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STRENGTH AND DURABILITY CHARACTERISTICS OF SOIL STABILIZED WITH VARIOUS CEMENT TYPES FOR SLOPE PROTECTION APPLICATIONS

Jaime Angelo S. Victor
Geotechnical Engineering Group
Institute of Civil Engineering, University of the Philippines

ABSTRACT

Protection of in-situ soils is one of the most common methods of slope condition improvement. Weak surface soils often affect slope stability. The objective of this study is to investigate the effect of cement treatment to the shear strength and erodibility of stabilized soil. The results of the study are potentially useful for slope protection applications. Soil samples were collected and treated with three types of cement (Type I, Type IP and Type P) at 6%, 8% and 10% concentration by mass. To determine the specific effects of each cement type and amount, factors such as water content, size of the specimens and curing period were kept constant. Unconsolidated undrained shear strength of the samples was measured using Unconfined Compressive Strength Test, while the erodibility was determined by quantifying the percent of soil loss after exposing the specimens into an accelerated rainfall simulation setup with an intensity of 900,000 mm/hr. The shear strength and resistance to erosion of the treated soil were generally observed to increase with the increase in cement content. Both the shear strength and erodibility tests show that among the three cement types of cement utilized in this study, Type I cement is potentially the most efficient in stabilizing soil as slope protection material. Type P cement was observed as the least effective.

1. INTRODUCTION

Protection of in-situ soils is one of the most common methods of slope condition improvement. Weak surface soils often affect slope stability. The objective of this study is to investigate the effect of cement treatment to the shear strength and erodibility of stabilized soil. The results of the study are potentially useful for slope protection applications. Soil samples were collected and treated with three types of cement (Type I, Type IP and Type P) at 6%, 8% and 10% concentration by mass. To determine the specific effects of each cement type and amount, factors such as water content, size of the specimens and curing period were kept constant. Unconsolidated undrained shear strength of the samples was measured using Unconfined Compressive Strength Test, while the erodibility was determined by quantifying the percent of

Correspondence to: Jaime Angelo S. Victor, Geotechnical Engineering Group, Institute of Civil Engineering, University of the Philippines, 1101 Diliman

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soil loss after exposing the specimens into an accelerated rainfall simulation setup with an intensity of 900,000 mm/hr. The shear strength and resistance to erosion of the treated.soil were generally observed to increase with the increase in cement content. Both the shear strength and erodibility tests show that among the three cement types of cement utilized in this study, Type I cement is potentially the most efficient in stabilizing soil as slope protection material. Type P cement was observed as the least effective.

To address rising expenses on conventional (mechanical and structural) methods of improving soil properties, researches were initiated to study different methods to improve engineering properties of local soils. Additives such as lime, cement, cement kiln dust, emulsified asphalt, Geofiber, industrial waste products, calcium chloride, potassium chloride, phosphoric acid and polymer stabilizers were all found to be efficient in stabilizing soils. However, choice and effectiveness of additives still depend on the type of soil and its field condition. Various examinations of the mechanical properties are also needed since same types of soils may still exhibit different treatment effectiveness if their mechanical properties differ (Muhunthan et al., 2008).

With regards to using cement as stabilizing agent, most researchers focused on the use ofOrdinary Portland cement (Type I) in stabilizing or improving different properties of soil, such as compressive strength, shear behavior, swelling characteristics, durability, drying rate, elasticity, workability, and compaction characteristics. Other cement types were also used in previous researches, but studies aiming to investigate the difference between the effects of different cements on a specific soil type were not given much attention. This observation has led to an idea on using other types of cements, such as Type P Portland-pozzolan and Type IP Portland-pozzolan cements, in stabilizing soil as slope protection material

This study will focus on evaluating the influence of the type and amount of cement on the shear strength of soil cement through laboratory experiments. The results will be compared and analyzed to determine specific effects of each cement type and amount on the shear behavior of the soil and to identify which cement type is more efficient in improving the shear strength of soil as a slope material for embankments. This study aims to evaluate the performance of various types of cement, concentration on the undrained shear strength and erodibility of stabilized soil by means of laboratory experimentation. Moreover, this study will identify which type of cement is more appropriate for soil stabilization.

The stability of slopes is one the major design considerations of both large scale and small scale engineering projects. These include dams, riverbanks, dikes, levees and embankments. There are several factors that affect the stability of slopes including: topography and physical conditions; geological site characteristics; extent of weathering, alteration and jointedness of the rock mass; geomechanical properties of the slope material; hydrological conditions; and presence of external loading and surcharges. Unprotected natural or constructed earthen slope can cause erosion problems which may then result to serious sediment flows to lower catchment sites, contamination of rivers and streams, water quality reduction, slope failure and slippage that often result in landslides, economic damage to properties and loss of life.

Soil cement, based on the results of the laboratory studies initiated by the U.S. Bureau of Reclamation (USBR), was specified to produce durable erosion-resistant facings and can be used as an alternative slope protection material. Soil cement was also found to be less than half of the cost of the conventional riprap. It has been seen in previous studies that slope materials shall have sufficient shear strength and erosion resistance in order to withstand the sliding movement due to gravitational forces, and prevent possible removal of a massive weight of soil which may lead to a decrease in the slope stability. This study of this study was limited to the evaluation of performance of the various cement types and concentrations with reference to shear strength and durability characteristics. The shear strength assessed on the basis of unconfined compression tests while durability was evaluated by erodibility properties. Standard tests and recommended methods from the American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO) and American Concrete Institute (ACI) where implemented in the laboratory experiments. For the erodibility test, the effect of rainfall is the only factor considered in the identification and comparison of the resistance of the soil samples to erosion. Consideration of other factors that might affect soil's erodibility, like surface flow, seepage, infiltration, structure design, site drainage and topography, are currently not taken into account. The three cements used in these study are Type I Ordinary Portland cement, Type P Portland- pozzolan cement and Type IP Portland- pozzolan cement

2. METHODOLOGY

This section describes the experimental and statistical methods employed in the study.

2.1 Identification of the Geotechnical Properties of the Untreated Soil

One type of soil was collected for the study. Basic geotechnical properties of the untreated soil were determined using the standard test methods for classification of soils for engineering purposes (ASTM D2487-11), particle-size analysis of soils (ASTM D422-63), liquid limit, plastic limit and plasticity index of soils (ASTM D4318-10), specific gravity of soil solids by water pycnometer (ASTM D854-10), and moisture- density relations (unit weight) of soil-cement mixture (ASTM D558-11). Three trials were conducted for all the tests to obtain more reliable results.

2.2 Specimen Preparation

For all the cement types, an amount of air dried soil required for the desired dry unit weight of specimen were weighed and mixed with the specified cement content (6%, 8% and 10%). The mixture were then compacted at the optimum moisture content in the molds and tamped properly to achieve the required maximum dry density. The molds with the compacted soil were then placed in a moist container for 12 hours to permit subsequent removal from the molds using sample extruder. After removing from the molds, specimens were returned to the moist container and were allowed to cure for 7 days. Three samples for each test case were prepared. Prior to testing for strength and durability, specimens were soaked in water for four hours, as recommended by ASTM.

2.3 Testing Method

To properly evaluate the effectiveness of stabilization, shear strength test and erodibility test were conducted to both untreated and cement-treated samples.

2.3.1 Shear Strength Test

A total of 30 4-inch diameter cylindrical specimens where created. The height to diameter (h/d) is 2. Specimens were moist cured for 7 days. The relative humidity is maintained at 95% minimum. During the testing, the soil sample was placed in a loading frame on a stationary metal plate and restrained by the top plate attached to a calibrated proving ring. As the top plate descends, the axial load being applied was gradually increased to shear the sample. Readings on the force applied to the sample and the resulting vertical deformations were recorded. The loading was continued until the soil develops an obvious shearing plane or the deformations become excessive.

The series of unconfined compressive strength tests for both untreated soil and cement-treated soils were done according to ASTM D2166. Collected data were analyzed to determine the effect of cement type and amount on the shear strength of the cement- stabilized soil. The effects of each type of cement were compared to identify which type is most efficient in improving the shear strength of soil.

2.3.2 Erodibility Test

Thirty cylindrical specimens of size 4 inches in diameter by 6 inches in height were prepared for the erodibility test. Samples were allowed to cure for 7 days in a moisture container. After curing, samples were soaked in water for four hours prior to testing.

End surfaces are also trimmed such that all the specimens have a relatively identical mass of 1200 grams. Since erodibility of the soil specimens is to be presented as percentage of soil loss, trimming was done to guarantee that the initial mass of the sample would not cause any discrepancy in the results.

An accelerated rainfall simulation model was developed to determine the erodibility of the soil samples. Rainfall was applied with a hemispherical sprinkler type of rainfall simulator consisting of 210 0.5mm-diameter holes. The discharge outlet was fixed at 35 cm above the center of the specimen. It was raised relatively low so as to maintain terminal velocity of the simulated rain as it strikes the specimen. A cylindrical plastic bucket, 30 cm in height and open on each end, was also provided to minimize external force effects. A one-centimeter clearance was set between the specimen and the plastic bucket to allow the eroded soil to fall freely from the molded specimen. It was assumed that the distribution of the simulated rain is uniform over the specimen, and the mean rainfall intensity is constant and not varying with time. Rainfall intensity was measured using pan method, in which rain is collected with a pan that has the same cross section area of the specimen. The intensity was determined by measuring the height of the collected rain over time.

Rainfall simulation was conducted at an intensity of approximately 900,000 mm/hour. Each specimen was subjected to accelerated rainfall for 2 hours. After simulation, it was immediately put in the oven and allowed to dry for at least 48 hours. Upon removal from the oven, the specimen was weighed and the percent of soil loss was determined.

2.4 Statistical Analysis

The statistical method used to analyze experimental results is One-way Analysis of Variance (ANOVA) with Tukey's Pairwise comparison as the supplementary test. These tests determine if there are statistically significant difference on the experimental test cases for shear strength and erodibility. All analysis where done at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Geotechnical Properties of the Untreated Soil

The results of the geotechnical characterization of the natural, untreated soil is presented in Table 1.

Table 1. Summary of the Geotechnical Properties of the Natural Soil

Property	Untreated Soil	Standard Method
Particle Size Analysis	Poorly-graded	ASTM D 422
Liquid Limit, %	567	ASTM D4318
Plastic Limit, %	26	ASTM D4318
Plasticity Index, %	30	ASTM D4318
Specific Gravity	2.95	ASTM D854
Optimum Moisture Content, (%)	29.84	ASTM D698
Maximum Compaction, kN/m^3	13.87	ASTM D698
USCS Classification	SC, Clayey Sand	ASTM D2487
AASHTO Classification	Type A-2-7, Clayey Gravel and Sand	---
Shear Strength, psi	11.94	ASTM D2166
Erodibility, % soil loss	26.14	---

3.2 Optimum Moisture Content of Cement-treated Soil

To identify the effect of cement addition, series of optimum moisture content tests were also conducted for the cement treated soils (8% Type I cement, 8% Type P cement, and 8% Type IP cement). The results of the tests are as shown in Table 2. It was observed addition of cement causes the optimum moisture content to increase and the maximum dry unit weight to decrease.

Table 2. Optimum Moisture Content and Maximum Dry Unit Weight of Non-treated and Cement-treated Soil

Soil Type	Optimum Moisture Content, %	Maximum Dry Unit Weight, kN/m^3
Non-treated Soil	29.84	13.87
Soil Treated with 8% Type I cement	31.97	13.87
Soil Treated with 8% Type P cement	34.87	13.27
Soil Treated with 8% Type IP cement	35.83	13.22

3.3 Shear Strength of Untreated and Cement-treated Soil

The effect of cement treatment on the UU shear strength of the selected soil is illustrated in Figure 3. The result only shows that increase in cement content leads to a significant increase in the UU shear strength of the untreated soil, especially for the 8% and 10% cement contents. It is also observed that soil samples treated with Type I Portland cement exhibited greater shear strength compared with the samples treated with Type P and Type IP cements.

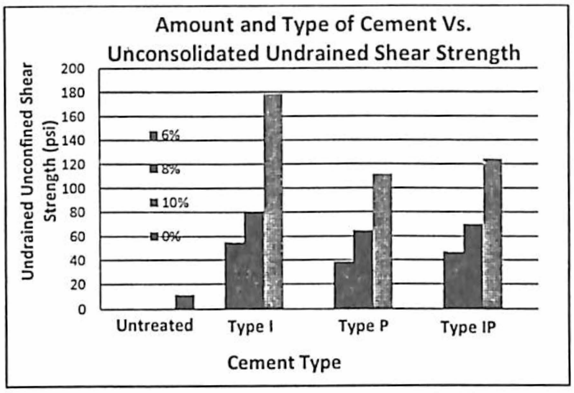

Figure 1. Effect of Amount and Type of Cement on the Undrained Unconsolidated Shear Strength of Soil

Using ANOVA and Tukey's Method, specific effects of the amount and type of cement on the UU shear strength were examined. Figure 4 shows a summary of the analysis on the effect of varying cement contents of Type I, Type P and Type IP cements. It is observed that addition of 6%, 8% and 10% of both Type P and Type IP cements resulted in a significant increase in the shear strength of soil. However, in the case of Type I cement, addition of 6% and 8% cement is found to have no significant difference in improving the shear strength. The increase in the shear strength caused by each cement type was also examined for each cement amount (6%, 8% and 10%).

UU Shear Strength Vs. Cement Amount			
Cement Amount (%)	Type I Cement	Type P Cement	Type IP Cement
0	A	A	A
6	B	B	B
8	B	C	C
10	C	D	D

Figure 2. Statistical Analysis of the Differences in the Effect of Varying Amounts of Type I, Type P and Type IP Portland Cements on the Shear Strength Stabilized Soil

The increase in the shear strength caused by each cement type was also evaluated for each cement amount (6%, 8% and 10%).A summary of the analysis is shown in Figure 5.Based on the initial condition of the untreated soil, all the cement types were able to significantly increase the shear strength. When added to soil at an amount of 6%, the effect of all cement types is also observed to have significance differences. At 8% and 10% cement content, Type P and Type IP caused relatively similar effects in the improvement of the specimen's shear strength. Only treatment with Type I and Type P cements exhibited considerably different effects in the shear behavior of the treated soil.

UU Shear Strength Vs. Cement Type			
Soil Type	6%	8%	10%
Non-treated	A	A	A
Treated with Type I	B	B	B
Treated with Type P	C	C	C
Treated with Type IP	D	B C	C

Figure 3. Statistical Analysis on the Effect of Cement Type (of Same Amount) on the Shear Strength of Stabilized Soil

3.4 Erodibility of Untreated and Cement-treated Soil

The erodibility test results obtained for the non-treated and treated soil specimens are shown in Appendix F. In Figure 6, the effect of cement treatment on the erodibility of the soil is illustrated as a function of the percentage of soil loss and cement content. The figure only shows that the amount of eroded material from the specimen decreased as the cement content is increased. Among the three types of cement, Type I Portland cement is observed to be the most efficient in reducing the amount of eroded soil.

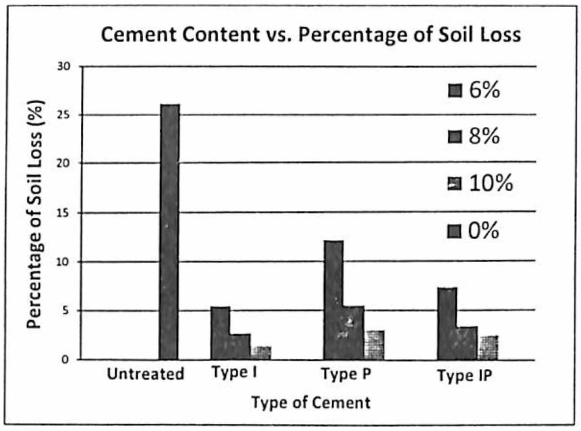

Figure 4. Effect of Cement Treatment on the Erodibility of Cement-treated Soil

With the aid of Minitab Software, variations in the erodibility of the specimens due to the amount and type of cement content were analyzed using ANOVA and Tukey's Method. Analysis on the effect of varying cement contents of Type I, Type P and Type IP cements on the percentage of soil loss is summarized in Figure 7. As seen from the table, the percentage of soil loss is significantly reduced due to cement treatment. However, the effect of addition of 8% and 10% of any cement type are found to have no significant difference.

Percentage of Soil Loss Vs. Cement Amount			
Cement Amount (%)	Type I Cement	Type P Cement	Type IP Cement
0	A	A	A
6	B	B	B
8	B C	C	C
10	C	C	C

Figure 5. Statistical Analysis of the Differences in the Effect of Varying Amounts of Type I, Type P and Type IP Portland Cements on the Erodibility of Stabilized Soil

The improvement of the soil's resistance to erosion caused by each cement type was also examined for each cement amount (6%, 8% and 10%). A summary of the analysis is shown in Figure 8. It is observed that at 6% cement amount, addition of Type P and Type IP cements lead to relatively similar effects on the erodibility of soil. On the other hand, effects of addition of any cement type are found to have no significant difference at 8% and 10% cement amount.

Percentage of Soil Loss Vs. Cement Type			
Soil Type	6%	8%	10%
Non-treated	A	A	A
Treated with Type I	B	B	B
Treated with Type P	C	B	B
Treated with Type IP	C	B	B

Figure 6. Statistical Analysis on the Effect of Cement Type (of Same Amount) on the Erodibility of Stabilized Soil

4. SUMMARY

4.1 Conclusions

Based on the results of the study, it was observed that cement treatment results to a significant increase in the unconsolidated unconfined shear strength and erosion resistance of soil. It was also observed that the increase in the cement content causes an increase in the optimum moisture content and a decrease in the maximum dry density.

With reference to the results of the strength and durability tests, it can be concluded the Type I cement is the most appropriate cement type in stabilizing the soil. The stabilization significantly improved the engineering properties of the soil in terms of shear strength and erodibility.

4.2 Recommendation

This study is limited only to the basic rainfall factors to identify the effect of cement type and amount on the erodibility of stabilized soil. Thus, it is recommended to include considerations of other factors that may potentially affect the erodibility of soil; such as surface flow, seepage, infiltration, structure design, site drainage and topography. Implementing other testing methods in determining the absolute shear strength is also suggested to evaluate specific effects of cement treatment on the cohesion and angle of internal friction of soils.

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