Hydraulic Conductivity of Residual Soil-Cement Mix

P Govindasamy¹ and M R Taha¹
¹Faculty Of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia
E-mail: pgpam_21@yahoo.com

Abstract. In Malaysia, although there are several researches on engineering properties of residual soils, however study on the hydraulic conductivity properties of metasedimentary residual soils is still lacking. Construction of containment walls like slurry wall techniques can be achieved with hydraulic conductivity of approximately $5 \times 10^{-7}$ cm/sec. The objectives of the study were to determine the physical properties of metasedimentary residual soils and to determine the influence of 1%, 3%, 5% and 10% of cement on hydraulic conductivity parameters. The coefficient of hydraulic conductivity of the soil naturally and soil-cement mixtures were determined by using the falling head test. According to the test, the hydraulic conductivity of the original soil was $4.16 \times 10^{-8}$ m/s. The value decreases to $3.89 \times 10^{-8}$ m/s, $2.78 \times 10^{-8}$ m/s then $6.83 \times 10^{-9}$ m/s with the addition of 1%, 3% and 5% of cement additives, respectively. During the hydration process, cement hydrates is formed followed by the increase in pH value and Ca(OH)$_2$ which will alter the modification of pores size and distribution. When the quantity of cement increases, the pores size decrease. But, the addition of 10% cement gives an increased hydraulic conductivity value to $2.78 \times 10^{-8}$ m/s. With 10%, the pore size increase might due to flocculation and agglomeration reaction. The generated hydraulic conductivity values will indirectly become a guide in the preliminary soil cement stabilization to modify the properties of the soil to become more like the properties of a soft rock. 1. Introduction

Keywords: residual soil, cement, hydraulic conductivity.

1.0 Introduction

Alternative areas for construction become more and more important since last decades, due to 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 [1]. Soil mixing is also commonly used as a stabilization method for containing hazardous wastes and sludge. Containment walls can be constructed with hydraulic conductivity of approximately $5 \times 10^{-7}$ cm/sec, similar to that achieved by most slurry wall techniques [2]. 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 hydraulic conductivity 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 hydraulic conductivity. Dense, compact, or cemented soil layers have very slow rates of hydraulic conductivity. Hydraulic conductivity of soil in its natural setting is highly variable and extremely difficult to measure. Soil hydraulic conductivity can be determined in a laboratory by measuring the rate of flow through a column of soil [3].

The aims of this study are to examine the original soil hydraulic conductivity actually encountered and comparing with those anticipated in the soil-cement modification, to carry out a laboratory testing in order to study the effect on hydraulic conductivity due to inclusion of cement in residual soil and to determine the influence of variability percentage of cement on hydraulic conductivity parameters of the residual soil.

In this study, disturbed sample were taken from hilly area at Bangi, Selangor as the sample is originally unpolluted. A study on the effect of hydraulic conductivity by mixing cement to residual
soil was conducted. The hydraulic conductivity data was 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 limit, specific gravity, compaction and hydraulic conductivity parameter testing which was the falling - head permeameter. The entire laboratory tests were performed in Universiti Tun Hussein Onn (UTHM)'s geotechnical laboratory. 

These methods of testing were to ensure that adequate mixing and treatment has been achieved. The study focused on finding the most efficient and the best percentage of cement mixture with soil, which can cause the properties of the soil to become more like the properties of a dense soil or soft rock [3]. This production is also for reduction of settlements by decreasing the hydraulic conductivity of residual soil.

Table 1. Typical strength and permeability characteristics of treated soils [3].

| Soil Type               | Cement Usage | UCS          | Permeability |
|------------------------|--------------|--------------|--------------|
| Sludge                 | 240 to 400 kg/m³ (400 to 700 lbs/cy) | 70-350 kPa (10-50 psi) | 1x10^{-6} cm/sec |
| Organic silts and clays| 150 to 260 kg/m³ (260 to 450 lbs/cy) | 350-1400 kPa (50-200 psi) | 5x10^{-7} cm/sec |
| Cohesive silts         | 120 to 240 kg/m³ (200 to 400 lbs/cy) | 700-2100 kPa (100-300 psi) | 5x10^{-7} cm/sec |
| Silty sands and sands   | 120 to 240 kg/m³ (200 to 400 lbs/cy) | 1400-3500 kPa (200-500 psi) | 5x10^{-6} cm/sec |
| Sands and gravels      | 120 to 240 kg/m³ (200 to 400 lbs/cy) | 3000-7000 kPa (400-1000 psi) | 1x10^{-5} cm/sec |

Soil cement is a near impermeable material from the results of high-pressure hydraulic conductivity tests, and the hydraulic conductivity coefficient decreased as the mixed cement content of soil cement increased. Thus, through this study, it was concluded that the hydraulic conductivity of soil-cement decreases with the increasing cement content. Three types of soil cement have been categorized, which are, [4]:

1. Normal soil-cement usually contains 5 to 14% cement by volume and is used generally for stabilizing low-plasticity soils and sandy soils.
2. Plastic soil-cement has enough water to produce a wet consistency similar to mortar. This material is suitable for use as waterproof canal linings and for erosion protection on steep slopes where road-building equipment may not be used.
3. Cement-modified soil is a mix that generally contains less than 5% cement by volume. This forms a less rigid system than either of the other types, but improves the engineering properties of the soil and reduces the ability of the soil to expand by drawing in water.
2. Methodology

2.1 Sample Preparation

The sampling of residual soil is essential in order to undertake laboratory testing. For this study, samples were excavated or dug using a hoe. These disturbed soil samples or remolded samples were obtained from a depth of 0.2m below ground surface. The disturbed natural soil 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 alkalies, acid or organic matter. With these preparations, the physical tests such as particle size analysis, Atterberg limit, specific gravity and compaction were done to classify the engineering properties of the natural residual soil. Then, for the hydraulic conductivity tests, 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 is Ordinary Portland cement. Soil samples were tested for 0 % cement as a control sample and after mixing with the cement powder.

Before performing hydraulic conductivity test, soil - cement samples, which have been compacted using standard Proctor compaction method at optimum moisture content 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 (control sample) that were submerged in the water only for 24 hours. Curing was carried out for saturation purpose as well as given enough time for cement to be fully hydrated. Fully hydrated cement takes up about 20 percent of its own weight of water. At high moisture contents in a cement-stabilized 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 a stabilized soil is decreased the degree of hydration of the cement is reduced [5]. Thus, proper curing process is a necessity before carrying out further testings.

| 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 | 1900 | 100 | 2 |
| Soil + 5% Cement | 2000 | 1800 | 200 | 2 |
| Soil + 10% Cement | 2000 | 1700 | 300 | 2 |
| TOTAL | 10 |

2.2 Basic Geotechnical Test

After preparing the soil samples, a series of physical test has been carried out as follows;

a. Moisture content -the determination of the moisture content of a specimen of soil as a percentage of its dry mass using British Standard (BS) 1377: Part 2:1990 Clause 3.
b. Particle size analysis (dry sieving and CILAS machine) -generally applied to the soil fraction larger than 75mm (dry sieving) and for soil fraction which passes the 2mm sieve size using CILAS particle size analyzer.
c. Atterberg Limits -to determine plastic limit, liquid limit and plasticity index of natural residual soil using BS1377 : Part 2 : 1990 : 4.3.
d. Specific gravity - for accurate measurement of the density of particles heavier than water using BS 1377:1990.
e. Proctor compaction test - to identify the maximum dry density and optimum moisture content for natural residual soil using BS 1377: Part 4: 1990: 3.3.

2.3 Hydraulic conductivity Test
 Hydraulic conductivity 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 hydraulic conductivity tests were conducted on them. For measuring the hydraulic conductivity of soil of intermediate and low hydraulic conductivity (less than $10^{-4}$ m/s), i.e. silts and clays, the falling head procedure was used. The procedure is generally an accepted practice as recommended [6].

3. Results

3.1 Physical Properties the Residual Soil
 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, the effective size, $D_{10}$ is 1.577, uniformity coefficient, $C_u$ is 21.88 and the coefficient of gradation, $C_k$ is 0.842. The specific gravity for the studied soil is 2.63. The plastic limit was 24.75 ad liquid limit was 25.3. The soil can be classified as yellowish brown sandy SILT with slight clay and low-plasticity soil, where plasticity index is 0.55. In this study, the soil firstly categorized in a major group of fine-grained soils which is the L groups, which have LLs < 50. The symbol L has low and high compressibility. Fine-grained soils are further divided based on their position above or below the A-line of the plasticity chart. Typical soils of the (ML) and (MH) groups are inorganic silts. Those of low plasticity are in the (ML) group; others are in the (MH) group [7]. Since the studied soil is a silty soil with fine sands with slight plasticity, it is categorized in the ML group. 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 1. Determination of maximum dry density (kg/m$^3$) and optimum moisture content (%) for natural residual soil.](image-url)
3.2 Hydraulic Conductivity Parameters

According to the falling head hydraulic conductivity test, the hydraulic conductivity of the original soil was $4.16 \times 10^{-8}$ m/s. Figure 2 shows that the value of hydraulic conductivity decreases to $3.89 \times 10^{-8}$ m/s, $2.78 \times 10^{-8}$ m/s then $6.83 \times 10^{-9}$ m/s with the addition of 1%, 3% and 5% of cement additives, respectively. However, the addition of 10% cement gives an increased value to $2.78 \times 10^{-8}$ m/s.

![Figure 2. Relationship of coefficient of hydraulic conductivity, k (m/s) with cement additives (%).](image)

4. 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%. The particle size analysis indicated that residual soils have variable texture contain all fractions of particles. In residual soils consistent results are difficult to achieve. This was probably due to weathering process by which the structure of residual soil easily breaking down. The results were also influenced by time and condition of storage. The fresh samples were generally observed to be initially soft which further hardened with time. Hence particle size distribution for same sample in fresh state might have differed with that of in weathered state [8]. 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. It is categorized in the ML group as it is a silty soil with fine sands with slight plasticity. 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 [9].

The dry density of soil produced by compaction depends mainly on the moisture content of the soil and the amount of compaction applied. Each soil has its own unique optimum moisture content, the value depending mainly on the amount and type of plastic fines that it contains. However, as the optimum moisture content is critically dependent on the compaction effort, the term always needs to be considered in relation to the type of compaction test used to define the property.

The hydraulic conductivity of the original soil was $4.16 \times 10^{-8}$ m/s. Fine-textured soils have very tiny pores and very slow hydraulic conductivity rates (Figure 2). The hydraulic conductivity of the soil-cement is influenced by the increment of cement, where it decreases with the added content [10]. The value of hydraulic conductivity decreases to $3.89 \times 10^{-8}$ m/s, $2.78 \times 10^{-8}$ m/s then $6.83 \times 10^{-9}$ m/s with the addition of 1%, 3% and 5% of cement additives, respectively. 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 [10]. 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 minimized. hydraulic conductivity will then decreases and soil – cement gains higher strength and stiffness.

But, Figure 2 also shows that the addition of 10% cement gives an increased value to 2.78 x 10^{-8} m/s. With cement percentages more than 9%, the pore size of soil-cement increases due to flocculation and agglomeration reaction. Hence, the hydraulic conductivity of the soil increases. Thus, flocculation and agglomeration reaction could have also influenced the increased hydraulic conductivity value of 10% cement addition to the soil in this study [11].

5. Conclusion
Properties of soil such as hydraulic conductivity can be altered by the addition of stabilizing 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 stabilizes soil by cementing the particles together so that the effect of water on the structure is lessened. The effectiveness of this type of stabilizer depends on the strength of the stabilized 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 stabilize 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 hydraulic conductivity value with water curing process. However, 10% cement content has increased the hydraulic conductivity value. It is believed the flocculation and agglomeration reaction aggravates the pore size of soil-cement and thus increase the hydraulic conductivity.

References
[1] Pinto 2003 A guide to the formation, classification and geotechnical properties of residual soils, with advice for geotechnical design. Mechanics of Residual Soils. Balkema A A, Rotterdam.
[2] Nicholson P J, 1998 Cement Soil Mixing in Soft Ground, University of Houston.
[3] Huddleston J H 1996 How Soil Properties Affect Groundwater Vulnerability to Pesticide Contamination, Oregon State Extension Service.
[4] Bell F G 1993 Engineering Treatment of Soils, E & FN Spon.
[5] Sherwood P T 1993 Soil Stabilization with Cement and Lime, Transport Research Laboratory State of the Art Review, HMSO.
[6] Head K H, 1994 Manual of soil laboratory testing- Volume 1: Soil Classification and Compaction tests, London: Pentech Press.
[7] Information on http://www.eng-ips.com/viewthread.cfm pcSITES User Manual Version 1.2., ACLEP Technical Report No. 5 (1997)
[8] Aminaton M, Fauziah K, Mohd F Y & Khairul N, 2002 Physical and Chemical Compositions of Residual Soils Of Eastern Region of Peninsular Malaysia. 2nd World Engineering Congress Sarawak, Malaysia, 22-25.
[9] Information on http://www.ems-i.com/wmshelp/Grids/GSSHA/Sediments "Sediments" GSSHA (2001)
[10] Ingles O G and Metcalf J B 1972 Soil Stabilization Principle and Practice, Butterworths, Melbourne, Australia.
[11] Basha E A, Hashim R & Muntohar A S, 2003 Effect of cement-rice husk ash on the plasticity and compaction of soil. EJCE Paper.