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APPLICABILITY OF ELECTRICAL RESISTIVITY TOMOGRAPHY IN SUBSURFACE UTILITIES ENGINEERING

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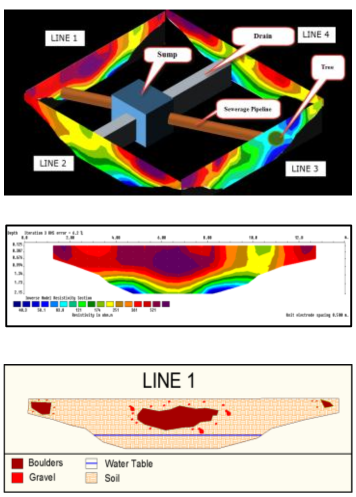
Graphical abstract



Abstract

This paper presents the applicability of Electrical Resistivity Tomography (ERT) in Subsurface Utilities Engineering (SUE). The objective is to use pseudosection generated by ERT to located known subsurface utilities. For construction industry, the investigation of subsurface utility is essential to avoid unforeseen condition that may cause project delay. According to the result, performing ERT using fundamental tester in this study is not suitable to locate subsurface utilities, however it can locate the loose part of the ground which likely to indicate the location of subsurface utilities. Therefore, ERT exhibits potential to be used before the actual subsurface utilities mapping to simplify the work of gathering information to locate the subsurface utilities accurately.

Keywords: Electrical resistivity tomography; subsurface utilities engineering

Abstrak

Kertas kerja ini adalah berkaitan kebolehgunaan Tomografi Kerintangan Elektrik (ERT) pada Kejuruteraan Utiliti Bawah Permukaan (SUE). Objektif kajian adalah untuk menggunakan seksyen pseudo yang dihasilkan oleh ERT bagi menentukan lokasi utiliti bawah tanah yang diketahui. Di dalam industri pembinaan, penyiasatan secara menyeluruh terhadap utiliti bawah permukaan adalah penting untuk mengelakkan keadaan yang tidak dijangkakan berlaku dan ini boleh menyebabkan kelewatan sesuatu projek. Hasil daripada kajian yang dijalankan, seksyen pseudo tidak memberikan nilai kerintangan yang unik untuk menentukan lokasi utiliti bawah tanah yang dicari, tetapi ia mampu mengesan tanah yang kurang padat di bahagian atas utiliti. Oleh itu, ERT berpotensi tinggi untuk digunakan sebelum projek pemetaan utiliti bawah tanah dijalankan, bagi memudahkan kerja ketika projek pemetaan yang sebenar dijalankan.

Kata kunci: Tomografi kerintangan elektrik; kejuruteraan utiliti bawah permukaan

1.0 INTRODUCTION

Subsurface Utility Engineering (SUE) is an engineering process that utilizes new and existing technologies to accurately identify, characterize, and map underground utilities early in the development of a project [1]. SUE will be the most reliable and suitable method for reducing risks associated with utilities damages due to uncertainty of the exact location of the underground utilities. There are many methods to be used for SUE. One of the commonly used subsurface geophysical method is Electrical Resistivity Tomography

(ERT) which yet to be used widely in SUE. ERT is sure to be a cheap and time efficiency method [2] to be used, if able, in SUE which will definitely save cost and further encourage SUE in the world.

The general principle of geophysical exploration is to collect data to predict the subsurface soil structure with non-intrusive method, which means in a way that does not intrude or disturb the survey site. Among the vast variety of methods, the ones that utilize the electric properties seem promising because soil materials and properties are strongly correlated [3]. ERT has been vastly used in soil science for the detection of root mass [3], detection of sinkholes [4], hydraulic redistribution [5], corrosion of pipeline [6], seepage in dykes and dam [7][8] and geological research [9][10][11], and subsurface contamination [12][13][14].

However, there are only few researches that apply ERT in searching subsurface utilities. Allred in his research to search buried agricultural drainage pipe with various physical methods assured that ERT is not effective in identifying subsurface man-made object [15]. However, the research was only done on pipeline and no other subsurface utilities. The methodology is not similar to the conventional ERT where pseudosection is generated but rather soil resistivity contour map that is based on the surface soil resistivity only and not the vertical soil section. Thus, because ERT has been vastly used in other area and almost all of the research is convinced that ERT is cheap, time efficient, and simple to carry out, it would be a new breakthrough if ERT can be used in subsurface utilities identification.

The main objective of the study is to investigate the applicability of Electrical Resistivity Tomography in Subsurface Utilities Engineering. The detail objectives are described as follows:

(i) To study Electrical Resistivity Tomography as a non-intrusive geophysical exploration method.
(ii) To investigate the way to acquire and process data using ECTR 3000B Soil Resistivity Tester.
(iii) To locate known subsurface utilities using Electrical Resistivity Tomography via pseudosections generated by RES2DINV.

2.0 SUBSURFACE UTILITIES ENGINEERING

Subsurface Utilities Engineering (SUE) has acquired relevance in the nowadays civilization in mapping existing subsurface utilities. In an urban area, the inability to obtain reliable underground utility information has long been a problem for high way construction, utilities relocation, and other construction project. An appropriate use of Subsurface Utility Engineering will help to avoid unnecessary utility relocations. Utility relocations will reduce the overall project cost and possibility of project delays. As Subsurface Utilities Mapping is a preliminary work to reduce the cost of the actual project, it is important to reduce the cost and time as much as possible in mapping accurately the utilities beneath the ground. As such is the case, ERT is the method that is suitable for this task as it is both cheaper and fast in comparison to other geophysical method [2]. Moreover, if ERT is suitable for SUE, thus not only ERT is able to map the subsurface utilities but at the same time identify the subsurface profile beneath the ground. Thus, if it prove to be via mean for SUE, thus it will great contribution to SUE in lower the cost of SUE and coinciding SUE with preliminary geotechnical investigation, it would promote the usage of SUE and lower the overall cost of a construction project.

3.0 ELECTRICAL RESISTIVITY TOMOGRAPHY

Electrical Resistivity Tomography (ERT) is a geophysical technique for imaging subsurface structure from electrical resistivity measurements, made at the surface, or by electrodes. ERT utilizes direct current method. Early work on mathematical problem in the 1930s had an assumption that there is a medium which is layered. Tikhonov [16] is well-known in the history of ERT because of his work on regularization of inverse problems. He has an explanation to solve the ERT problem as successfully discovered a large deposits of copper in 1940s.

With the advancement in the field of ERT, alongside with the advancement of computer technology, ERT problem can be solved numerically, which Loke and Barker pioneered and still is widely used [14]. As ERT advances forwards alongside technology, now ERT one dimension (1D), two dimension (2D), and even three dimension (3D) can be easy generated and for this reason, ERT has explored many fields. Nowadays, ERT is used for fault investigation [10], ground water table investigation [17][18], soil moisture content [19] and many others.

ERT, in short, utilizes the measured resistivity values to generate numerically a model that has similar resistivity distribution as the actual field resistivity via least square inversion method. Thus field resistivity data is essential for this method. The field resistivity data can be measured using soil resistivity tester. This statement is also agreed by Dahlin in his paper on comparison of different array and summarized that Wenner array will offer best-resolved-images in some occasion with its high anomaly effect and low noise contamination [20] [21][22].

Allred [15] and his fellow researchers conducted a study to detect the buried agricultural drainage pipe with geophysical methods and one of it is the Electrical Resistivity Tomography. However, Allred did conclude that Electrical Resistivity Tomography is not efficient to locate subsurface utilities. However, the weakness of his methodology is that this study utilized dipole-dipole array, which has low efficiency in identifying vertical and horizontal changes [23].

In this study, the contour map of plan view resistivity value rather than the conventional pseudosection used by RES2DINV, which shows the vertical section of the resistivity survey line at that particular area. Various researchers have already agreed on the applicability of Electrical Resistivity Tomography in detecting sink holes [4], detection of seepage in dykes and dam [7][24] and countless other application which yields result. Thus this method is promising in the detection of the subsurface utilities as it is relatively cheap and fast in the process of acquiring and processing the data to become a pseudosection from RES2DINV.

4.0 DATA ACQUISITION, PROCESSING, AND ANALYSIS

The study site is located at Kolej Tun Hussein Onn, Universiti Teknologi Malaysia Skudai in the state of Johor of Malaysia with coordinate N 1°33'48" E 103°37'57". The location was chosen because there are two known subsurface utilities in this area: the covered monsoon drain and also the subsurface sewerage pipeline. Thus it is designed that there will be two line of resistivity survey to cross the same utility so as to confirm the pseudosection of other parallel line. Thus there will be four-resistivity survey line in the study area, forming a rectangular as shown in Figure 1.

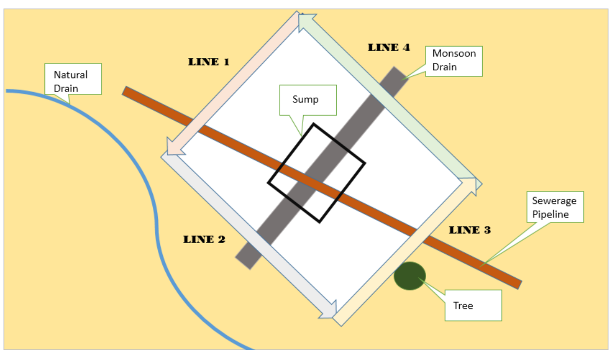


Figure 1 Plan view of the survey site.

The main equipment used in this study is ECTR 3000B Soil Resistivity Tester. This tester is used to measure the resistivity value of the soil. Along with four wires and four electrodes which are needed to be used along the tester.

Based on the above plan view, LINE 1 and LINE 2 crosses the sewerage pipeline while LINE 2 and LINE 4 crosses the subsurface monsoon drain. The length of LINE 1 and LINE 3 are 14 m while LINE 2 and LINE 4 are 16m. The sump located near to the center of the survey area. Also, the natural drain exist 1m from LINE 2 to indicate the location of water table of the area.

For each of the ERT line, four electrodes are punch into the soil with 1m apart of each electrode. After the first set of resistivity data was taken and recorded using a notebook, the electrodes is moved to the right hand side with 1m step and the resistivity data is recorded again. The processes continue until the end of the ERT survey line. The process is repeated by increasing the distance of each electrode to 2m, 3m, 4m, and 5m consecutively.

The acquired data were processed with RES2DINV program developed by Loke and Barker [14]. RES2DINV will able to generate the pseudosection as above. By reading the DAT file generated from Notepad, RES2DINV is able to use the resistivity value from the DAT files, and then use least-square inversion technique to model the pseudosection, which nominally represent the subsurface beneath the ERT survey line. The three pseudosections are the iteration taken to model the pseudosection.

RES2DINV utilizes the inverse problem theory, which find a model that give a response similar to the actual meaured values acquired at the field. The model is an idealized representation of the secton of the earth under the ERT survey line. A set of model parameters that are also physical quantities we want to estimate the observed data. Thus, a two dimensional inversion of a geophysical data set results in a model or resistivity characteristic of the subsurface structure. The inversion method used in RES2DINV is smoothness constrained least square method. Root Mean Square Error (RMS) in the result of inversion shows the difference between measured resistivity and calculated resistivity of the model. The best model is not necessary the model with lowest RMS as it may be unrealistic [23].

5.0 RESULTS AND INTERPRETATION

Pseudosections are generated from RES2DINV based on the data recorded using the tester. Based from the raw data gathered from the field, it is then arranged in DAT data file format, readable by RES2DINV to generate the following pseusosection which shows the resistivity distribution of the field. There are four lines of resistivity data gathered from the field.

a) b)

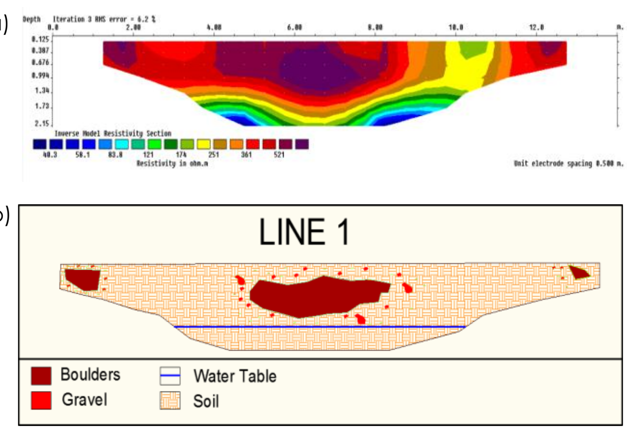


Figure 2 Subsurface profile of LINE 1
a) Pseudosection b) Predicted

LINE 1 is the first line of resistivity data taken from the field and its orientation is as Figure 1. The sewerage pipeline crosses underneath Line 1 and the section is used to investigate the ability of resistivity survey in identifying the pipeline.

The pseudosection in Figure 2 shown remarkably high resistivity under the surface. The red and purple area has the range of resistivity from 361Ωm to 521Ωm or more. In this case, as proved by Loke [25] also that the higher the resistivity, the harder the material under the subsurface. However, based on this pseudosection, there is no clear disturbance from 4m to 6m of the pseudosection to show the existence of the sewerage pipeline.

Based on the location of manhole, the direction and lateral location of the pipeline can be estimated and it is estimated to be in between 4m and 5m of the pseudosection. But there is no clear indication in the pseudosection that allows the research to identify the existence of the sewerage pipeline. Thus, ERT failed to identify the existence of sewerage pipeline for this pseudosection. The findings for this section is consistent with the finding of Sass, Bell, and Glade that stated that resistivity failed to identify the location of subsurface utilities accurately [24].

In Figure 2 also shows the predicted subsurface profile based on the pseudosection of LINE 1. The area with high resistivity in the pseudosection is likely to be boulders as boulders and other natural geological material has high resistivity according to Loke [25] whom also suggest that subsurface water has resistivity below 100Ωm. Thus based on the pseudosection, the possible depth of the water table is drawn.

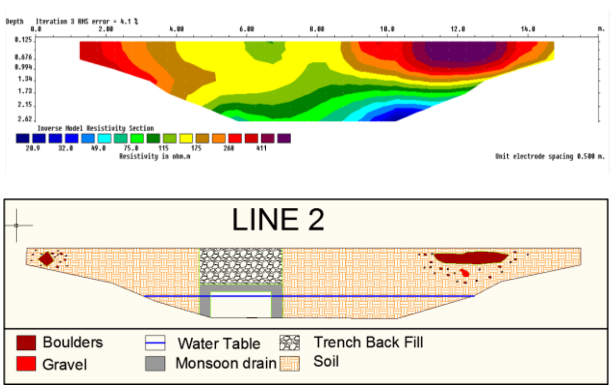
a)
b)


Figure 3 Subsurface profile of LINE 2
a) Pseudosection b) Predicted

LINE 2 is the second line of resistivity data taken from the field and its orientation as shown in Figure 3. The monsoon drain crosses underneath Line 2 and the section is used to investigate the ability of resistivity survey in identifying the monsoon drain, which is buried underneath the surface. This line of resistivity data is also near and parallel to the edge of the ground and natural drain.

Based the pseudosection in Figure 3, the subsurface profile is consistent with LINE 1 because of the existence of high resistivity area which can be indicated as hard rock or boulders. However, differing from the previous pseudosection, the area range from 4m to 9m indicates the low resistivity area. The oddity of this section is noticed as both end of the section is covered with hard resistivity but the resistivity becomes less as the section approaches 6m.

The location of the monsoon drain is also at the location of 6m of the ERT LINE 2. Although there is no clear indication of the shape of the drain at this area based the pseudosection generated by RES2DINV, nevertheless it shows that the monsoon drain is actually a disturbance for the pseudosection. This disturbance can be explained using the logic of how the monsoon drain is constructed.

The construction of the monsoon drain is as the above figure where they will be trench backfill. Compared to undisturbed soil, trench backfill has a more loosen soil and an area of loose soil can be identified with a lower resistivity compared to the surrounding soil [6]. Thus in this case, ERT can identified the trace of construction based on the soil construction. Although via this means, we can make assumption of the location of subsurface utilities and using other method to identify it more accurately, however, ERT in itself is not suitable to the task of identifying subsurface utilities as a standalone method as mention in Standard Guideline for the Collection and Depiction of Existing Subsurface Utility published by American Society of Civil Engineers [1].

Based on the pseudosection, the possible location of the monsoon drain is located. Also, within the pseudosection, the left most and right most area shows high resistivity, thus it is suggested that it is likely a small boulders. The size of the boulders is estimated based the pseudosection.

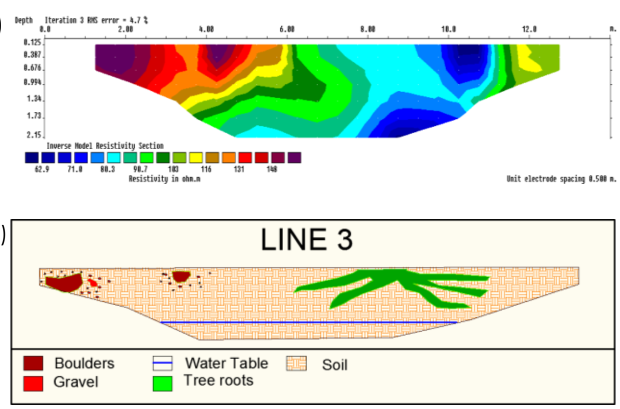
a)
b)


Figure 4 Subsurface profile of LINE 3
a) Pseudosection b) Predicted

LINE 3 shown in Figure 4 is the third line of resistivity data taken from the field and its orientation is as Figure 1. The sewerage pipeline that crosses underneath LINE 1 crosses this line as well. This section is used to investigate the ability of resistivity survey in identifying the sewerage pipeline, which is buried underneath the surface and also as a crosscheck if LINE 1 shows ability to identify the sewerage pipeline. Although parallel to LINE 1 with separation width 16m, there is a tree that located 0.30m from the resistivity line.

Although LINE 3 and LINE 1 are parallel, the difference of the distribution of the resistivity value is very large. The maximum resistivity range of the area is 148Ωm or higher compared to LINE 1 having the maximum resistivity range of 521Ωm or higher. Also, there is no significant disturbance in the pseudosection to indicate the identification of the sewerage pipeline, which approximately located at the 7m. Once again the pseudosection failed to recognize the existence of the sewerage pipeline as suggested by Sass, Bell, and Glade [24].

Aside from the identification of the subsurface utilities, which this method failed, however there is an explanation for the differing distribution which is mainly due to the tree root of the tree near the resistivity line. The electrical resistivity variation is likely influence by the moisture dynamic of the subsurface. The moisture near to the tree root is more stable compared to the non-tree root area. Thus the higher content of moisture around the tree root influence the resistivity of the soil of tree root area and non-tree root area causing the tree root area the whole pseudosection to be affected by the existence of tree root, thus having lower resistivity compared to other lines [5],[26].

All in all, this LINE failed to identify the existence of the sewerage pipeline but however, it is able to testify that the tree roots bears effect to the resistivity of the subsurface and likely to influence it. LINE 3 identified an area of very low resistivity under the surface, which is caused by the existence of tree roots. As explained earlier in this section, tree roots is within the area of low resistivity while the water table is estimated based on the resistivity of the pseudosection as a whole.

a)

b)

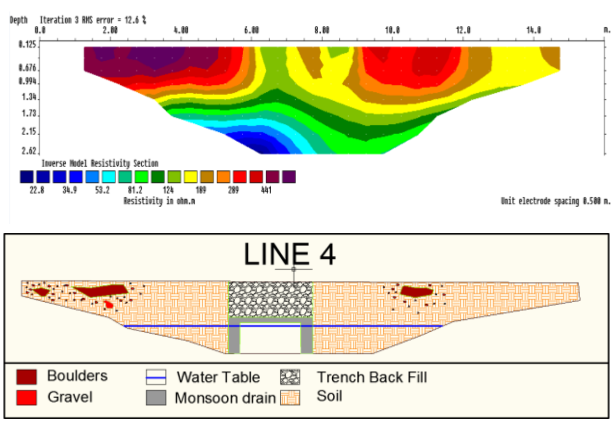


Figure 5 Subsurface profile of LINE 4
a) Pseudosection of LINE 4. b) Predicted

LINE 4 as shown in Figure 5 is the fourth and last line of resistivity data taken from the field and its orientation is as Figure 1. The monsoon drain that crosses underneath LINE 2 crosses this line as well. This section is used to investigate the ability of ERT in identifying the monsoon drain, which is buried underneath the surface and also as a crosscheck if LINE 2 shows ability to identify the sewerage pipeline. LINE 4 is parallel to LINE 2 with separation width 14 m.

Based on the pseudosection, LINE 4 is similar to LINE 2 because both of this resistivity survey line crosses the subsurface monsoon drain. Thus the location of the monsoon drain, along with the trench back fill is predicted. There are three boulders are identified throughout the section, and also the depth of the water table based on the pseudosection.

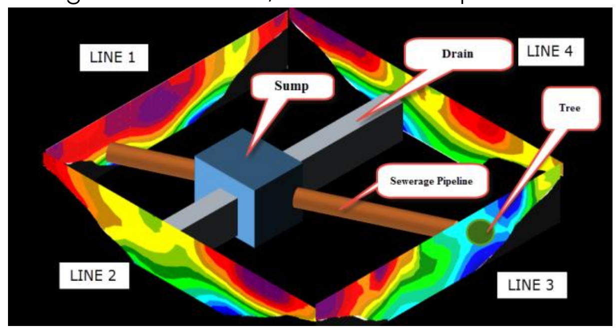


Figure 6 3-D view of the subsurface condition and the respective pseudosection of the different line.

The consistency of the resistivity of the soil is verified with the graph plot of the percentage of area of resistivity based on the pseudosections of four lines. The graphs are plotted using Percentage of the resistivity against the range of resistivity. Initially, by using AutoCAD, the area of pseudosection according to the range of resistivity can be calculated. Based on the area, the percentage is calculated for the analysis. This analysis is used to cross check the result obtained by lines of resistivity data in Figure 6.

Based on the Table 1, higher percentile of the resistivity distribution is above 361Ωm, which show that the soil is relatively unweathered and compact. Based on the observation of the surface, the soil is classified as stony ground. Most of soil with laterite component will have resistivity higher than 100Ωm, showing that the soil is relatively hard and comprise of high percentage of pebble which weathered from boulder identified from the pseudosection LINE 1 [25].

For the graph of LINE 2, almost half of area of the pseudosection area comprised of resistivity range in between 115 Ωm and 268 Ωm which indicates higher percentile of the soil is loose soil which consistent from the inference by [6]. The soil is loose due to the construction of monsoon drain, which in the process excavated undisturbed soil and later back fill the soil back after the construction of the drain. These events however loosen the soil thus contributing to the high percentile of soil having lower resistivity than that of the LINE 1 [7],[27].

For LINE 3, which is parallel to LINE 1, however it is not as expected. The graph for LINE 3 is expected to have distribution similar to LINE 1 as both of the line are parallel to each other and is just 16m apart where the subsurface profile have not deviated much unless there is any sudden change [28]. Also the higher percentage of the soil at low resistivity range due to the existence of tree nearby the resistivity line.

Tree roots has the ability to retain water before the water seep to the nearest flowing water. Also, moisture level will greatly influence the resistivity because the presences of moisture in soil reduce the resistance for current to traverse through the subsurface soil [3][5][29]. Thus if the resistivity data is taken near to the tree, the data will be influence by the existence of tree root underground.

The shape of the distribution graph of LINE 2 and LINE 4 are almost identical. This graph obviously have higher percentile of soil having lower resistivity, which is in between 124Ωm and 289Ωm. The subsurface monsoon drain crosses this line of resistivity data at almost 90 degree. The higher percentile of area with lower resistivity is due to the loose soil about the monsoon drain. The soil, which undergoes trench backfill, will be looser than the undisturbed soil surrounding it. This is consistent with the findings by Chinedu where loose soils have lower resistivity [7].

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Table 1 Percentage of resistivity from all lines

Percentage of Resistivity (%)							
Resistivity, *r*	**LINE 1 (%)**	**Resistivity, *r***	**LINE 2 (%)**	**Resistivity, *r***	**LINE 3(%)**	**Resistivity, *r***	**LINE 4 (%)**
0 to <121	5.9	0 to <115	22.5	0 to <116	77.3	0 to <124	25.3
>121 to <251	21.7	>115 to <268	56.6	>116 to <148	19.3	>124 to <289	48.3
>251 to <361	15.7	>268 to <411	13.0	>148	3.5	>289 to <411	16.6
>361 to <521	29.8	>411	7.9			>411	9.7
>521	26.9						

Based on the observation of the surface, the soil is classified as stony ground. From Loke [23], most of soil with laterite component will have resistivity higher than 100Ωm, showing that the soil is relatively hard and comprise of high percentage of pebble, which weathered from boulder identified from the pseudosection LINE 1.

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6.0 CONCLUSION

Based on the study work performed, the following conclusions were obtained:

1. From literature review that has been studied, ERT has been found very suitable for such kind of non-intrusive geophysical studies. ERT vastly used in other area and almost all of the research is convinced that ERT is cheap, time efficient, and simple to carry out. Beside that, it also can be used in subsurface utilities identification.
2. ECTR 3000B Soil Resistivity Tester should not be used as standalone method to determine subsurface soil structure as well as subsurface utilities. However, it is highly recommended by researcher to be used as the preliminary investigation to locate the location which is

suitable to get maximum information about the subsurface structure and object.

3. From the pseudosection results generated from RES2DINV, the ERT as a singular method is inaccurate to map subsurface utilities because of its lack of precision from the resistivity tester in searching and locating the subsurface utilities and the resistivity data likely to be influenced by natural object like the tree root.

As a whole, based on the predicted subsurface profile of the area, it is obvious that the study area comprises of many boulders. Thus, the soil is possibly the weathered rock from all these boulders which allows the researcher to infer that this area has a stable soil with high soil strength parameter. The location of the water table is consistent in each of the pseudosection. The slight difference of the water table is due to the slope at the survey area.

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