Laboratory investigation of internal drainage on the deformation behavior of geosynthetics reinforced soil wall (GRSW) during rainfall

Qaisar Abbas & Chungsik Yoo
Department of Civil, Architectural and Environmental Engineering, Sungkyunkwan University, Korea

ABSTRACT: Global warming is now considered to be one of greatest threats to the earth. The direct consequence of temperature increases due to the global warming include a rise in sea level and a change in the amount and pattern of precipitation. Since the amount of precipitation have of dominant inferences to the short and long-term performance of geo-structure, geo-engineers should pay attention to the progeny of global warming. In this paper, the results of laboratory investigation to check the performance of geosynthetic reinforced soil wall (GRSW) along with horizontal drain layers (HGG) by using hybrid geogrid are presented. A series of model tests were performed using reduced scale model wall to check the effect of internal drainage layers and rainfall intensity parameters to evaluate the behavior of reinforced wall under rainfall. The results of present study indicate that the use of HGG in an effective way can significantly reduce not only reinforced wall failure but also reduce the wall displacement as well as backfill soil water content.

Keywords: Geosynthetics, Sinkhole, Reduced-scale model test, Ground deformation, Earth pressure

1 INTRODUCTION

Indications of global climate changes are constantly stated. The global mean temperature has increased by from last 100 years with about two-third of the increase happening since 1980. 2000 to 2010 decade was considered to be the warmest decade, and 2010 along with 2005 was reported as warmest years in the surveillance history record. The increase of temperature and its unbalanced spatiotemporal allocation accelerated the atmosphere and hydrologic cycle relentlessly. The Intergovernmental panel on climate change (IPCC 2013) designated that the total precipitation, return frequency and the extreme rainfall has enlarged continuously, founded on the consequences of simulation and studies of past data. An increase in temperature will cause the sea level to rise and will change the amount and prototype of precipitation as well. Korea is no exemption from the progeny of global warming. It is projected that, because of previous studies, the temperature increase will be as great as with an annual increase of precipitation about 17% by the end of 21st century. Since the increase of precipitation has of dominant inferences to short and long-term performance of geo-structure, geo-engineers should pay care to the subject of global warming.

These days reinforced earth walls are well accepted as compared to the conventional retaining walls in all over the world. Despite geotechnical engineers pay great attention to the design and construction of retaining wall from different prospective point of view but still because of heavy rainfall there have been many failure case histories of earth retaining walls from minor structure collapse to total collapse. The failure case history of reinforced earth wall because of heavy rainfall during summer season as studied by Yoo and Jung (2007). The failure of reinforced earth retaining walls are usually because of (i) Improper design of drainage system and (ii) use of improper draining fine-grained soil as a backfilling during construction of retaining wall as deliberated by (Koerner and Soong 2001, Yoo and Jung 2007). In response to the need for addressing the effect of rainfall on geo-structures for design and construction, a number of studies have been commenced. Most of the available studies are, however, concentrating more or less on the effect of rainfall on natural slopes (Gasmo et al. 2000, Cai and Ugai 2005, Cheuk et a l. 2005, Garcia et al. 2006, Zhan and Ng 2004) except Yoo et al. (2008a, 2008b) in which the effect of rainfall on retaining structures was investigated. Therefore, mitigation measures to prevent rainfall triggered retaining wall failure are needed.

The present study, demonstrate the results of laboratory investigation into the effect of internal drainage layers (HGG) on the performance of GRSWs. The series of model tests were carried out by using reduced scale model walls, which were reduced from a full-scale GRSWs according to similitude law. The model GRSWs were subjected to cycles of wetting and drying process to investigate the rainfall intensity and number of drainage layers effect. The results of experimental study presented thoroughly to investigate the effect of internal drainage system on the performance of GRSW under heavy rainfall.

2 LABORATORY MODEL TEST

A series of reduced scale model tests were performed with due consideration of the wetting and drying process. Details of the model tests and the results are given in the subsequent sections.

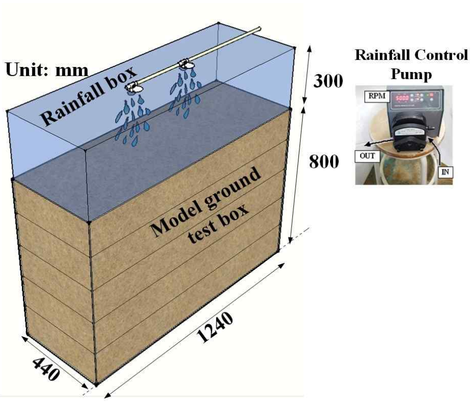
2.1 *Experimental setup*

2.1.1 *Test configurations*

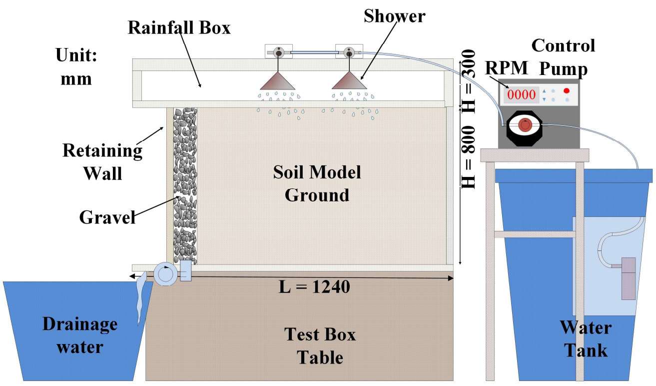
The series of laboratory model test box experiments were performed in a test box made of transparent plexiglass to easily observe the soil movement and wall deformation. The reduced scale model tests were performed using 0.75m high reduced scale model GRSWs constructed in a test box, having dimensions of 1.24 m x 0.44 m in plan and 0.8 m in height, made of 3cm thick Plexiglas as shown the schematic view in Figure 1(a). The wall facing, made of 0.5 cm thick Plexiglas, was hinged at the bottom of the test box to allow the free movement of wall during and after the period of rainfall on soil model ground.

2.1.2 *Rainfall simulation*

For rainfall simulation, a box was used having same dimensions as dimensions of test box in plan and 0.3m height, made of 2cm plexiglass as schematic view of rainfall box shown in Figure 1(a). The rainfall was simulated by spraying water at the top of the backfill using spray shower with 15HP (Horsepower) compressor and a 20W stepping motor having flow capacity 0.06~2300 mL/min with 0.1~600RPM (Revolution per minute) as shown in Figure 1(a). The rainfall simulation process used in this study shown in Figure 1(b). To select the RPM value of motor for specific rainfall, 1st check the quantity of flow at different RPM values in container at specific time duration and 300RPM value of motor were selected for required rainfall intensities.



(a) Test box and rainfall simulation setup



(b) Rainfall simulation process

Figure 1. Test box setup and rainfall simulation process

2.2 *Material used*

2.2.1 *Backfill soil*

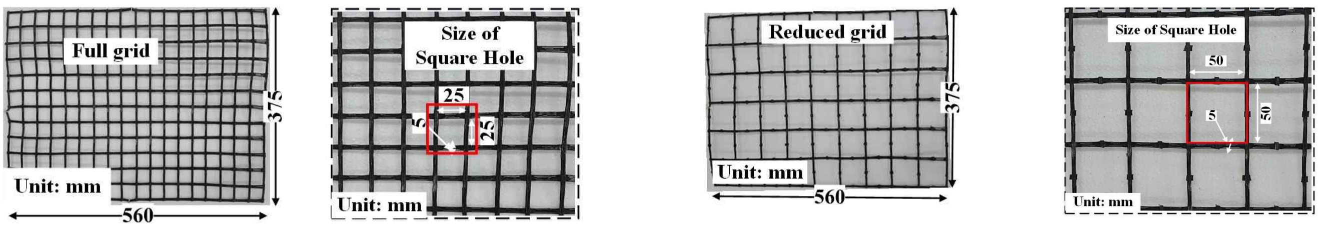
The backfill soil used in this study was a cohesive soil commonly known as decomposed granite soil (DGS) with 20% of fines clay minerals. 20% kaolinite as fine particles were mixed with granite soil after five cycles of wetting and drying process to maintain the fine particles ratio within soil. Classified as SM soil as per unified soil classification system (ASTM 2487-90 1992). The frictional characteristics, compaction characteristics based on consolidated-undrained triaxial compression tests and permeability characteristics of used soil shown in Table 1.

2.2.2 *Reinforcement and internal drainage layers*

The geosynthetic polymeric geogrid was used in this study to demonstrate the effect of reinforcement for wall performance during rainfall. The tensile strength of geogrid was intentionally reduced by creating 5cm x 5cm square holes in original geogrid as shown in Fig. 2. Where Fig. 2(a) and (b) show the original geogrid along with square hole size and down scale geogrid shown in Fig. 2(c) and (d) along with nominal thickness and aperture size of geogrid. The length of geogrid kept constant up to 0.7H in all test cases. The reinforcement layers were firmly connected to the wall facing by bolting. The tensile strength of geogrid was measured by standard test method for wide width tensile test (ASTM D4595 2011). From results, tensile strength of geogrid is 40kN/m at strain rate of 12% and for reduce stiffness purpose the tensile strength of geogrid reduced up to half as mention above by creating 5cm x 5cm square holes.

Table 1. Characteristics of the backfill soil.

Properties	Values	Standard
Liquid limit (%)	34	ASTM D4318-10e1
Plastic limit (%)	20	ASTM D4318-10e1
Maximum dry unit weight (kN/m^3)	17.8	ASTM D1557
Optimum moisture content (%)	14.5	ASTM D1557
Cohesion (kPa)	19.70	ASTM D7181
Friction angle (deg)	20.01	ASTM D7181
Permeability (cm/sec)	6.54×10^{-4}	ASTM D5856-15



(a) Original geogrid (b) Square hole size (c) Reduced grid geogrid (d) Reduced grid size

Figure 2. Geosynthetic reinforcement and square hole size for original and reduced grid geogrid

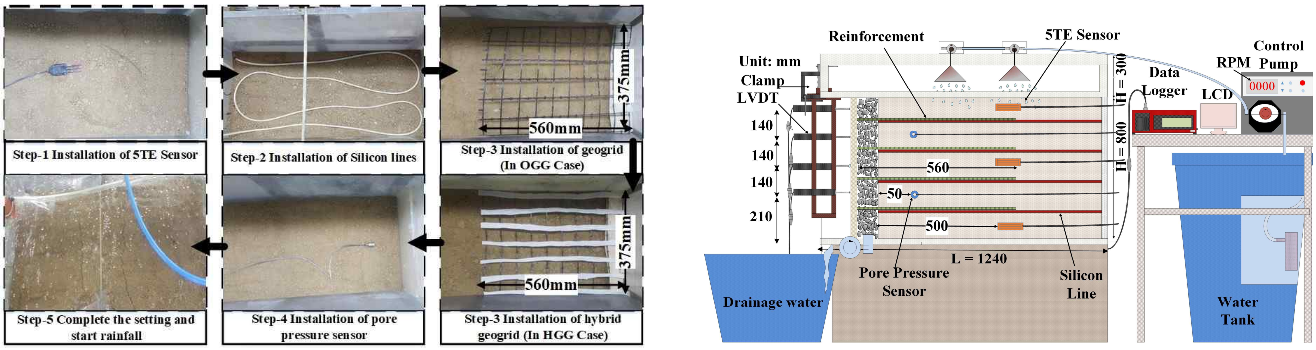
For internal drainage system, a geotextile paper was selected because of its high absorption of water and very small stiffness. During wall construction, it was placed over the web of polymeric geogrid with strips of geotextile strips. The length of strips is same as the length of geogrid and width is equal to web thickness of geogrid. The plan view of geotextile strips over the web of polymeric geogrid shown in Figure 3. Where Figure 3(a) shows the placement procedure of drain layers over the polymeric geogrid and Figure 3(b) top view of hybrid geogrid along with polymeric geogrid.

(a) Drainage layers placement over geogrid (b) Setup of internal drainage layers

Figure 3. Geogrid internal drainage setup

2.3 *Model ground preparation and instrumentation*

The model ground for reinforced wall reduced scale test was prepared using decomposed granite soil with 20% fines and initial water content of soil 14.5% keep constant in all test cases. Each soil layer was compacted with 200 blows to achieve the required compaction energy. The model ground was created in five soil layers at 0.140m height of each soil layer up to 0.7m high retaining wall with proper compaction and used the same weight of soil 92.5kg in each layer as per 90% of dry unit weight of soil with a dry unit weight of 17.8kN/m^3 as per drive-cylinder method (ASTM D2937) and height of compaction hammer was selected 1.5m with weight of hammer 5kg. Four layers of geogrid were placed at spacing of 0.140m and length of 0.7H (H = Height of wall). For water content 5TE sensor was used in 1st, 3rd and 5th layer of soil. Silicon lines with hot water controlled by temperature controller were embedded into the ground on each layer of soil to keep the soil normal temperature up to 20^{o}C. 0.10m width gravel layer was placed along the retaining wall for proper drainage. The geogrid reinforcement and drain layers of geogrid as per testing program were installed into the model ground and firmly attached with retaining wall with bolting. The detail test procedure and instrumentation setup shown in Figure 4(a) and (b).



(a) Model ground preparation (b) Instrumentation program

Figure 4. Test procedure and instrumentation program for GRSW

2.4 *Parametric study*

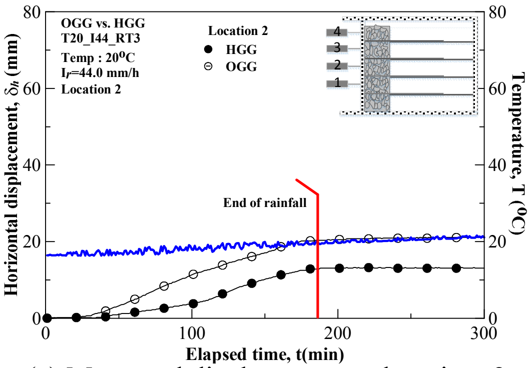
To monitor the performance of geosynthetic reinforced soil wall (GRSW) and effect of internal drainage system on deformation behavior of wall during rainfall, laboratory experiments were performed with all ordinary geogrid layers (OGG) and all internal drainage layers (HGG). Further to investigate the proper arrangement of internal drainage layers experiments were performed with one, two and all four nmber of internal drainage layers (HGG). The results were presented in form of wall displacement, flow quantity and volumetric water content of soil to draw proper conclusions for the performance of GRSWs under effect of internal drainage layers.

3 RESULTS AND DISCUSSION

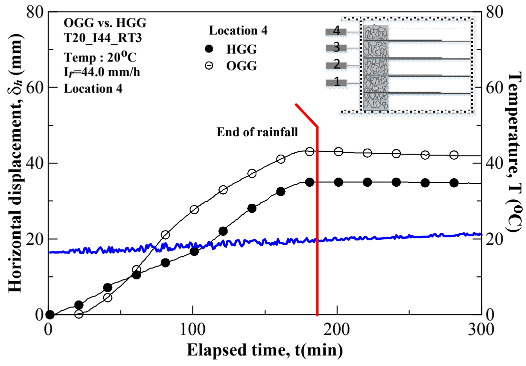
3.1 *General behavior of internal drainage layers*

To check the effect of internal drainage system on the performance of reinforced wall, reduced scale laboratory experiments were performed by using all horizontal drain layers (HGG) and without drainage layers (OGG) just placing ordinary geogrid layers at constant spacing. Rainfall intensity Ir = 44.0mm/hr kept constant for both cases at 3hr duration of rainfall. Results were drawn for horizontal wall displacement, soil water content with time variation and for out flow quantity of water with the passage of time.

Figure 5. shows the results for horizontal wall displacement with passage of time for both test cases, without drainage layers (OGG) and with drainage layers (HGG) at the measured location of 2 and 4 at 0.35, and 0.63 m from the base of wall respectively. From results, it is clearly seen that, horizontal wall movement significantly reduces with horizontal drain layers and wall displacement increase continually during the period of rainfall only. Maximum displacement occurs at the end of rainfall period of 3hr and after rainfall period there is no meaningful change in displacement. From results it is also observed that, maximum displacement occurred at the top of reinforced wall and decreases along the depth of wall from top to bottom as shown the wall displacement profile in Figure 6 with the passage of time.

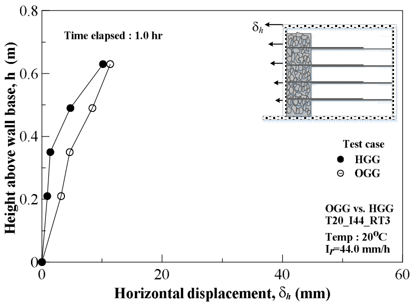


(a) Measured displacement at location_2

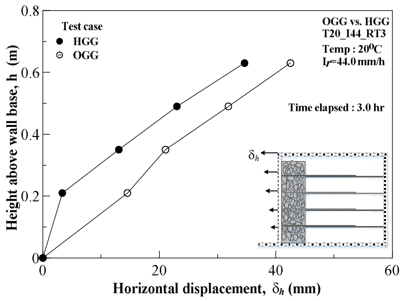


(b) Measured displacement at location_4

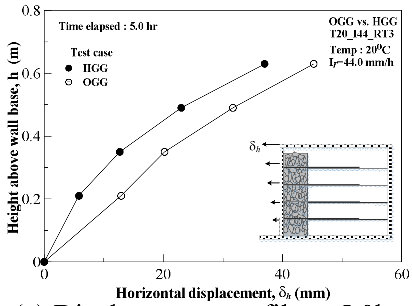
Figure 5. Test procedure and instrumentation program for GRSW



(a) Displacement profile at 1.0hr



(b) Displacement profile at 3.0hr



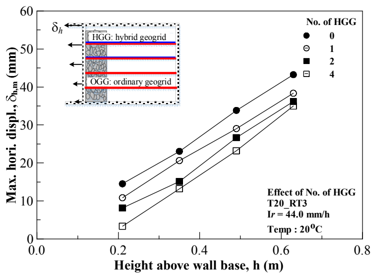
(c) Displacement profile at 5.0hr

Figure 6. Wall displacement profile against the elapsed time for OGG and HGG

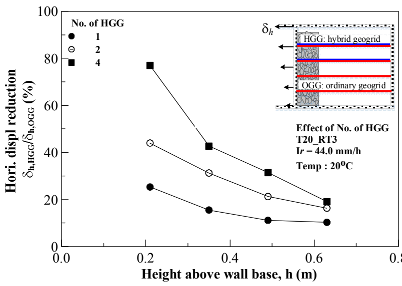
3.2 *Effect of internal drainage layers*

To check the effect of internal drainage layers and to select the optimum layers of horizontal drainage layers for reinforced wall performance under heavy rainfall, the laboratory experiment was executed by using all drain layers, two drain layers and one drain layer. The results were drawn for horizontal wall displacement, cumulative flow quantity of rain water and water content of soil to investigate the maximum drainage effect on wall performance.

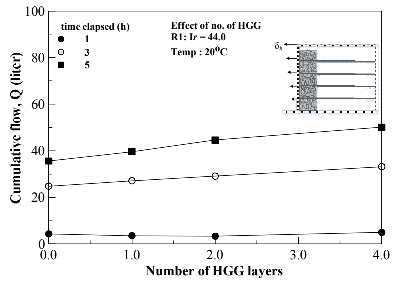
Figure 7(a) shows the results of maximum wall displacement against the measured locations along with number of drain layers and from results it is noticed that, wall displacement decreases with increasing the number of drain layer. From results it is clearly seen, that without drain layers' highest wall displacement occur and by placing the horizontal drain layers wall displacement significantly reduce along the increase of drainage layers. Figure 7(b) shows the percentage reduction in wall displacement with number of internal drainage layers with respect to ordinary geogrid (OGG) and from results the percentage reduction in wall displacement increases with increasing the number of drainage layers and maximum reduction almost up to 40% in case of all four internal drainage layers (HGG) with respect to OGG. Where Figure 7(c) shows the results for maximum cumulative flow quantity through drainage layers and from results it is seen that the flow quantity of rainfall increases with increasing the number of internal drainage layers which make the reinforced wall safe during heavy rainfall.



(a) Max. Hori. displacement



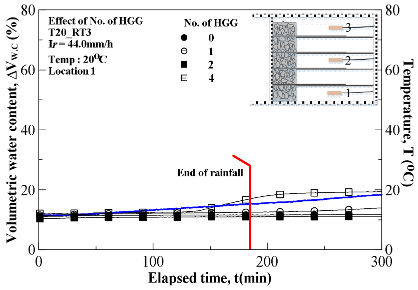
(b) Hori wall. Displ reduction



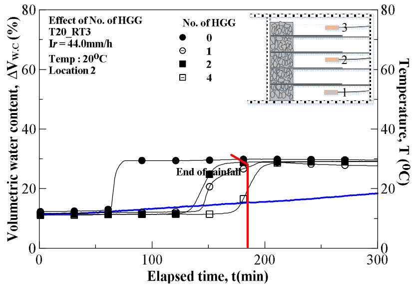
(c) Max. flow quantity

Figure 7. Horizontal wall displacement and maximum flow quantity under different HGG layers

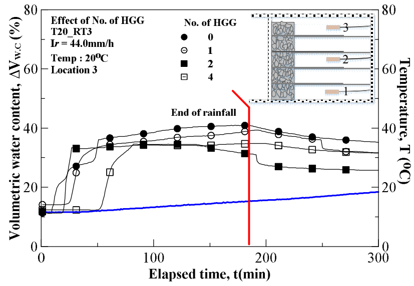
The volumetric water content at three different location of backfill ground measured with 5TE sensor as per instrumentation program for different number of drainage layers are shown in Figure 8(a), (b) and (c) for measured location 1, 2 and 3. From below mention results it is seen that water content of backfill soil decreases with higher number of drain layers, from this it is suggested that, by increasing the number of drain layers' maximum rain water drain out through drainage layers which keep the backfill dry as compared to small and without drain layers due to this volumetric water content also decreases with higher number of drain layers. From these results it is also notice that, for all drainage layers' rain water with the passage of time drain through all drain layers that's why in case of all drain layers water content measured at point three have small value as compared to two and one drain layer. Because in case of two and one drain layer maximum water drain out through top drainage layers and bottom layer remain dry.



(a) Water content location_1



(b) Water content location_2



(c) Water content location_3

Figure 8. Horizontal wall displacement and maximum flow quantity under different HGG layers

4 CONCLUSIONS

A series of reduced-scale model test box experiment were performed to investigate the effect internal drainage layers on the performance of GRSWs. A number of cases were tested considering the general observed behavior of internal drainage layers (HGG) with respect to ordinary geogrid (OGG) reinforced wall and effect of number of drainage layers. The results indicated that the use of internal drainage layers can significantly reduce the potential for ground deformation towards reinforced wall under heavy rainfall with respect to ordinary geogrid reinforced soil wall. Also, from the experiments results under the effect of number of drainage layers, it is investigated that the wall performance significantly improves with increasing the number of drainage layers in term of reduction in wall displacement, increase of flow quantity from reinforced wall backfill and reduction in volumetric water content of backfill. Further study is required to generalize the effect of internal drainage on reducing the potential reinforced wall failures during rainfall.

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