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Unsaturated infiltration on artificial embankments reinforced with geosynthetics

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ABSTRACT: It is well known that geosynthetics have been used successfully in separation, reinforced and consolidation of engineered earth systems. However, the drainage behavior due to rainfall infiltration of geosynthetics in reinforced embankments has not been well addressed so far. Drainage ability of geosynthetics is important since soil strength increases and decreases when water content changes. In order to analyze the effect of water infiltration due to rainfall on soil-geosynthetic systems, reinforced and non-reinforced embankment tests were conducted. The artificial reinforced embankments were built using two layers of geosynthetics; rainfall was simulated by using spray irrigation tube. Cycles of wetting (rainfall) and drying processes were applied to the embankments. The change in pore water pressure and water content during drying and wetting processes were monitored by modified water pressure sensors attached with ceramic cup and moisture sensors, respectively. Water retention characteristic curves were measured for soil and geosynthetics. Geosynthetics worked as a capillary barrier maintaining the soil above them with high degree of saturation. Failure was observed in both cases, reinforced and no-reinforced embankments. It was found that failure in no-reinforced embankments was initiated by the growth up of pore pressure within the soil at the toe of the embankment. The failure in reinforced embankment showed a different pattern; water content and pore pressure increased immediately above the geosynthetic layers and failure started above them.

1 INTRODUCTION

It is recognized that permeable geosynthetics can transmit water within the plane of their structures (i.e. they can act like drains). Due to their high porosity, permeable geosynthetics contribute to the dissipation of positive pore pressures during construction of soil-structures and minimize the build up of the water table due to subsequent infiltrations.

However, in many practical applications the water content of the fill material is relatively low and the pore pressures are negative during and after construction; consequently, it is important to examine the hydraulic behavior of permeable geosynthetics within unsaturated soil when it is subjected to rainfall infiltration from a water source such a rainfall.

2 BRIEF REVIEW

Successfully, permeable geosynthetics have been used as drainage materials: Ling (1993) investigated cross plane and in-plane hydraulic conductivities and showed geosynthetics as effective for dissipating excess pore water pressure; Zognberg & Mitchell (1994) evaluate the performance of some reinforced soil structures and explain that permeable reinforcement may be useful for soil structures with poorly draining material because of the drainage capabilities of the geosynthetics; Tan et al (2001) showed that permeable geosynthetics within poor drainage material help to the dissipation of pore pressure. Geosynthetics seem to work very well under saturated conditions.

Nevertheless, after construction and during service, reinforced soil-structures are working under unsaturated conditions and they are subjected to cycles of drying and wetting processes due to the rainfall infiltration. Soils and geosynthetics behave different under unsaturated conditions (negative pore pressures); the presence of negative pore water pressure (called soil suction) causes the difference in nature and behavior between saturated and unsaturated soils. Morris (2000), conducted a series of test on three geotextiles to evaluate their ability to conduct water under unsaturated conditions; it was found that geosynthetics tended to be hydrophobic and did not begin wetting until suctions were close to zero or positive; Iryo (2004) reported many cases in which geosynthetics were impeding the water flow and suggested that geosynthetics work as drainage layers for the case where the soil surrounding the geosynthetic is saturated and positive pressure is developed.

Very little information exists about hydraulic interaction of unsaturated soil-geosynthetic layers. From the previous review it is seen that more experimental data is necessary to understand the hydraulic behavior of saturated/unsaturated soil-geosynthetic systems.

3 MATERIALS AND APPARATUS

3.1 *Materials*

In the model tests, a soil namely Edosaki sand was used to construct artificial embankments. The physical properties of the soil are: specific gravity (Gs) 2.750, maximum void ratio (e_{max}) 1.59, minimum void ratio (e_{min}) 1.01, maximum dry density 1.72 (g/cm^3), optimum water content (w_{opt}) 16.01%, mean particle diameter (D_{50}) 0.23 mm and fine content 16.40%.

A nonwoven geotextile (NW), a woven nonwoven geocomposite (WG) and stripes of nonwoven geotextile (SNW) were used as drainage material within the embankments; thickness of the geosynthetics was 4 mm.

3.2 *Model tests*

Model slopes 80 cm height, 80 cm width and 150 cm length were constructed; Figure 1 shows the general view of the slope models with geosynthetics and their sensor distribution. The model slope was prepared by the method of moist placement. Each layer was tamped equally by tamping wood to achieve a specific height of 5 cm and dry density 1.35 g/cm^3. ADR (Amplitude Domain Reflectometry) type soil moisture sensors were used in the model tests to measure volumetric water content during water infiltration. In order to measure both positive and negative pore pressures, pore pressure transducers 50 kPa capacity were modified with a ceramic cup of 100 kPa air entry value.

Model tests were prepared and they were kept during one day for observation and sensors stabilization. Evaflow spray side irrigation pipe was used to applied rainfall on the embankments and observe wetting process. Rainfalls with intensity in between 40 and 50 mm/hr were applied twice to each model following by 24 h of drying processes. General information about the model tests is shown in Table 1.

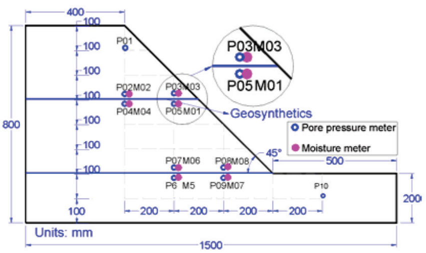

Figure 1. Diagram of the model test slope.

Table 1. General information of the performed model tests.

	Model No. 2	Model No. 3	Model No. 5	Model No. 6
Geosynthetic	-	NW	WG	SNW
Rainfall 1 (mm/hr)	40-50	40-50	40-50	40-50
Duration rainfall 1	19 h	4 h	2 h	5 h
Rainfall 2 (mm/hr)	90-100	40-50	40-50	40-50
Duration rainfall 2	2 h	1.2 h	1 h	3.5 h
Duration test	5 days	3 days	3 days	3 days

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 *Pore water pressure distribution – No reinforced model*

After a cycle of wetting (first rainfall) and a cycle of drying, a second rainfall was applied to model No. 2. Pore water pressure distribution for this model after two hours of the second rainfall is shown in Figure 2; at this time, infiltrated water started to accumulate at the bottom of the model, increasing the pore pressure; but, at the top it was possible to observe higher negative pore pressures. Water table started to build up from the bottom to the top, toe became loose and partial failure gradually progressed.

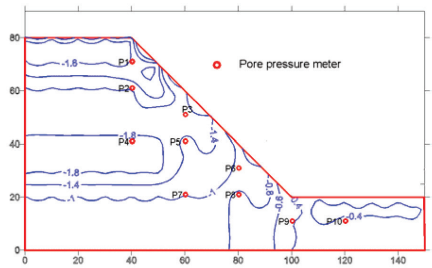

Figure 2. Pore pressure distribution after 2 hours second rainfall. Model No. 2.

4.2 *Pore pressure and water content histories*

Figure 3 shows a comparison among water content histories of sensor M3 in models 2, 3, 5 and 6. Sensor M3 was placed above the geosynthetics in the reinforced models as shown in figure 1. From the volumetric water content histories it is observed that both geotextile and geocomposite caused a discontinuity in the infiltration process; the soil that is above these geosynthetics remained wetter if compared with the model without reinforcement

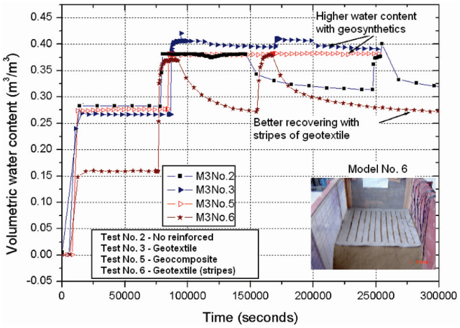

Figure 3. Volumetric water content histories of sensor M3 in models 2, 3, 5, 6.

(Model 2); it suggests that water was infiltrating during rainfall and it was retained by the geosynthetics and accumulated above them.

To study how to avoid this accumulation of water above the geosynthetic, a model reinforced by stripes of geotextile was performed (Model 6). It was observed that once rainfalls were stopped, volumetric water content within the soil above the geotextile decreased because water could pass through the spaces in between.

During model test 3 and 5 it was observed that geosynthetics became a barrier impeding that the water could drain freely down within the model embankment. This barrier caused by the geosynthetics was observed by measurement of pore pressure immediately above and below the geosynthetics. During the tests and when rainfalls were applied to the models, higher pore pressures were register above the geosynthetics; on the other hand, soil located below the geosynthetics showed lower pore pressures; it means that geosynthetics acted as a capillary barrier within the model.

Figure 4 shows a comparison between sensor P3 and P5 in model 3. When first rainfall was applied to the model, sensors P5 and P3 responded very quickly and the suction within the soil was reduced considerably due to the rainfall infiltration. But, it was observed that during and immediately first rainfall

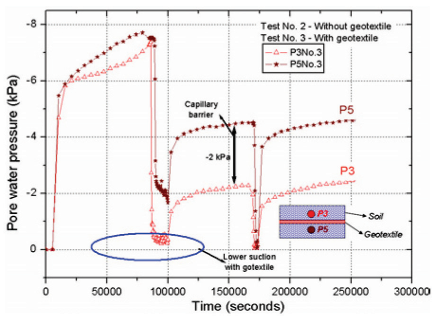

Figure 4. Comparison between sensors P3 and P5 in model 3.

there was a difference of -2 kPa between the pore pressures above and below the geotextile, it suggested that there was higher water content above the geotextile than below it; moreover, during rainfall 1, water pressure above the geotextile was close to zero while the pore water pressure within the soil below it remained negative (suction). Capillary barrier existed during and after rainfall.

Figure 5 shows the response of sensors 3 and 5 when first rainfall was applied. Sensor above the geotextile (P3) responded first to the water infiltration, but it took 45 minutes that water passed through the geotextile and reached the sensor below it (P5). It means that geotextile retained the water during 45 minutes above it. Geotextile did not allow water filtration until suction was near to zero. When second rainfall was applied, similar response was observed, showing that it took 20 minutes that water passed though the geotextiles. It suggests that once geotextile is wet the time gap that water requires to pass through it decreased.

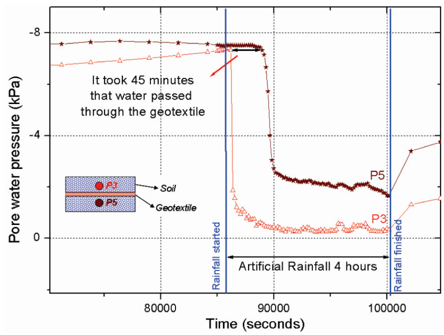

Figure 5. Comparison between sensors P3 and P5 during first rainfall.

Similar behavior was observed when sensor P3 and P5 were compared in model 5 where geocomposite was used.

4.3 *Water retention characteristic curves*

Water retention characteristic curves were measured for soil and geotextile using tempe pressure cell and hanging column test, respectively. Data obtained was modeled using Fredlund's equation, Fredlund & Xing (1994). Infiltration in a soil-geosynthetic system can be explained as follow (figure 6): *Wetting process*: From point 1 to 2. Due to rainfall infiltration soil starts to saturate and suction decreases; at point 2, soil is almost saturated. Geosynthetic cannot get much water at these levels of suction; then, water started to accumulate within the soil immediately above the geosynthetic. Geosynthetic acted as a barrier giving rise to the measured water content and pore pressure above it. This is the capillary barrier. *Wetting process*: From point 2 to 3. At point 2, soil is almost saturated,

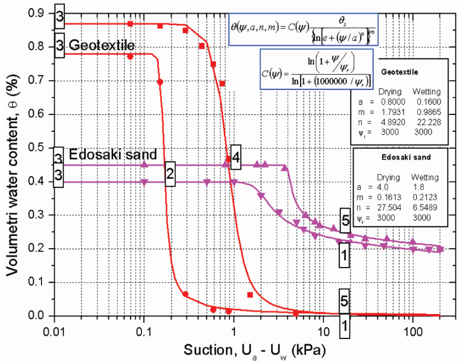

Figure 6. Water retention characteristic curves.

so, water is accumulating and geosynthetic is increasing its water content until reaching point 3. At point 3, soil and geosynthetic are almost saturated, and due to the saturation of the geosynthetic, water can pass through it and also it can be drained laterally. Drying process: From point 3 to point 4. Once rainfall infiltration stops, soil and geosynthetic starts the drying process. Geosynthetic dries faster than soil, coming to point 4 very fast. At point 4, soil still is saturated; then, water remained above the geosynthetic because it can not pass through it. Capillary barrier appeared again at that moment, when suction started to increase. Drying process: From point 4 to point 5. Slowly, soil and geosynthetic continues together drying process.

4.4 *Failure mechanisms*

No-reinforced model started to fail when water accumulated at the bottom and water table started to build up. Failure was progressing to the upstream portion as water pressure and volumetric water content increased. Similar behavior was observed in model 6.

Model 3 and 5 showed local failure faster that the no-reinforced model. Figures 7 shows the photographs

Figure 7. Local failure model 5.

at the moment local failure started. Failure started from the erosion of the slope surface due to the high water content in the vicinity of the geosynthetics. It seemed that water accumulated above the geosynthetics and it started to drain laterally above them; seepage was presented and particles above the geosynthetics became loose. Nishigaki et al (1993) reported similar behavior in laboratory experiments with geosynthetics. There is the possibility that this variety of geosynthetics can retard or stop the water due to rainfall infiltration, accumulating it and causing local failure in their vicinities.

5 CONCLUSIONS

The following conclusions are drawn from the present study:

- Geotextile and geocomposite used, worked as a capillary barrier, maintaining the soil above them with high degree of saturation. On the other hand, when stripes of geotextile were used, capillary barrier was avoided.
- In no-reinforced embankment failure was progressive initiating at the bottom due to the accumulation of the infiltrated water. Reinforced models showed that water accumulated along the geosynthetics causing local failure above them. Models reinforced by geosynthetics (except model reinforced by stripes) behaved less stable that model without reinforcement.

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