

Pinhole Test of Dispersive Soil treated with Cement Content by Deep Mixing Method: A Case Study on Morasuab Dam

S. Bhattarai¹, S. Soralump¹

¹Department of Civil Engineering, Kasetsart University, Bangkok, Thailand

Email: suraj.b@ku.th, suraj1995b@gmail.com

Abstract:

Morasuab Dam in Thailand has undergone four seepage failures since 2012 despite of follow-up rehabilitation. Recent rehabilitation commenced in 2022 that included installation of overlapping soil-cement columns along dam crest and excavation of breached zone of 2019. The soil cement column (SCC), each column of 0.6-meter diameter installed in three overlapped rows along dam crest, is extended to the weathered rock foundation. On the other hand, the section of dam (Station 0+380 to 0+480) was planned to be recompacted and then set up with SCC. In the start of April 2022, when the SCC work and excavation works were carried out simultaneously, dispersive soil were encountered in the excavation area. The pinhole test performed on low plastic clay or silt soil samples, collected from excavated area, were identified as highly to moderately dispersive (D1, D2, and ND4). But the pinhole test of sample soils mixed with cement, proportional to the content used in soil cement column i.e., 16.9%, showed non-dispersive behavior (ND1). Moreover, other parameters of the pinhole test, i.e., flow rate, discharge cloudiness, and particle fall, were also improved when the soil was admixed with cement (content used in field SCC). The cloudiness of effluent was completely clear; no particles were observed falling, and the final pinhole size was found to be almost unchanged. The graph between flow rate and test time showed constant flow behavior for a definite flow head. This affirmatively supports the soil cement column's ability to control dispersivity and particle erosion of embankment soil along the SCC and assists soil treated with cement could control continuation and progression phases of internal erosion.

KEYWORDS: Dispersive Soil, Soil-Cement column, Pinhole Test and Particle Erosion

1. INTRODUCTION

Dispersive soils are the types that are highly susceptible to internal erosion and piping and has yet become common materials for the construction industry (Vakili et al., 2018). Dispersive soils are clayey soils that rapidly deflocculates in waters with low salt concentration, even when the waters are still (Paige-Green, 2008). When dispersive clay soil is immersed in water, the clay fraction behaves like single-grained particles; that is, the clay particles have a minimum of electrochemical attraction and fail to closely adhere to, or bond with, other soil particles. Thus, dispersive clay soil erodes in the presence of flowing water when individual clay platelets are split off and carried away. The erosion may start in a drying crack, settlement crack, hydraulic fracture crack, or other channel of high permeability in a soil mass. These soils are found in many parts of the world such as India, United States, Australia, Greece, America, South Africa, Thailand, and others (Mohanty et al., 2018). They pose serious problems in stability of earthen structures, road fills, and other engineering structures because the dominant presence of sodium (Na^+) ion. The conventional soil mechanics test such that Atterberg's limits and grain size distribution cannot differentiate ordinary erosion resistant clays to dispersive clays (Belarbi et al., 2013; Ismael et al., 2021). Specific tests like Crumb test, double hydrometer test, pinhole test and chemical test are required to check the dispersivity in soil. Among these, the physical method of pinhole test is recognized as more reliable for classification and identification of the dispersive soil since it involves direct measurement of dispersibility of compacted fine grained soil, where water is made to flow through a small hole that simulates the water flowing through a crack or concentrated leakage channel in the impervious core of the dam or other structure (Knodel, 1991).

According to ASTM (2006), a pinhole test classifies the erodibility of the soil based on the flow rate, cloudiness of discharge, the final size of pinhole, and the applied pressure (ASTM, 2006; Dinh et al., 2021). There are six readings of the dispersive ranging from very high dispersive soils to non-dispersive soils (D1, D2, ND4, ND3, ND2 and ND1).

Researches has shown dispersive soil was found mainly in the northeast, the north, the central and the east region and fewer in southern part of Thailand (Phienwej et al., 1994). Soil classified as low to medium plastic fines (Cl and ML) in the Unified Soil Classification System (USCS) are prone to have dispersive properties. (Singh et al., 2018).

This paper investigates the erodibility of different soil types found in embankment zone of Morasuab Dam using pinhole test and compares with soil mixed with cement at proportion used in soil-cement column.

2. LOCATION AND MATERIALS

Morasuab Dam is located in Prachuap Khiri Khan Province of Thailand. The dam is 12 meter deep and 540 m long that categorizes it as a large dam as per ICOLD. The dam has undergone breaching in 2012, 2016, 2017 and 2019 even though the dam had been rehabilitated in 2015 and 2017. The recent rehabilitation was stated on early 2022 and its ongoing. The recent breached section and excavation area is shown in Figure 1.

The soil-cement column is constructed by hybrid method of mechanical mixing and high-pressure injection. When the cement slurry (water to cement ratio of 1.1:1) is injected from the outer end of rotating blade at pressure of 20 kPa, three 0.5m diameter-blades mechanically mixes binder with soil. This technique produces central portion of deep mixed column, whose size is governed by the size of horizontally rotating blades. The high-pressure cement-slurry is injected outward to create a ring-shaped treated soil. The 50 cm-thick outer ring-shaped (crust) soil treatment depends on soil condition and the applied pressure. This hybrid method is effective when adjacent deep-mixed soil columns are overlapped or when the contact of stabilized soil to the existing structure is required. The overlapping of mechanically mixed soil is difficult as the formed soil cement column is hardened. Therefore, the outer shell of soil cement column made from high pressure injection is overlapped to create water-tight wall. Figure 2 shows the plan view of the deep mixed column along the crest of the dam that resembles as

impermeable core of the dam and helps as water barrier. The most vital requirement for the construction of deep mixed is effective overlapping of adjacent column, which is governed by the diameter of column and direction of the column axis. In case the adjacent columns are not overlapped, high hydraulic gradients would be generated including concentrated leakage with very high seepage rates and consequent risk of piping. Moreover, if there is presence of dispersive soil in that region, the possibility of internal erosion is higher.



(a)



(b)

Figure 1 (a) Dam Breach Section (b) Soil Sampling Area

Source: https://www.youtube.com/watch?v=jYX6WRuE2UY&list=PL0i5y-F3bE3LalGszSdyABMB7DWfVH8mh&index=1&ab_channel=Geotechnow

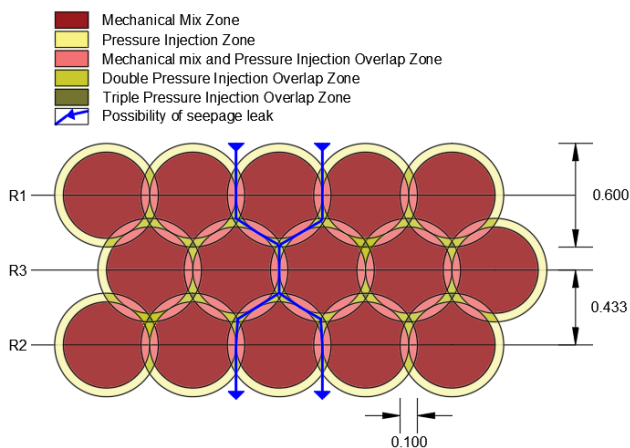


Figure 2 Plan of deep mixing soil cement column along axis of Morasuab Dam

Materials for this investigation were gathered from the Morasuab Dam excavation slope. Table 1, Figure 3 and Figure 4 display the USCS soil classification, size distribution curves, Atterberg's limit

and grain size distribution curves of the collected soil sample respectively. The six samples that were taken from the location fall under low- plastic clay or silty sand (CL or SM) group, according to USCS classification. The sample soils are identified as SS-1, SS-2, SS-3, SS-4, SS-5, and SS-6. The remaining six soil sample (SC-1 to SC-6) refers as samples combined with 16.9% of cement, which is the mean value of cement content utilized in field's soil-cement column.

Table 1 USCS Soil Classification

SN	Soil Sample ID	Soil Classification					USCS
		Percentage Passing Sieve No.200	Cu	Cc	LL	PL	
1	SS-1	57	200.0	5.6	37.1	20.8	CL
2	SS-2	68	120.0	3.3	47.7	25.1	CL
3	SS-3	51	228.6	8.0	39.6	19.7	CL
4	SS-4	43	7.5	0.7	NP	NP	SM
5	SS-5	60	133.3	6.8	34.3	18.9	CL
6	SS-6	72	100.0	2.6	43	22	CL

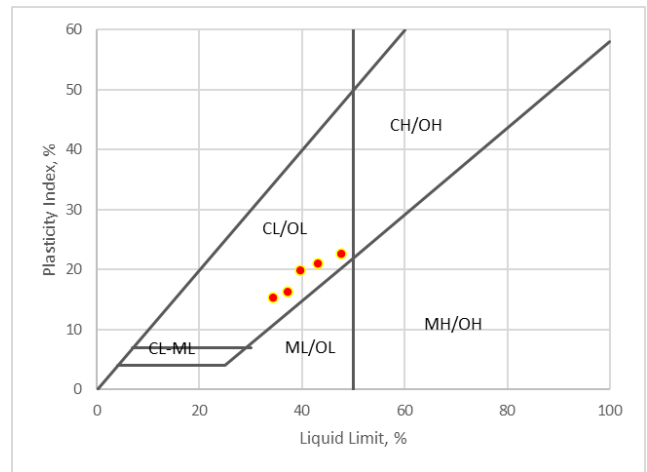


Figure 3 Plasticity Index Chart

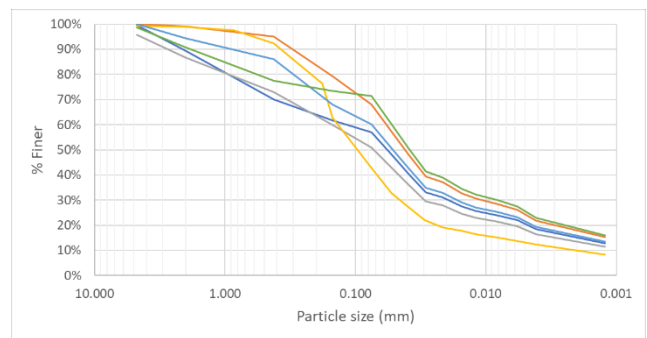


Figure 4 Particle size distribution of Soil Samples

The identification of dispersive soils was started with field reconnaissance investigations, which determined unusual erosion patterns with tunnels and dribble patterns (deep gullies) that shows the possibility of presence of dispersive soil, as shown in Figure 5. When the dispersive soil comes into contact with rainfall, these unusual erosion patterns are created.



Figure 5 Dribble pattern and pothole in d/s slope of the dam

3. LABORATORY TEST

Figure 6 shows the schematic diagram of pinhole test apparatus. The layer of soil specimen is sandwiched between coarse gravel measuring 32.8 mm in diameter and 38.0 mm in height. The wire screen is placed between the specimen and coarse gravel to prevent gravel penetration into the specimen. The inlet valve is connected to the constant head tank in order to supply distilled water. A pressure transducer with an accuracy of 0.1 mm pressure is employed to measure the hydraulic head at the inlet. The erosion time is measured using a stopwatch with a reading of 0.1 seconds. The volume of outlet water is measured using graduated cylinders and beaker with capacities ranging from 10 to 100 mL.

The disturbed soil that had passed through sieve No. 10 (2mm) was dried in an oven prior to the test's start. The soil was then compacted in a pinhole test cylinder with 12.2% water content (i.e., optimum moisture content of soil) until a length of 38 mm was achieved. The specimens were compacted at optimum water content to simulate the dam's construction condition. The compaction was carried out in 3 soil layers and hammering with 31.5 mm diameter rammer with 15 strikes per layer. The degree of compaction has no significant influence on class of dispersion in pinhole test (Djokovic et al., 2018). Hence, the force of strikes was not measured. The truncated cone with a 1.5 mm diameter hole was inserted into the center of the top of each specimens using finger pressure. One mm diameter

needle was inserted into the cone and forced through the soil sample. After that, the wire screen was placed on top of the either side of specimens and the remaining void of the test cylinder was filled with clean gravel. Finally, the top plate was assembled, connected with the distilled water tank, and the pressure transducer.

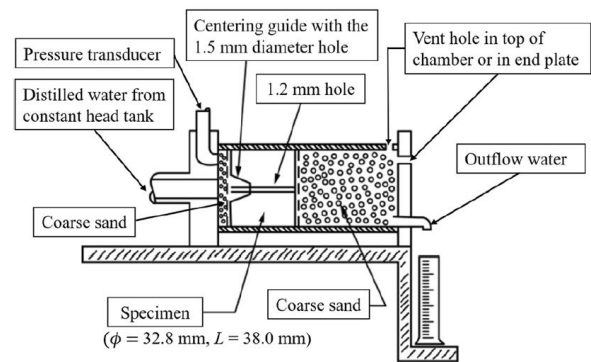


Figure 6 Schematic diagram of Pinhole test apparatus.

In the context of SC-1 to SC-6 sample, the dried soil sample is combined with 16.9% of cement content with 1.1:1 of water to cement ratio. The mixture is left over for 30 mins for pozzolanic reaction then the sample is followed through previous procedure. The steps of pinhole sample preparation, setup and collected discharge is shown in Figure 7



Figure 7 Pinhole test setup and sample preparation

The experimental procedure involving the classification of dispersivity of soil is depicted in Figure 8. To measure the flow rate of the discharge, the outlet water was collected at an interval of 60 s, to measure the flow rate and character of the discharge. If there is no outlet water at the start, the test should be stopped and then re-puncture the hole on the specimen. The cloudiness of the effluent, the flow rate, and the hole diameter are recorded as dispersive classification parameters. Based on these parameters, the soil can be classified as nondispersive (ND1 and ND2), slightly to moderately dispersive (ND3), moderately dispersive (ND4), dispersive (D2), and highly dispersive (D1) (ASTM, 2006; Umesh et al., 2011).

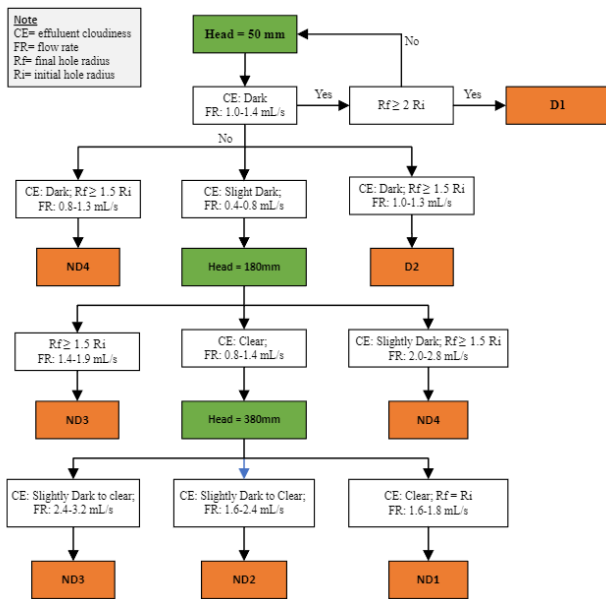


Figure 8 Pinhole test procedure and classification

4. RESULT AND DISCUSSION

The pinhole test classification of disturbed soil sample (SS-1 to SS-6 in table) were identified as highly to moderately dispersive (i.e., four samples D2, one each D1 and ND4 group). The final pinhole diameter ratio was found to be more than 2.0 and the cloudiness of discharges was visualized as dark to moderately dark with presence of few to many particles. However, the result on soil-cement samples (SC-1 to SC-6 in table) were classified as non-dispersive soil (i.e., all classified as ND1). The final pinhole diameter ratios were also less than 1.2. The discharges were monitored as completely clear with no particles present. The pinhole test result is tabulated in Table 2.

Table 2 Result on Pinhole Test

SN	Soil Sample	Time of Flow (minutes)	Final Flow head (mm)	Final Rate of Flow (mL/s)	Final Pinhole diameter ratio	Cloudiness of effluent	Result
1	SS-1	10	50	1.37	2.1	Dark	D2
2	SS-2	15	180	2.30	2.8	Dark	ND4
3	SS-3	10	50	1.13	2.4	Dark	D2
4	SS-4	10	50	1.20	3.1	Dark	D2
5	SS-5	5	50	1.25	3.4	Dark	D1
6	SS-6	10	50	1.17	2.5	Dark	D2
7	SC-1	20	380	1.13	1.2	Clear	ND1
8	SC-2	20	380	1.25	1.2	Clear	ND1
9	SC-3	20	380	1.27	1.2	Clear	ND1
10	SC-4	20	380	1.32	1.1	Clear	ND1
11	SC-5	20	380	1.32	1.1	Clear	ND1
12	SC-6	20	380	1.28	1.2	Clear	ND1

Figure 9 displays graphical representation of flow rate and test time of samples. The flow rate of sample SS-5 ranged between 1.17-1.25 mL/s for head 50 mm within first 5 minutes of test. Throughout the first 10 minutes, the flow rate for sample SS-2 at head 50 mm varied between 0.43 and 0.88 mL/s. The flow rate climbed to 2.35 mL/s after the pressure was raised by 180 mm. Other than these, the flow rate patterns of the other four soil samples were identical. The flow rates were below 1.0 mL/s for the first five minutes, but over the following five minutes, they increased to above 1.0 mL/s at a head of 50 mm.

In case of soil mixed with cement, the flow rates were practically constant for definite head flow. The flow rate for 50 mm head ranged from 0.3 to 0.7 mL/s. The flow rates increased to between 0.5 and 1.15 mL/s and 1.0 and 1.35 mL/s as the head climbed to 180 and 380 mm over time, respectively.

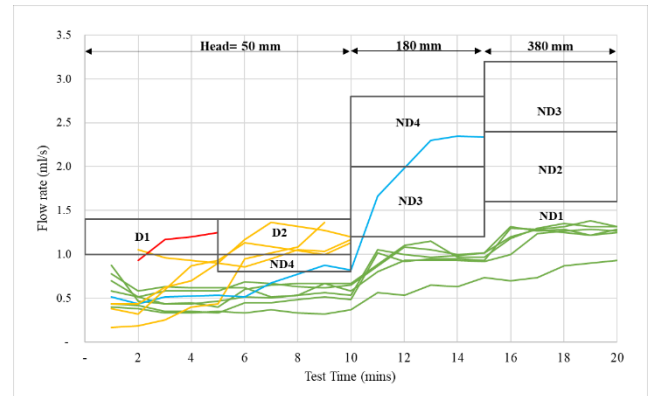


Figure 9 Flow rate against test time and dispersivity grades.

Figure 9 shows red line as sample SS-5 indicating D1 i.e., highly dispersive, blue line resembles SS-2 behaving ND4 i.e., moderately dispersive, yellow lines resemble SS-1, SS-3, SS-4 and SS-6 falls on D2 i.e., dispersive. Additionally, green line denotes the soil sample mixed with 16.9% of cement.

Figure 10 and Figure 11 shows the final pinhole diameter, discharge turbidity and particles falling for disturbed soil samples and samples mixed with cement respectively.

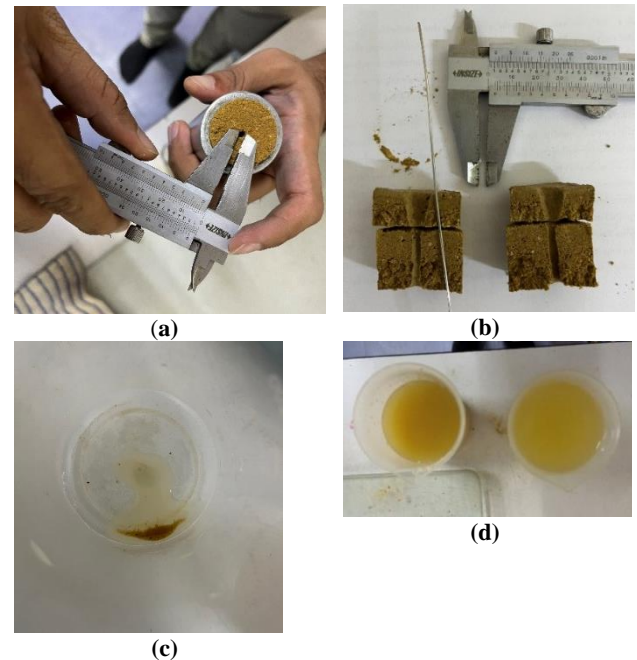


Figure 10 (a) & (b) Hole size after test (c) Particle fall (d) Cloudiness of Discharge for Soil Sample SS-1 to SS-6

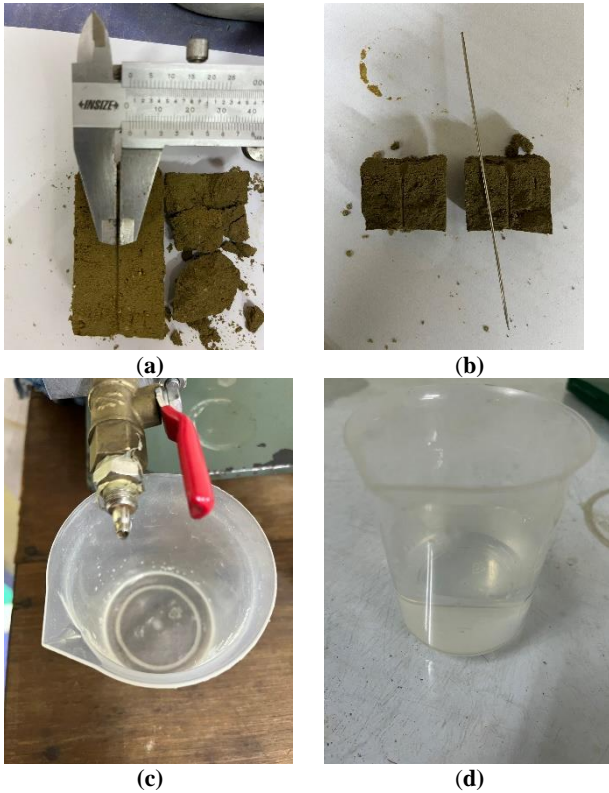


Figure 11 (a) & (b) Hole size after test (c) & (d) Cloudiness of Discharge for Soil Sample SC-1 to SC-6

5. CONCLUSION

The conclusion of this laboratory tests is parted into two sections. First concerns with the pinhole test result of on dispersive soil.

- The pinhole test carried out on CL and SM-classified embankment soil were identified as highly (D2 and D1) to moderately (ND4) dispersive.
- The increase in head or prolong flow through the pinhole through dispersive soil can result in increase of particle erosion thus leading to increment of discharge and enlargement of pinhole size.

Another conclusion is related with the soil-cement mixture.

- The turbidity of discharge was changed from dark or moderately dark to completely clear with no sign of particles falling throughout the test time, the soil-cement composition is resistant to particle erosion.
- The size of pinhole was almost unchanged, flow rate for given test head was almost constant, suggesting almost no development of crack or concentrated leak size with consistent seepage flow.

Hence, dispersive soil with cement can control the dispersivity and erosivity character even though cracks or concentrated leak are present on the column.

Although the test of the pinhole test was carried out as per ASTM standards, there are certain limitation of this test.

- Maximum pressure head along soil-cement column is 10m. But pinhole test can withstand 380 mm of head.
- The normal seepage discharge in the lab test is higher than estimated from the field.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the team of Geotechnical Engineering Research and Development Center (GERD) for their efforts in the research as well as would also extend gratitude towards Department of Water Resource, Thailand, Smart Engineering Consultants Co. Ltd., Right Tunnelling PLC, and Krungthep Geotechnique Co. Ltd. (KGT). The research is not supported by any grants.

7. REFERENCES

- ASTM. (2006). Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test. *Vol. D4647-93*
- Belarbi, A., Zadjouli, A., & Bekkouche, A. (2013). Dispersive clay: influence of physical and chemical properties on dispersion degree. *EJGE*, 18, 1727-1738.
- Dinh, B. H., Nguyen, A.-D., Jang, S.-Y., & Kim, Y.-S. (2021). Evaluation of erosion characteristics of soils using the pinhole test. *International Journal of Geo-Engineering*, 12, 1-14.
- Djokovic, K., Čaki, L., Šisic, N., & Hadzi-Nikovic, G. (2018). Methods for assessment and identification of dispersive soils. *ce/papers*, 2(2-3), 205-210.
- Ismael, R. H., Fattah, M. Y., & Aswad, M. F. (2021). Consistency characteristics of dispersive clays. *Engineering and Technology Journal*, 39(12), 1753-1759.
- Knodel, P. C. (1991). *Characteristics and problems of dispersive clay soils* (Vol. 9). US Bureau of Reclamation.
- Mohanty, S., Roy, N., & Singh, S. P. (2018). Strength characteristics of dispersive soil by using industrial by-products. *Contemporary Issues in Geoenvironmental Engineering: Proceedings of the 1st GeoMEast International Congress and Exhibition, Egypt 2017 on Sustainable Civil Infrastructures 1*,
- Paige-Green, P. (2008). Dispersive and erodible soils-fundamental differences.
- Phienweij, N., Nutalaya, P., Udomchoke, V., Pientong, T., & Balasubramaniam, A. (1994). Properties of problem soils of arid Northeastern Thailand. *International conference on soil mechanics and foundation engineering*,
- Singh, B., Gahlot, P., & Purohit, D. (2018). Dispersive soils-characterization, problems and remedies. *Int. Res. J. Eng. Technol*, 5(6), 2478-2484.
- Umesh, T., Dinesh, S., & Sivapullaiah, P. V. (2011). Characterization of dispersive soils. *Materials Sciences and Applications*, 2(6), 629-633.
- Vakili, A. H., Selamat, M. R. b., Mohajeri, P., & Moayedi, H. (2018). A critical review on filter design criteria for dispersive base soils. *Geotechnical and Geological Engineering*, 36, 1933-1951.