World Academics Journal of Engineering Sciences
Vol.8, Issue.1, pp.08-12, March (2021)

Research Paper

E-ISSN: 2348-635X

Effects of Soil Stabilizers on the Free Swell Index and Unconfined Compressive Strength of Clayey Soil

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Available online at: www.isroset.org

Received: 17/Feb/2021, Accepted: 10/Mar/2021, Online: 31/Mar/2021

***Abstract*—**Excessive moisture content in soil due to rain significantly decreases its bearing capacity, for this reason, stabilizers are used to stabilize the soil, however, the production and use of such chemicals generates large quantities of carbon dioxide that has negative impact to the environment. Table salt is one sustainable alternative for cement and lime, as its hygroscopic property helps remove moisture in soil. The study aims to develop a comparative analysis between cement, lime, and salt as soil stabilizers by determining their strength using free swell index and unconfined compressive strength. Results from experiments with fat clay soil show that stabilized soils achieved an ultimate strength at stabilizer amount of 6% of the mass of soil. Salt attained the smallest amount of swelling, while cement gained the highest compressive strength. In addition, results show that as the percentage amount of stabilizer in clayey soil increases, the swelling potential decreases while unconfined compressive strength increases.

Keywords— Clayey Soil, Free Swell Index, Soil Stabilizers, Stabilize, Unconfined Compressive Strength

I. INTRODUCTION

Due to its tropical climate, the Philippines frequently experiences rainy monsoonal seasons. The excessive moisture originating from downpours significantly affects the soil moisture content, especially to areas near bodies of water. This comes as an issue, especially to vertical and horizontal structure constructions, as increased moisture content greatly decreases the soil bearing capacity, thus producing foundation settlements that are undesirable to structures and hence must be avoided.

Moreover, certain soils that swell in the presence of water offer stresses that are often unrecognized in design and thus might cause damages to foundations. These soils pose a serious risk as they widely distributed in large areas of volcanic depositions with tropical climate. The Philippines, being a tropical country and sitting upon a volcanic mobile belt, is exactly the place where extensive occurrence of soils with high expansion potential should exist.

As a result of this issue, various methods of soil stabilization are carried out for different constructions and purposes, each with their own strengths and weaknesses. One of these methods includes the use of chemical additives called soil stabilizers.

A study held at Washington, USA used Portland cement to modify and stabilize the geotechnical properties of soil [1]. The solidification, plasticity limit, compaction characteristics, unconfined compressive strength, and undrained triaxial shear behavior of Aberdeen, Everett, and Palouse Soil mixed with 2.5, 5, 7.5, and 10% of cement were determined. Results of undrained triaxial test showed that while cement treatment improved shear strength significantly, the type of failure behavior varied greatly. From 0, 5, and 10% soil samples displayed ductile, planar, and splitting type of failure, respectively. A study of El Shinawi [2] from Zagazig University in Egypt, investigated the properties of subgrade soils stabilized with lime at Borg El-Arab, Egypt. The study focused on the effects of the addition of lime specifically at an optimum lime content of 6%. Consistency limits and free swell decreased by adding lime to the soil. However, the specific gravity and the optimum moisture content increased due to high calcium content of lime. Analysts from India studied the strength and volume change behavior of pore space in soil with the addition of several lime contents (0, 2, 4, and 6%) and with curing periods (0, 7, 14, and 28 days) [3]. The result shows that the liquid limit, plasticity index, and the MDD decreases, hence the plastic limit, shrinkage limit, and the OMC increase, with increase in lime content. Another study conducted by Dubey and Jain [4] from the California bearing ratio increased from 1.43% to 3.10% and the unconfined compressive stress increased from 73.54 kN/m^2 to 119.64 kN/m^2.

This study focused only on the comparative analysis of the free swell index and the unconfined compressive strength of clayey soil. The clayey soil was stabilized with cement, lime, and salt to determine its correlation as soil stabilizer.

There are several factors that may affect the stability of soil but this study focused only on the effects of soil stabilizers to clayey soil.

II. RELATED WORK

Soil is one of the primary materials encountered in civil engineering. It is a combination of natural deposits, organic particles, liquid, and numerous organisms that supports life on Earth. Soil is a dynamic matter that continuously develops by diverse physical, chemical and biological processes. Stabilization is usually applied to expansive soils like clay, and loam to attain desirable engineering properties [5]. Standardization of soil is such a great initiative to modify the engineering properties of soil, using additive with various concentration [6].

Soil stabilization is the process of modifying and transforming the properties of soil to enhance its engineering properties specifically improving its shrink-swell tendency as well as increasing its strength. Stabilization of soil is necessary when the soil is inadequate to support structural loads. Chemical stabilization of soil is the common and effective method to develop the workability, permeability, and durability of soil. Lime, cement, fly ash, and rice husks are some of the additives that have been used in previous studies which are effective to improve the quality of soil [5].

Cement has been used as a binding agent since 1960s when soil stabilization technology was invented thus making it the oldest stabilizer among the additives in today's era. Cement does not react based on soil minerals but rather on the possible availability of water in it. It can be used either alone or combined with other materials to meet the required stabilizing action [7].

III. METHODOLOGY

3.1. Materials and Methods

In this study, the soil stabilizers and their percentage amount mixed in the soil are considered the independent variables, while the free swell index and unconfined compressive strength are the dependent variables. The unconfined compressive strength and swelling potential with the percentage amount of stabilizer were correlated to determine the degree of relationship of the variables.

3.2. Material Preparation

The comparative analysis of unconfined compressive strength and free swell index used a total of 30 soil samples: three (3) samples each for 2%, 4%, and 6% mixture, thus nine samples each for cement, lime, and salt, plus three (3) more samples for the un-stabilized soil. Prior to testing, the soil samples were initially air dried. The soil, together with the cement, lime and salt, were kept sealed to avoid atmospheric absorption of moisture. The geotechnical properties of the clayey soil, or the un-stabilized soil sample, were determined. These are the particle size distribution, consistency limits, specific gravity, compaction characteristics, and the free swell index and the unconfined compressive strength. After the evaluation of the properties of the clayey soil, it was mixed with 0%, 2%, 4%, and 6% concentration of cement, lime, and salt by dry weight of soil. Figure 1 shows the mixing of the samples.

Figure 1. Mixing of samples

3.3. Geotechnical Properties

The particle size distribution, moisture content, consistency limits, specific gravity, and compaction characteristics of the soil samples were evaluated and analyzed to determine the significant changes of the un-stabilized soil from the stabilized soil sample. Table 1 presents the specific standards used in determining the geotechnical properties.

Table 1: Standards on Geotechnical Tests Used

Geotechnical Property	Standard
Particle size distribution	ASTM D422
Moisture content	ASTM D2216
Consistency limits	ASTM D4318 ASTM 4943
Specific gravity	ASTM D854
Compaction properties	ASTM D698

The free swell index and the unconfined compressive strength of the soil samples were also tested.

The results gathered from the geotechnical tests conducted, was used to develop a comparative analysis of the free swell index and the unconfined compressive strength of the clayey soil to determine the correlation of cement, lime, and salt as per the increase in percentages of the soil stabilizers.

To test the correlation of the effects of use of the different soil stabilizers, the linear regression was used.

IV. RESULTS AND DISCUSSION

4.1. Geotechnical Properties

Table 2 presents the geotechnical properties of the soil samples. The table shows the different values of the properties of the samples that were tested in the laboratory which is in conformance to the international standards. The value of the geotechnical properties of the soil indicates a low shear strength and high swelling potential of soil and under the USCS soil classification it is considered as cohesive and compressible clay of high plasticity.

Table 2: Geotechnical Properties of the Soil Samples

Geotechnical Property	Value
Natural moisture content	15.11 %
Liquid limit	84.22%
Plastic limit	59.92%
Plasticity index	24.30%
Shrinkage limit	19.08%
Specific gravity	1.76
Maximum dry density	11.92 kN/m^3
Optimum moisture content	38.90%

Since more than 36% of the grains of the soil passed the No. 200 sieve, the liquid limit and plasticity index exceeded 41% and 11%, respectively, and the plasticity index did not reach 30% less of the liquid limit, the soil is classified as A-7-5, which falls under clayey soils, or fat clay.

Table 3 further reveals that as per sieve analysis, more than 50% of the soil sample passed through the No. 200 sieve, which can be considered that the soil is a fine-grained soil. The soil sample also shows a free swell index greater than 50% which indicate a very high degree of expansiveness.

The average liquid limit records a value of 84.22% and a plasticity index of 24.30%, which is identified as clayey soil of high plastic limit and has a high-expansion potential. In summary based on the results of the different tests on the properties of the soil sample, the sample can be defined as cohesive and compressible clay of high plasticity. As per the properties of the soil sample, the stabilization methods as presented in the study is in connection of the statement Afrin [5], that stabilisation is usually applied to expansive soils.

Table 3: Results of the Grain Size Analysis

Sieve Size	Cummulative Mass Retained	Cummulative % Retained	% Finer
No. 4	0.79	0.21	100
No. 10	9.84	2.66	97
No. 20	17.79	4.81	95
No. 40	22.87	6.19	94
No. 60	27.41	7.42	93
No. 140	35.98	9.74	90
No. 200	38.62	10.45	90

4.2. Effects of Soil Stabilizers

Figure 2 shows the averages of the Free Swell Index (FSI) of the three (3) stabilizers. The figure reveals which among the stabilizers significantly affects the swelling potential of the soil. It can be gleaned that the highest point in the graph represents the pure soil with an FSI of 33.33%, wherein when it is subjected to water, there is a moderate increase in the volume. Further, the figures shows that the lowest point that occurs at 6% concentration of stabilizer, indicates a low degree of expansion. The results show that the lime has accumulated 14.33%, cement has 13.67%, and salt obtained 11.00%. It can be implied that the lime is the least stabilizer that affected the FSI of the soil with percentage difference of 56.960%, followed by the cement with 58.828%, and the salt with the maximum percentage difference of 66.886%. This signifies that the salt is the most effective in improving the FSI of the soil.

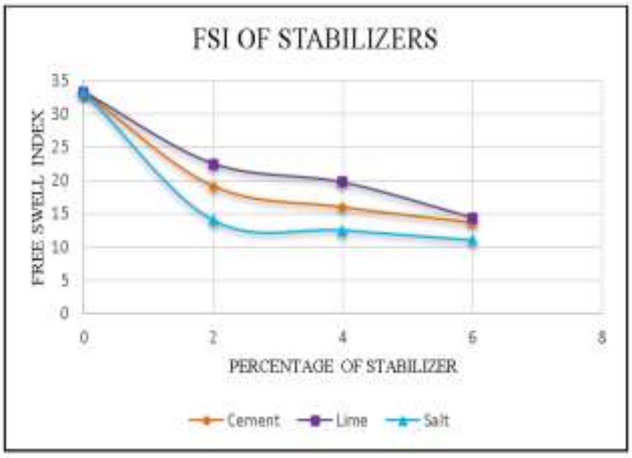

Figure 2: Average free swell index vs percentage of stabilizer

Figure 3 shows the average unconfined compressive strength for each stabilizer. The result shows that the cement gives the highest improvement value in the unconfined compressive strength at 6% amount of stabilizer among the three (3) soil stabilizers. The amount of salt on the soil shows a positive correlation with the unconfined compressive strength and is second in rank in terms of stability improvement. The lime gives the lowest unconfined compressive strength among the three (3) stabilizers.

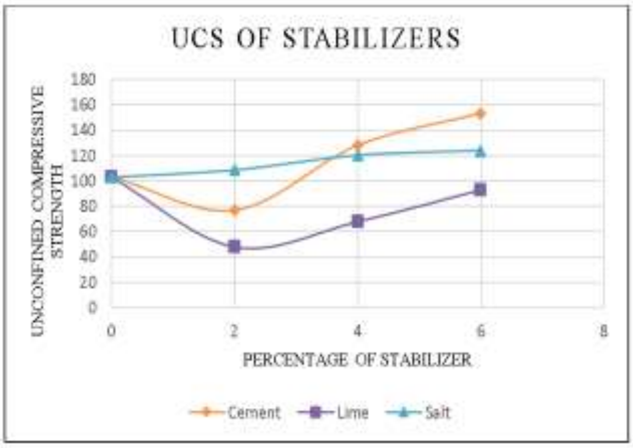

Figure 3: Average unconfined compressive strength vs percentage of stabilizer

V. CONCLUSION AND FUTURE SCOPE

From the 27 samples of stabilized fat clay that were analysed, the results have shown that cement, lime, and

salt indeed have impact to soil improvement. Free swell index (FSI) and unconfined compressive strength (UCS) correlatively shows a positive outcome with the increment of stabilizers added. The soils stabilized with cement, lime, and salt all reached their ultimate strength at 6%.
The free swell index of stabilized soil with cement, lime, and salt were 13.67%, 14.33%, and 11.00%, respectively. Among the three stabilizers, it is concluded that the salt-stabilized soil had the utmost decreased in swelling potential at 6%. The swelling potential of the soil sample was reduced up to 66.89% as compared with 58.83% for cement and 56.96% for lime. This can be concluded further that the hygroscopic nature of salt diminishes the swelling potential of clayey soil. As for the unconfined compressive strength test, the findings conclude that the cement- stabilized soil is the highest with an unconfined compressive strength of 153.33 kPa. On the other hand, the salt recorded a 124 kPa, thus making lime as the weakest soil stabilizer which only produced 93 kPa.

Lastly, the unconfined compressive strength of stabilized soil heightens while the swelling potential declines as the amount of percentage of stabilizers increases. This correlation concludes that these stabilizers are effective in soil improvement.

Finally, in order to simplify the analysis of the research, several factors are selectively disregarded. As for these limiting factors of the study, such as the effects of location, temperature, weather, and the like, a research on soil stabilization focusing on these factors on the stabilization of clayey soils is recommended for future researchers.

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AUTHORS PROFILE

Florante D. Poso, Jr., pursed BSCE in Adamson University, MCE and PhD in the University of Eastern Philippines, in 1996, 2004 & 2008 respectively. He is a Philippine registered civil engineer and registered professional secondary teacher. He had been working for more than 20 years in various fields of civil engineering both in the construction industry and in the academe. At present, working as a full-time professor of Far Eastern University (FEU) Institute of Technology. He worked with Daewoo Engineering and Construction Co., Ltd. as Civil Engineer/Quantity Surveyor for the construction of Safi Independent Power Plant Project in Safi, Morocco. He performs analysis to develop design solutions using computer softwares such as Structural Analysis Program (SAP), Structural Analysis Aided Design (STAAD), GeoSlope, Plaxis and AutoCAD2010. He worked as Design Engineer in Duqm Drydock and Shipyard Project and as Civil Engineer in Sur Independent Power Plant (SIPP) Project both in Sultanate of Oman under Daewoo Engineering and Construction Co., Ltd.

Gerardo Abestilla completed his BS in Civil Engineering and Sanitary Engineering both in the National University. He pursued his Master of Engineering at the University of Santo Tomas. He is a Lecturer of Far Eastern University, Adamson University and Technological Institute of Technology. He has a broad experience in the construction industry both as a Consultant and an Engineer.

Doreen Edsel M. Babina was born in Quezon City, Philippines in 1998. She studied at Far Eastern University – Institute of Technology and became a university scholar for two years after passing the entrance exam. She graduated in 2019 with a degree of Bachelor of Science in Civil Engineering. She worked as a Quality Control Engineer on the MRT7 Project of EEI Corporation in her internship for three months. She also worked as a freelance tutor for civil engineering students.

Maria Grelielle Bernabe., a graduate from FEU – Institute of Technology in 2019 with a degree of Bachelor of Science in Civil Engineering. She is a Philippine Registered Civil Engineer who started her professional career in a multi-disciplinary engineering company right after her university in January 2020. Her passion for design and her capacity for learning led her to acquire knowledge and skills that are vital and timely for her position in Arcadis Consulting Middle East Limited where she worked as a Graduate Structural Design Engineer for the construction of WestConnex 3B Project in Sydney, Australia. Her involvement in these projects includes the design and analysis of reinforced concrete structures using RAM and RAPT, structural steel design in Microstran and Limcon, and structural element design using excel spreadsheets.

Jane Valerie Clores graduated with a degree in Bachelor of Science in Civil Engineering at Far Eastern University – Institute of Technology in 2019. She was a class valedictorian in high school and received a full scholarship from the Scholarship for Youth and Development Program (SYDP) of the Quezon City government. She was a member of the Association of Civil Engineering Students (ACES) from 2014 to 2015 and Huwarang Mag-aaral ng Bayan (HMB) from 2014 to 2019. She did her internship at EEI Corporation for the Metro Rail Transit Line 7 (MRT-7) as a quality control engineer. She worked as a cad operator at E.H. Sison Engineers Co. for a few months. She also worked as a civil engineer at Shin Leak Construction Supply Corporation where she was involved in cost-estimation, architectural design, and structural design of residential houses. Currently, she has been preparing for the Civil Engineering Licensure Examination in the Philippines.

Joshua P. Mangila was born in Quezon City, Philippines in 1998. He studied at Far Eastern University – Institute of Technology as a scholar of SM Foundation. He graduated in 2019 with a degree of Bachelor of Science in Civil Engineering. He was a member of the Association of Civil Engineering Students in 2015. He worked for EEI Corporation as a quality control engineer on the MRT7 Project during his internship. He also worked for Shui Carbon Industrial Sales as a draftsman. His academic background and work experience involve familiarity with structural design codes and engineering-related software such as AutoCAD 2019 and ETABS 17.

