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EFFECT OF DIKE SLOPE ON THE DEVELOPMENT OF MATRIC SUCTION AND VOLUMETRIC WATER CONTENT DURING OVERTOPPING TESTS

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ABSTRACT

The infiltration of water flow inside soil particles has a serious effect on dike stability. It causes increasing in water content inside soil particles and thus breach channel is initiated inside dike crest and body during overtopping failure. In this study, the evolution of matric suction and volumetric water content are discussed during spatial overtopping tests. The overtopping tests are conducted in small flume channel in Hydraulic Geotechnical laboratories at the Universiti Sains of Malaysia. Two dike slopes of 1:3H and 1:2.5H for both upstream and downstream slopes are constructed under constant inflow discharges of 30L/min. The results show that the saturation process decreases and increases matric suction and volumetric water content, respectively for both dike slopes. The saturation process of water content is faster for 1:3H than those for 1V:2.5H prior to overtopping failure while it is higher in latter slope than in previous one after the initiation of breach failure.

Key words: Tensiometer, TDR, Matric suction and Volumetric water content.

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1. INTRODUCTION

The safety of dike construction has a great relationship with the surrounding hydraulic condition such as the reservoir water of see or river. The reservoir water located in the upstream slope of dike may result in increasing the percentage of water content inside soil and thus causes dike instability during overtopping failure. The dike embankment is defined as an earthfill material constructed to prevent dangerous of water flooding (Costa 1985; Xu &

Zhang 2009) [5, 20]. Flooding occurred as results of water overtopping above the dike crest and considered the most destructive failures for different dam's types such as landslide dams (Costa & Schuster 1988) [6] while about 57000 dams were damaged due to overtopping (Ralston 1987) [16]. The overtopping failure eroded the downstream slope through developing a breach channel, formed as trapezoidal shape, in horizontal and vertical directions (Froehlich 2008) [10]. Different geotechnical and hydraulic parameters effect on the saturation process of dike's soil have been studied during overtopping tests (Fujita & Tamura 1987; DeLooff et al.1997) [11, 7]. It have been conducted in small and large flume channels in order to simulate the behavior of dike failure during Laboratory test e.g. (Tinney & Hsu 1962; Pugh 1985; Visser 1988; Broich 1998; Chinnarasri et al. 2004; Morris et al. 2007) [17,15, 19,2, 4,13] as well as simulated in numerical models (Brown & Rogers 1977; Bechteler & Broich 1991; Ponce & Tsivoglou 1981; Franca & Almeida 2004) [3,1,14,9].The development of erosion process for cohesive soil is differ from non-cohesive one while in some cases the erosion rate for homogeneous gravel embankment (Vaskinn et al. 2004) [18]. (Dodge 1988) [8] studied the influence of compaction effort on a cohesive (clay) dike. He indicated that increasing the compaction effort from 95% to 103% of standard proctor value would reduce empty pores between soil particles, and thus delay the reduction of matric suction during overtopping failure. Six overtopping tests were conducted by Department of Agriculture (USDA) Agricultural Research Service Hydraulic Engineering Research Unit (ARS-HERU) to predict the evolution of erosion process for silty soil under two types of vegetated and non-vegetated grass channel. The erosion process was highly dependent on the covered channel so that it was decreased with vegetated channel faster than that for non-vegetated one (Hahn et al.2000) [20]. In this study, two dike slopes of 1:3H and 1V:2.5H, termed as S1 and S2, respectively, for upstream and downstream slopes are highlighted and discussed under a constant inflow discharge of 30 L/min to observe the matric suction and volumetric water content during spatial overtopping tests.

2. DIMENSIONS OF DIKE AND FLUME CHANNEL

A spatial overtopping tests were conducted in the Hydraulic Geotechnical Laboratories of Universiti Sains of Malaysia to observe the responses of matric suction and volumetric water content during erosion process occurred due to overtopping failure. The sand dike had a trapezoidal shape with the following dimensions: length of 1.9 and 1.6m for S1 and S2, respectively, width of 0.5m, and height of 0.3m constructed at the end of the PVC flume channel. The dimensions of flume channel are 4.5, 0.5, and 0.6m in length, width, and height, respectively. A trapezoidal pilot channel, with dimensions of 4cm width and 3cm height, was initiated in the dike crest along the side-wall of flume channel to initiate the spatial breach channel. The flume is supplied with a pump of maximum inflow discharge (Q_0 = 70l/min), connected with Flowmeter above the reservoir water. A sediment box is placed down at the end of flume channel to collect eroded soil material as shown in Figures 1 and 2 for S1 and S2, respectively. The type of soil used in dike construction is poorly graded coarse sand (SP) with geotechnical properties shown in (Table1).

Table 1 Sieve analysis test for dike soil

Dike components (%)		**Parameters (mm)**	**(C_u)**	**(C_c)**
Sand	80.71	D_{60}= 1	3.03	1.019
Gravel	17.89	D_{30}= 0.58		
Silt &Clay	0.3	D_{10}= 0.33		

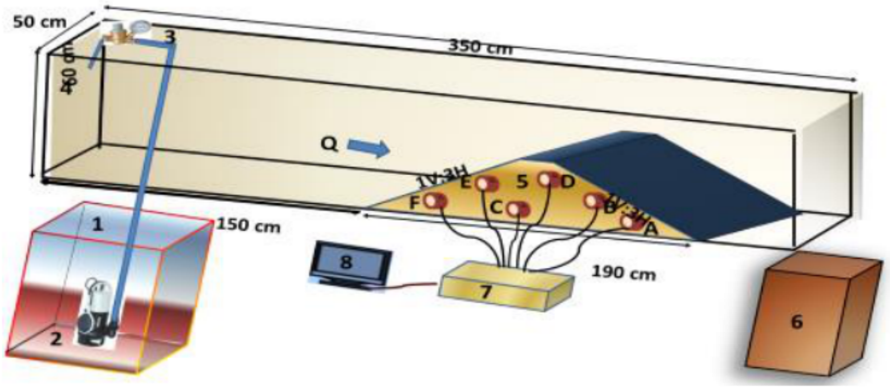


Figure 1 Components of overtopping channel test for S1: 1) Water tank, 2) Discharge pump, 3) Flowmeter, 4) Flume channel, 5) Dike construction, 6) Sediment tank,7) Data logger, 8) PC.

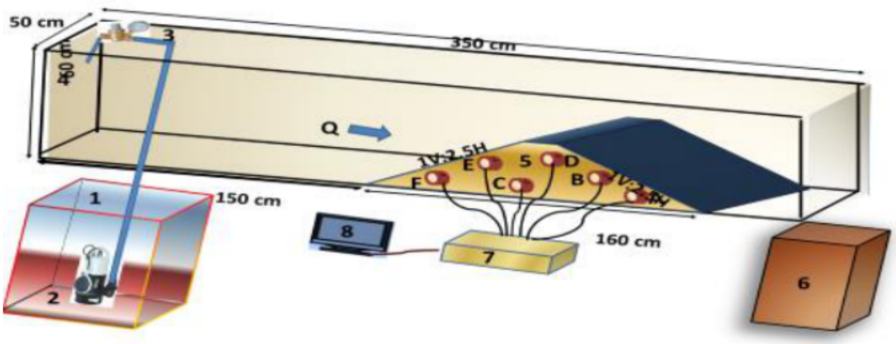


Figure 2 Components of overtopping channel test for S2: 1) Water tank, 2) Discharge pump, 3) Flowmeter, 4) Flume channel, 5) Dike construction, 6) Sediment tank,7) Data logger, 8) PC.

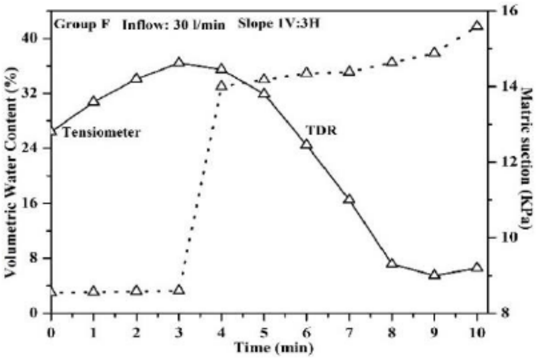
The 2100F Tensiometer and Trime-pico32 TDR sensors are developed by Soil moisture Equipment Corporation and IMKO Micromodultechnik GmbH, respectively. These instruments were installed on the side wall of the flume channel with different locations and depths to conduct the matric suctions and volumetric water contents, respectively. Tensiometer contains porous ceramic round bottom with dimensions of 6mm in diameter and 25mm in length while TDR probe body has dimensions of 155mm and 32mm in length and diameter, respectively. The two sensors are distributed into six groups named as: A, B, C, D, E and F, along the downstream and upstream slopes. Each group contains one tensiometer and one TDR sensors.

2.1. Experimental Tests Procedure

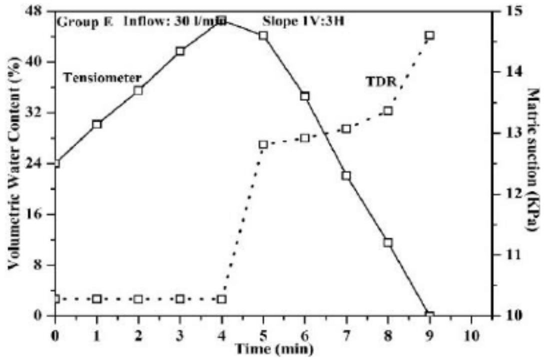
The sand dike is constructed inside flume channel under dry condition while the initial water content is equal to zero. The construction of dike is occurred by dividing the soil into three layers with a height of 10 cm for each one. Each layer has been compacted in order to get a bulk density of 1.8 g/cm^3 for the whole dike. A constant inflow discharge of 30L/min is supplied into flume channel and continue crossing above the pilot channel until the end of spatial tests. The results of matric section and volumetric water content for six groups are measured during transit water flow from upstream into downstream slopes by using tensiometer and TDR sensors, respectively. They are connected with data logger and computer (PC) to analyze the test results. The test results ended when the erosion of soil material surrounding each group is finished.

3. RESULTS AND DISCUSSION

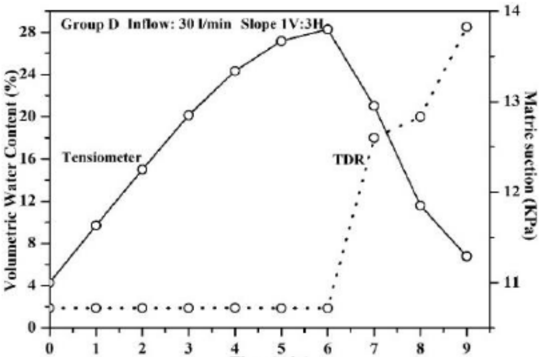
The infiltration of water flow has been represented through applying a constant inflow of 30 L/min during overtopping test. (Figure 3 (a), 3(b), 3(c), 3(d), 3 (e) and 3(f)) and (Figure 4(a), 4(b), 4(c), 4(d), 4(e) and 4(f)) show the development of matric suction and volumetric water, respectively for each group during the transmitting water flow from upstream into downstream slopes for S1 and S2. For group F , matric suction starts to increase in the beginning of overtopping test before t = 4 and 5 minutes for S1 and S2, respectively, while the volumetric water content results are still not variable during these periods. This is because of increasing air between soil particles and the lack penetration of water flow near soil area surrounding group F. The infiltration water is saturated soil particles in horizontal and vertical directions in which the horizontal level penetrates the soil base along the horizontal distance of dike embankment, while the vertical one changes the soil condition from dry into partially saturated. Consequently the matric suction and volumetric water content inside soil particles started to decrease and increase, respectively fast depending on the dike slope. The relationship between matric suction and volumetric water content is reversed. The suction binds particles is reduced gradually due to the increasing water content occupied particles voids and thus the shear strength of soil decreased. The vertical soil water pressure transfer infiltration water from lower tension zone to higher tension zone. As the soil particles saturated with water, the permeability to air flow is reduced and vice versa. The resistance of dike soil could be overcome by the water waves during overtopping test and the continuity of saturation process leads to dike slope instability over the time. The reductions of matric suctions for groups F and E occurred at t = 4 and 5 minutes. The sharp increasing of water content indicates the highest permeability of soil to water flow in the initial contact voids with water infiltration.



(a)



(b)



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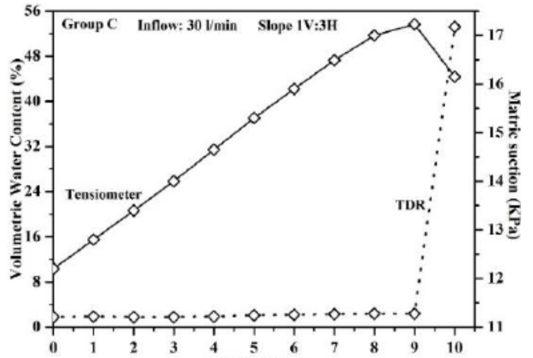

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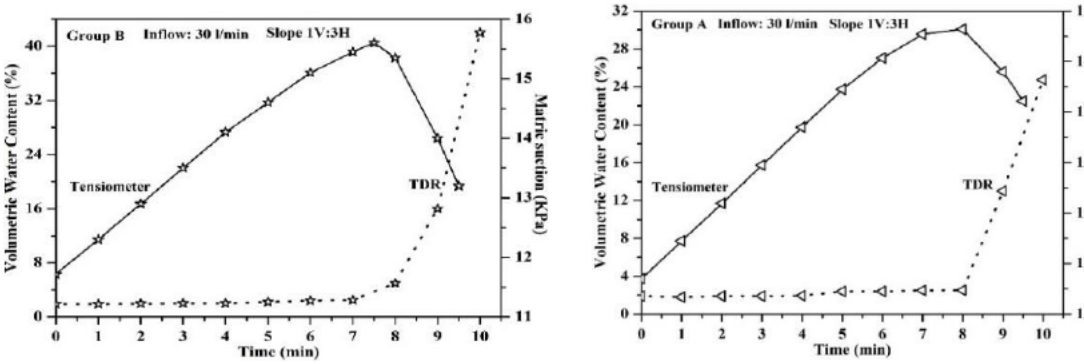
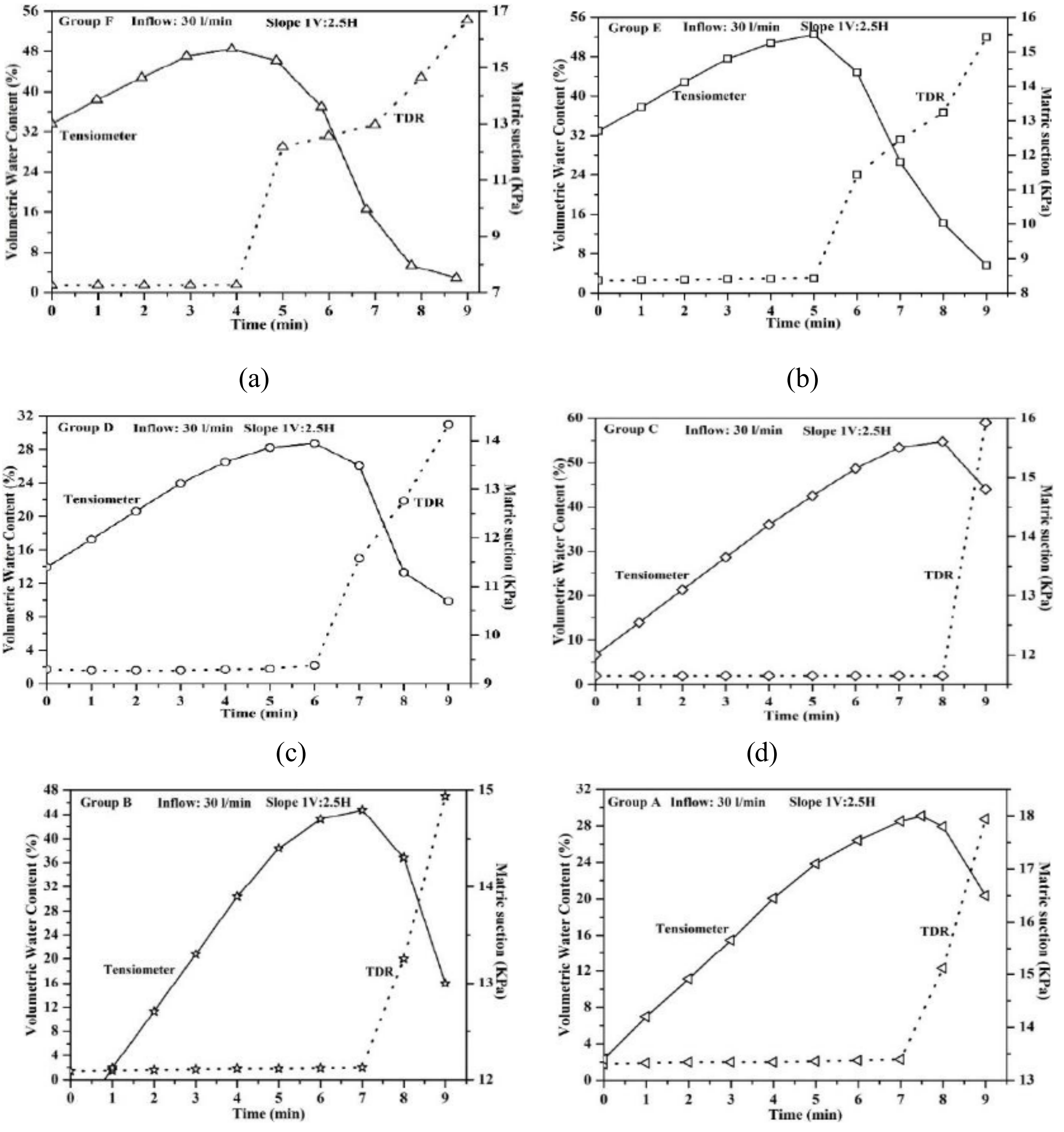


(e) (f)

Figure 3 Evolution of matric suction and volumetric water content for groups of S1: a) F, b) E, c) D, d) C, e) B, f) A, respectively



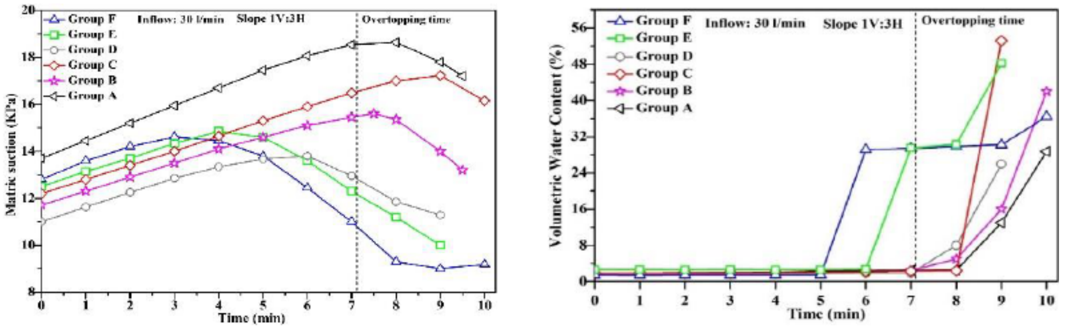
(a) (b)

(c) (d)

(e) (f)

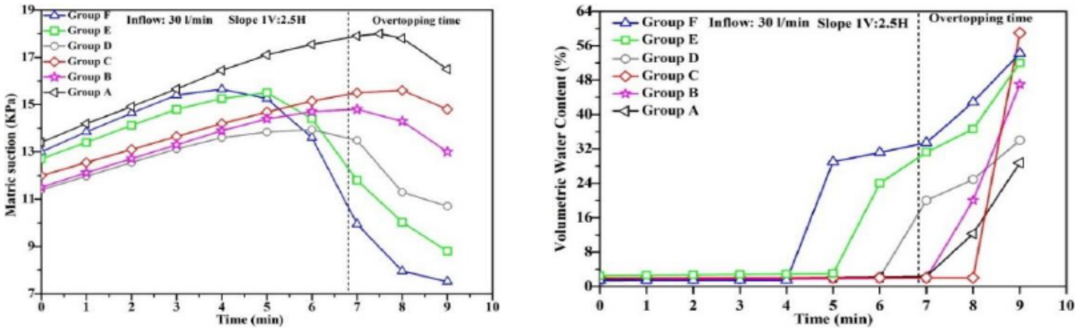
Figure 4 Evolution of matric suction and volumetric water content for groups of S2: a) F, b) E, c) D, d) C, e) B, f) A, respectively.

The vertical water level migrates up into soil surrounding groups E while the matric suction and volumetric content decreased and increased respectively at t= 5 and 6 minutes for S1 and S2, respectively. The water saturation process, of groups A, B, C and D are similar to groups E and F with the exception of beginning noticeable responses for previous groups. (Figure 5(a) and 5 (b)) and (Figure 6(a) and 6(b)) show the arrangement responses of all groups during overtopping test for both S1 and S2. Groups F and E are earlier saturation faster than other groups due to their positioned near toe and middle of upstream slope, respectively. During the progression of saturation process, the matric suction and volumetric water content are continued decreasing and increasing, respectively prior to overtopping failure in upstream slope for S1 and S2. The overtopping failure occurred when water flow across above pilot channel in dike crest at t = 7.16 and 6.83 minutes for S1 and S2, respectively while the infiltration water gradually started to saturate the middle area between upstream and downstream slopes and area of downstream slope. The noticeable development of matric suction and volumetric water content in group D is occurred at t = 8 and 7 minutes for S1 and S2, respectively. Increasing amount of water content resulted in reduction factor of safety (FOS) for soil layer due to faster saturation of layers below dike crest. The meniscus curve connected between matric suction and water content in unsaturated sand soil is reduced significantly due to presence of water content (lower matric suction). The behavior of saturation process for groups A, B and C is shown clearly after overtopping failure due to infiltration water effected in downstream slope. Reduction of matric suction for S1 in groups A, B and C is occurred at t= 9, 8 and 10 minutes, while for S2, it occurred at t= 8, 8 and 9 minutes, respectively in which the evolutions of volumetric water content and matric suction are occurred faster in group B than those in groups A and C. This is due to the widening of breach channel of pilot channel near top of downstream slope.



(a) (b)

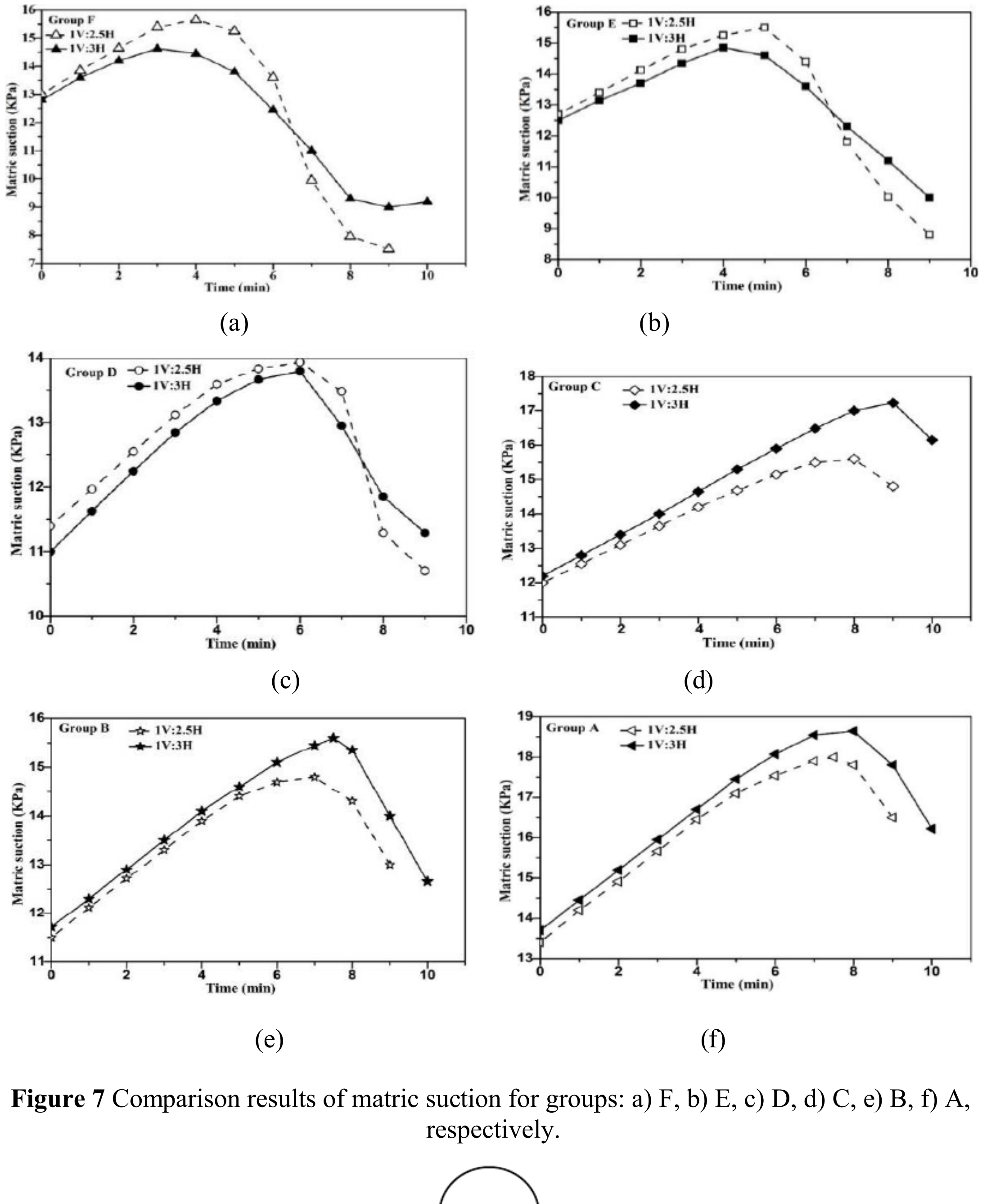
Figure 5 The arrangement groups of S1 in terms of: a) matric suction and b) volumetric water content, respectively.



(a) (b)

Figure 6 The arrangement groups of S2 in terms of: a) matric suction and b) volumetric water content, respectively.

(Figure 7 (a), 7(b), 7(c), 7(d), 7(e) and 7(f)) and (Figure 8 (a), 8(b), 8(c), 8(d), 8(e) and 8(f)) show the comparison results of matric suction and volumetric water content, respectively between S1 and S2 for each group. S1 provide large dike volume compared with S2 and considered as flat slope compared with steep slope for S2. For group F, the beginning decreasing and increasing of matric suction and volumetric water content, respectively are occurred faster for S1 compared with S2 due to flat slope. The horizontal and vertical water levels penetrated soil near group F for S1 faster than S2 while steep slope for the latter slope is little hampered the water distribution near toe of upstream slope. The sharp decreasing and increasing of matric suction and volumetric water content, respectively is faster in S2 than in S1 at t=7 minutes. This is due to the vertical and horizontal erosion process eroded the upstream slope and thus accelerate the velocity of water infiltration. The response of matric suction and volumetric water content is continued until t = 10 and 9 minutes for S1 and S_2, respectively while the erosion process reaches near the bed of dike construction. This is because of the longest erosion process of S1 compared with S2 in the water velocity for S1 is slow compared with that in S2.

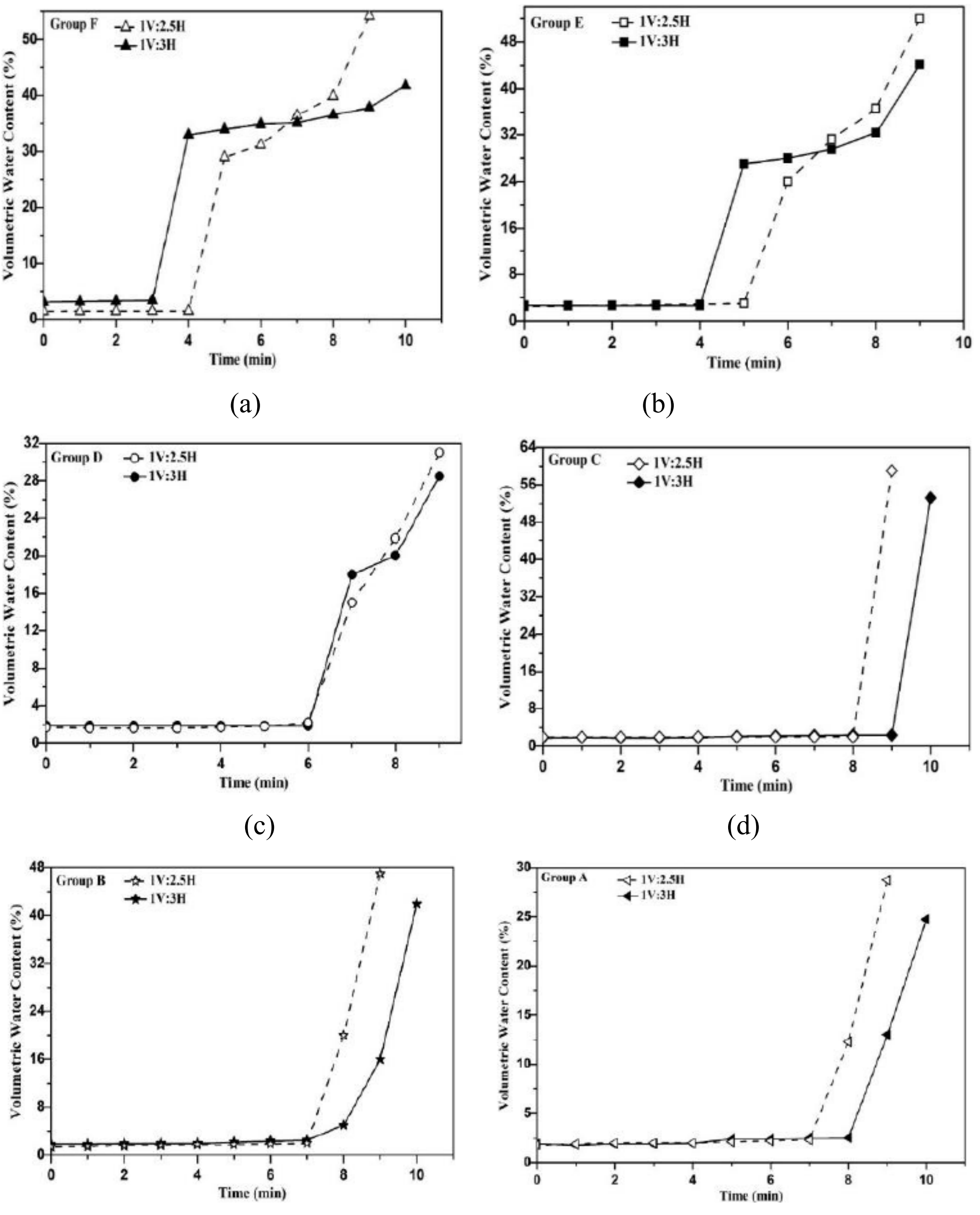


(a) (b)

(c) (d)

(e) (f)

Figure 7 Comparison results of matric suction for groups: a) F, b) E, c) D, d) C, e) B, f) A, respectively.



(a) (b)

(c) (d)

(e) (f)

Figure 8 Comparison results of volumetric water content for groups: a) F, b) E, c) D, d) C, e) B, f) A, respectively.

The distribution of water level is reduced gradually near group E for S1, due to large quantity of soil void that need to be saturated in the downstream slope. The distribution of water level is saturated faster particles voids in S2 at t= 7 minutes because of the progressive reduction of dike crest height during overtopping failure and thus increased the water velocity. Both of matric suction and volumetric water content results are ended at t= 9 minutes for S1 and S2. This is due to the earlier cumulative reduction of FOS for saturated soil near the top of upstream slope and thus collapses of soil materials are faster for both S1 and S2. The reduction of matric suction is shown the importance effect of seepage analysis on initiating breach channel near group D. At t= 7 minute, the percentage of water contents for S1 is higher than that in S2 due to flat slope of previous slope with volumetric water content of 18 and 15%, respectively. The steep slope of S2 restricted the movement of water infiltration towards group D in which it behaves similar to a rigid column against gravity. At t = 8 minutes, the steep slope helps to increase the rate of lateral and vertical erosion processes in downstream slope and thus increase water velocity and water discharge near group D. Over the time, the reduction of dike height slow down the rate of erosion process higher in S2 compared with S1. The erosion process in group C indicates the development of breach channel failure occurred in the transition area between downstream and upstream slope due to the reduction of matric suction. The late responses of both sensors showed the deepest location of group C in the middle of dike construction in which half of dike materials are eroded due to increasing water content in the dike crest and downstream slope areas. The steep slope reduced the dike crest and downstream slope zones under high velocity and turbulence with sharp shape of dike crest height during erosion process. For groups A and B, the voids are saturated faster in S2 than in S1 because of changing water conditions from transitional in the dike crest into supercritical in the downstream slope for steep slope faster than the flat one and thus nearly half of downstream slope dike are eroded.

4. CONCLUSIONS

This paper has aimed to study the effect of dike slope on the development of matric suction and volumetric water content for sand dike inside flume channel during overtopping tests. Two dikes slope tests of 1V:3H (S1) and 1V:2.5H (S2) for both upstream and downstream slopes are conducted in Hydraulic Geotechnical laboratories at the Universiti Sains of Malaysia. Two types of sensors of tensiometer and TDR are used to measure the responses of matric suction and volumetric water content. The figures show that the matric suction and volumetric water content are decreased and increased, respectively due to infiltration of reservoir water. Increasing the percentage of water content is reduce the ability of dike to withstand against overtopping failure due to reduce matric suction (negative pore water pressure) between soil particles and thus soil slope failure occurred. The noticeable responses for groups F and E are occurred prior to overtopping failure while for group D occurred in the moment of water overtopping above dike crest. The infiltration water attached the downstream slope and caused reduction in matric suction for groups A, B and C. The reduction and increasing of matric suction and volumetric water content, respectively is occurred for S1 faster than those for S2 for groups F and E while they are higher for S2 for groups A, B, C and D due to initiation of breach channel in the downstream slope.

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