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SHORT TERM CONSOLIDATION OF CONTAMINATED CLAY SOIL

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ABSTRACT

The petroleum industry's rapid growth causes several effects on the environment especially towards soil properties. This case puts a number of environmental and geotechnical problems from accidental spills of oil, leaking and its derivatives. Petrol, diesel and tars are examples of contaminant that affect the physical properties of the soil thus the consolidation and settlement too. In clay soils, contaminant diffusion is a significant process that impacts geotechnical and geo-environmental engineering systems. The chemical gives an influence on determining the performances of clay. The results indicated a increase in the coefficient of consolidation, *cv* and decrease in the coefficient of volume compressibility, *mv*, up to 6% oil content. There was great reduction in the amount of fines fraction with higher doses of contaminant by dry weight of soil. The percentage of clay size fraction in the uncontaminated soil was 84.79% and then reduced to 3.7 %, 0.51% and 0.2% when contaminated with contaminant content at 2%, 4% and 6% by dry weight of soil, respectively.

ABSTRAK

Pertumbuhan pesat industri petroleum ini menyebabkan beberapa kesan ke atas alam sekitar terutamanya ke arah sifat-sifat tanah. Kes ini meletakkan beberapa masalah alam sekitar dan geoteknikal dari tumpahan sengaja minyak, bocor dan terbitannya. Petrol diesel dan tar adalah contoh bahan cemar yang memberi kesan kepada sifat-sifat fizikal tanah tersebut selain pemampatan dan pemendapan juga. Bagi tanah liat , penyebaran bahan cemar adalah satu proses penting yang memberi impak pada system kejuruteraan geoteknikal dan geo- alam sekitar. Kimia ini memberikan pengaruh kepada sifat tanah liat. Keputusan menunjukkan peningkatan dalam nilai pemboleh ubah mendapan, cv dan pengurangan dalam nilai pemboleh ubah isipadu kebolehmampatan, mv „pada kandungan minyak sehingga 6 % didalamnya. Terdapat pengurangan besar dalam jumlah butiran halus/kecil dengan dos bahan cemar yang lebih tinggi mengikut berat kering tanah. Peratusan saiz tanah liat kecil di dalam tanah yang tidak tercemar adalah 84,79 % dan kemudian berkurang kepada 3.7 %, 0.51 % dan 0.2 % apabila tercemar dengan kandungan bahan cemar pada 2%, 4% dan 6 % mengikut berat kering tanah masing-masing.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The petroleum industry's rapid growth causes several effects on the environment especially towards soil properties. This case puts a number of environmental and geotechnical problems from accidental spills of oil, leaking and its derivatives. Petrol, diesel and tars are examples of contaminant that affect the physical properties of the soil thus the consolidation and settlement too. In clay soils, contaminant diffusion is a significant process that impacts geotechnical and geo-environmental engineering systems. The chemical gives an influence on determining the performances of clay. The extremely large values of hydraulic conductivity were observed when liquid hydrocarbons dominated the fluid phase as reported by Michaels and Lin (1954). The contaminants can move easily and reach the critical ground water resources in a shorter time that as predicted from ground water model assuming the hydraulic conductivity is constant. That case can only apply if the hydraulic conductivity values increase during the seepage of chemicals.

For engineering and environmental purpose, it is important to investigate the geotechnical properties of contaminated soils and sediment (M. Khamehchiyan *et al.*, 2007). The test was carried out to determine the effects of contaminant on physical and consolidation properties of clayey soils. Physic-chemical interactions may occur between the soils and contaminant when the soils are contaminated with chemicals and the physical properties of soils might be changed from this interaction (Namunu J. Meegoda *et al.*, 2012). The extent of contamination depends on the chemical composition of the contaminant and properties of the soil (Fine *et al.*, 1997). There are very few research dealt with geotechnical properties of contaminated soils in literature.

Consolidation is the process of forcing water from the spaces between soil particles. Soil is more permeable to air than in water. This means that the compaction process may remove a large percentage of air from the soil, but a significant percentage of water may remain. The soil properties are changing in different ways depending upon the physical and chemical properties of the contaminants and the soils.

The changes of soil properties from the contaminant have made an interest to engineers for many years. This case might be bigger than as seen nowadays. The saturation of soil by fluid characterized by physical-chemical properties different from water has been found to have a deteriorating effect on its mechanical and filtration parameters, plasticity, swelling and others (e.g,. Bowders, Daniel, 1987; Stephenson, 1989; Baranski, 2000; Herzig, 2001; Konzeniowska-Rejmer, 2001; Garbulewski, Fronczyk, 2004; Izdebska-Mucha, 2005; Korzeniowska-Rejmer,Izdebska-Mucha, 2006; Khamehchiyan *et al.*, 2007). Engineering-geological parameter changes, particularly infiltration properties seem to be interest and significance. Results published so far have been limited to data obtained from samples after filtration tests or suspension studies (e.g., Fernandez, Quigley, 1985; Berger *et al.*, 2002; Kaya, Fang, 2005).

The purposes of this study are to obtain the consolidation properties of the clay soil due to the contamination effects. This study will be focusing on the coefficient of consolidation, C_v and the coefficient of volume compressibility, M_v. In this study also, the physical properties such as particle size, moisture content and void ratio also need to be obtained to help the further experiment. The coefficient of consolidation, C_v signifies the rate at which a saturated clay undergoes one dimensional consolidation when subjected to an increase in pressure. Measured in m^2/s , the coefficient of consolidation is a function of hydraulic conductivity, *k* (m/s), coefficient of volume compressibility m_v (m2/kg) and unit weight of pore liquid, γ_w (kg/m$^{3)}$. As hydraulic conductivity, *k* and the coefficient of volume compressibility, m_v decrease with increase in consolidation pressure, the coefficient of consolidation, c_v is not constant over the pressure range of interest, contrary to the prediction of Terzaghi and Perk (1967) (Retnamony G. Robinson and Mehter M. Allam *et al.*, 1998). The coefficient of volume compressibility, M_v , which is the volume change per unit increase in effective stress for a unit volume of soil (Craig, *et al.,* 1992). The volume change may be expressed in terms of void ratio or specimen thickness. This parameter is very useful to estimate the primary consolidation settlement (Afolagboye O. Lekan and Talabi A. Ojo *et al.*, 2013).

Clay soil is low in compressibility properties and this usually affected the stabilization, consolidation and settlement particularly. Understanding these properties might help avoiding any problem arise from the construction of the clay soil. Cracks in the building and some other destruction are few examples effect of the consolidation and settlement of clay. Result obtains from this study hope to be used for further investigation.

1.2 PROBLEM STATEMENT

It appears that development emerging fast in every country. This scenario needs a very detailed understanding and careful study of the soil properties. Clays are happened to have low strength and making structure to fail. Since the soft soils have a low shear strength and high compressibility, the constructions on this soft soil in a challenge to engineers (Mitchell, 1993). It is proven that clay has high friction ratio and cohesive value.

In this study, the physical and consolidation properties of the clay will be determined experimentally. The experiments on contaminated soils will showed the different parameters values compared to normal soils. The parameters values used are particle size and moisture content from the physical properties of the soil and also the coefficient of volume compressibility and coefficient of consolidation from the consolidation properties of the soil used. Contaminant will affected physical and consolidation properties at most. Many soils have proven to be problematic in geotechnical engineering because of the way they expand, collapse, disperse, undergo excessive settlement and have a distinct lack of strength (Fauziah, 2007). Regarding to the use of clay on construction site, problems such as low compressibility, low stabilization, consolidation and settlement problem of soil will occurs. It has happened that some of the failure occurs in the building is because of the soil. If this scenario is not reinforced with a proper ground improvement technique, building collapse will happen and affecting human and environmental safety. Hence, brief investigation on the characteristic and properties of soil need will help the engineer to build safer and better building structures for further development.

Overall, knowing the physical properties of clay give a significance for the engineers to know the condition of soil. Determining the strength of soil will include the pore water pressure condition, seepage, soil consistency, consolidation parameters and suitable tests.

1.3 OBJECTIVES

i) To compare the particle distribution size between non-contaminated and contaminated soil.

ii) To compare the coefficient of consolidation, Cv between non-contaminated and contaminated soil

iii) To compare the coefficient of volume compressibility, M_v between non-contaminated and contaminated soil.

1.4 SCOPE OF STUDY

Two artificial soils and one natural soil are used in this investigation. Both the artificial soils are used as for the low plasticity and high plasticity while the natural soil as constant. The soil samples can be collected at Pekan, Pahang with latitude of 3.5000°N and longitude of 103.4167°E. These soils were selected such that they represent high plastic or fat clay, low plastic or lean clay and silty clay. The type of contaminant is diesel oil as choose from a high chemical composition product such petrol, diesel and crude oil. The samples are prepared by mixing the soils with contaminant with 2%, 4% and 6% by dry weight. Dana *et* al. (2011) say that impact of contaminant is decreasing within time due to the evaporation of soil volatile compounds. Since the investigations are determining the short term consolidation, the samples also constantly leached with the contaminants for different period of time – ranging from one to three months. At the end of each time interval, the soil samples are tested to study the behavior of the soils in the contaminated environment. As the soils and chemicals are natural products, the short term is used to describe time periods shorter than two years. The long term is used to describe geologically long time periods, longer than ten years. However, the time span depends on the reactive nature of soils and chemicals, and other factors (eg. quantity of chemical flow through soil). In this study, long term consolidation is not done due to the insufficient time to do the experiment.

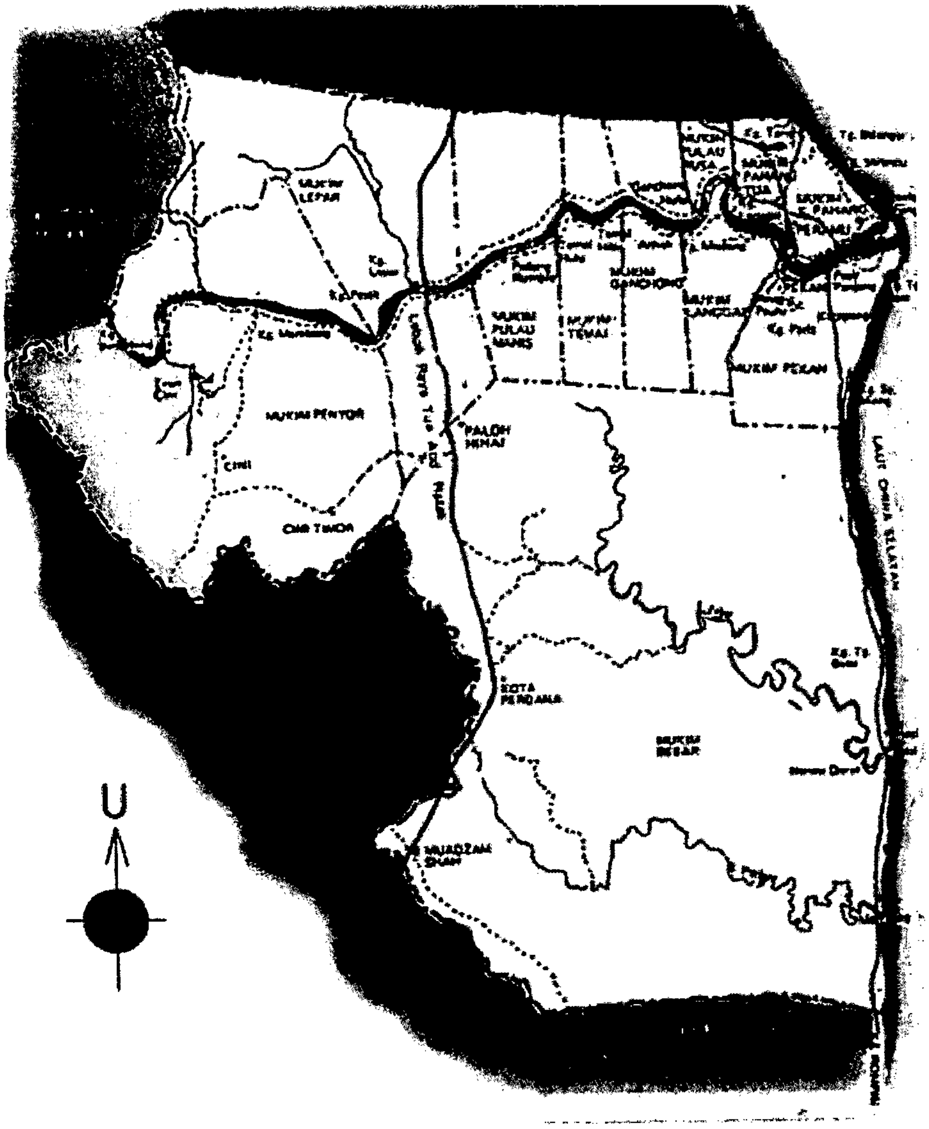

Figure 1.1 : Map of Pekan on the study case.

1.5 SIGNIFICANCE OF STUDY

Soil composition always gets concerned from engineers and any construction teams. Buildings and other structures on clay soil can cause problems when it comes to land shifting and settlements are concerned. Clay tends to expand and contract as the clay particles absorb and release water, which causes gradual shifting. This case lead to cracked foundation, lopsided and collapsed.

From this study, overcoming the clay soil problems towards construction had been highlighted as an important outcome. The soil used has low compressibility and most of the structure constructed on it usually will affect especially in consolidation and settlement. To prevent it from occur, the engineering properties of the contaminated soils must be determined before design work start. Therefore, any problems related to constructions on contaminated clay soil can be overcome. Since many districts in Pahang had not been explored much, this study will be guideline and helpful information for the engineers especially in clay soil. The result also can be useful to apply in the construction site made from clay soil.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

The fact that Malaysia has many parts of coastal areas and also rivers that located in many states including Pahang. This gives a major distribution on many areas in Malaysia. Clay soil has particle sizes less than about 0.005mm (McCarthy, 2007). Clays are typically formed over long periods of time by the gradual chemical weathering of rocks. Clay may be formed in place as residual deposits in soil, but thick deposits usually are formed as the result of a secondary sedimentary deposition process after have been eroded and transported from their original location of formation. Generally, fine soils such as clays and clay-silts are differing from the chemical weathering. It depends on parent rock and on local drainage to classify the clay minerals into types.

Clay soils are known for lower shear strength and high compressibility. This problematic soil gives weak foundation soil condition crisis for all buildings and project built on it. It is no longer an option to the limited construction site to choose as a suitable ground for further development. Nowadays, strategic area is the most important aspect which been looking forward by some engineers to a new construction site.

Aside from that, there is no exception to this soil from the effect of contamination. Pipe leakages, pollutions, oil spill and leachate are some of contamination examples. Oil contaminations of soil are common. The bearing capacity of the contaminated soils is reported to be reduced drastically. Euchun and Braja, 2001 stated that the bearing capacity of such soils is drastically reduced and made engineering structures unsuitable to run, or plant growth by reducing the availability of nutrients or by increasing toxic contents in the soil.

In addition, the magnitude of crude oil pollution and damage caused by multi-national oil companies operation in the Niger Delta of Nigeria has precipitated a slow poisoning of waters in the region, destruction of vegetation and agricultural lands which occurs during oil spills (e.g, Marr, Hooper, 1998; Corbett, 2004; Sahel, 2007; Ijimdiya, 2010).

Recently, researchers have attempted to address this problem. Mazzieri et *al* (2002) stated that the pollutant transport parameters in natural or compacted clay are, in principle, all dependent upon the soil void ratio, and as a consequence, upon the effective stress.

2.2 CLAY SOIL

Gravel, clay and sand are small particle disintegrated from rock during the weathering process. Temperature is the main factor in this process. Different high temperature exposed to the rock causing it to expand and contract accordingly to the temperature. Expands and contracts continuously process breaking the rock apart.

The physical and chemical characteristics of soil are determined from the chemical decomposition during chemical weathering. The environment contains oxygen, water, acids and salts. These combinations with rock cause a rapid reaction. Volume of materials might increase and subsequently materials breaking down seen from the reaction of these combinations. It will also dissolve rock matter parts and yielding voids inside the rock. Water and gas are filling the voids between particles. Carbonation and oxidation process happen between particles and organic matter. The carbonation and the oxidation process also causing a weak cementation among the particles.

Clay minerals are mainly from the breakdown of feldspar minerals although feldspar is the major constituent of clay soil, but they still contain silt sized particles. Geologic clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. A clayey soil, though distinguished by the color which it bears, namely black, white, yellow and red, differs from all other soils. The size of the clay particles is very small and very flaky in shape. Moisture clay will not crumble and in a plastic state condition. While in the dry state condition, clay is hardly breaking up. The clay characteristic of plasticity, compressibility and shrinkage potential comes from the structural arrangement of clay itself. Having a small size particle, plastic and sticky condition explained the behavior of clay due to the properties which has high moisture content in its structure. There are few types of clay such as clayey silt, silty clay, soft clay, organic clay and many. The three groups of clay minerals are montmorillonites, kaolinites and illites.

i. **Montmorillonites**

   Formed by the alteration of basic igneous rocks containing silicates rich

ii. **Kaolinites**

   Formed by the decomposition of orthoclase feldspar; principle constituent in china clay and ball clay; include kaolinite, dickite and nacrite.

iii. **Illites**

   The commonest clay minerals; formed by the decomposition of some micas and feldspars; predominant in marine clays and shales; include illite and glauconite.

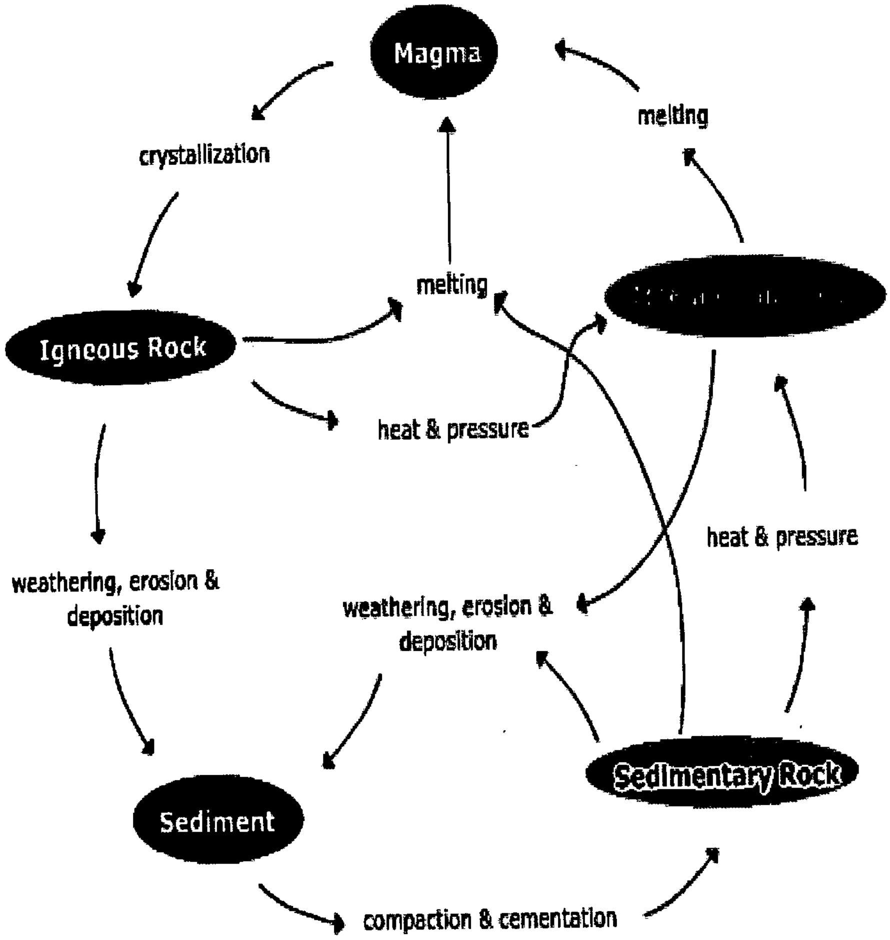

Figure 2.1 : Rock cycle.

2.3 SOIL CLASSIFICATION

Particle size, plasticity and moisture content can be important to be determined by the geotechnical engineer to design any construction. The three main tools used to classify soil are soil description, particle size distribution analysis and plasticity testing (Whitlow, 2001). It is carried out to differentiate among the group of soils on any site. Different soils with similar properties may be classified into groups and subgroups according to their engineering behavior (Das, 2006).

Sieve analysis was conducted on the soil samples to show the grain size distribution of all the selected samples. Majority they are classified according to the Unified Soil Classification System (USCS) or Association of State Highway and Transportation Officials (AASTHO). X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) analysis were used to determine the mineralogy and chemical composition of soils respectively. This study will use a mechanical sieve machine to determine the grain size distribution. It is important to distinguish between soil description and soil classification as mention from Atkinson (2007). Description is simply what can see with the eyes and how the soil responds to simple test. A classification is a scheme for separating soils into broad groups, each with broadly similar behavior.

The soil textural class is determined by the gravimetric percentage of sand silt and clay. Figure 2.2 shows the soil texture classifications based on gravimetric percentage. Sands, silts, clays and organics represent the solid particle composition of soil while air and water fill the pore spaces between the solid particles. When soil is completely saturated with water, the porosity will be equal to the volumetric soil moisture content (Warrick 2003). The amount of organics in soil will affect the bulk density and the porosity. Some organic soils may have porosities of over 90%, but in general, most inorganic agricultural loams will have a porosity of near 50%. The pores can be nearly microscopic (micro-pores) or visible with the naked eye (macro-pores) (Brady 1974).

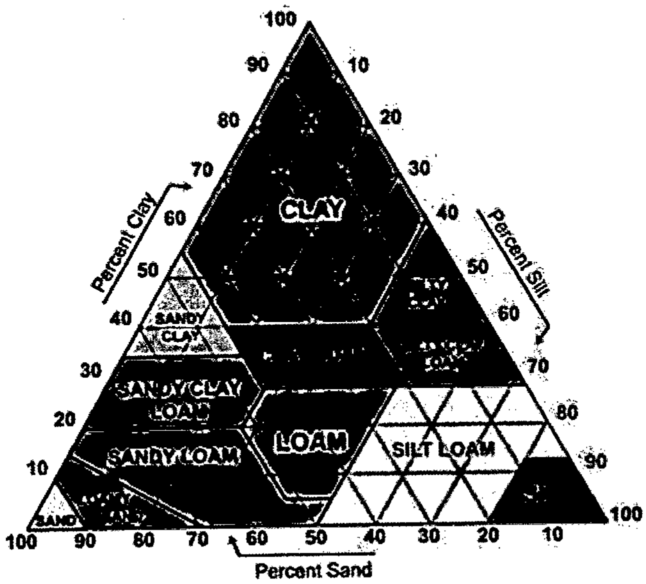

Figure 2.2 : Percentages of clay, silt and sand in the basic textural classes.

2.3.1 American Association State Highway and Transportation Officials Classification System (AASHTO)

Developed in 1929, American Association State Highway and Transportation Officials (AASHTO) system was served as Public Road Administration classification system. The clay particle of a size less than 0.002mm grain, the AASHTO system classifies the soil using 7 major groups. The groups are A-1 until A-7. Soils which are classified under A-1, A-2 and A-3 are known as granular materials which 35% or less of the particles pass through the No. 200 sieve. Particles in group A-3, A-4, A-5, A-6 and A-7 are mostly silt and clay-type materials as more than 35% pass through the No.200 sieve (Das, 2006). The classification is as shown Table 2.1.

Table 2.1 : American Association State Highway and Transportation Officials (ASSHTO) classification criteria (Das, 2006).

Criteria	Description
Grain size	a) Gravel : Fraction passing the 75mm sieve and retained on the No. 10 US sieve
	b) Sand : Fraction passing the No. 10 US sieve and retained on the No. 200 US sieve
	c) Clay and Silt : Fraction passing the No. 200 US sieve

2.3.2 Unified Soil Classification System (USCS)

This preferred system chooses by geotechnical engineer as accordance with American Society for Testing and Material (ASTM) in D-2487. In 1942, Casagrande recovered this system during engineering work in the World War. As shown in Table 2.2, the particles that passing through No. 200 with less than 50% are classified as coarse-grained soils, gravelly and sandy in nature. This system symbolizes the group with GW, GP, GM, GC, SW, SP, SM, and SC. The symbols that started with a prefix G stands for gravel or gravelly soil and symbol that started with S are sand or sandy soil (Liu & Evett, 2005). The other symbols used are W for well graded soil and P for poorly graded soil. however, fine-graded soils are 50% or more passing through the No. 200 sieve with symbols of M, which represent inorganic silt, C for inorganic clay, or O for organic silts and clay. The symbol of Pt is for peat, muck and other highly organic soils (Das, 2006). Table below shows how soils are identified according to the letter of group symbol.

Table 2.2 : First and second letter of group symbols (Aysen, 2005)

Soil Identification	First Letter of Group Symbol	Second Letter of Group Symbol
Coarse grained soil	G : gravel S : sand	W : well graded P : poorly graded
Fine grained soil	M : silt C : clay	L : low plasticity (LL less than 50) H : high plasticity (LL more than 50)
Organic soil	O	L : low plasticity (LL less than 50) H : high plasticity (LL more than 50)
Highly organic soils	Pt	No second letter

2.4 Grain Size Distribution of Soil

The size of natural soil deposits particles varies from 100m to less than 0.001mm. The different in engineering properties also defined by the different ranging size of the soil particles. From the particle size, the soil also can be separated into coarse-grained soil (gravel and sands) and fine-grained soil (silt and clay) groups. Under the coarse-grained group, the soil can be classified into cohesiveless soils whereas cohesive soils as for the fine-grained group. Few systems are used in the grain size distribution analysis based on the particle size including AASHTO, USCS, ASTM and also BS (British soil classification system). The following table shows a soil type based on particle sizes of soils.