Investigation of Soft Layer in between Hard Layer for Sedimentary Rock Formation by using Electrical Resistivity Analysis

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Abstract. This study aims to predict the occurrences of soft layers in between hard layers in sedimentary rock formation based on electrical resistivity analysis. ABEM Terrameter LS Box with 40 electrodes with 2.5 meters spacing in pole-dipole method was used. Standard Penetration Test (SPT) was conducted to obtain the value for the number of blows (N-value). RES2DINV was used to analyse a two-dimensional illustration of the soil layers in the pseudo section diagram. Results show that the groundwater table is located 2.0 meters below the ground surface. Based on the resistivity analysis, the subsurface profile is consists of topsoil, soft silty clay (N0-N4, 6 > Ω > 20 ohm), medium-stiff silty clay (N5-N6, 20<Ω<360 ohm), medium dense coarse sands (N13-N16, 361<Ω<550 ohm), stiff silty clay (N10-N18, 550<Ω<720 ohm), hard silty clay and gravel (N50, 720<Ω<1100 ohm), and moderate weathered and slightly fractured shale stone (N50, Ω<1100 ohm). Although the correlation between resistivity values and SPT N-values shows a very good relationship with R^2 ranges from 0.83 to 0.89, electrical resistivity analysis is not suitable to determine the soft layer in between hard layer in a sedimentary rock formation due to the presence of high ground water table.

1. Introduction
Time and cost are two main components to fuel a construction. In this modern development, developers are eager to finish construction within its completion period. Therefore, any problems arise need to be resolve immediately [1]. Subsurface exploration or Soil Investigation (SI) is used to analyse earth’s subsurface materials by identifying physical properties of embedded soil layers. This information is crucial as it is needed in the preliminary stage of a construction where the values are used in designing, planning and construction of structures [1]. Tropical climate can affect severely to engineering structures as weathering process of rocks occurred at its most extreme rate in hot and wet climate [2]. This condition can trigger weathering process to extent to deeper depth in soil. Rocks that disintegrate will become sedimentary rock, therefore existence, distribution and location of sedimentary rocks below soil surface is best to be identified at early stages of a construction stage [3].
This study is performed due to existence of soft layers between hard layers in sedimentary rock formation that are difficult to be detected by using conventional method such as borehole. Borehole involves higher expenditures as it requires more workers to conduct the test. Furthermore, there is no sustainability approaches in performing borehole as it damages the site such as soil erosion and soil pollution [4]. Conventional method also only considered one dimensional view. By applying electrical resistivity method, underground profile can be seen in two dimensional profiles with larger area and lower cost. Pole - dipole array via electrical resistivity technique is used to conduct field study for sedimentary rock formation. By combining borehole data and resistivity analysis, this study would be able to predict the distribution of soft and hard layers on site. Then, correlation between SPT - value and resistivity 2D pseudo sections can be produced. Hence by conducting this research, investigation of soft layer between hard layers below ground surface can be predicted as well as better understanding of the soil characteristics.

2. Geological setting
This study was conducted at geological site in Mersing, Johor Bharu, which is located at southeast of Peninsular Malaysia. The site is selected due to the occurrences of sedimentary rock with formation of soft and hard layer. Figure 1(a) shows geological map of the study area [5]. Figure 1(b) shows the geological map of Mersing based on [6]. The geological formation of the study area is classified as soil type Permian (20) and Carboniferous which are composed of phyllite, shale and slate with subordinate schist and sandstone.

![Figure 1. (a) Geological Map of Peninsular Malaysia [5], and (b) Geological Map of Mersing [6]](image)

3. Research method
3.1. Layout and field testing
Arrangements of four resistivity lines on the site studied denoted as RL1, RL2, RL3 and RL4 that are analysed in this study is shown in Figure 2(a). The distance of RL1 and RL2 is 50 meters and parallel to each other. The distance of RL3 and RL4 is 25 meters and also parallel to each other. Three boreholes were drilled with depth up to 30 meters, located at BH1, BH2 and BH3.
ABEM Terrameter LS Box was used for onsite measurement. This field study also includes 40 stainless steel electrodes, hammer, cable connectors, 1 unit of battery and 4 units of electric cables. Onsite resistivity line length was 100 meters and electrodes spacing was 2.5 meters. Figure 2(b) shows equipment for resistivity electrical field study. Electrodes is generally probed into ground along a straight line. Electric wave is launched by probing two current electrodes into the ground and...
will produce pseudo section diagram as its analysis [7]. Then, calculation of difference between the two potential electrodes is produced. These calculations are then converted to apparent resistivity (ohms) by taking electrodes configurations into account [1].

For this study, pole – dipole array arrangement was used as shown in Figure 2(c). Pole – dipole array consists of two potential and current electrodes arranged in a straight line [8]. Pole – dipole array offers deeper penetration and better underground resolution even though the survey line is shorter than other arrays [9]. A study by [10] also reveals that the depth of penetration is more sensitive and its responses for near – surface readings can be as high as 400 meters over the proposed site area. Pole – dipole has higher and uniform lateral sensitivity which means it improves resolution includes resolution between lines.

![Figure 2. (a) Site Map for Resistivity Lines, (b) Electrical resistivity equipment for field study and (c) Onsite configuration of pole-dipole array](image)

3.2. Interpretation of data using RES2DINV software

Resistivity raw data obtained from site analysis using equipment such as Terrameter SAS 1000 is interpreted in DAT data file format and analysed using computer software RES2DINV to view and have a better understanding of the result in 2D [11]. The pseudo section diagram produced would display the resistivity distribution of the site [11]. Resistivity values ranges differently and overlaps. It cannot be directly pointed to a specific type of rock or soil [12]. 2D pseudo section appeared in a multi – colour diagram. The colours represent different weathering grade. According to [13], materials which are harder emits higher resistivity values. Hence, darker colours in the pseudo section represent lower weathering grade material and lighter colours represent higher weathering grade material.

4. Results and Discussions

The resistivity raw data was analysed using RES2DINV software. This analysis test was conducted to study the presence of a hard layer between soft layers in the specified area. There are three boreholes
located linearly with resistivity line. The borehole log data were studied and analysed to correlate with resistivity analysis findings.

4.1. Borehole log data
There are three boreholes on site that are prepared by Alur Bina Sdn Bhd. These boreholes are situated along resistivity lines with depth up to 30 meters. Interpretation of borehole data according to its depth and classification of the layer are tabulated in Table 1 to 3.

Table 1. Interpretation of Borehole 1 Data

| Borehole 1 | Description               | Depth (meters) | N - Value | Resistivity Value (ohm) |
|------------|---------------------------|----------------|-----------|------------------------|
| Topsoil    | 0.00 to 0.30              |                |           | 80 – 720               |
| Stiff Silty Clay | 1.50 to 1.95           | 10             | 80 – 360  |
| Soft Silty Clay     | 3.0 to 6.95             | 0 – 1          | 1.0 – 5.0 |
| Medium Stiff Silty Clay | 7.5 to 7.95     | 6              | 1.0 – 5.0 |
| Stiff Silty Clay     | 9.00 to 9.45            | 10             | 1.0 – 5.0 |
| Hard Silty Clay and Gravel | 10.50 to 30.00 | 30 to 50   | 20 – 1100 |

Table 1 shows the interpretation of SPT obtained from borehole 1. There are six layers of soil and each layer is different in terms of resistivity values and N-values. The first layer of soil is topsoil with a depth of 0 meters to 0.30 meters and resistivity values ranges from 80 ohms to 720 ohms. The second layer of soil with depth from 1.50 meters to 1.95 meters, is identified as stiff silty clay. N-value obtained is N10 and resistivity values ranges from 80 ohms to 360 ohms. The third layer of soil with depth from 3.0 meters to 6.95 meters is identified as soft silty clay with SPT N0-N1 and resistivity values range from 1.0 ohms to 5.0 ohms. The fourth layer is medium stiff silty clay with depth from 7.5 meters to 7.95 meters. Its N-value is N6 and corresponding resistivity values are 1.0 ohms to 5.0 ohms. Stiff silty clay is the fifth soil layer is identified in borehole 1 with depth from 9.0 meters to 9.45 meters. Its N-value is N10 and resistivity values ranges from 1.0 ohms to 5.0 ohms. The sixth layer of soil is as identified hard silty clay and gravel is located at 10.50 meters to 30.00 meters. Its N-values are from N30-N50 and its corresponding resistivity values ranges from 20 ohms to 1100 ohms. Table 2 shows the interpretation of SPT obtained from borehole 2.

Based on Figure 2, there are seven layers of soil and each layer is different in terms of resistivity values and N-values. The first layer of soil is topsoil with a depth of 0 meters to 0.30 meters and resistivity values range from 80 ohms to 360 ohms. The second layer of soil with depth from 1.50 meters to 1.95 meters, is identified as stiff silty clay. N-value obtained is N18 and resistivity values ranges from 80 ohms to 360 ohms. The third layer of soil with depth from 3.0 meters to 4.95 meters is identified as medium stiff silty clay with SPT N5-N6 and resistivity values ranges from 20.0 ohms to 80.0 ohms. Fourth layer is soft stiff silty clay with depth from 6.0 meters to 8.0 meters. Its N-value is
N3 and corresponding resistivity value is 20.0 ohms to 80.0 ohms. Medium stiff silty clay is the fifth soil layer is identified in borehole 2 with depth from 8.0 meters to 8.45 meters. It’s N-value is N8 and resistivity values range from 20.0 ohms to 80.0 ohms. The sixth layer of soil is identified as medium dense coarse sands are located at 9.00 meters to 10.95 meters. Its N-values are from N13-N16 and its corresponding resistivity values range from 80 ohms to 360 ohms. Seventh layer is identified as hard silty clay and gravel is located at 12.0 meters to 30.0 meters with N-values ranges from N32-N50. Its resistivity values are from 80 ohms to 360 ohms. The interpretation of SPT obtained from borehole 3 can be seen in Table 3.

**Table 2. Interpretation of Borehole 2 Data**

| Borehole 2 | Description                  | Depth (meters) | N - Value | Resistivity Value (ohm) |
|------------|------------------------------|----------------|-----------|-------------------------|
|            | Topsoil                      | 0.00 to 0.30   |           | 80 – 360                |
|            | Stiff Silty Clay             | 1.50 to 1.95   | 18        | 80 – 360                |
|            | Medium Stiff Silty Clay      | 3.00 to 4.95   | 5 - 6     | 20 – 80                 |
|            | Soft Silty Clay              | 6.00 to 8.00   | 3         | 20 – 80                 |
|            | Medium Stiff Silty Clay      | 8.00 to 8.45   | 8         | 20 – 80                 |
|            | Medium Dense Coarse Sands    | 9.00 to 10.95  | 13 - 16   | 80 – 360                |
|            | Hard Silty Clay and Gravel   | 12.00 to 30.00 | 32 – 50   | 80 – 360                |

**Table 3. Interpretation of Borehole 3 Data**

| Borehole 3 | Depth (meters) | N - Value | Resistivity Value (ohm) |
|------------|----------------|-----------|-------------------------|
|            | Topsoil        | 0.00 to 0.30 |           | 80 – 360                |
|            | Stiff Silty Clay | 1.50 to 1.95 | 13       | 80 – 360                |
|            | Soft Silty Clay | 3.00 to 7.95 | 1 – 4   | 1.0 – 5.0               |
|            | Hard Silty Clay and Gravel | 9.00 to 10.85 | 50   | 20 – 80                 |
|            | Stiff Silty Clay | 12.00 to 12.45 | 21   | 20 – 80                 |
|            | Hard Silty Clay | 16.50 to 21.40 | 50   | 80 – 550                |
|            | Moderare weathered and slightly fractured shale stone | 24.00 to 25.50 | 50 | 550 – 1100 |
Based on Figure 3, there are seven layers of soil and each layer is different in terms of resistivity values and N-values. First layer of soil is topsoil with depth of 0 meters to 0.30 meters and resistivity values ranges from 80 ohms to 360 ohms. Second layer of soil with depth from 1.50 meters to 1.95 meters, is identified as stiff silty clay. N-value obtained is N13 and resistivity values ranges from 80 ohms to 360 ohms. Third layer of soil with depth from 3.0 meters to 7.95 meters is identified as soft silty clay with SPT N1 – N4 and resistivity values ranges from 1.0 ohms to 5.0 ohms. Fourth layer is hard silty clay and gravel with depth from 9.0 meters to 10.85 meters. Its N-value is N50 and corresponding resistivity values is 20.0 ohms to 80.0 ohms. Stiff silty clay is the fifth soil layer is identified in borehole 3 with depth from 12.0 meters to 12.45 meters. Its N – value N21 and resistivity values ranges from 20.0 ohms to 80.0 ohms. The sixth layer of soil is identified hard silty clay and gravel is located at 16.50 meters to 21.40 meters. Its N-value is N50 and its corresponding resistivity values ranges from 80 ohms to 550 ohms. Seventh layer is identified as moderately weathered and slightly fractured shale stones are located at 24.0 meters to 25.50 meters with N-value is N50. Its resistivity values are from 550 ohms to 1100 ohms.

4.2. Resistivity 2D pseudosection
Based on site analysis, three resistivity lines were assessed along with three boreholes. No boulders were found embedded along resistivity line. Site investigation (S.I) report revealed that the site contained interbedded shale layer.

The layers that were found on Figure 3 shows 2D pseudosection for resistivity line 1. Based on borehole data, depth 0 meters to 13.95 meters consist of soft layers as N-value ranges from 0 to 30. This indicates the hammer encounter soft layer of the soil and this can be verified by low resistivity value. As the borehole penetrate deeper into the ground from 15 meters to 30 meters, its N-values stay constant at 50 which means it has encountered hard layer and the hammer could not blow more than 50 blows. This result is consistent as reported by [14]. This data is also shown in resistivity value where it ranges from 20ohm metres to 1100ohm metres.

![Figure 3. 2D Pseudo section for Resistivity Line 1](image)

Figure 4 shows pseudo section for RL 2. It can be shown from depth of 0 meters to 12.45 meters borehole encountered soft layer and this can be seen in low resistivity values that ranges from 1.0ohm meters to 20 ohms meters. Depth 13.5 meters to 30m obtained constant N – value of 50 which means hard layer. This can be correlated with higher resistivity value from 80ohm meters to 1100 meters.
Figure 4. 2D Pseudo section for Resistivity Line 2

Figure 5 shows 2D pseudo section for RL 3. For RL 3, from depth 0 meters to 7.95 meters is soft layer with resistivity values from 1.0ohm meters to 5.0ohm meters. N-value of 50 starts to be constant at depth of 15 meters to 30 meters with resistivity values of 80ohm meters to 1100ohm meters.

Figure 5. 2D Pseudo section for Resistivity Line 3

Figure 6 shows 2D pseudo section for RL 4. For BH3 in RL4, from depth 0 meters to 7.95 meters is soft layer with resistivity values from 1.0 ohm meters to 5.0 ohm meters. N-value of 50 starts to be constant at depth of 9 meters to 25.50 meters with resistivity values of 20 ohm meters to 1100 ohm meters and encounter soft layer are 12 meters to 12.45 meters. N50 is achieved again at depth 13.50 meters to 25.50 meters. Site possesses high resistivity values with values over 1000 ohm.

Figure 6. 2D Pseudo section for Resistivity Line 4
4.3. Correlation of bore log data and resistivity values

There are four resistivity lines named RL 1, RL 2, RL 3 and RL 4. Figure 7 shows that the resistivity values for borehole 1 is increased proportionally with depth. Low resistivity values indicate soft layers that dominantly consist of clay, silt and sand. The SPT N-value is consistently increasing with depth as it passes through soft and hard layers. The soft layer has N-values ranges from 0 to 10. Medium stiff layers range from 6 to 10. Hard layers have N-values that ranges from 30 to 50.

Based on Figure 7, BH2 RL1 shows the resistivity values increase linearly with depth from 1.5 m to 15 m depth. SPT N-value is consistently increasing as it passes through soft and hard layers. No increment of SPT-N values was found for both BH for depth more than 15 m. Borehole 2 started with very stiff layers with N-value of 18 then it hits soft layers with N-values of N3 at 6.0 meters to 8.0 meters. Low resistivity values indicate soft layers that dominantly consist of clay, silt and sand. This finding is in line with [15]. Medium stiff layers range from 8 to 16 with depth 8.45 meters to 10.95 meters. Hard layers have N-values that ranges from 32 to 50. The result shows that SPT N-value and electrical resistivity value (ohm) are significant with an approximate value of 0.7573.

Figure 8 shows the resistivity values for BH 1 RL 2 which is increases with depth. Low resistivity values indicate soft layers that dominantly consist of clay, silt and sand. Medium stiff layers ranges from 8 to 16 with depth 8.45 meters to 10.95 meters. SPT N-value consistently increases as it passes through soft and hard layers. No increment of SPT-N values was found for both BH for depth more than 15 m. Borehole 2 started with very stiff layers with N-value of 18 then it hits soft layers with N-values of N3 at 6.0 meters to 8.0 meters. Hard layers have N-values ranges from 32 to 50. The result shows that the correlation between depth to the SPT N-value and electrical resistivity value (ohm) is very significant with $R^2$ is 0.8048 and 0.919, respectively.

**Figure 7.** Correlation of resistivity values for BH1 RL1 and BH2 RL1
Figure 8. Correlation of resistivity values with BH1, RL2

Figure 9 for BH 3 RL 4 shows that resistivity values increase with depth but it hits soft layer which is located in between hard layers. SPT N-value is consistently changes as it passes through soft and hard layers. Borehole 3 started with stiff layers with N-values from 5 to 18 then it hits soft layers with N-values that ranges of N13 at 1.50 meters to 1.95 meters. Low resistivity values indicate soft layers that dominantly consist of clay, silt and sand. Soft layers ranges from 1 to 2 with depth 3.00 meters to 7.95 meters. This finding is consist as reported by [16]. Hard layers have N-values that ranges from 32 to 50 from 9.00 meters to 10.85 meters, but it hits stiff layers with N-value of 21 at 12 meters to 12.45 meters. At 15 meters to 28.50 meters, N-values are consistent at 50 with resistivity values ranges from 360 ohm to 1100 ohm. The result shows that the correlation between depth to the SPT N-value and electrical resistivity value (ohm) is very significant with $R^2$ is 0.6358 and 0.9194, respectively.

Figure 9. Correlation of resistivity values with BH3, RL4
5. Conclusion
Although the correlation between resistivity values and SPT N-values shows a very good relationship with R² ranges from 0.83 to 0.89, electrical resistivity analysis is not suitable to determine the soft layer in between the hard layer in sedimentary rock formation due to the presence of the high ground water table. This is because resistivity analysis cannot predict the actual hard and soft layer due to the saturated zone of soil profile. Ground water table is found at 2 meters depth and therefore, soil profile after 2 meters is saturated with water. This condition caused low resistivity for soil with high N – value and vice versa.

N-value showed different values according to soil type, while resistivity values increased with depth. Even though there is a low N-value in between high value such as in borehole 3 where N-value obtained is N50 at 9.00 meters to 10.85 meters in depth but at 12 meters to 12.45 meters depth, N – value obtained is N21. Then at 13.50 meters depth until 25.50 meters N-value obtained is N50. Resistivity values obtained increased with depth without showing any decrease to indicate a low N-value.

As water is a good conductor for electric current, when it hits a soft layer in borehole 3, its resistivity values keep increasing. It is supposed to show a low resistivity value. But due to the presence of water, its resistivity values shows no decrease. Hard layers discovered in this study are not considered as hard rock as water flows through its discontinuities and this condition increased resistivity values.

6. References

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