THE BEHAVIOUR OF GRANITIC RESIDUAL SOIL WITH POFA AND LIME ADDITIVES

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PROSIDING KEBANGSAAN AWAM '07,
LANGKAWI, KEDAH (AWAM 2007)
29 – 31 MEI 2007

The Behaviour of Granitic Residual Soil with Pofa and Lime Additives

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Abstract

Granitic residual soil is well-known as having potential to shear failure. Utilization of additive is one method that can be applied to stabilize the soil. This study was conducted to determine the effectiveness of using POFA which is a local available material as one alternative in stabilizing the soil by increasing its shear strength. A series of laboratory tests were conducted in determining the physical properties, compaction and shear strength on granitic residual soil. The soil samples; both disturbed and undisturbed were obtained from the vicinity of Taman Bukit Perdana, Batu Pahat, Johor. The samples were divided into three categories for the compaction and shear strength tests; (i) origin granitic residual soil, (ii) soil + POFA (passing 425μm sieving) + lime and (iii) soil + POFA (passing 300μm sieving) + lime. The optimum percentage that yields the highest strength is at soil + 8%POFA (passing 300μm sieving) + 8%lime. All proportions are measured by weight. Analysis also shows that mixing soil with POFA and lime increasing shear strength of soil. The highest value of shear strength that was obtained from this study is 100.55 kPa. Permeability tests have shown that the value of k in the range of 1.1689 x 10^{-6} to 1.9956 x 10^{-7} m/s were produced from mixture with the percentages of 8 % POFA and the size of 425 μm + 8% lime. Besides that, mixtures with POFA 8% (300 μm) and 12% (300 μm and 425 μm) also substantially reduced the k value which is suitable for the construction of earth dam core.

Keywords: Granitic Residual Soil, Palm-oil Fuel Ash (POFA), Lime, Compaction, Direct Shear Test, Shear Strength, Permeability

1.0 Introduction

Granitic residual soils, originated from granitic parent rocks, are widely distributed in Malaysia. Granite family rocks occupy almost half the surface area of the Peninsular Malaysia (Todo and Pauzi, 1989 in Aminaton Marto *et al.*, 2002). Figure 1 shows the distribution of granite rocks in Peninsular Malaysia.

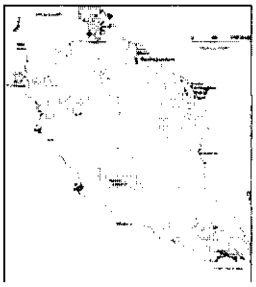

Figure 1: Distribution of granite rocks in Peninsular Malaysia
(Komo in Aminaton Marto *et al.*, 2002)

Residual soils in Southern Peninsular Malaysia are classified as Sandy Clay (SC) or Sandy Silt (SM). These soils are generally partially saturated. The strength of these soils comprises elements of cohesion, matrix suction and particulate bonding. When these soils become wet, matrix suction and bonding can be lost and failures occur (Aminaton Marto *et al.*, 2002).

The increasing number of construction sites in the area of granite residual has caused difficulties to engineer to design their building as they are facing the potential shear failure. Many geotechnical problems and failures such as slope instability and failure in foundations occur in residual soils (Mohd Raihan, *et al.*, 1997). In addition, it is beneficial to make use of local available material as one alternative of soil stabilization to increase the shear strength of the soil.

This paper presents physical properties of the granitic residual soil, the analysis of shear strength and the varying percentages of potential lime additives in producing the optimum mixture that produces the highest shear strength.

The effect of POFA mix with residual soil on the permeability of residual is also studied. The modified material is mixed with certain percentages of POFA and dehydrated lime. Disturbed soil samples will be used and by-weight method of mixing as well as air-cured. This modification is expected to decrease the permeability of residual soil and to reduce the compressibility of residual soil.

2.0 Laboratory Investigation

The scope of this study is to focus on the effect of soil strength properties and shear strength of granitic residual soil when mixed with POFA and lime. This study is carried out based on the shear strength parameters such as phi (ϕ) and cohesion (c) from all samples based on percentage POFA and lime. Shear strength value can be obtained from equation (1).

$$\tau = c + \sigma_n \tan \phi \qquad (1)$$

In order to achieve the objectives, scopes of study has been stipulated. The material tested for this study was granitic residual soil. The soil was taken from Bukit Perdana, Batu Pahat with the depth of 0.3m below the surface layer. Soil sample were taken in the form of disturbed and undisturbed by using box sampler method.

The additive materials used in this research consist of palm-oil fuel ash and lime. Palm-oil fuel ash known as POFA is the farm ashes produced from the remains of the palm oil bunch burned in a furnace. According to Awal and Husin (1997), POFA is a waste material obtained by burning of palm oil husk and shell as fuel in palm oil mill boilers. POFA has pozzalanic characteristics, which enables it to be a stabilizer but due to its large particle size and porous structure, POFA has low pozzalanic reaction (Sata *et al.*, 2004). However, according to Husin and Awal (1996) and Sukuntapree *et al.* (2002) and Sata *et al.* (2004) the pozzolanic reaction of the POFA can be improved by grinding.

In the study, the stockpile ash was collected from a palm oil factory at Semenchu, Kota Tinggi, in the state of Johor. The POFA sample was air dried and any large foreign materials are manually removed. It was then ground to finer particles in a Los Angeles abrasion machine at full cycle and sieved through a 425μm and 300μm sieve. POFA were tested for specific gravity to make comparison to previous research and between different sizes.

The type of lime used in this study is hydrated lime. The use of hydrated lime as compared to quick lime is because hydrated lime is a fine powder and less caustic (Little, 1995 in Bambang, *et al.*, 2004). The percentage of mixture used in this research is shown in Table 1.

According to Bowles (1986), if fly ash is used with lime (or cement), it is usually held to a constant ratio. Admixtures percentage for cement is in the range of 3 to 12 percent for A-1 through A-4 soils while lime-fly ash (LFA) between 12 to 30 percent with larger percentage for poorer soils (Bowles, 1986).

Table 1: Percentage admixture used in research

Sample (Soil+POFA+Lime)	
POFA (%)	LIME (%)
4%	4%
	6%
	8%
8%	4%
	6%
	8%
12%	4%
	6%
	8%

The admixture sample (soil+POFA+lime) were air-cured for 2 days. Besides 2 days, the curing time was also done in 7 and 28 days (Bowles, 1986).

The physical test such as Atterberg limit, moisture content, particle size distribution and specific gravity of the soil were performed according to British Standard (BS 1377:1990). The data of these index properties were used to classify the soil in the Unified Soil Classification System (USCS).

This pozzolanic substance will react with cement or lime to show its cement like characteristics, which enables it to bond together with other materials. Many researches regarding POFA were done by blending POFA with concrete or soil to see a more positive POFA mixture effect. The Palm Oil Fuel Ash (POFA) can be classified as class F according to ASTM C 618:1984 (Abu, Z, 1990), because of the following:

i) POFA was not made naturally but easily created from furnace burning in the factory, different from natural flying ash such as volcanic flying ash.

ii) POFA when on its own or when not added with other substances like water and lime, cannot show its cement like bonding characteristics.

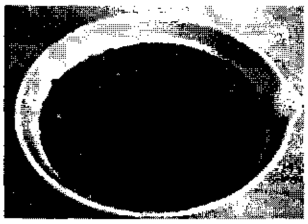

Figure 2: Palm Oil Fuel Ash

Compaction tests were conducted using standard proctor test (BS 1377: Part 4: 1990:3.5) using 2.5kg hammer 27 blows per layer with 3 layers. Soil density can be altered by compaction to control and improve other engineering properties such as compressibility and strength. The purpose of doing this test is to get optimum moisture content and maximum dry density for the granitic residual soil and optimum moisture content for every mixing sample (soil+POFA+lime) with their percentages and 95% from their maximum dry density (based on JKR standard) to make the sample for direct shear test.

Granitic residual soil strength was determined using direct shear test in accordance with the BS 1377: Part 2 procedure. The test was performed on square specimens having dimension 60mm x 60mm x 20mm. The samples were tested in direct shear test machine and will be compressed with three different loads that were 1.25kg, 2.50kg and 3.75kg (normal load). In the shear box test, the specimen is consolidated prior to shearing and slow rate of displacement was applied during shearing. Specimens will fail under the increment of normal stress and at a particular value of shear stress. Figure 3 shows the digital laboratory direct shear test equipment.

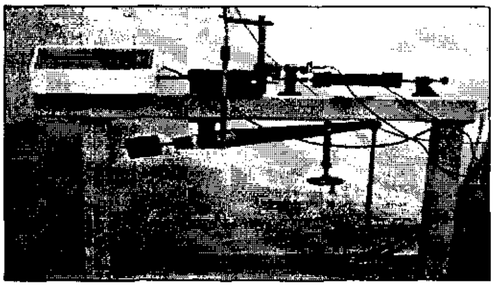

Figure 3: Laboratory direct shear test equipment

All the data collected from the test was analyzed using the ELE International analysis. The parameters that were obtained from the analysis is cohesion(c) and angle of shear resistance (ϕ).

The sampling methods and tests used in this research are; Sampler Box Method (site), Core cutter sampler, Proctor Test (compaction) and Falling Head Test (permeability)

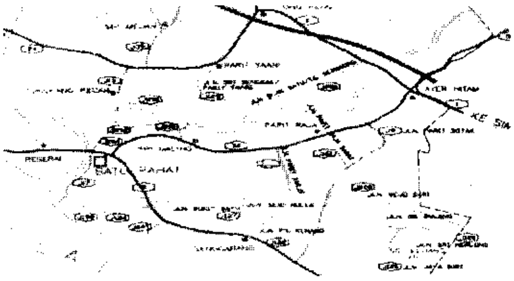

Figure 4: The location of sampling

Figure 5: The sampling area

All disturbed samples were taken at 0.3m depth at 3 different locations by means of hoe equipment. Plastic packages were used to carry sample from the site. Table 2 show the sampling station of these studies.

Table 2: Location sampling station

Location	Sampling station	Depth (m)
Taman Bukit Perdana	TBP 1	0.3
	TBP2	
	TBP 3	

The undisturbed sample used in this study was taken by block sampler and core cutter.

3.0 Results and Discussion

3.1 Soil Index Properties

Typical particle size distribution curve are shown in Figure 6. The percentages of gravel, sand, silt and clay are 8-13%, 33-36%, 17-19.5% and 34-36% respectively. The soil can be classified as CH-MH. The results obtained from the Atterberg limit test are liquid limit (LL) = 53.3%, plastic limit (PL) = 38.2% and the plasticity index (PI = LL - PL) = 15.1%.

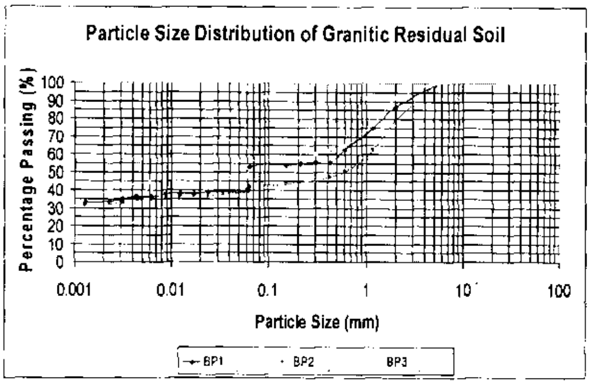

Figure 6: Grading curves of specimens from Bukit Perdana, Johor samples

3.2 Specific Gravity of Residual Soil

The specific gravity value of granitic residual soil is 2.68 while the moisture content of soil is 23.78%. The difference in value obtained from this study with previous study is probably due to the weathering process by which the structure of residual soil breaks down easily (Marto *et al.*, 2002). Therefore, consistence results are difficult to achieve.

3.3 Specific Gravity of POFA

The specific gravity of POFA is 2.25 (sieve passing 300μm) and 2.35 (sieve passing 425μm). The value of POFA is different because of the different particle sizes and porous textures. Table 3 shows the comparison of specific gravity value of POFA with other researchers. It shows the range of the specific gravity between 2.22 – 2.64.

Table 3: Comparisons of specific gravity value of POFA with other researchers

Location	Specific Gravity,Gs
Bukit Lawang *(Osman, S.,1991)*	2.64
Banting *(Osman, S., 1991)*	2.40
Bukit lawang *(Abdul Awal, A. S.M. and Hussin, M.W. ,1997)*	2.22 (sieve through 300μm)
Southern Part in Thailand *(Sata, et.al.,2004)*	1.97
Kluang *(Wan Hashim, W.A., 2005)*	2.40 (sieve through 425μm)

3.4 Compaction Test

Compaction studies are used to determine the optimum moisture contents for a specific compaction where by the field compaction moisture contents selected. For this research, standard proctor compaction was used. The results of the compaction tests are shows in Figure 7.

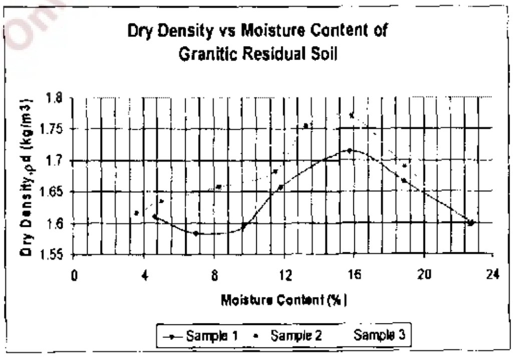

Figure 7: Results of standard proctor compaction for three samples of residual soil (with no additives)

Figure 7 shows the compaction soils curve. From the graph, maximum dry density, ρ_{dmax} are in the range of 1.715-1.775kg/m^3 and the optimum moisture content is between 15.2-15.8%. The values are used as guidelines to make samples for direct shear testing.

Table 4: Data from compaction test

State of compaction	Max. dry density, (kg/m3)	Opt. moisture contents (%)
Residual soil	1.742	17.68
4%P(425µm) + 8%L	1.880	28.16
8%P (425µm) +8%L	1.820	23.46
12%P (425µm) +8%L	1.840	27.27

The result of mixing POFA is shown in Figure 8. The result shows the percentage with the highest dry density for compaction test.

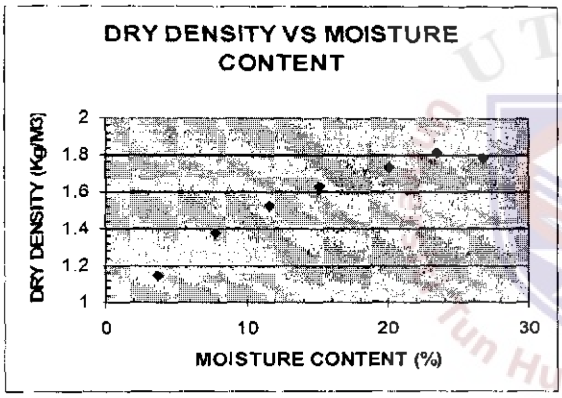

Figure 8: Result of Mixing 8%P (425 µm) + 8%L

3.5 Direct Shear Test

Direct shear test were conducted to observe the shear strength of a soil when it fails due to water infiltration under a relatively high shear stress condition. The granitic soil through sieve size 4.75mm was used to get uniform specimen for this testing. Figure 9 shows the results of direct shear test for the origin soil. The strength parameter of soils; phi, θ° and cohesion, c determined from direct shear stress is 20.61° and 17.004.

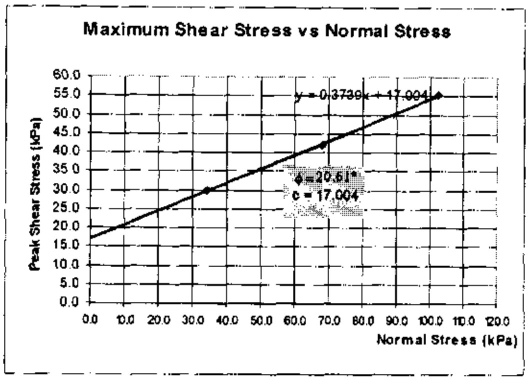

Figure 9: Results of direct shear test for granitic residual soil (with no additives) at Bukit Perdana, Batu Pahat.

Figure 10 and 11 show the increment of percentage different size of POFA versus shear strength on percentage lime. Both graphs show the maximum increment on admixture samples on the percentage 8%P+8%L. Uses of 8% lime to increase the shear strength is proven by previous research (Novial, 2000). However, the increasing percentage of POFA did not show the increment of shear strength. It is because the increasing additive material in a large amount have overcame soil weight in this test and seemingly lower the reaction rate as at the right side of the curve.

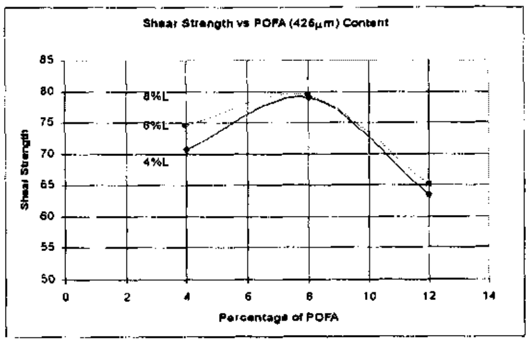

Figure 10: Percentage POFA through 425µm sieving versus shear strength on percentage lime

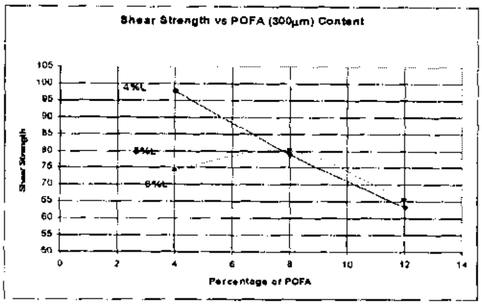

Figure 11: Percentage POFA through 300µm sieving versus shear strength on percentage lime

Figure 12 and 13, shows the comparison of maximum shear strength values of the sample for each different size of POFA particles. For the comparison of maximum shear strength of every sample with different size of POFA particles, the results are shown in Figure 14.

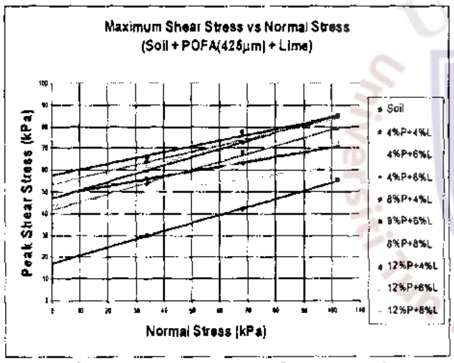

Figure 12: Shear strength for admixture with POFA(425µm)

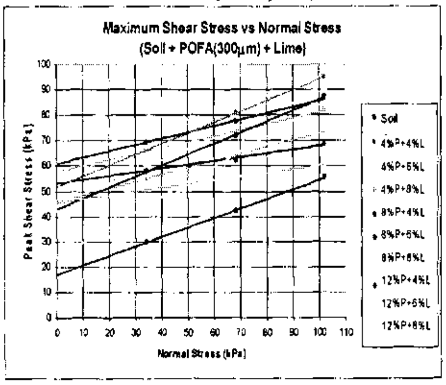

Figure 13: Shear strength for admixture with POFA(300µm)

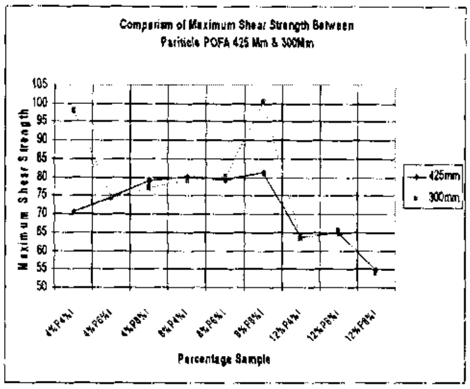

Figure 14: The results of Maximum Shear Strength between different sizes of POFA.

From the analyzed data, optimum admixture sample to increase the shear strength is in percentages of 8% POFA and 8% lime in both size of POFA. These percentages show the shear strength increment compared with the origin soil's shear strength, Figure 9. Pozzolanic characteristics in POFA have been proven in the increase of soil shear strength and the potential of its being the stabilization agent for the soil. However, the maximum shear strength value for the test is found for POFA particles size of 300µm, Figure 11. The fact has been proven by Husin and Awal (1996) Sukuntapree *et al.* (2002) and Sata *et al.* (2004).

3.6 Permeability

The permeability was determined by mean of falling head permeability test. The soil was compacted at its optimum moisture contents of 17.68%, Table 5 and Table 6 show the array value of permeability of soil mixed with POFA and lime at the predetermined percentages.

Table 5: Permeability of soil and soil mixed with POFA and lime at certain percentages.

Sample	Permeability, k (m/s)
Original Soil	6.0242×10^{-6}
4%P (425μm) + 8%L	1.1689×10^{-6}
8%P (425μm) +8%L	1.9956×10^{-7}
12%P (425μm) +8%L	2.2715×10^{-7}

From the table, the optimum percentage of POFA and lime are 8% where the permeability was reduced until 10^{-7} m/s. Therefore, this result shows that POFA and lime with this percent can be used as being embankment core earth dam.

Table 6: The typical values of the permeability coefficient, *k* on various soil types (Lambe and Whitman, 1969)

Soil	Permeability Coefficient, *k* (m/s)	Relative Permeability
Coarse gravel	$>10^{-1}$	High
Sand, clean	10^{-1}-10^{-3}	Medium
Sand, dirty	10^{-3}-10^{-5}	Low
Silt	10^{-5}-10^{-7}	Very Low
Clay	$<10^{-7}$	Practically impermeable

4.0 Conclusion

POFA, the available local material has the ability as an additive material in soil stabilization. According to direct shear test, the optimum percentage mixing sample is 8% of POFA and 8% of lime on POFA particles passing 300μm sieving. Values of shear strength of the mixed soil sample had been compared with the shear strength of original soil sample and it shows the increment in shear strength in every sample.

The result from this research shall give much benefit to all engineers especially for the construction industry which are facing with the problem of stabilizing granite residual soil.

The desired end-result of using the mixture of POFA-lime with residual soil in reducing the permeability of the soil is achieved. Further research on establishing the correlation of the soil – POFA – lime needed to be continued. This hopefully could lead to the new invention of construction material in the future.

5.0 Suggestion and Recommendation

Soil samples taken at depth of more than 0.3m, i.e. at the depth of 1.0m, 2.0m or 3.0m would reduce the *k* value to a desired value (such as $k < 10^{-8}$ m/s).

The varying of POFA percentages and types of soil needed to be studied to gather more information on the correlation of POFA – lime – soil. More data can be compiled for future references. The mixture with the value of reduced k shall be used as input for PLAXIS modeling of the earth dam with impermeable core.

Further research on POFA-lime-residual soil mixture should be done in improving its shear strength. This will enable them to be used as a column in improving the stability of residual soil slope. Modeling using software on the slope W would show some improvement on its factor of safety.

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