# Effectiveness of Soilcrete to Reinforce Earth Levees

Bich Thi Luong[1] and Hoang-Hung Tran-Nguyen[1]
[1]*Department of Civil Engineering, Ho Chi Minh City University of Technology*
*Vietnam National University, Ho Chi Minh City, Vietnam*
*E-mail: ltbich.sdh19@hcmut.edu.vn*

**ABSTRACT:** Soil-cement (soilcrete) columns have a high potential to create seepage cut-off walls and to enhance slope stability for earth levees against annual floods in the Mekong Delta. This paper evaluated the effectiveness of soilcrete walls to reinforce earth levees. The strength and hydraulic conductivity of several typical soil types taken in the Mekong Delta, such as soft clay, medium soft clay, and medium stiff clay mixing with cement at a content of 300 kg/m$^3$, were determined in the laboratory. Soilcrete walls were designed based on the tested results in the laboratory to reinforce earth levees in Dong Thap and An Giang provinces in the Mekong Delta. The seepage and slope stability of the levees were analyzed using the SEEP/W and SLOPE/W softwares. The results indicate that the soilcrete walls were highly effective on cutting seepage off and increasing stability significantly in the case of rapid drawdown of floodwater. A 0.4-m single-row soilcrete wall can reinforce successfully for earth levees. A 0.8-m double-row soilcrete wall can reinforce earth levees sustainably.

**KEYWORDS:** Permeability, Soilcrete, Earth levee, Seepage, and Slope stability.

## 1. INTRODUCTION

The Mekong Delta in Vietnam is annually affected by floods due to the downstream of the Mekong River. The local governments and local people have constructed thousands of kilometers-long earth levees against floods to protect paddy fields. The earth levees were also rural roads to serve the local people. However, almost all earth levees were built using dredging soils along rivers or canals on soft ground. Earth levee embankments contain void pores connecting together to form seepage flows due to less compaction. In flood seasons, the seepage flows wash fine particles out of the levee body. In addition, the floodwater also erodes the levee body and rises the groundwater level inducing the lower shear strength of the levee body. Rapid drawdown is considered the most dangerous factor for the levee's slope stability (Tung et al., 2015; Fredlund et al., 2011; Berilgen, 2007). Pore water pressure is slowly dissipated, and the groundwater level in the levee body is higher than the water level in a river. As a result, the safety factor against slope failure reduces (Zieba et al., 2017; Tung et al., 2015; Berilgen, 2007).

Some solutions to reinforce earth levees have been applied, such as timber piles, sandbags, or gabions. However, these techniques are temporary and do not treat completely piping or earth levee failures. Soilcrete columns are proposed as seepage cut-off walls for earth levees. Cement can improve the engineering properties of soil significantly, including strength, stiffness, and permeability (Tran-Nguyen et al., 2022; 2015). Several applications of soilcrete as improving soft ground and cutting off walls, have been commonly applied in the world (Huat et al., 2002). In Vietnam, soilcrete walls to prevent flood water have been piloted in Dong Thap and An Giang with initial effectiveness (Tran-Nguyen et al., 2018). However, the soilcrete hydraulic conductivity is difficult to determine and is one of the key parameters to design seepage cut-off walls. This paper attempts to determine the acceptable hydraulic conductivity and strength of soilcrete specimens created from typical soils in the Mekong Delta, such as soft clay, medium soft clay, and medium stiff clay mixed with cement in the laboratory. The effectiveness of soilcrete walls to reinforce earth levees against floods was evaluated based on the seepage and slope stability analysis under the rapid drawdown using the SEEP/W and SLOPE/W softwares.

## 2. THE STRENGTH AND PERMEABILITY TESTS

### 2.1 Materials

The three typical soil types in the Mekong Delta, including soft clay, medium soft clay, and medium stiff clay, were taken in Dong Thap and Hau Giang provinces. The key properties and the particle size distribution of the soil samples are displayed in Table 1 and Figure 1, respectively. The slight difference of the two clay properties can be interpreted based on their formation. The medium-soft clay is originally from the dredging soft clay taken in the riverbed along the earth levee to rise the elevation of the earth levee. The medium-soft clay layer was moderately compacted and low water content. On the contrary, the medium stiff clay layer is underneath the soft clay layer and under the groundwater table. The medium-stiff clay was fully saturated. Portland cement blended (PCB40) and tap water were utilized in this study.

**Table 1 The key properties of soil types**

| Properties | Soft clay | Medium soft clay | Medium stiff clay |
|---|---|---|---|
| Water content, (%) | 53.1 | 34.1 | 34.9 |
| Unit weight (kN/m$^3$) | 16.46 | 18.24 | 16.59 |
| Liquid Limit, (%) | 50.5 | 42.1 | 48.2 |
| Plastic Limit, (%) | 30.5 | 23.9 | 28.6 |
| Plasticity Index, (%) | 20 | 18.2 | 19.6 |
| Void ratio | 1.42 | 0.982 | 1.334 |
| Organic content, (%) | 6.13 | 4.07 | 3.17 |

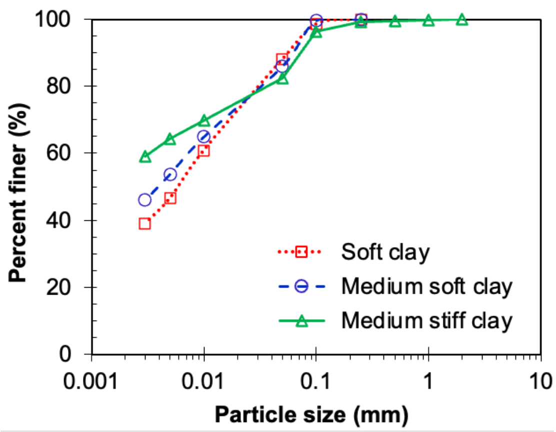



**Figure 1 The grain size distribution of the soils**

### 2.2 Soilcrete Specimen Preparation

The cement content of 100 to 500 kg/m$^3$ is economically and technical efficiency to reinforce soft soil or create seepage cut-off walls by deep mixing method (Topolnicki, 2004; Bruce, 2001). Tran-Nguyen et al. (2015) reported that the strength of soilcrete specimens was greater than 500 kPa as using cement contents in the range of 200 - 350 kg/m$^3$ to mix with clay soils in Dong Thap and An Giang. Therefore, the cement content of 300 kg/m$^3$ was used to create soilcrete specimens for this study. Cement slurry was made by mixing dry cement ($c$) with water amount ($w$) in an appropriate ratio depending on soil types to form a liquid mixture which is comfortable for compacting and eliminating air bubbles for casting specimens. The $w/c$ ratios employed for soft clay, medium soft clay, and medium stiff clay were 1.2/1, 2/1, and 1.4/1, respectively. The soilcrete specimens were cast in cylindrical plastic molds with dimensions of (55 × 120) mm for unconfined compression tests and (62 × 65) mm for permeability tests. The specimen preparation was similar to that described by Tran-Nguyen et al. (2022).

### 2.3 Test Procedures

The unconfined compressive strength (UCS) of the soilcrete specimens, $q_u$, were determined at the ages of 7 and 28 days according to the ASTM D2166 standard. The permeability tests were conducted for 90 days or more by the falling head-constant tailwater method on the flexible wall permeameters under a hydraulic gradient of 40 ± 5 in accordance with the ASTM D5084. The hydraulic conductivity ($k_s$) of the soilcrete specimens was measured at room temperature and converted to a standard temperature of 20°C according to the ASTM D5084.

### 2.4 Test Results

#### 2.4.1 The Strength of Soilcrete

The strength of the soilcrete specimens at 7 and 28 days is presented in Figure 2. The results show that the unconfined compressive strength of all soilcrete specimens increased with increasing in curing time (Tran-Nguyen et al., 2015; Horpibulsuk et al., 2003; Tan et al., 2002). The strength of specimens made from soft clay, medium soft clay, and medium stiff clay mixed with the PCB at a content of 300 kg/m$^3$ at 28 days were 530, 640, and 550 kPa, respectively. These strengths indicate that soilcrete walls can be applied to reinforce earth levees in the Mekong Delta (Tran-Nguyen et al., 2018).

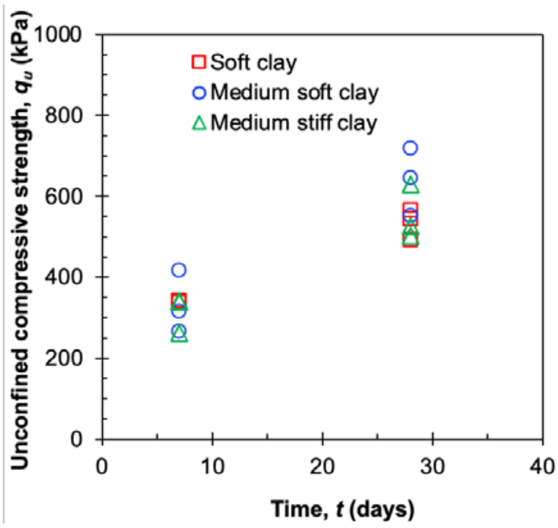



**Figure 2 The strength of soilcrete versus time**

#### 2.4.2 The Hydraulic Conductivity of Soilcrete

Figure 3 shows a significant reduction of the hydraulic conductivity of all soilcrete specimens in the first four weeks and then a gradual reduction as a function of curing time. These results are consistent with other researchers (Luong et al., 2021; Helson et al., 2018; Kamruzzaman, 2002). The pozzolanic reaction between cation $Ca^{2+}$ and pozzolan ($SiO_2$ and $Al_2O_3$) took place slowly in the soilcrete specimens leading to cementitious products formed continually to fill the soilcrete pores (Helson et al., 2018; Kamruzzaman, 2002). As a result, the soilcrete permeability decreased with increasing in curing times. The $k_s$ of the soilcrete specimens varied between 2.92.10$^{-9}$ and 2.4.10$^{-10}$ m/s (Figure 3). These values demonstrate that the permeability of the soilcrete specimens made from soft clay, medium soft clay, and medium stiff clay mixing with cement content of 300 kg/m$^3$ were very low and can be applied as seepage cut-off walls for earth levees against floods in the Mekong Delta.

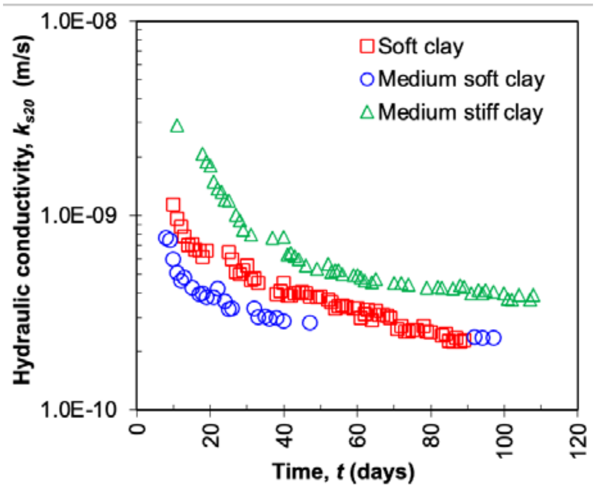



**Figure 3 The hydraulic conductivity of soilcrete versus time**

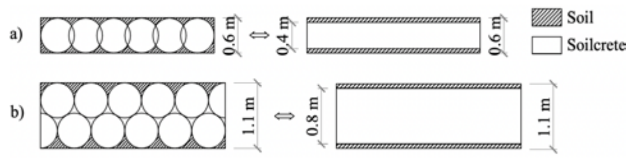
## 3. ANALYSIS OF THE EFFECTIVENESS OF SOILCRETE TO REINFORCE EARTH LEVEES

### 3.1 Implementation

For the soilcrete material, the in-situ soil is disturbed during the construction process, and the clay fraction in soil is considered as the main factor affecting soilcrete hydraulic properties. The strength and hydraulic conductivity of the soilcrete specimens created from soft clay, medium soft clay, and medium stiff clay in the laboratory were used to design the soilcrete walls to reinforce earth levees in Dong Thap and An Giang. The designed properties of the soilcrete walls are suggested in Table 2. The two forms of the soilcrete walls were proposed to reinforce the earth levees, including a single-row soilcrete wall and a double-row soilcrete wall with equivalent wall thickness of 0.4 m and 0.8 m, respectively (Figure 4) (Tran-Nguyen et al. 2018; 2015). The SEEP/W and SLOPE/W softwares were used to analyze the seepage and the slope stability of the levee in the case of the rapid drawdown. The simplified Bishop method was applied for the slope stability analysis. The truck of 2.8 tons was used to design rural roads (22TCN 210-92, Vietnam standard), which was converted to the equivalent distribution load of 3.8 kN/m$^2$ applying on the earth levee surface (22TCN 262-2000, Vietnam standard).

**Table 2 The properties of soilcrete to simulate**

| Properties | Soilcrete made from soils | |
|---|---|---|
| | Medium soft clay | Soft clay |
| Strength, $q_u$ (kPa) | 448 | 371 |
| Hydraulic conductivity, $k$ (m/s) | 4.34×10$^{-10}$ | 6.43×10$^{-10}$ |
| Cohesion, $c_u$,(kPa) | 224 | 185.5 |
| Unit weight, $\gamma_w$ (kN/m$^3$) | 16.2 | 15.86 |
| Internal friction angle, $\phi$ (°) | 0 | 0 |




(a) Single row, (b) Double row

**Figure 4 Soilcrete Walls to Reinforce Earth Levees**

### 3.2 The Field Pilot Experiments

**The 2/9 earth levee in Dong Thap province**

The properties of the undisturbed soil samples along the soil profile of the 2/9 canal located in An Hoa Ward Tam Nong District Dong Thap province are given in Table 3. Particularly, the top layer of the earth levee body, medium soft clay, is not uniform and is cracked. The $k_s$ of this layer was assumed as $10^{-6}$ m/s for simulation. The highest and lowest water level in the river were +4.5 m and +0.3 m, respectively. The water level in the paddy field was +2.6 m above sea level. The drawdown of the floodwater was 0.2 m/day (Le, 2014). Soilcrete wall was 8 m in depth through three soil layers of medium soft clay, soft clay, and medium stiff clay (Figure 5).

**Table 3 Soils properties at the 2/9 canal - Dong Thap**

| Properties | Layer 1 - Medium soft clay | Layer 2 – Soft clay | Layer 3 – Medium stiff clay |
|---|---|---|---|
| Thickness, *H* (m) | 4.6 | 2.9 | 7 |
| Unit weight, $\gamma_w$ (kN/m$^3$) | 19.36 | 16 | 20.3 |
| Permeability, *k* (m/s) | $1\times10^{-6}$ | $3.29\times10^{-8}$ | $1.57\times10^{-8}$ |
| Cohesion, *c* (kN/m$^2$) | 23.9 | 7.6 | 14.8 |
| Internal friction angle, $\phi$ ($^o$) | 13.57 | 6.32 | 18.29 |

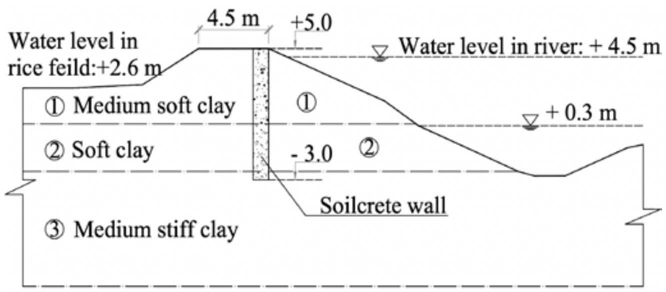



**Figure 5 Cross section of the 2/9 levee**

**The Muoi Cai earth levee in An Giang province.**

A section of Muoi Cai earth levee in Vinh Trach Ward Thoai Son District An Giang Province is shown in Figure 6. The highest and lowest river water level were +3.1 m and +0.6 m, respectively. The water level in a paddy field was +1.42 m above sea level. The drawdown rate of floodwater was 0.2 m/day. Soilcrete wall depth was 10.5 m, as presented in Figure 6. The properties of soils at the site of Muoi Cai Canal are displayed in Table 4 (Mai, 2015).

**Table 4 Soils properties at the Muoi Cai – An Giang**

| Properties | Layer 1 - Medium soft clay | Layer 2 – Soft clay | Layer 3 – Medium stiff clay |
|---|---|---|---|
| Thickness, *H* (m) | 4.1 | 6.4 | 2 |
| Unit weight, $\gamma_w$ (kN/m$^3$) | 17.95 | 15.64 | 19.07 |
| Permeability, *k* (m/s) | $1\times10^{-6}$ | $3.64\times10^{-8}$ | $1.65\times10^{-8}$ |
| Cohesion, *c* (kN/m$^2$) | 20.1 | 6.2 | 19.1 |
| Internal friction angle, $\phi$ ($^o$) | 11.87 | 5.45 | 14.97 |

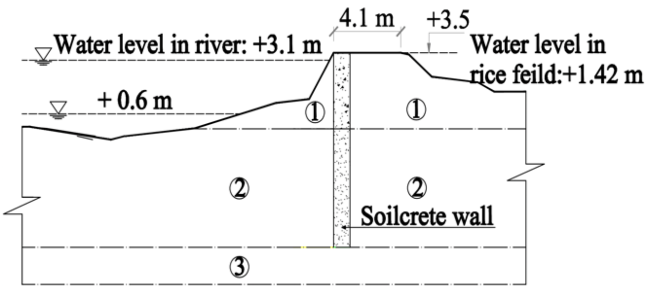
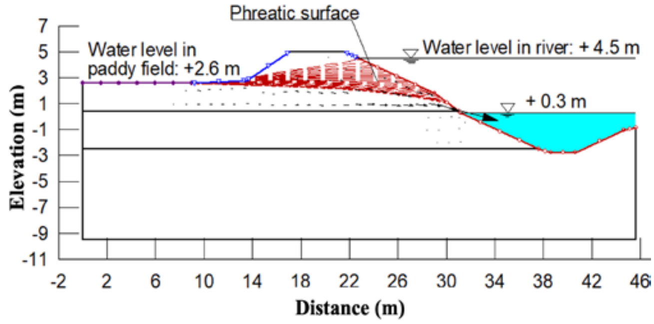



**Figure 6 Cross section of the Muoi Cai levee**

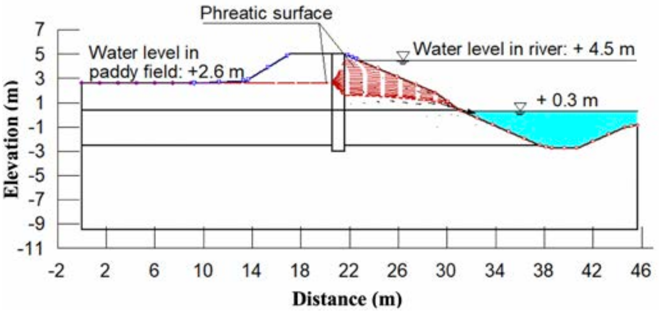
### 3.3 Results and Discussions

#### 3.3.1 Effect of the Soilcrete Walls on Seepage under the Floodwater Rapid Drawdown

Figure 7 and Figure 8 demonstrate the changes of the seepage surfaces in the embankments of the 2/9 and the Muoi Cai levees during the floodwater drew down with reinforcement and without reinforcement by the soilcrete walls, respectively. The phreatic surfaces reduced gradually, and the seepage flow direction varied with the floodwater level without reinforcement (Figure 7a, 8a). Velocity vectors indicate where seepage flow is occurring in the levees (GEO-SLOPE International Ltd., 2012). The presence of the seepage in the levee decreases soil strength and increases shear stress causing earth levee failure (Nordin et al., 2007). For the earth levees reinforced by the soilcrete walls, the seepage surface in the river slope varied with the water level while the groundwater table in the paddy field was constant and the same as the water level in the paddy field (Figure 7b, Figure 8b). These results suggest that the soilcrete walls cut off seepage flow successfully.

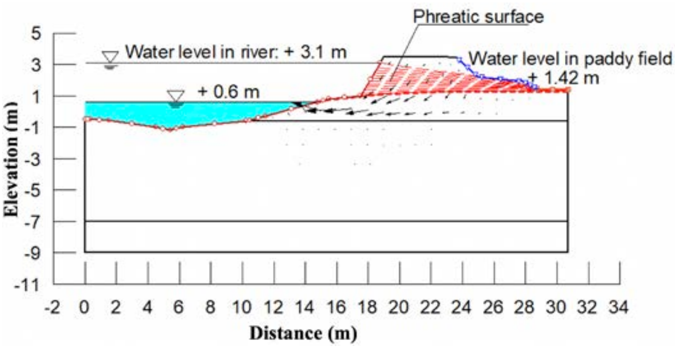



a) No reinforcement

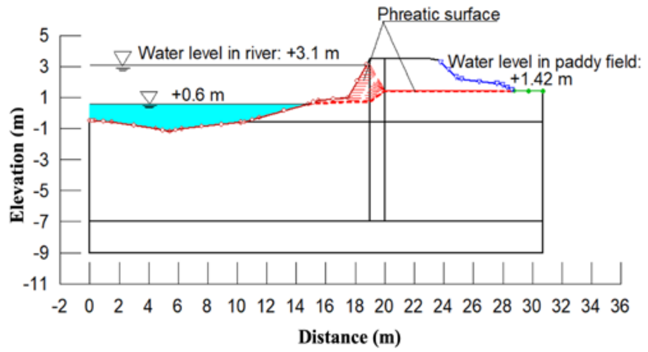



b) Reinforced by soilcrete wall

**Figure 7 Seepage analysis under drawdown condition of the 2/9 levee – Dong Thap**




a) No reinforcement

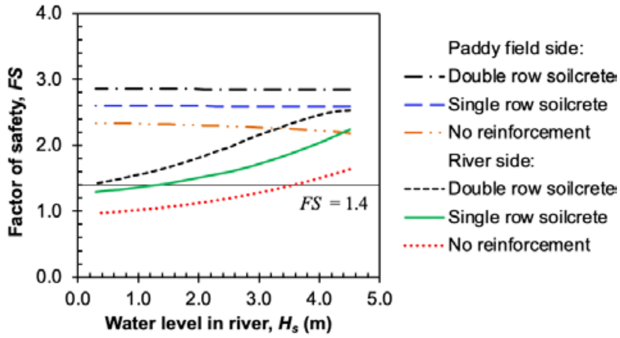



b) Reinforced by soilcrete wall

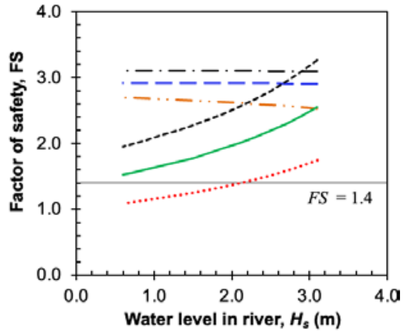
**Figure 8 Seepage analysis under drawdown condition of the Muoi Cai levee – An Giang**

### 3.3.2 Effect of the Soilcrete Walls on Slope Stability under the Floodwater Rapid Drawdown

Factor of safety (*FS*) of the both river and paddy field sides of the earth levees of the 2/9 and Muoi Cai analyzed under floodwater drawdown rate 0.2 m/day are indicated in Figure 9. The results show that the rapid drawdown of the floodwater affected insignificantly the paddy field side slopes, especially almost no effect in the cases of the earth levees reinforced by the soilcrete walls. For the river side, the *FS* decreased about 40% for the levees as the floodwater drew down, leading to a collapse of earth levees without reinforcement (Figure 9). The cause is attributed to the presence of seepage flows in the levees reducing the shear strength of the soil mass. Furthermore, the drawdown of the water levels in the rivers reduced the horizontal pressure that was an anti-slip force of the earth levees. As a result, the levee slopes in the river became unstable. However, the soilcrete walls in the forms of the single wall or the double wall, the *FS* in the riverside increased from 35% to 61% and from 43% to 83% for the 2/9 levee and the Muoi Cai levee, respectively. Thus, the soilcrete walls prevented the seepage and enhanced the stability of the earth levees effectively. Depending on the earth levee states, it is recommended to select the reinforced form, either a 0.4-m single-row soilcrete wall (the Muoi Cai levee - Figure 8b) or a 0.8-m double-row soilcrete wall (the 2/9 levee - Figure 9b) to ensure stability sustainably.




a) The 2/9 levee – Dong Thap




b) The Muoi Cai levee – An Giang

**Figure 9 Slope stability analysis under rapid drawdown conditions of levees**

## 4. CONCLUSIONS

The soilcrete specimens were created in the laboratory from the soils taken in the Mekong Delta mixing with the PCB40 at the content of 300 kg/m$^3$ to determine the strength and hydraulic conductivity. The designed soilcrete wall properties were proposed based on the laboratory tests. The SEEP/W and SLOPE/W softwares were employed to analyse the seepage and slope stability of the earth levees under the rapid drawdown of the floodwater. The results indicate that (1) The soilcrete hydraulic conductivity was low and suitable for seepage cut-off walls; (2) the rapid drawdown caused levee instability; and (3) Soilcrete walls cut seepage off successfully and improved the stability of the earth levees. The 0.8-m double-row soilcrete wall can be sustainable to reinforce earth levees.

## 5. ACKNOWLEDGMENTS

The authors acknowledge the support of the time and facilities from Ho Chi Minh City University of Technology (HCMUT), VNU-HCM, for this study.

## 6. REFERENCES


American Society for Testing and Materials (ASTM) (2010). "Standard Test for Measurement of Hydraulic Conductivity of Saturated Porous Material Using a Flexible Wall Permeameter." D5084, USA.

American Society for Testing and Materials (ASTM) (2000). "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil." D2166, USA.

Berilgen, M. M. (2007). "Investigation of Stability of Slopes under Drawdown Conditions." *Computers and Geotechnics*, 34, 81-91.

Bruce, D. A. (2001). "An Introduction to the Deep Soil Mixing Methods as Used in Geotechnical Applications." Publication No. FHW-RD-99-168, 458.

Bruce, M. E. C., Berg, R. R., Collin, J. G., Filz, G. M., Terashi, M., and Yang, D. S. (2013). "Deep Mixing for Embankment and Foundation Support." *Federal Highway Administration Design Manual*, Washington, USA.

Fredlund, M. and Lu H., Feng, T. (2011). "Combined Seepage and Slope Stability Analysis of Rapid Drawdown Scenarios for Levee Design." *Geo – Frontiers 2011*, *ASCE*, 1595-1604.

GEO-SLOPE International Ltd (2012). "Seepage Modeling with SEEP/W."

Helson, O., Eslami, J., Beaucour, A., Noumowe, A., and Gotteland, P. (2018). "Hydro-Mechanical Behaviour of Soilcrete Through a Parametric Laboratory Study." *Construction and Building Materials*, 166, 657-667.

Horpibulsuk, S., Miura, N., and Nagaraj, T. S. (2003). "Assessment of Strength Development in Cement-Admixture High Water Content Clays with Abram's Law a Basis." *Geotechnique*, 53(4), 439-444.

Huat, B. B. K., Kazemian, S., Prasad, A., and Barghchi, M. (2011). "A Study of the Compressibility Behavior of Peat Stabilized by DMM: Lab Model and FE Analysis." *Scientific Research and Essays*, 6(1), 196-204.

Kamruzzaman, A. H. M. (2002). "Physico-Chemical and Engineering of Cement Treated Singapore Marine Clay." *M. E, Thesis, National University of Singapore.*

Le, K. B. (2014). "Laboratory Investigation of Soilcrete Behaviors Created by Soil Cement Deep Mixing Technology Applying to Reinforce Earth Levees Utilized as Rural Roads in Dong Thap Province." *M. E. Thesis, Ho Chi Minh City University of Technology, Vietnam.*

Luong, B. T., Tran-Nguyen H. H., and Nguyen, P. D. (2021). "Investigation of Hydraulic Conductivity of Soilcrete Specimens Made from Dredging Sand and Cement." *In Proceedings of CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure*, 203, 715-724, Springer. https://doi.org/10.1007/978-981-16-7160-9_72.

Mai, A. P. (2015). "Laboratory investigation of An Giang Soilcrete Behaviors Created by Soil Cement Deep Mixing Technology Applying to Reinforce Earth Levees Utilized as Rural Roads in An Giang Province." *M.E. Thesis, Ho Chi Minh City University of Technology, Vietnam.*

Mengue, E., Mroueh, H., Lancelot, L., and Eko, R. M. (2017). "Physicochemical and Consolidation Properties of Compacted Lateritic Soil Treated with Cement." *Soils and Foundations*, 57, 60-79.

Ministry of Transport (2000). "Design Guidelines for Highway on Soft Ground." 22TCN262, Vietnam.

Ministry of Transport (1992). "Rural Road – Design Guidelines." 22TCN210, Vietnam.

Nordin, N. F. M., Mohamad, H., and Alarifi, H. (2020). "Numerical Modelling of Seepage Analysis Using SEEP/W: A Case Study for the Kerian River Flood Mitigation Project (Phase 3) in Bandar Baharu, Kedah." *In Proceeding of the 13th International UNIMAS Engineering Conference 2020 (ENCON 2020).*

Tan, T. S., Goh, T. L., and Yong, K. Y. (2002). "Properties of Singapore Marine Clays Improved by Cement Mixing." *Geotechnical Testing Journal*, 25(4), 1-12.

Topolnicki, M. (2004). "In Situ Soil Mixing." *In Ground improvement, 2nd ed. M.P. Moseley & K. Kirsch, Ed. New York: Spon Press,* 331-428.

Tran Nguyen, H. H., Le, B. K., Le, L. P., and Do, C. T. M. (2015). "Laboratory Investigation of Soilcrete Created from Mekong Delta's Soils Mixed with Cement." *In Proceedings of Deep Mixing 2015 conference, San Francisco, USA*, 2-5 June, 725-734.

Tran Nguyen, H. H., Luong, B. T., and Nguyen, K. T. D. (2022). "Investigation of the Hydraulic Conductivity of Soilcrete Specimens Made by Soft Clays and Medium Soft Clays Mixed with Cement." *Geotech Geol Eng.* https://doi.org/10.1007/s10706-022-02323-2.

Tran Nguyen, H. H., Le, L. P., Le, B. K., and Ly, H. M. T. (2018). "Field Trials on the Soil Cement Mixing Technology to Reinforce Earth Levees in the Mekong Delta, Vietnam." *Malaysian Journal of Civil Engineering,* 8(1), 14-26.

Tung, S., Bhandari, G. N., and Mukherjee, S. P. (2015). "Effect of Seepage Cut Off below Earthen Dam under Rapid Drawdown." *In Proceeding of the 50th Indian Geotechnical Conference, Maharashtra, India.*

Zieba, Z., Molenda, M., and Witek, K. (2017). "Earth Structures Stability under Rapid Drawdown Conditions." *Architecture Civil Engineering Environment, No.1.*