaan Malaysia.

Accepted 23 May, 2011

**As development on hill slope areas has increased in Ulu Klang Malaysia, a number of landslides have occurred during the rainy season in this area since 1993, including Highland Towers (1993), Taman Zooview (2006), and Bukit Antarabangsa (2008). Recent studies have suggested the large influence of antecedent rainfall, amount of rainfall, rainfall intensity, and the physical properties of the soil on slope stability. In order to clarify the physical processes between water and soil interaction, and its effect on soil slope stability, this study conducted physical observation using mini-centrifuge modeling of 50 cm radius. This physical model was subsequently used to monitor the settlement and stability of the slope. Granite soils from the Bukit Antarabangsa landslide area were used as a soil embankment. We conducted the experiment by imposing various conditions of soil water content, soil density, slope gradient, soil particle diameter and soil thickness. Results showed that higher soil moisture content, soil density, soil thickness and smaller soil particle as well as steeper slope gradient, resulted in deeper soil settlement and greater potential for slope failure.**

**Key words:** Centrifuge, soil water interaction, settlement and slope failure.

## INTRODUCTION

Landslides are one of the major natural disasters in mountainous areas. In Malaysia, development on hill slope areas has increased the occurrence of landslides, such as in the Ulu Klang area. In this area, most of the landslide events have been reported to occur during the rainy season. On hill slope areas, landslides occur when soil slopes are threatened by heavy rainwater infiltration. Previous studies focused on the hydrological response of slopes to heavy rainfall and analyzed slope stability (Iverson, 2000; Mukhlisin et al., 2006, 2008; Mukhlisin and Taha 2009). These studies attempted to quantify the hydrological processes on hill slopes using observation of rigorous physical models. However, clarifying hydrological responses and the occurrence of slope failures in natural systems remains difficult due to the generally heterogeneous hydrological properties of slope soils.

Moreover, a thorough understanding of soil depth, soil material distribution, and soil water movement is critical in understanding slope failures. The complexity of natural field sites, and the difficulty in obtaining accurate data on the hydrological properties of a natural slope soil, have encouraged the development of laboratory physical modeling strategies to investigate slope stability processes (Viswanadham and Konig, 2009; Ling et al., 2009). These have the advantage of well controlled material properties and boundary conditions, and facilitate detailed monitoring. For example, Ling et al. (2009) conducted centrifuge physical modeling. In this study, the slope models were prepared from sand, and sand mixed with 15 and 30% fines by weight, compacted at optimum water content. Rainfall of different intensities was then applied on the 60° stable slopes of sand with 15% fines. They found that failure of the slope under rainfall may be interpreted as a decrease in apparent cohesion.

*Corresponding author. E-mail: mmukhlis2@yahoo.com

The centrifuge tests also allowed the rainfall intensity-duration threshold curve (local curve) to be generated for the test slopes, and the collected rainfall corresponded well to some of the reported field observations. Marto et al. (2009) used the geotechnical centrifuge to model a fly ash embankment constructed on hard and very soft foundation soils. Tests were triggered by increasing self-weight as the acceleration increased, and failure was determined photographically. They concluded that using fly ash as fill material in embankment construction can affect the performance of the model. It improves stability and reduces settlement of embankment layers. On the other hand, field observations and modeling studies also showed that rainstorm activity, antecedent rainfall and the initial physical condition of soils making up the soil can have a significant effect on slope stability (Rahardjo et al., 2001; Pasuto and Silvan, 1998; Terlien, 1997).

Modeling rainwater infiltration in hillslopes is needed for the analysis of slope failure induced by heavy rainfall. Mukhlisin et al. (2006) present a model of hillslope stability. A numerical model was developed to simulate two-dimensional rainwater infiltration into an unsaturated layer, the development of a saturated zone, and subsequent changes in slope stability. The model was used to analyze the effects of soil porosity, initial water content, slope gradient, and soil depth parameters on slope failure and movement of debris flow for weathered granitic hillslopes. In the case of the effects of soil porosity, sloping surface soils having relatively large effective soil porosity (ESP) have greater capacity to hold water, which delays infiltration and an increase in pore water pressure in the subsurface. Greater ESP contributes to delaying slope failure, but if failure occurs, the increased water content of the displaced material results in faster movement, larger travel distances and a broader extent of debris flow. However, these results need to be proved by physical modeling. In this study, we investigate mechanisms of settlement and slope stability with particular emphasis on the significance of soil properties using a mini geotechnical centrifuge with a radius of 50 cm. We describe scaled physical modeling of settlement and slope stability processes in susceptible soils. Five scenarios are reported to evaluate significant effects on slope stability under various soil water interactions by imposing on the sample different water contents, soil densities, gradient of slope, thickness of soil and soil particle diameter in a geotechnical centrifuge. The processes of settlement are measured using stroboscope lighting with a digital video camera.

## CENTRIFUGE MODEL TEST

### Centrifuge modeling

This study utilized the mini-centrifuge at Faculty Science and Technology, Universiti Kebangsaan Malaysia (National University of Malaysia) with a dead load capacity of 6kg. The centrifuge has a 50cm radius and a capacity of 0.84 g-tone machine. On the pitch end of the beam is a basket which swings up during flight, and at the other end is an adjustable counterweight to balance the entire set-up. During a 60 minute flight with 40g accelerations, the model is monitored through a digital video camera with stroboscopic lighting (Figs 1a and b). The swing basket and centrifuge beam are revolved and the monitoring digital video camera is connected to computers in the control room adjacent to the centrifuge chamber. The running model can be monitored in real time as the experiment is conducted through image-capturing software.

The small container used to set up the models for this study was a strongbox having inside dimensions of 290 mm long, 120 mm wide, and 195 mm deep. All sides of the container box are made from aluminum plates, except the front side of the box which consists of a thick Perspex glass sheet for a viewing window. A perspective of the model test package is shown in Figure 1c.

### Soil properties

Ulu Klang, which is geographically located at 3° 12' 00" North latitude and 101° 46' 01" longitude is under the jurisdiction of Ampang Jaya Municipality and Kajang Public Works Department. As an area close to Kuala Lumpur City, Ulu Klang has increased demand on its land, resulting in a rapid increase in development and housing projects in this area, particularly in Klang Valley.

Since 1993, a number of landslides have been reported in Ulu Klang, Malaysia. These landslides caused fatalities and economic losses. One huge landslide occurred on December 6, 2008 in the Bukit Antarabangsa, Ulu Klang area. The landslide deposits buried 14 bungalows in Taman Bukit Mewah and Taman Bukit Utama, causing the deaths of five people and burying more than eight others in the landslide deposit. This study used weathered granitic soil from the landslide area as material for the soil embankment in the centrifuge experiment. Table 1 shows the results of laboratory tests conducted on the soil samples.

The soil media used for all experiments was granite residual soil with a grain size distribution 17.5% silt, 45% sand and 37.5% clay. The soil was filtered through a 4.75 mm sieve to produce a uniformly porous soil material media. The container was packed with soil having moisture contents of 10, 15 and 20% before a layer was placed. The height of each layer was around 2 cm, and after placing the soil it was compacted with a board of nails. The target density was 1.50 to 2.00 g/cm$^3$. While the whole flume was filled layer by layer to a height of 120 cm, the soil material on one side was set up to obtain the shape of the slope with an angle of 40, 50 and 60° depending on the scenario and case of the experiment. The averaged values for each experiment are shown in Table 2.

### Scenario for centrifuge experiment

Five scenarios were used for the centrifuge experiment, are summarized in Table 2. The first scenario (scenario 1 in Table 2) used the standard conditions discussed previously; that is, a standard slope profile with a soil length, soil depth and slope gradient of 290 mm, 120 mm and 40°, respectively, while soil density was maintained at 1.75 g/cm$^3$ and soil particle size was maintained as material passing the 4.75 mm sieve. Water content values were changed for the soil slope, for three cases of 10, 15 and 20% with a curing time of 24 h as summarized in Table 2. In this scenario, the effects of the soil moisture conditions were examined.

In scenario 2, slope angle was changed for case 1, 2, and 3 to 40, 50 and 60°, respectively for the slope soil, while the other conditions were the same as in scenario 1 (Table 2). In scenario 3, the dry densities of the soil were changed from 1.5 to 2.00 g/cm$^3$, while the other parameters remained the same as in scenario 1. In scenario 4, the effects of the grain size diameter of the soil were

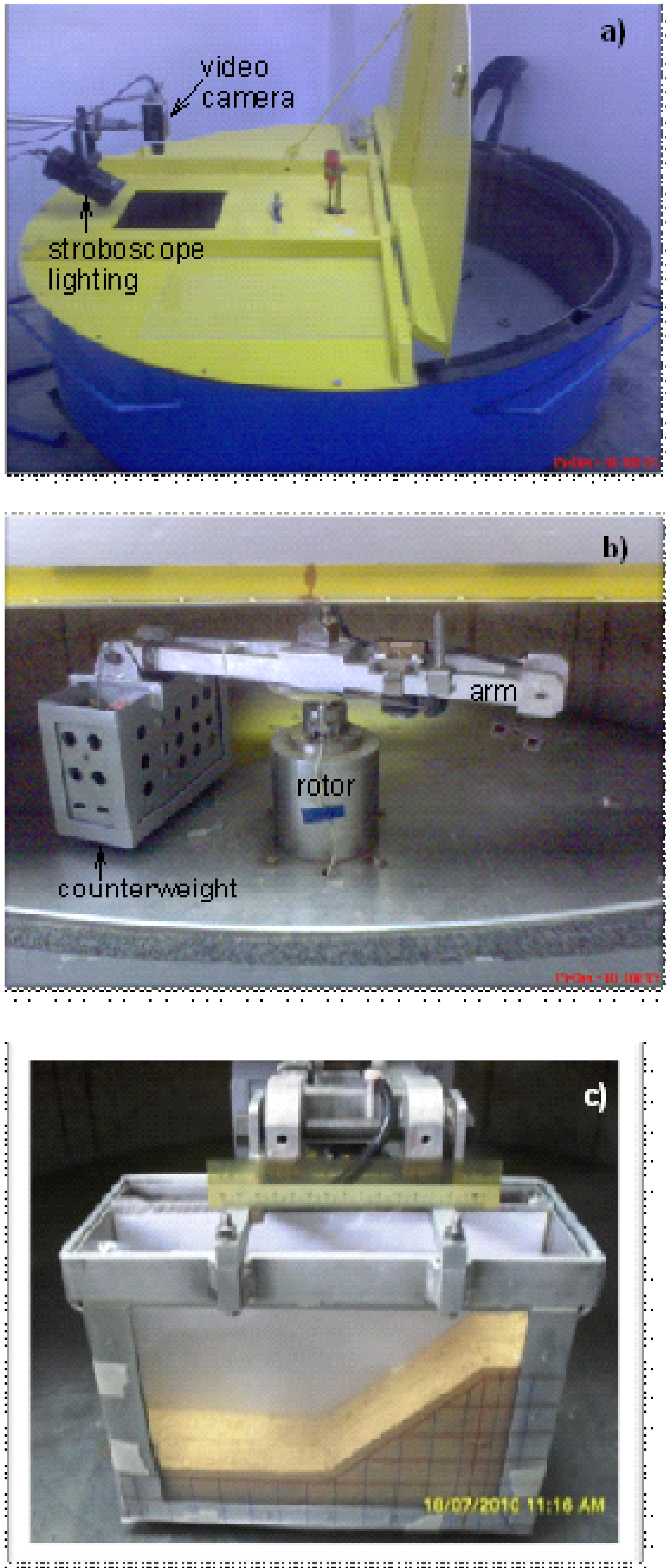


**Figure 1.** (a, b) mini-centrifuge instrument and (c) centrifuge container for slope experiments.

**Table 1.** Characteristics of soil for Bukit Antarabangsa.

| **Soil characteristic** | |
|---|---|
| Weight unit (γ) $kN/m^3$ | 18.50 |
| Specific gravity ($G_s$) | 2.65 |
| Dry weight unit ($kN/m^3$) | 1.42 |
| | |
| **Soil texture** | |
| Silt (%) | 17.50 |
| Sand (%) | 45.00 |
| Clay (%) | 37.50 |
| Soil types | Sandy clay |
| | |
| **Shear strength parameter** | |
| Friction angle (ϕ́) | 23 |
| Cohession (ć) kPa | 8.70 |
| Permeability (m/s) | $2.4048 \times 10^{-3}$ |
| Porosity | 43.00 |

**Table 2.** Summary of parameters and centrifuge experiment scenario.

| Scenario | Water content (%) | Slope angle (°) | Dry density ($g/cm^3$) | Particle size (mm) | Soil thickness (cm) | Analyzed cases |
|---|---|---|---|---|---|---|
| 1 | 10; 15; 20 | 40 | 1.75 | 4.75 | Slope profile | Case 1, 2, 3 |
| 2 | 20 | 40; 50; 60 | 1.75 | 4.75 | Slope profile | Case 1, 2, 3 |
| 3 | 20 | 40° | 1.5; 1.75; 2.00 | 4.75 | Slope profile | Case 1, 2, 3 |
| 4 | 20 | 40° | 1.75 | 4.75, 2.00, 1.18 | Slope profile | Case 1, 2, 3 |
| 5 | 20 | 40° | 1.75 | 4.75 | 2.5; 5.0; 7.5 | Case 1, 2, 3 |

examined. Particles passing 4.75, 2.00 and 1.18 mm sieves were used for cases 1, 2 and 3, respectively, while the other parameters remained the same as in scenario 1. In scenario 5, the effects of soil thickness were examined. The total soil thicknesses were set at 2.50, 5.00 and 7.50 cm, respectively. The other parameters were the same as in scenario 1.

## RESULTS AND DISCUSSION

In order to examine the movement of the slope, graphs of settlement of the slope model over time have been produced. The settlement was obtained from measurement on the transparent sheet on the strongbox.

### Effect of soil moisture water content

In scenario 1, the effect of soil water content on the soil slope was examined. After 60 min of centrifuging, the settlements of the top of slope were measured. Figures 2 and 7a show settlement of 4, 6 and 9 mm occured in scenario 1 for cases 1, 2 and 3 respectively. It can be seen that the settlement of the top of slope model increased rapidly after 15, 30 and 45 min (Figure 7a). The higher settlement occured on the slope with greater moisture content and smaller settlement occurred on slope with lower water content. This result show that soil water content has a significant effect to soil slope settlement, where greater water content in the soil slope affect on greater settlement in the slope. These findings correspond well with those of the previous studies (Julian and Anthony, 1996; Terlien, 1997; Van Asch et al., 1999; Mukhlisin et al., 2006) in that slope instability is generally initiated when the moisture content in the soil becomes close to saturation.

### Effect of slope gradient

In scenario 2, the effect of slope gradient on the soil slope was examined. After 60 min of centrifuging, the settlement of the top of slope were measured. From Figures 3 and 7b it can be seen that the final readings of settlement for scenario 2 cases 1, 2 and 3 are 5, 7 and 8 mm, respectively. Figures 3a to c shows clearly that the steeper slope gradient has greater settlement than smaller

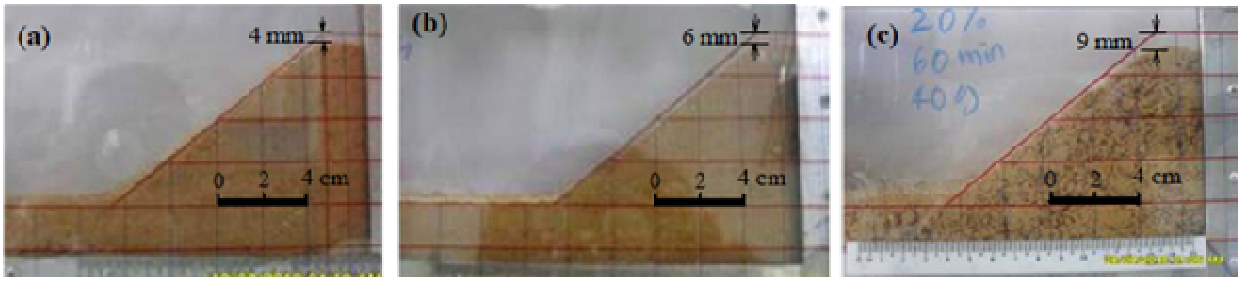


**Figure 2.** Slope settlement after 60 min centrifuging as effect of soil water content for (a) case 1, (b) case 2, and (c) case 3 with moisture water content 10, 15, 20%, respectively.

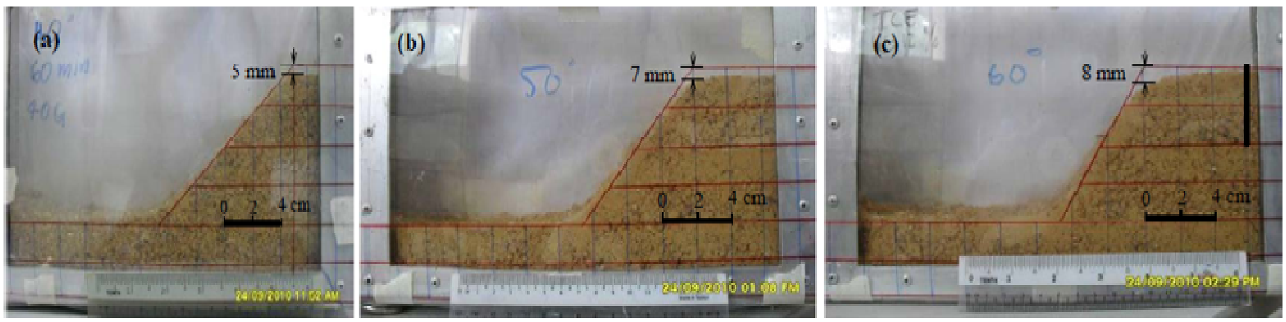


**Figure 3.** Slope settlement after 60 min centrifuging as effect of slope gradient of 40, 50 and 60° for (a) case 1, (b) case 2, and (c) case 3, respectively.

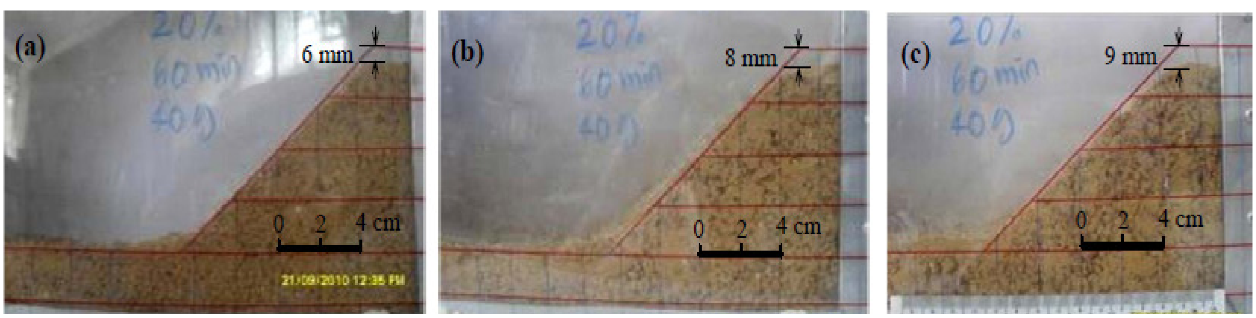


**Figure 4.** Slope settlement after 60 min centrifuging as effect of soil density for (a) case 1, (b) case 2, and (c) case 3 with soil density 1.5, 1.75, 2.00 g/cm$^3$, respectively.

of the slope.

From these results, it can be concluded that the model with the most critical slope angle shows the highest settlement of the top of the slope. It shows that the steeper the angle of the slope, the higher the risk of landslide. These finding is well known for many previous studies.

## Effect of soil density

In scenario 3, the effect of soil density on the soil slope was examined. Based on Figures 4 and 7c, after 60 min of the centrifuge experiment it can be seen that final readings of settlement for scenario 3 cases 1, 2 and 3 are 6, 8 and 9 mm, respectively. Settlement of the top of the slope model increased rapidly after 15, 30 and 45 min. The settlement of the model for cases 2 and 3 increased rapidly after 15 min. On the other hand, settlement of the slope model for case 1 occured after 15 min. Analysis of the effect of soil density showed that greater soil density resulted in greater weight of the soil in the slope container. As a result, the greater weight of the soil affected a deeper part of the soil settlement (Figures 4a to c). These results show that greater density of the slope soil resulted in greater settlement of the slope

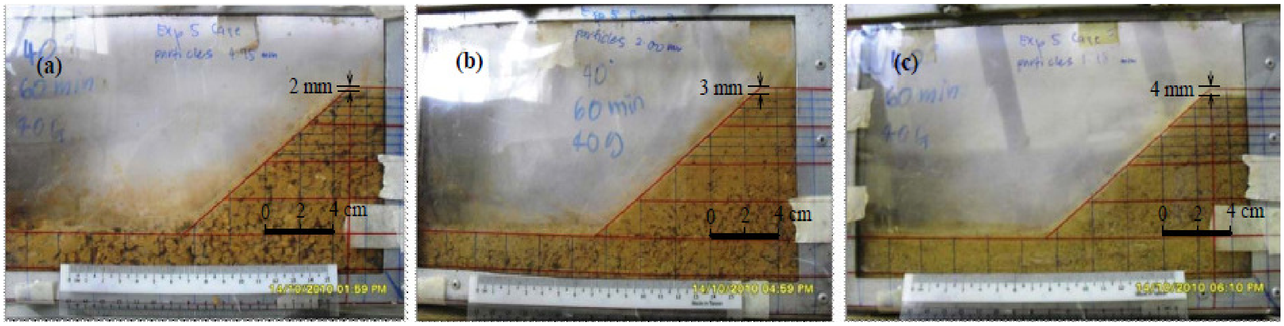


**Figure 5.** Slope settlement after 60 min centrifuging as effect of soil particle for (a) case 1, (b) case 2, and (c) case 3 with particle size of 4.75, 2.00, 1.18 mm, respectively.

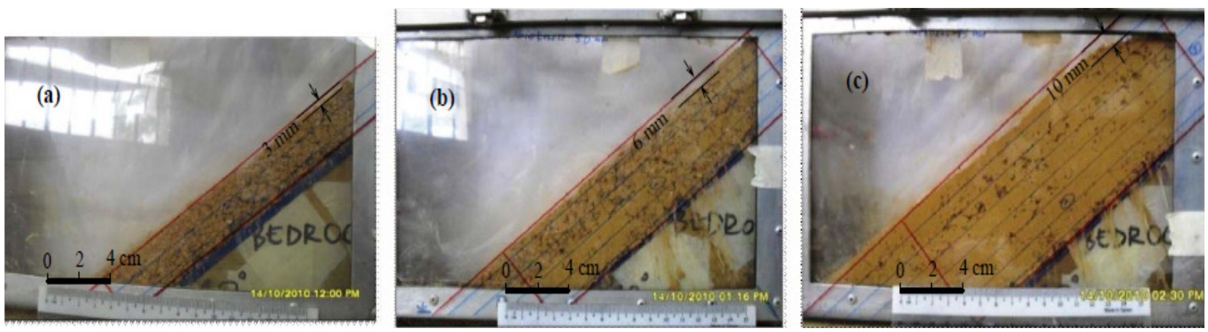


**Figure 6.** Slope settlement after 60 min centrifuging as effect of soil thickness for (a) case 1, (b) case 2, and (c) case 3 with soil depth 2.5, 5.0, 7.5 cm, respectively.

## Effect of diameter of soil particles

In scenario 4, the effect of the grain size diameter of soil particles in the slope was examined. After 60 min, final readings of settlement for scenario 4 cases 1, 2 and 3 are 2, 3 and 4 mm, respectively as illustrated on Figures 5 and 7d. It can be seen that the settlement of the top of the slopes increases rapidly after 15 min and the settlement stopped after 45 min. The settlement of the slope with 4.75 mm diameter soil particles started to occur after 15 min and stopped after 45 min. The settlement of slope with 1.18 mm diameter soil particles rapidly increased between 15 and 45 min. Analysis of the effect of soil particle on slope stability experiment showed that smaller soil particle resulted in greater weight of the soil in the slope container. As a result, the greater weight of the soil affected a deeper part of the soil settlement (Figures 5a to c). However, changing of settlement as effect of soil particle is smaller when compare with the other parameters (Figure 7d). These results also indicate that size of soil particle is also a significant parameter in slope stability.

## Effect of soil thickness

In scenario 5, the effect of soil thickness on the soil slope was examined. The difference of scenario 5 compared to the other scenarios is that scenario 5 is based on a 40° slope angle bedrock model. The slope models with 20% water content and different thicknesses were laid on the bedrock. After 60 min of the centrifuge experiment, the final readings of settlement that occured in scenario 5 for cases 1, 2 and 3 are 3,6 and10 mm respectively.The final settlement of the slope in case 3 was 10 mm when the centrifuge test was stopped as shown in Figures 6a to c and 7e. Analysis of the effect of soil thickness on slope stability of the centrifuge experiment showed that deeper soil depths affected the soil thickness of the sliding segment, increased the weight of the soil and the pore water pressure, and thus decreased soil strength, resulting in slope failure. These results indicate that soil thickness is also a significant parameter in slope stability.

## Conclusion

All experiments were safely conducted without any damage to the strongbox or computer. For the experiment on the effect of moisture content, 9 mm of settlement for the soil package with 20% water content can be seen after it was centrifuged for 60 min at 40 g compared to 4 mm of settlement for the soil package with 10% water content. For the experiment on the effect of

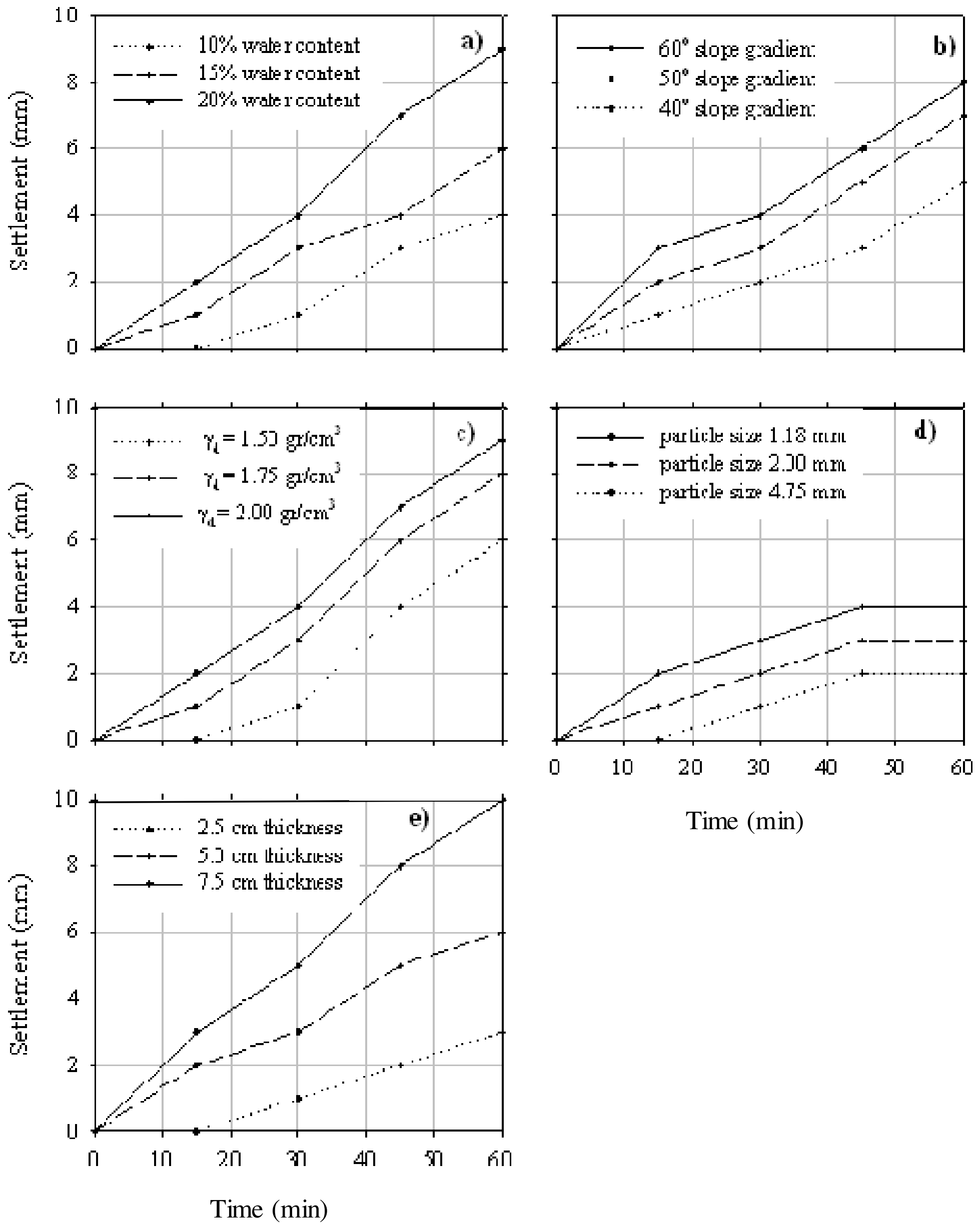


**Figure 7.** Settlement of the top of soil slope based on effect of (a) soil water content, (b) slope gradient, (c) dry density, (d) particle size of soil and (e) soil thickness for scenarios 1, 2, 3, 4, and 5, respectively.

slope gradient,it is shown that the slope with the steepest angle (60°) will have maximum settlement of the top of the slope compared with slopes of 40 and 50°. In the third experiment, which examined the effect of density, 9 mm of settlement occured on the model with a soil dry density of 2.00 g/cm$^3$. The test showed the highest value of settlement occured on the highest density soil. The experiment on the effect of soil particle size showed that the highest value of settlement occured on soil with the smallest particle size (1.18 mm). From the experiment on the effect of soil thickness, it can be seen that the higher value of settlement occured on thickest soil depth. For case 3 (thickest soil depth), cracks occured on the top of the slope. Results of the experiment on the effect of soil thickness on slope stability showed that deeper soil depths contain heavier soil and higher pore water pressures, thus decreasing soil strength, and resulting in slope failure. These results show that soil thickness is also an important parameter in slope stability. From this study can be concluded that higher soil moisture content, soil density, soil thickness and smaller soil particle as well as steeper slope gradient, resulted in deeper soil settlement and greater potential for slope failure.

## Acknowledgements

This research was supported by the research grant from Universiti Kebangsaan Malaysia and Fundamental Research Grand Scheme (FRGS), Ministry of High Education Malaysia.

### References

Iverson RM (2000). Landslide Trigering by rain infiltration. Water Resour. Res., 36(7): 1897-1910.

Julian M, Anthony E (1996). Aspect of landslide activity in the Mercantour Massif and the French Riviera, southeastern France. Geomorpho., 15(3-4): 275–289.

Ling HI, Wu MH, Leshchinsky D, Leshchinsky B (2009). Centrifuge Modeling of Slope Instability, J. Geotech. Geoenviron. Eng. ASCE., 135(6): 758-767.

Marto A, Makhtar AM, Kassim KA, Yaacob WZ, Muhardi (2009). Physical Modelling of Fly Ash Embankment in Mini-Geotechnical Centrifuge. Int. Conference on Sustainable Infrastructure and Built Environment in Developing Countries, Bandung, West Java, Indonesia.

Mukhlisin M, Kosugi K, Satofuka Y, Mizuyama T (2006). Effect of Soil Porosity on Slope Stability and Debris Flow Runout at a Weathered Granitic Hillslope. Vadose Zone J., 5(1): 283-295.

Mukhlisin M, Taha MR (2009). Slope Stability Analysis of a Weathered Granitic Hillslope as Effects of Soil Thickness. Eur. J. Sci. Res., 30(1): 36-44.

Mukhlisin M, Taha MR, Kosugi K (2008). Numerical analysis of effective soil porosity and soil thickness effects on slope stability at a hillslope of weathered granitic soil formation. Geosci. J., 12(4): 401-410.

Pasuto A, Silvano S (1998). Rainfall as a trigger of shallow mass movements. A case study in the Dolomites, Italy. Environ. Geol., 35(2–3): 184–189.

Rahardjo H, Li XW, Toll DG, Leong EC (2001). The effect of antecedent rainfall on slope stability. Geotech. Geol. Eng., 19(3-4): 371–399.

Terlien MTJ (1997). Hydrological landslide triggering in ash-covered slopes of Manizales (Colombia). Geomorphol., 20(1-2): 165–175.

Van Asch ThWJ, Buma J, Van Beek LPH (1999). A view on some hydro. triggering syst. ini landslides. Geomorpho., 30: 25–32.

Viswanadham BVS, Konig D (2009). Centrifuge Modeling of Geotextile-Reinforced Slopes Subjected to Diferential Settlements. Geotext. Geomembr. 27(2): 77–88.