Geosynthetic Reinforced Soil Wall Performance under Heavy Rainfall

La performance du mur en sol renforcé par géosynthétiques sous de fortes pluies

Yoo C., Jang D.W.
Dept. of Civil and Environmental Engineering, Sungkyunkwan University, Suwon, Korea

ABSTRACT: Global warming is now considered to be one of the greatest threats to earth. The direct consequence of the temperature increase due to the global warming include a rise in sea levels and a change in the amount and pattern of precipitation. Since the amount pattern of precipitation have of paramount implications to short and long-term performance of geo-structures, geo-engineers should pay attention to the issue of global warming. In this paper, the results of laboratory investigation into the effect of rainfall on the performance of geosynthetic reinforced soil wall (GRSW) are presented. A series of model tests were performed using reduced scale model walls, which were reduced from a full-scale GRS wall according to the similitude law. The model GRSWs were subjected to cycles of wetting and drying process with different rainfall intensties but with a same amount. The results show that the cycles of wetting and drying associated with a heavy rainfall may induce additional wall displacement and reinforcement strains in GRSWs, and that such trends have significant implications to GRSW stability, especially for walls designed with marginal factor of safety in terms of long-term performance.

RÉSUMÉ : Le réchauffement climatique est aujourd'hui considéré comme l'une des plus grandes menaces pour la terre. Les conséquences directes de l'augmentation de température due au réchauffement climatique incluent notamment l'élévation du niveau des mers et un changement dans la quantité et le régime des précipitations. Ces paramètres ayant des implications primordiales sur les performances à court et à long terme de géo-structures, les géo-ingénieurs devraient prêter attention à la question du réchauffement climatique. Dans cet article, les résultats des études en laboratoire sur les effets de fortes précipitations pour la performance des murs en sol renforcé par géosynthétiques (GRSW) sont présentés. Une série d'essais sur modèles réduits a été réalisée avec des modèles réduits d'un mur à pleine échelle GRS suivant la loi de similitude. Les modèles GRSW ont été soumis à des cycles de mouillage et de séchage avec des intensités pluviométriques différentes. Les résultats montrent que les cycles de mouillage et de séchage associés à une forte pluie peuvent provoquer un déplacement supplémentaire du mur et les tensions dans le renforcement, et que ces tendances ont des implications importantes pour les GRSW conçus avec un faible facteur de sécurité en termes de performance à long terme

KEYWORDS: Climate change, Rainfall, Reduced-scale model test, Matric suction, Pore water pressure

1 INTRODUCTION

Since the early 20th century, Earth's mean surface temperature has increased by about 0.8^oC with about two-thirds of the increase occurring since 1980. A climate model projects that the global surface temperature will probably rise further 1.1 to $6.4°C$ during the twenty-first century (IPCC 2007). An increase in global temperature will cause sea levels to rise and will change amount and pattern of precipitation as well. Korea is no exception from the issue of global warming. The Korean Meteorological Administration (KMA) has made a report on climate change characteristics during the period of 1996~2005 that the mean temperature has increased by $0.6°C$ from the last 30 year mean temperature during the period between 1971 to 2000 (KMA 2008). The annual precipitation has also increased by 11%. It is projected that the temperature increase will be as great as $4°C$ with an annual precipitation increase of 17% by the end of 21st century. Since the increase in precipitation has of paramount implications to short and long-term performance of geo-structures, geo-engineers should pay attention to the issue of global warming.

In response to the need for addressing the effect of rainfall on geo-structures for design and construction, a number of studies have been undertaken. Most of the available studies are, however, focused more or less on the effect of rainfall on natural slopes (Gasmo et al. 2000, Tsaparas et al. 2002, Zhan and Ng 2004, Cai and Ugai 2004, Cheuk et a l. 2005, Garcia et al. 2006, Rahardio et al. 2007, Rahimi et al. 2011) except Blake et al. (2003) and Yoo et al. (2008a, 2008b) in which the effect of rainfall on retaining structures was investigated. More specifically, Yoo et al. (2008a, 2008b) investigated the effect of rainfall on GRSWs using a series of limit equilibrium analyses within the framework of unsaturated shear strength, coupled with transient infiltration analyses. Much still need to be studied on the subject of the effect of rainfall on geo-structures.

In this paper, the results of a laboratory investigation into the effect of rainfall on the performance of geosynthetic reinforced soil wall (GRSW) are presented. A series of model tests were performed using reduced scale model walls, which were reduced from a full-scale GRS wall according to the similitude law. The model GRSWs were subjected to cycles of wetting and drying process with different rainfall intensties but with the same total rainfall.

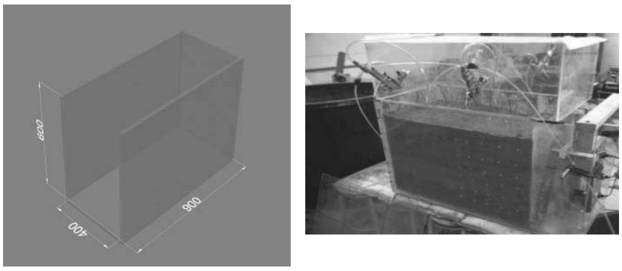
2 REDUCED SCALE MODEL TEST

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 Model wall and backfill soil

The reduced scale model tests were performed using 0.5 m high reduced scale model GRSWs constructed in a test box, having dimensions of 0.9 m x 0.4 m in plan and 0.6 m in height, made of 2 cm thick Plexiglas as shown in Figure 1. The test box was made sufficiently rigid to maintain the plane-strain condition during test. The wall facing, made of 0.5 cm thick Plexiglas, was hinged at the bottom of the test box so as to allow lateral displacement to occur during the wetting and drying process.

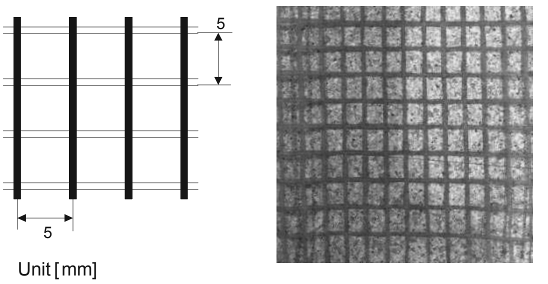
The backfill soil was a non-plastic poorly-graded sand, commonly known as decomposed granite soils (DCG) in Korea, classified as SP as per ASTM 2487 (ASTM 1992) with the effective size (D_{10}), uniformity coefficient (C_u), and coefficient of curvature (C_c) of 0.36 mm, 5.3 and 1.1, respectively. The soil was compacted to 70% of its maximum unit weight ($19kN/m^3$) to create reinforced as well as retained zones. The estimated effective internal friction angle (ϕ') using a series of consolidated-undrained (CU) triaxial compression tests with pore pressure measurements at a density corresponding to the as-compacted state was determined as approximately 35° with a shear stress intercept of 8 kPa.



(a) Test box (unit mm) (b) photo of model GRSW

Figure 1. Test box and model GRSW

A non-woven geotextile was used as reinforcement. Note however that the tensile strength of the non-woven geotextile was intentionally reduced by creating 5 mm x 5 mm square holes (Figure 2) to have an ultimate tensile strength of $3.8\times10^{-2}\ kN/m$. Six layers of reinforcement, 35 cm in length each, were placed at a vertical spacing of 6 cm (Figure 3). The reinforcement layers were firmly connected to the wall facing by bolting.



(a) square hole size (b) photo of model reinforcement

Figure 2. Model geotextile reinforcement

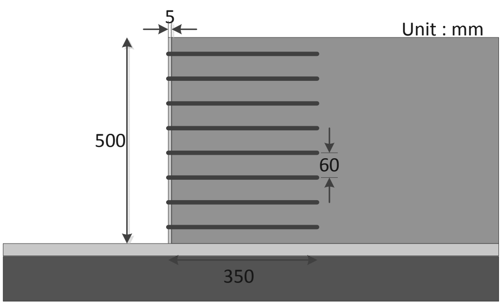


Figure 3. Schematic sectional view of model GRSW

2.2 Rainfall simulation

Three cycles of wetting and drying were applied to the model walls to simulate the natural weather condition. Two rainfall intensities (I_r) were considered, i.e., 18.7 mm/h and 56.2 mm/h for a given total precipitation of 450 mm. The duration of the rainfall for the case with $I_r = 18.7\,mm/h$ was therefore 24 hours while 8 hour duration was used for the case with $I_r = 56.2\,mm/h$. Note that these rainfall conditions were based on the actual rainfall occurred in 2011 in Kyoung-Gi province, Korea. Followed after each wetting process was a 24 hour drying period prior to the ensuing wetting to observe the wall behavior during the repeated wetting and drying.

The rainfall was simulated by spraying water at the top of the backfill using spray guns with 15HP compressor and a 20W water motor (Figure 4).

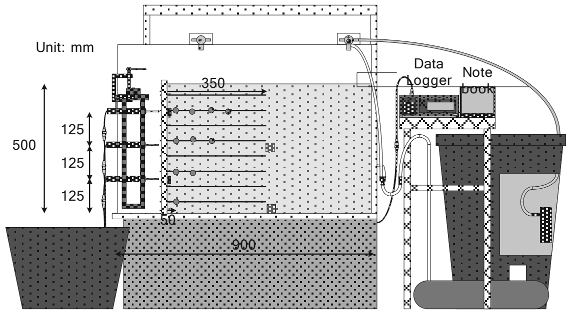


Figure 4. Schematic diagram of rainfall simulator

2.3 Instrumentation

The performance of the model GRSW under a series of wetting and drying cycles was evaluated in terms of wall facing displacements, pore water pressures, and reinforcement strains. The layout of instrumentation program is shown in Figure 5.

As shown, the horizontal displacements of the wall facing were measured by using three LVDTs having gauge length of 100 mm, placed at locations along a vertical row. In addition, the wetting and drying cycle induced reinforcement strains were measured using high-elongation strain gauges, manufactured by Tokyo Sokki Kenyujo Company (Model YFLA-5-5L) which were mounted directly onto the selected reinforcement layers in one array. Also installed at the back of the reinforced zone were two pore pressure cells (Model BPR-A-200 kPa) at the bottom (0 mm) and 250 mm above the wall base. The volumetric water content of the backfill soil during the wetting and the drying process was also measured using a tensiometer (Model EC-5).

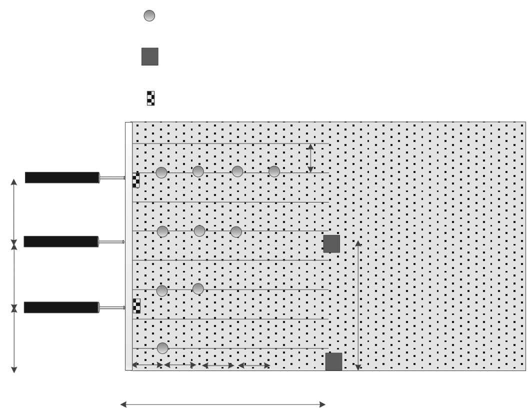
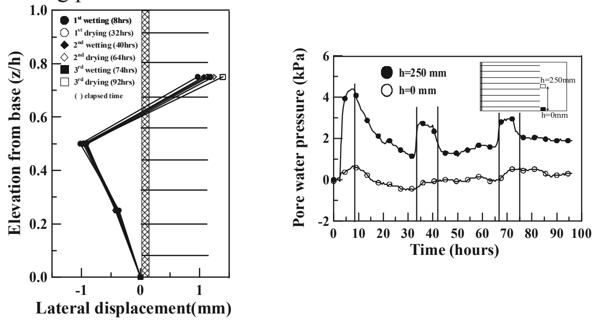


Figure 5. Instrumentation layout

3 RESULTS AND DISCUSSION

3.1 General behavior

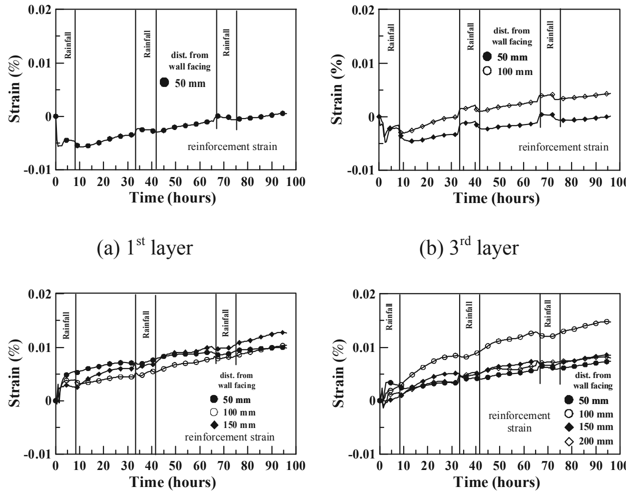
Figure 6 show the measured data for the rainfall intensity of $I_r = 56.2\,mm/h$. As mentioned, the $56.2\,mm/h$ intensity rainfall lasted for 8 hours for wetting. As shown in Figure 6(a), the wall displacement increased about 1 mm during the 1st cycle of wetting after which no significant increase was recorded. The pore water pressures measured at the bottom and the mid-height at the back of reinforced zone tended to increase during the first wetting period as great as 4 kPa, followed by gradual decreases during the ensuing 24 hour drying period as shown in Figure 6(b). As observed in the wall displacement, the largest increase in the pore water pressure was measured during in the first wetting period.



(a) wall displacement (b) pore pressure

Figure 6. Wall displacement and pore pressure ($I_r = 56.2\,mm/h$)

Shown in Figure 7 are the measured reinforcement strains in the selected reinforcement layers. Of salient features are twofold. First, the reinforcement strains tended to steadily increase over the repeated wetting and drying cycles unlike the wall displacements and the pore water pressures which showed cycles of fluctuation during the wetting and draying process. Second, larger strains, as great as 0.015%, are measured in the upper reinforcement layers than in the lower layers due possibly to the downward movement of wetting front caused by the rainfall infiltration.



(a) 1st layer (b) 3rd layer

(c) 5th layer (d) 7th layer

Figure 7. Reinforcement strains ($I_r = 56.2\,mm/h$)

Figure 8 shows the time variation of volumetric water content (θ) measured at 160 mm above the wall base at the back of the reinforced zone. As shown, the initial volumetric water content of 0.05 at the measuring point sharply increased to 0.35 after which it remained constant over the remaining wetting period. During the drying period, θ then sharply decreased to 0.2 and remained constant during the entire drying period. A similar trend can be observed in the following cycles suggesting that the cycles of the wetting and drying with the rainfall intensity and duration considered in this study may increase the water content of the backfill soil.

The results shown here indicate that the repeated cycles of wetting and drying associated with a heavy rainfall may induce additional wall displacement and reinforcement strains in GRSWs. Such results suggest that the weather induced wetting drying has significant implications to GRSWs designed with marginal factor of safety in terms of long-term stability.

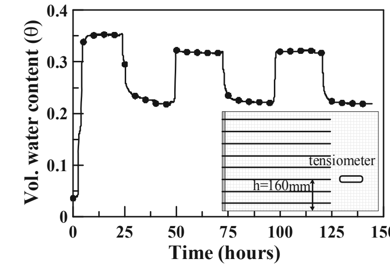
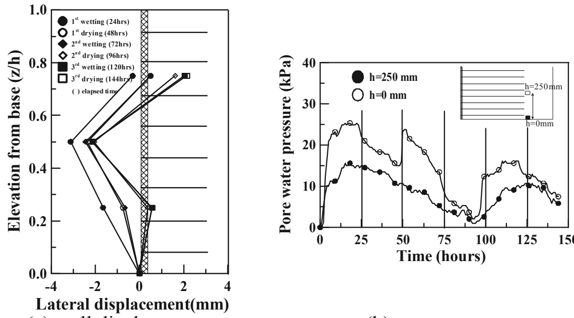


Figure 8. Time variation of volumetric water content (θ)

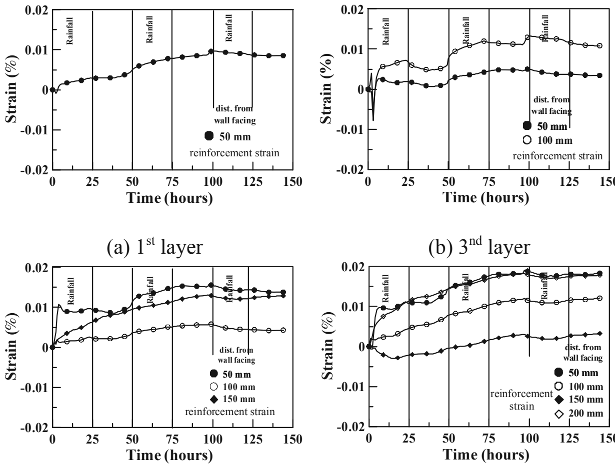
3.2 Effect of rainfall intensity

Figures 9 and 10 show the measured wall displacements and the reinforcement strains for the case with a rainfall intensity of 18.7 mm/h. Note that the total rainfall was kept same at 450 mm as in the case of $I_r = 56.2\,mm/h$ but with a longer wetting period of 24 hours. The discrepancies in the wall performance between the two cases can therefore be thought to stem from the rainfall intensity.



(a) wall displacement (b) pore pressure

Figure 9. Wall displacement and pore pressure ($I_r = 18.7\,mm/h$)



(a) 1st layer (b) 3nd layer

(c) 5th layer (d) 7th layer

Figure 10. Reinforcement strains ($I_r = 18.7\,mm/h$)

The direct comparison between the two cases reveals that the case with the smaller rainfall intensity but with the longer duration generally induces larger wall displacements and reinforcement strains except for the pore water pressure measured at the back of reinforced zone. Considering the backfill soil being a high permeability soil, these results contradict those reported by Cai and Ugai (2005) as well as Rahardjo et al. (2007) which were based on a numerical study. A further study is therefore warranted to confirm the effect of rainfall intensity. It can however be stated that the rainfall intensity is a controlling factor for the performance of a GRSW during rainfall infiltration as reported by Rahardjo et al. (2007) in their study concerning natural slopes.

4 CONCLUSIONS

In this study, the results of laboratory investigation into the effect of rainfall on the performance of a geosynthetic reinforced soil wall (GRSW) using reduced scale model tests are presented. The model GRSWs were subjected to cycles of wetting and drying process with different rainfall intensties but with the same total rainfall. The results show that the cycles of wetting and drying associated with a heavy rainfall may induce additional wall displacement and reinforcement strains in GRSWs, and that such trends have significant implications to GRSWs with marginal factor of safety in terms of long-term performance. The effect of rainfall intensity for a given total rainfall is such that the case with a smaller rainfall intensity but with a longer duration generally induces larger wall displacements and reinforcement strains except for the pore water pressure measured at the back of reinforced zone. Although a further study is required to confirm the effect of rainfall intensity, it can be concluded that the rainfall intensity is a governing factor for the performance of a GRSW during rainfall infiltration.

5 ACKNOLEDGEMENT

This research is supported by Grant No. 20100008227 from the Basic Research Program of the Korea Science & Engineering Foundation. The financial support is gratefully acknowledged.

6 REFERENCES

ASTM 1992. Standard test method for classification of soils for engineering purposes. ASTM D2487-90, Annual Books of ASTM Standards, West Conshohocken, PA., 4.08, 326-336.

Cai, F. and Ugai, K. 2005. Numerical Analysis of Rainfall Effects on Slope Stability. *International Journal of Geomechanics*, 4(2), 69-78.

Cheuk, C.Y., Ng, C.W.W., and Sun, H.W. 2005. Numerical experiments of soil nails in loose fill slopes subjected to rainfall infiltration effects. *Computers and Geotechnics*, **32**(4), 290-303.

Garcia, E.F., Gallage, C.P.K., and Uchimura, T. 2006, Unsaturated infiltration on artificial embankments reinforced with geosynthetics. *Prof. of 8th International Symposium on Geosynthetics*, Kuwano and Koseki (eds). 1417~1420.

Gasmo, J.M., Rahardjo, H., and Leong, E.C. 2000. Infiltration effects on stability of a residual soil slope. *Computers and Geotechnics*, 26, 145-165.

IPCC 2007. Summary for Policymakers" (PDF). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf.

Korean Meteorological Administration 2008. Report on Climate Change and Mitigation: Dept. of Climate Change Response: Climate Change Information Center, (in Korean).

Rahardjo, H., ong, T.H., Rezaur, R.B., and Leong, E.C. 2007. Factors controlling Instabiity of Hogeneous Soil Slopes under Rainfall. J*ournal of Geotechincal and Geoenvironmental Engineering*, ASCE, 133(12), 1532~1543.

Rahimi, A., Rahardjo, H., Leong, E. C. 2011. Effect of Antecedent Rainfall Patterns on Rainfall-Induced Slope Failure, *Journal of Geotechincal and Geoenvironmental Engineering*, ASCE, 137(5), 483~491

Tsaparas, I., Rahardjo, H., Toll, D.G., and Leong, E.C. 2002. Controlling parameters for rainfall-induced landslides. *Computers and Geotechnics,* 29(1), 1-27.

Yoo, C., Kim, S.B., and Jung, H.S. 2008a. A numerical investigation on effect of vertical drainage system on geosynthetic reinforced soil wall during rainfall. *Journal of Korean Geotechnical Engineering*, 24(5), 99-106.

Yoo, C., Kim, S.B., and Han, J.Y. 2008b. A numerical investigation on stability of geosynthetic reinforced soil wall during rainfall. *Journal of Korean Geotechnical Engineering*, 24(12), 1-12.

Zhan, L.T. and Ng, C.W.W. 2004. Analytical Analysis of Rainfall Infiltration Mechanism in Unsaturated Soils. *International Journal of Geomechanics*, **4**(4), 273-284.