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THE CHEMICAL PROPERTIES OF SOFT CLAY IN KUiTTHO AT SOUTHERN PENINSULAR MALAYSIA

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ABSTRACT

Geoconstruction element especially buried structures like concrete footings and foundation can be affected by chemical reaction involving sulphate, chloride, ammonium, and others element that present in high concentration in clay along with a source of moisture. The sulphate will reacts with cement within concrete causing it to expand, crack and resulting disintegration failure. The recent evidence of this harmful chemical attack is the Middle Ring Road 2 (MRR2) incidence in Kuala Lumpur. The remedial action to sulphate attack is normally to remove all the defective concrete and contaminated hardcore and replace them which is a disruptive and costly process. This paper has reviewed on some major chemical properties of clay soil in KUiTTHO for the suitability for geoconstruction. The chemical properties that have been determined were cations (calcium, natrium, magnesium, and kalium), anions (sulphate, chloride), pH, soil organic matter (loss on ignition and organic content), cation exchange capacity and conductivity. The entire chemical laboratory tests were conducted based on BS 1377. The soil sample was taken at depth 0.5 m to 5.5 m from RECESS. The results obtained are pH ranged from 2.87 to 7.11; conductivity ranged from 1446 µs/cm to 1786 µs/cm; loss on ignition ranged from 4.76 % to 11.68 %; organic content ranged from 4.47 % to 9.22 %, sulphate content ranged from 0.55 % to 1.00 %; chloride content ranged from 0.64 % to 0.97 %; kalium content ranged from 0.57 % to 2.67 %; magnesium ranged from 0.15 % to 5.16 %, calcium content ranged from 0.1 % to 5.4 %; natrium content ranged from 0.01 % to 0.13 %; and cation exchange capacity ranged from 4.86 meq/100g to 36.21 meq/100g. The sulphate-attack test was carried out on concrete cubes by expose to the sulphate solution that prepared in accordance to sulphate concentration of KUiTTHO clay. From the chemical testing, the results shows that KUiTTHO clay are categorized as DS-3 (design sulphate class) in accordance to BS 8500-1:2002, Hence, the minimum cement or combination content of dense fully compacted concrete for foundation design are ranged from 340 kg/m^3 to 400 kg/m^3.

***Keywords**: sulphate, chloride, chemical concentration, anion, concentration.*

INTRODUCTION

Peninsular Malaysia lies in a tectonically stable region known as the Sundra Land (Tjia, 1980). About 20 % of the area is occupied by soft clay (Aziz, 1993). There are extensive deposits of very soft normally consolidated marine clay in both East and West Malaysia (Pitts, 1983). Soft clay is found e.g. along the west coast of West Malaysia at Johore, Malacca, Port Klang, Penang, and Alor Setar, where locally depth may even exceed 40 m. Normally the thickness is 5 m to 20 m. The water content of the soft marine clay is generally high. Typically about 60 % to 80 % while undrained shear strength is low. It increases approximately linearly with depth from about 7 kPa to 12 kPa close to the ground surface.

Clay is known as one of the most problematic soil in construction field and requires special geotechnical consideration and treatment as well as ground improvement. According to Unified Soil Classification System (USCS), clay's particle diameter is less than 2.0 µm. Clay particle shaped like flakes and makes their aggregate surface area much greater than their thickness and allows them to take up large amounts of water. Depending upon the rock materials from which they were derived, clay's assorted mineral particles ultimately release the chemicals

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on which plants depend for survival, such as kalium, calcium, magnesium, phosphorus, sulphur, ferum, and manganese. The chemical compound may be varying depending on location.

Researchers like Ting and Ooi (1977), Abdullah and Chandra (1987), Kobayashi, *et al.* (1990), and others have carried out a review of the chemical properties of Malaysia soft soil. The chemical properties obtained included chloride, sulphate, carbonate, pH and organic content.

Generally, the soil physical parameters were the main parameter in designing the building foundation or during the site investigation. While, the chemical aspect is less considered and geochemistry research is seldom touched since the chemical composition is not playing role. However, high density of chemical content in soil is able to gradually deform the concrete structure, which constructed or drove into ground. Sulphate-attack is one of the most common aggressive actions leading to the deterioration of concrete. The large number of concrete structures that have degraded prematurely over the last forty years has shocked structural engineers who had previously been of the opinion that reinforced concrete was maintenance free.

The soil sample will be taken from Research Centre for Soft Soil, RECESS, which is a new Research and Development (R & D) initiative by University College Technology of Tun Hussein Onn (KUiTTHO).

BACKGROUNDS AND LITERATURE REVIEWS

The proportions between the mineral and organic components in soils can vary widely. The very fine clay soil can contain up to 95 % of organic matter. Variations in the chemical composition of clay soil result mainly from variability in the ratio of the mineral and organic matter contents in soils and from variability of the types of compounds comprising the mineral faction. Only the eight elements oxygen, O; silicon, Si; aluminium, Al; ferum, Fe; calcium, Ca; magnesium, Mg; natrium, Na; and kalium, K occur at concentrations exceeding 1 % in the earth crust, and they are always classified as major elements. The concentrations of elements in soils are usually based on the mass of the soil, even though the solid phases (mineral and organic) make up only about one-half of the soil volume. The others half of the soil volume is occupied by the soil solution and air.

There are 10 most abundant elements that can be obtained in most dry soils are oxygen, O; silicon, Si; aluminium, Al; ferum, Fe; calcium, Ca; magnesium, Mg; natrium, Na; kalium, K; titanium, Ti and carbon, C. The reason that these elements are the most abundant in soils and rocks become very clear when one considers the nuclear processes responsible for the formation of the elements and their subsequent fractionation by chemical and physical processes. Over 99 % of the total atoms in the universe are hydrogen, H atoms (Ross and Aller, 1976).

Determining the concentration of elements in soils is not a trivial endeavour. Soils are mixture of inorganic and organic compounds that have refractory and volatile properties. Some of these compounds resist dissolution by simple treatments with strong acids or oxidizing agents. Special care must be exercised to ensure that the soil samples are completely dissolved in preparation for analytical procedures that require aqueous samples.

EXPERIMENTAL PROGRAM

Geotechnical investigation programme was planned and executed. For the present study, the soil samples were collected from a clay soil area within RECESS KUiTTHO, Batu Pahat, Johor. Undisturbed sample were obtained from a depth 0.5 m to 5.5 m below ground surface by using hand auger with 100 mm thin wall tubes. The soil sample was treated before all chemical testing.

The study of chemical properties includes determination of loss on ignition (LOI), organic content (OC), soil conductivity, acidity or alkalinity (pH), cation exchange capacity (CEC), anions content (sulphate, chloride) and cations contents (kalium, magnesium, natrium and calcium). All the tests were conducted by referring to the procedure as explained by Head (1992) and in accordance with BS 1377 (1990).

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RESULTS AND DISCUSSIONS

The results obtained are discussed as below. Analysis of comparison was done according to the findings from previous researchers who had conducted the similar research. Table 1 tabulated the soft clay chemical properties obtained by various researchers; Table 2 tabulated the chemical testing results of KUiTTHO soft clay.

Table 1: Chemical Properties of Malaysia Soft Clay from Past Researchers

	Organic Content (%)	**Salinity (gm/L)**	**Chloride Content (%)**	**Sulphate Content (%)**	**Carbonate Content (%)**	**pH**
Ting & Ooi (1977)	1 – 17	20 - 40	-	-	-	-
Abdullah & Chandra(1987)	1 - 22.5	13.7	-	-	-	3.0 - 8.0
Kobayashi, *et al.* (1990)	-	-	0.05 - 0.70	0.03 - 0.90	-	5.3 - 8.2
Aziz (1993)	0.3 – 20	-	0.01 - 4.50	-	-	4.0 - 8.5
Nicholls & Ho (1990)	-	0.01 - 43	-	-	-	-
Hussein, *et al.* (1996)	2 – 15	24 - 38	0.01 - 0.03	0.10 - 1.70	13.5-22.0	5.0 - 9.0
Khairul Nizar, *et al* (2006)	4.5 - 9.2	-	0.64 - 0.97	0.55 - 1.00	-	2.87 - 7.11

- : No research has been conducted

Table 2: Chemical Properties of KUiTTHO Soft Clay

Depth (m)	**0.5 – 1.5**	**1.5 – 2.5**	**2.5 - 3.5**	**3.5 - 4.5**	**4.5 -. 5.5**
pH	2.87	3.95	6.89	7.11	6.56
Conductivity (µs/cm)	2.69	1707.50	1676.67	1780.17	1446.00
LOI (%)	11.68	9.61	8.64	7.48	4.76
OC (%)	9.22	6.89	6.26	6.09	4.47
SO_4^{2-} (%)	1.000	0.83	0.55	0.70	0.72
Cl^- (%)	0.642	0.97	0.76	0.96	0.90
K^+ (%)	2.667	2.45	2.20	1.62	0.57
Mg^{2+} (%)	0.145	1.30	2.69	3.07	5.16
Ca^{2+} (%)	0.100	2.65	2.89	3.88	5.35
Na^+ (%)	0.079	0.01	0.03	0.04	0.13
CEC (meq/100g)	4.86	15.79	21.85	25.16	36.21

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pH

One other critical soil chemical properties are the acidity and alkalinity. The concentration of hydrogen ions, H^+; and hydroxyl ions, OH^- in the soil are commonly ascertained by measuring the pH. From Table 1, it shows values of some chemical properties of soft soil in Malaysia, which pH were ranges from 2.87 to 9.00. From the Table 4.2, it can be observed that the pH values of top soil are acidity. The values of the pH are increasing to the depth. Soil with lower pH value than 3.5 can be categorized as acid sulphate soil (Shamshuddin, 1983). At depth of 2.5 m, the value is slightly to become neutral which 6.89. The further increasing in depth has showed the alkalinity values, which is 7.11 for the depth of 3.5 m to 4.5 m. As can be seen from the Table 2, the bottom layer of this research has give 6.56 of pH value.

The pH values were ranged from 2.87 to 7.11. This result is quite similar to pH results which have been carried out by Abdullah and Chandra (1987). The pH values of this research were found to lie within the range of other published data obtained from various researchers. Figure 1 show a correlation between pH values and depth and it could conclude that the pH values increase with depth. This is due to the upper depth were exposed to the air and heat, and more dissipation of water were lost.

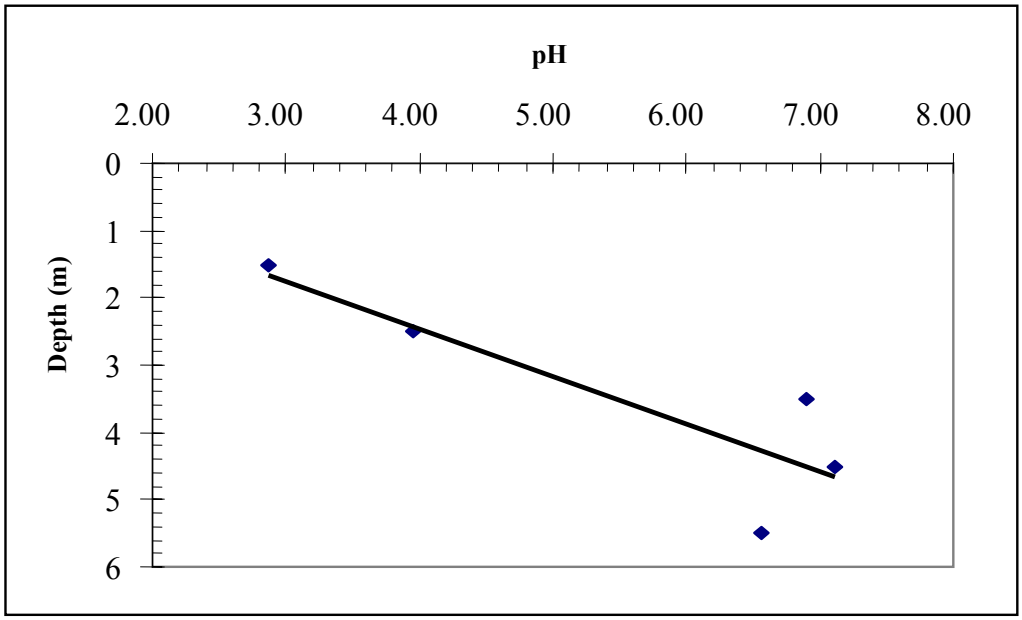

Figure 1: Correlation between pH and Depth

Conductivity

Conductivity is a measure of an ability of a solution to conduct an electrical current and is proportional to the concentration of ions in the soil solution. The values of the conductivity test are within the range of 2.69 to 1780.17 µs/cm. From the results, it can be noticed that the top soil's conductivity are very low. From depth 1.5 m onward, the conductivities obtained more than 1000 µs/cm. The values of the conductivity for depth 1.5 to 2.5 m, 2.5 to 3.5 m and 3.5 to 4.5 m are close; it is 1707.50 µs/cm, 1676.67 µs/cm and 1780.17 µs/cm, respectively. The lowest layer that is 4.5 m to 5.5 m from ground surface has average conductivity values of 1446µs/cm. The results of conductivity test are tabulated as Table 2. From Figure 2, its shows that the conductivity concentration decreases with depth.

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The increasing of the conductivity to the depth means the lower soil layers contain high amount of ions, the higher amount of ions, the higher the ionic mobility and the magnitude of conductivity. The researcher found that the concentration of kalium and magnesium of bottom layers of soil are higher than top soil, this phenomena contribute to the higher conductivity at these layers. Because of smaller pore sizes in soil when increasing the POC additive percentages, the passage of certain ions through the soil particle may be increased. Hence the values of conductivity increase.

Loss on Ignition

The mass lost from a soil on ignition is related to the organic content of soils such as sandy soil containing little or no clay chalky material, peats and clays containing more than about 10 % of an organic matter. In the test, the carbon burns to combine with oxygen forming carbon dioxide, and other constituents of the organic compounds break down.

From the Table 2, it can be noticed that the top soil have the highest percentage of organic matter which is 11.68 % of soil mass. The values are decreasing to the depth. The second layer reported 9.61 % of organic matter following by 8.64 % at 2.5 m to 3.5 m. For depth 3.5 m to 4.5 m, the values obtained from loss on ignition
testing are 7.48 %. The depthest layer, which is 4.5 to 5.5 m, has the lowest percentage of organic matter, which is 4.76 %.

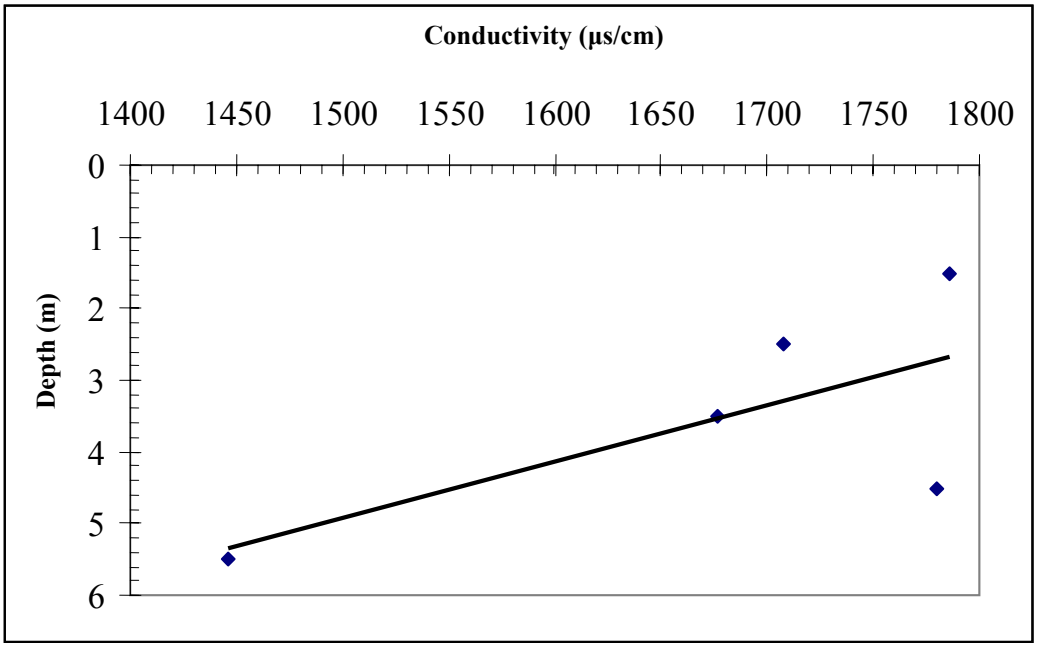

Figure 2: Correlation between Conductivity and Depth

The top layer contains more organic matter than others layer, it may be caused by the palm oil plantation duff, where the trunk and leaf are fall on ground to naturally rotted to provide nutrient. Form Figure 3, the coefficient of determination is very high.

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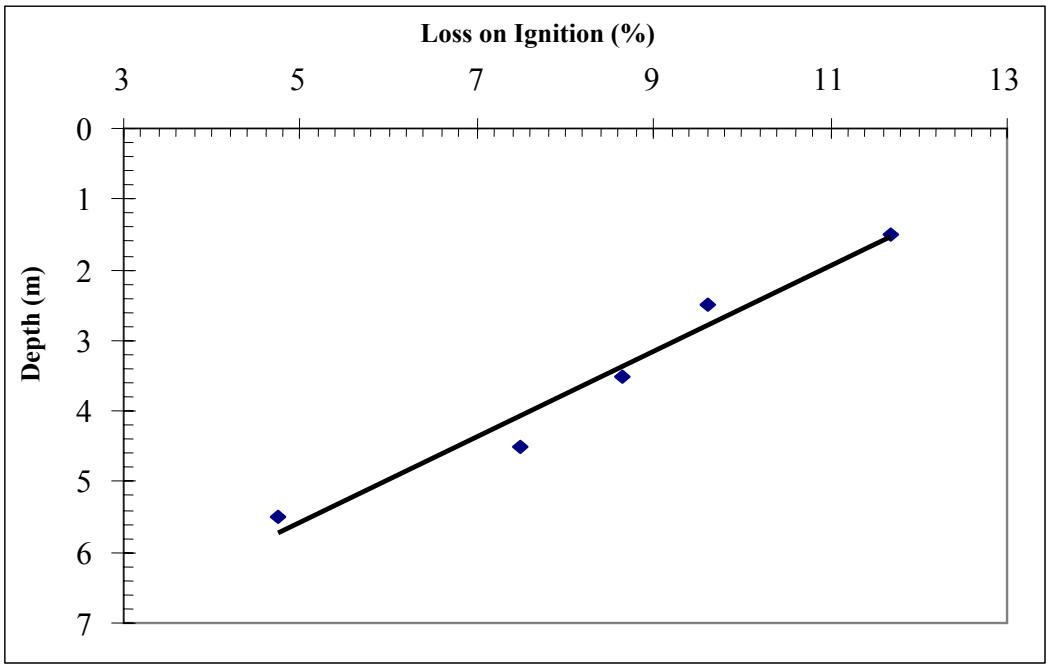

Figure 3: Correlation between Loss on Ignition and Depth

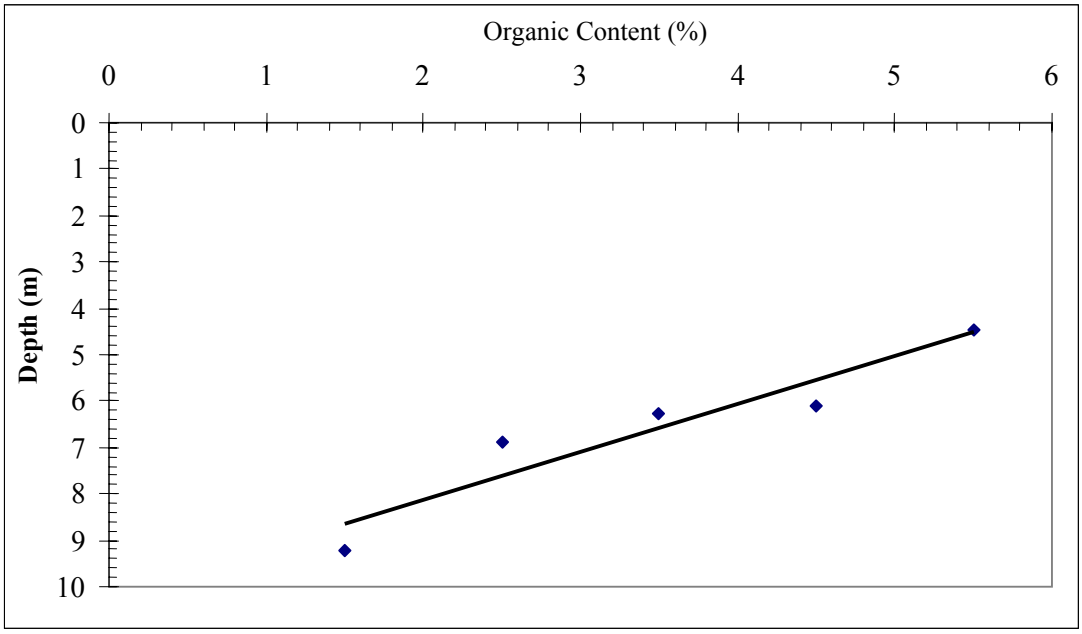

Figure 4: Correlation between Organic Content and Depth

Organic Content

The results of organic content determination testing are tabulated as Table 2. From the data, it can be observed that top layer has higher value of organic content. The first layer has detected 9.22 % of organic content. The last layer has 4.47 % in organic content. The percentages of the organic matter are decrease to depth, as obtained from loss on ignition test. It can be observed from Figure 4. The top layers are containing high amount of organic matter than

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lower layers. At the top layer, the activities of palm oil tree have contributed to the high organic matter. The palm oil plantation production takes large amounts of atmospheric carbon in photosynthesis are sequestered in the abundant plant tissue, which eventually become part of soil organic matter. The fall leaf also contributed to the amount of organic matter, where the trunk and leaf are cumulated on ground to naturally rot in order to provide nutrient for palm oil trees.

Anions

There concentration of anion that is sulphate, SO_4^{2-} and chloride, Cl^- were tested in this research. Referring to Table 2, the range of the sulphate content is within 0.55 % to 1.00 %. It is almost the same with sulphate percentage obtained by Kobayashi, *et al.* (1990) and Hussein, *et al.* (1996).The former reported sulphate content is within 0.03 to 0.9 %. The latter results are much higher in range, which is 0.1 % to 1.7 %. It can be said that the top soil of KUiTTHO clay consist more sulphate ion. The values of sulphate are decreasing to depth (Figure 5).

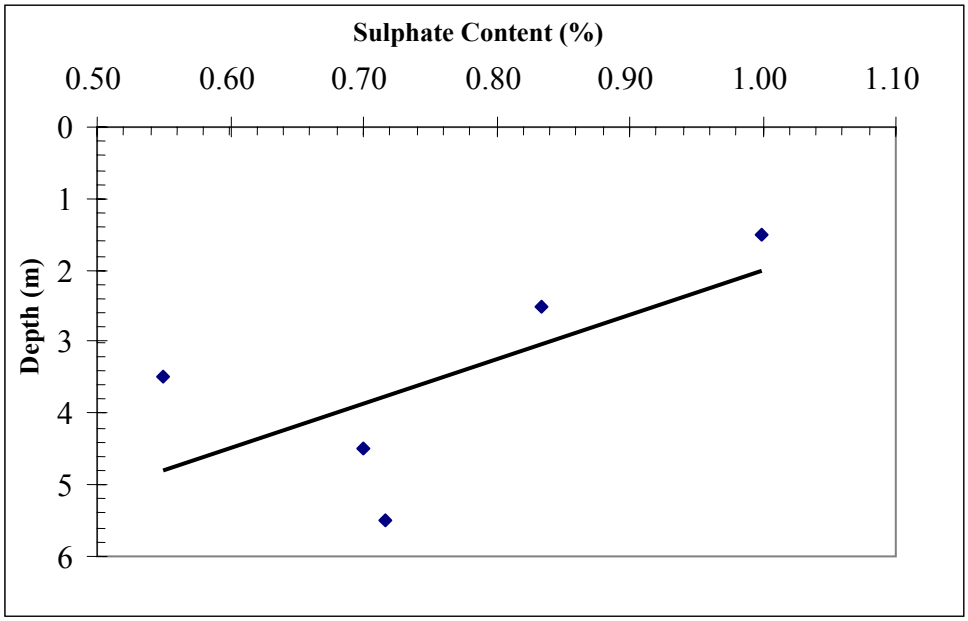

Figure 5: Correlation between Sulphate Content and Depth

The sulphate content at the site may contributed by fertilizer used for palm oil plantation. The fertilizer may contain of polysulfides, thiosulfides or bisulfides. When these compounds are oxidized, it will become sulphate and remain in soil. Equation 4.1 shows the oxidation reaction.

$$H_2S + 2O_2 \rightarrow H_2SO_4 + SO_4^{2-} \qquad (4.1)$$

where;

H_2S: Hydrogen Sulphate.
O_2: Oxygen.
SO_4^{2-}: Sulphate.

The overall concentration of chloride is below 1.0 %. The first layer below the top soil has reported has 0.642 % in chloride. The second layer that is 1.5 m to 2.5 m has 0.97 % chloride content per dry mass. Following by third layer that is 2.5 m to 3.5 m, it has 0.76 %, is slightly lower than upper layer. The last two layers have 0.96 % and 0.90 %, which is 3.5 m to 4.5 m and 4.5 to 5.5 m, respectively. The chloride content determination results are tabulated as Table 2. From Figure 6, it can be observed that the chloride content is decreasing to the depth.

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Cations

There are four major cations in soil. They are calcium, magnesium, natrium and kalium. Calcium and natrium are most consistently affects the dispersion. The results for cation determination test are tabulates as Table 2, where the kalium percentage of dry mass is around 0.567 % to 2.667 %. The layer below top soil has more kalium content compare to lower layers. However, magnesium has different pattern in percentage; the first layer below top soil has the least percentage in magnesium content, while the percentage of magnesium is increasing to depth. The maximum percentage is 5.163 %, which detected at lowest layer at 4.5 m to 5.5 m.

The calcium concentration pattern is same as kalium; the percentage is increasing to depth. The first layer contain least percentage compare to the bottom layer, the former is 0.1 % while the latter is about 5.353 %. For natrium content, the first layer has 0.079% of natrium, following by second layer with 0.010 % and third layer 0.030 %. The last two layers contain 0.044 % and 0.128 % of natrium.

Cations Exchange Capacity (CEC)

Clay minerals have high negative charges, which make most of the clayey soil exhibit the properties of cation exchange. Three main types of surface charge in soils are isomorphic substitution or crystal lattice defects in the internal structure of the mineral, ionic dissolution on surfaces of soil colloids, and ionization of active organic functional groups (Mitchell, 1993). From Table 2, the cation exchange capacity is in range of 4.86 meq/100g to 36.21 meq/100g. The layer below top soil has least cation exchange capacity. The last layer that is 4.5 m to 5.5 m has the highest values of CEC.

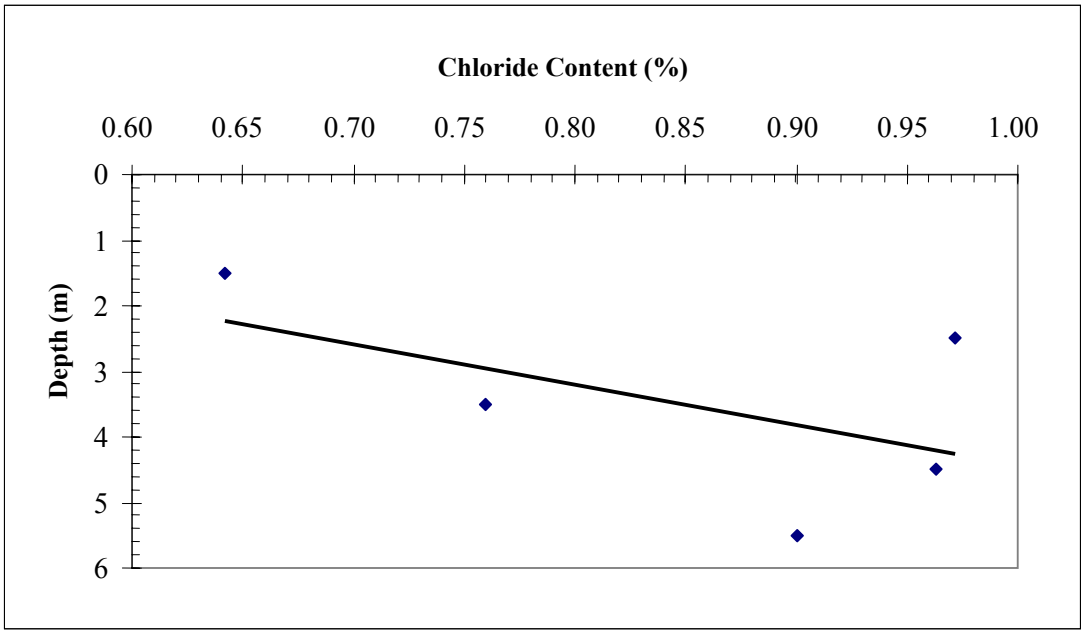

Figure 6: Correlation between Chloride Content and Depth

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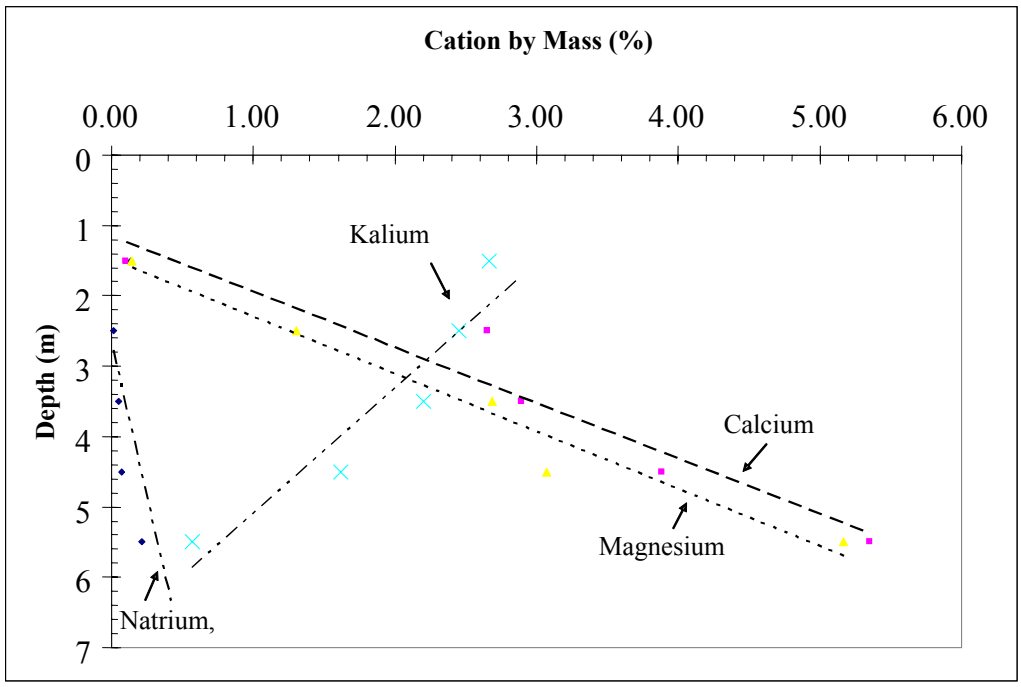

Figure 7: Correlation between Cations Content and Depth

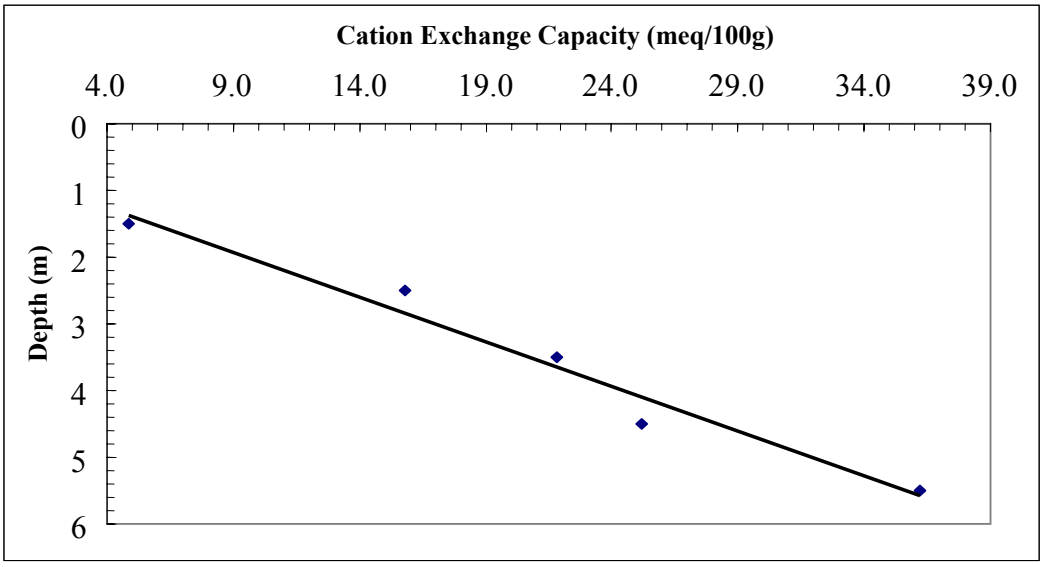

Figure 8: Correlation between Cation Exchange Capacity and Depth

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CONCLUSION

The conclusions of the research can be drawn as follows:-

(i) The results of pH ranged from 2.87 to 7.11, it show that the KUiTTHO clay is acidic. The correlation also shows that the pH increase with depth.

(ii) The conductivity ranged from 1446 μs/cm to 1786 μs/cm, it show that the clay is contains high amount of active ions.

(iii) The values of loss on ignition ranged from 4.76 % to 11.68 %, while the organic content ranged from 4.47 % to 9.22 %. Both method reports almost same value for organic matter. The correlation shows that the organic matter decrease with depth.

(iv) The sulphate content ranged from 0.55 % to 1.00 %, the higher sulphate content values obtained are 980 mg/kg, According to BS 8500-1:2002 Table A-2, KUiTTHO clay sulphate content categorized as DS-3 (design sulphate class) or AC-3s (ACEC class). According to standard, the minimum cement or combination content of dense fully compacted concrete for foundation design are ranged from 340 kg/m^3 to 400 kg/m^3 (table A15). Refer to BS EN 206-1:2000 Table 2, the chemical compositions are without the chemical attack consideration.

(v) The chloride content ranged from 0.64 % to 0.97 %, the correlation shows that the chloride content increases with depth.

(vi) The kalium content ranged from 0.57 % to 2.67 %, the correlation shows that the kalium content decreases with depth.

(vii) The magnesium ranged from 0.15 % to 5.16 %, the correlation shows that the magnesium content increases with depth.

(viii) The calcium content ranged from 0.1 % to 5.4 %, the correlation shows that the calcium content increases with depth.

(ix) The natrium content ranged from 0.01 % to 0.13 %, the correlation shows that the natrium content increases with depth.

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