Special Issue
Sci.Int.(Lahore),29(2),201-205, 2016 ISSN 1013-5316;CODEN: SINTE 8

EFFECTS OF POFA AND LIME ON SOFT SOIL STABILIZATION

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ABSTRACT: *With the rapid development within the urban area and increase of the price of land due to demand, new development tends to move outwards nearer to the coastline area which contain soft soil. Soft soil is considerable unsafe for construction [9] with the weak physical and mechanical properties such as high water content, high void ratio, high compressibility, low shear strength, and high sensitivity [10]. Soil stabilization is the most economical way to improve the properties of the soft soil [15]. It uses additives such as Portland cement, lime, POFA, fly ash, silica fume, rice husk. Therefore, the mixture of lime and POFA with clay soil has been used for research. Four preliminary tests have been conducted which are sieve analysis, compaction test, Atterberg limit test and Pycnometer test on the clay soil. The properties of the used clay soil, had specific gravity of 2.7, plasticity Index of 9, optimum moisture content 16%, maximum dry density 1.77 g/cm^3 and 51% pass through sieve No. 200. For main test, consolidation test and compaction test on the 20% replacement of clay soil with POFA and lime with alternate 16% to 4%, till 4% to 16% ratio between POFA and lime. It is recorded that with the addition of POFA and lime as a stabilizer it slightly changes the maximum dry density and optimum moisture content. Based on the One-Dimensional Consolidation Test on the clay soil, the result shows that by increasing the lime content it shows a significant improvement on compressibility which reduction of consolidation index Cc.*

Keywords: *Lime, POFA, Stabilization, Clay, Consolidation, Compaction*

1. INTRODUCTION

There are many different types of soils, and each has unique characteristic such as texture, colour, structure, and mineral content. Soil is a form of mixture which consists of approximately 45% mineral, 5% organic matter, 20-30% water, and 20-30% of air. Malaysia has a tropical climate, with about 27 °C average annual temperatures and permanent high humidity. Due to this condition the soil in Malaysia has weak properties which make up to 70% of the 5,000 km of the coastline to have a thickness between 20 m to 40 m of soft soil. Soft soil has no secondary significance capabilities to carry additional load and it will lead to deformation if additional loads are applied. If the soil does not reach the required soil bearing capacity specification it will lead to structural settlement. Structure cracking is usually caused by soil settlement due to surcharge or change of ground water table and the lack of soil stability. By replacing original soil, soil improvement or also known as soil stabilization with the change of chemical or physical properties will gradually improve the bearing capacity [14,17]

Soils that are having high clay content have a tendency to swell when the moisture content is allowed to increase [1]. In order to stabilize the soil, chemical modification is required. To achieve stabilized condition for the strength and stiffness of the soft soil, adding sufficient amount of binders or stabilizers is required. Cement and/or lime are commonly used for stabilization purpose, but it is not always economical, especially in places where resources are scarce. Preliminary work has been conducted to exploit the used of POFA as a stabilizing agent [1]. With the use of POFA as the combined admixture it is intended to reduce the cost as well as to promote a more environmental friendly and sustainable stabilizing agent. Since the rapid increase in palm oil industry, the ash produced had become a large impact to the environment. POFA is a pozzolanic material which has properties of cement [12]. It acts as a binder between soft soil and lime. It has been found that with the proper process and ratio, the unstable soil was greatly improved. Therefore, the stabilization of soil is important in the construction field, as stabilization modifies the characteristic of soil in order to enhance the strength and durability of the soil. With the significant use of the mixture of POFA and lime will lead to the change of chemical and physical properties and increase of soil performance.

Figure (1): Location of soil sample collected at Kota Damansara, Selangor, Malaysia

2. EXPERIMENTAL DETAILS

The preliminary research methodology was divided into two parts basically to determine the physical properties and the mechanical properties of the soil retrieved beside Cova Square Lake, Kota Damansara, Selangor. All the experiment will follow the standard method [2-6] Four preliminary tests such as sieve analysis test to get the particle size and grading of soil, atterberg limit test to get the plasticity index, pycnometer test to get the specific gravity and compaction test to determine the maximum dry density were carried out. Secondly the mechanical tests such as compaction test for maximum optimum moisture content and odeometer test to get the consolidation results to compare with the POFA and lime stabilized with soil were also carried out. The combination of POFA and lime (20%-80%, 40%-60%, 60%-40%, & 80%-20%) replacement of 20% soft soil was adopted to improve the properties of the stabilized soil. Stabilization is a process of fundamentally changing the chemical properties of the soil by adding admixture or stabilizer with water to improve the strength, physical properties and mechanical properties of the soil [9]

Table (1) shows the chemical composition of POFA. Table (2) shows the chemical composition of the hydrated lime that was used in this study. Table (3) shows all the proportion percentage of laboratory experiment design that was carried out.

Table (1): Chemical composition of POFA

Composition	**Percentage, %**
Silicon Dioxide, SiO_2	65.3
Aluminium Oxide, Al_2O_3	2.6
Iron Oxide, Fe_2O_3	2.0
Calcium Oxide, CaO	6.4
Magnesium Oxide, MgO	3.1
Sulphur Oxide, SO_3	0.5
Potassium Oxide, K_2O	5.7
Sodium Oxide, Na_2O	0.3
Loss on ignition	10.1

Table (2): Chemical composition of hydrated lime

Composition	Percentage, %
Calcium Hydroxide, $Ca(OH)_2$	88.0
Magnesium Oxide, MgO	1.2
Iron Oxide, FeO	2.5
Aluminium Oxide, Al_2O_3	1.0
Silicon Dioxide, SiO_2	3.0

Table (3): Proportion percentage of lime and POFA used for clay soil

Soil, %	Lime, %	POFA, %
100	0	0
80	4	16
	8	12
	12	8
	16	4

3. RESULTS AND DISCUSSION

Physical Properties of Soil Sample

The soil sample taken was carried out with four types of physical properties experiments such as particle size distribution, plasticity index, optimum moisture content and specific gravity to classify the type of soil used before conducting the main experiment.

Pycnometer Test

At the preliminary stage of experiment, the density and void ratio of the soil sample was identified. The purpose of the preliminary test was to find the ratio of the weight in air of a given volume of a material at standard temperature. [3] was adopted to determine the specific gravity, G_s of the soil sample. Pycnometer was cleaned and dried thoroughly with the weight of empty pycnometer, W_P recorded. 10 g of dry soil sample was placed (Passed through the sieve No. 10) into the pycnometer. Distilled water was then filled to about half to three-quarter of the pycnometer and the sample was soaked for 10 minutes. After soaking, partial vacuum was applied to the pycnometer with soaked sample for another 10 minutes, so that the entrapped air in the soil is removed. The vacuum pump was stopped and carefully removed from the pycnometer. The pycnometer was filled with distilled water till the mark, the exterior of the pycnometer was cleaned and the weight of the pycnometer and the soil sample was recorded, W_B. The content from the pycnometer was removed and then the pycnometer was cleaned. The empty pycnometer was filled with distilled water to the mark on the pycnometer. The weight of the cleaned pycnometer and distilled water, W_A was recorded. The specific gravity obtained from the soil is used to calculate the phase relationship of soils, such as degree of saturation, void ratio, and density of the soil. This can be done by multiplying the soil specific gravity by the density of water at controlled temperature.

Compaction Test

The laboratory test was to determine the maximum dry unit weight ($\gamma_{d,max}$) and optimum moisture content (w_{opt}) of the soil sample and the stabilized soil that were subjected to specific compactive efforts by standard proctor (SP) compactive test. The result can be used for determining the relationship between the compaction of water content and the resulting dry unit weight of the sample that were tested. The compactive efforts was investigated with original soft soil and with admixtures stabilized soil. The obtain the result of original soft soil with admixture and without admixture. The comparison of different combination between POFA and lime within the 20% replacement in soft soil. Followed the test procedure [4] was adopted and the soil was compacted into a 22 mm (4 in.) in diameter mold in three equal layers with 25 blows from 24.4 N (5.5 Ibf.) rammer dropped from the height of 300 mm. The total compaction energy that was applied during a standard compaction test was 600 kN-m/m^3. The ratio varies with percentages based on type of soil, water ratio, chemical effect, the material used and method of preparation.

Table (4): Summary Results of Compaction Test

Sample	Maximum Dry Density (kg/m³)	Optimum Moisture Content (%)
Clay Soil	1.77	15.5
Clay 80% + POFA 16% + Lime 4%	1.715	17.3
Clay 80% + POFA 12% + Lime 8%	1.72	16
Clay 80% + POFA 8% +Lime 12%	1.73	14.8
Clay 80% + POFA 4% + Lime 16%	1.74	14

Figure (2) shows the compaction curves of the soil original sample and stabilized by POFA and lime with using different proportions of 20% replacement ratio such as (lime 16% + POFA 4%), (lime 12% + POFA 8%), (lime 8% + POFA 12%), and (lime 4% + POFA 16%). Table (4) shows the optimum moisture content and maximum dry density for the original clay sample and 20% replacement sample result. The test sample was carefully prepared by maintaining uniform density, moisture content, and curing time in order to ensure a fair assessment of the effects of the admixture on the mechanical properties.

The testing for stabilized soils was done by giving a constant period for all mixture samples prepared for stabilization reaction to take place. The treatment of samples with POFA and lime content changed the optimum moisture content and maximum dry density values of the samples. From the pattern of the graph it can be observed that the effect of POFA and lime replacement on the soft soil results in decreased in maximum dry density. With the decrease of the dry density there is improvement as compared with original sample as the decrease of dry density will eventually reduce the volume and void ratio resulting in a more compact soil. While the higher lime content gives a lower optimum moisture content and with higher POFA content it gives a higher optimum moisture content.

It is observed that with the increase of POFA and decrease of lime within the 20% replacement of clay soil the maximum dry density decreases and the optimum moisture content increases. When lime is added to the soil with the presence of water instant reaction occurred as cation exchange occurs and clay particles flocculate together. When at high moisture content, the maximum dry density is achieved and the soil is compacted to near saturation, all the air was driven out from the sample.

POFA also acts as a binder between soil and lime which flocculate and causes aggregation between the particles and gives a lower density due to replacement of soil particles with lower specific gravity material such as POFA and lime. The increase of POFA or lime leads to decrease in maximum dry density because of its low specific gravity. Although lime have a lower specific gravity compared to clay but still considerable higher than POFA which has a very low specific gravity. Therefore, the value of maximum dry density (MDD) will be manipulated by POFA rather than lime.

The optimum moisture content increases with the increase of POFA. As absorption of water in POFA is higher compared to lime and clay soil therefore the optimum moisture content increases with increase of POFA content. It is observed that with a small amount of POFA added to the soil sample the optimum moisture content decreases as POFA has a rounded surface where it increases the surface area and also increases the workability. With the increase of lime content, it will decrease the optimum moisture content due to flocculation within the particles and reduce the void and therefore decrease in optimum moisture content [11], but if the lime content is too low the flocculation between particle is insufficient therefore increase in void so the optimum moisture content will increase due to higher water absorption with the presence of POFA and leads to the increase of optimum moisture content.

From the overall observation pattern it can be determined that the optimum moisture content and maximum dry density of the sample is dependent more on POFA rather than lime. When the clay soil is dry or at low moisture content the texture is stiff and it is difficult for the particles to pack together [13]. As the water content in the soil increases the water starts to lubricant, then the particles of the soil start moving closer under a given amount of compactive effort and increased in workability. The water starts occupying the air void and thus gradual increased in dry density but as more water is added the volume of air content attains a minimum volume in the soil and thus reach an optimum moisture content, thereafter the sample will be flooded with water. With the addition of lime and POFA where POFA acts as a binder which flocculate the clay soil and lime and increase in density compare to the original sample. Therefore, when the density increases the more stable the soil.

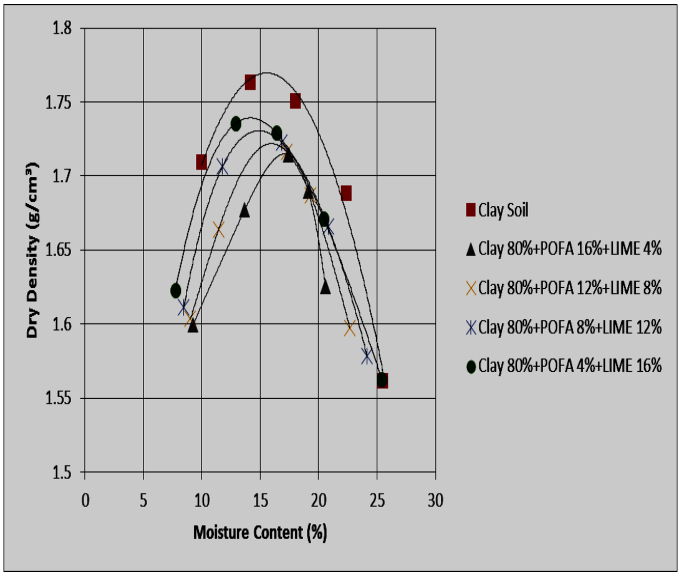

Figure (2): Compaction Curve Graph for Clay Soil and Stabilized Sample

Consolidation Test

The laboratory test was conducted to determine the soil settlement. By following the method of preparation [6] from the measured data, the consolidation (e/log σ') relationship can be plotted. The data can be used for determine the consolidation characteristics of soil such as a Compression index (Cc). The soil sample was placed inside a metal ring with porous stone at the top and the bottom of the soil sample. The ring size are 63.5 mm in diameter and 25.4 mm thick. The load applied through a lever arm and the settlement was measured by a micrometre dial gauge. The apparatus with sample was submerged with distilled water when carrying out the test. The load applied was 5 N, 10 N, 20 N, 40N, 80 N, and 160N. This has been repeated conventionally, with 5 sample prepared shown in table (3). At the end of the test, the dry weight of the sample was determined.

Table (5): Compression Index (Cc) for Clay Soil and Stabilized Sample

Sample	Compression Index (Cc)
Clay Soil	0.295
Clay 80% + POFA 16% + Lime 4%	0.174
Clay 80% + POFA 12% + Lime 8%	0.157
Clay 80% + POFA 8% +Lime 12%	0.140
Clay 80% + POFA 4% + Lime 16%	0.110

Consolidation characteristics of soil is based on the rate and amount of consolidation settlement, coefficient of consolidation, and void ratio of the sample. The compression index (Cc) is an important parameter used in geotechnical engineering as it is relates to the consolidation settlement of that soil stratum that the soil experience with the present of loads that are greater than the history [7]. Figure (3) shows the compression index (Cc) chart and Table (5) shows the actual compression index value of clay soil and stabilized sample. According to Figure (3), the bar chart shows the decreased in compression index (Cc) with the increasing of lime content. The lime content significantly improves the compressibility of clay soil by reducing the compression index (Cc) due to the pozzolanic effect of the lime and POFA. From the chart it can also be observed that lime has a better pozzolanic properties than POFA. Therefore, lime has more contribution of consolidation reduction. [8] stated that with the increases of lime content the compression index (Cc) decreases but, if insufficient lime content the change in void ratio will increase which lead to higher compression index (Cc). However, due to high replacement of admixture the compression index (Cc) does not show any increase as POFA and lime each has pozzolanic properties.

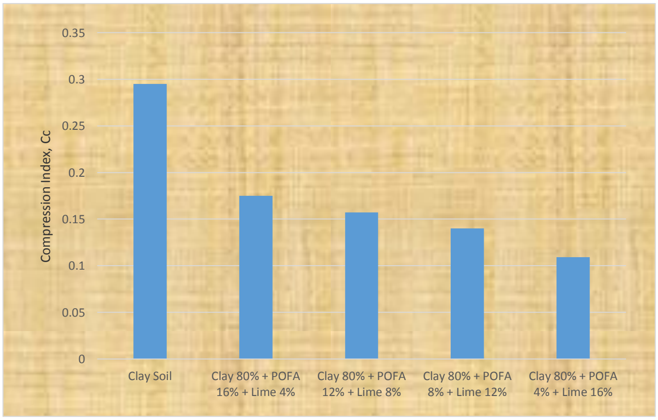

Figure (3): Compression Index (Cc) for Clay Soil and Stabilized Sample

4. CONCLUSIONS

The maximum dry density of soil decreases due to flocculation and causes aggregation between the particles by occupying larger space and the decreases of density is due to replacement of soil particles with lower specific gravity admixture [16]. The increase of POFA or lime leads to decrease in maximum dry density because of its low specific gravity than clay. The optimum moisture content increases because the water absorption of POFA is high therefore with the increase of POFA the optimum moisture content also increases. Other than that, as the lime content increases the optimum moisture content decreases due to the flocculation of clay particles with lime and reduction of the void between the particles. For the consolidation test, the lime content and POFA content helped improve the compressibility of the clay soil by reducing the compression index (Cc). While lime has more contribution of consolidation reduction than POFA due to higher pozzolanic properties of lime. With the increases of lime content, the compression index (Cc) decreases but with insufficient lime content it will change the void ratio and increase compression index (Cc) but the result shows that no increase in compression index (Cc) because POFA have pozzolanic properties which will still decrease the compression index even with low or no lime content but with lower effect on compression index (Cc) reduction.

In conclusion, the replacement of POFA and lime admixtures can be used for soft soil stabilization with sufficient reduction of consolidation and increase in the density. The recommendation of optimum replacement content is with 16% lime and 4% POFA but with either amount of ratio admixture use it will still have a significant improvement in settlement reduction. Therefore, depending on the requirement different ratio can be use with optimum efficiency. With the effective use of waste material on soft soil for stabilization will lead to more economic and environmental friendly.

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