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GEOTECHNICAL CHARACTERIZATION OF BENGKALIS' PEAT USING PORTABLE TOOLS

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ABSTRACT: Indonesia's peatland covers almost 10% of its land i.e. about 20 million hectares. Due to economic development, infrastructure construction on peatland is frequently unavoidable. However, determination of geotechnical properties of peat, especially shear strength, is cumbersome due to its very fragile and soft nature. This study is a preliminary work to characterize geotechnical properties of peat using highly portable and low-cost in-situ soil investigation tools i.e. hand cone penetrometer (HCP), resistivity, and particularly soil strength probe (DK), a relatively new apparatus developed by Public Work Research Institute (PWRI) Japan. The location of this study is at Bengkalis Island, Riau Province Indonesia. Laboratory test shows that peat at the location is sapric (highly decomposed) with fibre content about 7-20%. Hand cone penetration values and resistivity range from 50-900 kPa and 41-130 ohm-m, respectively. Peat resistivity strongly correlates to its water resistivity. Soil strength probe penetration is generally higher than HCP i.e., 150-1900 kPa. HCP and DK penetrations correlates strongly. Shear strength from soil strength probe vane cone revealed low cohesion values (1-5 kPa) and friction angle between 14^0-47^0. Fibre content has a moderate positive correlation to penetration resistance. Resistivity has a very weak correlation with penetration resistance.

Keywords: Peat, Soil strength probe, Hand cone penetration, Resistivity

1. INTRODUCTION

Peat is defined as soil with high organic content which originated from partially decomposed vegetation and organic materials. Peat is usually accumulated in a low land area or basin, although it may develop in the former river bed. Peat can simply be categorized according to its degree of decomposition *fibric* (young), *hemi*c (intermediate) and sapric (old). Fibric has fibre content more than 67%. Hemic has fibre content between 33-67%, while *sapric* has less than 33 % [1].

Indonesia is one of the countries in the world which has a large area of peatland i.e. about 20 million hectares. Indonesia has the second-largest abundance of peatland after Brazil. In terms of construction, peatland has been considered a marginal area due to low bearing capacity and high compressibility. Following Indonesia's rapid economic development, construction on peat is not uncommon any more. One problem with peatland is the tool for its investigation.

Soil investigation in Indonesia is usually conducted using standard penetration test (SPT), full-scale cone penetration test (CPT) and field vane shear test (VST). SPT is not sensitive, a crude test (measure only number of blow) thus little use on soft peat, indicated by narrow range of SPT values, typically 0-3. CPT is theoretically more meaningful than SPT because it measures stress required to push the cone into the ground. It is more sensitive on peat than SPT. However, CPT on peat has some issues such as low and scattered tip resistance thus difficult to resolve the resistance accurately [2]. Landva [3] believed that a large amount of vertical compression is required to mobilize peat strength thus CPT is "little use" in determining engineering peat properties. On top all those facts, both SPT and CPT not practical on very soft to soft peatland because of their weight. They are also considered high in cost. On the other hand, VST is relatively portable and have been widely used on soft clay and silt. However, the main problem with VST on peat is the failure mechanism is tearing not shearing [4,5].

This study is a preliminary work in search of portable and low-cost investigation tools that can be used effectively and efficiently on peat. For this particular study, the choices are hand cone penetration (HCP) test, resistivity test, and soil strength probe test (DK) [6]. This study also is a continuation of the recent first trial by the Authors [7, 8] which indicated the potential of the tools on peat. In addition, some laboratory tests were also conducted to determine physical properties.

2. LOCATION, EQUIPMENT, AND METHODOLOGY

2.1 Location

Bengkalis island is located at the eastern coast of Sumatra Island with coordinate about 1° 15′ 00″ – 1° 35′ 0″ N and102° 00′ 0″ – 102° 30′ 0″E. This study is located in the northern part of Bengkalis Island Riau Province-Indonesia which is located near the Malacca strait. Figure 1 shows the location of the study. According to the geological map, the lithology of the location is quaternary alluvial composed of clay, silt, clean gravel, vegetation raft, and peat swamp. The aquifer can be classified as moderate to low transmissivity, depth to water table varies, and well generally yields less than 5 litres/sec [9]. Peat thickness ranges from shallow (< 1 m) to very deep (>3 m) e.g., peat thickness of 9.5 m has been encountered in the recent study [10].

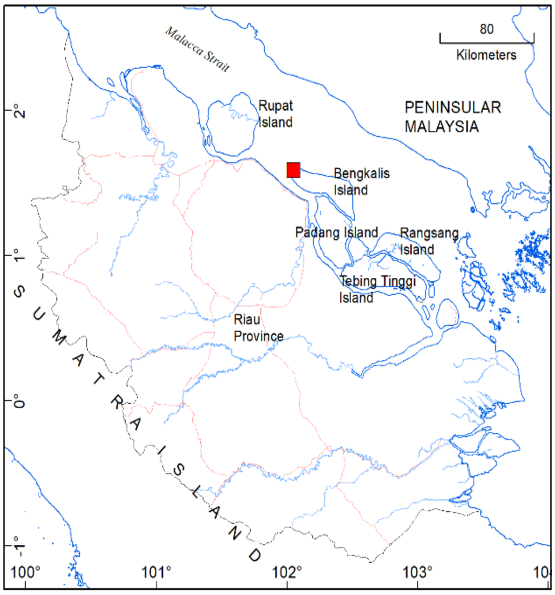


Fig.1 Site location

2.2 Equipment

2.2.1 Hand cone penetration test

Hand cone penetration is a small version of CPT. It weighs only about 11 kg. The tip of the apparatus is a cone with a diameter of 28.6 mm and has an angle of 30^0. The rod diameter is 16 mm. The cone and the rod are pushed into the ground at a speed of 1 cm/s [11]. A calibrated proving ring is used to measure force. Penetration resistance is then calculated as:

$$q_c = \{Q_{rd} + (m_0 + nm_1)9.81\}/(1000A) \qquad (1)$$

where Q_{rd}=weight of first rod; m_0=weight of cone; n=number of rods; m_1=weight of rod: A=cone area

2.2.2 Resistivity-meter

The 4-pin soil resistance meter used in this study is Nilsson S400 with 12 V battery, sample box, electrodes for current and voltage, and cable (Fig. 2). After a sample of peat is obtained from peat boring, the soil box is gently toward it until it is filled. Two electrodes are used to inject current to the soil sample in the box and two electrodes are used to measure the voltage.

Fig.2 Resistivity-meter

2.2.3 Soil strength probe

The apparatus was developed recently by the Public Work Research Institute (PWRI) of Japan. It is called Dosoukyoudokensabou (Japanese) and can be shortened as dokenbo or doken. Similar to HCP, DK can be used to measure penetration resistance (in term of stress). However, they have different tip angle, cone diameter and rod diameter. Compared to HCP, DK has larger tip angle i.e., 60^0, smaller cone diameter i.e. 15 mm and smaller rod i.e. 10 mm. DK consist of a calibrated spring to measure force, torque wrench, doken cone, vane cone, and a handle (Fig. 3). Another difference is that DK can be used to measure torsion. Thus, two measurements can be done using DK i.e. penetration resistance profile (typical interval 20 cm) using doken penetration cone and estimation of shear strength (cohesion and angle of friction) at certain depth using vane cone. The vane cone is the doken penetration cone which has been added blade. The blade part is composed of four blades and the blade width is 6.06 mm (intrusion). For shear strength measurement in particular (van cone shear test), at a certain depth a vertical load (less than maximum doken penetration resistance) is held at a certain value then the rod is rotated until the torque measurement does not increase anymore (Fig. 4). The vertical load (at the same depth and hole) then is increased then torque is measured again. The process is repeated at increased vertical load as necessary. A plot of vertical load and shear stress can be drawn to determine cohesion (y-intercept) and angle of friction i.e., slope of regression line [12]. The mechanism of failure of various peat type during vane cone test of DK is still unknown. On VST, the interaction between the vertical blade and the peat generated void behind the blade and while the in front of the blade the peat is compressed thus modified peat. Fibre also often wraps around the blade of VST [5]. On sapric peat, the mechanism of during vane cone test of DK is likely to be the same as in the clay i.e. shearing. However, the interaction between the blade of DK and fibre in fibrous peat has not been investigated. It is expected to be different than VST because the blades of DK have tipping angle not vertical. In short, the mechanism and interaction will be investigated in the future. The apparatus has been used in recent years for various soil investigation purposes such as assessment of surface slope stability, river embankment, and embankment [13]. As the author's knowledge, this study might be the first use of soil strength probe on peat.

Fig. 3 Soil strength probe

Fig. 4 Vane cone shear test

The equations used in the calculation are

$$q_{dk} = \frac{Q_{dk}/_{1000}}{A} \quad (2)$$

$$Q_{dk} = W + (m^0 + nm^1)g \quad (3)$$

where:
q_{dk}= Doken penetration resistance
Q_{dk}= Total vertical force (N)
A= *cone area* (1,76 x 10^4 m^2)
W= Vertical force reading (N)
m^0= weight of cone and 450 mm rod (kg)
n= number of 500 mm rod
m^1= weight of 500 mm rod (kg)
g= gravity acceleration 9,81 m/s^2

Empirical formulas below may be used to calculate vertical stress and shear stress.

$$\boldsymbol{\sigma = 2,4 \text{ x } 10^2 \text{ x } W_{vc}} \quad (4)$$

$$\mathbf{W_{vc} = W_N + (m^0 + n \text{ x } m^1) \text{ x } g} \quad (5)$$

$$\boldsymbol{\tau = 1,5 \text{ x } 10^4 \text{ x } T_{vc}} \quad (6)$$

$$\mathbf{T_{vc} = T_N - T_0} \quad (7)$$

where:
W_{vc}= Applied vertical force on *vane cone* (N)
T_{vc}= Net applied torque (N.m)
W_N= Vertical load (N)
T_N= Maximum torque with load W_N (N.m)
T_0= Maximum torque without vertical (N.m)

2.2.3 Peat sampler

Figure 5 presents a locally made Russian-type peat auger which was used in this study. It consists of a peat sampler, extension rods, and rotating handle. The peat sampler consists of a hooked blade(fin) and a half-cylindrical tube (gouge) that has a sharp edge to cut peat. Initially gouge is open and when the rod handle is rotated it close and covers the cut peat sample. Samples were obtained at an interval 50 cm.

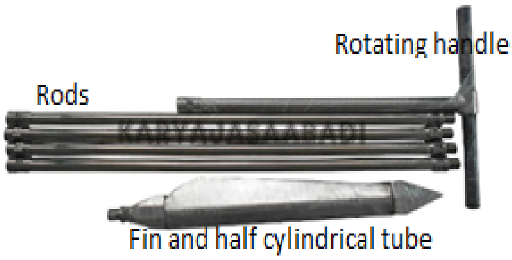


Fig. 5 Peat sampler

2.3 Methodology

Figure 6 shows conducted points of investigation (red circled). In total there are 5 points of HCP, DK and peat samplings used in this study. HCP, DK, and peat sampling are conducted at the same time, close to each other less than 1-2 m. Resistivity value was measured directly in the field using the soil box method. Likewise, wet unit weight was also measured on-site from the peat sample on a ring with a known volume. Other physical properties were taken to the soil mechanic laboratory to be tested.

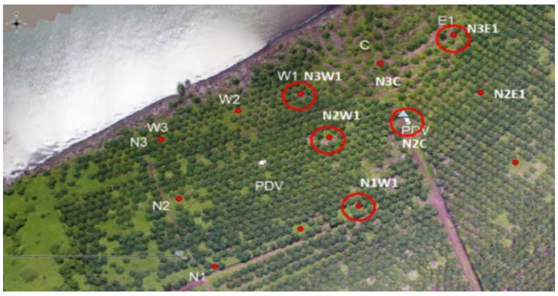


Fig. 6 Investigation points

3. RESULTS

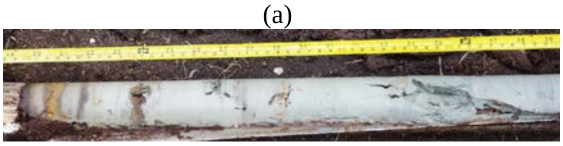
3.1 General

In general, the stratification consists of peat overlying clay layer (Fig. 7). Peat thickness at the site is about 5 m. Thus, peat at the site can be classified as deep peat. Based on visual observation the peat is mainly sapric. The groundwater table ranges from 0.5-1.5 m below the surface.

3.2 Physical Properties

Table 1 shows some of the results from the resistivity test i.e., soil resistivity value (r) and laboratory test. Due to space limitation, only dry unit weight (γ_d), specific gravity (G_s), and fibre content (FC) are presented in the table. Water resistivity was also measured at 4 points (shown in the third column, bracketed). Water pH range from 4.02-5.75. From the table, soil resistivity values range from 41-130 ohm-meter, which is in accordance with previous research [14,15]. Water content range from 275-1000%. The range of specific gravity is about 1-2 while those of dry unit weight 0.9-2 kN/m^3. Fibre content is less than 33%. Ash content is generally less than 5%. Based on the fibre and ash content, peat at the location can be classified as *sapric and low ash content.* To sum up, physical properties are consistent with the results from previous research of tropical peat properties [16-19].

(a)



(b)

Fig. 7 Peat sample (a) clay (b)

Some of the data from Table 1 are plotted graphically in the following figures to check their tendency. Figure 8 shows that water resistivity strongly correlates to soil resistivity. This is consistent with the fact that resistivity is much affected by water properties. Figure 9 shows that increasing water content results in decreasing dry unit weight, which is reasonable. This study gives higher dry unit weight for the same water content than the relationship for Dutch's peat. This may be due to different peat origin between tropical peat and sub-tropical peat. Figure 10 shows that increasing fibre content tends to decrease dry unit weight. A similar observation was found by Hikmatullah and Suparman [20].

3.3 Mechanical Properties

Penetration resistance profiles from HCP and DK are presented in Figure 11 and Figure 12 respectively. The figures show that in general penetration resistance from HCP is lower than those from DK. HCP penetration range from 50-900 kPa whereas DK penetration range from 150-1900 kPa. For comparison, typical value of full CPT on peat ranges from 0-750 kPa [21]. A plot of DK and HCP resistance at the same depth (number of data, n =15) is shown in Figure 13. The figure reveals that there is a strong linear correlation [22] between both of them with the coefficient of correlation of r = 0.76 with probability value p = 0.001. The p value is less is less than 0.05 thus the correlation can be considered statistically significant. Linear correlation was selected in this preliminary study because its simplicity and practicality.

Table 1 Physical properties

ID	Depth (m)	R (ohm.m)	G_s	γ_d (kN/m^3)	FC (%)
N2C	1	85	2.1	1.31	13.3
	2	87 (117)	1.40	1.54	12.8
	3	120	1.41	1.38	13.3
N3E1	2	73(50.6)	1.03	1.03	17.0
N2W1	2	74(66.2)	1.46	1.39	28.7
	4	75	1.24	1.16	18.6
N3W1	2	92	1.08	1.29	20.3
	3	130	1.38	1.74	8.3
	5	42	1.30	1.19	17.2
N1W1	1	105	1.39	2.02	7.8
	2	76(71.4)	1.40	2.04	13.3
	4	75	2.02	1.12	17.8

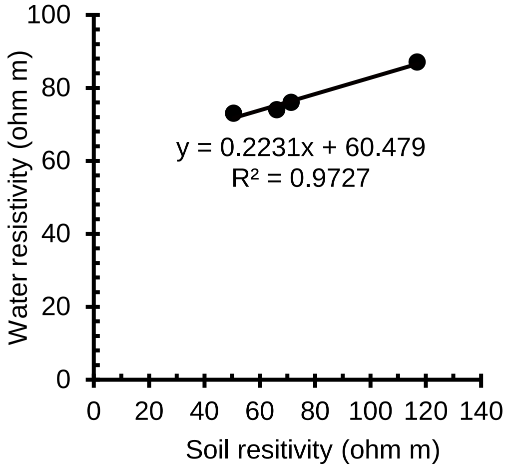


Fig. 8 Soil versus water resistivity

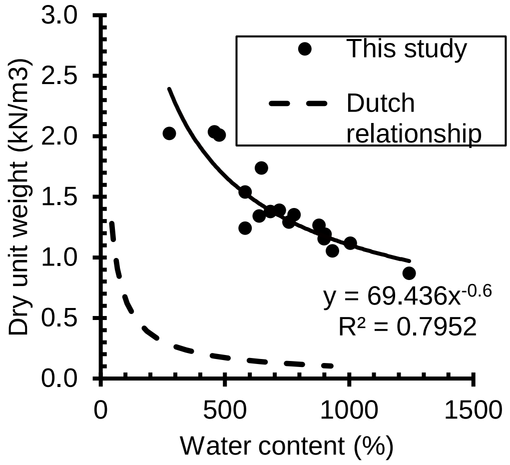


Fig. 9 Water content versus dry unit weight

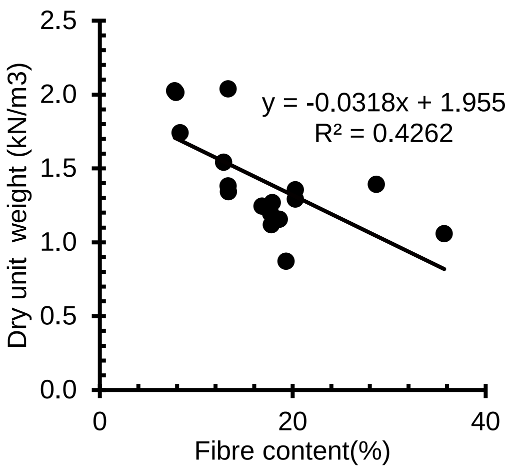


Fig. 10 Fibre content vs dry unit weight

Vane cone shear test was conducted at some depths. An example of the result is shown in Figure 14. Estimated shear strength parameters i.e., cohesion and friction angle are tabulated in Table 2. Low cohesion values i.e., 1-5 kPa reveal that peat is mainly frictional material, as argued also by Hanrahan [23]. Although the range of friction angle is in accordance with previous studies [24-33], it should be noted that Eq (4) and Eq (6) are based on limited comparison with laboratory shear strength tests. Further calibration is required thus shear strength parameters should be used with caution.

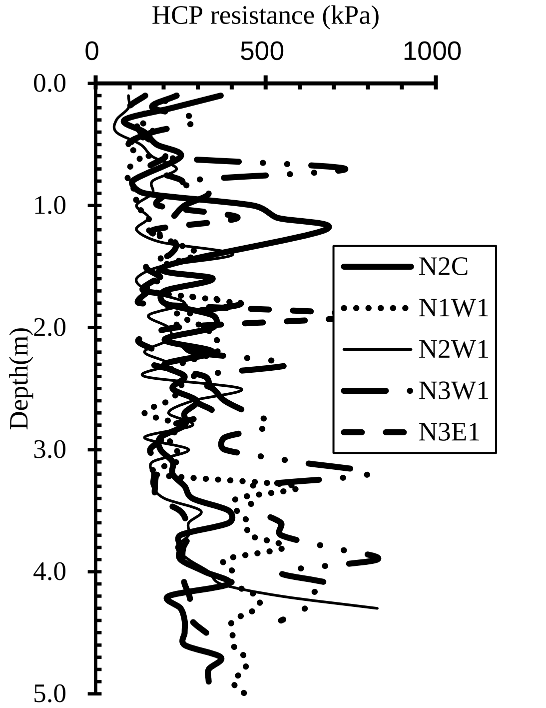


Fig. 11 Hand cone penetration results

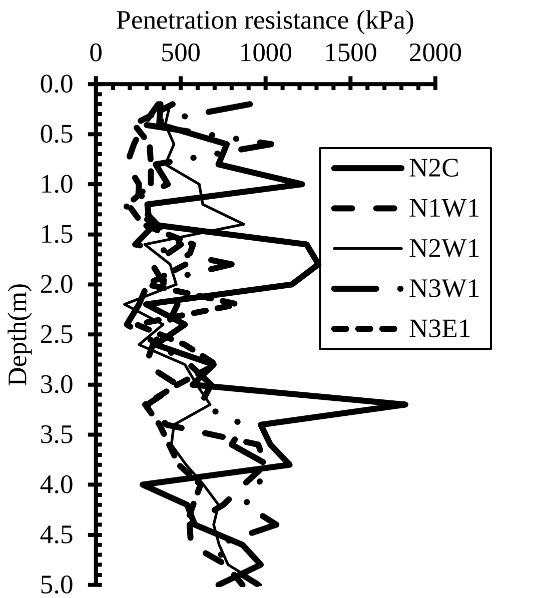


Fig. 12 Soil strength probe results

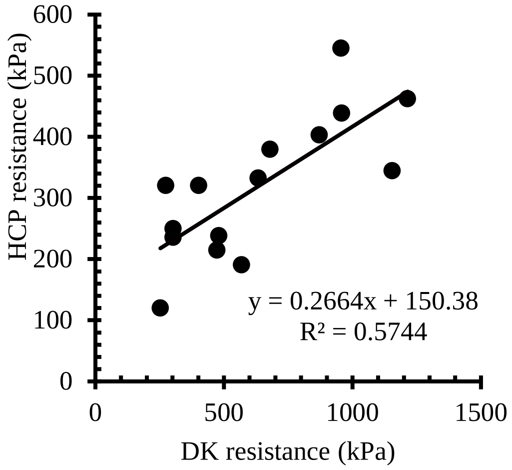


Fig. 13 Correlation penetration of HCP and DK

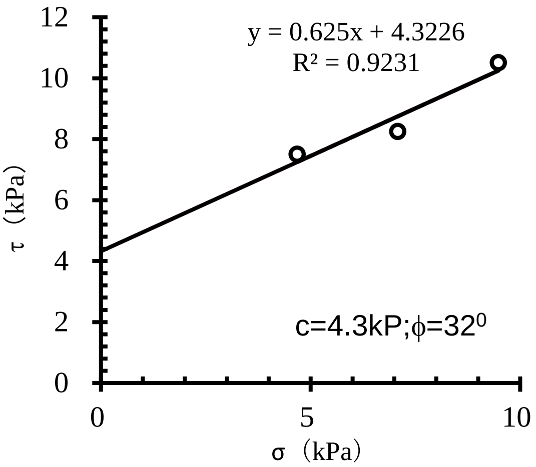


Fig. 14 Example of normal and shear stress

Table 2 Shear strength component

Point	Depth (m)	c (kPa)	ϕ^0
N2C	1	4.32	32.01
	2	3.16	38.00
	3	2.96	47.56
N3E1	1	3.27	29.36
N2W1	2	1.19	37.,20
	4	1.62	17.35
N3W1	2	4.95	14.04
	3	3.76	15.71
	5	5.42	14.04
N1W1	1	4.95	14.04
	2	3.76	15.71
	4	5.42	14.04

3.4 Mechanical and Physical Properties Correlation

Attempts were made to investigate correlation between physical properties and mechanical properties. As the number of physical properties is in the 1-meter interval, the penetration used in this study is the geometric mean of a 1-meter interval. Figure 15 shows that higher fibre content tends to increase penetration resistance, which was expected. This is similar tendency with the result of the first trial work by the Authors. The correlation can be classified as moderate ($0.4< r <0.59$), in which DK gives a higher correlation compared to HCP. This may be due to the higher sensitivity of DK measurement than HCP measurement.

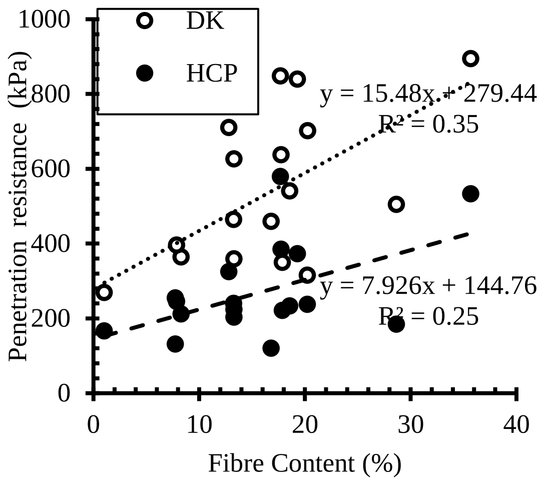


Fig. 15 Fibre content vs penetration resistance

Assuming peat as frictional material, peat shear strength (s) can be approximated as

$$s \approx \sigma' \tan \phi; \quad \sigma'=\text{effective stress} \qquad (8)$$

Visual observation of Figure 16 indicates that that there is tendency that larger fibre content results in higher shear strength. Statistically, the coefficient correlation r of 0.43 suggests a moderate correlation. However, the p- value is 0.07 more than threshold value of 0.05 thus the correlation is not statistically significant. Nevertheless, linear regression is still used in this preliminary study for comparison with the relationship between fibre content and penetration resistance. Lower linear correlation between fibre content and shear strength compared to penetration resistance is due to the fact that Eq. (4) and Eq. (6) are based on limited calibration with laboratory data using clay and sand material. Calibration between soil strength probe measurement and laboratory data using peat material will be investigated in the future. Resistivity has been also plotted again penetration resistance (Fig.17). The figure reveals that resistivity has a very weak correlation with penetration resistance of peat. This may be due to the high heterogeneity of peat. This trend is different from clay and sand material which have moderate to strong correlation with resistivity [34-36].

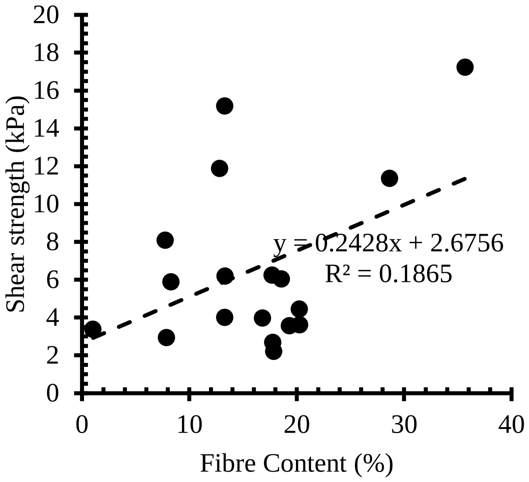


Fig. 16 Fibre content vs shear strength

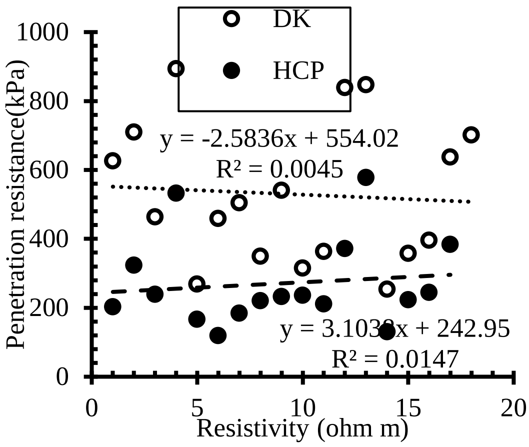


Fig. 17 Resistivity vs penetration resistance

4. CONCLUSIONS

This study is a preliminary work to characterize geotechnical peat properties using portable soil investigation tools: hand cone penetration, resistivity, and soil strength probe. This study shows that sapric peat at the location has HCP range 50-900 kPa and resistivity between 41-130 ohm-meter. Peat resistivity strongly correlates to its water resistivity. DK has higher penetration resistance than HCP with a value range from 150-1900 kPa. Soil strength probe penetration correlates strongly to hand cone penetration. Soil strength probe shear strength parameter reveals that peat is mainly frictional. Fibre content has a moderate correlation with penetration resistance and shear strength. Resistivity has a very weak correlation with penetration resistance. Further calibration between soil strength probe shear strength parameters with laboratory shear strength tests of various peat is recommended. Considering the heterogeneity of the peat, it is also recommended to do soil investigation using portable tools at narrower interval than specified in the Indonesian National Standard (SNI) 8640-2017.

5. ACKNOWLEDGMENTS

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