INTEGRATION OF ELECTRICAL RESISTIVITY IMAGING WITH BOREHOLE AND HAND AUGER DATA FOR PEAT CHARACTERISATION: A CASE STUDY AT KUALA LANGAT, SELANGOR, MALAYSIA

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ABSTRACT

Peat is one of the Quaternary sediments found in the Kuala Langat area. Peat contains organic matter where its high natural water content can cause the subsurface to becomes unstable and unsuitable for supporting any building structures. It can either react with a steady settlement, which is generally less harmful or suddenly experience shear failure of the peat, causing sudden subsidence. This study aims to characterise a subsurface peat layer by integrating borehole data and hand auger samples with electrical resistivity imaging (ERI) results. The collected soil samples physical and chemical properties were analysed to determine its moisture content, total organic content (TOC) and von Post's degree of humification. Three electrical resistivity survey lines were conducted using Wenner-Schlumberger protocol at certain key locations in the study area to map the vertical subsurface electrical resistivity profile. The studies show that the thickness of the peat layer from the borehole data and hand auger data is perfectly matched with the electrical resistivity pseudo section. The study area is covered up to 5 meters thick of peat with a resistivity value ranging from 16 Ωm to 24 Ωm, followed by a thick layer of marine clay with a resistivity value ranging from 24 Ωm to 46 Ωm. This study can support the engineer's selection of site suitability and equipment for engineering construction.

Keywords: electrical resistivity imaging (ERI), peat characterisation, peat resistivity, soil sampling

INTRODUCTION

Peat represents an accumulation of partially decomposed and disintegrated plant remains that have not completely decomposed under conditions of little exposure to air and high-water content [1]. From a civil engineering perspective, peat is frequently referred to as an unstable soil to support building structures. Soft clays are commonly found below the peat layer [2]. This soft clay can affect the stability and long term settlement and needed to be taken into consideration. The peat in Malaysia is classified as tropical peat [3]. Malaysia has peatlands that cover approximately 27,600 km^2 [4] of which Peninsular Malaysia constituents about 7,967 km^2 [5].

This investigation intends to assist a development company with infrastructure planning in a peat area. Thus, a correlation study of borehole soil data and hand auger data with electrical resistivity imaging (ERI) survey was conducted to investigate the study area's subsurface conditions. Geophysical methods have proven to be a better approach that helps the engineer resolve subsurface issues, especially when encountering an unstable organic soil like peat [6]-[7]. Electrical resistivity imaging (ERI) is widely used to investigate the suitability of the subsurface soil to act as foundations for building structures [8-11]. Laboratory tests conducted by Asadi and Huat [12] show an excellent correlation between the low resistivity response and the peat behaviour. Kowalczyk et al. [13] determined the thickness of a top layer of peat by using ERI at Całowanie Fen, Poland and found the resistivity value range for peat to be from 40 Ωm to 70 Ωm.

In contrast, Basri et al. [14] obtained the resistivity value range for peat from 100.8 Ωm to 139.5 Ωm by using ERI methods in Parit Nipah, Johor, Malaysia. The resistivity values may vary with the peat originality caused by differences in the peat's chemical composition. In Malaysia, most of the ERI study focuses on the Quaternary alluvium like sand, clay, and silt deposit. Little literature has discussed the electrical characteristics and profiling of peat. Hence, this project initiates a case study of peat's condition by using ERI in Malaysia to determine the occurrence, depth, and thickness of subsurface peat and its behavior based on the electrical resistivity contrast.

Study Area

The study area is located at Kuala Langat District, situated in the southwestern part of Selangor, Malaysia. The total area covered in this study is approximately 1.28 km^2, which lies between longitude 101.5092° to 101.5236° and latitude between 2.9232° to 2.9160°. The study area is mostly influenced by Langat River basin where the Langat River is situated approximately 4 km towards the southwest of the study area. Figure 1 shows the base map of the study area with electrical resistivity survey lines. The lithology of the study area is generally made up of peat, humic clay and silt.

Geological Setting

Kuala Langat is generally composed of Quaternary deposits based on the geological map of Selangor Darul Ehsan provided by Jabatan Mineral dan Geosains Malaysia (JMG) [15] as shown in Figure 2. Four stratigraphic units from oldest to youngest have been identified, which are the Simpang Formation, Kempadang Formation, Gula Formation and Beruas Formation [16]-[17]. The uppermost layer is Beruas Formation, which consists of fluviatile-estuarine-lacustrine deposits made up of clay, sandy clay, sandy gravel, silt, and peat. The underlying layer of Gula Formation is made up of mainly grey to greenish-grey marine to estuarine clay and subordinate sand. Kempadang Formation mainly consists of marine clay with shells and sand. The lowermost Simpang Formation is made up of gravel, sand, clay, and silt overlying the Kenny Hill Formation, which is the bedrock.

MATERIALS AND METHODS

Electrical Resistivity Survey

Three electrical resistivity survey lines were conducted using ABEM SAS4000 with 61 electrodes, 5 m electrode spacing. The full spread length for these three survey lines is 200 m. Electrical resistivity survey Line 1 and Line 2 were intercepted one another for data quality control while Line 3 is located about 700 m away to the East from the location of Line 1 and Line 2. The coordinates for each electrode was taken for every ERI survey line. The data were processed

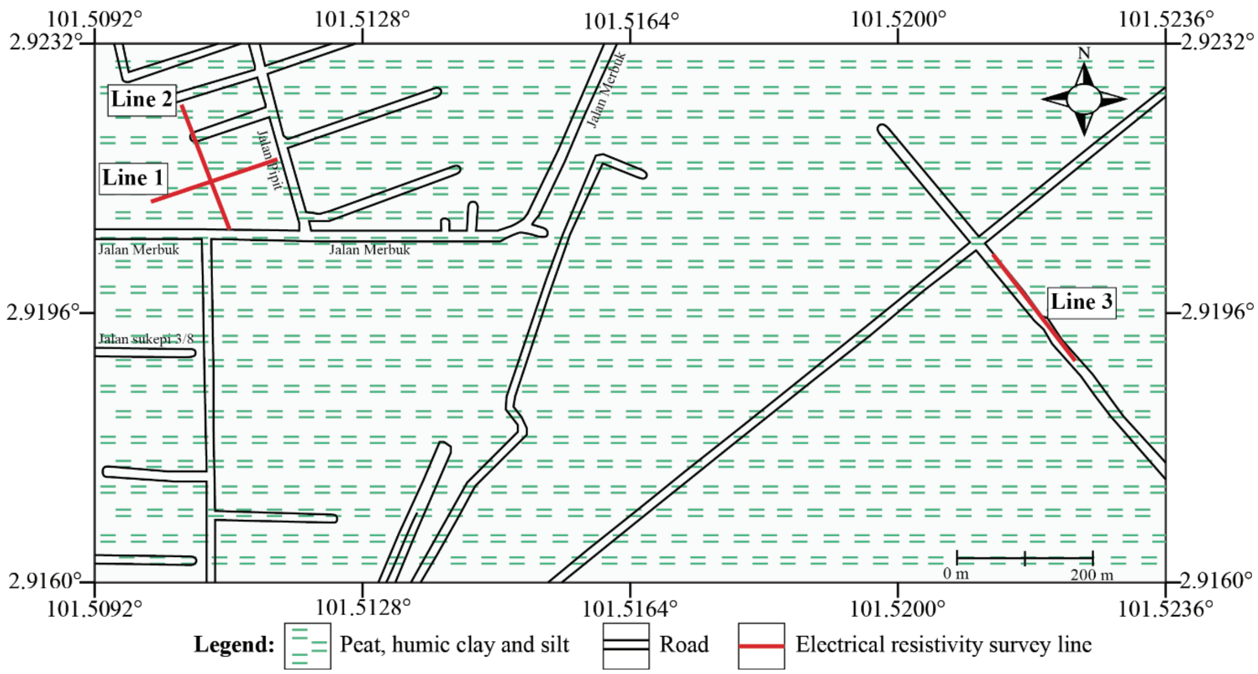

Figure 1 Base map of the study area with electrical resistivity survey lines

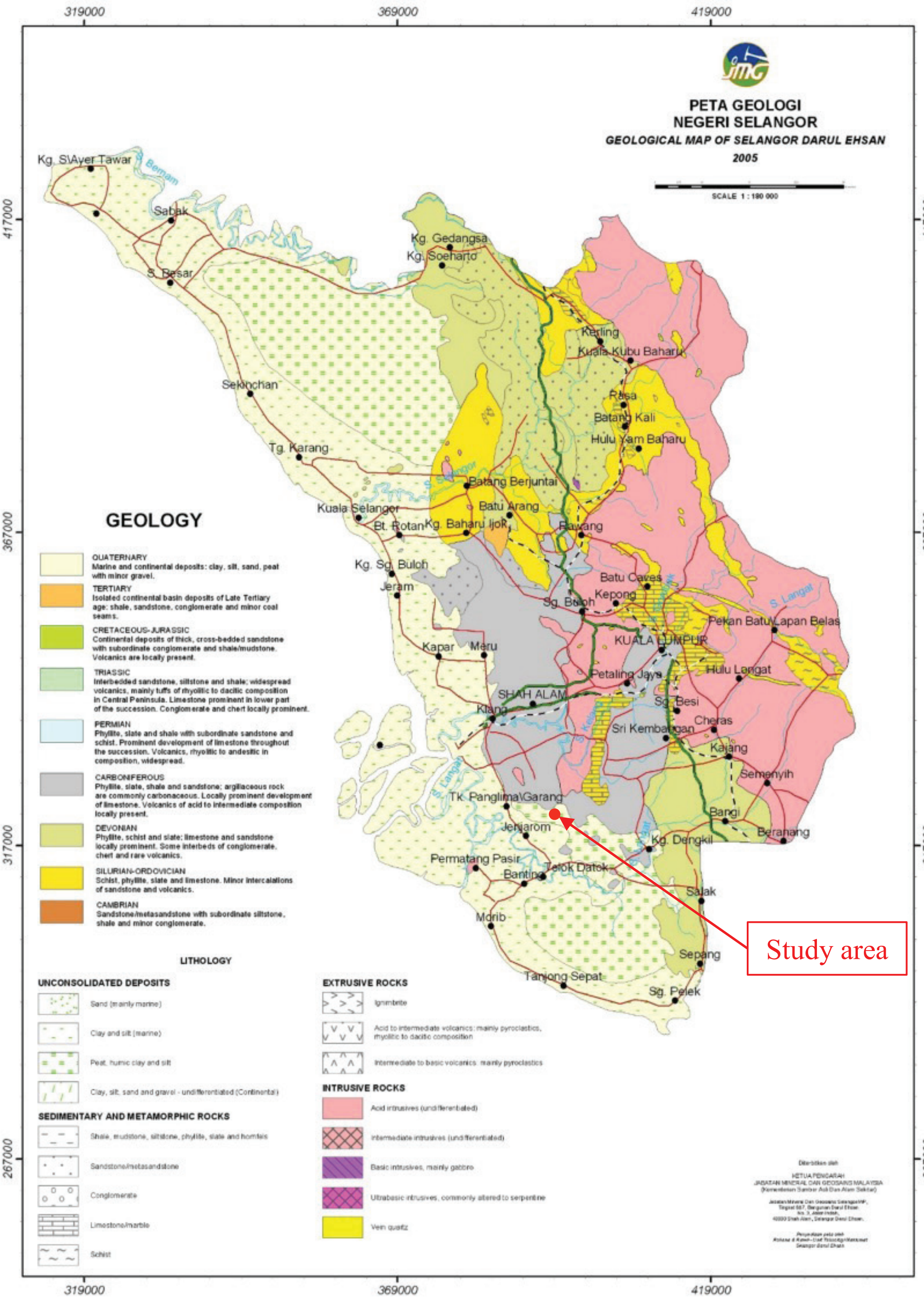

Figure 2 Geological map of Selangor Darul Ehsan [15]

using the RES2DINV program [18]-[19] to produce 2-D inverse resistivity pseudo section. The locations of the electrical resistivity survey lines were chosen based on the location of the boreholes for correlation purposes.

Soil Sampling

Two types of soil sampling methods were carried out in this project, a) peat sampling and b) borehole soil investigation. Peat sampling, also better known as hand auger sampling, is used to collect soil/peat samples down to several meters from the surface. However, this technique is different from common soil sampling using a hand auger and must be according to the procedure of Walt [20] with specific peat sample equipment, as shown in Figure 3. A total of 3 peat samples, namely HA-1, HA-2 and HA-3 collected at each electrical resistivity survey line for laboratory analysis. Two boreholes, borehole 1 (BH-1) and borehole 2 (BH-2), were drilled near the electrical resistivity survey lines. BH-1 is located close to survey Line 1 and survey Line 2, while BH-2 is placed near to survey Line 3.

Laboratory Analysis

All the soil samples obtained by the hand auger and borehole were sent to a development company laboratory to undergo several tests such as moisture content, total organic content (TOC) and von Post [21] scale of humification (Table 1). All the tests were conducted to determine the peat's physical and chemical properties for correlation with the electrical resistivity imaging (ERI).

Figure 3 Soil sampling using peat sampler equipment

Table 1 The von Post scale of humification (modified from Landva and Pheeney [22])

<table>
<tr><th colspan="3">Conditions of peat before squeezed</th><th colspan="4">Conditions of peat after squeezed</th></tr>
<tr><th>Degree of humification</th><th>Soil colour</th><th>Degree of decomposition</th><th>Watercolour</th><th>Plant remains</th><th>Material extruded between fingers</th><th>Nature of residue</th></tr>
<tr><td>H1</td><td>White or yellow</td><td>None</td><td>Almost clear/ colourless</td><td>Easily identifiable</td><td rowspan="3">Nothing</td><td rowspan="3">Not pasty</td></tr>
<tr><td>H2</td><td>Very pale brown</td><td>Insignificant</td><td>Clear/ yellowish</td><td>Still easily identifiable</td></tr>
<tr><td>H3</td><td rowspan="2">Pale brown</td><td>Very slightly</td><td>Muddy brown</td><td>Still identifiable</td></tr>
<tr><td>H4</td><td>Slightly</td><td rowspan="4">Very muddy dark brown</td><td>Not easily identifiable</td><td rowspan="2">Some peat</td><td>Rather pasty</td></tr>
<tr><td>H5</td><td rowspan="2">Brown</td><td>Moderately</td><td>Recognisable but indistinct</td><td>Strongly pasty</td></tr>
<tr><td>H6</td><td>Moderately strong</td><td>Indistinct (clearer after squeezing)</td><td>About 1/3 of the peat</td><td rowspan="4">Very strongly pasty</td></tr>
<tr><td>H7</td><td rowspan="2">Dark brown</td><td>Strong</td><td>Slightly recognisable</td><td>About 1/2 of the peat</td></tr>
<tr><td>H8</td><td>Very strong</td><td>Very dark brown, pasty</td><td>Very indistinct</td><td>About 2/3 of the peat</td></tr>
<tr><td>H9</td><td>Very dark brown</td><td>Nearly complete</td><td>Very dark brown, muddy</td><td>Almost unrecognisable</td><td>Nearly all peat as uniform paste</td></tr>
<tr><td>H10</td><td>Black</td><td>Complete</td><td>Very dark brown, muddy</td><td>Not recognisable</td><td>All the peat; absent of free water</td><td>Not available</td></tr>
</table>

RESULTS AND DISCUSSION

Soil Analysis

The general data acquired from the peat sampler is shown in Table 2. Based on the results in Table 2, the subsurface generally consists of three layers. The uppermost layer is the topsoil, followed by the peat layer, and below it is a mixture of silty clay and organic matter, as shown in Figure 4 and Figure 5. Only two boreholes were considered in this study because they were located near the electrical resistivity survey lines. The lithology determined from the two boreholes is almost identical as the peat sampling using a hand auger up to approximately 5 m depth. The lithology found here can be classified into three layers, as shown in Table 3. The first layer is defined as a peat layer from the ground surface up to 2 m depth. The second layer is then defined as silty clay with organic matter or a mixture of silty clay and organic matter. This layer is from 2.0 m to 3.5 m in BH-2 and up to 4.5 m in BH-1. The third layer is silty clay and is suspected to be marine clay. This layer is very thick with a depth of up to

Table 2 Peat sampler logging data

Sampler	Depth (metre)	Lithology
HA-1	0.00 m to 0.20 m	Top soil
	0.20 m to 0.80 m	Peat
	0.80 m to 5.00 m	Peat + clay
HA-2	0.00 m to 0.10 m	Top soil
	0.10 m to 0.80 m	Peat
	0.50 m to 5.00 m	Peat + clay
HA-3	0.00 m to 0.10 m	Top soil
	0.10 m to 0.45 m	Peat
	0.45 m to 5.00 m	Peat + clay

Table 3 Boreholes logging data

Borehole	Depth (metre)	Lithology	Water level (metre)
BH-1	0.00 m to 2.00 m	Peat	4.50 m
	2.00 m to 4.50 m	Clay (organic)	
	4.50 m to 49.50 m	Marine clay	
BH-2	0.00 m to 2.00 m	Peat	5.00 m
	2.00 m to 3.50 m	Clay (organic)	
	3.50 m to 49.50 m	Marine clay	

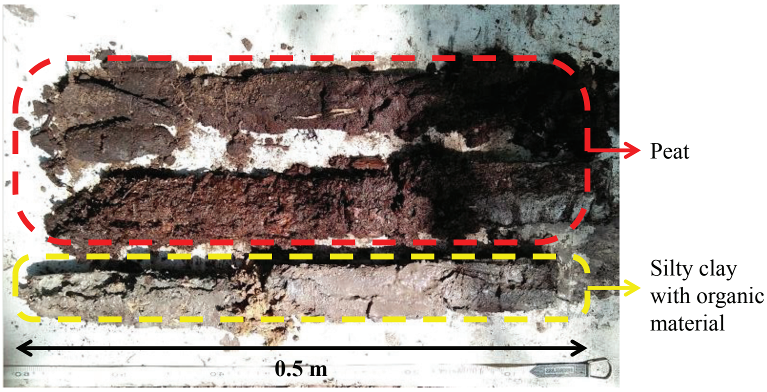

Figure 4 Logging sample of HA-1

Figure 5 Close up look of the peat sample

49.5 m from the second layer and probably continues to a depth of 50 m to 100 m.

From the borehole data and peat sampling data, the two main soil samples (peat and clay) have been chosen for laboratory analysis. Due to the soil sample's condition, each peat from each hand auger sampling at different depths and the clay obtained from the borehole (BH-1 and BH-2) from the same depth is only taken for laboratory analysis. Table 4 shows a summary of laboratory analysis.

Based on the result shown in Table 4, the moisture content has a minimum percentage of 290% and a maximum percentage of 425%. The total organic content (TOC) has an average value of 73.10% for the three-peat samples. The von Post Scale of humification for the three peats samples showed a scale of H8, which is a very highly decomposed peat. Hence, by taking the minimum and maximum value of the moisture content and the average value of TOC, a cross-plot was constructed to identify the resistivity value range for the peat. Since the peat sample has a von Post scale of H8, a highly decomposed peat graph by [12] is used for the correlation. The cross-plot of the graph is as shown in Figure 6.

Based on Figure 5, only HA-1 and HA-2 were able to be plotted in the graph, whereas, for HA-3 the value cannot be correlated due to inadequate data provided by Asadi and Huat [12]. The resistivity value range of the peat obtained from the cross-plot is ranging

Table 4 Summary of laboratory analysis

Parameters	Peat			Clay	
	HA-1	HA-2	HA-3	BH-1	BH-2
Depth (metre)	1.50 m	0.50 m	0.70 m	6.50 m	6.50 m
Moisture content (%)	425 %	340 %	290 %	40 %	100 %
Total Organic Content (%)	74.00 %	79.20 %	66.20 %	0.70 %	4.14 %
Von Post Scale	H8	H8	H8	-	-

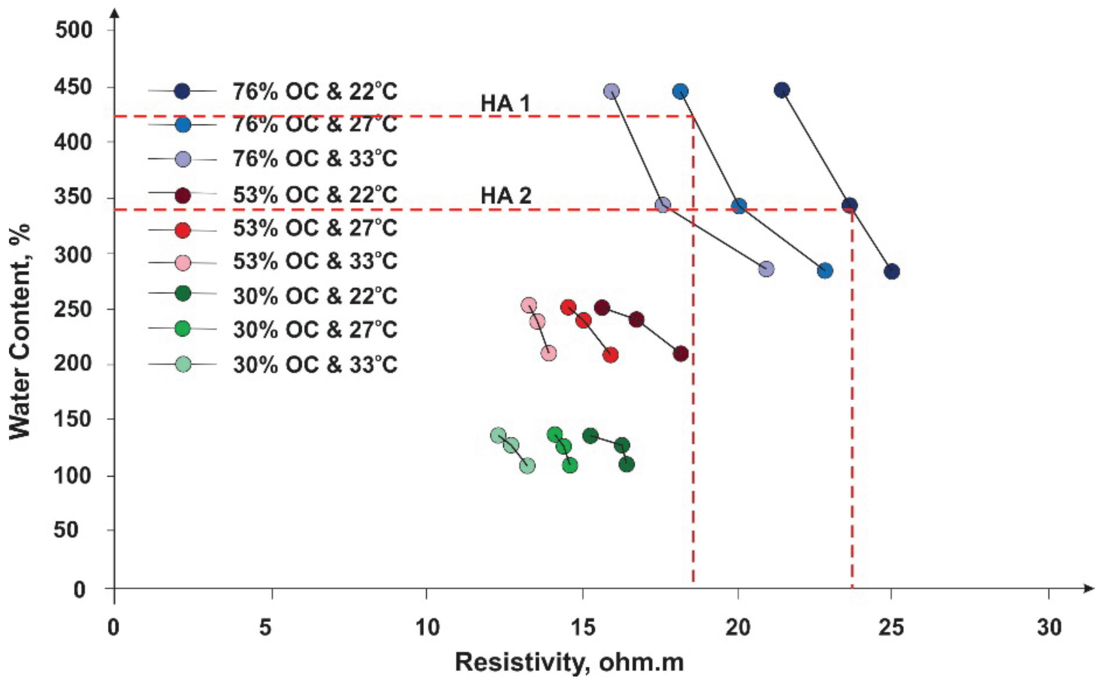

Figure 6 Resistivity and water content relationship on highly decomposed peat, ≈ 76% organic content (modified from Asadi and Huat [12])

between 18 Ωm to 24 Ωm. This range of resistivity value is used in determining the layer of peat in the ERI section.

Electrical Resistivity Imaging

The inversion of electrical resistivity survey Line 1, Line 2 and Line 3 are shown in Figure 7, 8 and 9 with a resistivity values range of 1 Ωm to 120 Ωm. This range indicates the occurrence of peat, clay (with organic matter) and silty clay (marine clay) whose ranges are from 16 Ωm to 24 Ωm, 10 Ωm to 50 Ωm, and 24 Ωm to 46 Ωm, respectively. As aforementioned, the resistivity value range for peat was taken from the laboratory assessment while the other two resistivity value ranges are estimated based on the control of nearby boreholes and peat sampler records. Both Figure 7 and Figure 8 show relatively identical inversion resistivity profiles. The first layer from the ground surface down to 5 m has a resistivity range from 16 Ωm to 24 Ωm and is interpreted as the peat and clay mixture layer which agrees with the laboratory analysis results and peat sampler records. The second layer indicated as clay and organic mixture associated with the water-saturated zone with a thickness of 13 m, and it occurs at a depth of 5 m from the ground surface where the water table recorded in BH-1 is around 4.5 m. The results

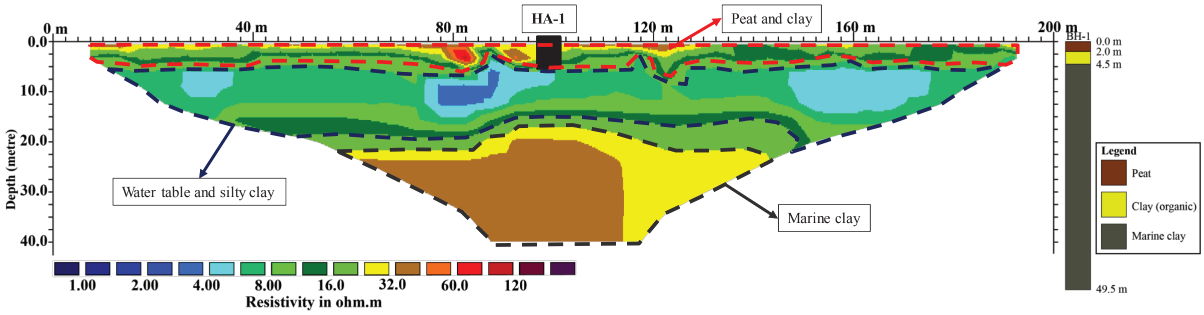

Figure 7 Inversed electrical resistivity profile Line 1

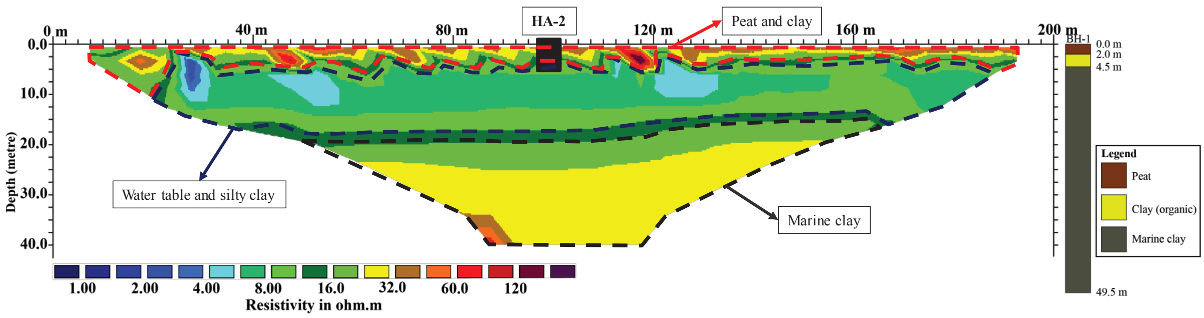

Figure 8 Inversed electrical resistivity profile Line 2

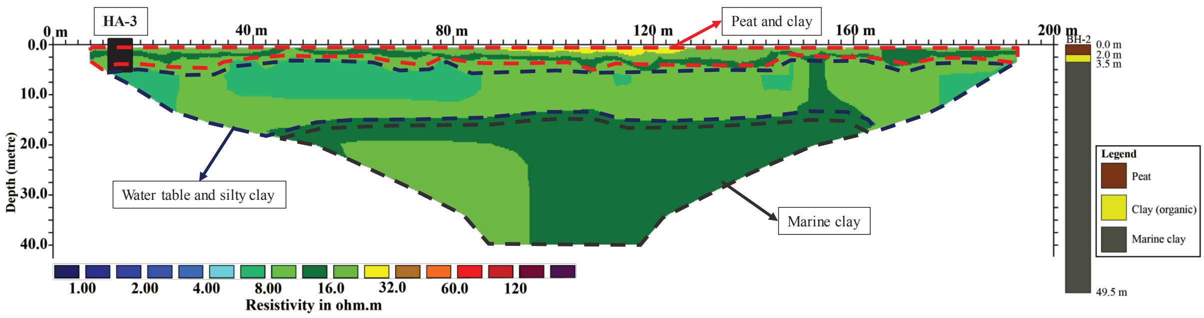

Figure 9 Inversed electrical resistivity profile Line 3

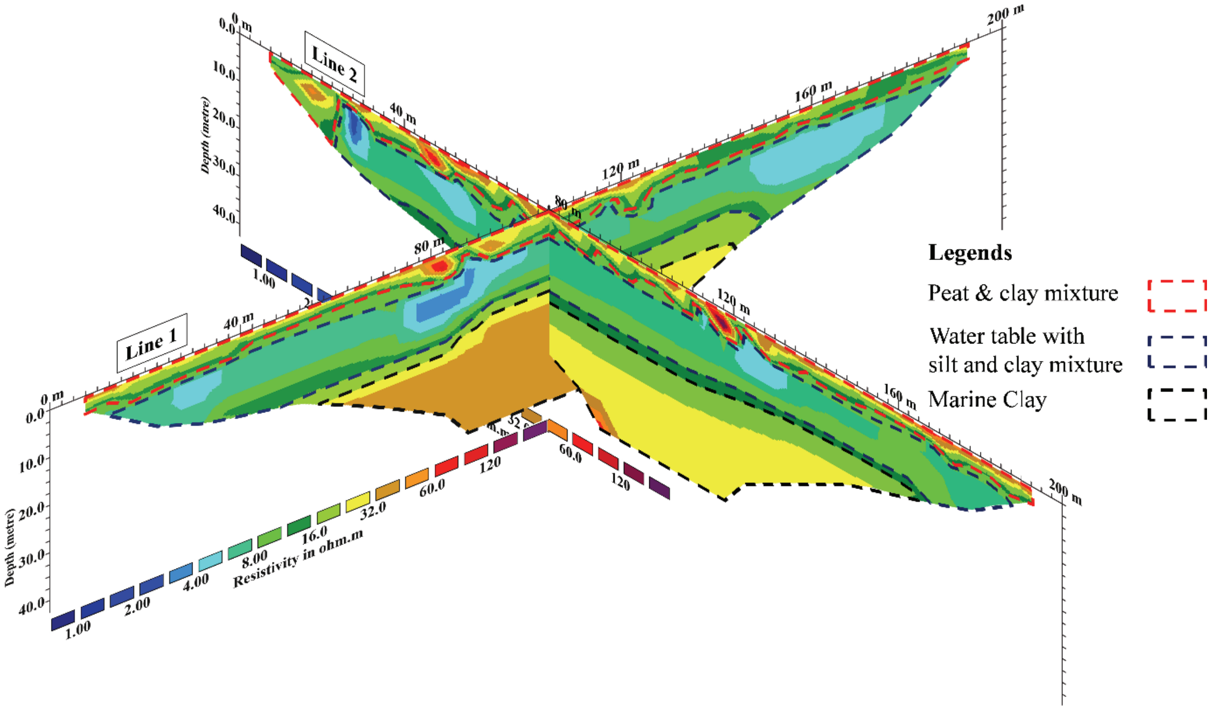

Figure 10 Intersection of electrical resistivity survey Line 1 and Line 2

from borehole data and inversion electrical resistivity profiles assumed that the higher resistivity value (24 Ωm to 46 Ωm) of the third layer composed of marine clay starts from 16 m to 20 m depth from the ground surface. For Line 3, the profile can be correlated with the other profiles where all the three layers can be identified based on resistivity contrast. However, the layers' resistivity ranges are slightly different from Line 1 and Line 2, probably due to groundwater variation in that area. An intersection between survey Line 1 and Line 2 is established to get a correlation and data quality control of both sections, as shown in Figure 10.

CONCLUSION

A comprehensive foundation study needs to be conducted prior to any development, especially when considering the unstable soil conditions like the peat layer's presence. Electrical resistivity imaging (ERI) is one of the best geophysical techniques that can be applied to evaluate the subsurface conditions. The electrical resistivity images show similar stratigraphy layering with resistivity values ranging from 1 Ωm to 60 Ωm. The uppermost layer shows resistivity values ranging from 16 Ωm to 24 Ωm, representing a peat layer with a thickness up to 5 m. The second layer is a mixture of clay and organic matters associated with a water-saturated zone with a depth varies from 5 m to 20 m below the ground surface and has resistivity values ranging from 5 Ωm to 16 Ωm. The third layer at a depth of 20 m consists of marine clay that has resistivity values ranging from 16 Ωm to 46 Ωm. The peat layer has a von Post scale of H8, indicating a very strong degree of decomposition. The total organic content and moisture content of the peat layer recorded an average value of 73% and 352% respectively. This study has shown that the thickness of the peat layer from the borehole data and hand auger data matched with the electrical resistivity pseudo-section. In conclusion, this study is significant as it provides the subsurface conditions of Kuala Langat, Selangor to detect the depth and identify the thickness of the peat layer. This study can support the engineer's selection of site suitability and equipment for engineering construction.

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