ANALYSIS ON THE EFFECTS OF GRADATION OF SAND ON SHEAR STRENGTH CHARACTERISTICS

PRABAGARAN A/L SRIGARAN

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2019

ANALYSIS ON THE EFFECTS OF GRADATION OF SAND ON SHEAR STRENGTH CHARACTERISTICS

By

PRABAGARAN A/L SRIGARAN

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2019

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to several individuals for supporting me throughout my undergraduate degree study. I would like to express my utmost sincere thanks to my supervisor, Dr. Mastura Azmi for her endless guidance, motivations and supports. Thank you for always providing me hope and encouragement during my hard times.

I am also indebted to the assistant engineer of Geotechnical Engineering Laboratory, Universiti Sains Malaysia, Mr. Zabidi, who has shared his knowledge and guided me throughout my project. With his help and guidance, I have completed my project which is definitely considered to be great a challenge for me.

Special thanks to my friends, Satiskumar and Vijeykumar for sharing his knowledge and helping me in doing this project.

ABSTRAK

Kajian ini tertumpu pada penggredan pasir yang mempengaruhi parameter kekuatan ricih dengan ketara. Kajian ini juga memberi tumpuan kepada kesan kotak ricih kecil dan besar pada penggredan tanah yang berlainan. Semua ujian dijalankan pada pasir kering, saiznya dari 0.063mm hingga 2mm. Analisis ayakan dilakukan untuk mengklasifikasikan bahan ke pasir halus, pasir sederhana dan pasir kasar, manakala, ujian ricih langsung dalam skala kecil dan besar dijalankan untuk menentukan parameter kekuatan ricih sampel. Peningkatan ini disebabkan oleh kesudutan yang lebih baik dan kekasaran permukaan pasir kasar yang menjadikan pasir lebih tahan terhadap ricih. Saiz kotak ricih mempunyai kesan terhadap keputusan ujian. Skala kotak ricih yang lebih besar memberikan sudut geseran yang rendah. Penurunan sudut geseran disebabkan oleh ruang yang cukup untuk zarah-zarah pasir di dalam kotak untuk mengembangkan kumpulan geseran individu sepenuhnya dalam zon ricih. Dibuktikan bahawa pasir kasar mempunyai sifat kekuatan ricih yang lebih baik dan sesuai digunakan untuk pembinaan struktur geoteknik yang akan menghalang kegagalan pada masa akan datang. Hasil kotak ricih yang lebih besar lebih dipercayai kerana ia memberikan hasil yang lebih tapat berbanding dengan kotak ricih kecil. Ia akan menghalang penganggran berlebihan parameter kekuatan ricih dalam reka bentuk.

ABSTRACT

This study concentrated on gradation of sand which affects shear strength parameters significantly. This study also focusing on the effects of small and large shear boxes on different soil gradation. All tests were conducted on fully dried sand, sizes ranging from 0.063mm to 2mm. Sieve analysis is done to classify the material into fine sand, medium sand and coarse sand, while direct shear test in small and large scale were conducted to determine shear strength parameters of the samples. It was found that friction angle tend to increase as the percentage of coarse sand increases in the sample. This is due to the improved angularity and surface roughness of the coarser sand which makes the sand to be more resistant against shearing. Size of shear box has an impact on test results as friction angle decreases when larger scale of shear box is used. The decrement in friction angle is caused by space enough for the sand particles in the box to develop individual shear bands fully within the shear zone. It is proven that coarser sand has better shear strength properties and suitable to be used for the construction of geotechnical structures which will prevent failures in future. Results of larger shear box is more reliable as it gives more accurate results compared to small shear box. It will will prevent overestimation of shear strength parameters in design.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

Penang island is located at Malacca Straits, off the northwestern coast of Penisular Malaysia. The climate of this island is tropical with the average mean daily temperature of about 27^{o}C. The mean daily minimum and maximum temperature ranging between 23.5^{o}C to 35.7^{o}C. It is a famous tourism spot which has attracted a lot of people worldwide. This 293km^2 hilly island is inhabited by 700,000 people. Due to high demand of residential areas and economic centers, most of the flat land is used for development. Inadequate flat land has led local and foreign developers to develop their projects in hilly and terrain areas which is considered risky and dangerous in terms of geotechnical engineering depending on several factors. Development in these areas can resulted in landslides and other catastrophic disasters. To obtain appropriate understanding, it is necessary to analyze them not only through geotechnical engineering knowledge but also through other associated fields like geology, geomorphology, hydrogeology, climatology and other earth and atmosphere related sciences. Research is actively conducted by many parties focusing on natural deposits of local significance, and a unified framework that can account for all important effects is still being developed.

Most part of Penang Island is underlain by igneous rocks. All igneous rocks are granites as stated by Streckeisen et al. (1967). As a result, distribution of granitic residual soil widely found in Penang island. These granites can be classified on the basis of proportions of alkali feldspar to total feldspars. Different researchers give different definitions for residual soil. However, from all such definitions we can conclude that the residual soil is a material formed in situ by weathering of rocks and remained at the place where it was formed. For instance, one of the definition says "residual soils are those that form from rock or accumulation of organic material and remain at the place where they were formed" as described by Bergman et al. (2000). Based on Public Works Department of Malaysia the soil is defined as 'a soil which has been formed in situ by decomposition of parent material and which has not been transported any significant distance' and residual soil as "a soil formed in situ under tropical weathering conditions" Public Work Institute (1996).

F. Ahmad et al. (2008) conducted a study on the characteristics of soil taken from the hilly areas in Penang Island. From the study, they concluded that slopes become unstable and might fail when higher moisture content, higher value of liquid limit, higher % of clay portion and thicker layer of clayey soils existed in the stable soil slope. The composition of Penang residual soil varies slightly over the island. Researchers stressed that the higher the percentage of sand and silt, the higher is the risk of the stable slope to be eroded. S. Maail et al. (2004) mentioned that immediate action should be taken to prevent major slope failure where uncontrolled erosion is taking place. Gue et al. (2006) stated that most of the tropical residual soils are affected by drying where the index properties may change drastically even by partial drying. Effective actions must be taken to ensure that moisture loss from the soil samples is prevented and laboratory tests to be carried out as fast as possible.

F.Ahmad et al. (2006) described in detailed about the characteristics, nature, structural features, engineering behaviour and field properties of soil samples in Penang Island. They found that the soil around Penang Island is either silty, clayey or sandy. M.H. Chu et al. (1997) report concludes that the coastal area in the north and south of Penang Island is of rocky type and partially sandy beach. Based on aerial photographs, topography and coastal map and field observation works, Abdul Hadi Abd Rahman et al. (2000) pointed out some results which can be visually compared with the TiungSAT-1 image. Streckeisen et al. (2000) mentioned that the thickness of residual soil layer varies from place to place depending upon the factors responsible for weathering like temperature, rainfall, chemicals present, compositions of parent rocks, etc. and the extent to which the weathering process has advanced.

Investigating the moisture content of the natural residual soil is very important because it shows the ground characteristics that affected by the water content especially the lands that contain high percentage of fines. However, natural moisture content increases with increasing clay content due to the ability of clay particles to absorb the water. Generally, moisture content of the soil is increasing with increasing depth because evaporation is taking place at top part of the ground. Studies show that natural moisture content of granite residual soil in Malaysia is in the range of 5% - 50%. According to Lee, C.M. (1967), Tan et al. (1993) and Zhao, J (1994), sand and silt content increases with depth while clay content decreases with depth. Granite residual can be classified as a composition of sand-silt-clay as stated by Ting, W.H. et al. (1976). As mentioned by most of the researchers, the shear strength of residual soil is highly affected by the percentage of fines especially clay. Thus, an analysis on the effects of composition of residual soil on shear strength will give significant information about the behaviour of the soil.

1.2 Problem Statement

Many man-made and natural slopes and geotechnical structures fail in Penang even though designed by experienced engineers. One of the factor is lacking of knowledge on sand which leads to overestimating the shear strength parameters of the soil. These engineering failures will contribute to losses to the country directly and indirectly in terms of lives, properties and economy. Thus, a study is needed to understand the characteristics and properties of sand to avoid any failures in future. The characteristics and behaviours of coarse grained soil are controlled by grain size, grain size distribution, and particle size and shape, and characteristics of fine grained soil are controlled by minerals and water content. Size of particles influences the engineering properties of soil. Soil containing wide range of particle size is referred as well graded while others containing several particle size is referred as uniform graded and containing narrow range of particle called gap graded soil. Soil gradation is a classification of particle size distribution of coarse grained soil and fine grained soil that controls the coefficient of uniformity, C_u and coefficient of gradation, C_c which affects shear strength parameters extremely. C_u and C_c control shear strength parameters like friction angle directly. Therefore, this research will study about the effects of soil gradation of sand on shear strength characteristics using direct shear test. Small shear box and large shear box will be used in this study. J. D. Parsons. (1936) conducted a test on few samples of sand by using different sizes and concluded that friction angle of sand was slight decrease with increasing the size of shear box. Thus, effects of sizes of shear box on the test results also will be studied in this experiment.

1.3 Aim and Objectives

The aim of this study is to analyze the effects of gradation of sand on shear strength characteristics and to compare the results of direct shear test using small and large shear boxes.

Objective

At the end of this study,

i. we will able to determine the effects of soil gradation of sand on shear strength characteristics.

ii. we will able to compare the results of small and large shear boxes using different gradation of sand.

1.4 Scope and Limitations

The scope of this project is limited to the geotechnical engineering projects that involve granular particles as materials. This project only involves use of direct shear test which limits the collection of data compared to other tests. Apart from that, direct shear test also fails on predetermined failure plane which differs from real cases.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In order to develop a safe, efficient and cost effective geotechnical structures in Penang Island, few productive methods can be carried out. Understanding the characteristics and properties of sand remarkably is definitely one of the very important method to change the current scenario. The gradation of sand plays a vital role in controlling the shear strength. There are many studies conducted on sand that will unquestionably improve the productivity and safety of natural and man-made geotechnical structures in Penang.

Thickness of residual soil layer changes from place to place depending upon several factors (Table 2.1) responsible for weathering such as, rainfall,compositions of parent rocks, temperature chemicals present etc. and the level to which the weathering process has advanced as stated by Bergman et al. (2000) .

Table 2.1:Factors responsible for weathering: Bergman et al. (2000)

Factors	Description
Climate	Refers to the effect on the surface by temperature and precipitation.
Geologic	Refers to parent material (bedrock or loose rock fragments) that provide the bulk of most soils.
Geomorphic	Refers to the configuration of the surface and is manifested primarily by aspects of slope and drainage.
Biotic	Consists of living plants and animals as well as dead organic material incorporated into the soil.
Chronological	Refers to the length of time over which the other factors interact in the formation of the particular soil

In Malaysia, tropical residual deposits are found in abundance and because the climate is hot and humid throughout the year, the formations are intense with a predominance of chemical weathering over other form of weathering, thus resulting in deep weathering profiles and soil mantles often exceeding 30 m as mentioned by Tan, B.K (2004).

Table 2.2: Classification of weathering profile: Komoo et al. (1988)

Term	Zone	Description
Residual soil	VI	All rock material is converted to soil. The mass structure and the material fabric (texture) are completely destroyed. The material is generally silty or clayey and shows homogenous color
Completely weathered	V	All material rock is decomposed to soil. Material partially preserved. The material is sandy and is friable if soaked in water or squeezed by hand. No rebound from N Schmidt hammer.
Highly weathered	IV	The rock material is in the transitional stage to form soil. Material condition is either rock or soil. Material s completely discolored but the fabric is completely preserved. Mass structure partially present. Positive N Schmidt rebound value up to 25.
Moderately weathered	III	The rock material shows partial discoloration. The mass structure and material structure is completely preserved. Discontinuity is commonly filled by ironrich material. Material fragment or block corner can be chipped by hand. N Schmidt rebound value 25 to 40.
Slightly weathered	II	Discoloration along discontinuity and may be part of rock material texture are completely preserved. The material is generally weaker but fragment corners cannot be chipped by

		hand. N Schmidt rebound value greater than 45.
Fresh rock	I	No visible sign of rock material weathering. Some discoloration on major discontinuity surfaces. Makes ringing sound when struck by hammer.

Oedometer and triaxial compression tests can be used to determine compressibility of tropical residual soils. Even though it is difficult to get undisturbed residual soil samples due to trimming which contain gravel, it is advisable to use undisturbed sample to get more reliable results. Usually 2 - 8 tests should be conducted depending upon the complexity of the condition as stated by Brand et al. (1985) . However, compressibility of coarse grained soils cannot be measured using oedometer and hence not advisable for testing predominantly coarse grained residual soils. In that case triaxial test is more suitable. Geoguide 3, Public Works Department (1996) recommends the use of Rowe Cell, which is suitable larger samples and provide better drainage conditions. Compression tests normally take days to complete.

According to U.S Bureau of Reclamation, poorly graded sand (SP) has the highest permeability coefficient compared to other nature of soil. Goktepe and Sezer (2010) mentioned that a constant head-permeability test is used to determine the effect of particle size and shape distribution on the permeability of the soil. The materials used for testing were separated into poorly graded uniform coarse, medium and fine sand and also well graded sand.

2.2 Shear strength of sand

Based on P.W Rowe (1962) findings, three components contribute to the shear strength of sand which are strength mobilized by frictional resistance, strength developed by energy required to cause expansion or dilation of materials and strength developed by energy required to rearrange and reorient materials. Frictional resistance often referred as sliding friction while the second and third components known as interlocking friction and rolling friction. According to Yong et al. (1975) sliding friction results from surface roughness; physical resistance to relative particle translation affected by adjacent particles causes interlocking friction while rolling friction can be ignored. Based on Santamarina et al. (2001) and Been et al. (1991) frictional characteristics is directly influenced by the nature of contacts between soil particles. Higher shear strength is caused by dense sand angular particles, loaded in shearing, presents at early stage tangle grains which mobilize more friction. No matter what is the density, when subjected to large deformations, the critical state reached for the sand, gives the material a quasi-constant friction angle.

According to Viggiani et al. (2001) who are aiming at the changes of internal friction angle according to the gradation, have shown that sands consisting of feldspar and calcite, the friction angle increases with the increase of the Uniformity Coefficient C_u . At the same time, Zelasko et al. (1975) explain that for sands which are mainly consisting of quartz, the studies did not show any bond between the two. The shape of the particles can be identified through the sphericity and the roundness of the particles, by visual comparison with charts.

The shape of soil grains affects the engineering behaviour of the soils. Round grains are more likely to slip and roll than angular fragments. Natural sand and crushed sand has difference shape. Natural sand has the roundness and roughness. The shape of natural sand can be altered during transportation or through weathering. On the other hand, crushed quartz sand tends to be equidimensional or elongated in shape. This is because quartz has no cleavage. According to G. Mesri et al. (2009), particle rotation is a basic component of deformation during compressibility of granular materials, which is affected by the shape of the grains.

According to Lambe et al. (1969), reduction in particle size causes the characteristics of shear behavior of coarse-grained soil to change when compared with coarse-grained soils with an actual size. Notable differences in coarse grained soils can be seen in terms of type of parent rock, the density of sample, particle size and the crushing of particles pursuant to compaction energy when compared with other ground materials. Based on the studies conducted by Islam et al. (2011), the variation of strength behaviour is caused by the size of the particles in the granular mass.

Effects of particle size on two cohesionless materials conducted by Kirkpatrick (2011) shows that an increase in particle size reduces the friction angle. Holtz and Kovacs (1981) metioned that peak friction angle will not be affected by the particle size if the void ratio is same. Ultimate friction angle is equal to the angle of repose in direct shear tests as stated by Atkinson (2007). Angle of repose of the coarse, medium and fine sands were determined as per ASTM C1444 (2001) to confirm with the findings. The method is conducted by using a glass funnel filled with dry sand that is held at a specific height to form a sand heap until the funnel touches the heap.

Charles and Watts (1980) showed that with the maximum grain size of 75 mm, the friction angle in material is 3 degrees greater than the friction angle in material with maximum diameter of 10mm. Ogbonnaya et al. (2009) had found that well-graded specimens in medium dense to dense states have higher values of peak strength than the rest of the specimens at the same condition, with the difference appearing to increase with relative density. The values are ranked as, well graded > intermediately graded > narrowly graded > gap graded. Better interlocking in the well graded specimens of particles at contacts achieved by mixing a wide range of particle sizes is thought to be responsible for the higher peak strength values associated with the well graded specimens.

According to Wang et al. (2013), the effects of particle size distribution on shear strength of accumulation soil showed that the angle of shearing resistance is generally increasing with increasing median particle diameter and gravel content.

2.3 Comparison between small and large shear box test results

Linear incremental strain in the soil along the central plane is restricted due to the rigid end boundaries in a direct shear test remain fixed. this restriction also applies locally in the soil along the central plane that is shown by internal measurement using radiography as stated by Assadi (1975). Test arrangement notably affects the measured properties of the soil especially comprehensive and peak shearing resistances that were measured, varied only by changing the boundary conditions in the test as mentioned by Assadi (1975).

The size of direct shear test specimen affects friction angle of the sample. This is proven by previous researchers, Parsons (1936) and Palmeira and Miligan (1989) as they found different results from small and large shear box tests. Results of Parsons

(1936) of Ottawa and crushed quartz revealed that friction angle decreases with increasing size of shear box.

Results of Leighton Buzzard Sand used by Palmeira and Miligan (1989) showed no difference in friction angle when used different sizes of shear boxes. However, they did find that size of shear boxes significantly affects the thickness of the shearing zone. According to Ingold (1982), friction angle obtained from 300x300mm shear box is 2-3° lower than that obtained from 60x60mm shear box. Taylor and Leps (1938) mentioned that friction angle of oven-dried Ottawa sand measured in small direct shear box is 0.5° larger, on average, than that measured in large shear box.

According to Scarpelli and Wood (1982) and Stone and Wood (1992), shear zone formed in the direct shear box is affected by box length and height. Shear bands will start to form at the edge of the box and continue toward middle of the specimen as the shear box starts to move. At one point, soil particles near the edge of the box experience greater strain than the soil particles at the middle of the specimen as a result of continuous failure. As the shear box size increases, horizontal shear shear rupture gets bigger as there will be more space for the soil particles to rearrange themselves and more space for the shear zone to completely develop and dilate to a critical state. Thus, larger size of shear box is suitable to represent the strength found in field conditions.

As mentioned by Hight and Leroueil (2003), shear box height also affects friction angle of the sample. A smaller direct shear box has larger thickness of shear zone compared to the box thickness. This will result in overestimation of friction angle as there is not enough space for the sand particles in the box to develop individual shear bands within the shear zone.

According to Cerato and Lutenegger (2006), friction angle can vary up to almost 10^o when shear box sizes between 60mm and 305mm are used depending on the type of sand and density. The significant decrease in friction angle will influence any design in which friction angle is involved. Wu et al. (2008) concluded that lower friction angle is obtained as shear box scale increases.

Based on Rahman et al. (2010) findings, shear strength parameters decrease with increasing oil contamination. It is mainly due to inter-particle slippage that reduces friction induced by the presence of biodiesel which acts as lubricant.

One aspect that worth keeping in mind is that shear strength of sand is affected by gradation. Coarser materials tend to posses good shear strength properties compared to fine materials. It is observed that shear strength of sand is affected by size of direct shear box. It is also studied that large shear box gives more accurate results compared to small shear box.

CHAPTER 3

METHODOLOGY

3.1 Overview

Methodology is a process used to collect data and information for a known study or investigation in which the collected data will be used for making decision or conclusion. Examples of known methodology is experiment, survey, publication research, interviews and other research techniques which could consists of both present and historical values.

The method used is important to represent each of the work need to be done in order to collect all the data for the experiment. The steps in this methodology act as a guidance and bench mark to achieve the objectives of this experiment. The research strategy in this experiment is conducted by doing direct shear test to study the effects of granular sizes on shear strength characteristics. The study also involves the comparison of small and large shear box tests results. The experiment is conducted by using small and large shear boxes.

This experiment helps to explain the real situations in geotechnical engineering. From another point of view, the results from this experiment will help in understanding the construction failures arise from inadequate geotechnical engineering knowledge. This result will help in designing geotechnical structures in future projects.

The direct shear test is used to determine the shear strength of soils on predetermined failure surface. The shear box test to be used in this experiment is the simplest and the most straightforward method in measuring the 'immediate’ or short-term shear strength of soils in terms of total stresses. Although it has a number of shortcomings, but still it is the easiest test to understand. The sample for this experiment is taken from a mining site in Ipoh, Perak.

Table 3.1: Classification of sand based on BS1377 and gradation of test samples

Soil sample	**Sand**		
	Coarse (%)	**Medium (%)**	**Fine (%)**
No / Particle size mm	**2.0 to 0.6**	**0.6 to 0.2**	**0.2 to 0.06**
1	40	40	20
2	50	40	10
3	60	30	10
4	70	25	5
5	80	15	5

3.2 Flowchart

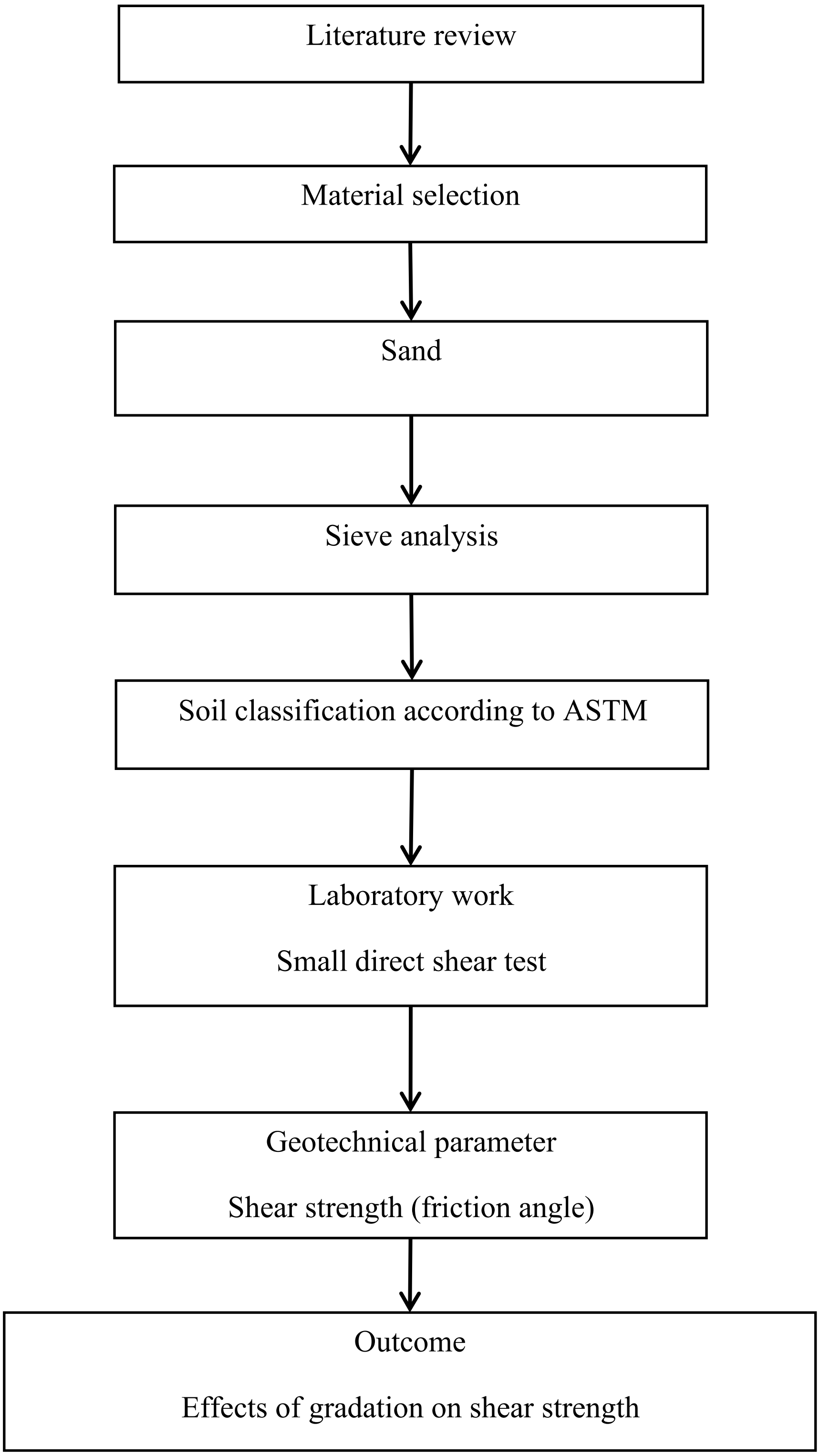

Figure 3.1 : Flowchart of this research study

3.3 Dry sieving method

This method covers the quantitative determination of the particle size distribution in a cohesionless soil down to the fine-sand size. Sieves having aperture size from 63 μm to 2 mm were used in this test. Initially, test samples were cleaned and oven-dried at temperature of 105 °C to 110 °C for 24 hours. A mechanical sieve shaker was used for the sieve analysis. The procedures for dry sieving and sample preparation are specified in BS 1377-2:1990. The result is then expressed in semi-logarithmic chart and table form. Values of D_{10}, D_{30} and D_{60} in mm is taken from the graph plotted. Next, coefficient of uniformity, C_u and coefficient of gradation, C_c is determined from D_{10}, D_{30} and D_{60} to categorize the sample according to ASTM D2487-11.

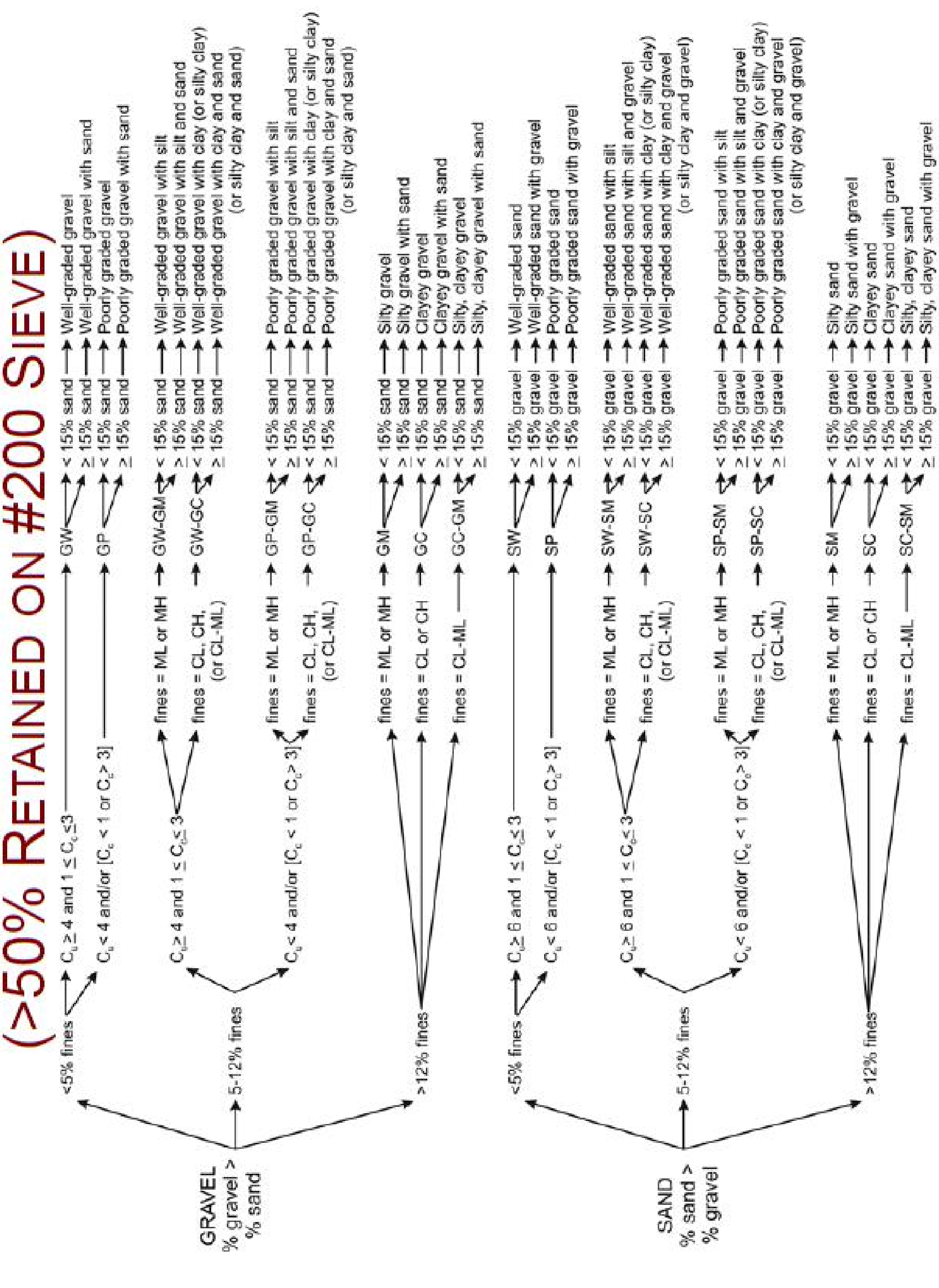

Figure 3.2: Classification of soil according to ASTM D2487-11

Calculation of C_u and C_c:

Coefficient of uniformity (C_u):

$$C_u = D_{60}/D_{10} \tag{3.1}$$

Coefficient of gradation (C_c):

$$C_c = D_{30}^2/(D_{10}*D_{60}) \tag{3.2}$$

This step was repeated for all the samples.

Figure 3.3: Original mining sand

Figure 3.4: Sieve analysis

3.4 Small Direct Shear Box Test

Direct shear box test was conducted to determine the shear strength of the samples prepared. The shear box used in this test has a dimension of 60x60x30mm high. 415g of sand sample was used for each test. This test was conducted according to BS 1377: Part 7: 1990.

10kg, 20kg and 40kg loads were used in this study. These loads are equivalent to 14.2kPa, 24.2kPa and 44.2kPa of normal stresses. The shearing used for this test is 1mm/min. Graphs of shear stress vs horizontal displacement, vertical displacement vs horizontal displacement and ultimate shear stress vs normal stress were plotted from the result to obtain friction angle and to evaluate the vertical movement of the sample during shearing.

The interface shear strength parameter, friction angle is obtained by fitting a straight line through the plots of interface shear strength versus the applied normal stress used in the direct shear tests, and friction angle values calculated at each normal stress assuming adhesion to be zero.

Figure 3.5: Direct shear test apparatus

3.5 Large Shear Box Test

The large shear box has the same function as small direct shear box, but in larger scale which is three times larger than small direct shear box. The dimension of large shear box is 300x300x153mm, while, small shear box has a dimension of 100x100x30mm. 21kg of sand sample was prepared for each test. Large shear box uses hydraulic pump to apply normal load to the sample and we have to control it manually using pressure controller.

The rigid plate that applies normal load to the specimen is not exactly horizontal. Thus, the vertical movement of the sample is measured by using a electronic vertical displacement transducer that is connected to a perspex plate which was directly placed on the specimen. The upper half of the large shear box is kept at stable position during shearing. The shearing rate used for this test is 1mm/min. Three normal loads are used for large shear test which are 5kN, 10kN and 20kN and these loads are equivalent to 55.60kPa, 111.20kPa and 222.20kPa of normal stresses.

The interface shear strength parameter, friction angle is obtained by fitting a straight line through the plots of interface shear strength versus the applied normal stress used in the direct shear tests, and friction angle values calculated at each normal stress assuming adhesion to be zero.

Calculation of normal stress:

Normal stress = Normal load / Area of large shear box (3.3)

Area of large shear box: 0.3mx0.3m = 0.09m^2

Normal stress:

5kN / 0.09m^2 = 55.56kPa

10kN / 0.09m^2 = 111.20kPa

20kN / 0.09m^2 = 222.20kPa

Figure 3.6: Large shear box