A Study on Permeability of Soil Cement

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ABSTRACT

Although there have been several research on engineering properties of residual soils in Malaysia, studies on the permeability properties of meta-sedimentary residual soils are still lacking. The objective of this study is to determine the influence of low percentage cement on permeability parameters of the meta-sedimentary soil. Samples of the residual soil were taken from Bangi, Selangor. Basic properties of soils, such as the natural water content, grain size distribution, specific gravity, and Atterberg limits were determined. Mainly, the coefficient of permeability of the soils both naturally and with those anticipated in the soil-cement modification is determined by using the Falling Head Permeability test. The results of analysis show that the permeability of low-cement admixed soil reduce as the quantity of cement increase. However, the addition of 10% cement gives an increased permeability value. The generated permeability parameters will indirectly become a guide in the preliminary soil cement stabilisation to modify the properties of the soil to become more like the properties of a soft rock.

Keywords: *permeability, residual soil, Falling Head Permeability test*

Introduction

Alternative areas for construction have become more and more important since the last decades due to the growing shortage of better quality soils for construction. These limitations could be overcome with the introduction of new mixing materials such as soil – cement mixture (Pinto 2003). Thus, this study focused on cement, which was used as a modification material to be mixed with the disturbed sample of residual soil, which is classified as metasedimentary soil in various percentages. The modification was to decrease the permeability of the soil. For the aforementioned reason, laboratory testing was carried out in order to study the effect of inclusion of cement on the engineering behaviour of residual soil in reducing its permeability.

Basically, the study was done to identify the sensitivity of permeability behaviour of residual soil toward cement content. For this study, disturbed sample were taken from a hilly area in Bangi, Selangor. A study on the effect of permeability by mixing cement to residual soil was conducted to:

a. examine the original soil permeability actually encountered and comparing with those anticipated in the soil-cement modification.
b. carry out a laboratory testing in order to study the effect on permeability due to inclusion of cement in residual soil.
c. determine the influence of variability percentage of cement on permeability parameters of the residual soil.

Dense, compact, or cemented soil layers have very slow rates of permeability. Permeability of soil in its natural setting is highly variable and extremely difficult to measure. Soil permeability can be determined in a laboratory by measuring the rate of flow through a column of soil under a constant head of water (Huddleston 1996).

The permeability data were compared to the residual soil, which has no cement. A range of 1%, 3%, 5% and 10% of cement were used in this study. The laboratory tests that were done to determine physical analysis are Particle Size Analysis, Atterberg limits, Specific Gravity and Compaction and permeability parameter testing which was the Falling - Head permeameter. The entire laboratory tests were performed in Kolej Universiti Teknologi Tun Hussein Onn's (KUiTTHO) geotechnical laboratory.

The permeability of a soil mass is dependant on both its microstructure (e.g. whether particle size, shape, arrangement, etc) and its macrostructure (e.g whether or not stratified, presence of fissures, pipes, lenses, etc.). For obvious practical reasons the size of samples taken for laboratory tests is quite small, and therefore, unlikely to be satisfactorily representative in soils with significant macrostructure characteristics. To some extent, this deficiency may be overcome by obtaining carefully selected groups of samples (Whitlow 2001).

Sherwood (1993) found that fully hydrated cement takes up about 20% of its own weight of water. At high moisture contents in a cement-stabilised material the cement would have no difficulty in obtaining this water but as the moisture content is decreased the cement has to compete with the soil for moisture; if the soil has a high suction it may have a greater affinity for water than the cement and, the cement cannot fully hydrate. As the moisture content of stabilised soil is decreased, the degree of hydration of the cement is reduced. Continuing decrease in moisture content is, therefore, assumed important and a point is reached where decrease in moisture content is accompanied by a decrease in strength. Hence, all the soil cement samples for this study were submerged in the water throughout the curing period in order to make sure that the cement have enough water for hydration process.

Methodology

A laboratory study was carried out to determine the physical properties and permeability parameters.

Test Sample Preparation

The sampling of residual soil is essential in order to undertake laboratory testing. For the present study, samples were excavated or dug using a hoe. These disturbed soil samples or remolded samples were obtained from a depth of 0.2 m below ground surface. The disturbed natural soils were oven – dried in 105°C before tested. Distilled water was used for all the laboratory tests. Distilled water should be relatively clean and free from harmful amounts of alkali, acid or organic matter. With these preparations, the physical tests were done to classify the engineering properties of the natural residual soil.

The permeability tests were carried out in the second stage test. A range of 1%, 3%, 5% and 10% of cement from the mass of residual soil taken were used in this study. The soil was mixed with these various cement percentages to make soil cement specimens. Table 1 shows the soil – cement sampling for the laboratory tests. The cement that was used was Ordinary Portland cement. Soil samples were tested for 0% cement as a control sample and after mixing with the cement powder.

Before performing permeability test, soil – cement samples, which have been compacted using Standard Proctor Compaction method, were immersed in the water for curing purposes. This process was carried on for 30 days for all the samples as stated in Table 1 except for the soil samples with 0% cement. Those were submerged in the water only for 24 hours. Curing was carried out for saturation purpose as well as allowing enough time for cement to be fully hydrated.

Table 1: Samples of Testing

Soil + Cement Percentage	Total Mass (g)	Mass of Soil (g)	Mass of Cement (g)	Number of Samples
Soil+ 0% cement (control sample)	2000	2000	0	2
Soil + 1% cement	2000	1980	20	2
Soil + 3% cement	2000	1940	60	2
Soil + 5% cement	2000	1900	100	2
Soil + 10% cement	2000	1800	200	2
TOTAL				10

Physical Test

After preparing the soil samples, a series of physical or index test has been carried out as follow:

a. Moisture Content – To determine the moisture content of soil as a percentage of its dry mass;
b. Particle Size Analysis (dry sieving and CILAS machine) – Generally applied to the soil fraction larger than 75 mm (dry sieving) and applied to the soil fraction smaller than 0.0025 mm for CILAS machine;
c. Atterberg Limit tests – To determine Plastic Limits, Liquid Limits and Plasticity Index of natural soil;
d. Specific Gravity test – A traditional method for heavier than water;
e. Proctor Compaction test – To identify the maximum dry density, and optimum moisture content for remolding.

Permeability Test

Permeability tests were done for natural residual soil and soil-cement samples from all the ranges of cement percentages as studied. After second stage of compaction involving soil – cement specimens were done; samples were cured for 30 days before permeability tests were conducted on them. In this study, Falling Head Test was used to measure the permeability of soil of intermediate and low permeability (less than 10-4 m/s), i.e. silts and clays. This test is neither covered as present (2006) by British Standards, nor by ASTM Standards. The procedure is generally an accepted practice.

Results

The results of the study are divided into two groups; physical properties and permeability parameter.

Physical Properties of Studied Soil

Soil was categorised as ML according to the Unified Soil Classification System (USCS). The soil can be classified as yellowish brown sandy SILT with slight clay and low-plasticity soil, where plasticity index is 0.55 (Liquid limit, LL = 25.3%, Plastic limit, PL = 24.75%). Based on particle size analysis, the distribution of soil is silt 49%, sand 39%, and clay 12%. Silt and sand consume almost half of the soil portion, whereas clay exists only in small quantity. From the grain distribution graph in Figure 1, the effective size, D_{10} is 1.6 mm, uniformity coefficient, C_u is 21.88 and the coefficient of gradation, C_k is 0.842.

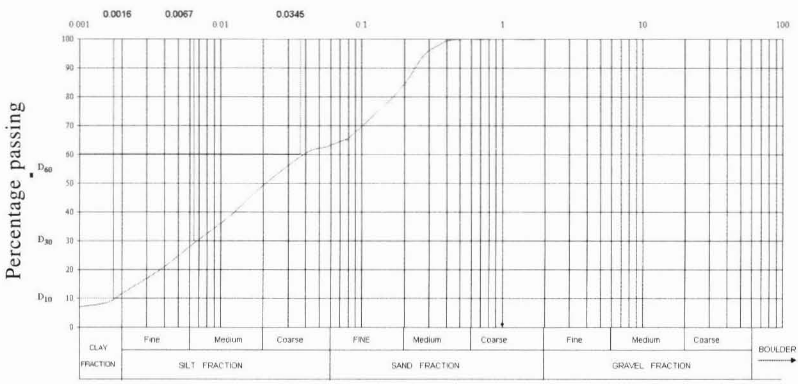

Figure 1: Grain Size Distribution

The specific gravity for the studied soil is 2.63. Through the Proctor Compaction Test, maximum dry density obtained for the natural residual soil sample is 1760 kg/m^3 and the optimum moisture content for the sample is 14% (Figure 2).

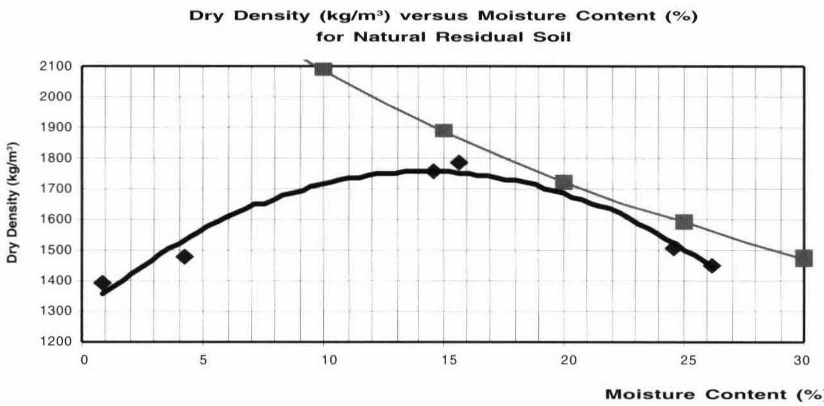

Figure 2: Determination of Maximum Dry Density (kg/m^3) and Optimum Moisture Content (%) for Natural Residual Soil

Permeability Parameters

Based on the Falling Head Permeability test, the permeability of the original soil is 4.16 x 10^{-8} m/s. Figure 3 shows that the value of permeability decreases to 3.89 x 10^{-8} m/s, 2.78 x 10^{-8} m/s then 6.83 x 10^{-9} m/s with the addition of 1%, 3 % and 5% of cement additives, respectively. But, the addition of 10% cement gives an increased permeability value to 2.78 x 10^{-8} m/s.

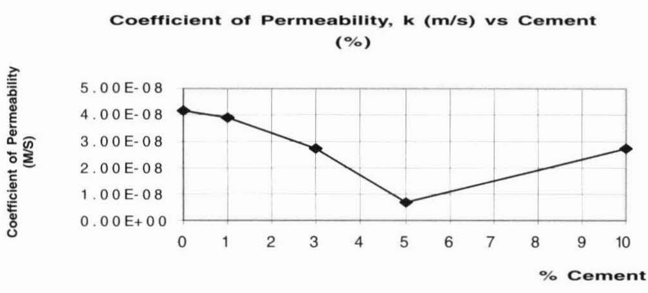

Figure 3: Relationship of Coefficient of Permeability, K (M/S) with Cement Additives (%)

Discussion

The distinctive feature of the residual soil is that it is a mixture of silt, sand and clay in varying proportions with silt 49%, sand 39%, and clay 12% (refer to Figure 1). The particle size analysis indicates that residual soils have variable texture and contain all fractions of particles. The soil was classified as yellowish brown sandy SILT with slight clay. With Cu > 5, it indicates a well-graded soil and Ck between 0.5 and 2.0 indicates a well-graded soil too. The studied residual soil is a low – plasticity soil based on the Plasticity Index. Since the studied soil is a silty soil with fine sands with slight plasticity, it is categorised in the ML group.

The specific gravity for the studied soil is 2.63. The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.80. Most minerals, of which the solid matter of soil particles is composed, have a specific gravity greater than 2.60. Therefore, smaller values of specific gravity indicate the possible presence of organic matter (GSSHA 2001).

The permeability of the original soil was found to be 4.16×10^{-8} m/s. Fine-textured soils have very tiny pores and very slow permeability rates (Figure 3). Ingles and Metcalf (1972) stated that, the permeability of the soil-cement is influenced by the increment of cement, where it decreases with the added content. The value of permeability decreases to 3.89×10^{-8} m/s, 2.78×10^{-8} m/s then 6.83×10^{-9} m/s with the addition of 1%, 3% and 5% of cement additives, respectively. According to Ingles and Metcalf (1972), during the hydration process, cement hydrates is formed followed by the increase in pH value and $Ca(OH)_2$ concentration can break the clay particles and free the silica and aluminium to joint the calcium forming the second hydrate material. This will alter the modification of pores size and distribution. When the quantity of cement increases, the pores size decrease. In this study, with 1%, 3% and 5% of cement additives, the pores size decreased. Moreover, in the curing process, pores size can be minimised. Permeability will then decreases and soil – cement gains higher strength and stiffness.

However, Figure 3 also shows that the addition of 10% cement gives an increased value to 2.78×10^{-8} m/s. According to the study done by Sam (2004), with cement percentage more than 8%, the pore size of soil-cement increases due to flocculation and agglomeration reaction. Hence, the permeability of the soil increases. Thus, flocculation and agglomeration reaction could have also influenced the increased permeability value of 10% cement addition to the soil in this study.

Conclusion

Properties of soil such as permeability can be altered by the addition of stabilising agents as the main interest is usually in finding a means of increasing soil strength and resistance to softening by water. In this case, cement has been used as a bonding agent. It stabilises soil by cementing the particles together so that the effect of water on the structure is lessened. The effectiveness of this type of stabiliser depends on the strength of the stabilised matrix; on a bond, which is formed between the soil and the matrix, and on individual particles or agglomerations of particles that are bonded together.

Based on the study, the best amount of cement to improve and stabilise the studied residual soil is 5% by weight compared to 1%, 3% and 10% cement additives. The increase of 1%, 3% and 5% cement content reduces the permeability value with water curing process. However, with the 10% cement content has increased the permeability value. It is believed that the minimised pores size through curing process took place when adequate cement hydration process reduces the permeability of soil with cement content of 1%, 3% and 5%. Hence, generally, the permeability of cement treated soil is lower than that of untreated soil because of the hydration process of the pore water with the chemical compounds of Type I Portland cement which produces the insoluble compounds (secondary cementitious products) when cured. However, at 10% cement added, it is believed that flocculation and agglomeration reaction aggravates the pore sizes of soil-cement and thus increase permeability.

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