PHYSICAL MODEL TESTS ON MECHANICALLY STABILIZED EARTH WALLS WITH GEOCOMPOSITE DRAINAGE UNDER SEEPAGE CONDITION

A. Udomchai[1], A. Chinkulkijniwat[2], and S. Horpibulsuk[3]
[1]M.Eng. student, School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand, Tel: +66-44 22 4420; Fax: +66-44 22 4607
[2]Assistant Professor, School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand, Tel: +66-44 22 4353; Fax: +66-44 22 4607; Email: avirut@sut.ac.th
[3]Professor, School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand, Tel: +66-44 22 4322; Fax: +66-44 22 4607; Email: suksun@g.sut.ac.th

ABSTRACT

Both external and internal stabilities are a main concern in design and construction manuals for the mechanically stabilized earth (MSE) wall. Literature showed that the failure of the MSE walls, especially in mountainous areas, is mainly caused by the attack of seasonal heavy rainfall. The seepage through the MSE wall due to the rainfall causes the increase in the lateral stress and the reduction in the effective stress, stiffness and strength of the backfill; hence the reduction in the factors of safety against external and internal failure. This paper investigates the flow and mechanical behaviors of the MSE wall with and without geocomposite grain under seepage condition. The investigation is performed using laboratory physical model tests. It is found that the water pressure significantly controls the performance and the failure of the MSE wall. As the water pressure increases, the settlements in the unreinforced zone increase. The failure of the MSE wall is caused by the piping of the reinforced soil. The geocomposite drainage reduces the water pressure and water content in the reinforced zone, hence the improvement of the stability of the MSE wall. For the same water pressure, the MSE wall with geocomposite drainage sustains lower settlements.

Keywords: Mechanical stabilized earth wall, geocomposite, drainage system, physical model test

INTRODUCTION

The use of reinforcements to stabilize earth structures has grown rapidly in the past two decades. When used for retaining walls or steep slopes, they can be laid continuously along width of the reinforced soil system or laid intervals. The backfill is generally granular materials, according to a specification of the Department of Highways. The MSE wall can be used as an earth retaining structure along the mountainous area. The first project in Thailand was constructed in the Highway route no. 11 (Utaradit-Denchai) in 2011. Several MSE wall projects along the mountainous area will be released from the Department of Highways, Thailand such as in Khao Pub Pa and Lomsak. For the design of MSE wall in the mountainous areas, the external and internal stabilities must be confirmed. Generally, the examination of the external and internal stabilities can be referred to standard design manuals such as the American Association of State Highway Transportation Officials (AASHTO) and the Federal Highway Admistration (FHWA), etc. It is worth noting that the design condition is generally assumed that the drainage system still functions. Shibuya et al. (2007) reported the causes of failure of a MSE wall constructed in a mountain in Yabu, Hyogo prefecture, Japan. The failure occurred in 2004 after the attack of typhoon. One of the causes of failure is the inappropriate installation of the drainage system. Shibuya et al. (2009) recommended that the geocomposite drain with a high coefficient of permeability (10 to 200 times higher than that of the compacted backfill) can be used as a drain in the MSE wall. The advantage of the geocomposite drain over the conventional material (well-graded sand) is the high drainage capacity even under the MSE wall movement caused by dead and live loads. Besides, the geosynthetic drainage system is cheaper and simpler installed than the conventional system.

Presently knowledge in design of drainage system in MSE wall using geocomposite is very limited. Rigorous knowledge on influencing factors to drainage efficiency would enhance design potential. Understanding flow mechanism in MSE wall is crucial to develop design direction. This paper investigates the flow mechanism in the MSE wall with and without geocomposite. The investigation is performed using laboratory physical model tests. Results from the tests will be useful for further parameters analysis.

LABORATORY INVESTIGATION

Materials

The soil used in this investigation is a clean sand. It consists of 10% gravel, 87.3% sand, and 2.7% silt. The gradation of the sand is presented in Fig. 1. This sand is classified as poorly graded sand (SP), according to the Unified Soil Classification System (USCS). Its specific gravity is 2.74. The compaction characteristics under standard Proctor energy are optimum water content (OWC) = 5.7% and maximum dry unit weight, $\gamma_{d,max}$ = 16.7 kN/m^3. Strength parameters of this sand at the optimum point obtained from a large direct shear apparatus with the diameter of 35 cm are c' = 0 kN/m^2, and ϕ' = 40 degrees. Generally, well-graded materials are used as backfill due to high efficiency of field compaction. The uniform sand was however used in this investigation for the consistency of the laboratory compaction for each test. Even though the tested sand is uniformly graded but its percent finer than 37, 4.75, 0.425, 0.150, and 0.075mm particle and its internal friction angle meet the specification of the Department of highways, Thailand.

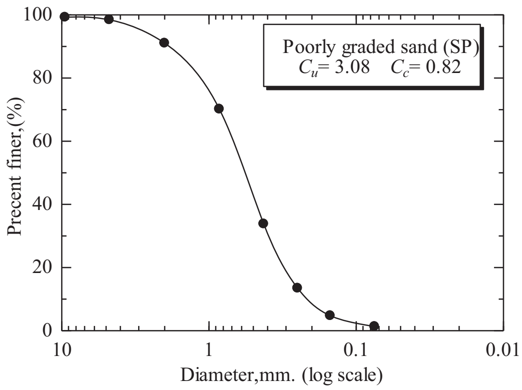

Fig. 1 Particle size distribution of the clean sand

Experimental Setup

A large scale tests were conducted in the campus of Suranaree University of Technology to simulate MSE wall under a condition of high ground water table. A reinforce concrete tank was built to carry out the experiment. The Dimensions of the tank is illustrated in Fig. 2. The sand was filled to the tank to a dimension of 1.4x3.6x1.6 m. It was compacted in layers of about 0.15 m thickness to a density of higher than 90% the standard Proctor density. The compaction was carried out by hand compactors. The degree of compaction and water content were checked regularly at several points by the sand cone method. Wherever the degree of compaction was found to be inadequate, additional compaction was done until the desired standards were met. The wall facing was made of an acrylic plate with 5 layers of steel reinforcement. The vertical and horizontal spacing between each layer was fixed at 0.20 m and 0.25 m, respectively. The reinforcements for all layers are 3 mm diameter and 0.7 m length (equal to 0.8H where H is the wall height). The reinforcement length of larger than 0.7H is recommended by ASSHTO (2002).

The MSE wall was extensively instrumented within the wall and the wall facing panel. Locations of the instruments are illustrated in Fig. 2. Three piezometers, 10 surface settlement plates and 10 water sensor were installed to measure the change in water levels, settlements and water contents during seepage flow. The surface settlement plates were installed in middle of the backfill. Settlements were measured by a precise leveling with reference to a benchmark. Three linear potentionmeters were installed at the wall facing panel to measure the lateral wall movement at different points during seepage.

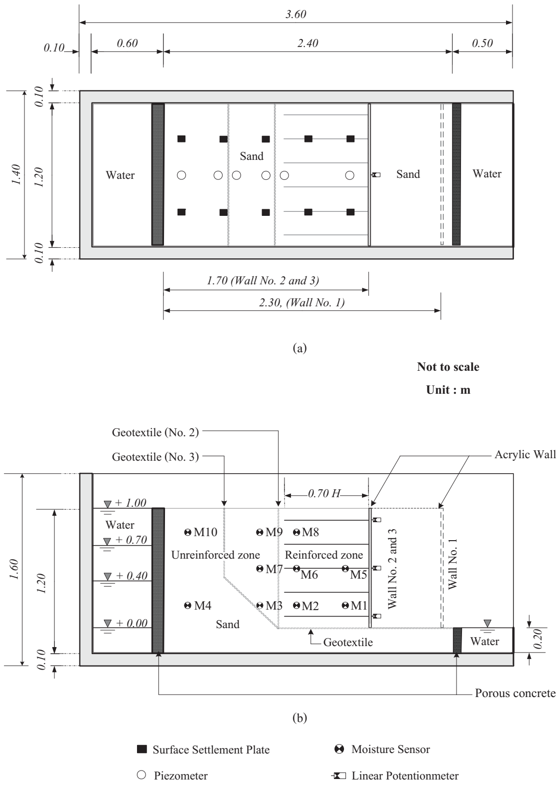

Fig. 2 Dimension of the tank and instrumentations.

The ground water table during the tests was controlled by water levels in the upstream and downstream water tanks. The water level in the downstream water tank was kept constant at 0.2 m height by a control weir. The water level in the upstream tank was varied from 0.2 m height to 1.0 m height as indicated in Table 1. Each test was begun with the water level of 0.2 m height in the upstream tank. At each level of upstream water, the upstream water level was kept constant until steady state flow was arrived.

Table 1 Detail of the conducted experiments

Case	Wall distance [m]	Upstream water level [m]	Drainage Direction [deg.]
I	2.4	0.2, 0.4, 0.6	-
II	1.7	0.2, 0.4, 0.7, 1.0	-
III	1.7	0.2, 0.4, 0.7, 1.0	90
IV		0.2, 0.4, 0.7, 1.0	45

TEST RESULTS

Seepage Flow

Figure 3 shows the phreatic drawdown for different water levels for cases I and II. The water heights behind the unreinforced zone were 0.4 m and 0.6 m for the case I and 0.4 m and 0.7 m for the case II. The phreatic level decreases through the wall face due to the head loss in the sandy backfill. The distance of the wall face insignificantly affects the phreatic level. In other words, pore pressure acting on the wall face decreases as the distance from the water source to the wall face increases. The advantage of the geocomposite drainage on the reduction in water pressure in the reinforced zone is illustrated in Fig. 4. The measured data of the water pressure for case II (no geocomposite) are compared with those for case III (with geocomposite). For both cases, the distance from the water source to the wall face is the same. The highly permeable geocomposite can collect the water in the unreinforced zone and drain out at the wall face. This reduces the water pressure acting on the wall face and pore water pressure in the reinforced zone.

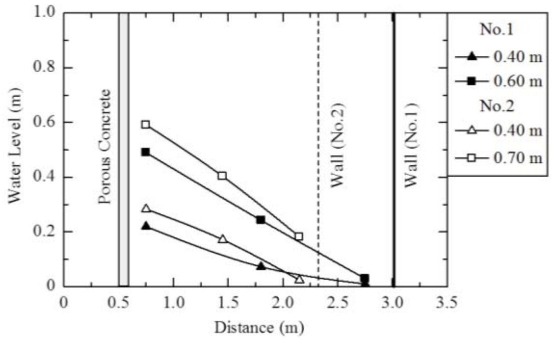

Fig. 3 Comparison between phreatic lines for cases I and II

It is interest to mention that the arrangement of the geocomposite plays a significant role on the drainage capacity. The inclined geocomposite drainage is not suitable in terms of workability, economic and engineering points of view. The inclined arrangement is hard in practice and uses more drainage. It is clearly seen from Figure 5 that the vertical arrangement is more effective than the inclined arrangement.

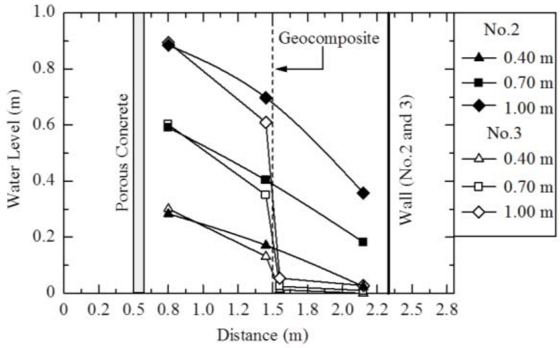

Fig. 4 Comparison between phreatic line for cases II and III

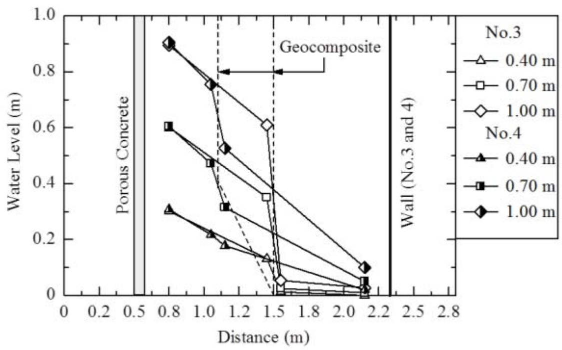

Fig. 5 Comparison between phreatic line for cases III and IV

Deformations

Comparisons among final surface settlements along a longitudinal direction at a specific water level in the upstream tank are presented in Figs. 6 to 8. Figure 6 compares settlements for case I and those for case II. It is clearly shown that the settlements for case I are lower than those for case II. There are two factors induced the difference; 1) level of water in the upstream tank and 2) distance of the upstream water tank to the wall face. The water levels in the upstream water tank for cases I and II are 0.6 m and 0.7 m, respectively. Theoretically, the higher water level provides the greater magnitude of settlement. However, the more important factor is the distance of the upstream water tank to the wall face. As the phreatic level decreases through the wall face, the shorter distance results the higher phreatic level at the wall face. Figure 3 shows that at the water level in the upstream water tank is 0.7 m the level of the phreatic line at the wall face remains relatively high at level of 0.3 m. The high phreatic line at the wall face induces piping of the soil at vicinity to the wall face. The piping later induces massive failure in the reinforced zone and hence, there occurs a relatively large settlement in the reinforcement zone as indicted in Fig. 6.

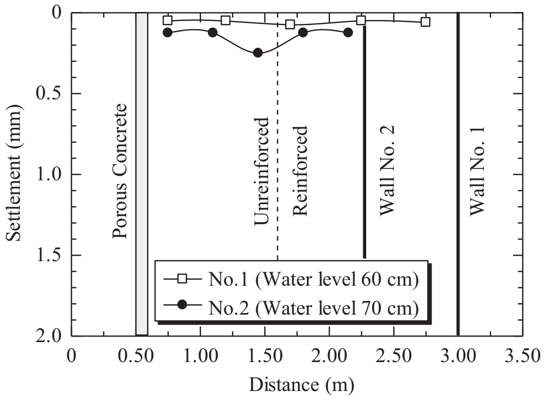

Fig. 6 Comparison between surface settlements for cases I and II.

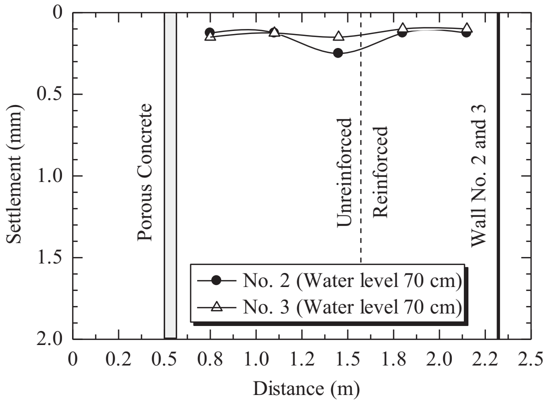

Fig. 7 Comparison between surface settlements for cases II and III.

Figure 7 compares the surface settlements for cases II and III. It is shown that the drainage system works well on its function. The surface settlements shown in Figure 8 show that the inclined geocomposite drainage opposes poor performance comparing with the vertical drainage. Comparing with the vertical drainage, the inclined drainage gives the higher level of phreatic line inside the reinforced zone as shown in Figure 5 resulting in the lower effective stresses inside the reinforced zone. As such the greater magnitude of settlements for the inclined drainage than the vertical drainage is observed as shown in Figure 8.

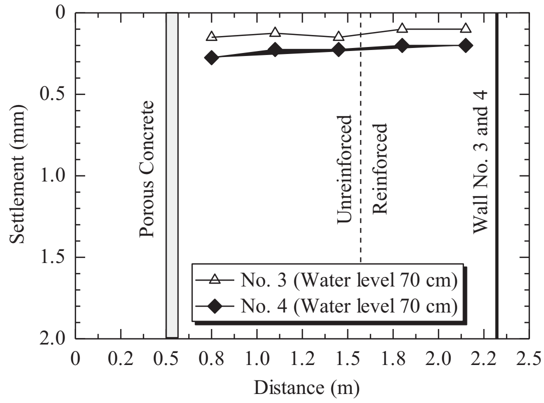

Fig. 8 Comparison between surface settlements for cases III and IV.

CONCLUSIONS

A series experiments for multistep flow through the MSE wall were conducted with and without geocomposite drainage in the campus of Suranaree University of Technology. Phreatic lines at a specific level of water level in the upstream tank of all cases are presented. It is found that geocomposite can be used as drainage material in the drainage system in MSE wall. Regarding the drainage efficiency, the performance of the vertical drainage is better than that of the inclined drainage. Surface settlements along longitudinal direction at a specific level of water level in the upstream water tank are presented for all cases. The measured settlements are consistent with the measure phreatic lines.

REFERENCES

AASHTO (2002), Standard Specifications for Highway and Bridge, 7th Ed. Washington D.C., American Association of State Highway and Transportation Officials.

Shibuya, S., Kawagushi, T., and Chae, J. (2007), Failure of reinforced earth as attacked by typhoon no. 23 in 2004, Soils and Foundations, 47(1):153-160.

Shibuya, S., Saito, M., Torii, N., and Hara, K. (2009), Mitigating embankment failure due to heavy rainfall using L-shaped geosynthetic drain (LGD), Proc. Prediction and Simulation Methods for Geohazard Mitgation, Kyoto, Japan, :229-306.