DENSITY AND PERMEABILITY PROPERTIES OF OVER COMPACTED SANDS AND LATERITES

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DENSITY AND PERMEABILITY PROPERTIES OF OVER COMPACTED SANDS AND LATERITES

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ABSTRAK

Pemadatan tanah yang betul adalah penting dalam mana-mana jenis projek pembinaan. Ia sangat penting kerana ia menyediakan platform yang diperlukan untuk memberi sokongan penting bagi bangunan, pelbagai substruktur pembinaan, tapak pelupusan dan struktur pembinaan lain. Oleh itu, pemadatan tanah perlu dilakukan dengan secukupi dan praktikal dengan memperhatikan terhadap aspek parameter tanah yang dikehendaki, namun mengambil perhatian terhadap masa dan kos keseluruhan proses pemadatan. Disertasi ini memperkenalkan hubungan antara 3 parameter utama, iaitu ketumpatan kering yang diperoleh, pekali kebolehtelapan dikurangkan dan tenaga pemadatan digunakan untuk tanah. Laterit tanah dan pasir sungai adalah dua bahan tanah yang paling biasa terdapat dalam bidang pembinaan telah dipilih sebagai sampel tanah untuk kajian penyelidikan ini. Sampel tanah telah menjalani ujian permeabilitas dan pemadatan proctor dengan tahap pemadatan yang berbeza untuk mendapatkan data yang mencukupi untuk analisis dan penafsiran hubungan antara 3 parameter utama. Ujian pemadatan Proctor dijalankan pada awalnya kerana keputusan datanya diperlukan untuk digunakan sebagai pembolehubah malar dalam ujian kebolehtelapan kemudian Keputusan menunjukkan bahawa tanah laterit mempunyai sensitiviti yang lebih besar terhadap perubahan daya pemadatan dari segi ketumpatan kering dan pekali kebolehtelapan yang terjejas. Walaupun tanah laterit mempunyai pekali kebolehtelapan yang lebih rendah berbanding dengan pasir sungai, tetapi kedua-dua sampel tanah masih berjauhan dari sifat-sifat kebolehtelapan yang diperlukan untuk tujuan tapak pelupusan. Daya pemadatan optimum untuk kepadatan kering dan tujuan kebolehtelapan adalah berbeza dan juga ia berbeza dengan jenis sampel tanah. Akhir sekali, pendapatan dari kajian ini memberikan maklumat berguna untuk jurutera untuk menganggarkan daya pemadatan yang sesuai yang diperlukan untuk projek pembinaannya.

ABSTRACT

Proper soil compaction is essential in any type of construction project. It is very important because it provides the necessary platform that will sustain the crucial support for the buildings, various construction foundations, landfills, and any other construction structures. Therefore, soil compaction have to be applied sufficiently and practically with the concern to the aspect of the desired soil parameters, yet taking consideration to the time and cost of the entire compaction process. This dissertation presents the relationship between the 3 major parameters, which are the dry density gained, the permeability coefficient reduced and the compaction energy applied to the soil. Laterite soil and river sand are the two of the most abundant soil materials present in construction field were chosen as the soil sample for this research study. The soil samples have undergone permeability and proctor compaction tests with different level of compaction energy to acquire sufficient data for the analysis and interpretation of the relationship between the 3 major parameters. Proctor compaction tests were conducted at first as the results of the data are required to use as the constant variables in the permeability test later. The results show that the laterite soil have greater sensitive to the change of compaction energy in term of the dry density and permeability coefficient that are affected. Besides that, laterite soil shows properties with higher maximum dry density and lower permeability coefficient obtained from the same compaction energy with the river sand. However, although the laterite soil show lower permeability coefficient as compared to the river sand, both of the soil samples are still far beyond from the impervious permeability properties that are required for landfill purpose. The optimum compaction energy for dry density and permeability purpose are different and it varies with type of soil sample. Last but not least, the findings from this research provides useful information for the engineer to estimate the suitable compaction energy that are required for their construction project.

TABLE OF CONTENTS

ACKNOWLEDGEMENT II

ABSTRAK III

ABSTRACT IV

TABLE OF CONTENTS V

LIST OF FIGURES VII

LIST OF TABLES IX

LIST OF ABBREVIATIONS X

NOMENCLATURES XI

CHAPTER 1 1

1.1 Background 1
1.2 Problem Statement 4
1.3 Objectives 5
1.4 Scope of Work 5

CHAPTER 2 7

2.1 Overview 7
2.2 Ground Improvement Methods 7
2.2.1 Compaction Methods 8
2.2.1 Proctor Compaction test 10
2.3 Properties of Sand and Laterite 11
2.3.1 Laterites 11
2.3.2 Sand 12
2.3.3 Role of Clay 13
2.4 Compaction Behavior 14
2.4.1 Compaction Behaviors of Soil 14
2.4.2 Effect of Compaction to the Hydraulic Conductivity of Soil 16

CHAPTER 3 18

3.1 Overview 18
3.2 Preliminary Action 18

3.3 Experimental Procedure 20
3.3.1 Sample Preparation 20
3.3.1 Soil Classification 20
3.3.2 Proctor Compaction test 24
3.3.3 Permeability test 25
3.4 Data Analysis 26

CHAPTER 4 28

4.1 Soil Classification for soil samples 28
4.2 Proctor compaction analysis 30
4.2.1 Laterite soil: 30
4.2.1 River sand: 38
4.3 Permeability test analysis 46
4.3.1 Permeability of laterite soil: 46
4.3.2 Permeability of river sand: 48
4.4 Effect of Compaction Energy against Maximum Dry Density 50
4.4.1 Level of Compaction Energy vs Maximum Dry Density (laterite): 50
4.4.2 Level of Compaction Energy vs Maximum Dry Density (sand): 51
4.5 Effect of Compaction Energy against Permeability Properties 52
4.5.1 Permeability vs Compaction Energy (laterite): 52
4.5.2 Permeability vs Compaction Energy (sand): 53
4.6 Overall Discussion 54

CHAPTER 5 56

5.2 Recommendations 57

REFERENCES 58

APPENDIX A 1

LIST OF FIGURES

Figure 3.1: Flowchart of Experimental Methodology 19

Figure 3.2: Guideline of soil classification (USCS) (Das and Sobhan, 2014)............... 21

Figure 3.3: Particle grain size distribution according to USCS 21

Figure 3.4: Grain size ranges according to several engineering soil classification system 22

Figure 3.5: Viscosity of water... 23

Figure 3.6: Essential measurement for calibration of hydrometer................................ 24

Figure 3.7: The comparison of Standard and Modified Proctor 25

Figure 4.1: Sieve analysis of laterite soil 28

Figure 4.2: Sieve analysis of sand.. 28

Figure 4.3: Half Standard Proctor test (laterite)... 30

Figure 4.4: Standard Proctor test (laterite).. 31

Figure 4.5: Half Modified Proctor test (laterite)... 32

Figure 4.6: Modified Proctor test (laterite) 33

Figure 4.7: 2 times Modified Proctor test (laterite) 34

Figure 4.8: 3 times Modified Proctor test (laterite) 35

Figure 4.9: The combination of compaction curves for laterite soil............................. 36

Figure 4.10: Half Standard Proctor test (sand) 38

Figure 4.11: Standard Proctor test (sand) 39

Figure 4.12: Half Modified Proctor test (sand)... 40

Figure 4.13: Modified Proctor test (sand)... 41

Figure 4.14: 2 times Modified Proctor test (sand) 42

Figure 4.15: 3 times Modified Proctor test (sand) 43

Figure 4.16: The Combination of Compaction Curves for sand................................... 44

Figure 4.17: The combination of compaction curves for sand and laterites 44

Figure 4.18: MDD vs Permeability constant (Laterite) (semi-log)................................ 47

Figure 4.19: MDD vs Permeability constant (laterite)... 47

Figure 4.20: MDD vs Permeability constant (Sand) (semi-log) 48

Figure 4.21: MDD vs Permeability constant (Sand).. 49

Figure 4.22: Compaction energy vs MDD (laterite) 50

Figure 4.23: Compaction energy vs MDD (sand).. 51

Figure 4.24: Permeability Coefficient vs Level of Compaction Energy (laterite)......... 52

Figure 4.25: Permeability Coefficient vs Level of Compaction Energy (sand) 53

LIST OF TABLES

Table 4.1: Half Standard Proctor test (laterite) 30

Table 4.2: Standard Proctor test (laterite) 31

Table 4.3: Half Modified Proctor test (laterite) 32

Table 4.4: Modified Proctor test (laterite) 33

Table 4.5: 2 times Modified Proctor test (laterite) 34

Table 4.6: 3 times Modified Proctor test (laterite) 35

Table 4.7: Half Standard Proctor test (sand) 38

Table 4.8: Standard Proctor test (sand) 39

Table 4.9: Half Modified Proctor test (sand) 40

Table 4.10: Modified Proctor test (sand) 41

Table 4.11: 2 times Modified Proctor test (sand) 42

Table 4.12: 3 times Modified Proctor test (sand) 43

Table 4.13: Permeability of laterite soil 46

Table 4.14: Permeability of river sand 48

LIST OF ABBREVIATIONS

CBR	**California Bearing Ratio**
DC	**Dynamic Compaction**
LCE	**Level of Compaction Energy**
LL	**Liquid Limit**
MDD	**Maximum Dry Density**
OMC	**Optimum Moisture Content**
PI	**Plastic Index**
PL	**Plastic Limit**
USCS	**Unified Soil Classification System**
SWCC	**Soil-Water Characteristic Curves**

NOMENCLATURES

A	Area
Cu	Cohesion
D	Diameter of particle
H	Height
Hr	Particle Fall Distance
k	Coefficient of Permeability
L	Length
n	Dynamic Viscosity
Q	Volume Flow Rate
Pa	Atmospheric Pressure
Ps	Mass Density of Solid Particle
T	Time taken
V	Volume

CHAPTER 1

INTRODUCTION

1.1 Background

A developing country like Malaysia is having a huge amount of construction projects that including vast commercial development, large-scale of infrastructure and industrial evolution to stimulate the economic growth, as well as the extensive development of the residential to boost the population growth in the country. But regardless of the size, the purpose or the benefits of a project, almost all the construction work of the project will be conduct and build on the soil. Therefore, before any of these construction works can actually start, the behavior of soils that the construction works are going to build on and any of the potential geotechnical hazards must be clearly investigated.

There are several well-known construction failure in the world due to the geological instability and drawbacks that including the Leaning Tower of Pisa that built on the soft ground, the beautiful highway failure that happened at Kennecott Mine Landslide, and also the collapse of the Transcona Grain Elevator due to the bearing capacity Failure. Although the development of country is a dominant aspect, but we should not rush for the goals only that diminishing the level of importance of every single construction process, especially the part of geotechnical engineering. A good foundation is an essential key element for all the construction project in providing a stable platform and a strong bearing resistant foundation against settlement, plane failure, and other geotechnical problems.

Basically in the developed or developing country like Malaysia, most of the favorable and strategic locations and lands had already been fully developed and leaving out the challenging ground with either hilly terrain or land with unfavorable underlying materials. Construction on soft compressible soil or loose granular deposits with the modern demands on larger, heavier, and taller structure is a great challenge in the field of geotechnical engineering. There are wide range of geotechnical issues and problems that will gradually emerge in the process of construction in which the problems may include slope instability, bearing capacity failure, shear failure, or excessive settlement. The Leaning Tower of Pisa is one of the famous building in the world at the same time the best example to remind people the important of a foundation. The uneven settlement of the soft clayey underlying materials causes the structural building tilted before the construction completed.

Soil compaction is one of the ground improvement method and a vital step of construction process that are commonly implemented at the site to improve the soil properties after a proper ground investigation is carried out and adequate geotechnical design that is engaged. Soil compaction can defined as the process in which a stress is applied repeatedly to the soil that causes densification through the removal of water and air void from the soil. Besides that, rearrangement of soil grains take place during the compaction without the change in the volume of the solid grains. As compared to the other ground improvement techniques such as vacuum consolidation, preloading of soil, vibro-replacement stone columns, thermal stripping, electro-kinesis, bio-remediation, and the others, compaction technique is considerably a more practical method as it is cheaper, time saving, and efficient.

Soil are materials that are not always orderly arranged and not always exhibit the desired engineering properties for the construction purpose, thus, modification of soil properties at the site become necessary. The ability of the compactness of the soil layer will depend on the nature of the soil material, water content of the soil, site condition, weather, and layer thickness which may affect the compaction performance. The improper compaction process such as insufficient soil compaction, uneven loading, and overloading could causes significant problems to the desired strength of the foundation. Compaction is commonly attained by the use of heavy equipment that usually adjacent with vibration function to encourage the re-orientation of the soil particles into a denser formation.

Proctor compaction test will be carry out at the laboratory to determine the relationship between the dry density and the moisture content of the soil at a given compaction energy level. Compaction curve will be obtained from the result of the compaction test at which the optimum water content and maximum dry density of the soil at certain compaction energy could be identified. There are 2 common compaction standard at the laboratory which are Standard Proctor and Modified Proctor compaction test. The total compaction energy for the Modified Proctor (2695 kJ/m^3) is approximately 4.5 times as compared to the Standard Proctor (593 kJ/m^3).

The soil properties of a soil material are considered been improved when its dry density is increased and its permeability coefficient is decreased. The main objectives of the soil compaction is to achieve the favorable engineering properties for construction purpose such as high load bearing capacity, stable, great stiffness and hardness, high shear strength, low rate of settlement, low porosity and deflection, low permeability, low seepage flow rate, and low infiltration and percolation. All these properties are possible to attain as the soil has achieved the dry density that close to its maximum dry density in which determined from the laboratory test. However, if a great amount of compaction energy that is continuingly apply to a soil that had already achieved a certain degree of compactness which is close to its maximum dry density and the consequence result in a tiny little improvement to the soil properties only, the further compaction will only considered as an unpractical move as it consumed huge amount of energy and cost a lot of money for a small-scale of benefit in return.

Therefore, this research is carry out to determine the optimum compaction energy that is worth to be applied at the site for the most abundant and commonly used soil materials, which are the sand and the laterite soil in term of the density gained and the permeability that is reduced.

1.2 Problem Statement

Over compaction at the field is sometimes thought to improve the soil properties even greater, however, more compaction to the soil that had already achieved a certain level of compactness might considered as an unpractical mitigation as it consume more energy and cost more money to achieve a tiny improvement to the soil properties. Further compaction affords apply to the soil will no longer increase the dry density of the soil due to the absolute compactness of the soil grain and completely fixed orientation of the solid particles that restrain all movement driven by forces from any direction. Therefore, without the re-orientation of the soil particles into a denser formation, there will be no further improvement to the other soil properties consequently.

It is quite uncertain and perplexed when deciding the degree of compaction required at the field by concerning the greatest soil properties that is possible to be achieved with respect to the cost required for the compaction process. When the soil attained its densest density, the desired engineering properties such as high shear strength, high bearing capacity, low compressibility, low future settlement, low infiltration and percolation which is what required and essential to the construction purpose. Thus, the problem that needs to come across is the lacking of the specific laboratory data that show the relationship between the compaction energy level with the dry unit weight and the permeability properties of the soil.

1.3 Objectives

The objectives of this study are:

1. To investigate the relationship between the degree of compaction with the density and permeability coefficient of sand and laterites.
2. To investigate the results of applying higher compaction energy to the soil and evaluate the profitability of doing such in term of the density gained and the permeability that is reduced.

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1.4 Scope of Work

A sufficient amount of proctor compaction test was carried out at the laboratory for both sand and laterite soil to determine the relationship between the dry unit density of the soil and its water content and to obtain their compaction curves consequently. All the compaction curves obtained for each soil type was then integrated into a logarithmic functional graph that comply to the principle of Ohio's curve that show the relationship between the dry unit density and compaction energy level. Further advance analysis was made between the variables that included the compaction energy, the dry unit density and the compaction curve.

From the data obtained in the proctor compaction test, the soil was then subjected to the permeability test with its maximum dry density condition at each compaction energy level. The compaction behavior of the soil that subjected to different compaction energy was then analyzed in term of the density and permeability properties changed. The comparison between the sand and laterites was made in term of all the responsive properties that change along the variable compaction energy factor.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

As all the good land and strategic location have been fully developed and utilized, while the economic demand is continuingly on growth and more development and project is generating, the role of geotechnical ground improvement methods has become crucial to the future earthworks that are mostly present in the unfavorable and undesired engineering properties for construction. Soil are material that are not "made to order" and do not always exhibit the properties desired for construction purpose. Therefore, modification of soil at sites has become necessary to improve the engineering properties of soil to the desired values. Not to mention the importance of the soil's structural strengths, there are also highly essential of the determination of the permeability properties of the soil for the purpose of design and construction of structures. The purposes including the evaluation of seepage through earth dams, dewatering of excavated sites, and the ability to act as the containment barrier in landfill.

2.2 Ground Improvement Methods

There are several options when facing a project encounters to difficult foundation conditions and problems, that included the removal and replacement of the unsuitable soils at the site, adapt with the condition by using deep foundation or shallow foundation, attempt to modify the existing ground, or avoid construction on the particular site. In general, there are two types of ground improvement method that are commonly used at the site, it is simply classified into mechanical and chemical soil stabilization methods.

2.2.1 Compaction Methods

Soil stabilization is the process in which a specific mechanism is applied to the soil to change its physical properties in order to improve its strength, durability and the other engineering properties. The feasibility and suitability on choosing a ground improvement method for a particular project will be depend on several factors. These factors included the type of soil, geological structure, seepage conditions, the cost required, the construction time available, quality of work required, availability of equipment and materials, the impact to the surrounding environment, the type and degree of improvement required, and feasibility of construction control (Patra, 2012).

Vibro-compaction, may also referred as Vibroflotation, is a process of mechanical ground improvement that rearrange the soil particles into a denser configuration to create stable soil foundation. The compaction is done by the use of essence equipment, vibroflot probe for powerful depth vibration. The principle of vibro-compaction is the combined action of vibration and water jetting, the probe is lowered down to the desired depth through the help of water pressure penetration. Suitable granular material is shoveled in to the hole to create a compacted zone for effective vibration mode. Soil materials are considered as suitable for vibro-compaction if the fines content does not exceed 10%. According to a case study at Lome Container Terminal, the maximum depth of vibroflot probe that it should reached have to be taken into consideration if there exists clay layer just below the granular soil materials. The high impact energy of vibroflot water jetting will possibly causes disaggregation of the clay and might reduce the effectiveness of the ground treatment (Cristovao et al., 2016). Vibro-compaction performs excellently for loose sand that underlay below the water table. The advantages of Vibro-compaction are reduction of the risk of liquefaction due to seismic activity and permit construction on granular fills.

Blasting compaction is a deep soil improvement method that is carried out through the setting off of explosive charges in variety depths of ground to densify the soil materials. The explosive energy released causes short-term volume reduction and a sudden increase of pore water pressure within the soil. Liquefaction will potentially occur due to the huge pore water pressure induced within the soil. After an explosive compaction, re-consolidation happens within hours to days right after the dissipation of water pressure, it depends on the permeability of the subsoil and drainage boundary conditions. As comparison, the other compaction method such as vibro-compaction and grouting are expensive while dynamic compaction is limited to shallow and middle depths. Hence, the advantages of blast compaction are fast ground improvement treatment, simple installation and implementation, and cost-effective compaction method (Daryaei and Eslami, 2017).

Dynamic compaction is one of the most common compaction method that used in the construction of parking lots, roadways, and embankments. The extra function of dynamic compaction compared to other compaction methods is that it has greater ability in eliminating appearance of sinkhole. The principle of DC is the process of dropping of heavy weight pounder from a significant height on the ground repeatedly to cause instant densification effect to the soil. Impact roller compaction has the same principle as dynamic compaction, just that the number of impacts per unit of time is higher. Both of these compaction methods is suitable for all soil types, and often used to treat old fills and granular soil (Feng et al., 2013). However, this method is considerably lower effectiveness in deep compaction treatment.

Kneading is a type of compaction where engineering vehicle compactor is rolling or passing through the soil in which the compaction load is mostly depend on the vehicle’s self-weight. The most frequently used kneading compactors are smooth-wheel roller, pneumatic roller, sheep-foot roller, vibrating plates, and tamping foot roller (Holtz and Kovacs, 1981). There are two general types of kneading compaction, it is classified into static and vibratory kneading. Vibratory kneading is suitable for non-cohesion granular soil in which the oscillation of the roller promotes rearrangement of particle orientation. According to a vibratory compaction case study, the compaction efficiency can increased approximately 20% by operating the vibratory frequency close to the resonance (Wersäll et al., 2018). The greater the vertical load of the compaction, the higher the dry density obtained. Besides that, the roller travel speed does not show significant different to the impacted soil, however, basically the slower the roller travel speed, the greater the densification effect (Chen et al., 2016). The compaction to each of the built-in layers is not necessary to be compacted until 100% degree of compaction, however, more compaction efforts applied to the bottom layer of earthwork like embankment is able to magnify the strength of foundation significantly (Kumor et al., 2017).

2.2.1 Proctor Compaction test

It is impossible to determine whether a density test is pass or fail without the determination from proctor test. Proctor compactions were invented to determine the optimum moisture content of a soil at which the soil attains its maximum dry density at a specific compaction energy (Brig et al., 2008). Each point on the compaction curve represents a single compaction test at a specific moisture content, and commonly 5 or more compaction tests are required to complete a compaction curve. At the dry water content side, water acts as lubricant within the soil that ease the movement of particles within the soil. However, as the water content has passed the optimum moisture content, the soil particles cannot move closer together as water has occupied most of the spaced between them (Holtz and Kovacs, 1981).

There are several factors which can affect the compaction behavior of the soil, which are the moisture content, soil materials, and the compaction effort. There are also several density determination methods can be carried out at the field after the compaction works have been done, including the Heavy oil, rubber balloon densometer, sand cone, Shelby tube, and nuclear gauge methods. Field control of compaction are commonly carried out to ensure the accomplishment of the required density of the compacted soil with ease and economy (Headquater, 1992). Proctor test were developed as a standard of comparison for field compaction works, therefore the approximation from the proctor test is not exact to the field compaction. This can be explained since the laboratory proctor compaction is a dynamic-impact compaction system, whereas most of the field compaction is essentially a kneading type compaction (Holtz and Kovacs, 1981). There are some kneading type laboratory compaction test that are able to simulate the compaction behavior at the field, which including the Texas gyratory shear, California kneading compactor, mobile steel wheel simulator, Arizona vibratory-kneading compactor, and Marshall mechanical hammer (Alberto et al., 1989).

2.3 Properties of Sand and Laterite

2.3.1 Laterites

Laterite soils are rapidly found at high level in Malaysia, and occupied the widest range in Brunei, Borneo, and Sarawak. Laterite is a highly weathered material that rich in content of oxide of iron and aluminum, quartz and kaolinite. Many laterites profiles have been studied in different region, therefore there are slightly various in soil properties upon the sources it came from. It is found that the higher the sesquioxide content (eg. Iron oxide, magnesium oxide, and other oxide compounds), the less hydrated the laterites, the greater the induration and hardness of the soil (Maignein, 1966). Lateritic soil is sensitive to the pre-treatment of the sample that prior to laboratory testing. From a research study, there is significant difference between the plasticity index of laterites sample prepared from air-drying and oven-drying method. Huge reduction in the plasticity of laterite that was prepared from oven-drying, air-dried sample is recommended as it more representative of in situ condition (Mahalinga-Iyer and Williams, 1991). The parent rock of laterites is weathered to form a clayey soil and consequence to the increasing of cohesion and decreases in the void ration of lateritic soil with increasing specific gravity. Thus, the engineering properties of the lateritic soil is more favorable as the degree of weathering of laterite's parent rock is more rapidly (Lohnes and Demirel, 1973).

2.3.2 Sand

Sand is a naturally loose granular material results from the disintegration of rocks and mineral particles. Sand is classified as coarse-grained soil as the size of the solid grain is greater than 75 micrometer in diameter according to the USCS standard. Although sand and laterites both are the natural soil materials on the earth, however, both exhibit a tremendous characteristics difference in term of the physical and engineering properties. To clarify, laterites is a cohesive fine-grained soil while sand is a non-cohesive coarse-grained soil. Due to the solid grain and weak cohesive properties of the sand, it usually exhibit strong hydraulic conductivity and greater permeability properties as compared to the fine-grained soil. The amount of fine-grained soil containment in the sand may change its hydraulic conductivity substantially (Braja and Khaled, 2014). Coarse granular sediment can have a serious erosion problem when subjected to seepage flow and rising of water table. Erosion and failure of loose sediments like riverbank can possibly occur due to the loss of matric suction and disappearance of apparent cohesion in loose sediment result of the rising of water table or river stream (Nardi et al., 2012).

Replacement of water into the pores of particles and forms water menisci which acts as a glue at the grain contact points, is so called as the matric suction of soil. This water menisci may enhance the friction and cohesion at the inter-particle contacts which proves that unsaturated sand exhibit greater strength than saturated sand. As compared to fine-grained soil, the coarse-grained soil like sand has a very low ability to sustain water menisci between the particles as water exists mainly as free pore water, while in fine-grained soil the water is adsorbed on particle surface by the strong adhesion force becomes dominant (Farouk et al, 2004).

2.3.3 Role of Clay

The first impression to the existence of clay is the cohesive properties that act as a binding agents to hold the soil together. The presence of clay in any coarse-grained particles can greatly change the physical and chemical properties of the soil. By comparing with the fine-grained soil, sand and silts are considerably inert and usually have an immoderate proportion of large pores with low water-holding capacity. Clay have greater textural pores and lower structural pores compared to coarse-grained soil, thus clay have relatively higher water holding capacity and lower permeability properties. Apart from that, with the stronger adsorption properties of soil in the presence of clay tends to have greater nutrient content (Page et al., 1949). As a consequence, the high portion of clay material that underlay beneath the construction's soil profile is markedly unfavorable due to its high volumetric strain properties. The swelling and shrinkage problems of the clay particles result from the change in moisture content will greatly affect the stability of the construction foundation. Atterberg limits test can be carried out to determine the change of soil behavior with the increment of water content. For soil in the presence of clay, clay may acts as filler to fill in the pores between the coarse-grained particles and increase the water absorption properties of the soil. Hence, it increases the plasticity of the soil which hold its shape when subjected to compaction in a mould. The shear strength of fine-grained soil will greatly depend on internal friction forces and cohesion force while for non-cohesive soil will depend upon the internal friction force only (Compton and Strohm, 1968).

2.4 Compaction Behavior

2.4.1 Compaction Behaviors of Soil

According to the research conducted by Horpibulsuk et al., (2013), the optimum moisture content of lateritic soil lies within 7% to 12% with 19.5kN/m^3 to 21.5 kN/m^3. There are total of 64 samples of each type of soil materials are used for compaction and CBR tests. Ohio's compaction curves were plotted that form from the combination all the compaction curves of the samples from each soil materials. The Ohio's curve shows clearly the range of optimum moisture content and maximum dry density for each soil type that are most possibly located at. The results also proved that the CBR values increases linearly with the increasing dry density value ranging from 90% and 100% degree of compaction. Besides that, the dry density and CBR values increase with the logarithm increment of the compaction energy, which means the greater the degree of compaction, the exponential increment of compaction energy is required. The results also identified that the further compaction efforts will no longer increase the dry density when the soil has achieved certain degree of compaction that range above 98% degree of compactness.

From the study carried out by Sreenivasulu et al., (2014), it investigated how the coarse-grained soil fraction can possibly influence the compaction characteristics and

CBR strength of the fine-grained soil. The results of the study shows that the optimum moisture content (OMC) decreases as the coarse fraction of the soil increases, whereas the OMC is found increases with the coarse fraction level after reached 40% of coarse-fraction. Apart from that, the optimum CBR strength of the soil is achieved when the coarse fraction of the soil is around 5% to 10%, however, the CBR strength decreases sharply after 10% of coarse fraction.

The paper from Sridharan and Nagaraj (2005), is about clarifying the correlation between the engineering properties and the plasticity characteristics of the compacted soil materials. The results of the paper proved that soil samples with similar liquid limit but different plastic limit and plastic index will result in different soil properties at which the compaction curves obtained are vastly different. Hence, the experiments proved that the correlation of the compaction characteristics with liquid limit is not justified. On the other hand, correlation between compaction characteristics with the plastic limit was carried out and it showed more satisfactory and consistent data. The consequent equations is then obtained: $OMC = 0.92PL$ and $\gamma_{dmax} = 0.23(93.3 - PL)$

The variation of void spaces of a compacted coarse-grained soil is typically depends on the compaction energy applied, nevertheless, it may also be remarkably influenced by the soil gradation properties. The present of finer fraction in coarse-grained soil play a relatively important role in the effectiveness of compaction. Hence, the well-graded and gap graded soil may induce greater densification effect from the compaction efforts (Chiaro et al., 2012). Besides that, a statement was made from a real case study, there is no necessary to compact each layer of the soil to the full degree of designed compactness, since the compaction efforts to each successive layer will generate the compaction effect in the previous built-in layer of the backfill (Kumor and Kumor, 2016).

2.4.2 Effect of Compaction to the Hydraulic Conductivity of Soil

According to Shackelford and Javed (1991), the permeability tests conducted in this paper is more or less similar with the methodology that carried out in my research. The soil sample from each type of soil was compacted using the same energy specified in the proctor compaction tests that was previously carried out. The samples were compacted at ±3% optimum water content, at which the dry unit weights were at least 95% of the maximum dry unit of the soil based on the compaction curves. This journal stated that the in-situ permeability of compacted clay soil can be as much as two to three orders of magnitude higher than the permeability values predicted by laboratory tests. There are two possible reasons that are able to explain to this fact. First is due to the soil samples prepared has passed through No.4 sieve where the portion of larger soil particles has been eliminated from the permeability test. Second is the fixation of the diameter in Proctor mould which are not representable to the compaction situation that happened in the wide field soil and this represents the attempt of the author to evaluate the effect of permeameter scale to the permeability of soil resulted from the permeability test. From the result obtained in this journal, the permeability values of large-scale permeameter are 2.3 to 2.4 orders of magnitude higher than the corresponding values from the small-scale premeameter. The explanation of the author to this occurrence is the horizontal displacement of the soil resulted from compaction are experienced more by the large-scale permeameter. The energy during compaction is more capable of breaking the clods apart in the small Proctor mould rather than displacing the soil laterally in the large-scale permeameter.

From the study of Chen et al. (2016), the hydraulic conductivity at different degree of compactness of soil is investigated and analyzed. The experimental results show that the higher degree compactness of unsaturated soil will give rise to a flatter soil-water characteristic curves (SWCC) and this is possibly due to the tighter compactness of soil resulting in greater degree of saturation of the soil. The increment in degree of saturation will result in lower matric suction of the soil. However, both saturated and unsaturated soil tend to have lower hydraulic conductivity due to the larger structural pores of the soil.

From the research of Tatsuoka and Correia (2016), to ensure efficient and effective soil compaction at the field, two aspects should be considered. First is to ensure the degree of saturation to be equal or close to the optimum degree of saturation as determined from the laboratory test. Second is to meet the dry density of the soil at the field to be within designed dry density region. The research do interpret the relationship between dry density and water content at which the regions where the soil is in high strength and stiffness, small settlement, and low permeability. By meeting this two criteria at the field, the soil is enough to achieve the soil properties required in design.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter discusses about the research methodology and the details of all the activities that carried out throughout the research period. The general processes that carried out throughout this research have included the desk study, laboratory experiments, data analysis, and result interpretation. The process of desk study plays an important role in strengthening the basic understanding and fundamental knowledge that related to the study area of the project. Apart from that, it also provides extra ideas in research implementation and clarify the process mechanism to smoothening the progress period. Laboratory tests were conducted to determine the important parameters and identify the relationships between the experimental variables. After all the necessary data and graphs have been fully acquired, result interpretation was carried out and comply the results with the expected outcomes.

3.2 Preliminary Action

All of the laboratory experiments and analysis were conducted for both of the research samples, which are the river sand and laterite soil. This experimental procedures was planned before the laboratory works get started in order to set out all the major works in detail and reduce the amount of human errors that might occurred. All the steps that listed in the flow chart below must be accomplished satisfactorily to ensure the final results of the research are able to interpret in comprehensive. There are total of 12 sets of proctor compaction tests with different degree of compaction energy and 12 sets of falling head permeability tests are required to carry out at the laboratory.

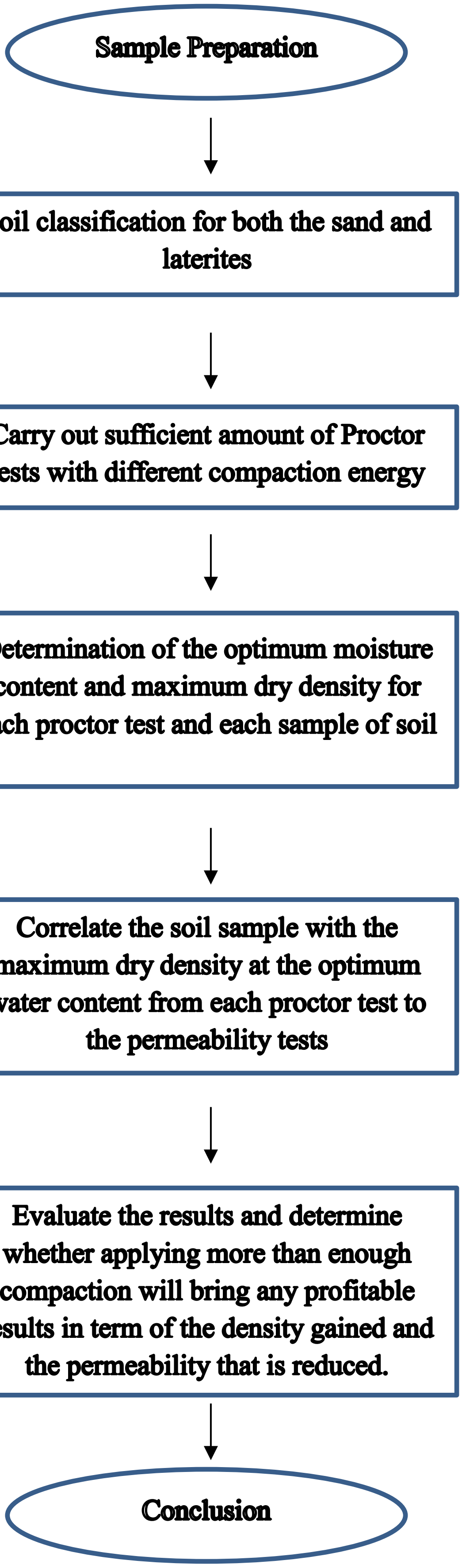

Figure 3.1: Flowchart of Experimental Methodology

3.3 Experimental Procedure

3.3.1 Sample Preparation

Sample preparation is a vital step in analytical experiment where the samples are treated prior to the purpose of analysis. Laterite soil is one of the study sample in this research at which was collected from the Bukit Benggali in Bandar Baru. Whereas, the next research sample is a non-cohesive coarse grain soil, the river sand. Before the soil samples is proceeded to any of the laboratory experimental use, the samples were oven-dried at 110˚C ± 5˚C for 24hours to remove the water content of the soil entirely.

3.3.1 Soil Classification

The main objective of soil classification is to describe the texture and grain size of the soil for engineering and geology purpose. There are two separated procedures for soil particles size analysis, which are mechanical sieve analysis and hydrometer sedimentation analysis.

Mechanical sieve analysis is carried out for the determination of the portion of each size range of particles that is at least greater than 75µm in diameter. In brief, sieve analysis is carried out for coarse-grained soil that the grains sizes range between gravel- and sand-size only. Before mechanical sieving is conducted to the sample, separation between the coarse-grained and fine-grained soil is an essential step to be carried out. The sample was carefully washing through the No.200 sieve (75µm) to prevent losing of material. The water and sediments that washed through the 75µm sieve was collected for the hydrometer sedimentation analysis later. The washed sample was oven-dried again before mechanical sieving to ensure the same sample weight before and after the experiment. The sample was put on the top sieve of a complete set of sieves, the sizes of the sieves that are included are 14mm, 10mm, 6.3mm, 5.0mm, 4.75mm, 2.0mm, 1.18mm, 0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm, 0.075mm and pan. Mechanical sieving was conducted for 10-15 minutes, the portion of soil sample retained at each sieve sizes was calculated and the particle size curve was plotted for the classification of the soil grade. Redo is required when the total percentage loss of weight before and after sieving is more than 2%. The classification of the sample soil is referred to the standard of Unified Soil Classification System (USCS) as shown in the figure below.

Criteria for assigning group symbols				Group symbol
Coarse-grained soils More than 50% of retained on No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW
			$C_u < 4$ and/or $1 > C_c > 3^c$	GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 5.3)	GM
			$PI > 7$ and plots on or above "A" line (Figure 5.3)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3^c$	SW
			$C_u < 6$ and/or $1 > C_c > 3^c$	SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 5.3)	SM
			$PI > 7$ and plots on or above "A" line (Figure 5.3)	SC
Fine-grained soils 50% or more passes No. 200 sieve	Silts and clays Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 5.3)[e]	CL
			$PI < 4$ or plots below "A" line (Figure 5.3)[e]	ML
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 5.3)	CH
			PI plots below "A" line (Figure 5.3)	MH
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

[a]Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

[b]Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

[c]$C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

[d]If $4 \leq PI \leq 7$ and plots in the hatched area, use dual symbol GC-GM or SC-SM.

[e]If $4 \leq PI \leq 7$ and plots in the hatched area, use dual symbol CL-ML.

Figure 3.2: Guideline of soil classification (USCS) (Das and Sobhan, 2014)

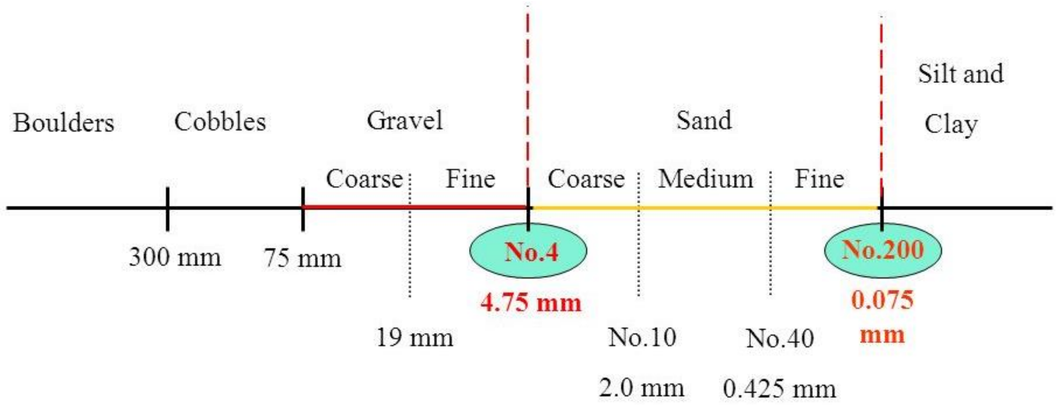

Figure 3.3: Particle grain size distribution according to USCS

(Likos, 2014)

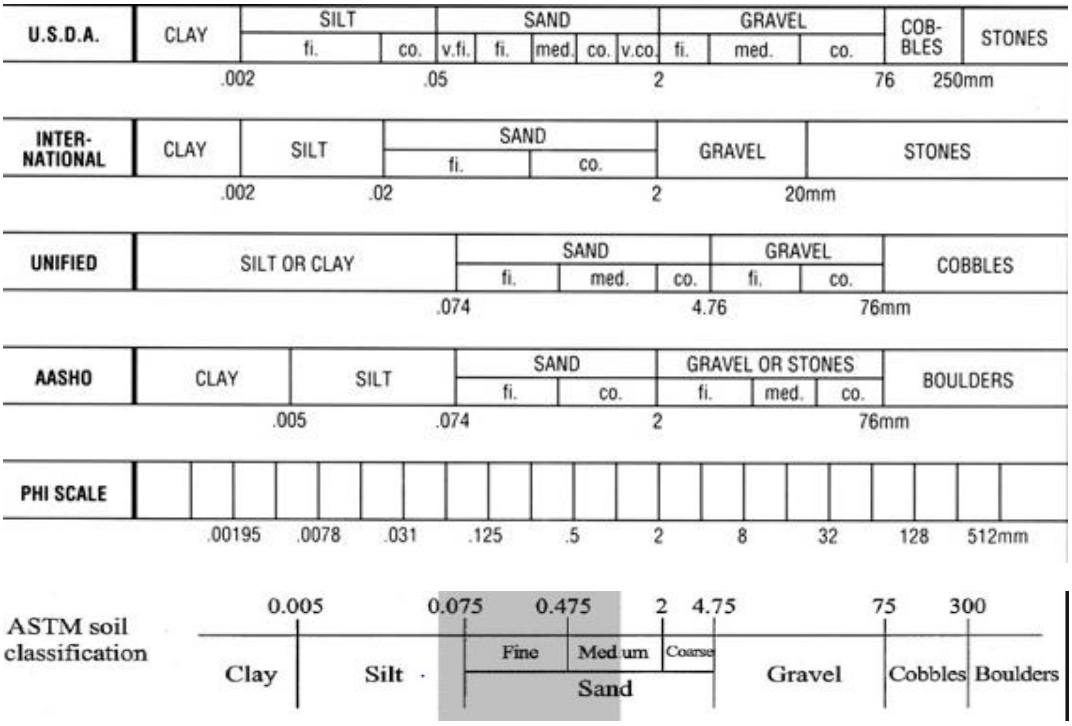

Figure 3.4: Grain size ranges according to several engineering soil classification system (Ditzler et al., 2017)

Hydrometer or sedimentation analysis is carried out to determine the portion of particle sizes of fine-grained soil (particle size diameter less than 63µm). According to Stokes' Law, the terminal velocity at which grains settles out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain. All particles is assumed to have similar density and shape. The relationship between terminal velocity, V and particle diameter, D is stated as $V \propto D^2$. The derived equation for the particle diameter of silts and clay is

$$\textbf{Effective Depth, Hr} = \mathbf{H} + \frac{1}{2}\left[h - \frac{Vh}{900}L\right] \quad \textbf{(3.1)}$$

$$\textbf{Particle Diameter, D} = \mathbf{0.005531}\left[\frac{nHr}{t(Ps-1)}\right]^{\frac{1}{2}} \quad \textbf{(3.2)}$$

Where, D is the diameter of particle, Ps is the mass density of the solid particle, Hr is the particle fall distance, T is the falling time, V is the volume of bulb, L is the distance from 100ml to 1000ml, n is the dynamic viscosity of fluid, h is the length of bulb, H is the length from the neck of the buck to graduation

Temperature (°C)	Water	
	Viscosity (μ) N·sec/m²	Kinematic Viscosity (ν) m²/sec
0	1.781×10^{-3}	1.785×10^{-6}
5	1.518×10^{-3}	1.519×10^{-6}
10	1.307×10^{-3}	1.306×10^{-6}
15	1.139×10^{-3}	1.139×10^{-6}
20	1.002×10^{-3}	1.003×10^{-6}
25	0.890×10^{-3}	0.893×10^{-6}
30	0.798×10^{-3}	0.800×10^{-6}
40	0.653×10^{-3}	0.658×10^{-6}
50	0.547×10^{-3}	0.553×10^{-6}
60	0.466×10^{-3}	0.474×10^{-6}
70	0.404×10^{-3}	0.413×10^{-6}
80	0.354×10^{-3}	0.364×10^{-6}
90	0.315×10^{-3}	0.326×10^{-6}
100	0.282×10^{-3}	0.294×10^{-6}

Figure 3.5: Viscosity of water

(Robert et al., 2009)

Next, the volume of solution prepared inside the cylinder was adjusted to $1000cm^3$ that included 125ml of 4% sodium silicate dispersing agent, distilled water and fine-grained soil of the sample. The hydrometer reading was recorded at 1, 2, 4, 8, 15, 30, 60, 120, and 1440 minutes. The scale calibration of hydrometer was recorded.

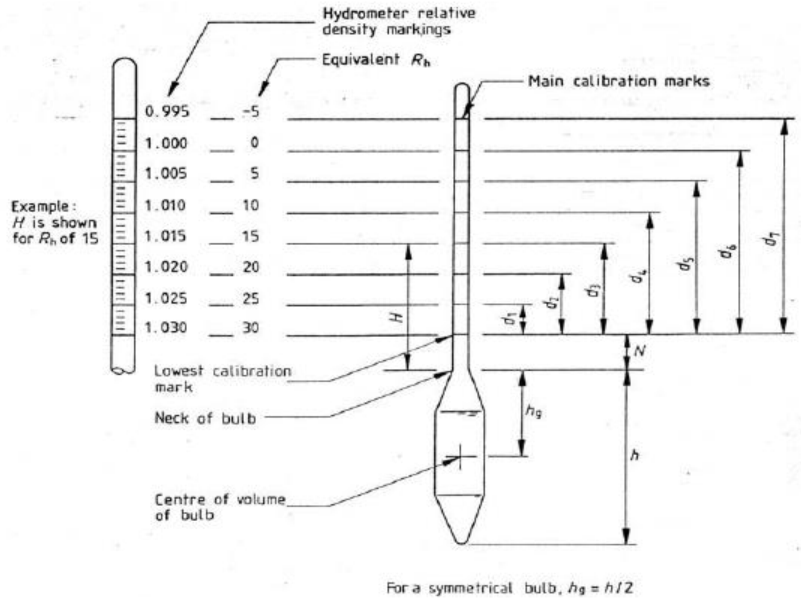

Figure 3.6: Essential measurement for calibration of hydrometer

(School of Civil Engineering, USM, 2013)

According to USCS, Atterberg Limit test may require to carry out at certain conditions of soil grade where plastic limit or liquid limit are required for the specific soil classification. Based on the results obtained from the mechanic sieve and hydrometer analysis, the final classification may refer to the guideline in Table 3.1.

3.3.2 Proctor Compaction test

Determination of optimum compaction number by the compactor at the site can be done by obtaining the in-situ density of soil and comparing it to its maximum dry density determined at the laboratory test. When conducting the compaction test, it is important to measure the dimensions of the mould and record the weight of the apparatus that are essential data during the calculation progress. The prepared sample are required to sieve through No.4 sieve to prevent oversize of the soil particles. There are basically