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Research Paper

Study on the Correlation of CPT value to Soil Parameters

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ABSTRACT

Soil is one of the factors that has the most important role because it bears the burden of all the constructions that stand on it. Based on this very important role of soil, prior to the start of construction in a location, a soil investigation must be carried out first to find out the condition of the subgrade at the construction site. One of the most frequently used soil investigation methods is Cone Penetration Test (CPT). The purpose of this study includes two things, namely to determine the soil profile at the CPT test location, and to determine the correlation between the data from the Cone Penetration Test results with soil parameters (Soil Volume Weight, Cohesion, and Internal Shear Angle). The method used in this study is to analyze the data from the Cone Penetration Test using the results of the research that has been carried out as a basis for determining the soil profile and the required soil parameters. The results obtained are, the first is based on the data plot on the soil type graph at the Cone Penetration Test (CPT) test location spread over 4 zones, namely Zone 3, Zone 4, Zone 5, and Zone 6. The second is the correlation between soil unit weight and Conus Resistance values are directly proportional, as are Cohesion and friction angles. In addition, the equations used in this paper cannot be used as the main reference, but only used to predict soil parameters when in the field

1. Introduction

In this modern era, technology is growing rapidly accompanied by rapid population growth. The large number of population growth from year to year requires various parties to build and improve various kinds of infrastructure, such as: buildings, bridges, roads, ports, airports, and so on. One of the important factors that can affect the success of the development of an infrastructure is the soil characteristics. Soil is one of the factors that has the most important role because it bears the burden of all the construction that stands on it.

Based on this very important role of soil, prior to the commencement of construction at a site, a soil investigation must be carried out in advance to determine the condition of the subgrade and to determine the effective and efficient design of the project to be undertaken. One of the most frequently used soil investigation methods is the Cone Penetration Test (CPT). CPT is a method that can distinguish soil profiles based on depth by identifying the resistance of the soil to the tip of the cone that enters the soil. CPT is carried out directly at the site of the soil investigation and is most effective when carried out on soft clay or sandy soils.

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However, the data from the CPT is not sufficient to form the basis of a design, therefore the soil that has been tested through the CPT will be brought to the laboratory for further investigation. However, sometimes there is a condition where it is no longer possible to carry out laboratory testing. Therefore, it is necessary to correlate the data from the CPT test results in the field with the soil parameters needed for construction. Based on this background, the research in this paper was carried out.

2. Literature Review

2.1 Cone Penetration Test

In the Cone Penetration Test (CPT), a cone used in a series of rods is driven into the ground at a constant speed and continuous measurements are made of the penetration resistance of the cone and the surface sleeve. The net force acting on the cone (Qc), divided by the cross-sectional area of the cone (Ac), will give qc. Meanwhile, the total force acting on the friction sleeve (Fs), divided by the surface area of the friction sleeve (As), gives the sleeve resistance (fs).

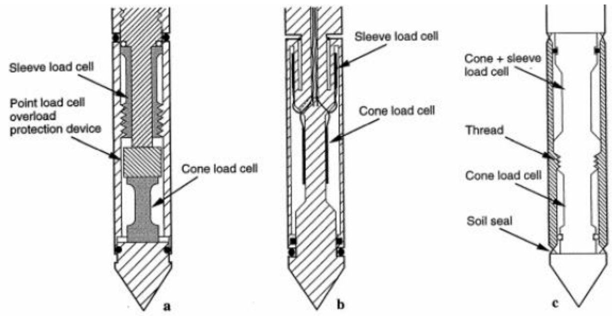


Fig. 1. Conical cone design (Lunne et al., 2014)

CPT can be carried out to depths exceeding 100 meters on soft soil using equipment with adequate capacity. To increase the depth of cone penetration, the friction along the rod must be reduced. This can be done using an extended clutch usually about 1 meter. Penetration will stop if it reaches the depth of hard soil, gravel, or rock layers. The cone is used to measure the cone resistance (qc) and local shear resistance (fs). Figure 1 illustrates the general principle by which a conical cone is used.

In Figure 2, a manually operated CPT with a thrust capacity of 100kN to 200kN. The CPT can be operated either on the ground or mounted on a truck. The use of CPT on land, screw anchors are used to resist the thrust generated by the ground.

One of the main applications of CPT is to determine the type of soil. However, CPT is not expected to provide an accurate prediction of soil type but can provide a type of soil behavior (SBT) based on mechanical characteristics (strength, stiffness, compressibility). In 2010, Robertson et al., provided an updated version of the soil behavior type graph (Figure 3). This graph uses the results of the CPT, namely the value of the cone resistance (qc) and the resistance ratio (Rf).

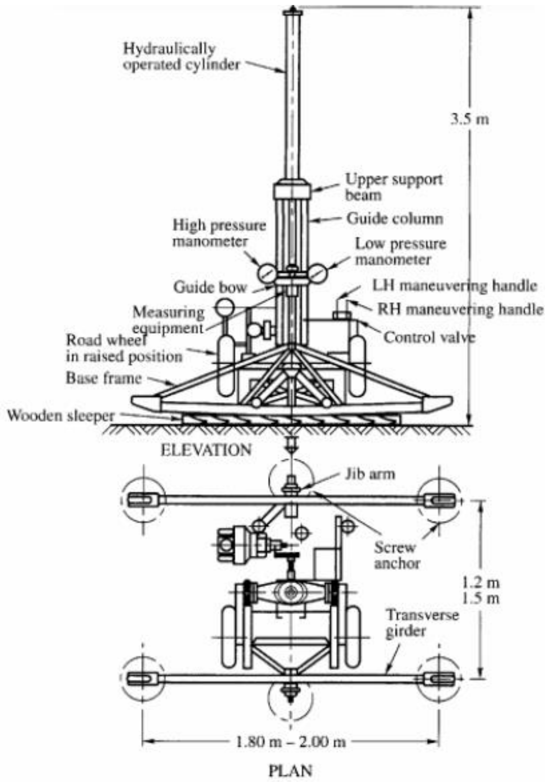
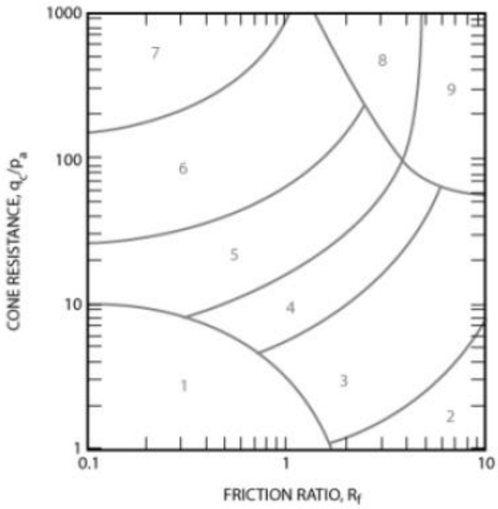


Fig. 2. CPT apparatus (V.N.S. Murthy, 2002)



Zone	Soil Behavior Type
1	Sensitive, fine grained
2	Organic soils - clay
3	Clay – silty clay to clay
4	Silt mixtures – clayey silt to silty clay
5	Sand mixtures – silty sand to sandy silt
6	Sands – clean sand to silty sand
7	Gravelly sand to dense sand
8	Very stiff sand to clayey sand*
9	Very stiff fine grained*

Fig. 3. Graph of non-normalized soil behavior type (Robertson et al., 2010)

CPT has been widely used in Indonesia. This test kit consists of a steel cylinder with a conical tip known as a cone which is pressed into the ground vertically, which is then continuously measured against the cone resistance and side friction. From this CPT test, it can produce data about the properties of the tested subgrade to assist in the design and construction of the foundation of a building. CPT has the advantages of soil testing in other fields, namely obtaining continuous data, can be repeated with relatively similar results, the results of the tests can be correlated, and quite economical and fast. However, this test also has the disadvantage of not being able to obtain soil samples under certain conditions, especially because it cannot penetrate gravel or dense layers.

2.2 Correlation of CPT value to Soil Parameters

2.2.1 Soil Unit Weight

The unit weight of soil in each soil layer is needed to estimate the overload stress. Unit weight is best measured by obtaining a whole sample. However, for many soils and for low-risk projects, it is difficult to obtain complete soil samples from each soil layer. Therefore, an alternative approach to obtain unit weight of soil from each soil layer is to estimate it directly from the CPT test.

Robertson (2009) developed a correlation between the results of the CPT and the Dilatometer Test (DMT) so that it was possible to relate the results of the unit weight soil correlation of the DMT with the results of the CPT test. In equation 1, it shows the results of the correlation by Robertson (2009).

$$\frac{\gamma}{\gamma_w} = 0{,}27\left[\log R_f\right] + 0{,}36\left[\log \frac{q_c}{p_a}\right] + 1{,}236 \quad (1)$$

where,
ɣ = Volume weight of soil (kN/m^3)

$$\tan\varphi = \frac{1}{7{,}629}\ln\left[\frac{(q_c/p'_0)}{0{,}194}\right] \quad (6)$$

$$p'_0 = (\gamma \times h) - (h_w \times \gamma_w) \quad (7)$$

ɣw = Volume weight of water (kN/m^3)
Rf = resistance ratio (%)
qc = value of cone resistance (MPa)
pa = atmospheric pressure (MPa)

2.2.2 Cohesion

Cohesion is the attractive force between particles in the soil, which is expressed in units of weight per unit area. Soil cohesion is directly proportional to the shear strength, meaning that the greater the cohesion, the greater the shear strength. Soil resistance to deformation caused by soil stress can be correlated with the cohesion value of the soil.

Cohesion can be obtained through direct shear strength test or triaxial test. However, there are times when soil samples cannot be brought to the laboratory. So, a correlation that can connect the value of CPT with the cohesion value (c) is needed. Therefore, based on the bearing capacity theory given by Terzaghi, it was developed to provide a correlation between the cone resistance value and the cohesion value written in equation 2 (Terzaghi, 1943).

$$c = 0{,}02\, q_c \quad (2)$$

c = cohesion
qc = value of cone resistance

In addition to the correlation given by Terzaghi (1996), Rajan Kumar et al. (2016) also provides a correlation between the value of soil cohesion with the value of N-SPT. Based on the results of research conducted by Rajan Kumar (2016), it produces two equations, namely:

where, N = the value of N-SPT and can be calculated

$$c = -2{,}2049 + 6{,}484N\,;\ 2 \le N \le 30 \quad (3)$$

$$c = -16{,}5 + 2{,}15\,N\,;\ 10 \le N \le 30 \quad (4)$$

by the correlation given by Meyerhof (1965), presented in equation 5.

$$N = \frac{q_c}{0{,}4} \text{ where qc (MN/m}^2\text{)} \quad (5)$$

2.2.3 Friction Angle

The internal shear angle (ϕ) is the angle formed between the normal stress and the shear stress of the soil or rock material. The internal shear angle is directly proportional to the resistance of the material to receive external stresses. As with the previous parameter, namely Cohesion, the magnitude of the internal friction angle can also be predicted using several correlation formulas if it is not possible to bring soil samples to the laboratory.

where,
Φ = internal friction angle
qc = cone resistance
p’0 = effective stress
ɣ = unit weight of soil
ɣw = unit weight of water = 9,81 kN/m3
h = height of soil from the ground
hw = height of soil from the ground water table.

In the last few cases, the soil parameters obtained based on the correlation results from the qc value can be used in designing the foundation. Many studies have been carried out to obtain the relationship between the value of qc and the internal shear angle, but the results often show significant differences. Research conducted by Durgunoglu and Mitchell (1975), based on the bearing capacity theory and well formulated theoretically produces equation 6. In addition to the equation by Durgunoglu and Mitchell (1975), Rajan Kumar (2016) also provides a correlation between the Internal Shear Angle and N -SPT, which is shown in the equation below:

where, N = the value of N-SPT and can be calculated by the correlation given by Meyerhof (1965), presented in equation 5.

$$\varphi = 7N\,; N \leq 4 \qquad (8)$$

$$\varphi = 27{,}12 + 0{,}2857N\,; 4 < N < 50 \qquad (9)$$

3. Methodology

3.1 Research Location

Geographically, this research location is located at coordinates 5˚09'30.4" South Latitude and 119˚24'55,7" East Longitude. This research was conducted in lowland areas and close to the coast.

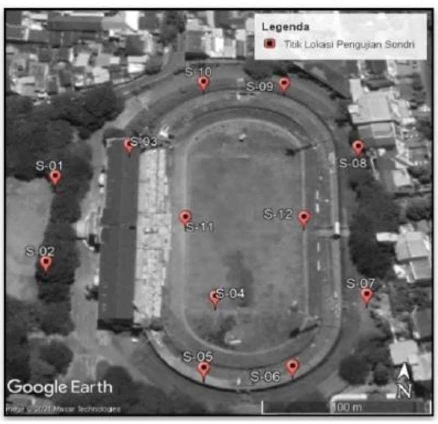


Fig. 4. Research Location

Table 1. CPT test point location

Code	Coordinate		Groundwater Table Depth (m)
	Longitude	Latitude	
S-01	767656.00	9429329.00	1.4
S-02	767656.00	9429269.00	1.6
S-03	767702.00	9429354.00	1.4
S-04	767702.00	9429250.00	1.4
S-05	767757.00	9429204.00	1.6
S-06	767810.00	9429207.00	1.6
S-07	767655.02	9429266.29	1.4
S-08	767861.60	9429358.96	1.4
S-09	767802.57	9429404.71	1.4
S-10	767748.62	9429403.32	1.4
S-11	767741.39	9429303.28	1.4
S-12	767816.33	9429306.43	1.4

In this area, CPT testing is carried out to determine the state of the soil profile and to estimate the required soil parameters. CPT testing in the research area spread over 12 points (can be seen in Figure 4). Table 1 presents the coordinates of the CPT test point along with the location of the depth of the ground water table.

3.2 Data Collection

In conducting this research using empirical calculations based on CPT secondary data in the field. Soil data generated from the CPT will then be used to classify soil types and correlated with soil parameters.

The results of the correlation of the CPT value to the soil parameters are the data that will be used as the basis for drawing conclusions at the end of this study.

3.3 Research Framework

The stages of research can be seen in Figure 5.

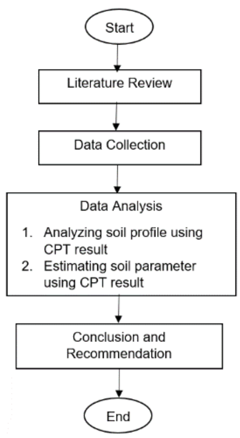


Fig. 5. Research Framework

3.4 CPT Data Analysis

3.4.1 Soil Classification using CPT Data

In this study, using a soil behavior graph by Robertson (2010), as shown in Figure 3. The results of the CPT test used to determine the type of soil are the cone resistance value (qc), and resistance ratio (Rf).

where,

qc = cone resistance (MPa)

pa = atmospheric pressure = 0.1 MPa

Rf = resistance ratio (%)

The qc/pa value and Rf value are recorded in Excel, then plotted into a soil behavior graph by Robertson (2010), to determine the type of soil at each depth based on the data that has been collected.

3.4.2 Estimating Soil Parameter using CPT Data

At this stage the data that has been collected is recorded in Excel, then correlated based on the formulas that have been described in the Literature Review section, then plotted on a graph to find out the distribution of the data generated from calculations with formulas. This research will estimate 3 soil parameters, namely: unit weight, cohesion, and internal friction angle.

4. Results and Discussion

4.1 Soil Classification using CPT Data

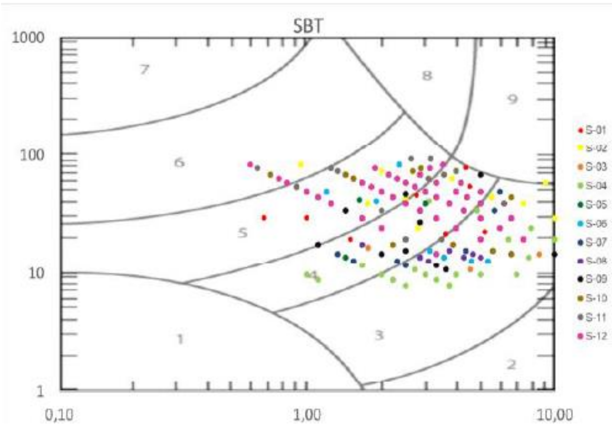


Fig. 6. Soil type distribution graph from CPT test data

From the results of the graph of the type of soil distribution in Figure 6, the type of soil at the test location at the twelve CPT test points in Zone 3 is a silty clay soil type; Zone 4 is a mixture of silt; Zone 5 is silty sand; and for Zone 6 is sand. In addition, Figures 7 to 12 show a graph of the CPT test at each test point showing the soil layers of each depth.

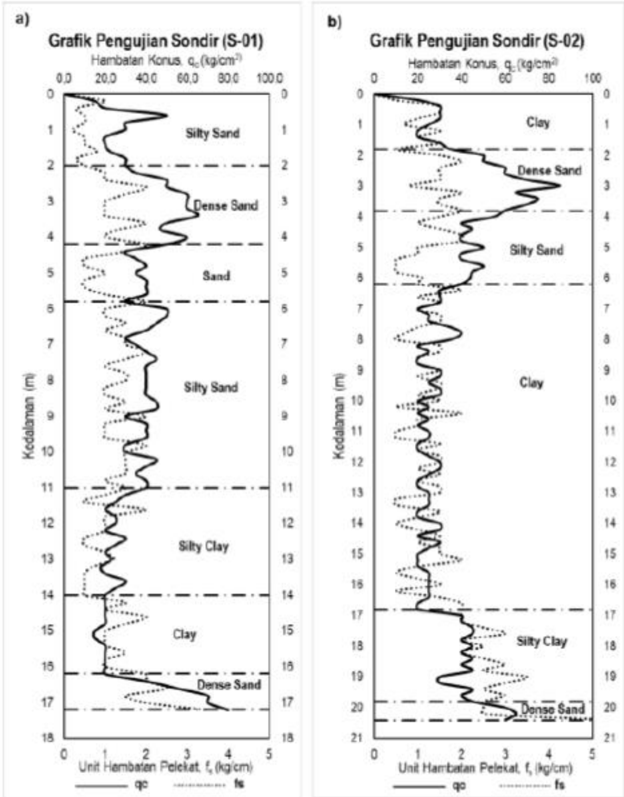


Fig. 7. Soil Layer, a) Point S-01; b) Point S-02

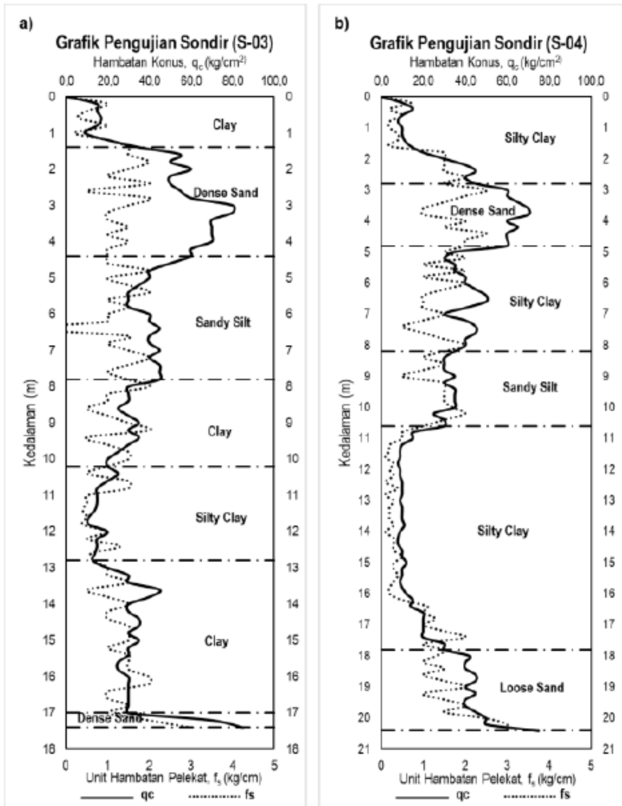


Fig. 8. Soil Layer, a) Point S-03; b) Point S-04

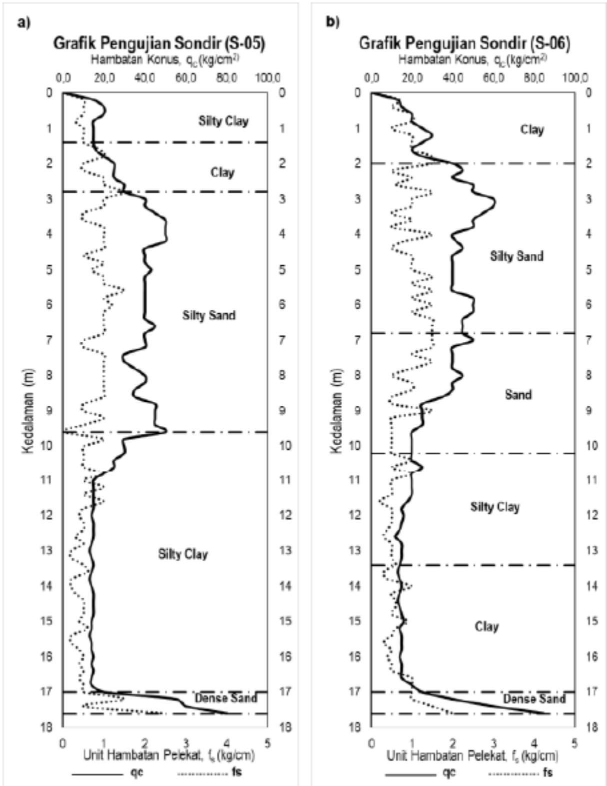


Fig. 9. Soil Layer, a) Point S-05; b) Point S-06

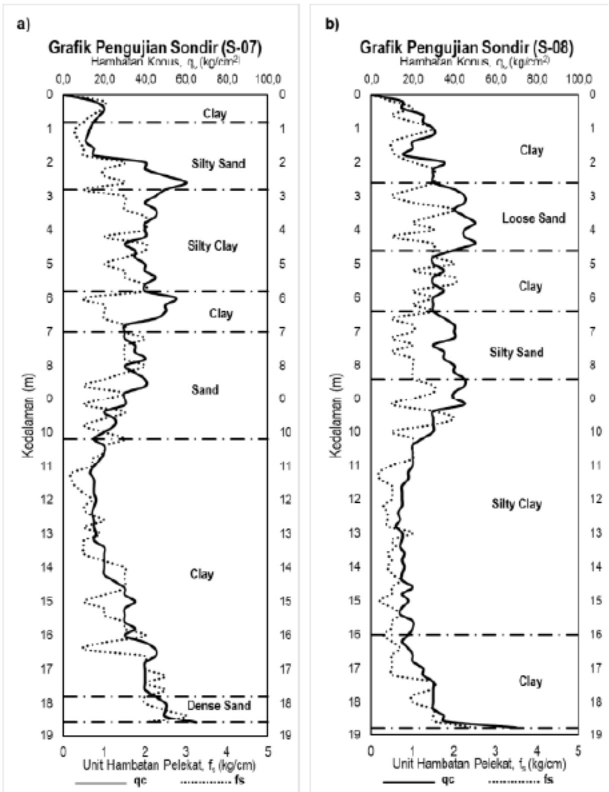


Fig. 10. Soil Layer, a) Point S-07; b) Point S-08

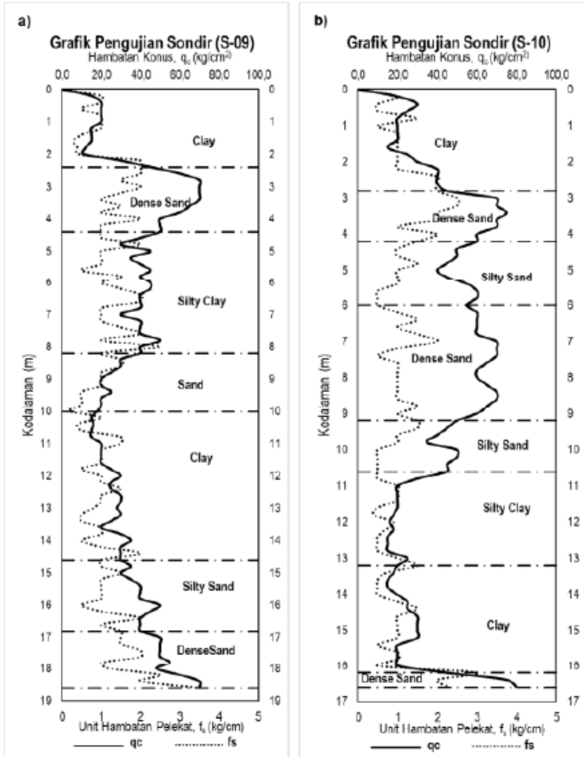


Fig. 11. Soil Layer, a) Point S-09; b) Point S-010

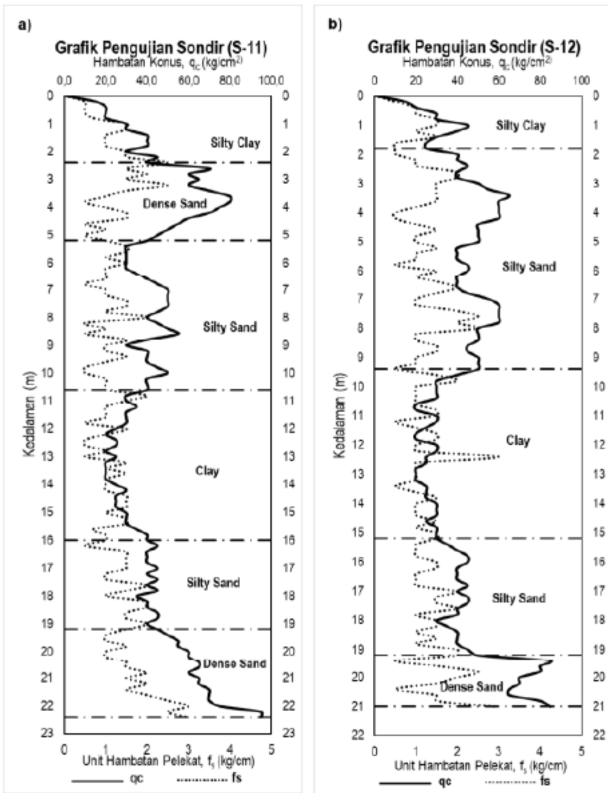


Fig. 12. Soil Layer, a) Point S-11; b) Point S-12

4.2 Estimating Soil Parameter using CPT Data

The following is an example of calculating data analysis at Point S-01 at a depth of 0.2 meters:

Known data:
Depth (h) = 0.2 m
Conus Resistance (qc) = 1.47 MPa
Resistance Ratio (%) = 6.67%
Atmospheric Pressure (pa) = 0.1 MPa
Weight Volume of Water (ɣw) = 9.81 kN/m³

Soil Unit Weight

$$\frac{\gamma}{\gamma_w} = 0{,}27\left[\log R_f\right] + 0{,}36\left[\log \frac{q_c}{p_a}\right] + 1{,}236$$
$$\frac{\gamma}{9{,}81} = 0{,}27\left[\log 6{,}67\right] + 0{,}36\left[\log \frac{1{,}47}{0{,}1}\right] + 1{,}236$$
$$\gamma = 18{,}08\ kN/m^3$$

Cohesion

- Terzaghi et al. (1996) Equation

$$c = 0{,}02\ q_c$$
$$c = 0{,}02 \times 15$$
$$c = 0{,}3\ kg/cm^2$$
$$c = 29{,}42\ kPa$$

- Rajan Kumar (2016) Equation

$$c = -2{,}2049 + 6{,}484N$$
$$N = \frac{q_c}{0{,}4}\ ;\ q_c = \frac{MN}{m^2}(Robertson, 2012)$$
$$N = \frac{(15/10{,}197)}{0{,}4}\ ;\ 1\frac{MN}{m^2} = 10{,}197\frac{kg}{cm^2}$$
$$N \approx 4$$
$$c = -2{,}2049 + (6{,}484 \times 4)$$
$$c = 21{,}64\ kPa$$

Internal Friction Angle

- Durgunoglu and Mitchell's (1975) Equation

$$\tan\varphi = \frac{1}{7{,}629} ln\left[\frac{(q_c/p'_0)}{0{,}194}\right]$$
$$p'_0 = (\gamma \times h) - (h_w \times \gamma_w)$$
$$p'_0 = (18{,}08 \times 0{,}2) - (0 \times 9{,}81)$$
$$p'_0 = 0{,}04\frac{kg}{m^3}$$
$$\tan\varphi = \frac{1}{7{,}629} ln\left[\frac{(15/0{,}04)}{0{,}194}\right]$$
$$\tan\varphi = 1{,}003$$
$$\varphi = 45{,}07\,°$$

- Rajan Kumar (2016) Equation

$$\varphi = 27{,}12 + 0{,}2857N$$
$$N = \frac{q_c}{0{,}4}\ ;\ q_c = \frac{MN}{m^2}(Robertson, 2012)$$
$$N = \frac{(15/10{,}197)}{0{,}4}\ ;\ 1\frac{MN}{m^2} = 10{,}197\frac{kg}{cm^2}$$
$$N \approx 4$$
$$\varphi = 27{,}12 + (0{,}2857 \times 4)$$
$$\varphi = 28{,}17\,°$$

4.3 Recapitulation of Correlation Results of Soil Parameters at Each Point

From the results of the calculation of the correlation of soil parameters based on CPT test data, 79 data from the total number of soil layers at 12 test points were plotted into a graph to determine the distribution of the data resulting from the calculated correlation.

From Figure 13, the greater the cone resistance value, the greater the unit weight value of the soil. In addition, the points at each depth are randomly distributed in the plotted area. This indicates that the correlation between the unit weight of soil and the value of qc is very small, so to obtain the unit weight value of the soil, laboratory testing of disturbed soil from the field is needed, so that it can produce a value that corresponds to the actual situation.

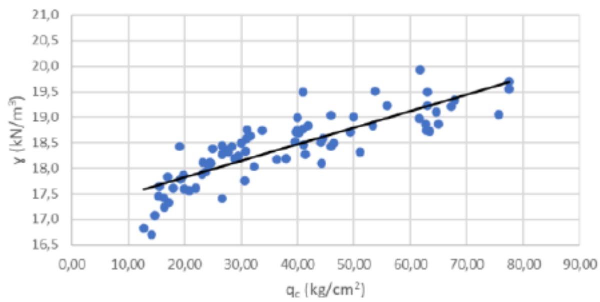


Fig. 13. Graph of the relationship between qc and unit weight of soil

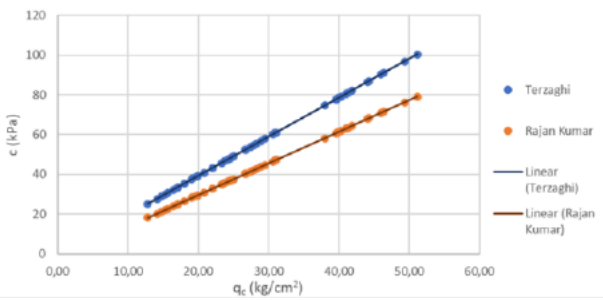


Fig. 14. Graph of the relationship between qc and cohesion

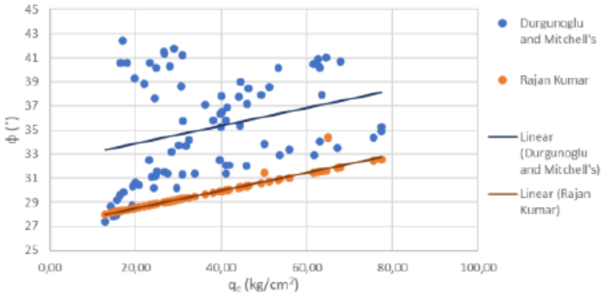


Fig. 15. Graph of the relationship between qc and internal friction angle

Based on observations made on the graph of the relationship between the value of cohesion and the value of qc, the correlation is generated through the formula given by Terzaghi (1975) and Rajan Kumar et al. (2016) shows that the greater the value of the cone resistance. In addition, from Figure 14, it shows that the two equations used provide a good relationship between the two. The test points at each depth, both from points S-01 to S-12 are not far from the resulting linear line.

From the graph of the relationship between the internal friction angle and the value of qc (Figure 15), it shows that using the equation given by Durgunoglu and Mitchell's distribution of data points is randomly distributed, some are close to the linear line, and some are far from the line. This happens because the equation by Durgunoglu and Mitchell's uses unit weight parameters of soil and effective stress, which is best obtained through laboratory testing. While the equation given by Rajan Kumar gives the results of data points that are very close to the line because the equation by Rajan Kumar provides random test data.

5. Conclusion and Recommendation

5.1 Conclusion

Based on the results of the study, several conclusions were drawn, as follows:

1. From the plot results to the soil type graph by Robertson, there are twelve points of CPT test locations, the distribution of the data is in zones 3, 4, 5, and 6. Meanwhile, using the table from Sunggono produces different soil layers at each point. The overall soil types at this location are Clay, Silty Clay, Sand, Silty Sand, and Dense Sand.
2. In this study, the correlation between the results of the CPT test and soil parameters (unit weight of soil, cohesion, and internal shear angle), can be used as a practical guide to determine soil parameters when it is not possible to carry out other tests other than the CPT test.

5.2 Recommendation

It is better to determine soil parameters (soil volume weight, cohesion, and internal shear angle) by taking undisturbed soil samples from the field which will be further investigated in the laboratory.

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