CRUSHED INDUCED LIQUEFACTION POTENTIAL OF SANDY SOILS IN KUANTAN

AHMAD FAUZAN BIN SOBERI

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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ID Number : AA13103

Date : 16^{th} JUNE 2017

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AHMAD FAUZAN BIN SOBERI

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ABSTRAK

Objektif kajian bagi projek penyelidikan ini adalah untuk mengkaji potensi pencairan pasir mudah hancur Kuantan. Kajian ini menekankan kawasan pantai terutamanya di bahagian pantai timur semenanjung Malaysia. Tanah dari kawasan-kawasan ini memenuhi dua faktor utama yang menyumbang kepada pencairan tanah iaitu tanah jenis longgar dan berpasir yang keadaannya tepu sepenuhnya. Kawasan-kawasan yang ditumpukan ini sinonim dengan pembangunan pesat di mana ia terdedah kepada aktiviti-aktiviti yang mampu menyebabkan kehancuran tanah. Ciri-ciri fizikal tanah dari tiga kawasan pantai yang berbeza ini telah dikaji dari aspek taburan saiz zarah, gravity tentu dan ketumpatan nisbi untuk kedua-dua keadaan iaitu sebelum dan selepas proses penghancuran tanah. Kemudian, hasil taburan saiz zarah dibandingkan pula dengan piawaian pelabuhan bagi mengkaji potensi pencairan di kawasan tersebut. Hasil kajian potensi pencairan bagi tanah di kawasan pantai timur semenanjung Malaysia dilaporkan dalam bentuk lengkung Taburan Saiz Zarah.

ABSTRACT

The objective of this research project is to study the liquefaction potential of crushable Kuantan sand. This research emphasizes mainly on the coastal areas of East Coast Peninsular Malaysia. Soil from these areas fulfils two major factors of liquefiable soil which are uniformly graded loose granular type of soils and in fully saturated soil condition. These areas are also involved to vast development where the soil are frequently exposed to activities that may cause soil crushing. Physical properties of soil from three different coastal areas in Kuantan such as the grain size distribution, specific gravity and relative density were determined before and after crushing the soil. The results of grain size distribution were then used to compare with the Technical Standards of Ports and Harbour to identify its potential of liquefaction. The liquefaction potential of soil in East Coast Malaysia was illustrated in the form of Particle Size Distribution (PSD) curve as the outcome of the research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background of study

Soil liquefaction causes otherwise solid soil to act temporarily as a viscous liquid as loss of strength (Rafferty J.P, 2016). The phenomenon occurs in water-saturated unconsolidated soils affected by seismic S waves (secondary waves), which leads to ground vibrations during earthquakes. Peninsular Malaysia assumed to be seismically free since it is located on a tectonically stable crust of Sunda Plate. However, low seismicity is still being detected as it is quite near (approximately 350 km away) to the Sumatran active fault and Sumatran subduction zone.

Technically, an earthquake could cause significant damages within the range of 100 to 200 km radius from epicenter as a nature, but high intensity earthquake could affect beyond this range which is up to 700 km away (Megawati et al, 2005). It is important to understand that earthquake does not need to be of large magnitude to produce severe damage. The degree of damage does not solely dependent on the physical size of an earthquake but also on other factors such as the time and location of the occurrence, population density in the area concerned and secondary events such as soil liquefaction. Considering the factors contributing to severe earthquake damages focusing on the occurrence of the secondary event, a thorough study needs to be done to identify the potential of soil liquefaction on coastal areas concentrating in Kuantan, Pahang.

Figure 1.1 and Table 1.1 show that Malaysia is indeed exposed to the possibility of earthquake occurrence. From the data, it can be seen that two of the locations of local earthquake occurrences were actually recorded in Pahang (Bukit Tinggi and Jerantut). In fact, Bukit Tinggi recorded the highest number of occurrences which is of 24 cases. Thus, it is not impossible for earthquake to take place in other parts of Pahang.

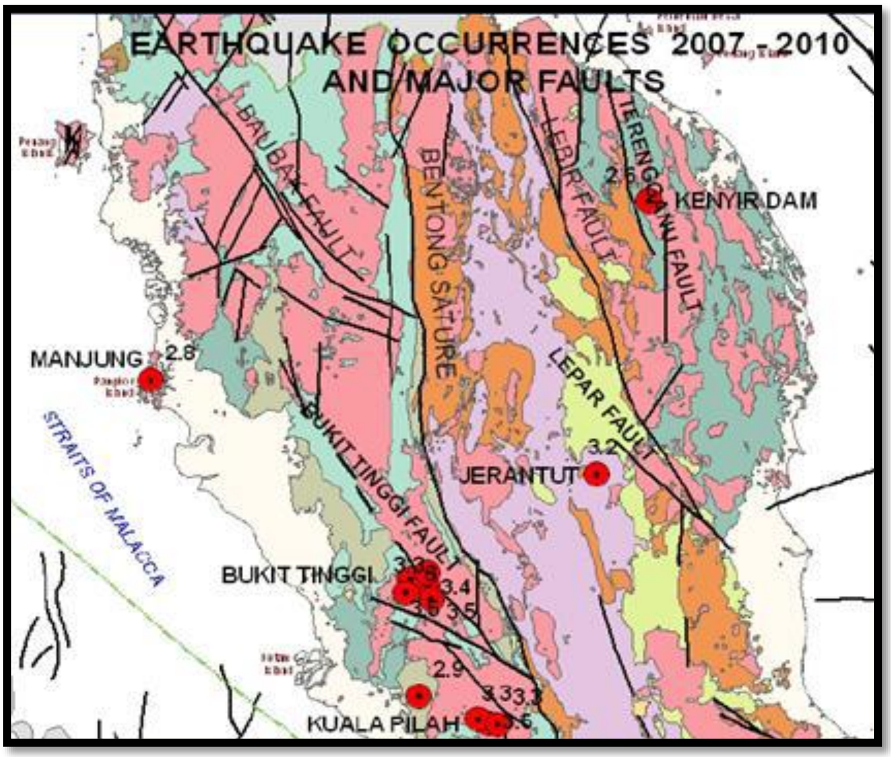

Figure 1.1 Seismotectonic Map of Malaysia

Source: (Mat Salleh and Ariffin, 2013)

Table 1.1 Local Earthquake Occurrences

Place (body wave magnitude)	*Case*
Bukit Tinggi(1.7-3.5 mb)	24
Kuala Pilah(2.6-3.2 mb)	4
Jerantut(3.2 mb)	1
Manjung(2.8mb)	1
Terengganu Earthquake(2.6mb)	1

Source: (Mat Salleh and Ariffin, 2013).

Although earthquake shock is considered as a major cause of liquefaction, construction practices, such as blasting and soil compaction and vibroflotation (which uses a vibrating probe to change the grain structure of the surrounding soil), also may unintentionally simulate this phenomenon. Poorly drained fine-grained soils such as sandy, silty, and gravelly soils are the most susceptible soil to liquefaction (Rafferty J.P. 2016). In this study we are focusing in liquefaction potential on crushable sand. Crushable sand comes from coastal area of Kuantan which have undergone the process of crushing caused by piling works in construction sites. The crushing process breaks the sand particles altering its size, angularity and density. Therefore, this study is going to further discuss the effect of crushing process on soil liquefaction.

1.2 Problem Statement

Soil liquefaction occurs when granular soil which are uniformly graded are in fully saturated condition. Since there is a vast development in the east coast region of the Peninsular Malaysia, it is highly potential for liquefaction. Coastal area in Kuantan where construction site are located may be vulnerable to liquefaction due to sand crushing.

1.3 Research Question

The proposed study aims to address the following research questions:

a) Is sandy soils in Kuantan have the potential to liquefy due to crushing?

b) Will liquefaction potential increase as the sandy soil particles breaks after particle crushing?

c) Is the existing guideline suitable for prediction of liquefaction in Kuantan?

1.4 Objective of Study

The objectives of the study are:

a) To identify the potential of liquefaction of Kuantan Sand before and after particle crushing.

b) To determine the engineering properties of sandy soil before and after particle crushing.

c) To come up with a guideline for liquefaction potential of coastal area in Kuantan.

1.5 Scope and Limitation of Study

This study focused on investigating the liquefaction potential of sandy soil around coastal areas in Kuantan, Pahang. The scope and limitation of study are:

a) The sandy soils for this research will be limited to three parts of the east coast coastal area in Kuantan, Pahang. Which are Teluk Chempedak, Pantai Batu Hitam and Taman Gelora.

b) Sand specimens collected will be crushed using a Proctor Hammer that will breaks the sand particles.

c) Study is limited to one factor which is the change in effective grain size due to crushing impact.

d) Sieve analysis was conducted to get the Particle Size Distribution of the sand samples and will follow the International and British Test Sieve Series (BS 1377: Part 2 1990:9.6; ASTM D422).

1.6 Significant of Study

Soil liquefaction can cause serious damage to buildings, bridges and roads. Crushing of sandy soil might increase the liquefaction potential of these three areas. Studying the liquefaction potential using the particle size distribution graph can provide an easy, cheap and fast result that can help in mitigation plan of that area. This is because analysing soil liquefaction using particle size distribution does not require special tools and also extra labour force. Unlike other methods like Standard Penetration Test (SPT) or Cone Penetration Test (CPT) that are used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Soil liquefaction, also known as loss of strength that causes otherwise solid soil to behave temporarily as a viscous liquid. The phenomenon occurs in water-saturated unconsolidated soils affected by seismic S waves (secondary waves), which cause ground vibrations during earthquakes. Although earthquake shock is the best known as the cause of liquefaction, certain construction practices, including blasting and soil compaction and vibroflotation (which uses a vibrating probe to change the grain structure of the surrounding soil), produce this phenomenon intentionally. Poorly drained fine-grained soils such as sandy, silty, and gravelly soils are the most susceptible to liquefaction (Rafferty J.P. 2016). However, from the main factors that contributes to liquefaction, the scope of this study would be focused on the uniformity of grain size and the influence of crushing impact on the sandy soil.

Granular soils are made up of a mix of soil and pore spaces. When earthquake shock occurs in waterlogged soils, the water-filled pore spaces collapse, which decreases the overall volume of the soil. This process increases the water pressure between individual soil grains, and the grains can then move freely in the watery matrix. This substantially lowers the soil’s resistance to shear stress and causes the mass of soil to take on the characteristics of a liquid. In its liquefied state, soil deforms easily, and heavy objects such as structures can be damaged from the sudden loss of support from below.

2.2 Crushing of Granular Soils

According to Bartake and Singh (2005) crushing of soil grains occurs from extremely high stresses that may generated during pile driving, constructions of high earth or rock fill dams, laying foundations of the offshore gravity structures, impact of projectiles, drilling at great depths for extraction. And as a results of various experiments, parameters like total breakage factor (Hardin, 1985), aggregate stability (Oztas et al. 1999), and probability of crushing and particle breakage factor (Nakata et al. 1999) have been defined. All of this parameters helps to understand the crushing behaviour of granular material. Other than that, it is found that the factors that influence crushing of grains are particle-size distribution, grain shape, hardness, density or the voids ratio and the aspect ratio (e.g., Miura et al. 1984; Hardin 1985; Feda 2002; Chuhan et al. 2003).

2.3 Liquefaction Potential

According to Sitharam (2015) in his journal titled Evaluation of Liquefaction Potential of soils liquefaction phenomenon is associated with a condition of zero effective stress due to progressive increase in pore water pressure that results from the tendency of densifications of sand structure subjected to cyclic loading and that the generation of excess pore pressure under undrained loading condition is the “main ingredient” of all liquefaction phenomena. In this journal it also stated that site specific factors that control the development of liquefaction of soil are grain size distribution of the soil mass, relative density of the soil deposit, depth and thickness of different soil strata, depth of ground water table etc. For this study purposes, we will take a look specifically into, particle size distribution of the soil samples.

2.4 Liquefaction Factors

In the recent past, a qualitative understanding from laboratory investigation on the liquefaction process, pore water pressure generation and post liquefaction behaviour in sandy soils has considerably enhanced by various researchers (Seed and Lee 1966; Peacock and Seed, 1968; Ishihara et al 1975; Finn et al., 1981; Dobry et al., 1982; Hyodo et al., 1994; Talaganov, 1996; GovidaRaju, 2005). The factors that is important are intensity of earthquake, duration of the earthquake, and ground water table location, and soil type, soil relative density, particle size gradation, and particle shape, depositional environment of soil, soil drainage condition, confining pressures, and aging and cementation deposits. Xenaki and Athanasopoulos (2003) as shown in Figure 2.1 shows two sets of grain curves showing the ranges of grain size distribution for most liquefiable and potentially liquefiable soils in geotechnical criterion. Stated here, the soil type most susceptible to liquefaction is sand. Sand that has uniform gradation and rounded particles, very loose density state, recently deposited with no cementation between soil grains, and no prior preloading or seismic shaking.

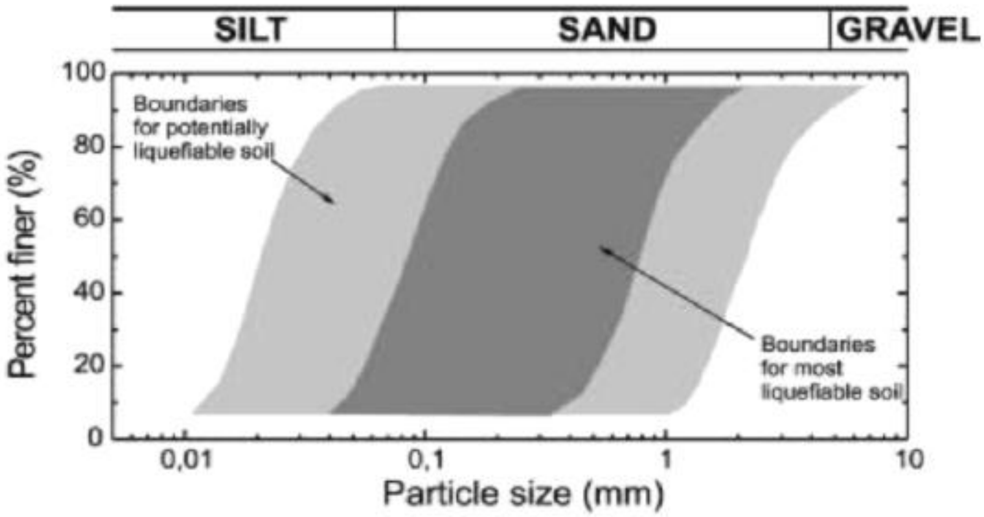

Figure 2.1 Liquefaction Potential based on Particle Size Distribution
Source: (Xenaki and Athanasopoulos, 2003)

2.5 Types of Prediction and Judgement of Liquefaction

There are many methods that can be used to make prediction and judgement of liquefaction. This evaluation of liquefaction potentials can be done using the following methods:-

- Cyclic Stress Approach

- Cyclic Strain Approach
- Cyclic Triaxial test
- Cyclic Simple Shear Test
- Cyclic Torsional Shear Test
- Particle Size Distribution
- N-Values

Other than that, in situ test:

- Standard Penetration Test
- Cone Penetration Test
- Shear Wave Velocity Method

Particle Size method is the most suitable evaluation of liquefaction for this study because it is the most feasible and convenient way. It does not require a complicated test procedure compared to other methods, it is cheaper and result can be obtained faster. Based on Vaid (1990) it is stated that the effect of grain size distribution on the dynamic loss of soil strength and liquefaction as a major topic that requires further research. Subsequently, physical characteristics of sands, such as grain size, shape, mineralogy and gradation, have all been suggested to influence resistance to liquefaction (Chang et al. 1982; Kaggwa 1988; Lee and Fitton 1969; "Liquefaction" 1985; Wong et al.1974).

2.6 Judgement Based on Particle Size Distribution

Based in the Technical Standards and Commentaries for Port and Harbour Facilities in Japan, the subsoil should be classified according to grain size, referring to figure below to which applications depends on the value of the uniformity coefficient. The threshold value of the uniformity coefficient ($U_c = D_{60}/D_{10}$) is 3.5, where U_c is the uniformity coefficient, and $D_{60}$and D_{10} denote the grain size corresponding to 60% and 10% passing respectively. Soil is judged not to liquefy when the grain distribution curve is not included in the range "possibility of liquefaction" in Figure 2.2 and 2.3

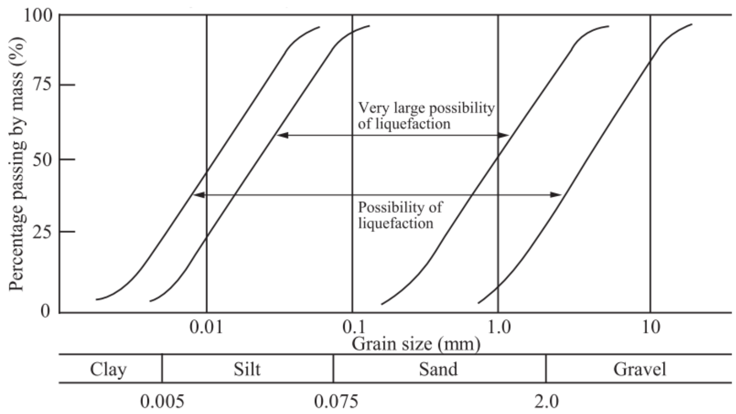

Figure 2.2 Possibility of Liquefaction with Large Uniformity Coefficient ($U_c \geq 3.5$)
Source: (Overseas & Area, 2009)

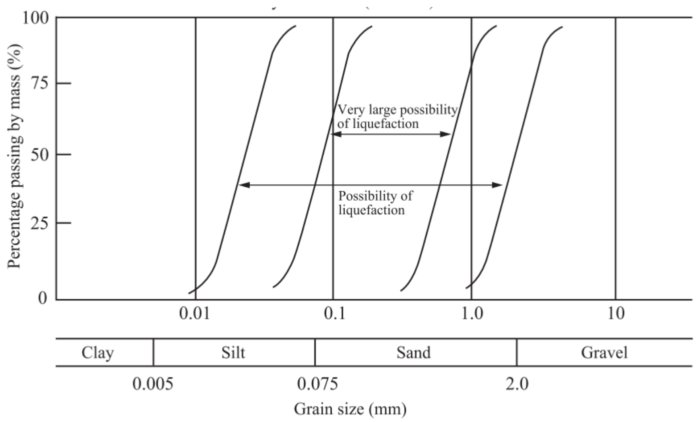

Figure 2.3 Possibility of Liquefaction with Small Uniformity Coefficient(U_c ≤3.5)

Source: (Overseas & Area, 2009)

Technical Standards of Ports and Harbour has many functions and benefits for example on a research done by Numata and Mori (2004) on their paper "Limits in The Gradation Curves of Liquefiable Soils". Numata and Mori (2004) (refer Figure 2.4) used this technical standards particle size distribution to compare with their soil samples' particle size distribution in obtaining their results.

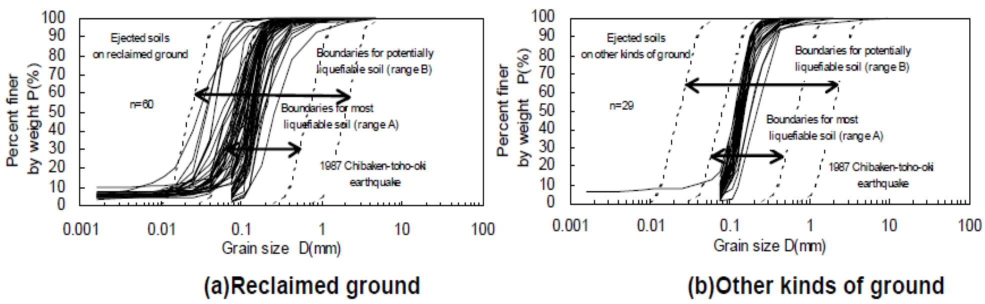

Figure 2.4 Comparison of soil samples using the Techincal Standards of Ports and Harbor

Source:(Chen, Ueng, and Lee, 2004)

Based on their results, their samples correspond to the Technical standard in the case of $U_c \leq 3.5$ on the finer side of the figure. Meanwhile, the models of ejected soil correspond in the case of $U_c \geq 3.5$ on the coarser side of the figure. The reason behind this is considered as follows, according to Numata and Mori (2004) When the grain size of general soil decreases, the soil contains much having high cohesion, thereby achieving high liquefaction resistance. But, when the grain size of poorly graded soil decreases, the liquefaction resistance does not increase, mainly because poorly-graded soil is scarcely cohesive with little clay. On the other hand, when grain size increase, liquefaction resistance increases because the drainability generally increases. However, in the case of well graded soil, liquefaction resistance does not increase even if the grain size increases, due to the low drainability because of the fines present in the well graded soil.

2.7 Breakage Factor and Breakage Index

Particle breakage have long been studied. For example, a few studies have attempted to quantify the degree of particle breakage (Lee and Farhoomand, 1967; Marsal, 1967, Miura and O'Hara, 1979; Hardin, 1985; Lade et al., 1996). There are some empirical methods by which is used to quantify particle breakage consider changes in specific particle size, for example Lee and Farhoomand's relative breakage, the entire grain size distribution before and after loading, and also Hardin's relative breakage and surface area increment. In this study, two technique were adopted in order to quantify the degree of particle breakage (Lade et al, 1996). I adopted the breakage factor B_{10} used in a number of studies and also breakage index B_{15} (Lee and Farhooman, 1967). Lee and Farhoomand (1967) proposed this concept of particle breakage when investigating earth dam filter material according to Tergazhi's design criteria of drains and filters. It is defined relative crushing$B_{15} = D_{15i}/D_{15f}$, as the ratio of initial 15% size passing to final 15% size passing.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, material preparation, material details, laboratory testing and data analysis are clearly described and discussed to carry out the experimental study with expected data and results (refer Figure 3.1). This chapter explains how the data was collected to address the research objectives and problem statement. Sieve Analysis, Sample Crushing and Hydrometer Test were conducted to support the experimental study with the data and the result that was collected. The procedure of each experimental works is explained in detail in this chapter.

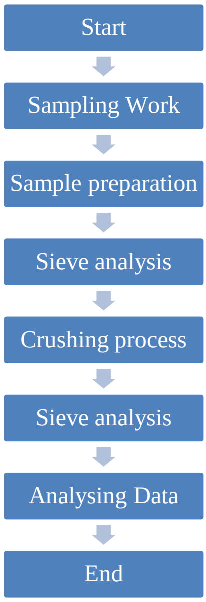

Figure 3.1 Methodology Flow Chart

3.2 Sampling Location

The sand soil samples for this research were collected from three different coastal areas around the district of Kuantan (refer Figure 3.2) to carry out the experimental study. The sampling work was carried out at Teluk Cempedak (3.8120° N, 103.3726° E), Taman Gelora (3.8073° N, 103.3475° E) and Pantai Batu Hitam (3.8685°N, 103.3654°E).

Figure 3.2 Sample Location

3.3 Sampling Work

The soil samples are taken from each location using a shovel as shown in Figure 3.3 and was stored into three plastic container for each of the samples. The soil samples that collected from all three locations were oven-dried at the temperature of 110°C for 24 hours before any test were carried out on it.

Figure 3.3 Sampling Work

3.4 Testing Apparatus

3.4.1 Sieve Analysis Apparatus

A standard sieve analysis test apparatus (BS 1377: Part 2 1990:9.6; ASTM D422) from Geotechnical Laboratory of University Malaysia Pahang was used to determine the distribution of the larger grain sizes. The soil is passed through a series of sieves with different mesh size which is 5.00mm, 3.35mm, 1.18mm, 600 um, 300 um, 150 um, 63 um and pan.

3.4.2 Standard Proctor Test

A standard proctor test apparatus (BS 1377:1975, Test 14; ASTM D 698; AASHTO T99) from Geotechnical Laboratory of University Malaysia Pahang was used to resembles the effect of grain crushing on soil samples. A standard 1 liter compaction mold and a 2.5 kg rammer was used.

3.5 Testing Procedure

3.5.1 Sieve Analysis

In order to get the particle size distribution. The soil samples is passed through a series of sieves with the mesh size reducing progressively, and the proportions by weight of soil retained on each sieve are measured. The sieve are angled together with the largest aperture sieve at top and remaining pan under the smallest aperture sieve at the bottom. Sieving are done using a mechanical shaker. The whole sieves is place in the shaker and are set for 10 minutes of agitation. After 10 minutes, the soil samples on each sieve is then weighed. The data is then calculated and particle size distribution curve is then plotted. The test are repeated once more after grain crushing are done, to obtain the particle size distribution after grain crushing

3.5.2 Grain Crushing

The three soil sample that have been oven dried are crushed using a 2.5kg rammer and also the standard proctor test mold. The mold is fix with the collar and also the baseplate. Free fall blows with 500 repetitions are applied to the soil. The blows are distributed uniformly to the soil samples. The number of blows of the rammer is then converted into energy using the following equation.

$$Compaction\ Energy = \frac{(NL)(NB)(W)(D)}{V} \quad 3.1$$

$$Compaction\ Energy = \frac{(3)(500)(2.5)(0.3048)}{0.8495}$$

$$= 1345.50\text{kJ}/m^3$$

Where,

NL = Number of layers (3)
NB = Number of blows (500)
W = Weight of hammer (2.5kg)
D = Distance between hammer & sample (0.3048m)
V = Volume of mold (0.8495m^3)

3.5.3 Specific Gravity

To determine the specific gravity of the soil samples, a pycnometer was used. Using the standard reference ASTM D 854-00, Standard Test for Specific Gravity of Soil Solids by Water Pycnometer. 125g of the dry sample was placed inside the pycnometer and was weighed and recorded, W_{ps}. Distilled water was added to fill about half of the pycnometer and was soaked for 10 minutes. After that the pycnometer is weigh again with its contents, W_{B} . Lastly, the pycnometer was emptied and fill with only distilled water and was weighed, W_{A}. Specific gravity was calculated using equation 3.2.

$$\mathrm{G_s} = \frac{\mathrm{W_0}}{W_0 + (W_{A-}W_B)} \qquad 3.2$$

Where,

W_0 = weight of sample of oven-dry soil, g = $W_{\mathrm{ps}} - W_{\mathrm{p}}$

W_{A}= weight of pycnometer filled with water

W_{B} = weight of pycnometer filled with water and soil

3.5.4 Relative Density

To determine the relative density of cohesionless, free-draining soils. A vibrating table is used. The relative density of a soil is the ratio, expressed as a percentage, of the difference between the maximum index void ratio and the field void ratio of a cohesionless, free-draining soil to the difference between its maximum and minimum index void ratios. The standard references used are ASTM D 4254 and ASTM D 4253. Equipments used in this experiment are Vibrating Table, Mold Assembly consisting of standard mold, guide sleeves, surcharge base-plate, surcharge weights, surcharge base-plate handle, and dial-indicator gage, Balance, Scoop, Straightedge. Step of analysis for this experiment are as follows:

1. Calculate the minimum index density (ρ_{dmin}) as follows:

$$\rho_{dmin} = \frac{\mathrm{M_{s1}}}{V_{\mathrm{C}}} \qquad 3.3$$

Where,

M_{s1}= mass of tested-dry soil

= Mass of mold with soil placed loose – mass of mold

V_C= Calibrated volume of the mold

2. Calculate the maximum index density (ρ_{dmax}) as follows:

$$\rho_{dmax} = \frac{M_{s2}}{V} \qquad 3.4$$

Where,

M_{s2}=mass of tested-dry soil

V=volume of tested-dry soil

3. Calculate the maximum and the minimum-index void ratios as follows:

$$e_{max} = \frac{\rho_w G_s}{\rho_{dmax}} - 1 \qquad 3.5$$

$$e_{min} = \frac{\rho_w G_s}{\rho_{dmin}} - 1 \qquad 3.6$$

4. Calculate the relative density as follows:

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \qquad 3.7$$

3.6 Analysis Procedure

3.6.1 Coefficient of Uniformity, Coefficient of Curvature & Sorting Coefficient

The coefficient of uniformity, coefficient of curvature and sorting coefficient are calculated using equation 3.5, 3.6 and 3.7.

$$C_u = \frac{D_{60}}{D_{10}} \quad 3.8$$

$$C_c = \frac{{D_{30}}^2}{D_{10} \times D_{60}} \quad 3.9$$

$$S_o = (\frac{D_{75}}{D_{25}})^{\frac{1}{2}} \quad 3.10$$

Where the value for D_{10},D_{25}, D_{30}, D_{60}, D_{75} are extracted from the particle size distribution results. The value are extracted using by extrapolating the value for percentage passing of 10%, 25%, 30% and also 60%.

3.6.2 Soil Classification

Soil classification are done to group the soils according to the common characteristics and common engineering behaviour. Soil are classifies using the Unified Soil Classification System (USCS) under the Laboratory Classification Criteria. This Laboratory Classification Criteria uses the value of Coefficient of Uniformity and Coefficient of curvature to classify the soil.

3.6.3 Index of Crushing

Index of crushing is calculated from the particle size distribution by using the equation below(Hattamleh, Al-deeky, Akhtar, & Al, 2013):

$$IC\ (\%) = \frac{\sum[M_i - M_f] \times 100}{\Sigma Mi} \quad 3.11$$

Where M_i is the initial size of the percent passing and M_f is the final size of the percent passing after crushing.

3.6.4 Breakage Factor

The amount of particle breakage were then evaluated from the grain size distribution curves using the formula below (Lade P. V. et al., 1996):

$$B_{10} = \frac{D_{10i} - D_{10f}}{D_{10i}} \qquad 3.12$$

Where a particle breakage factor named B_{10} were used to evaluate the crushing. D_{10i} is effective grain size of initial gradation and D_{10f} is effective grain size of final gradation.

3.6.5 Breakage Index

To quantitatively describe the degree particle crushing, one simple breakage index, B_{15} proposed by Lee& Farhooman (1967) is use in this study:

$$B_{15} = \frac{D_{15i}}{D_{15f}} \qquad 3.13$$

Where a particle breakage factor named B_{15} were used to evaluate the crushing. D_{15i} is effective grain size of initial gradation and D_{15f} is effective grain size of final gradation.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

In this chapter, the result on particle size distribution of soil samples taken from Teluk Chempedak, Pantai Batu Hitam and Taman Gelora were plotted before and after crushing. The particle size distribution of before and after crushing of each samples are compared to the Technical Standard for Ports and Harbour of Japan (2004) for liquefaction potential to see whether these sample fall into which liquefaction region. The soil samples are crushed using proctor hammer with 500 blows. Index of crushing, breakage factor and breakage index are quantified to see the degree of crushing and degree of breaking of each samples. These experimental data are shown in the form of tables and graphs for better analysis and comparison. This chapter is written in 5 sections. 4.2 discussed on Particle Size Distribution of the three samples, section 4.3 discussed the comparison of PSD curve of the three samples compare with the technical standards for Ports and Harbour of Japan, section 4.4 discussed the results of index of crushing. Finally, section 4.5 discussed the result for breakage factor and breakage index of the soil samples. Table 4.1 below summarizes all the engineering properties of sample used in this study.

Table 4.1 Engineering Properties of soil samples

Location		**D_{10}**	**D_{30}**	**D_{60}**	**C_u**	**C_c**	**S_o**	**Speficic Gravity**	**Relative Density**	**e_{min}**	**e_{max}**	**USCS**
PBH	Before	0.17	0.20	0.27	1.58	0.87	1.31	2.58	58.86	0.49	0.87	SP
	After	0.16	0.19	0.27	1.69	0.84	1.27	2.59	56.38	0.53	0.89	SP
TC	Before	0.40	0.69	1.20	3.0	0.99	1.70	2.67	43.36	0.39	0.67	SP
	After	0.37	0.62	1.2	3.24	0.87	1.80	2.57	41.18	0.45	0.69	SP
GEL	Before	0.19	0.25	0.67	7.4	1.04	2.28	2.44	56.52	0.46	0.81	SW
	After	0.16	0.20	0.26	1.6	0.96	1.24	2.58	59.75	0.49	0.89	SP

4.2 Particle Size Distribution

Particle size distribution is used to determine the size distribution of the soil sample. The size distribution is important because we can see the difference in its distribution before and after grain crushing. The result are illustrated in Figure 4.1.

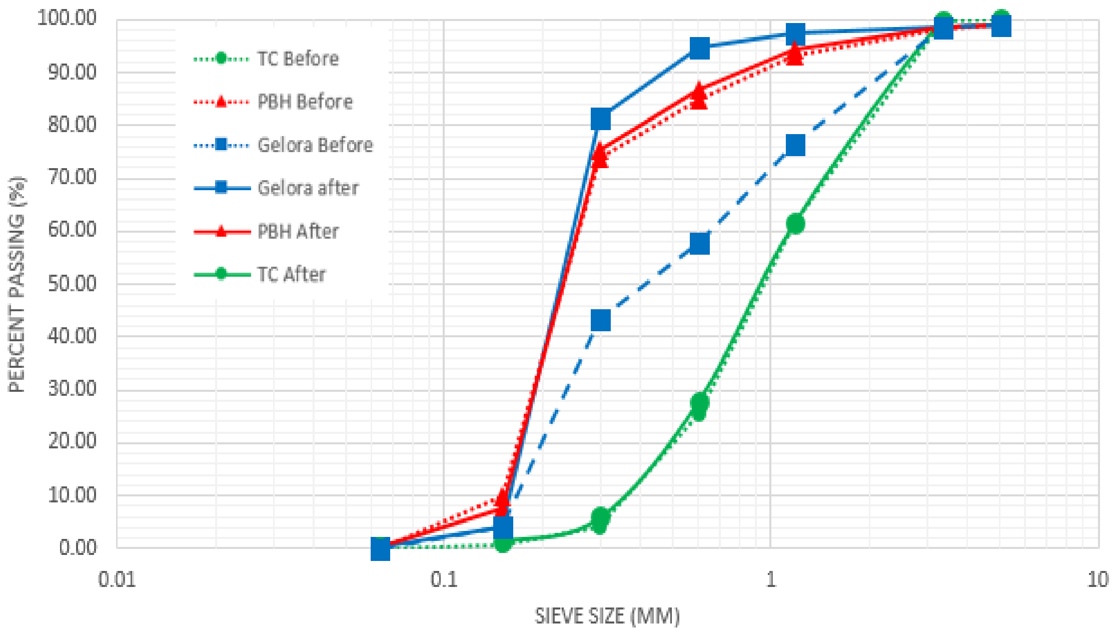

Figure 4.1: Particle Size Distribution of soil samples.

As shown in the Figure 4.1, PSD for Taman Gelora samples shows the most changes. Taman Gelora samples changes from being well-graded sand into poorly-graded sand. This could be due to. Teluk Cempedak and Pantai Batu Hitam also show small changes from before crushing to after crushing.

4.3 Liquefaction Potential

In this study, the particle size distribution result are analysed and compared with the Technical Standard of Ports and Harbour of Japan. This comparison are done before and after crushing to see in which region the soil sample fall on. The result are as illustrated in Figure 4.2 and 4.3.

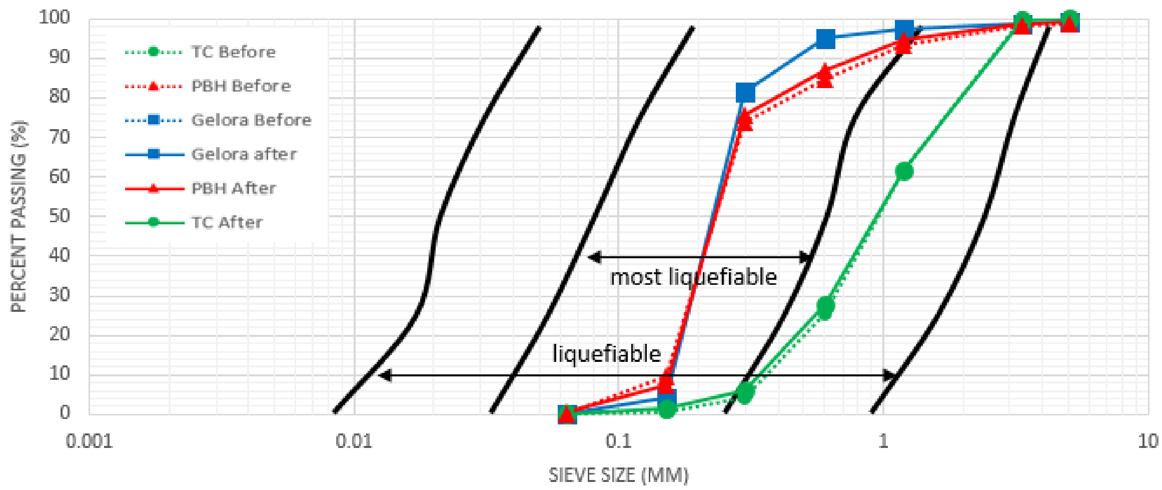

Figure 4.2: Comparison with Technical Standard of Ports and Harbour of Japan of soil samples (U_c ≤3.5)

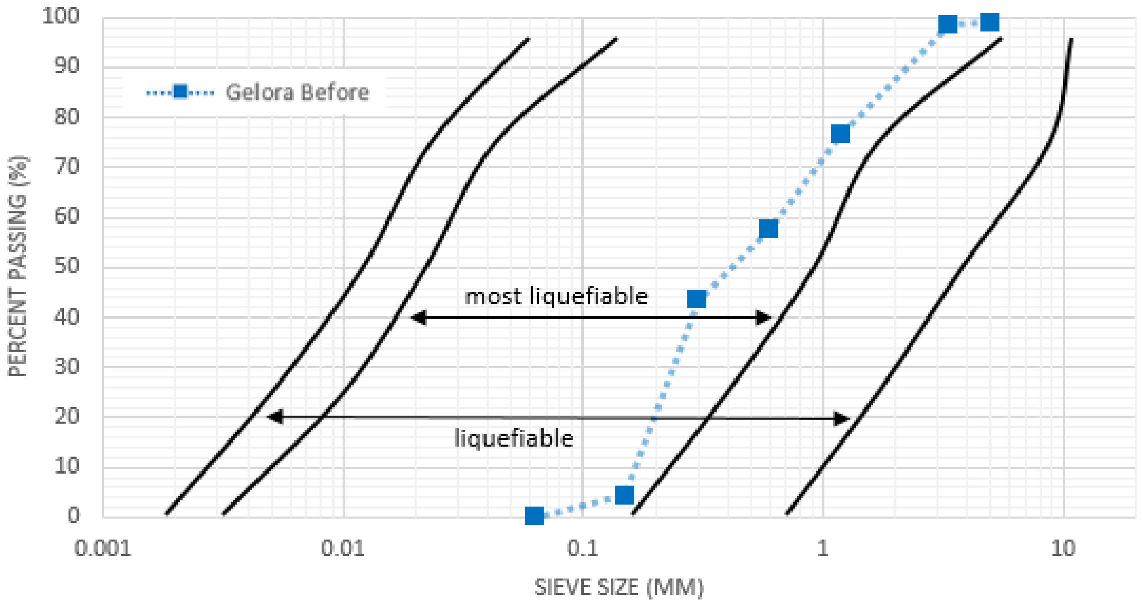

Figure 4.3: Comparison with Technical Standard of Ports and Harbour of Japan of soil samples (U_c ≥3.5)

Taman Gelora and Teluk Cempedak samples fall into the possibility of liquefaction region, while for Pantai Batu Hitam it falls into the very large possibility of liquefaction.

4.4 Liquefaction Potentials Coefficient

In this study, coefficients of uniformity, cohesion and sorting are calculated as it will be used later when doing the guidelines for liquefaction of Kuantan coastal area. List of coefficients are tabulated in Table 4.2 and 4.3.

Table 4.2: List of Coefficients for upper limit and lower limit of Standard of Ports and Harbour Japan (U_c ≤3.5)

	Upper Limit		Lower Limit	
	1	*2*	*3*	*4*
C_u	2.25	2.41	2.23	2.55
C_c	1.11	0.92	0.82	1.05
S_o	1.40	1.50	1.36	1.40

Table 4.3: List of Coefficients for upper limit and lower limit of Standard of Ports and Harbour Japan (U_c ≥3.5)

	Upper Limit		Lower Limit	
	1	*2*	*3*	*4*
C_u	6.15	7.44	6.82	5.30
C_c	0.89	1.27	0.70	0.78
S_o	2.08	2.07	2.35	2.28

4.5 Index of Crushing

This section, the results of index of crushing were calculated to all three soil samples:

Table 4.4 Result for calculation of Index of Crushing

Sample	*Index of crushing (%)*
Taman Gelora	25.48
Pantai Batu Hitam	1.85
Teluk Cempedak	0.85

Table 4.4 shows the result of index of crushing that is calculated using formula proposed by (Hattamleh, Al-deeky, Akhtar, & Al, 2013). It is shown that Taman Gelora have IC that is 25.48% which is the highest of all the three samples. While, Pantai Batu Hitam is at 1.85%, and Teluk Cempedak 0.85%.

4.6 Breakage Factor and Breakage Index

In this section, the results for breakage factor and breakage index were calculated as shown in Table 4.5:

Table 4.5: Result for Breakage Factor

	Breakage Factor		
	D_{10i}	D_{10f}	B_{10}
Taman Gelora	0.19	0.16	0.19
PBH	0.17	0.16	0.06
TC	0.40	0.37	0.075

Table 4.6: Result for Breakage Index

	Breakage Index		
	D_{15i}	D_{15f}	B_{15}
Taman Gelora	0.19	0.18	1.06
PBH	0.18	0.17	1.06
TC	0.48	0.43	1.12

Table 4.5 shows the breakage factor for the samples and Table 4.6 shows the breakage index. Breakage factor for Taman Gelora shows the highest amongst the sample 0.19 compared to PBH and TC only 0.06 and 0.075. While for breakage index, Taman Gelora and PBH have the same value of 1.06, TC has the highest value of breakage index which is 1.12

4.7 Summary

In this chapter, sieve analysis test were conducted on three types of soil sample. All of the soil were subjected to 500 blows of standard proctor test to induced crushing. The particle size distribution of samples before and after crushing were reported. Collected data and the experimental results were analysed based on adopted methods of crushing index and breakage factor parameters. The experimental result are tabulated in table 4.2, 4.3, 4.4, 4.5 and 4.6. Note that this research focused on particle size distribution and liquefaction potential which is shown on figure 4.2 and 4.3, and the breakage factor, index of crushing were used to support the test findings. Analysis of the test results revealed that:

1. A comparison of the particle size distribution and index of crushing reveal that Taman Gelora sand to be the most brittle sand, followed by Pantai Batu Hitam and Teluk Cempedak.

2. Both Lee and Farhooman's breakage index and Lade's breakage factor were used to measure the criteria related to particle size scale. It is found that in Lee and Farhooman's method, Taman Gelora and PBH have the same value maybe due to both samples have the same criteria in sand content, both of them have impurities of sea shells and desiccated tree barks, also they are finer in size if compared to teluk cempedak sample. Futhermore, comparing Lade's breakage factor with Hattamleh's Index of crushing, we can see the similarity in terms of which samples have the highest value, therefore clearly strengthen that Taman Gelora being the most brittle sand.

3. From USCS grading, it is found that Taman Gelora samples was well graded before it was induced with crushing and after crushing was induced it became poorly graded. This might be because of uneven crushing of the automated proctor test machine. As for any other samples, they are all poorly graded.

4. As for liquefaction potential, all of the samples falls under the coefficient of uniformity less than 3.5. All of the samples have no silt content, but it fines content ranges from 0% to 100%, and there is no gravel content in it. In the figure above shows that well-graded samples of Taman Gelora falls into the most liquefiable part, this fulfils according to (Xenaki and Athanasopoulos, 2003) on the most susceptible sand to liquefy is uniformly graded, and also by (Numata and Mori, 2004) saying that poorly graded soil and soil that decrease

in grain size have higher liquefaction resistance, because of having a little silt content or having higher cohesion between the particles. We can see this on Teluk Cempedak samples that falls in the region of liquefiable sand and not most liquefiable as it is poorly graded and decreasing in size.

CHAPTER 5

CONCLUSION

5.1 Introduction

In this chapter, a conclusion is drawn on the study that have been conducted on the soil samples taken. Conclusion were made based on the result of all the experiment that were made and objectives that was set up from this study.

5.2 Conclusion

The main results and conclusions drawn from this thesis are summarized below:

1. Summary for liquefaction potential of Kuantan Sand before and after crushing is reported. For Teluk Cempedak sand, both before and after have only a slight difference after crushing of 0.85%. On the coarser side of the distribution it falls into the liquefiable region, and on the 0%-10% finer side it falls into the most liquefiable region. Pantai Batu Hitam sand, also in terms of crushability only have a slight difference of 1.85%. As for liquefaction potential, most of its finer side and also coarser side falls into the most liquefiable region. Only passing of 96% to 100% falls into liquefiable region. Lastly, Taman Gelora having index of crushing of 25.48% this means it crushes the most. For liquefaction potential, before crushing on the finer side from 0%-60% falls into most liquefiable and 60% and above passing falls into the liquefiable region but after crushing is induced to the soil it appears all of it falls into the most liquefiable region. Taman gelora appear to be the most crushable and most liquefiable sand.

2. Engineering properties of Kuantan Sand before and after crushing is reported. The specific gravity, relative density and minimum and maximum void ratio are calculated. The maximum and minimum void ratio of Taman Gelora and PBH increases in high amount. This shows that these soil samples are in a loose sand state, hence explaining why they falls into the most liquefy region as the cohesive force between them as explain by (Numata and Mori, 2004)

3. Guidelines for liquefaction of Kuantan coastal area were established as shown in Figure 5.1 using the gathered experimental results of all the soil samples as well as the technical standard for ports and harbour. Guidelines were made by comparing the C_u, C_c, D_{10}, D_{30}, D_{50}, D_{60} values and averages of the grain size distribution.

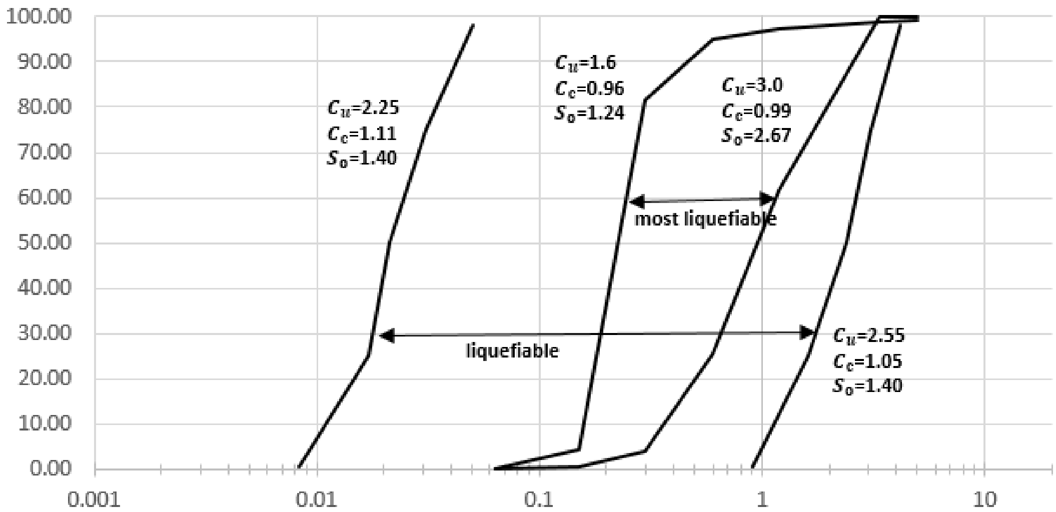

Figure 5.1: Guideline for Liquefaction potential for Kuantan coastal area

The outcomes for comparing all the coefficients. It can be said that for the most liquefiable region the range for Coefficient of Uniformity is from 1.6 until 3.0, while Coefficient of Gradation is from 0.96 until 0.99 and Sorting Coefficient ranges from 1.24-2.67.

5.3 Recommendation for Future Research

1. Increase in the number of soil samples taken from each study site area, this is for evaluating the particle breakage phenomenon. It shows that taking only one soil sample from each location can only give one similar result. It might differs in term of results if multiple samples are taken from different places in one area, thus creating a more accurate results.

2. Increasing the number of blows higher, creating higher energy value that could crush the soil even finer and could even see more significant changes in the engineering properties of the samples.

3. Include other relationship for different parameters and some types of constitutive models for studying the behaviour of particulate media, for example hydraulic conductivity and energy,etc.

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APPENDIX A

Table A1: Details on Particle size distribution of Taman Gelora before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	523.23	14.46	14.46	0.98	99.02
3.35mm	542.27	550.62	8.35	22.81	1.55	98.45
1.18mm	515.14	838.82	323.68	346.49	23.48	76.52
600 µm	484.04	761.62	277.58	624.07	42.30	57.70
300µm	432.63	644.41	211.78	835.85	56.65	43.35
150µm	429.5	1005.33	575.83	1411.68	95.68	4.32
63µm	257.59	321.30	63.71	1475.39	100.00	0.00
Pan	372.31	372.31	0.00	1475.39	100.00	0.00

Table A2: Details on Particle size distribution of Pantai Batu Hitam before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	523.80	15.03	15.03	1.18	98.82
3.35mm	542.27	550.30	8.03	23.06	1.81	98.19
1.18mm	515.14	576.99	61.85	84.91	6.67	93.33
600 µm	484.04	593.73	109.69	194.60	15.30	84.70
300µm	432.63	572.44	139.81	334.41	26.29	73.71
150µm	429.5	1241.60	812.10	1146.51	90.12	9.88
63µm	257.59	382.85	125.26	1271.77	99.96	0.04
Pan	372.31	372.78	0.47	1272.24	100.00	0.00

Table A3: Details on Particle size distribution of Teluk Cempedak before crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	509.32	0.55	0.55	0.03	99.97
3.35mm	542.27	543.93	1.66	2.21	0.12	99.88
1.18mm	515.14	1199.79	684.65	686.86	38.55	61.45
600 µm	484.04	1127.44	643.40	1330.26	74.65	25.35
300µm	432.63	810.98	378.35	1708.61	95.89	4.11
150µm	429.5	491.63	62.13	1770.74	99.37	0.63
63µm	257.59	267.24	9.65	1780.39	99.91	0.09
Pan	372.31	373.85	1.54	1781.93	100.00	0.00

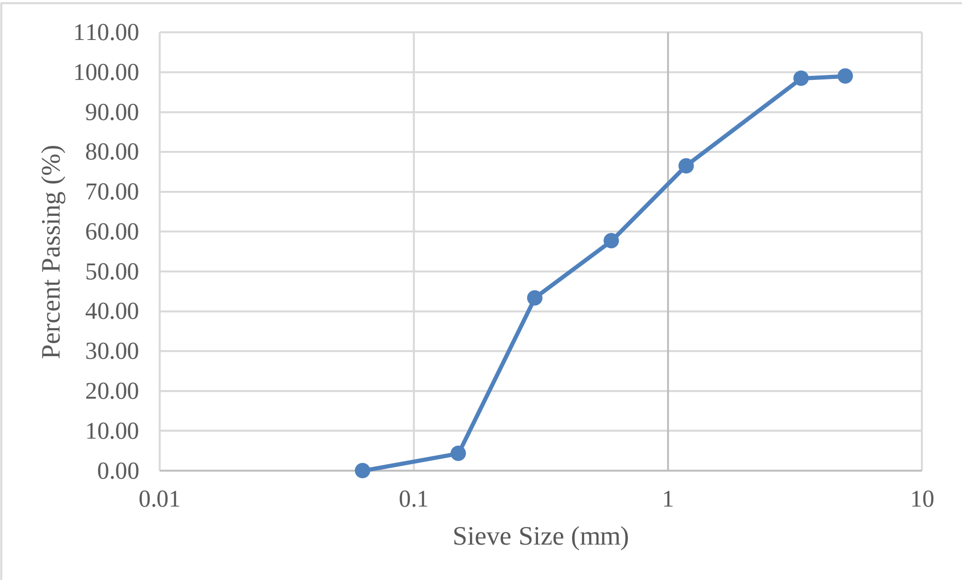

Figure A1: Particle size distribution curve of Taman Gelora soil sample before crushing

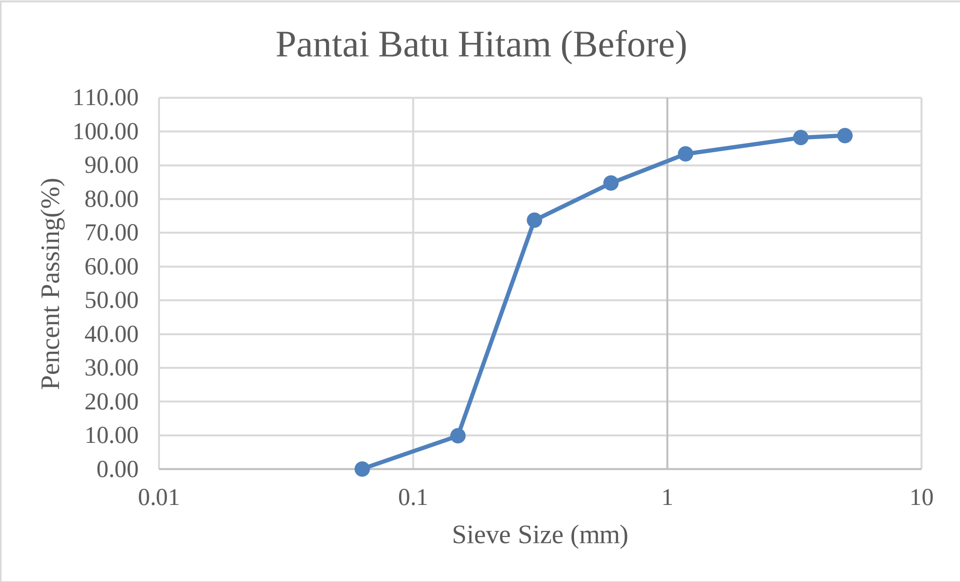

Figure A2: Particle size distribution curve of Pantai Batu Hitam soil sample before crushing

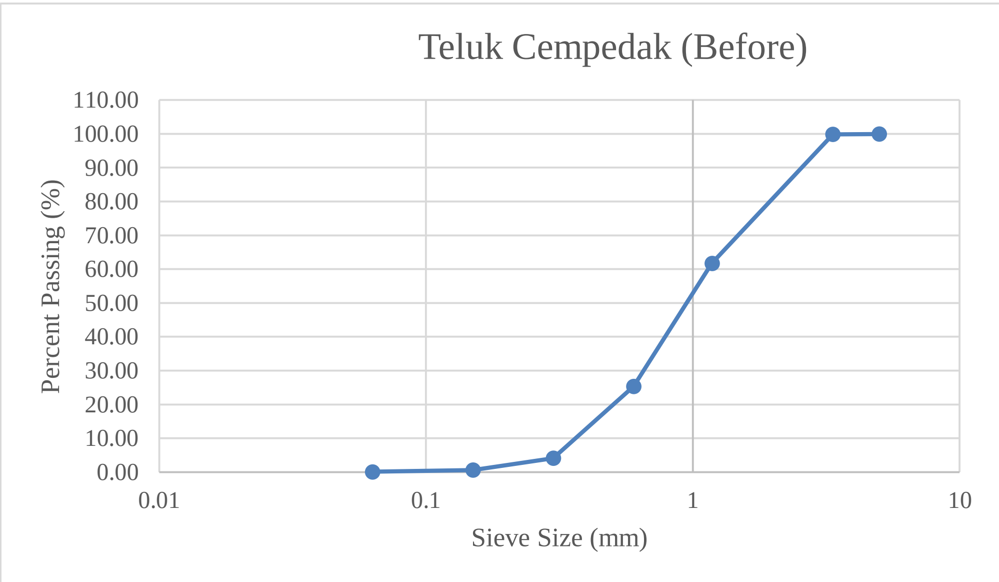

Figure A3: Particle size distribution curve of Teluk Cempedak soil sample before crushing

Table A4: Details on Particle size distribution of Taman Gelora after crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	518.89	10.12	10.12	0.96	99.04
3.35mm	542.27	545.37	3.10	13.22	1.26	98.74
1.18mm	515.14	530.92	15.78	29.00	2.76	97.24
600 µm	484.04	508.44	24.40	53.40	5.09	94.91
300µm	432.63	573.01	140.38	193.78	18.47	81.53
150µm	429.5	1239.67	810.17	1003.95	95.67	4.33
63µm	257.59	300.67	43.08	1047.03	99.78	0.22
Pan	372.31	374.62	2.31	1049.34	100.00	0.00

Table A5: Details on Particle size distribution of Pantai Batu Hitam after crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	523.07	14.30	14.30	0.92	99.08
3.35mm	542.27	549.09	6.82	21.12	1.36	98.64
1.18mm	515.14	579.00	63.86	84.98	5.47	94.53
600 µm	484.04	604.19	120.15	205.13	13.20	86.80
300µm	432.63	608.01	175.38	380.51	24.48	75.52
150µm	429.5	1486.16	1056.66	1437.17	92.47	7.53
63µm	257.59	367.63	110.04	1547.21	99.55	0.45
Pan	372.31	379.37	7.06	1554.27	100.00	0.00

Table A6: Details on Particle size distribution of Teluk Cempedak after crushing

Sieve Size	Weight of Sieve (g)	Weight of Sieve + Sample (g)	Weight of Sample (g)	Cumulative (g)	Cumulative (%)	Passing (%)
5mm	508.77	509.30	0.53	0.53	0.04	99.96
3.35mm	542.27	544.22	1.95	2.48	0.18	99.82
1.18mm	515.14	1049.80	534.66	537.14	38.31	61.69
600 µm	484.04	957.88	473.84	1010.98	72.10	27.90
300µm	432.63	741.32	308.69	1319.67	94.12	5.88
150µm	429.5	491.67	62.17	1381.84	98.55	1.45
63µm	257.59	272.43	14.84	1396.68	99.61	0.39
Pan	372.31	377.79	5.48	1402.16	100.00	0.00

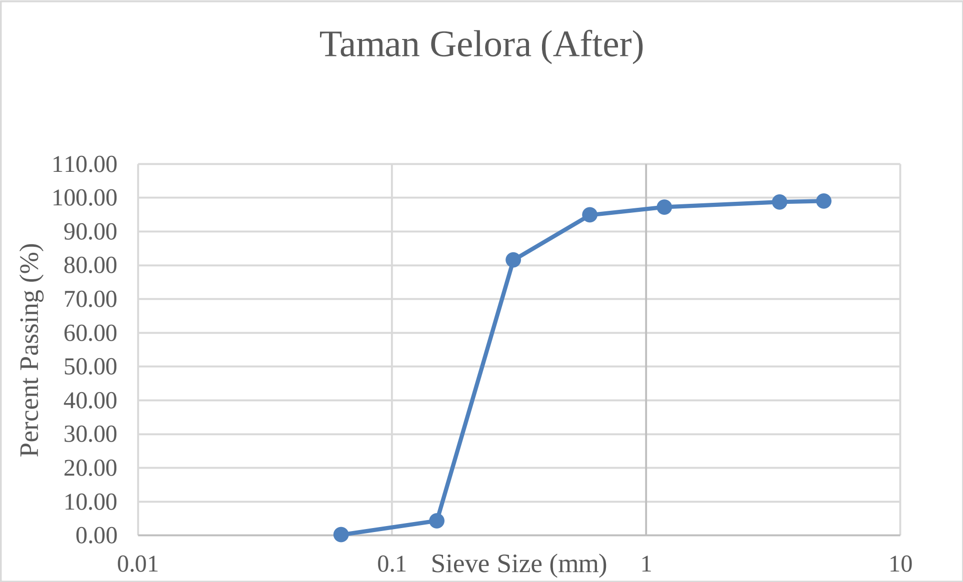

Figure A4: Particle size distribution curve of Taman Gelora soil sample after crushing

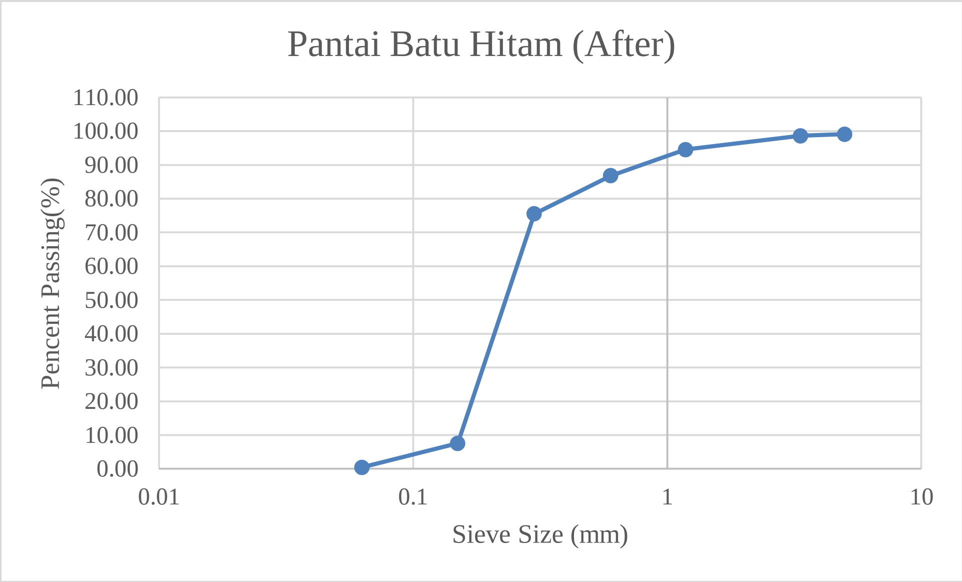

Figure A5: Particle size distribution curve of Pantai Batu Hitam after crushing

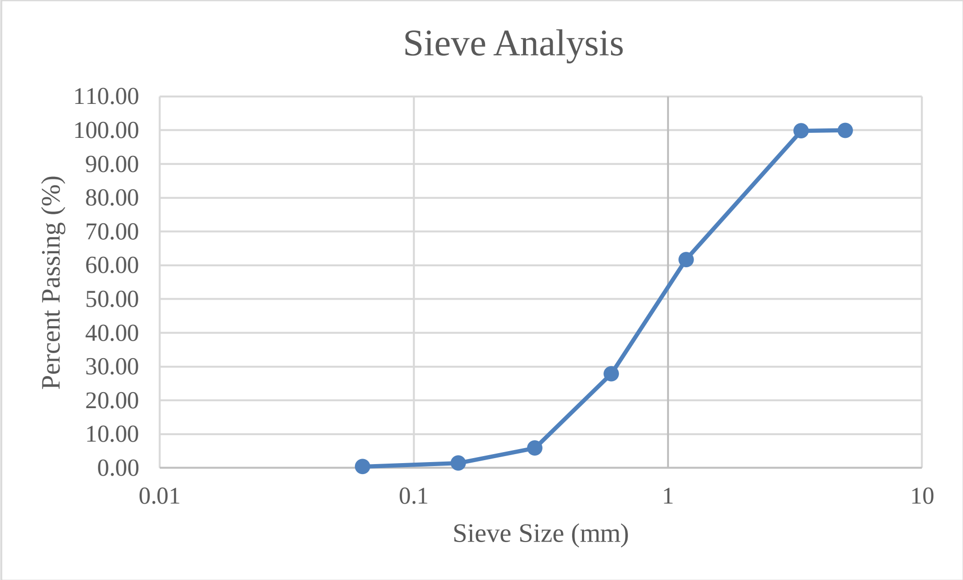

Figure A6: Particle size distribution of Teluk Cempedak soil sample after crushing

APPENDIX B

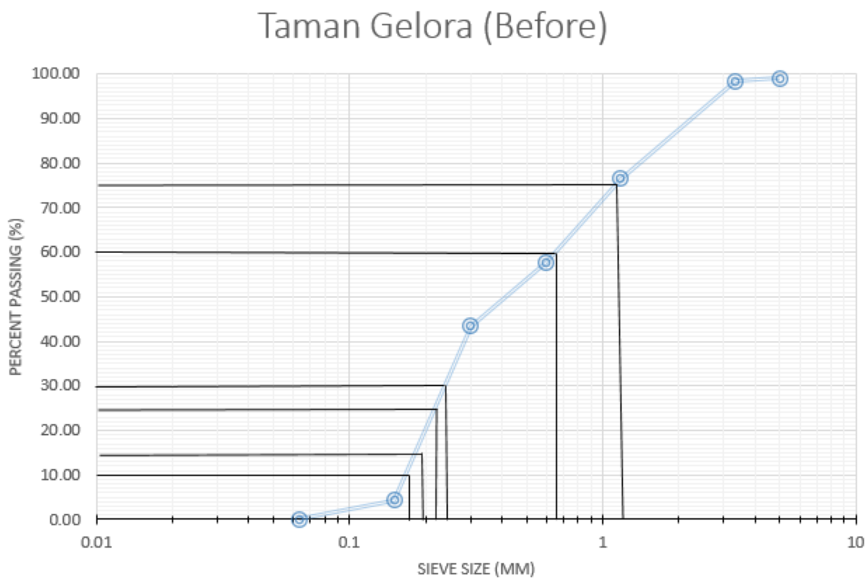

Figure B1: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Taman Gelora before crushing

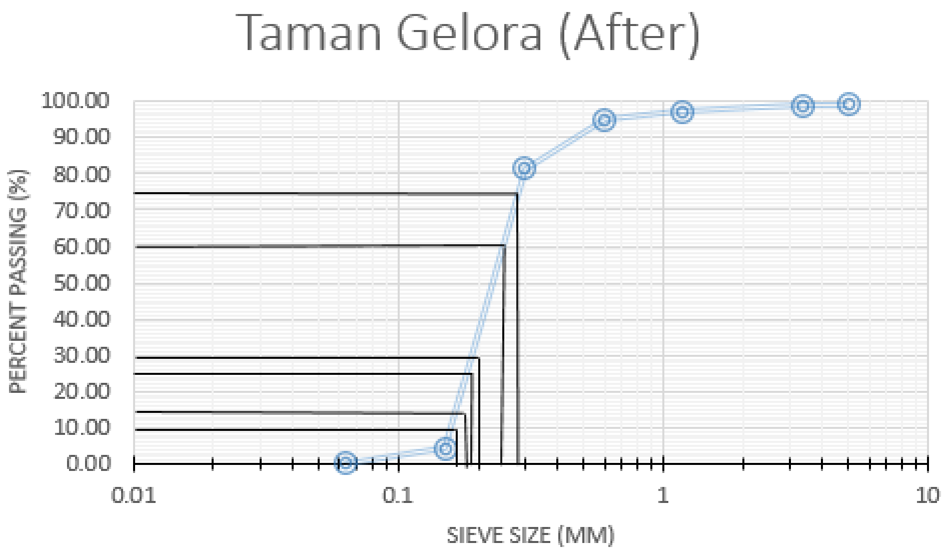

Figure B2: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Taman Gelora after crushing

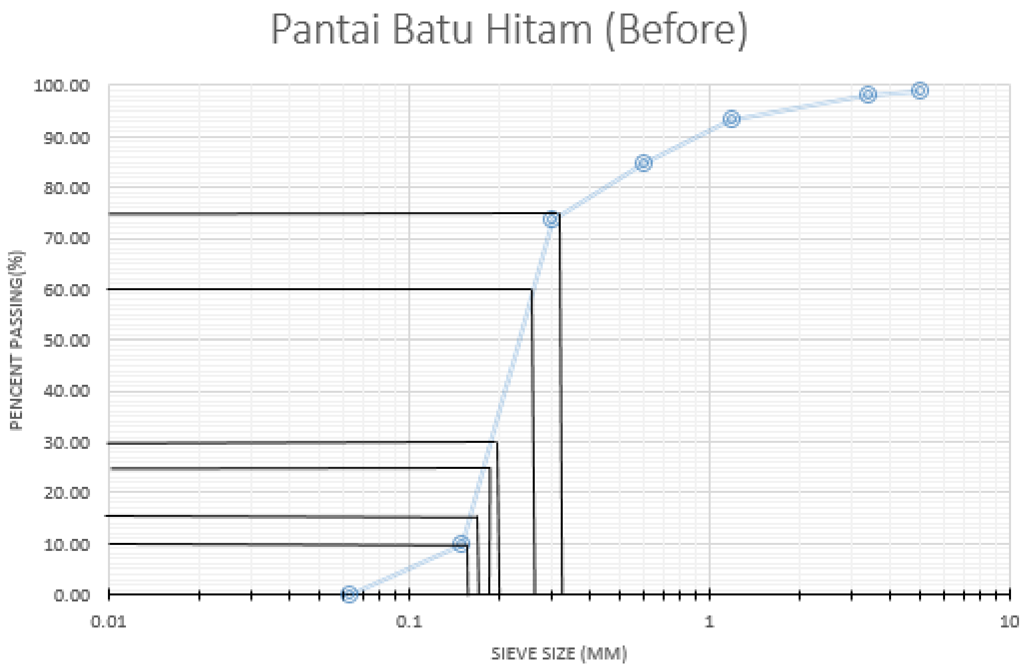

Figure B3: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Pantai Bati Hitam before crushing

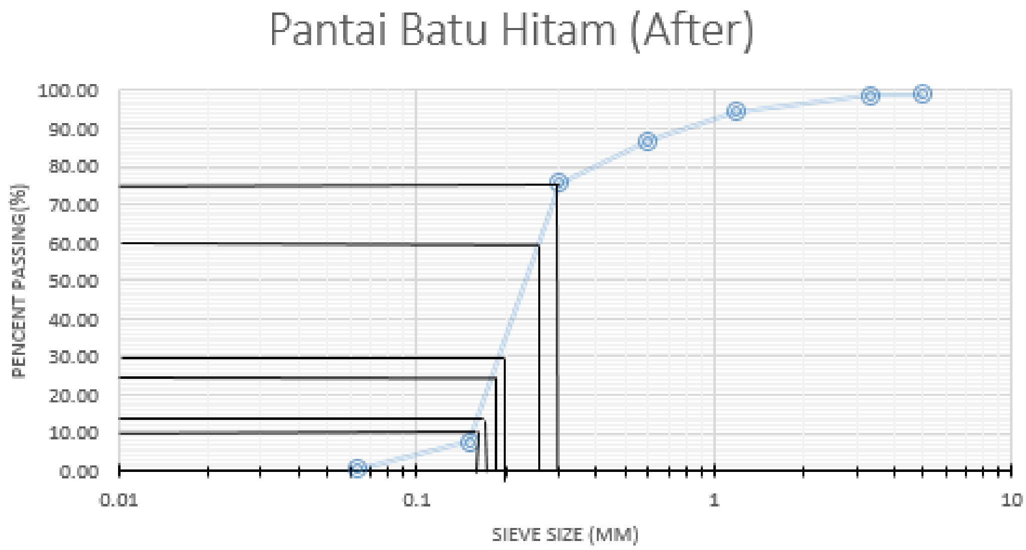

Figure B4: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Pantai Batu Hitam after crushing

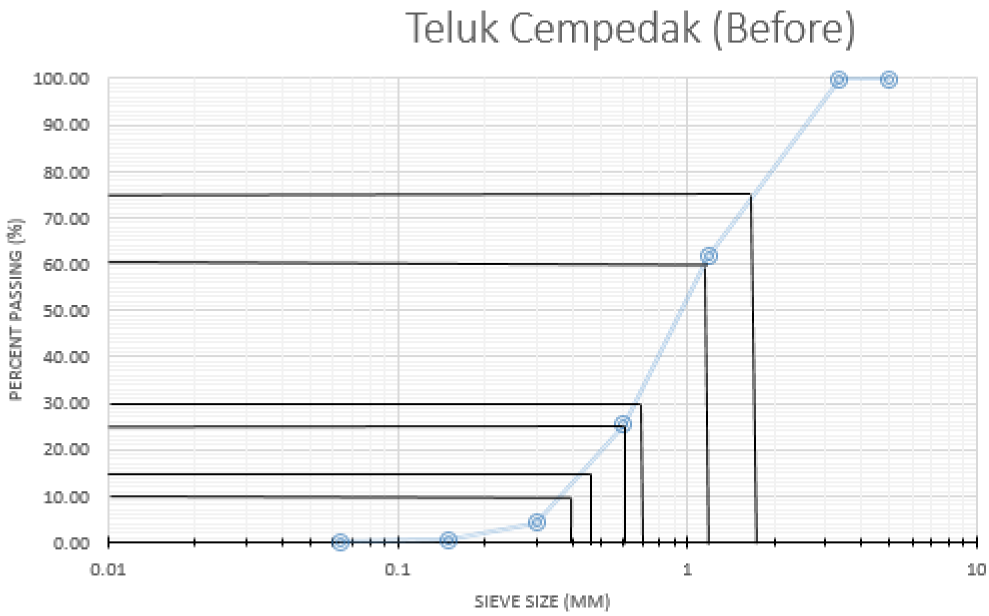

Figure B5: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Teluk Cempedak before crushing

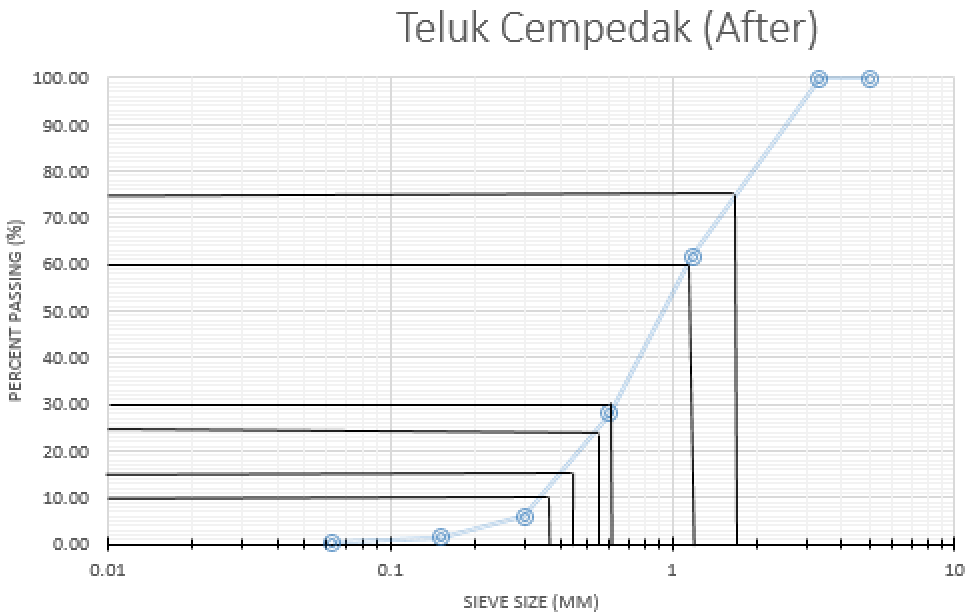

Figure B6: Determination of $D_{10}, D_{15}, D_{30}, D_{60}$ of Teluk Cempedak after crushing

Table B1: Overall result for USCS grading of soil samples

Location		D_{10}	D_{30}	D_{60}	C_u	C_c	USCS
PBH	Before Crushing	0.17	0.20	0.27	1.58	0.87	SP
	After Crushing	0.16	0.19	0.27	1.69	0.84	SP
TC	Before Crushing	0.40	0.69	1.20	3.0	0.99	SP
	After Crushing	0.37	0.62	1.2	3.24	0.87	SP
GELORA	Before Crushing	0.19	0.25	0.67	7.4	1.04	SW
	After Crushing	0.16	0.20	0.26	1.6	0.96	SP

Table B2: Overall result for Index of Crushing

Location	M_i	M_f	IC(%)
PBH	458.67	462.55	-1.85
TC	291.58	297.09	-0.85
GELORA	379.36	476.01	-25.48

Table B3: Overall result for Breakage Index

Breakage Index	TC	PBH	GELORA
D_{15i}	0.48	0.18	0.19
D_{15f}	0.43	0.17	0.18
B_{15}	1.12	1.06	1.06