CRUSHING IMPACT ON LIQUEFACTION OF VARIOUS SAND SOIL IN KUANTAN

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ABSTRAK

Pecahan butiran-butiran tanah adalah salah satu mekanisme yang mengawal tingkah laku tanah dengan mengubah taburan saiz butiran, bentuk zarah, nisbah lompang dan banyak aspek lain. Tanah berbutir yang berkaitan dengan fenomena seperti pacuan cerucuk yang boleh menyebabkan pecahan zarah apabila tekanan mencapai tahap tertentu. Disebabkan oleh pecahan butiran tanah, sifat-sifat fizikal tanah terganggu yang menjejaskan rintangan pencairan tanah. Kerosakan dan kemalangan yang melibatkan manusia yang disebabkan oleh pencairan menekankan kepentingan menganalisa potensi tanah untuk mengalami pencairan. Oleh kerana tanah pasir adalah antara tanah yang paling berpotensi tinggi untuk mengalami pencairan di kalangan semua kelas tanah, maka adalah wajar untuk mengkaji rintangan pencairan tanah selepas tanah dihancurkan, atau, untuk mengkaji potensi pencairan tanah pasir. Objektif kajian ini adalah untuk mengkaji impak penghancuran pada pencairan pelbagai tanah pasir dari lokasi yang berbeza di sepanjang kawasan pantai di Pantai Timur Semenanjung Malaysia. Sampel tanah telah dihancurkan menggunakan pemadat automatik menggunakan pukulan pada bilangan yang tetap untuk memastikan tahap penghancuran adalah konsisten. Sampel tanah telah dianalisis dengan menggunakan satu siri ujian yang terdiri daripada analisa ayakan, ujikaji graviti tentu dan ujikaji ketumpatan nisbi di mana sifat-sifat fizikal tanah telah dikaji. Ujian-ujian ini telah dilakukan dua kali; iaitu sebelum dan selepas penghancuran tanah pasir. Parameter-parameter seperti Indeks Kehancuran telah dikira daripada perubahan pada saiz butiran tanah. Berdasarkan keputusan ujian, terdapat hubungan antara pecahan butiran tanah yang disebabkan oleh impak penghancuran dan potensi pencairan tanah.

ABSTRACT

Soil particle breakage is one of the mechanism that govern the behaviour of the soil by altering its grain size distribution, particle shape, void ratio and many other aspects. Granular soil associated with phenomenon such as pile driving experience loading which may cause particle breakage when the loading reaches certain degree. Parallel to soil particle breakage, the physical properties of soil are disturbed which affects the liquefaction resistance of soil. The damage and human casualties caused by liquefaction highlights the importance of analysing soil's potential to liquefy. As sand soil is the most liquefiable soil among all the classes of soil, it is therefore relevant to study the liquefaction resistance of the soil after it has been crushed, in other word, to study the liquefaction potential of sand soil. The objective of this research is to study the impact of crushing on liquefaction of various sand soil from different locations along the coastal area of East Coast of Peninsular Malaysia. The soil samples were crushed using an automated compactor using fixed numbers of blows to keep constant the level of crushing impact. The soil samples were analysed using a series of test which comprised of sieve analysis test, specific gravity test and relative density test where the physical properties of the soil were studied. These tests were done twice; before and after crushing of sand soil. Few parameters such as Crushing Index were calculated from the changes in particle size distribution. Based on the test results, there is a correlation between the particle breakage due to crushing and its liquefaction potential.

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LIST OF SYMBOLS

W	Weight of Hammer
D	Distance between Hammer and Sample
V	Volume of Mold
M_w	Mass of container and wet soil sample
M_d	Mass of container and oven-dried soil sample
M_c	Mass of container
w	Moisture Content
W_1	Weight of bottle and stopper
W_2	Weight of bottle, stopper and dry soil
W_3	Weight of bottle, stopper, soil and water
W_4	Weight of bottle, stopper and water
ρ_{dmin}	Minimum density
M_l	Mass of tested-dry soil
V_C	Calibrated volume of the mold
ρ_{dmax}	maximum density
V	Volume of Mold
Vs	Volume of tested-dry soil
e_{min}	Minimum index void ratio
e_{max}	Maximum index void ratio
ρ_w	Density of water
G_s	Specific gravity of soil
e	Void ratio of soil
D_d	Relative Density of soil
Vs	Volume of tested-dry soil
C_u	Uniformity Coefficient
C_c	Coefficient of Gradation
S_0	Sorting Coefficient
Ic	Index of Crushing

LIST OF ABBREVIATIONS

IEM	Institute of Engineers Malaysia
USCS	Unified Soil Classification System
LL	Liquid Limit
PI	Plasticity Index
MMD	Malaysian Meteorological Department
MOSTI	Ministry of Science, Technology and Innocation
MMI	Modified Mercalli Intensity
SM	Silty Sand, Sand-silt Mixture
PSD	Particle Size Distribution
ASTM	American Society for Testing and Materials
PBH	Pantai Batu Hitam
TC	Teluk Cempedak
TG	Taman Gelora
SG	Specific Gravity
SP	Poorly Graded Sand
NSW	New South Wales
NL	Number of Layers
NB	Number of Blows

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background

In the last three decades, experimental study correlating the soil particle breakage and its liquefaction resistance has attracted many researchers. This is due to the liquefaction case histories which make this phenomenon as one of the most interesting, controversial and complicated one. In Nepal, for instance, the history of earthquakes there started as early as 1934 and continued till 2015. However, there were no liquefaction history recorded except for the year 2015, where several liquefaction surface manifestations were depicted across Kathmandu Valley (Gautam, de Magistris, & Fabbrocino, 2017). Narrowing down to liquefaction histories near to our research area which is located in Southeast Asia, countries like Indonesia has also encountered this phenomenon. Liquefaction occurred during the earthquake in Padang, Indonesia on 2009 which collapsed few buildings, damaged water facilities and also roadways (Hakam, 2012).

Even in Malaysia, particularly in East Malaysia, earthquakes were reported at Ranau and Kundasang, Sabah in June 2015 where Institution of Engineers Malaysia (IEM) has listed liquefaction as one of the post-earthquake potential hazards (Lim, 2015). Although Ranau has experienced earthquake since year 1897 (Sooria, Sawada, & Goto, 2012), no liquefaction histories has ever been recorded except for year 2015 where a warning has been announced. The history of earthquake occurrence frequency in Malaysia is another factor that draws to the study of liquefaction potential in Malaysia.

Liquefaction is a phenomenon where saturated soil loses its strength and stiffness as a response to an applied stress, usually caused by earthquake shaking or other conditions, causing the soil to behave like a liquid (Forootan, Silakhori, & Alvandi, 2015). Although the damages that can be caused by earthquakes are more severe, liquefaction can cause significant damages to underground pipelines, airports, harbour facilities, and roads or highway surfaces (Animaton, Tan & Fauziah, 2013). As sand soil easily liquefies compared to other soil types (Liu, Orense, & Pender, 2015), sand soil has been chosen to be tested in this research. Sandy soil is vastly used in construction industry such as in buildings, roadways, dams, embankments and many more. However, soil particle breakage occurs when the soil grains are exposed to high stresses during activities like pile driving, high earth and rock fill dams' construction, impact of projectile, and petroleum extraction (Bartake & Singh, 2007). Such breakage alters the existing characteristics of the soil, which makes the soil to lose its strength. Therefore, re-evaluation of soil behaviour after breakage of particles is essential for the design and construction of structures. Such research is prudent to assist engineers to produce a seismically resistant structures in locations susceptible to liquefaction.

1.2 Problem Statement

Liquefaction is more likely to occur in loose saturated granular soil. Such condition can be spotted along the coastal areas where the soil will be granular and saturated with water. Granular soil tends to break when they are subjected to high stresses due to activities such as compressing impact during installation of foundation like pile driving into the ground. Such activity leaves a crushing impact to the soil which eventually modifies the existing soil characteristic due to the breaking down of the soil particles. Thus, it is essential to identify the change in the soil characteristics after the crushing impact in order to know how significant is the changes so that the engineers can consider whether this criterion should be considered in designing a foundation.

There are few characteristics of soil that could be affected due to particle crushing such as grain size distribution, permeability of soil, angularity and mineral hardness. Methods to analyze some of these factors are complicated and the accuracy of the study is questionable. Thus, in choosing a factor to study about the soil characteristics, aspects like reliability and accuracy need to be considered.

Particle Size Distribution can be used as a method to study the effects of crushing impact on grain size distribution. It is a basic method that has been used in previous studies to study grain size distribution of soil. Generation of particle size distribution curve is simple and comparison with other type of soil can be done easily as each type of soil has its own range in particle size distribution curve.

1.3 Research Question

To achieve its research aim, the study targets to address the following research questions:

1) Do the engineering properties of the sand soil samples vary before and after crushing?
2) Does the grain size distribution parameters changes before and after crushing?
3) What is the relationship between the crushing impact and liquefaction of sand soil in Kuantan?

1.4 Research Objective

The main purpose of this research is to analyse the relationship between the crushing impact and the liquefaction potential of sand soil from different locations along the coastal area of East Coast Peninsular Malaysia (Kuantan area). Three specific objectives have been listed in order to achieve this research aim.

Objective 1: To determine the engineering properties of the sand soil samples from all locations before and after crushing.

Objective 2: To analyse the grain size distribution parameters of samples before and after crushing.

Objective 3: To identify the liquefaction potential of the samples by using Particle Size Distribution curve for various crushing impact.

1.5 Scope of Work

The scope and limitation of this study were as follows:

a) Type of Research/ Design:

This is an Experimental (Lab-based) research which comprises sieve analysis, automated crushing, specific gravity test and particle density test. This research was carried out in the Soil Mechanics and Geotechnic Laboratory, Universiti Malaysia Pahang, Gambang Campus.

b) Samples:

Type of samples were limited to sandy soil from coastal areas. Sand soil samples were collected at three different locations along the coastal area of East Coast Peninsular Malaysia, specifically at district of Kuantan.

c) Crushing Impact:

Crushing of soil samples were done using an automated compactor. The number of blows were limited to 500 and 1000 blows, hence the energy produced during the lab simulation is limited to approximately three times lower than the actual piling impact in construction industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Chapter

The purpose of this chapter is to provide a review of past researches and existing theories related to the research of "Crushing Impact on Liquefaction of Various Sand Soil in Kuantan". In this chapter, the type of soil that was used has been discussed alongside with its general properties according to Unified Soil Classification System. Next, the breakage of the soil particles is further discussed with details from previous researches, where the type of incidents that may cause such breakage will also be discussed. Next, the phenomenon of liquefaction has been discussed deliberately with past histories of its occurrence and its researches in the past correlated to crushing impact.

2.2 Definition of Soil and Classification of Sand Soil

Soils are naturally occurring materials, originating directly or indirectly from rocks through combination of physical and chemical processes. They are highly variable and complex materials, possessing engineering properties with wide range of possible values. Hence, at the beginning of any design process, soil must be accurately classified according to its nature, state and fabric. Sandy soil is granular soils that contain small rock and mineral particles. Sandy soil is the result of the weathering and disintegration of a variety of rocks. According to Unified Soil Classification System (USCS), the sand soil is characterized as coarse-grained soils. Coarse grained soils are the ones having less than 5 percent passing through No.200 sieve and having greater portion of the coarse fraction finer than the No.4 sieve.

In this research, the type of soils that will be used are silty sand which are classified based on Unified Soil Classification System. USCS identifies soils based on its textural and plasticity qualities. The soils are grouped with respect to their behaviors as an engineering construction material. Following properties are used to classify the soils, which is the percentage of gravel, sand and fines (fraction passing the No.200 sieve), shape of the grain size distribution curve, and the plasticity and compressibility characteristics. In the USCS, the soil is given a name and a letter symbol which indicates the soil's principal characteristics. USCS classifies soils according to the soil particle size ranges as in Table 2.1.

Table 2.1 Soil Particle Size Range

Component	**Size Range**
Cobbles	Above 3 inches
Gravel Coarse Fine	3 inches to No.4 sieve 3 inches to ¾ inch ¾ inch to No.4 sieve
Sand Coarse Medium Fine	No. 4 to No. 200 sieves No.4 to No.10 sieves No.10 to No.40 sieves No.40 to No.200 sieves
Fines (clay or silt)	Below No. 200 sieve (no minimum size)

Terms "cobbles", "gravel", "sand", and "fines (silt and clay)" are used to label the size ranges of the soil particles. Gravel and sand are then further divided into sub groups. The boundaries between the size ranges has been set according to the USCS standard sieve sizes as listed in Table 2.1. In fines component, silt and clay terms are used to differ the materials exhibiting lower plasticity and higher plasticity.

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
		Clean Gravels (Less than 5% fines)
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
		Gravels with fines (More than 12% fines)
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
		Clean Sands (Less than 5% fines)
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
		Sands with fines (More than 12% fines)
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

LABORATORY CLASSIFICATION CRITERIA

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART

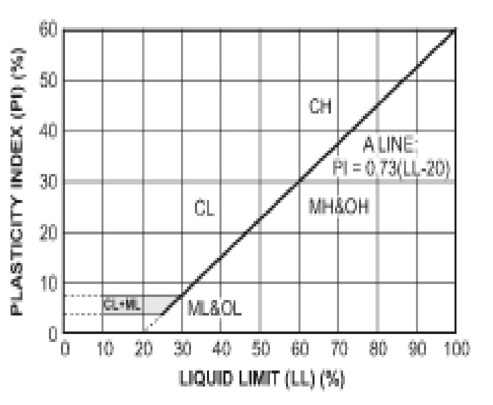


Figure 2.1 Unified Soil Classification System's Symbol Chart, Laboratory Classification Criteria, Plasticity Chart

Source: Amster K.,1986

Figure 2.1 shows the symbol chart, laboratory classification criteria and plasticity chart of Unified Soil Classification System (USCS). Referring to the plasticity chart, if the LL and PI plot below the "A" line, the soil is classified as silt whereas if LL and PI plot above the "A" line, the soil is labeled as clay.

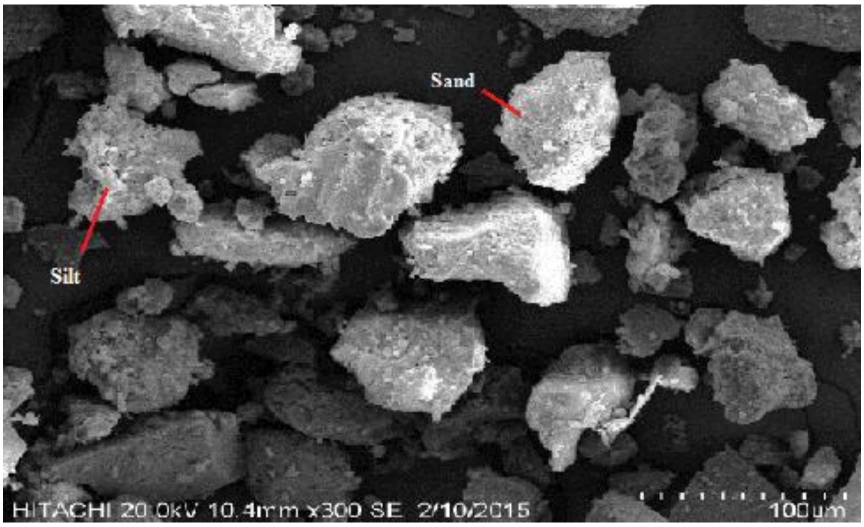


Figure 2.2 Silty Sand under microscope

Source : Daud, Norsyahariati, Hui, Ghafar, & Juliana, 2016.

Silty Sand particles are sub-angular with medium sphericity, which enables them possess greater shearing resistance (Daud et al., 2016.). It has semi rough texture. The variety of sand and silt particles causes the soil arrangement to be genuinely dense and this adds to the soil's stress behavior. The higher the silt content in the sand, the higher the cohesion of soil, hence the friction angle decreases. These are due to the shape and gradation of the soil sample. In this research, silty sand will be used alongside sandy soil to compare the liquefaction potential of sandy soil samples. This will be further discussed in Chapter 2.4.

2.3 Sand Particle Breakage

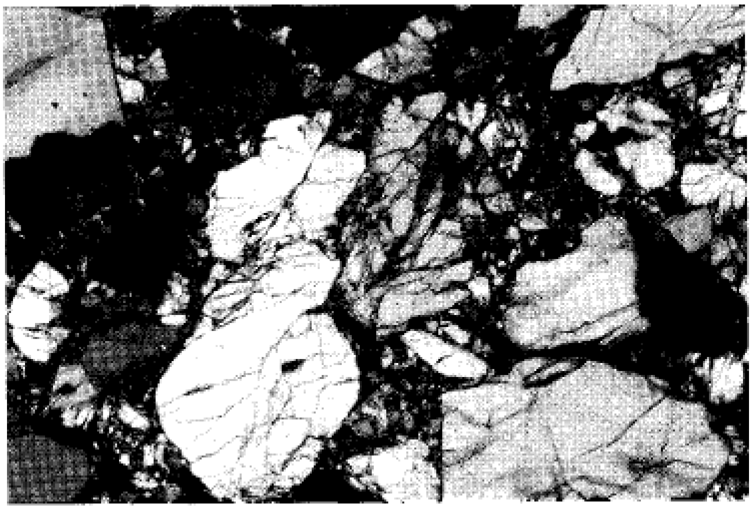
Crushing can be defined as an act of squeezing or pounding something into small fragments or particles, whereas the word “impact” means to have a strong effect on someone or something. As a phrase, “Crushing Impact” refers to the possible pressures, of all types, that may be imposed on sand, which may cause the sand particles to crack and break into smaller pieces or particles. Sand particles may break due to impact from phenomena like pile driving, construction of high earth or rock fill dams, impact of projectiles, repeated loading on railway embankment and so on.

Railway embankments are consisting of layers of granular materials. When granular materials are subjected to continuous and repeated loading, they failed to inherent strength and to withstand further tension from the repeated traffic loads. Although permanent deformation are taken into account during railway embankments design, engineers failed to realise the gradual accumulation of a large number of plastic deformation due to soil particle breakage after the loading is being transferred to the subgrades beneath the embankment (Brecciaroli & Kolisoja, 2006).

Likewise, pile foundation is normally installed by using methods such as dropping of weight, explosion, vibration and jacking. All these methods impose high pressure on the soil particles which then tend to crush or break the particles. The sand particles which are in contact with the pile shaft tend to break and consequently cause a change in its physical characteristic hence also a change in its behaviours. This will affect the strength of the soil, hence decreasing the bearing capacity of the soil. Recent assessments on pile driving (Toolan et al, 1990) has stated that the existing design approaches are not reliable as it does not consider the breakage of sand particles during the design of pile.

Figure 2.3 (a, b) and Figure 2.4 (a, b) show the particles of Quartz sand and Cambria sand under light polarizing microscope before and after crushing. The changes in the soil particles can be seen quite obviously as the particles deform and lose its shape.

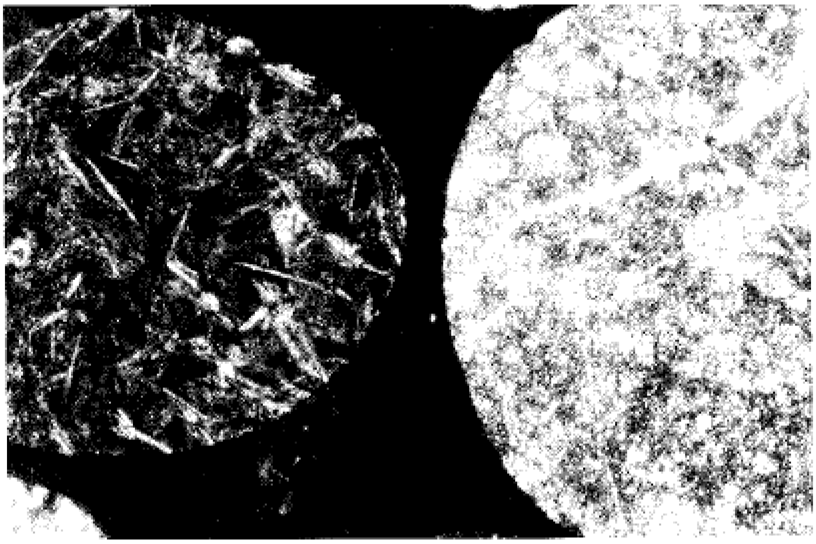
(a)



(b)

Figure 2.3 Photographs Using a Light Polarizing Microscope of Thin-Sections of Quartz Sand: (a) Original Condition; (b) After Crushing

Source: Jerry and Paul, 1996



(a)

(b)

Figure 2.4 Photographs Using a Light Polarizing Microscope of Thin-Sections of Cambria Sand: (a) Original Condition; (b) After Crushing

Source: Jerry and Paul, 1996

2.4 Liquefaction of Soil

Liquefaction is a phenomenon where saturated soil loses its strength and stiffness as a response to an applied stress, usually caused by earthquake shaking or other conditions, causing the soil to behave like a liquid (Forootan et al., 2015). Saturated sand ends to compact when they are exposed to vibrations such as earthquake. This causes a lack in drainage which leads to a higher pore pressure. An increment in the pore water pressure promotes the loss of soil resistance due to the loss of effective stress in between the soil particles. Hence, the soil changes from solid state to liquid state and that is what is being said as liquefaction of soil (Agung & Ahmad, 2014). Loose granular soil such as silty sand, sand and gravely sand are more likely to liquefy compared to other type of soil (Hakam, 2012). This is due to presence of larger void ratio in such soil which can develop higher water pressure thus easily liquefies (Muley, Maheshwari, & Paul, 2012). Although the damages that can be caused by earthquakes are more severe, liquefaction can cause significant damages to underground pipelines, airports, harbour facilities, and roads or highway surfaces (Animaton, Tan & Fauziah, 2013).

Table 2.2 shows the history of earthquake occurrence in Malaysia as recorded by Malaysian Meteorological Department (MMD) and Ministry of Science, Technology and Innocation (MOSTI). The severity of the earthquake occurrence in Table 2.2 is recorded using Modified Mercalli Intensity scale. The level of intensity and its descriptions are shown in Table 2.3. Based on Table 2.3, the state of Sabah has recorded the highest number of ground motions with 77 earthquake events recorded since 1897(Sooria et al., 2012). Meanwhile, Peninsular Malaysia has experienced minor earthquakes and been affected due to distant earthquakes from Sumatera as it is located only about 350 km away from the Sumatran active fault and Sumatran subduction zone(Animaton, Tan & Fauziah, 2013). Based on above-mentioned facts, it is a clear cut that Malaysia is vulnerable to earthquake. Hence, it is wise to study the liquefaction potential of Peninsular Malaysia as it can be clearly concluded that liquefaction occurs abruptly and earthquake histories do not influence its occurrence.

Table 2.2 Frequency and severity of earthquake recorded from 1874 till 2010 (Source: Sooria et al., 2012)

State	**Frequency of Occurrence**	**Maximum Intensity (MMI)**
Perlis	3	V
Kedah	18	V
Penang	41	VI
Perak	24	VI
Selangor	50	VI
Negeri Sembilan	14	V
Malacca	19	V
Johor	32	VI
Pahang	35	III
Terengganu	2	IV
Kelantan	3	IV
Kuala Lumpur	38	VI
Sabah	40 (77)*	VII
Sarawak	17 (21)**	VI

*Frequency of occurrence recorded as 40 by MMD but reported as 77 by MOSTI (2009)

** Frequency of occurrence recorded as 17 by MMD but reported as 21 by MOSTI (2009)

Table 2.3 Level of Intensity and Description based on Modified Mercalli Intensity (MMI)

(Source: US Geological Survey, 2016)

Intensity	Shaking	Description/Damage
I	Not Felt	Not felt except by a very few under especially favourable conditions.
II	Weak	Felt only by few person at rest, especially on upper floors of buildings.
II	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone, many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Great damage in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Sandy soil has been chosen to be tested in this research. Sandy soil is vastly used in construction industry such as in buildings, roadways, dams, embankments and many more especially when it involves construction along coastal areas. In order to compare the liquefaction potential of sandy soil in Kuantan, silty sand has been chosen as it is one of the most liquefiable soil. The silty soil used in this research is a decomposed granite from the catchment area of Lyell dam, New South Wales, Australia. This soil has been classified as silty sand (SM) based on the Unified Soil Classification System. The properties of Lyell Silty sand and its particle size distribution curve are as shown in figures below. As shown in Figure 2.5, the particle size distribution curve of Lyell Silty Sand covers wider ranges of soil sizes unlike any other soil, hence it is suitable to be set as a benchmark to be compared with the results of this research.

Table 2.4 Properties of Lyell Silty Sand

(Source: Yang and Russell, 2015)

Property	Value
Liquid Limit (%)	15.2
Specific Gravity	2.55
Gravel Content (%)	0
Sand Content (%)	73
Fines Content (%)	27
Clay Size Fraction (%)	4.4
Uniformity Coefficient (C_u)	85.71
Coefficient of Gradation (C_c)	0.72
Sorting Coefficient (S_0)	4.90
Unified Soil Classification	SM

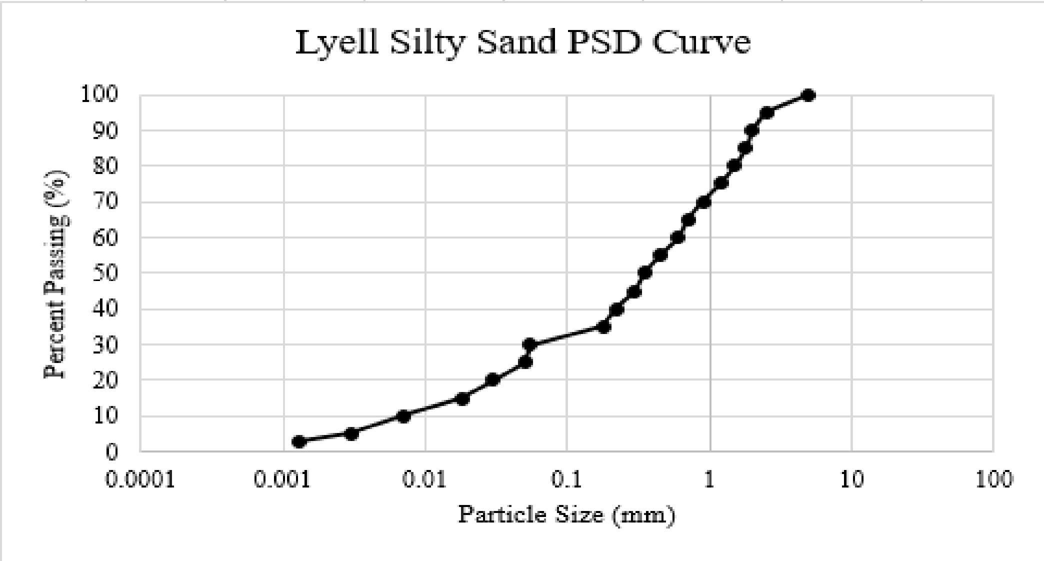


Figure 2.5 Particle Size Distribution Curve of Lyell Silty Sand (Replotted from the original graph)

In order to analyze the liquefaction potential of Lyell Silty Sand, a standard graph from Technical Standards and Commentaries for Ports and Harbors Facilities in Japan is used as a base (Panah & Dehghani, 2014). Figure 2.6 shows the standard graph where the ranges for liquefiable soil were depicted. In Figure 2.7, the standard graph was replotted together with the particle size distribution graph of Lyell Silty Sand in order to check the range of its liquefaction potential.

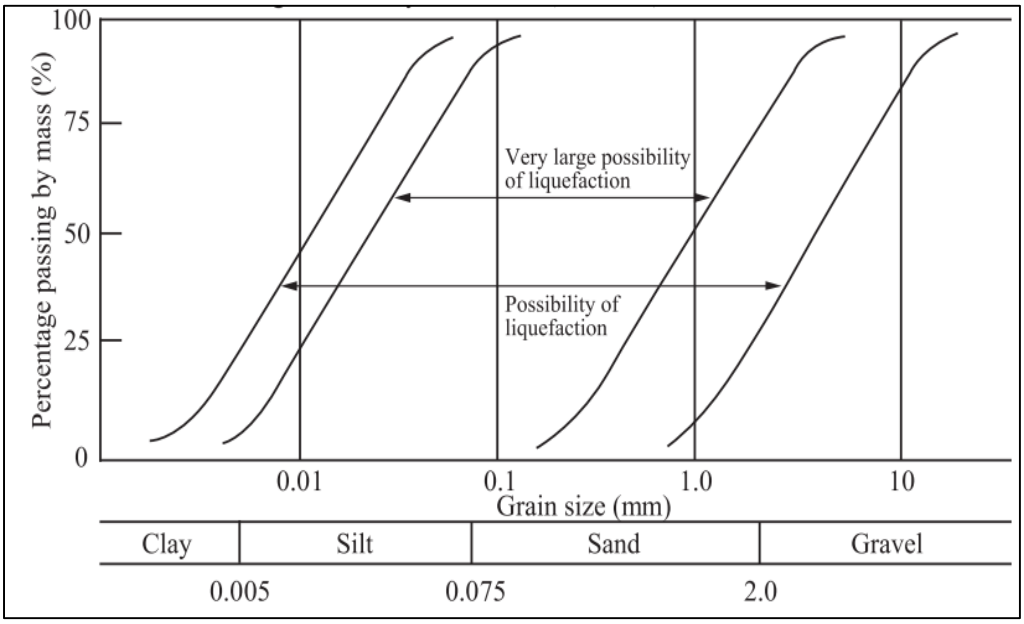


Figure 2.6 Liquefaction Potential of soil based on Technical Standards and Commentaries for Ports and Harbors Facilities in Japan (Panah & Dehghani, 2014)

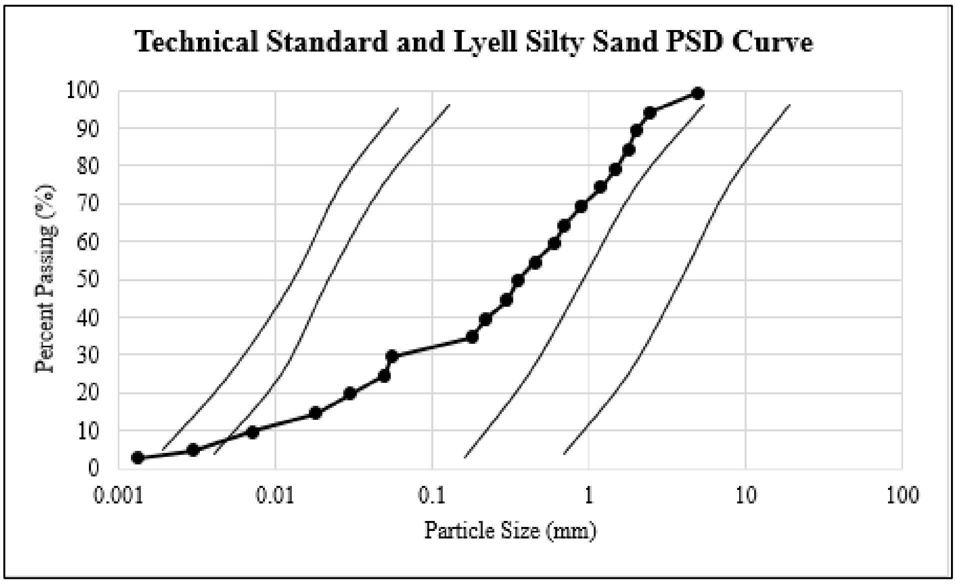


Figure 2.7 Graph combining the standard graph from Technical Standards and Commentaries for Ports and Harbors Facilities in Japan and Lyell Silty Sand PSD Curve

From Figure 2.7, particle size distribution curve of Lyell Silty Sand falls within the range of "very high possibility of liquefaction" area in the graph. Hence, it can be concluded that Lyell Silty Sand is an ideal soil with properties which possesses very high potential to liquefy, thus suitable to be used as a benchmark to be compared with the soil samples in this research.

2.5 Summary

The research of "Crushing Impact on Liquefaction of Various Sand Soil in Kuantan" deals with the study of breakage of sand soil particles which alters the existing particle size distribution of the soil, and its relationship with liquefaction potential of the soil. One of the most important criteria to be taken into account when it comes to design of a foundation is the soil condition. The type of foundation that are to be constructed will be chosen based on the existing strength of the soil. However, engineers fail to realize that the compressing impact due to installation of foundation like pile driving into the ground leaves a crushing impact to the soil which eventually modifies the existing particle size of the soil. This might alter the liquefaction potential of the soil. Likewise, there are few phenomena which contributes to soil particle breakage such as as pile driving, construction of high earth or rock fill dams, impact of projectiles, repeated loading on railway embankment and so on. The soil particles then deform and break into smaller pieces, hence affects the particle size of the soil which will contribute to the liquefaction of the soil. Ignoring this criterion might eventually result in the collapse of the entire structure that the soil holds when there is presence of seismic movement. Therefore, re-evaluation of soil behaviour after breakage of particles is essential for the design and construction of structures. In this research, a study has been made to analyse the liquefaction potential of various sand soil in Kuantan area after it has been crushed in order to identify the influence of particle breakage in liquefaction resistance. Such research is prudent to assist engineers to produce a seismically resistant structures in locations susceptible to liquefaction.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview of Chapter

The objective of this research is to analyse the relationship between the crushing impact and the liquefaction potential of sand soil from different locations along the coastal area of East Coast Peninsular Malaysia (Kuantan area). This chapter summarizes the methods of how the necessary data was collected to comply the research objective and materials that has been used. The chapter is divided into 3 sub-sections which comprises sampling work, laboratory testing and steps involved in plotting of range in Modified PSD Curve. Section 3.2 which is sampling work is further divided into 2 sections which is sampling location and sample preparation, whereas section 3.3 which comprises all the laboratory tests is further divided into 4 sections where the tests are explained in detail step by step. Lastly, the plotting of the range of the liquefaction potential in Modified PSD Curve is briefly explained. These has been summarized in the flowchart in Figure 3.1.

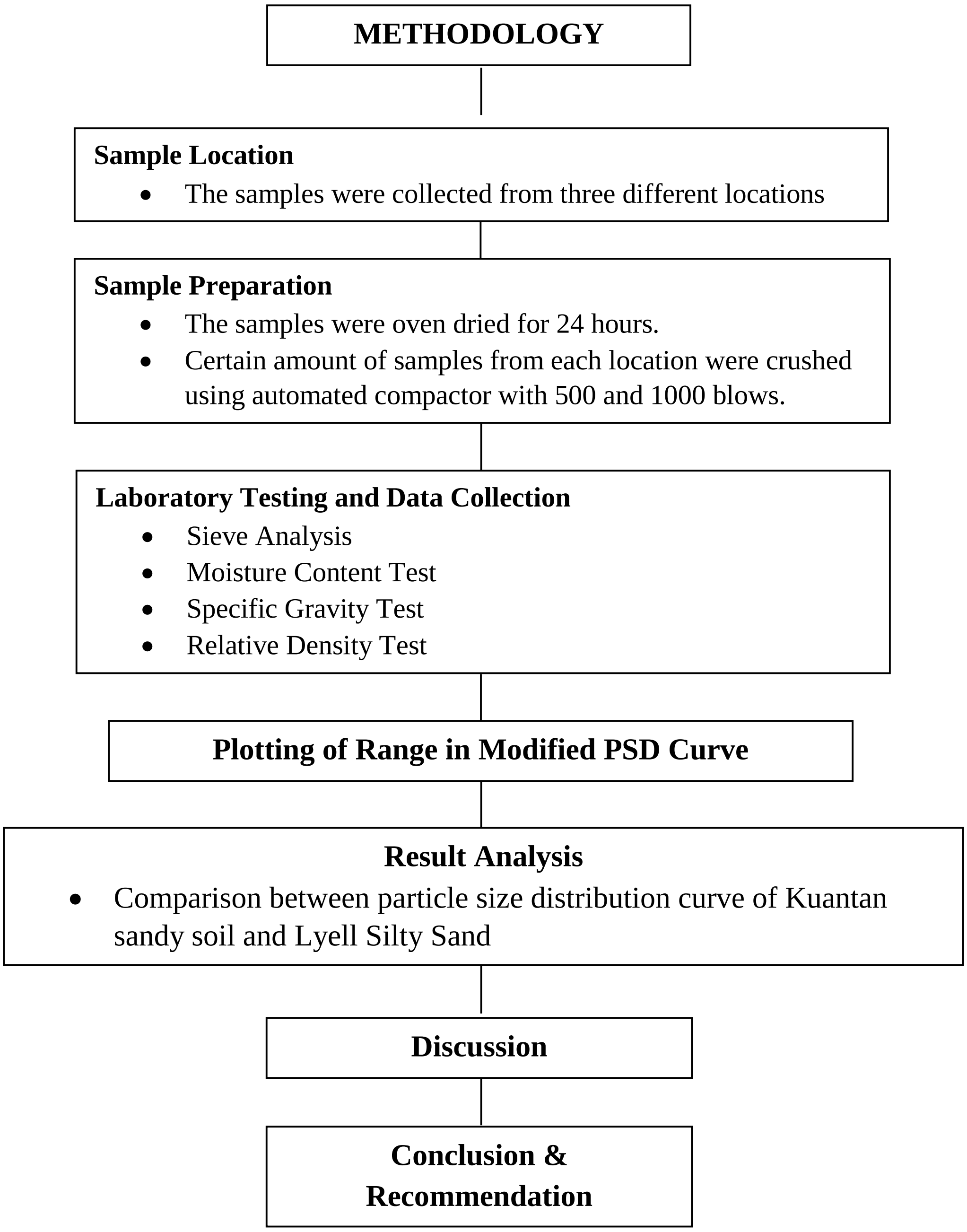


Figure 3.1 Flowchart of Research Methodology

3.2 SAMPLING WORK

3.2.1 Sampling Location

The sand soil samples for this research were collected from three different coastal areas at the district of Kuantan. The disturbed soil samples were obtained from Teluk Cempedak (3.8148950N, 103.3646850E), Taman Gelora (3.8067900N, 103.3472900E) and Pantai Batu Hitam (3.8685320N, 103.3654070E). The locations of the soil samples are shown in Figure 3.2. Excavation of soil samples were done using shovel (refer Figure 3.3) and the samples were kept in 3 different containers according to their locations so that the moisture content of the samples will be preserved. The samples were then kept in Soil Mechanics and Geotechnical Lab in Universiti Malaysia Pahang Gambang Campus where they undergone a series of laboratory testing in order to analyse the engineering properties of the soil for research purpose.

Figure 3.2 Soil Sample Locations

Figure 3.3 Excavation of soil using shovel

3.2.2 Sample Preparation

All the soil samples were oven dried for 24 hours in a temperature range of 97 to 99˚C. After the oven drying process, 2 kilograms of each soil sample were separated and crushed using an automatic soil compactor model ASTM 220-240V 60Hz 1Ph (refer to Figure 3.4). The soil samples were subjected to undergo two different number of blows which is 500 and 1000 blows. The energy that has been imposed on the sand particles were converted in kilojoule (kJ/m^3) by using Equation (1).

$$\text{Energy} = \frac{(\text{NL})(\text{NB})(\text{W})(\text{D})}{\text{V}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

NL = Number of layers

NB = Number of blows

W = Weight of hammer

D = Distance between hammer & sample

V = Volume of mold

The energy that has been imposed on the soil samples were 3972.46 kJ/m^3 for 500 blows and 7944.92 kJ/m^3 for 1000 blows. Hence, the energy produced during the lab simulation is approximately three times lower than the actual piling impact in construction industry which is around 25 kJ per blow (Kausel & Peek, 1982).

Figure 3.4 Automatic Soil Compactor

3.3 LABORATORY TESTING

3.3.1 Sieve Analysis

Sieve analysis is a test that is conducted to determine the particle size distribution of granular material and it is widely used in classification of soil. In this research, the test was conducted based on the standard of American Society for Testing and Materials (ASTM) D 422. As a result of this test, a particle size distribution curve was obtained and the soil was classified based on Unified Soil Classification System (USCS).

Sieve set of opening sizes 5mm, 3.35mm, 1.18mm, 600µm, 300µm, 150µm, 63µm and also including pan and cover, balance with accuracy to 0.01g, and a mechanical sieve shaker were used for sieve analysis. Some 2kg of soil samples from each location that has been over dried were weighed using the balance. All the sieves were also weighed. The sample were then poured into a stack of sieve which was arranged with the sieve of largest opening size at the top and the smallest one at the bottom before the pan (refer Figure 3.5). The sieve set together with the sand was fixed inside the mechanical sieve shaker and left to be shaken for 10 minutes. The weight of each sieve were recorded after 10 minutes together with the soil that was retained on the sieves.

Figure 3.5 Pouring of soil sample into a stack of sieves

3.3.2 Moisture Content Test

Before the oven drying and crushing were done, around 30 grams of soil samples were kept aside to be tested for its moisture content. The standard of ASTM D2216 was used. 10 grams of each soil samples were placed in a container and weighed for its original mass. Hence, there will be 3 containers for each location. The samples were then oven dried together with the container for about 24 hours under the temperature of 110°C. The mass of wet soil, dry soil and the container (refer Figure 3.6) were recorded to determine the moisture content of the soil which can be calculated by using the Equation (2):

$$w(\%) = \frac{M_w - M_d}{M_d - M_c} \times 100 \quad \text{.......................................(2)}$$

Where:

M_w = Mass of container and wet soil sample (g)

M_d = Mass of container and oven-dried soil sample (g)

M_c = Mass of container (g)

Figure 3.6 The process of weighing the containers

3.3.3 Specific Gravity Test

One of the method to determine the specific gravity of soil by using pycnometer which is known as pycnometer method of specific gravity test. In this research, the standard of ASTM D854 has been used in order to determine the specific gravity. This test was conducted twice, which is before and after the crushing process took place. The pycnometer is a glass flask with a close-fitting ground glass stopper with a capillary hole through it. Pycnometers with stoppers, weighing balance with accuracy of 0.1g and a vacuum pump were used.

Firstly, soil samples weighing 300 grams from each location which has been oven dried were taken out of the oven n let to cool down to room temperature. Nine pycnometers were cleaned and weighed together with its stoppers. They were then kept on a vacuum pump to remove entrapped air for an hour. After an hour, soil samples were added, 100 grams each in a pycnometer. Hence, there will be three pycnometers with soil samples from the same location. The pycnometers with soil samples were then weighed again with its stopper. It is important to label the stoppers according to the pycnometers to prevent any mispairing of pycnometer and its stopper which might affect the weighing. After weighing, distilled water was added into the bottles until they were two-third full and kept in the vacuum pump for another 1 hour without stoppers. Once the bottles were taken out of the vacuum pump, the content was shaken carefully with its stopper. After that, distilled water was added to the bottles to fill the bottle until it is full and were kept aside in room temperature for an hour (refer Figure 3.7). They were weighed after an hour with the stoppers. Finally, all the contents in the pycnometers were cleared, cleaned and filled with distilled water until they were full. They were left in room temperature for an hour without the stoppers and then weighed with the stoppers.

The specific gravity (Gs) of the sand soil samples were calculated by using the following equation:

$$G_s = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)} \quad \text{...(3)}$$

where:

W_1 = Weight of bottle and stopper (g)

W_2 = Weight of bottle, stopper and dry soil (g)

W_3 = Weight of bottle, stopper, soil and water (g)

W_4 = Weight of bottle, stopper and water (g)

Figure 3.7 Bottles with soil samples that were kept in room temperature

3.3.4 Relative Density Test

Relative density test is a test that is conducted to determine the relative density of cohesionless soil. In this research, the test was conducted according to ASTM D 4253 and ASTM D 4254. The test was carried out both before and after crushing was done, hence there were 2 sets of relative density test. The equipment that used for the test were vibrating table, mold assembly consisting of standard mold, guide sleeves, surcharge base-plate, surcharge weights, surcharge weights, surcharge base-plate handle, dial-indicator gauge, balance, scoop and straightedge.

Firstly, the mold was weighed and its mass was recorded. The mold was filled with soil loosely by pouring the soil using a funnel in spiral motion to minimize the particle segregation. Excess soil level at the top of the mold were trimmed off by using a straightedge. The mold and soil were weighed and the mass was recorded. Then the mold was emptied and filled with soil by using same funnel method however, this time it is not in a spiral motion. The surcharge base-plate was placed and twisted on the soil surface till it is placed uniformly in contact of soil surface and the base-plate handle was removed. After that, the mold was attached to the vibrating table. The initial dial reading was determined by inserting the dial indicator gauge holder in each of guide bracket with the dial gage stem in contact with the rim of the mold (refer Figure 3.8). The average of that six readings was the initial dial gage reading.

After the initial dial gauge reading was recorded, the surcharge weight was lowered onto the surcharge base-plate and the mold assembly was vibrated with the soil samples for 8 min. The final dial gauge reading was determined and recorded similar to the initial dial gauge reading. After that, the surcharge base-plate was removed from the mold and the mold was detached from the vibrating table. The mold and soil were weighed and the mass was recorded.

Figure 3.8 Recording the initial gauge reading

The minimum density (ρ_{dmin}) was calculated by using Equation (4):

$$\rho_{dmin} = \frac{M_l}{V_C} \quad \text{......(4)}$$

Where:

M_l = Mass of tested-dry soil = Mass of mold with soil placed loose – Mass of mold

V_C = Calibrated volume of the mold

The maximum density (ρ_{dmax}) was calculated by using Equation (5):

$$\rho_{dmax} = \frac{M_1}{Vs} \text{..(5)}$$

M_1 = Mass of tested-dry soil = Mass of mold with soil after vibration – Mass of mold

Vs = Volume of tested-dry soil

The maximum and minimum-index void ratios were calculated by using Equations (6) and (7).

$$e_{min} = \frac{\rho_w G_s}{\rho_{dmin}} - 1 \text{.......................................(6)}$$

$$e_{max} = \frac{\rho_w G_s}{\rho_{dmax}} - 1 \text{.......................................(7)}$$

The relative density of the sand soil samples was calculated by using Equation (8):

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \text{..(8)}$$

3.4 Plotting of Range in Modified PSD Curve

A standard graph with a range for liquefiable soil was needed to analyse the liquefaction potential of the soil samples of this research from the results that has been obtained from the laboratory tests. Hence, particle size distribution curve of Lyell Silty Sand was chosen to be used as a standard graph. In order to determine the maximum and minimum boundary of the range in the graph, the data or the points in the graph were replotted by increasing the values by percentages and calculating the fine fraction percentage which is the percent passing of No.200 sieve. Trial and error method was used to determine the boundaries, where the trial for maximum boundary was stopped once the percent passing of No.200 sieve reached 0% and the trial for minimum boundary was stopped once the percent passing of No.200 reached 100%. Parameters such as Uniformity Coefficient (C_u), Coefficient of Gradation (C_c) and Sorting Coefficient (S_0) were kept constant throughout the trial and error process. The minimum boundary was attained when the values of the curve was multiplied by 57 of its value (refer Figure 3.9) as the fine fraction percentage reaches 0%, whereas the maximum boundary was attained once the values of the curve was multiplied by 0.9985 of its value (refer Figure 3.10) as the fine fraction percentage reaches 100%. Other subsequent trials were attached in Appendix. Both graphs were combined and were set to be used as a standard graph to evaluate the liquefaction potential of the soil samples in this research, where the soil will be considered to be liquefiable if its particle size distribution falls anywhere in the range between the maximum and minimum boundary that has been fixed (refer Figure 3.11).

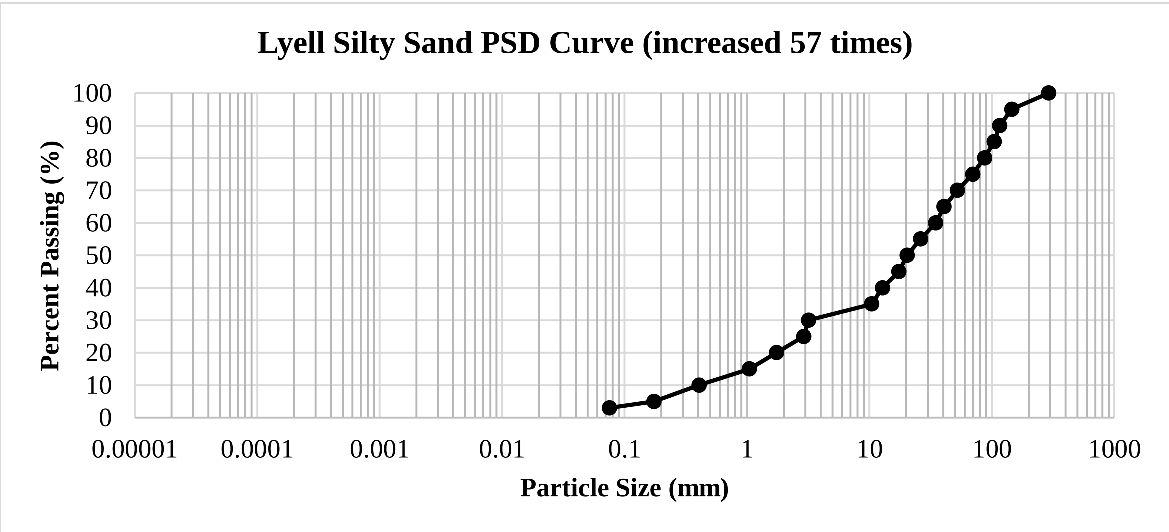


Figure 3.9 Lyell Silty Sand PSD curve after being increased by 5700% (minimum boundary)

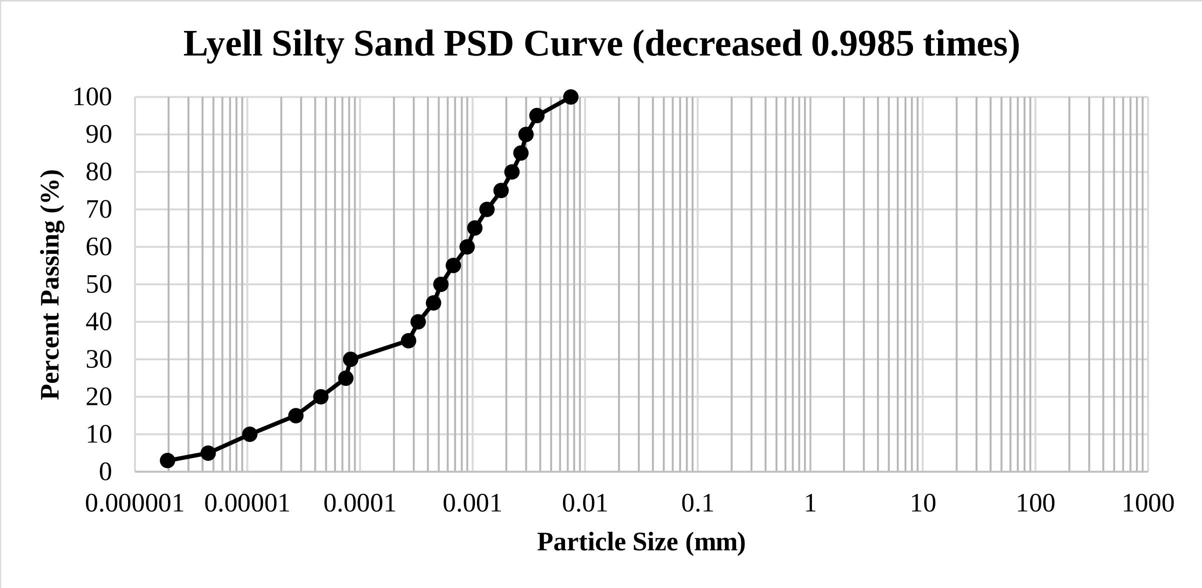


Figure 3.10 Lyell Silty Sand PSD curve after being decreased by 99.85% (maximum boundary)

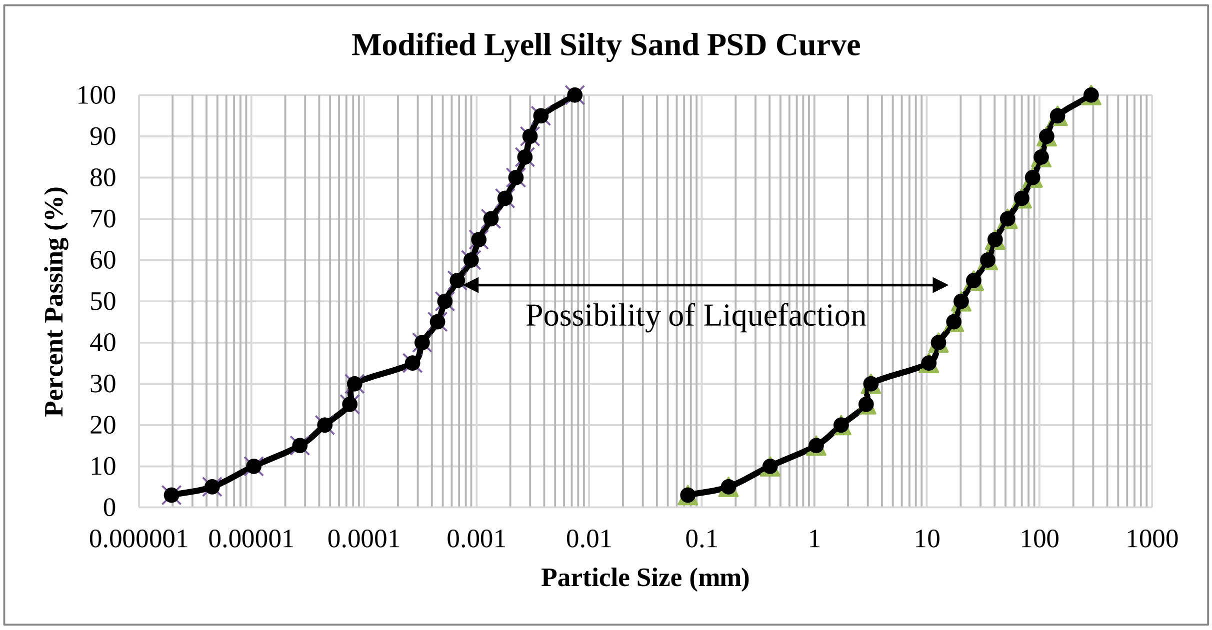


Figure 3.11 Modified Lyell Silty Sand PSD Curve with liquefaction range

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview of Chapter

In this chapter, the results of the research have been discussed. The results were obtained from the laboratory tests that has been conducted in Soil Mechanics and Geotechnical Laboratory in Universiti Malaysia Pahang Gambang Campus and from the findings from the past researches, the results have been analysed. The results are presented in the form of tables and graphs wherever necessary for better understanding.

4.2 Soil Properties

Soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora were subjected to undergo moisture content test, relative density test, and specific gravity test in order to analyse engineering properties of the soil samples. These tests were conducted for both before and after crushing of the soil samples except for the moisture content test. This is because the moisture content of the soil samples will not change after crushing and the soil samples were oven dried before they were crushed. The results of the test were further discussed below.

4.2.1 Engineering Properties

The results that were obtained from moisture content test, relative density test and specific gravity test are shown in Table 4.1.

Table 4.1 Engineering Properties of Soil

Properties	**Before Crushing**			**After Crushing**					
				500 blows			**1000 blows**		
	PBH	TC	TG	PBH	TC	TG	PBH	TC	TG
Water Content (%)	31.87	2.23	16.57	31.87	2.23	16.57	31.87	2.23	16.57
Specific Gravity	2.38	2.39	2.56	2.43	2.60	2.55	2.65	2.57	2.53
Relative Density (%)	59.36	59.76	77.00	54.74	77.87	69.33	54.21	29.68	63.31

4.2.1.1 Moisture Content

Three sets of soil samples were used for this test in order to obtain an accurate answer. Average of the results obtained were calculated. According to the test results obtained using mass loss percentage method, the average moisture content for soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora is 31.87%, 2.23% and 16.57% respectively. The result clearly shows that soil from Pantai Batu Hitam possesses highest water content compared to two other locations.

4.2.1.2 Specific Gravity

Same as the moisture content test, 3 sets of soil samples for each location were used and the average result of these 3 sets were used as the specific gravity of the soil. Before the soil samples were crushed, they possessed 2.38, 2.39 and 2.56 of specific gravity for Pantai Batu Hitam, Teluk Cempedak and Taman Gelora respectively. However, after soil samples were crushed and tested for its specific gravity, the values changed. The specific gravity of Pantai Batu Hitam increased from zero to 1000 blows, whereas the value of specific gravity for Teluk Cempedak increases then decreases and that of Taman Gelora decreases as the number of blows increases. Specific gravity value above 2 both before and after crushing indicates the presence of mineral matter in all soil samples. Based on the number of blows, Index of Crushing of each soil samples was calculated by using an equation formulated in previous research on crushability of soil (Hattamleh, Al-deeky, Akhtar, & Al, 2013). The Index of Crushing obtained was then plotted against the specific gravity of all locations in order to determine the relationship between them. The result is shown in Figure 4.1.

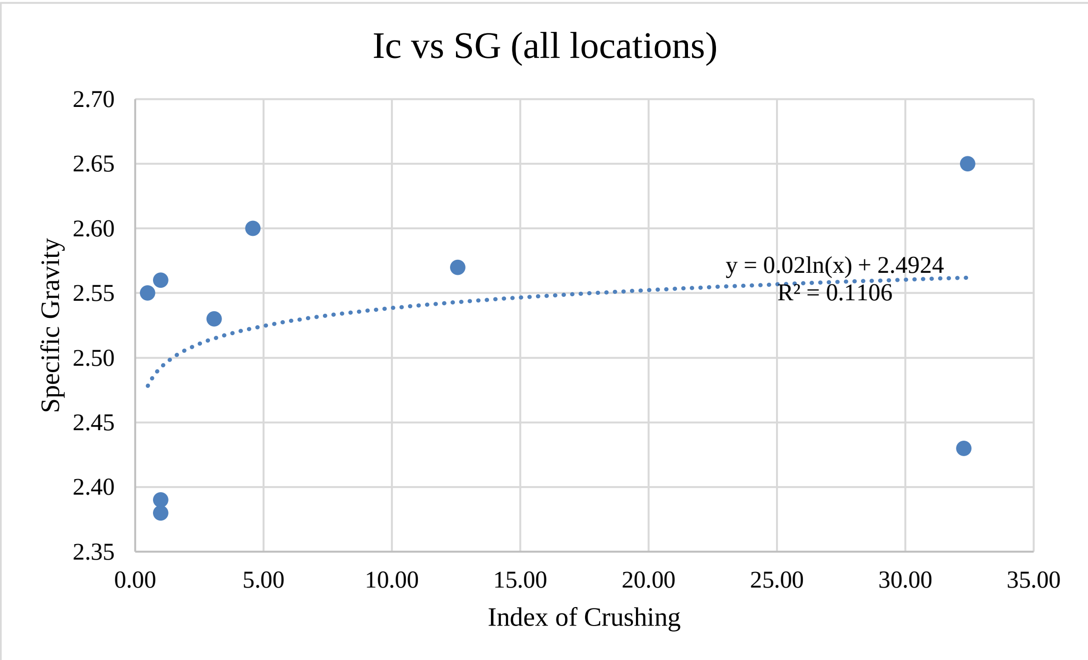


Figure 4.1 Index of Crushing versus Specific Gravity graph of all locations

Based on the graph plotted, Index of Crushing and specific gravity has a logarithmic relationship with the equation $y = 0.02\ln(x) + 2.4924$. Overall, the value of specific gravity increases as the crushing index of the soil increases.

4.2.1.3 Relative Density

The result of relative density test was calculated based on the equations stated in section 3.3.4. Based on the calculation, relative density of soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora is 59.36%, 59.76%, and 77.00% respectively. However, there were changes in these values as the soil samples were tested for its relative density again after they were crushed as stated in Table 4.1.

4.3 Particle Size Distribution-Sieve Analysis

The soil samples both before and after crushing were subjected to undergo sieve analysis in order to determine the changes in its grain size distribution after it is crushed. As this research is mainly based on Particle Size Distribution curve, the results that have been obtained from the analysis were used to plot the curves. Curve of the particle size distribution before the soil samples were crushed, when they were subjected to 500 blows and 1000 blowss were plotted in one graph, distinctively according to their locations. Changes in grain size distribution parameters are tabulated in Table 4.2. The graphs are as shown below.

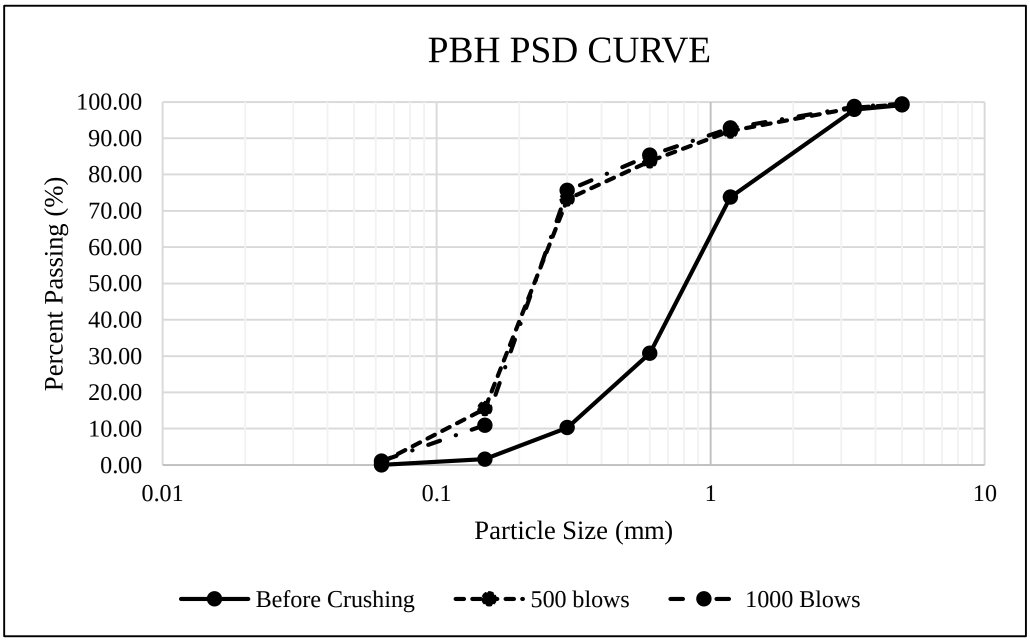


Figure 4.2 Particle Size Distribution Curve of Pantai Batu Hitam

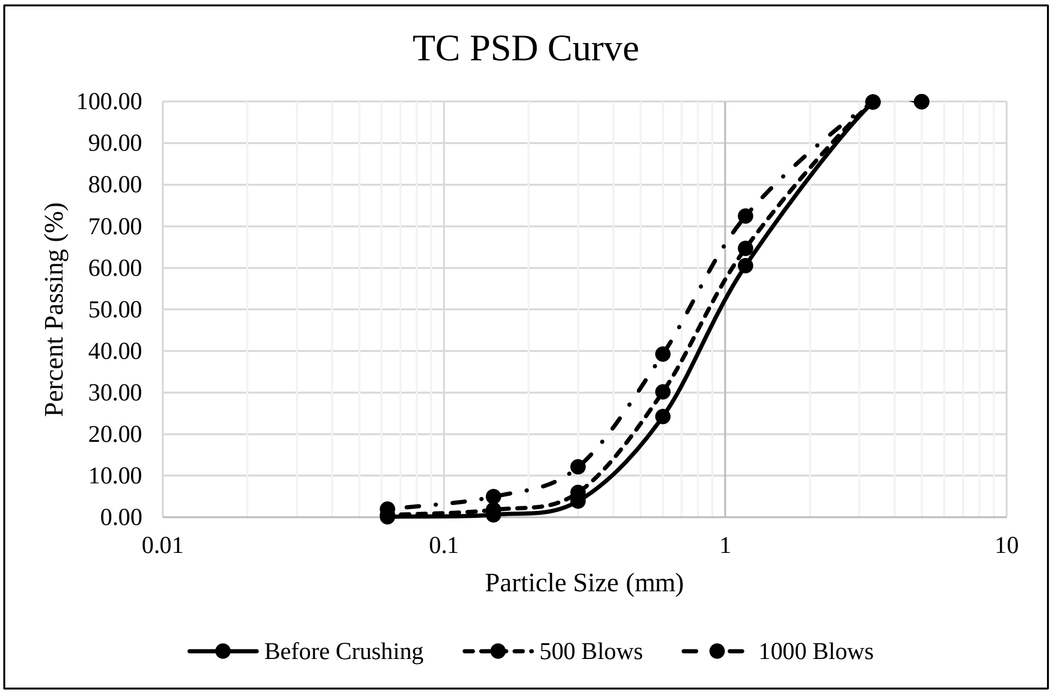


Figure 4.3 Particle Size Distribution Curve of Teluk Cempedak

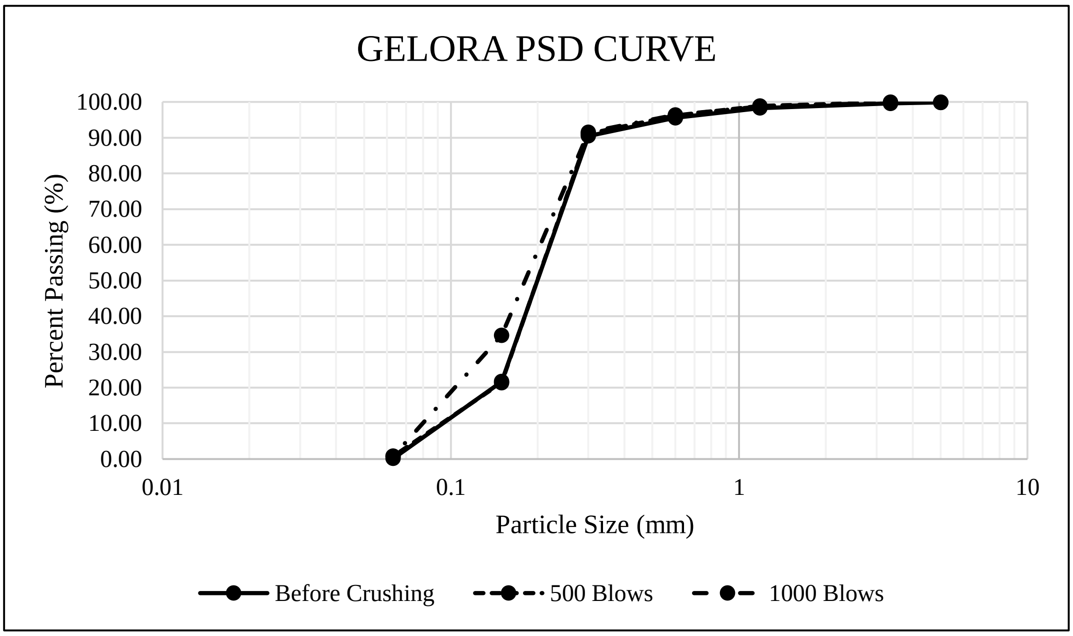


Figure 4.4 Particle Size Distribution Curve of Taman Gelora

Table 4.2 Grain Size Distribution Parameters before and after crushing

Parameters	Before Crushing			After Crushing					
				500 blows			1000 blows		
	PBH	TC	TG	PBH	TC	TG	PBH	TC	TG
Uniformity Coefficient (C_u)	3.17	3.25	2.20	2.36	3.06	2.20	1.63	3.33	2.33
Coefficient of Gradation (C_c)	1.26	0.94	1.47	1.26	1.17	1.47	0.78	1.02	1.19
Sorting Coefficient (S_0)	1.67	1.7	1.26	1.29	1.73	1.26	1.26	1.76	1.40

Based on the result obtained from the sieve analysis, grain size distribution of the soil samples from all the locations were used to classify the samples using Unified Soil Classification System (USCS). As a result, all the samples were categorized as Poorly Graded Sand (SP). In order to analyse the liquefaction potential of the soil samples, Lyell silty sand was chosen as stated in section 2.4. Hence, the result of this research has been compared with the Particle Size Distribution Curve of silty sand from a catchment area of Lyell dam, NSW, Australia (Yang & Russell, 2015). The sand has been classified based on Unified Soil Classification System. The particle size distribution curve of Lyell Silty Sand is as shown in Figure 2.5.

As mentioned in Chapter 3.4, a modified PSD curve with a range for possibility of soil liquefaction was plotted by increasing and decreasing the values of in the particle size distribution curve of Lyell Silty Sand. Particle Size Distribution curves of soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora have been plotted together with the modified PSD curve with liquefaction range in order to compare the grain size distribution and to analyse the liquefaction potential based on grain size. Based on the position of the soil samples' particle distribution in the graph, the liquefaction potential of the samples can be concluded. If the PSD curve falls within the liquefaction range, the soil is susceptible to liquefaction and vice versa.

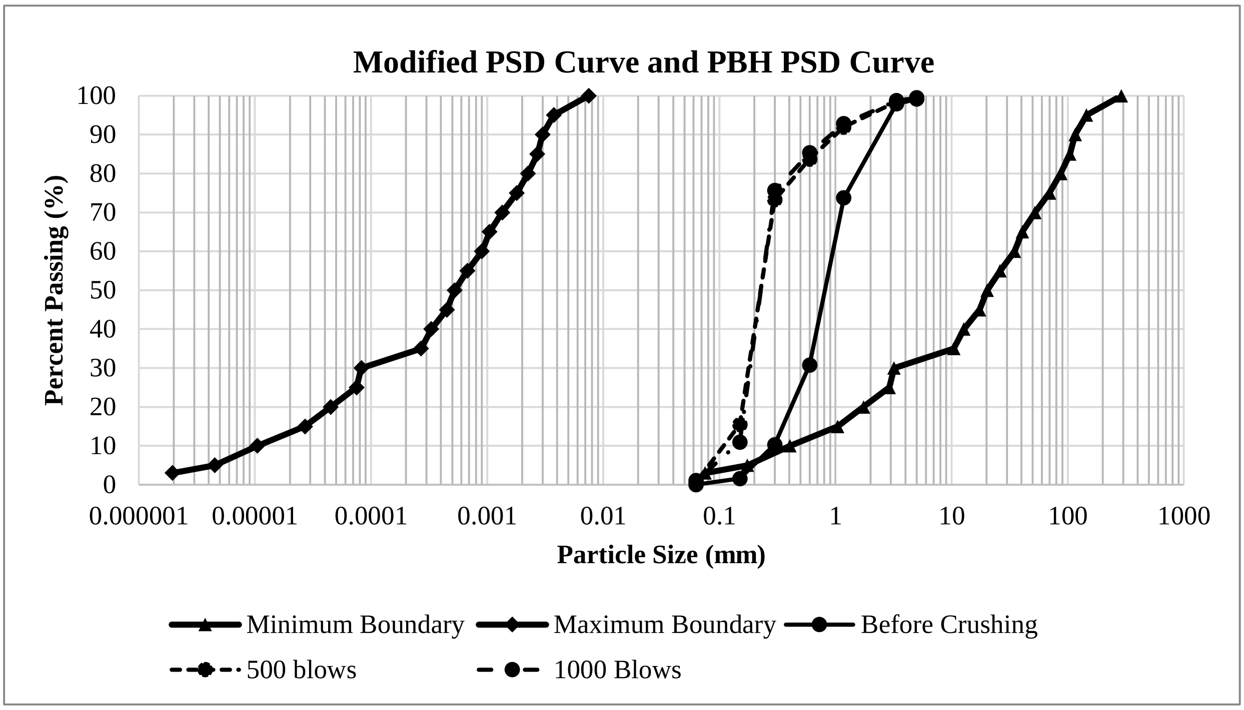


Figure 4.5 Modified PSD curve with Liquefaction Range and Pantai Batu Hitam PSD Curve

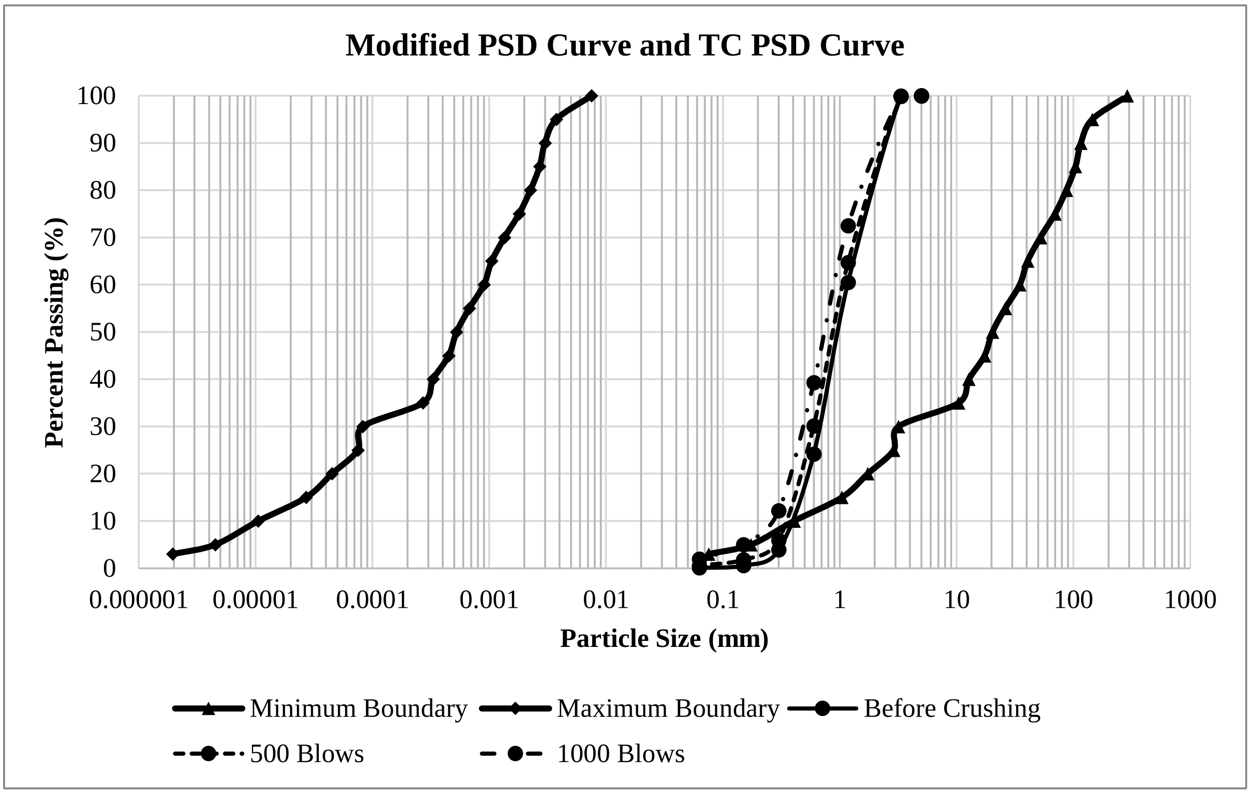


Figure 4.6 Modified PSD curve with Liquefaction Range and Teluk Cempedak PSD Curve

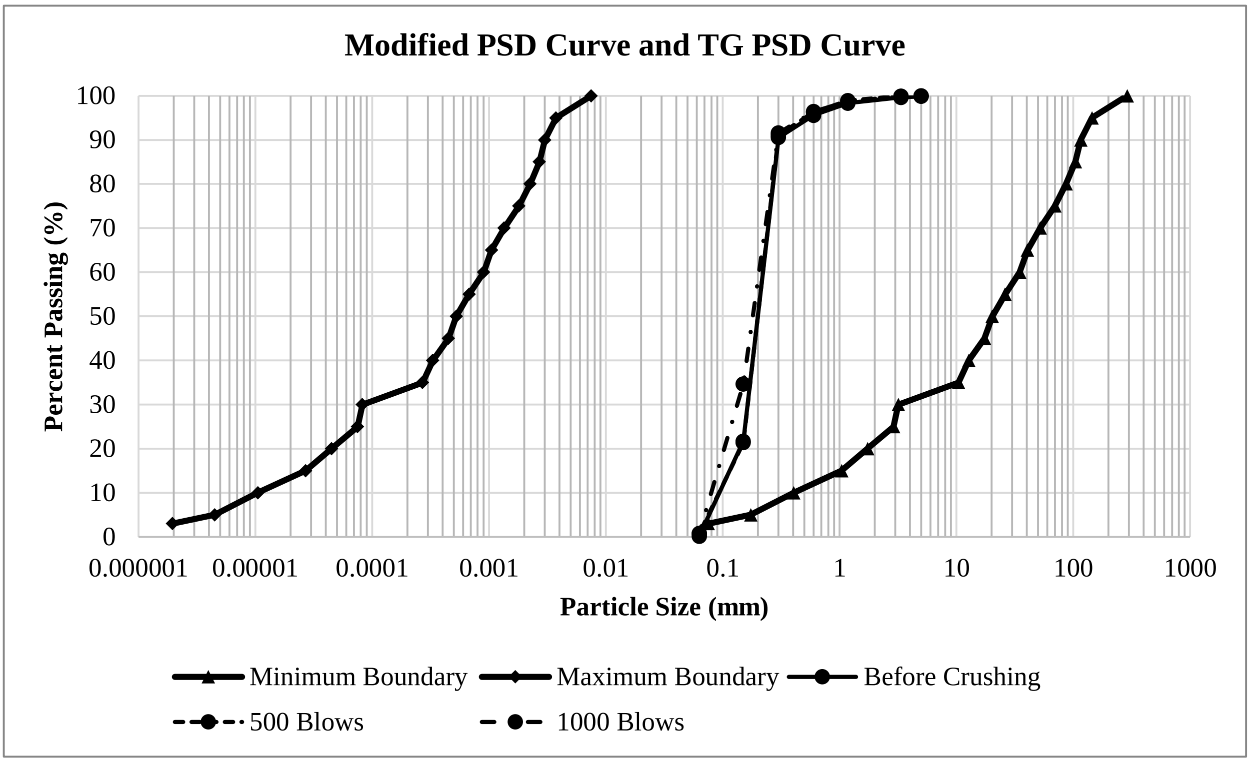


Figure 4.7 Modified PSD curve with Liquefaction Range and Taman Gelora PSD Curve

Figures 4.5, 4.6 and 4.7 shows the combination of modified PSD curve with liquefaction range and PSD curves of all the soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora distinctively. PSD curves of all the soil samples falls within the liquefaction range, both before and after crushing. PSD curves of Taman Gelora falls right in the middle of liquefaction range hence, it can be concluded that soil samples from Taman Gelora is highly susceptible to liquefaction both before and after crushing. On the other hand, PSD Curves of Pantai Batu Hitam after crushing falls right in the middle of the liquefaction range as well, however the PSD curve of this location before crushing falls more to the right of soil, making it less liquefiable before it was crushed. Thus, it is clearly proven that crushing has increased the liquefaction potential of this soil. For Teluk Cempedak, the PSD curves of this soil sample both before and after crushing falls more to the right of the graph, therefore it can be concluded that soil sample from this location is less liquefiable compared to that of other two locations.

As the soil samples were crushed or as the number of blows increases, it can be noticed that all the PSD curves moved towards the left of the liquefaction range after the soil samples were crushed, which is towards the maximum boundary where the fine fraction percentage is at its peak which is at 100% fine. Such changes in the graph shows that the soil is becoming more liquefiable and its resistance towards liquefaction gradually decreases as the number of blows increases. This clearly shows that the liquefaction potential of a soil is undoubtedly affected by crushing impact imposed on it. Liquefaction potential increases as the crushing impact increases.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The ultimate aim of this research is to analyse the relationship between the crushing impact and the liquefaction potential of sand soil from different locations along the coastal area of East Coast Peninsular Malaysia (Kuantan area). Soil samples from Pantai Batu Hitam, Teluk Cempedak and Taman Gelora undergone laboratory testings and the result were discussed and analysed in Chapter 4 by using a modified PSD curve with liquefaction range.

5.2 Conclusion

Based on the results and analysis made in Chapter 4, it can be concluded that:

i. Soil sample from Taman Gelora is the most liquefiable soil among all the soil samples, where the particle size distribution curve of both before and after crushing falls right in the middle of the liquefaction range.
ii. Soil sample from Teluk Cempedak is the least liquefiable soil among all the soil samples, where the particle size distribution curve of both before and after crushing falls more to right of the liquefaction range towards the minimum boundary, unlike soil sample from Taman Gelora.
iii. Particle size distribution curve of soil sample from Pantai Batu Hitam after crushing lies right in the middle of the liquefaction range, but before it was

crushed, the graph falls more towards the minimum boundary of the range. Hence it can be concluded that crushing impact that was imposed on the soil has increased the liquefaction susceptibility of the soil.

iv. Soil samples from all the locations were proven to be liquefiable both before and after crushing based on the analysis made. It can be noticed that all the PSD curves moved towards the left of the liquefaction range after the soil samples were crushed, which is towards the maximum boundary where the fine fraction percentage is at its peak. This clearly shows that the liquefaction potential of a soil is undoubtedly affected by crushing impact imposed on it. Liquefaction potential increases as the crushing impact increases.

v. Particle size distribution curve has high reliability to be used in the study of liquefaction potential of soil. It is a basic method where there is room for a lot of modification and improvisation that can be made according to the type of research that is conducted. Analysis can be done easily as the results will be clearly shown in the form of graph.

5.3 Recommendations

In this research, a graph was plotted using fine fraction percentage where the values in the PSD curve were increased and decreased until the fine fraction percentage reached 0% and 100%, indicating 0% of silt content and 100% silt content. This graph can be used to analyse liquefaction potential of sand soil which has almost the same engineering properties as the soil samples in this research. Besides that, further studies or research can be conducted on the liquefaction range that has been plotted in order to narrowing down the range to make it more specific. Another range can also be added within the existing range, for an example, a range for “very susceptible to liquefaction”, which can be done by further studies.

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APPENDIX A
SIEVE ANALYSIS

Table A1: Sieve Analysis of Pantai Batu Hitam soil before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.7	533.56	8.86	8.86	0.88	99.12
3.35mm	540.35	552.47	12.12	20.98	2.08	97.92
1.18mm	515.48	758.84	243.36	264.34	26.27	73.73
600 µm	484.83	917.40	432.57	696.91	69.25	30.75
300µm	431.92	637.81	205.89	902.80	89.70	10.30
150µm	421.83	509.60	87.77	990.57	98.42	1.58
63µm	257.5	273.36	15.86	1006.43	100.00	0.00
Pan	368.36	368.36	0.00	1006.43	100.00	0.00

Table A2: Sieve Analysis of Pantai Batu Hitam soil after 500 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.67	531.80	7.13	7.13	0.72	99.28
3.35mm	540.58	549.01	8.43	15.56	1.57	98.43
1.18mm	516.7	581.10	64.40	79.96	8.06	91.94
600 µm	392.11	473.76	81.65	161.61	16.28	83.72
300µm	449.1	553.08	103.98	265.59	26.76	73.24
150µm	421.96	995.22	573.26	838.85	84.52	15.48
63µm	257.55	403.90	146.35	985.20	99.27	0.73
Pan	243.48	250.73	7.25	992.45	100.00	0.00

Table A3: Sieve Analysis of Pantai Batu Hitam soil after 1000 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.71	530.14	5.43	5.43	0.54	99.46
3.35mm	542.5	549.86	7.36	12.79	1.28	98.72
1.18mm	486.98	546.05	59.07	71.86	7.21	92.79
600 µm	391.81	466.49	74.68	146.54	14.70	85.30
300µm	431.85	528.36	96.51	243.05	24.39	75.61
150µm	422.85	1067.39	644.54	887.59	89.05	10.95
63µm	418.67	517.35	98.68	986.27	98.95	1.05
Pan	368.08	378.52	10.44	996.71	100.00	0.00

Table A4: Sieve Analysis of Teluk Chempedak soil before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.68	525.29	0.61	0.61	0.06	99.94
3.35mm	540.39	541.04	0.65	1.26	0.13	99.87
1.18mm	516.1	910.03	393.93	395.19	39.48	60.52
600 µm	485.38	848.90	363.52	758.71	75.80	24.20
300µm	431.65	635.07	203.42	962.13	96.12	3.88
150µm	421.84	454.72	32.88	995.01	99.41	0.59
63µm	257.54	262.60	5.06	1000.07	99.92	0.08
Pan	368.37	369.22	0.85	1000.92	100.00	0.00

Table A5: Sieve Analysis of Teluk Chempedak soil after 500 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.67	524.82	0.15	0.15	0.01	99.99
3.35mm	540.7	541.53	0.83	0.98	0.10	99.90
1.18mm	517.2	873.32	356.12	357.10	35.32	64.68
600 µm	393	742.01	349.01	706.11	69.84	30.16
300µm	449.9	694.56	244.66	950.77	94.04	5.96
150µm	422.2	464.43	42.23	993.00	98.21	1.79
63µm	257.58	270.37	12.79	1005.79	99.48	0.52
Pan	243.5	248.78	5.28	1011.07	100.00	0.00

Table A6: Sieve Analysis of Teluk Chempedak soil after 1000 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.83	509.03	0.20	0.20	0.02	99.98
3.35mm	542.41	543.09	0.68	0.88	0.09	99.91
1.18mm	515.56	791.24	275.68	276.56	27.54	72.46
600 µm	484.11	817.42	333.31	609.87	60.74	39.26
300µm	433.25	705.65	272.40	882.27	87.86	12.14
150µm	429.13	501.02	71.89	954.16	95.02	4.98
63µm	257.56	288.05	30.49	984.65	98.06	1.94
Pan	364.77	384.26	19.49	1004.14	100.00	0.00

Table A7: Sieve Analysis of Taman Gelora soil before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	524.66	525.96	1.30	1.30	0.13	99.87
3.35mm	540.27	542.77	2.50	3.80	0.38	99.62
1.18mm	515.64	528.64	13.00	16.80	1.69	98.31
600 µm	484.64	511.95	27.31	44.11	4.43	95.57
300µm	431.83	482.06	50.23	94.34	9.47	90.53
150µm	421.9	1107.35	685.45	779.79	78.31	21.69
63µm	257.5	472.14	214.64	994.43	99.86	0.14
Pan	368.33	369.70	1.37	995.80	100.00	0.00

Table A8: Sieve Analysis of Taman Gelora soil after 500 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	509.88	1.11	1.11	0.11	99.89
3.35mm	542.15	543.14	0.99	2.10	0.21	99.79
1.18mm	485.8	496.03	10.23	12.33	1.22	98.78
600 µm	483.82	507.83	24.01	36.34	3.59	96.41
300µm	448.09	497.22	49.13	85.47	8.45	91.55
150µm	421.85	997.10	575.25	660.72	65.35	34.65
63µm	257.97	600.43	342.46	1003.18	99.22	0.78
Pan	368.27	376.14	7.87	1011.05	100.00	0.00

Table A9: Sieve Analysis of Taman Gelora soil after 1000 blows

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.84	509.33	0.49	0.49	0.05	99.95
3.35mm	542.44	542.80	0.36	0.85	0.09	99.91
1.18mm	515.66	525.61	9.95	10.80	1.09	98.91
600 µm	484.1	510.46	26.36	37.16	3.75	96.25
300µm	433.06	484.30	51.24	88.40	8.91	91.09
150µm	428.84	1120.34	691.50	779.90	78.63	21.37
63µm	257.56	462.13	204.57	984.47	99.26	0.74
Pan	364.81	372.15	7.34	991.81	100.00	0.00

APPENDIX B
RELATIVE DENSITY

Table B1: Relative Density of Soil Samples before Crushing

Location	Teluk Cempedak	Taman Gelora	Pantai Batu Hitam
Mass of empty mold (kg)	9.31	9.31	9.31
Diameter of empty mold (cm)	15.00	15.00	15.00
Height of empty mold (cm)	15.50	15.50	15.50
Mass of mold and soil, M_1 (kg)	13.86	12.90	13.20
Average initial dial gauge reading (R_i) cm	4.02	2.93	2.78
Average final dial gauge reading (R_f) cm	2.65	0.40	0.79
Thickness of surcharge base plate (cm)	1.30	1.30	1.30
Mass of mold and soil, M_2 (kg)	13.73	12.74	13.22
M_{s1} (g)	4550.00	3590.00	3890.00
M_{s2} (g)	4420.00	3430.00	3910.00
Ac (cm^2)	176.74	176.74	176.74
H (cm)	2.67	3.83	3.29
V_c (cm^3)	2739.43	2739.43	2739.43
V (cm^3)	2267.54	2062.53	2157.96
P_{dmin} (g/cm^3)	1.66	1.31	1.42
P_{dmax} (g/cm^3)	1.95	1.66	1.81
G_s	2.39	2.56	2.38
e_{min}	0.23	0.54	0.31
e_{max}	0.44	0.95	0.68
V	2497.30	2292.285	2387.724
ρ_d	1.82	1.57	1.63
e	0.31	0.63	0.46
Relative Density, D_r (%)	59.76	77.00	59.36

Table B2: Relative Density of Soil Samples after 500 blows

Location	Teluk Cempedak	Taman Gelora	Pantai Batu Hitam
Mass of empty mold (kg)	9.31	9.31	9.31
Diameter of empty mold (cm)	15.00	15.00	15.00
Height of empty mold (cm)	15.50	15.50	15.50
Mass of mold and soil, M_1 (kg)	13.72	12.98	13.43
Average initial dial gauge reading (R_i) cm	3.05	4.71	3.88
Average final dial gauge reading (R_f) cm	0.92	2.88	2.68
Thickness of surcharge base plate (cm)	1.30	1.30	1.30
Mass of mold and soil, M_2 (kg)	13.48	12.84	13.28
Ms_1 (g)	4410.00	3670.00	4120.00
Ms_2 (g)	4170.00	3530.00	3970.00
A_c (cm^2)	176.74	176.74	176.74
H (cm)	3.43	3.13	2.50
V_c (cm^3)	2739.43	2739.43	2739.43
V (cm^3)	2133.22	2186.24	2297.59
P_{dmin} (g/cm^3)	1.61	1.34	1.50
P_{dmax} (g/cm^3)	1.95	1.61	1.73
G_s	2.60	2.55	2.43
e_{min}	0.33	0.58	0.41
e_{max}	0.62	0.90	0.62
V	2362.98	2416.00	2527.35
ρ_d	1.87	1.52	1.63
e	0.39	0.68	0.49
Relative Density, D_r (%)	77.87	69.33	59.74

Table B3: Relative Density of Soil Samples after 1000 blows

Location	Teluk Cempedak	Taman Gelora	Pantai Batu Hitam
Mass of empty mold (kg)	9.31	9.31	9.31
Diameter of empty mold (cm)	15.00	15.00	15.00
Height of empty mold (cm)	15.50	15.50	15.50
Mass of mold and soil, M_1 (kg)	13.92	12.99	13.22
Average initial dial gauge reading (R_i) cm	3.06	4.67	3.81
Average final dial gauge reading (R_f) cm	2.39	2.99	2.55
Thickness of surcharge base plate (cm)	1.30	1.30	1.30
Mass of mold and soil, M_2 (kg)	14.02	12.79	13.15
M_{s1} (g)	4610.00	3680.00	3910.00
M_{s2} (g)	4710.00	3480.00	3840.00
A_c (cm^2)	176.74	176.74	176.74
H (cm)	1.97	2.98	2.56
V_c (cm^3)	2739.43	2739.43	2739.43
V (cm^3)	2391.26	2212.75	2286.98
P_{dmin} (g/cm^3)	1.68	1.34	1.43
P_{dmax} (g/cm^3)	1.97	1.57	1.68
G_s	2.57	2.53	2.65
e_{min}	0.30	0.61	0.58
e_{max}	0.53	0.88	0.86
V	2621.02	2442.51	2516.74
ρ_d	1.76	1.48	1.55
e	0.46	0.71	0.71
Relative Density, D_r (%)	29.68	63.31	54.21

APPENDIX C
SPECIFIC GRAVITY

Table C1: Specific Gravity of Soil Samples before Crushing

Location	**Teluk Cempedak**		**Taman Gelora**		**Pantai Batu Hitam**	
Density bottle No.	1	2	3	4	5	6
Weight of density bottle	31.91	31.33	31.36	31.70	29.14	32.96
Weight of bottle + Stopper (W_1)	36.11	35.72	35.81	35.81	33.55	37.42
Weight of bottle + Stopper + Dry Soil (W_2)	46.13	45.70	45.82	45.82	43.53	47.22
Weight of bottle + Stopper + Soil + Water (W_3)	141.73	141.52	141.77	141.48	139.15	143.78
Weight of bottle + Stopper + Water (W_4)	135.77	135.84	135.48	135.60	133.96	137.65
Weight of dry soil (W_2-W_1)	10.02	9.98	10.01	10.01	9.98	9.80
Weight of water (W_4-W_1)	99.66	100.12	99.67	99.79	100.41	100.23
Weight of soil + Water (W_3-W_2)	95.60	95.82	95.95	95.66	95.62	96.56
Specific Gravity	2.47	2.32	2.69	2.42	2.08	2.67
Average Specific Gravity	2.39		2.56		2.38	

Table C2: Specific Gravity of Soil Samples after 500 blows

Location	Teluk Cempedak		Taman Gelora		Pantai Batu Hitam	
Density bottle No.	1	2	3	4	5	6
Weight of density bottle	31.28	31.34	30.11	31.37	29.12	32.97
Weight of bottle + Stopper (W_1)	35.54	35.74	35.80	35.10	33.55	37.42
Weight of bottle + Stopper + Dry Soil (W_2)	45.53	45.76	45.88	45.82	43.53	47.42
Weight of bottle + Stopper + Soil + Water (W_3)	141.03	142.10	141.84	141.43	139.47	143.89
Weight of bottle + Stopper + Water (W_4)	134.97	135.85	135.53	135.12	134.00	137.66
Weight of dry soil (W_2-W_1)	9.99	10.02	10.08	10.72	9.98	10.00
Weight of water (W_4-W_1)	99.43	100.11	99.73	100.02	100.45	100.24
Weight of soil + Water (W_3-W_2)	95.50	96.34	95.96	95.61	95.94	96.47
Specific Gravity	2.54	2.66	2.67	2.43	2.21	2.65
Average Specific Gravity	2.60		2.55		2.43	

Table C3: Specific Gravity of Soil Samples after 1000 blows

Location	Teluk Cempedak		Taman Gelora		Pantai Batu Hitam	
Density bottle No.	1	2	3	4	5	6
Weight of density bottle	31.86	30.32	26.88	31.35	29.10	27.60
Weight of bottle + Stopper (W_1)	36.11	34.74	31.05	35.80	33.50	31.69
Weight of bottle + Stopper + Dry Soil (W_2)	46.13	44.73	41.06	45.80	43.44	41.62
Weight of bottle + Stopper + Soil + Water (W_3)	141.73	140.88	137.49	141.60	140.17	137.96
Weight of bottle + Stopper + Water (W_4)	135.77	134.62	131.51	135.49	133.98	131.79
Weight of dry soil (W_2-W_1)	10.02	9.99	10.01	10.00	9.94	9.93
Weight of water (W_4-W_1)	99.66	99.88	100.46	99.69	100.48	100.10
Weight of soil + Water (W_3-W_2)	95.60	96.15	96.43	95.80	96.73	96.34
Specific Gravity	2.47	2.68	2.48	2.57	2.65	2.64
Average Specific Gravity	2.57		2.53		2.65	

APPENDIX D
PLOTTING OF RANGE FOR MODIFIED PSD CURVE USING TRIAL AND ERROR METHOD

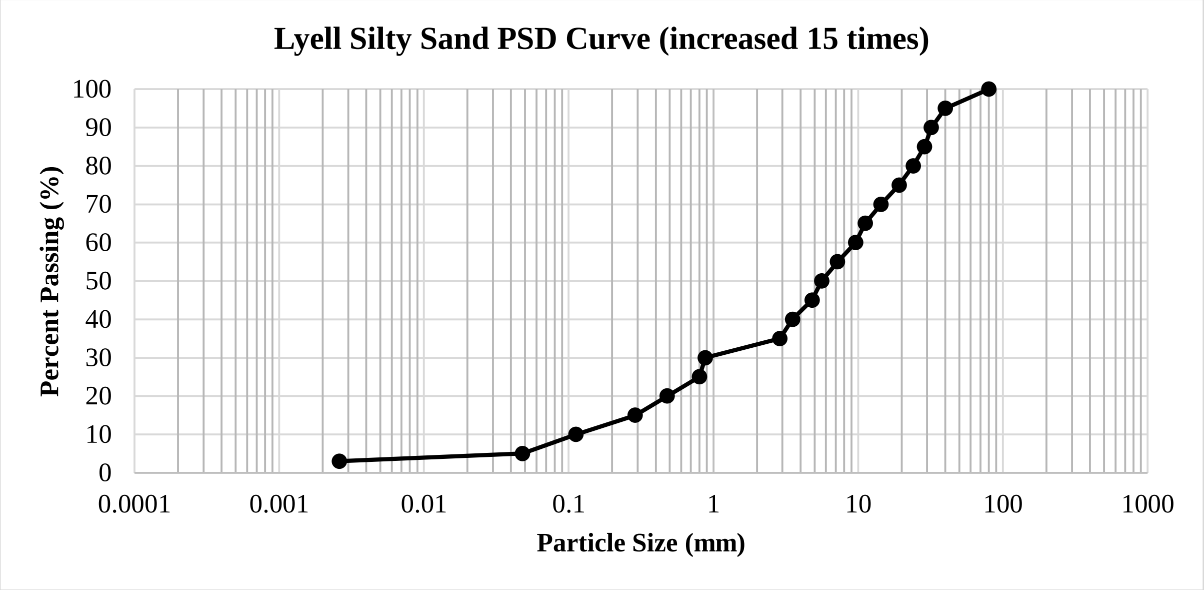

Figure D1: Lyell Silty Sand PSD Curve after increased by 15 times

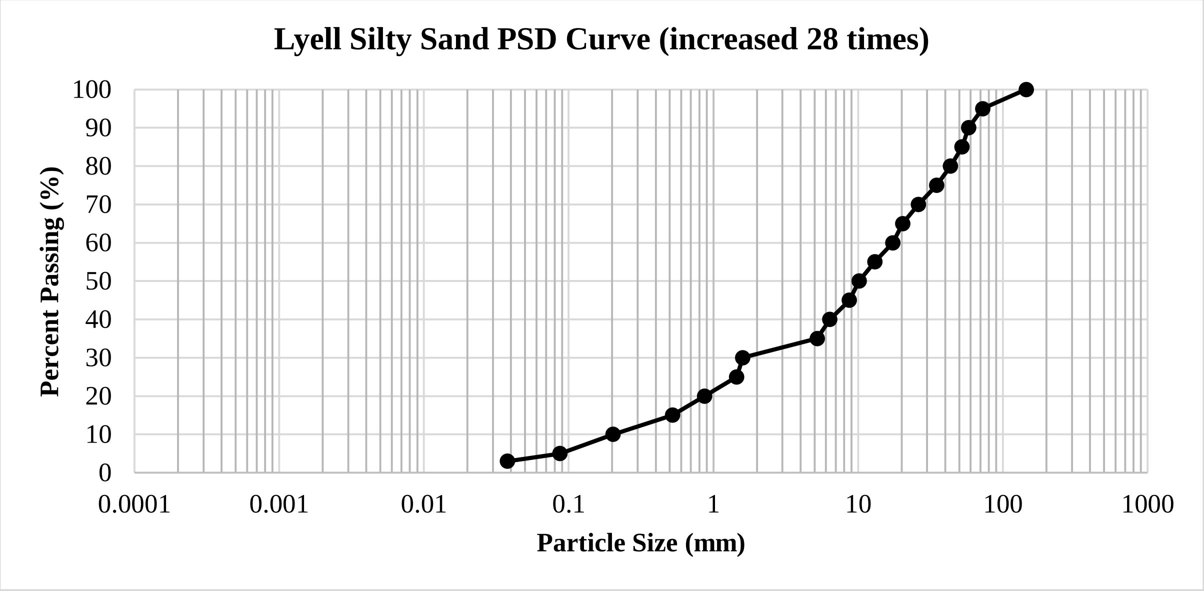

Figure D2: Lyell Silty Sand PSD Curve after increased by 28 times

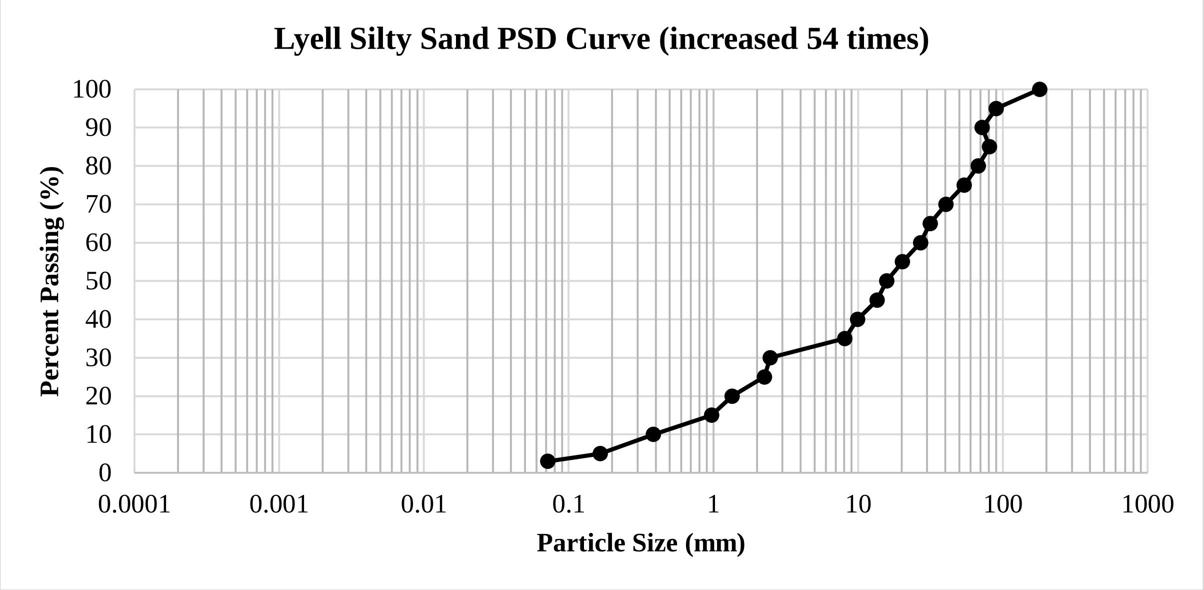

Figure D3: Lyell Silty Sand PSD Curve after increased by 54 times

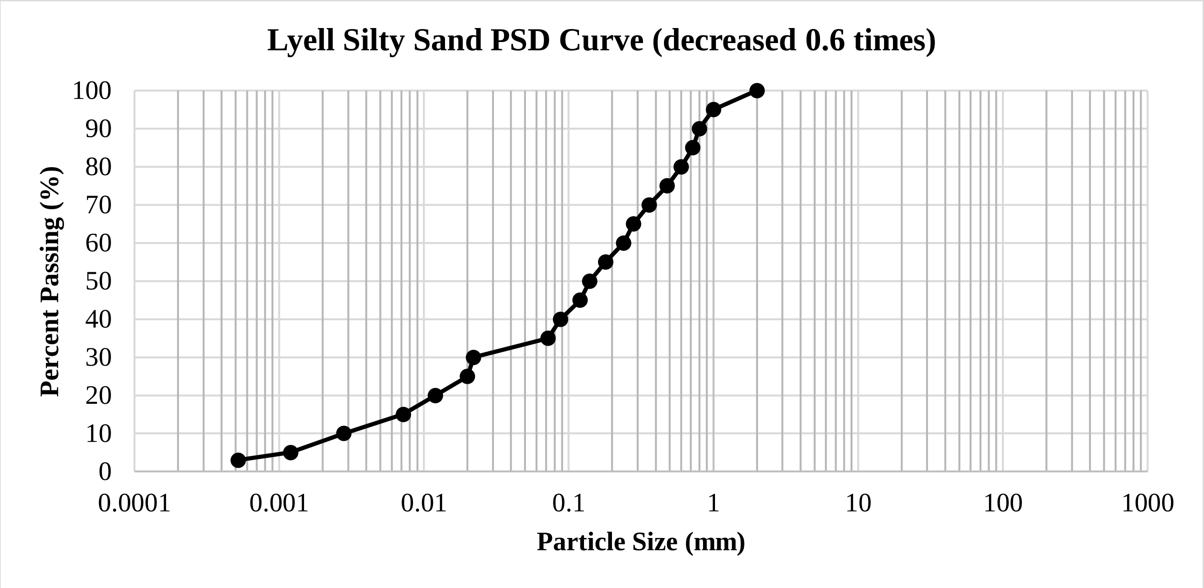

Figure D4: Lyell Silty Sand PSD Curve after decreased by 0.6 times

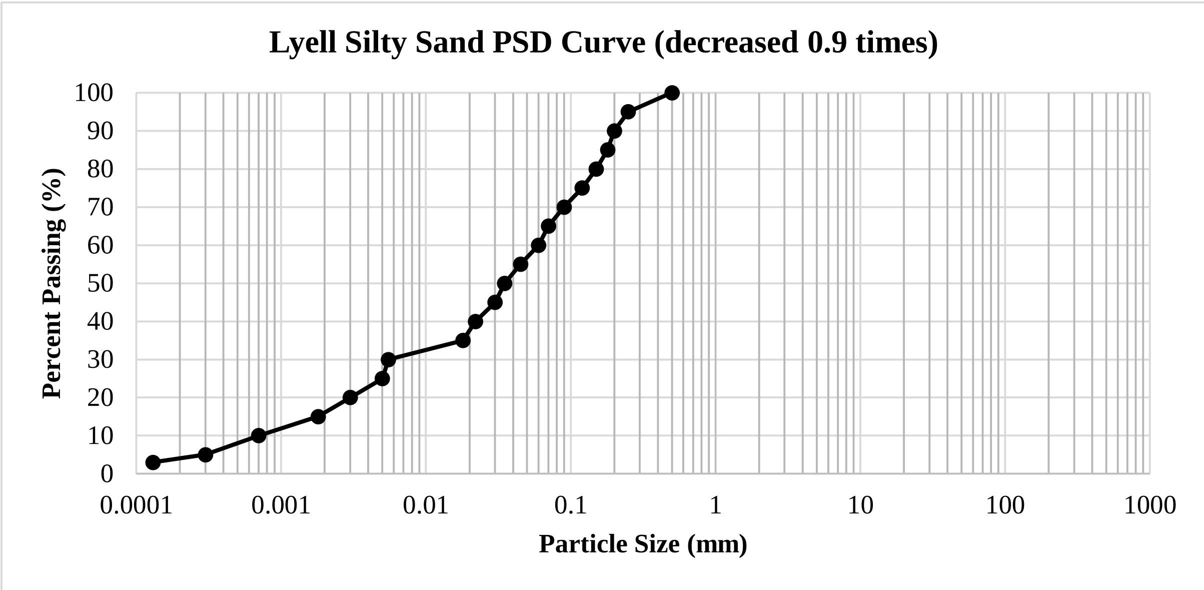

Figure D5: Lyell Silty Sand PSD Curve after decreased by 0.9 times

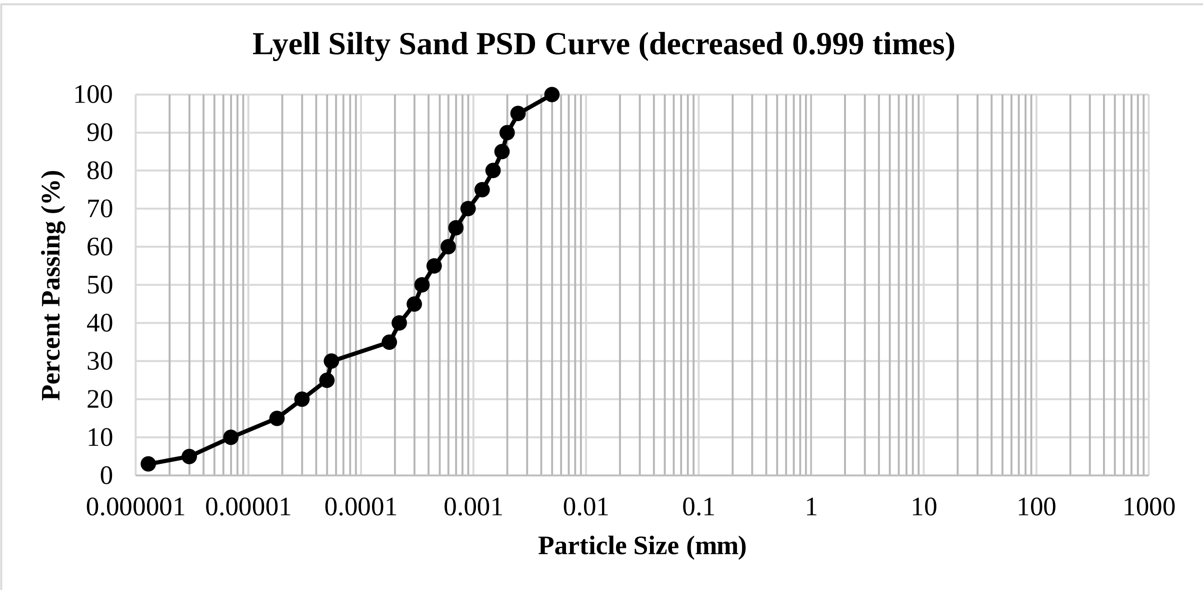

Figure D6: Lyell Silty Sand PSD Curve after decreased by 0.999 times