Long-Term Durability of Ordinary Portland Cement and Polypropylene Fiber Stabilized Clay

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Abstract. Soft soil stabilization frequently uses cement, lime, fly ash, etc., but very limited studies are available on its long-term durability. The present study deals with the long-term durability of commercially available EPK clay stabilized with Ordinary Portland Cement and polypropylene fiber. Experimental investigations were conducted to determine the percentage loss of soil during wetting-drying cycle, which is used as a durability indicator of cement and cement-fiber stabilized soil. Stabilized soil samples were subjected to harsh environmental conditions in a laboratory setup and their deterioration was observed in each wetting-drying cycle. In the real world, stabilized soil encounters seasonal cycles of monsoon and summer in long run of its service life which is simulated as rapid wetting-drying cycle in laboratory setup. Samples were stabilized using a different percentage of cement, and a mix of cement-fiber and subjected to 12 cycles of wetting-drying to determine the percentage loss of soil as per ASTM standard. Finally, based on the percentage loss of soil for those samples which survived up to 12 cycles, the optimum content of stabilizing agent was determined. The results indicated that only the EPK clay stabilized with 5% and 10% cement in combination with 0.5% fiber survived up to 12 cycles but, only 10% cement mixed with 0.5% fiber was durable against wetting-drying cycle. For all the combination of 10% cement mixed with 0.5% fiber stabilized soil samples, after durability test the soil loss was less than 7%, which satisfy the Portland Cement Association's durability specification.

Keywords: EPK Clay · Ordinary Portland Cement · Fiber · Durability · Wetting-drying · Soil Loss

1 Introduction

The concept of soil stabilization has been established since long ago when the shortage of aggregate and resource compel to think an alternative way to stabilize the poor site. History begins with the chemical stabilization of soil when Mesopotamians and Romans improve the load carrying capacity of pathway by mixing the underneath soil with pulverized limestone (Ellaby, 2010). In modern days, various chemicals like cement, lime, fly ash, bitumen, tar, by-products, chemical waste or sludge and blend of these chemicals are used for soil stabilization. The major advantage of chemical stabilization is that setting time and curing time of chemically stabilized soil can be controlled easily. Also, chemical stabilization gives more strength and decrease permeability. Because of this significant advantage, most of the soil stabilization is done using chemicals and thus chemical stabilization is also termed as soil stabilization (Kazemian et al., 2010; Zhao et al., 2014; Abid 2016; Firoozi et al., 2017).

Performance measurement of those stabilized soil is one of the important aspects. This is normally addressed as a durability test of stabilized soil. Durability of those stabilized soil mainly depends on the type of chemical stabilizer, quantity of stabilizer, nature of weathering phenomenon and number of deteriorating cycles. Stabilized soil undergoes various of deteriorating factors and weathering phenomenon. Sometimes stabilized soil even may encounter flood and drought cycle. Extreme high temperature followed by rainfall could be another weathering phenomenon. Normally, southern states of USA like Texas, Louisiana, Florida face the cycle of higher temperature followed by rainfall during summer and lower temperature during winter. Based on 1971 to 2000 climate data (rssweather.com), January average temperature of Chicago, IL was -9.8°C and July average temperature was 28.6°C. Average temperature of Houston, Texas in the month of January was 5.1°C and 34.2°C in July. Average precipitation in of Houston in June was 13.6 cm. From this data, it can be observed the cycle of lower temperature and higher temperature followed by rainfall occur in real-world phenomena. It can be expected the similar weathering phenomenon multiple times in the long run of stabilized soil. In general, every part of states encounters seasonal cycle of higher temperature and rainfall during summer and lower temperature during winter, which can be simulated as deteriorating factor. Durability of stabilized soil against these deteriorating factors is normally addressed by durability test. To represent the different environmental conditions, stabilized soil is subjected to harsh condition during the test and durability is measured based on dielectric value, pulse velocity, percentage loss of soil mass, and unconfined compressive strength before and after the weathering cycles. The present research investigates the long-term durability of EPK clay stabilized with ordinary Portland cement and polypropylene fiber based on percent loss of soil-cement-fiber mixtures after weathering cycle.

2 Materials and Methods

A durability test was performed on commercially available soil (EPK Clay) stabilized with ordinary Portland cement and 6.35 mm long polypropylene fiber. EPK clay is classified as high compressible silty soil i.e., MH as per Unified Soil Classification System (USCS) or A-7-5 type soil as per American Association of State Highway and Transportation Officials (AASHTO) classification. Cement meets the ASTM C150 cement requirement. Physical properties of EPK clay was determined by specific gravity test, hydrometer test, Atterberg limit test, and miniature Proctor compaction test using respective ASTM standards. EPK clay was stabilized with 5% and 10% ordinary Portland cement by dry weight of clay in combination with 0.5% polypropylene fiber. Optimum moisture content (OMC) and maximum dry density (MDD) for each combination were determined. X-Ray diffraction (XRD) was carried out for original EPK clay and EPK clay mixed with 5% and 10% ordinary Portland cement. Also, Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Analysis (EDAX) was conducted for original EPK clay and EPK clay mixed with 5% and 10% ordinary Portland cement. Wetting-Drying tests method was used for the evaluation of the durability of stabilized soil. For wetting-drying test 12 cycle of weathering action was simulated under laboratory control setup. Durability was measured based on percent loss of soil after weathering cycle. After the durability test, compressive strength test was also carried out on survived samples. For compacted sample preparation, ASTM D698 standard was used. Moisture content was determined based on ASTM D2216 standard. ASTM D559 was the standard test methods used for durability measurement of stabilized clay based on wetting-drying weathering cycle. Portland Cement Association (PCA) specification are used to evaluate the long-term performance of stabilized soil. Test results were also compared to the US Army Corps of Engineers (USACE) durability requirement and American Concrete Institute (ACI) committee durability requirement.

2.1 Durability Test Procedure

Sample Preparation. Approximately 5000 gm of soil was prepared in accordance with ASTM D558 Test Method A and mixed with cement confirming the ASTM C150 specification. Initially, soil and cement were dry mixed thoroughly to give a uniform color. Enough potable water was added to soil cement to raise the moisture content to optimum moisture content during compaction. Required amount of water is estimated based on result of miniature proctor test. After the absorption, soil cement, and water were mixed again and break up the mixture to smaller particle without affecting the natural particle size until it passes through US No. 4 sieve (4.76 mm). Standard Proctor sample, confirming D698 specification was prepared immediately after soil preparation. Soil was compacted in three layers with 25 blows in each layer with standard proctor rammer effort. During compaction, representative samples were taken from batch of mixed soil-cement to determine the moisture content of compacted specimen. Mass of compacted specimen was recorded, and dry unit of specimen was calculated. Obtained moisture content and calculated dry density was checked against design moisture content and designed dry density. OMC should be within tolerance limit of ±1% and MDD should be within the tolerance limit of ± 48 kg/m^3 (3 lbf/ft^3). Specimen was named as No. 1 specimen, and second and third specimens were molded as rapidly as possible in the same way as No. 1 and named as No. 2 and No. 3 specimen. Average diameter, height, and weight of No. 1 specimen were measured after molding. All the three specimens were stored for period of 7 days in moist condition protecting from free water.

Wetting-Drying Test (ASTM D559)

1. After 7 days, specimens were submerged in potable water for 5 hours and then removed.

2. After wetting phenomenon, specimens were placed in oven at 71 ± 3°C (160 ± 5°F) and removed after 42 hours. Again, mass of all specimens along with height and diameter of Specimen no. 1 were measured. This is the drying action of weathering cycle.
3. For Specimen no. 2 and 3, 13 N (3 lbf) force stokes was given on all area with standard wire scratch brush. Two strokes should be given. Generally, 18-20 stokes were required to cover the face twice, and each end requires 4 strokes to cover twice. This represents the deterioration factors that may occur in service life. To apply 13 N force stroke, specimen was clamped in weighing balance vertically on edge and zero set the reading Fig. 1. Then force was applied vertically until the reading shows 13 N.
4. Mass of all specimens, and height and diameter of Specimen no. 2 and Specimen no. 3 were measured.
5. This completes the one cycle of wetting-drying process. Step 1 to Step 4 were repeated 12 times to complete 12 cycles of weathering actions.
6. When the volume measurement of Specimen no. 1 is inaccurate due to soil-cement loss, Specimen 1 can be stopped before reaching the 12th cycle. At the end of 12 cycles, specimen was dried in oven at 110 ± 5°C (230 ± 9°F) until constant mass. Finally, oven dried mass of all specimens was measured to calculate the soil cement percent due to weathering action.

Fig. 1. Specimen subjected to brushing

3 Results and Discussion

3.1 Properties of soil and soil-cement mixture

EPK clay consists of 74% of clay fraction and 26% of silt fraction. From experimental test Liquid Limit (LL) was found to be 58.5 and Plastic Limit (PL) was found to be 33.3. Plasticity Index (PI) of clay is calculated as 25.20. Specific gravity of clay, clay mixed with 5% and 10% cement, and clay mixed with cement and fiber is shown in Table 1.

Table 1. Specific Gravity of different mixtures used in the study

Soil Combination	Specific Gravity
EPK Soil	2.59
Cement	3.14
Fiber	0.93
EPK + 5% Cement	2.64
EPK + 10% Cement	2.65
EPK + 5% Cement + 0.5% Fiber	2.62
EPK + 10% Cement + 0.5% Fiber	2.64

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for different combination of clay, cement, and fiber are presented in Fig. 2. From Fig. 2 it can be observed that MDD decreases and OMC increases with the addition of 5% cement. Further increasing the cement content to 10% shows that MDD increases than with 5% cement content but less than original EPK clay. Similarly, OMC also decreases than with 5% cement content but higher than original EPK clay. Addition of 0.5% fiber has no significant impact on MDD and OMC. The reasons for the unusual variation of MDD and OMC with cement content was further studied. The study shows that with EPK clay with 5% cement content has higher plasticity than the cement content with 10% cement as shown in Fig. 3. Muhunthan & Sariosseiri (2008) also found a similar result for two types of fine-grained soil, i.e. initial increases in plasticity index with cement content and then decreases in plasticity index with further addition of cement.

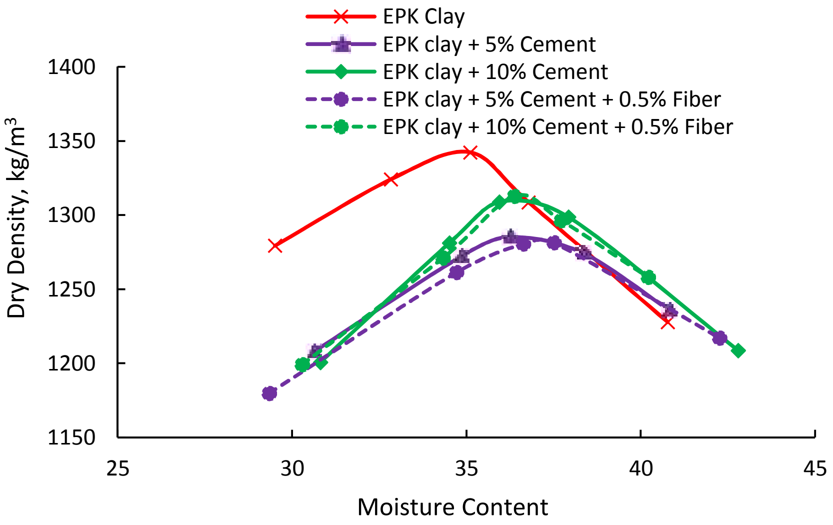


Fig. 2.. Variation of OMC and MDD with cement content

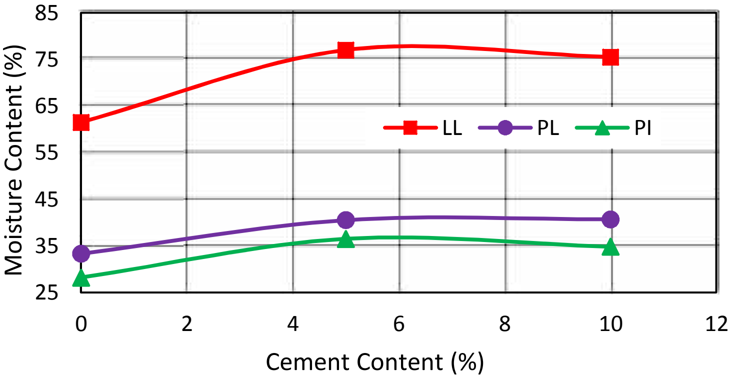
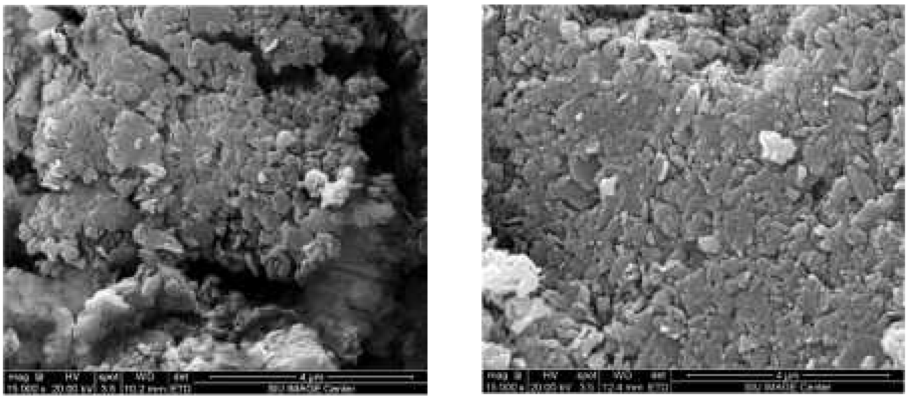


Fig. 3. Variation of plasticity with cement content

Scanning Electron Microscope (SEM) test on EPK clay and EPK clay mixed with cement indicate that EPK clay and EPK clay mixture have flaky structure Fig. 4. Average particle size is about 0.4 micron (400 nm) and particles are conglomerations and randomly oriented. Energy Dispersive X-Ray Analysis (EDAX) of EPK clay shows that Alumina and Silica are the major components. Titanium and Iron are also present in a small percentage. Addition of cement in EPK clay shows the additional calcium in soil-cement mixture.



(a) (b)

Fig. 4. SEM Image of: **(a)** EPK Clay and **(b)** EPK clay with cement

X-Ray Diffraction (XRD Test) was also performed to identify the mineral in EPK clay and EPK clay-cement mixture. Kaolinite- $Al_2Si_2O_5(OH)_4$ is the dominant minerals in all three combinations of soil-cement mixture. XRD plot for three different combinations of clay and cement – EPK clay, clay + 5% cement and clay + 10% cement shows that addition of 10% cement results the formation of two new minerals. Based on MDI Jade software analysis of XRD data, the minerals were identified as Frolovite- $CaB(OH)_{42}$ and Calcite- $CaCO_{3.}$ Calcite was also present in EPK clay + 5% cement combination.

3.2 Durability Test Result

Durability test was analyzed based on wetting-drying test. During wetting-drying test on samples made with only EPK clay, it was found that the percentage loss of soil after first cycle was significantly high and all the samples collapsed completely in the beginning stage of second cycle as shown in Fig. 5. To stabilize the EPK clay samples, 5% cement with clay was added and again wetting-drying test was performed. With the addition of 5% cement, one of the brushed samples (B2) collapsed during 3rd cycle and other two samples were stopped at 4th cycle due to heavy deterioration. Percentage loss of soil for unbrushed sample (UB1) was 16% and for brushed sample (B3) was 26.67% of original oven-dried sample after 4th cycle. Thus this result confirms that the EPK clay stabilized with only 5% cement is not durable against wetting-drying test. Again, 10% cement was added to EPK clay and durability test was performed. With the addition of 10% cement, one sample collapsed during the brushing operation of 10th cycle and other two samples completed all the weathering cycle. Percent loss of soil after 12th cycle was 1.63% for unbrushed sample and 8.68% brushed sample. Based on PCA criteria, EPK clay with 10% cement is also not durable against wetting-drying test.

Fig. 5.. EPK clay sample collapsed during wetting stage of 2nd cycle

To improve the durability performance of EPK clay fiber was added and durability test was conducted. Addition of 0.5% fiber to the mix of EPK clay and 5% cement results in the survivable of all three samples. Percent loss of unbrushed sample was 6.84% and percent loss of brushed samples were 20.89% and 16.20%. Although all the samples completed the weathering cycle, percent loss of soil was significantly higher and thus the combination is not considered as durable. Finally, EPK clay was mixed with 10% cement and 0.5% fiber and subjected to durability test. All the samples completed the 12 cycles of weathering action as shown in Fig. 6 and percent loss of soil along with compressive strength on oven-dried sample was carried out. Result shows the percent loss of soil for unbrushed sample was 1.61% and percent loss of soil for brushed samples were 6.55% and 6.39%. PCA criteria suggest that for the durability of high compressible silty soil, percent loss of soil after 12 weathering cycle should be less than 7%. Thus, based on PCA criteria, it can be confirmed that EPK clay stabilized with 10% and 0.5% fiber is durable against wetting-drying action. Compressive strength of oven dried unbrushed sample after 12 weathering cycle was 9.63 MPa (1396 psi). Similarly, compressive strength of brushed samples was 7.45 MPa (1080 psi) and 7.95 MPa (1153 psi).

Fig. 6. Sample stabilized with 10% cement and 0.5% fiber after 12 weathering cycle

Using the moisture content estimation concept of PCA specification and referencing the final oven-dried mass after 12th cycle as standard, approximate percent loss of soil in each cycle was estimated as shown in Fig. 7.

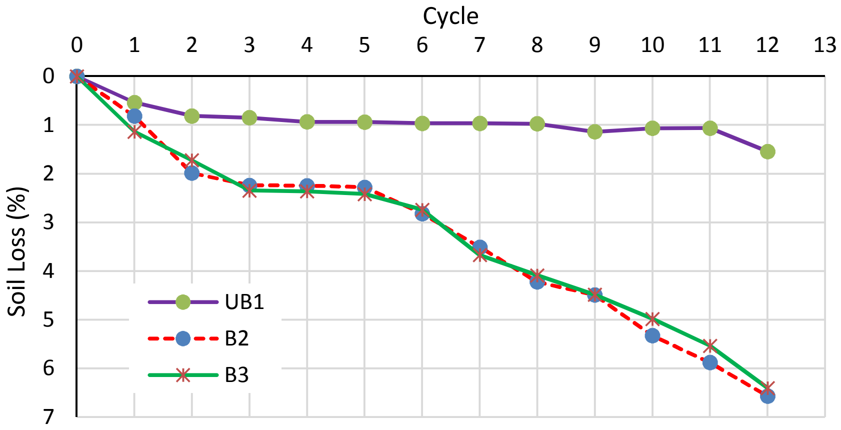


Fig. 7. Approximate soil loss percentage after each cycle for EPK clay stabilized with 10% cement and 0.5% fiber

3.3 Durability Result Comparison

Percent loss of soil was the main criteria used for the evaluation of durability. Percent loss of soil for all survived sample was represented in Fig. 8. Based on Fig. 8, only the clay stabilized with 10% cement and 0.5% fiber (WD_10C_0.5F) has percent loss less than the specified criteria. Thus, only the sample stabilized with 10% cement and 0.5% is durable and this combination can be considered as the optimum amount of stabilizer for the durability of EPK clay. For the clay stabilized with 10% cement only (WD_10C) and mix of 5% cement and 0.5% fiber (WD_5C_0.5F), only the unbrushed sample has percent loss less than 7%.

The cement content requirement for durability test as per ACI committee for A-7 type of soil is between 10-16%. Packard (1962) also suggested that minimum cement content for wetting-drying test should be at least 5%. Thus, EPK clay stabilized with 10% cement and 0.5% fiber satisfied the durability criteria for wetting-drying test set by PCA and fulfills the minimum cement content requirement criteria set by ACI committee and Packard (1962).

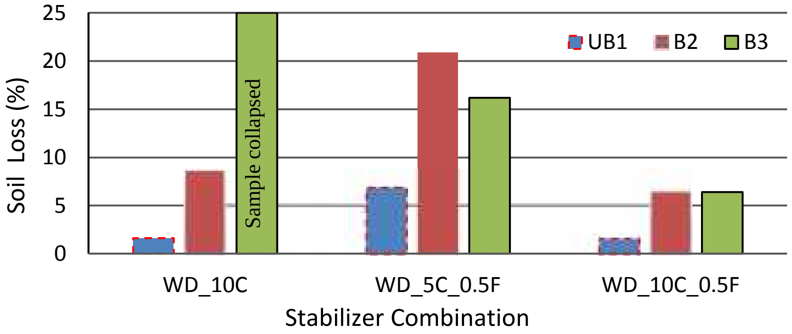


Fig. 8. Percent loss of soil for all survived samples

4 Conclusions

Based on the characterization of EPK clay and laboratory study of durability test, some conclusions were made. From miniature compaction test, it can be concluded that EPK clay has the Maximum Dry Density and minimum Optimum Moisture Content compared to EPK clay mixed with cement or fiber. When 5% cement is added on EPK clay, MDD decreases, and OMC increases. Further, increase in cement content to 10% results in the increase in MDD and decrease in OMC due to decrease in plasticity of soil, as compared to the result of 5% cement content. From XRD test it can be concluded that, in addition to the physical bonding, Calcite and Frolovite are responsible for the durability of soil stabilized with 10% cement and 0.5% fiber. EPK clay stabilized with combination of 10% cement and 0.5% fiber is only durable against wetting-drying test. Thus, this combination is considered as the optimum amount of stabilizer for EPK clay subjected to wetting-drying action. The addition of fiber not only improves the durability performance of EPK clay but also increases the tensile strength and improves the brittle failure pattern.

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