Correlation of Resistivity Value with Geotechnical N-Value of Sedimentary Area in Nusajaya, Johor, Malaysia

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Abstract. Electrical resistivity survey and the geotechnical SPT blow counts (N-value) were carried out simultaneously on the tropically weathered sedimentary rock mass for an excavation project at Nusajaya, Johor, Malaysia. This study aims to determine subsurface profile by using 2D-resistivity methods and correlate with N-value derived from boring works. Four boreholes were investigated in five survey lines that revealed the site is underlain by moderately to completely weathered sandstone, clay, silt and shale. Data analysis from 2D-resistivity image shows that zones with high resistivity value generally have high N-value, and vice versa. Five zones have inversed the proportional relation between N-value and resistivity Ωm value due to different types of soil lithology. It indicates that 2D-resistivity is significance to detect bodies of anomalous materials or estimating the depth of bedrock. As a conclusion, the integration of geophysical and geotechnical analysis provides a promise approach to understand some relationship concerning the subsurface ground through the combination of 2D-resistivity and N-value.

1. Introduction
In any engineering project, a comprehensive geotechnical assessment is required at the proposed site. This information can be acquired from the site investigation employing different type of technique, which are geophysical and geotechnical methods. In order to reduce the cost on site investigation, the geophysical surveys are widely applied to obtain the subsurface information for larger area [1]. When geotechnical assessment is conducted, there are many physical parameters entailed into consideration indicating their behaviour on the ground. As an important element to study the condition of core material, geophysical survey methods have been broadly adopted [2]. The characterization of in-situ soils is complex dependent upon several factors, hence it is essential to scrutinize the behaviour through different approaches such as geology, geomorphology, climatology and other earth and atmosphere related sciences for proper understanding [3]. Normally, drilling of exploratory holes to obtain subsurface materials for identification and laboratory analysis are the ultimate consideration by engineers for construction purpose. Moreover, Ako [4] believes that the integration of geophysical methods have becomes crucial in foundation studies, since geophysical methods provide subsurface
information at rational price. Therefore, a subsurface exploration should embrace surface geological survey, geophysical investigation and in situ engineering or laboratory tests.

In geotechnical studies, resistance of soil to penetration is vital information which can be used to evaluate the soil strength based on N-value from Standard Penetration Test (SPT). The SPT is known as an effective and direct method to analyse the soil stiffness [5]. But somehow, researcher has difficulty to accurately identify the soil strength as the changes in N-value from different type of soil is minimal [6]. Based on physics of electrical current flow on earth material, a relationship between the soil strength (N value) and resistivity value might be existed. However, resistivity is sensitive to fluid especially on salinity of saturating fluid whereas there is no connection with soil strength. Therefore, the relationship between resistivity and soil strength (N-value) is poor [7]. According to Kim et al. [8], resistivity survey is able to predict the water-saturated clay, which identified as a lower resistivity zone beside illustrated a change of apparent resistivity value with depth locally. Generally, low resistivity value is always assumed to be a high conductive zone, which reflects to be a weak zone and vice versa. Normally, humid tropical zone as Malaysia experienced high rainfall, often seasonal with high temperatures [9] Thus, weathering process is much progressive and causes the water content inconsistently present. The complexity of the subsurface composition, layers and geotechnical discontinuity sometimes comes out with unpredictably results from the electrical resistivity survey.

The main objective of this study is to determine the correlation in between electrical resistivity values with N value in order for good estimation of cost and time consuming in engineering field works for site investigation processes. In this study, four borehole data from the site were correlated with the resistivity data obtain from five survey lines. If resistivity value Ωm has positive correlation with the soil stiffness, therefore it should also show the same relation tendency with N value with the Ωm value [10]. Hence, N value from borehole data and the resistivity Ωm is interpreted with the soil properties as well. Finding of this work is quite encouraging in conducting more details investigate in order to establish more reliable relationships between resistivity and subsurface profiles.

2. Methodology

2.1 Resistivity

Electrical resistivity survey was selected to infer the ground subsurface; the locations of survey lines were decided on the existing borehole that has been done. Pole-Dipole array are used in this study because it has comparatively good horizontal coverage, significantly higher signal strength compared with the dipole-dipole array and it is not as sensitive to telluric noise as the pole-pole array. Different from other common arrays, the pole-dipole array is an asymmetrical array (Figure 1). Electrical Imaging System is carried out with a multi-electrode resistivity meter system. Such survey use a number (usually 25 to 100) of electrodes lay out in a straight line with a constant spacing. A computer-controlled system is then used to automatically select the active electrodes for each throughout the survey performed in the proposed site; the Pole-Dipole array has been used with the ABEM SAS4000 system. The data collected in the survey can interpret using an inexpensive microcomputer. Electrode Selector 10-64C is a four channel relay matrix switch, which connects to Terrameter SAS 4000. In additional, two resistivity cables, 41 stainless steel electrodes and 42 jumpers are used with Terrameter SAS4000 each time survey is done. Terrameter SAS400 and Electrode Selector were placed at the centre and connected to two resistivity cables. The arrangements for each resistivity profiles are given in Table 1.

![Figure 1. The pole-dipole arrays.][14]
### Table 1. Arrangement of all resistivity lines.

| Profile Name | Number of Station | Spacing (meter) | Profile Length (meter) |
|--------------|-------------------|-----------------|------------------------|
| SILC1        | 41                | 2               | 80                     |
| SILC2        | 41                | 2               | 80                     |
| SILC3        | 41                | 2               | 80                     |
| SILC4        | 41                | 2               | 80                     |
| SILC5        | 41                | 5               | 200                    |

Data obtained from each electrode is recorded by Terameter, ABEM SAS4000 then the measured data were inverted to resistivity image by RES2DINV software. RES2DINV can provide an inverse model that approximates the actual subsurface structure[11].

### 2.2 Study Location

The field studies are done at SiLC (Southern Industrial and Logistics Clusters) Nusajaya Johor which located at south-western tip of Peninsular Malaysia. The survey area is underlain by secondary rock indicated by red dot in Figure 2 which consists of sandstones, clay, silt and shale. The location of the survey profile is shows in Figure 2 and also displays the location of the four borehole sites (BH1, BH2, BH3, and BH4). In total, five resistivity profiles were surveyed namely SILC1 (BH1), SILC2 (BH2), SILC3 (BH3), SILC4 (BH3) and SILC5 (BH4). For two profiles on BH3, we made two survey lines perpendicular to each other double check of data quality and confidence of interpretation of the core condition.

![Figure 2. Geological map of Johor and location of survey lines [15].](image)

### 2.3 Standard Penetration Test (SPT)

Standard Penetration Tests (SPT) was carried in accordance with BS 1377-9:1990[12]., Seokhoon [5] stated that vertical drilling is useful for design and performance assessment evaluation of subsurface structure and structural foundations while SPT was additionally performed to determine overburden condition and soil sample. The test was done in 1.5m intervals. The value of the N as defined in the British Standard Method was recorded with the number of blow counts for each 75mm penetration of the sampling tube. The advantages of the test are the easy test procedure and the simplicity of the equipment employed. The test can be carried out in various types of soils ranging from soft clay and loose sand to very stiff clay and dense sand. Representative but disturbed samples can be taken, which is used for the classification of layers.
3. Result
The resistivity results and measured N value from each borehole are compared respectively to gather a relationship that may exist. The resistivity value obtained at each depth was determined by inversion results processed using RES2DINV software and then presented by SURFER software. Although the inversion results can provide a true resistivity image of the subsurface, it is necessary to aware of the limitations that may occur due to the non-uniqueness and smoothing condition of the inverted results. The drilling was executed at the centre of the survey line, but some of the borehole information for the core material are only available at certain depth at which the drilling are stop at most 50 blow counts for N value. Besides that, there are certain survey line have limited resistivity value, in which it only can compare to a number of N values. Therefore, only the results that match for each depth are plotted into graph.

3.1 SILC1
Based on resistivity results for SILC1 (Figure 3), the results indicate this area were made up of zone with resistivity value, 130-1800 Ωm covered with silt and clay. Low resistivity zones with value <225 Ωm were found at depth of 3m and 18m. The presence of high resistivity zones are also detected with resistivity value 1400-1800 Ωm at the first 1.5 m depth and at depth 7.50-10.50 m. Image obtain from the resistivity result show the present of boulder and fracture zone. From the borehole description in Table 2, clay materials are detected from 3.0m to 7.5m. However, the resistivity results indicated clay only existed at depth 3m and 18m depth (<225 Ωm). At the depth of 7.5 m 22.5m, the sample retrieved from borehole is sandy silt.

![Inversion model resistivity for SILC1 with BH1.](image)

**Figure 3. Inversion model resistivity for SILC1 with BH1.**

| Depth (m) | Resistivity (Ωm) | N value | Consistency | Soil Description     |
|-----------|------------------|---------|-------------|---------------------|
| 1.5       | 1436             | 9       | Stiff       | Slightly Sandy Silt |
| 3.0       | 137              | 9       | Stiff       | Slightly Sandy Clay |
| 4.5       | 242              | 15      | Stiff       | Slightly Sandy Clay |
| 6.0       | 924              | 39      | Hard        | Gravelly Sandy Clay |
| 7.5       | 1457             | 42      | Hard        | Slightly Sandy Silt |
| 9.0       | 1794             | 50      | Hard        | Slightly Sandy Silt |
| 10.5      | 1714             | 33      | Hard        | Sandy Silt         |

**Table 2: Resistivity Data and Borehole Descriptions for BH1.**
A graph for N value and resistivity value is plotted in Figure 4 for comparison. The SPT N values and resistivity for each line are compared to analyse their relation. The reduced level between resistivity data and borehole data need careful considerations in the data interpretations. Figure 4 show positive correlation specify in green colour from depth 3-6m (clay) with low resistivity value which then increased to higher resistivity value in the transition of material from clay to silt. From 7.5-12m, resistivity value increased while the N value exceed 50 at 9m depth but then going down to 33 at the next 1.5m depth. This make the zone marked with yellow colour. The resistivity were then drop from 1320 Ωm (N value = 18) to 432 Ωm at the depth of 22.5m with constant N value 50. The zone is marked with red colour in which it shows inconsistent result but the same material observed from borehole data.

| Depth (m) | Resistivity (Ωm) | N Value | Description |
|----------|------------------|---------|-------------|
| 12.0     | 1320             | 18      | Very Stiff  | Sandy Silt |
| 13.5     | 875              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 15.0     | 536              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 16.5     | 320              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 18.0     | 205              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 19.5     | 304              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 21.0     | 380              | 50      | Hard        | Slightly Gravelly Sandy Silt |
| 22.5     | 432              | 50      | Hard        | Slightly Gravelly Sandy Silt |

Figure 4. SPT N Value and Resistivity (Ωm) versus depth for BH1 at SILC1.

3.2 SILC2
Figure 5 indicate that SILC2 survey line which can be divided into three part, upper part with (300-12000 Ωm) with the existences of boulders at the first 10m depth, middle part (0-300 Ωm) with depth of 5m while some saturated zones are detected and lastly the lower part of 300 Ωm to 2000 Ωm. This area is made up from 2 kinds of materials which are clay from 1.50m to 15m and silt from 16.5 m to 18.00m. This line has resistivity value range of 80Ωm -1100 Ωm. Low resistivity zones with value <225 Ωm was detected at as known as clay materials at depth. The presences of high resistivity are also detected with resistivity value 1073 Ωm. Data obtained from the Borehole BH2 is not completely matched with the resistivity results. Based on borehole description in Table 3, clay materials is detected from ground to 15m and slight different with the resistivity results. First 3m shows high resistivity value of 995 Ωm and 1073 Ωm respectively which were not in the range of clay. The N
values slowly increase from ground to the depths of 10.5m, but then slightly decrease until 16.5m depth. The transition of clay to silt shows increase in both resistivity and N values. However, resistivity value identified big range in the same material of sandy clay. Generally, Figure 6 only shows a little zone of positive correlations at depth 7.5m to 10.5m. The first 7.5m depth show inconsistence results of resistivity even though the N value is slowly increased. The zone was highlighted in pink zone. In the transition of clay material to silt, the N values slightly increase from 8 to 17 while its resistivity value increased proportionally.

Figure 5. Inversion model resistivity of SILC2 with BH2.

Table 3: Resistivity Data and Borehole Descriptions for BH2.

| Depth (m) | Resistivity (Ωm) | N value | Consistency | Soil Description |
|-----------|------------------|---------|-------------|------------------|
| 1.5       | 995              | 0       | Very Soft   | Sandy Clay       |
| 3.0       | 1073             | 1       | Very Soft   | Sandy Clay       |
| 4.5       | 183              | 3       | Very Soft   | Sandy Clay       |
| 6.0       | 87               | 6       | Very Soft   | Sandy Clay       |
| 7.5       | 86               | 7       | Soft        | Slightly Sandy Clay |
| 9.0       | 125              | 12      | Firm        | Sandy Clay       |
| 10.5      | 197              | 13      | Firm        | Slightly Sandy Clay |
| 12.0      | 300              | 11      | Stiff       | Slightly Sandy Clay |
| 13.5      | 434              | 10      | Stiff       | Slightly Sandy Clay |
| 15.0      | 579              | 8       | Stiff       | Slightly Sandy Clay |
| 16.5      | 725              | 17      | Stiff       | Slightly Sandy Silt |
| 18.0      | 817              | 33      | Firm        | Slightly Sandy Silt |
Figure 6. SPT N Value and Resistivity (Ωm) versus depth for BH2 at SILC2.

### 3.3 SILC3

The resistivity results for SILC3 (Figure 7) indicate this area were made up of zone with resistivity value, 30-2000 Ωm covered with silt clay and sand. Low resistivity zones with value <225 Ωm were found at depth 4.5m-6m depth while high resistivity are detected at depth 7.5-12m with resistivity value 1100-2000 Ωm. Image obtains from the resistivity result show the present of boulder and saturated zones. Boulders were found within 5 m to 20 m from ground surface which consistent as reported by Md Dan et al. [16]. Table 4 indicate the borehole description for BH3 and the resistivity data for each 1.5m deep are recorded.

Figure 7. Inversion model resistivity of SILC3 and BH3.

Based on Table 4, clay materials exist in the first 1.5m, 4.5m to 7.5m, 10.5m and 15m. However, the resistivity results does not give a good range of clay material standard resistivity value (<225 Ωm).
From the table itself, we can see the transition of the materials and the inconsistence resistivity value recorded. The same material of sandy clay at depth 6 and 7.5m slightly recorded with 167 Ωm and 1186 Ωm. The different in the resistivity result given must be taken consideration to seek for their relationship. Many factors such as water content, particles size somehow affect the result. The graph of N value and resistivity was plotted in order to investigate the correlation.

**Table 4. Resistivity Data and Borehole Descriptions for BH3.**

| Depth (m) | Resistivity (Ωm) | N value | Consistency | Soil Description |
|-----------|------------------|---------|-------------|------------------|
| 1.5       | 588              | 5       | Firm        | Slightly Sandy Clay |
| 3.0       | 646              | 16      | Stiff       | Sandy Silt |
| 4.5       | 36               | 22      | Very Stiff  | Clay |
| 6.0       | 167              | 14      | Stiff       | Slightly Sandy Clay |
| 7.5       | 1186             | 17      | Very Stiff  | Slightly Sandy Clay |
| 9.0       | 1975             | 14      | Stiff       | Gravelly Sandy Silt |
| 10.5      | 1764             | 19      | Very Stiff  | Slightly Gravelly Sandy Clay |
| 12.0      | 1152             | 21      | Very Stiff  | Clayey Gravelly Sand |
| 13.5      | 707              | 27      | Very Stiff  | Coarse Sandy Silt |
| 15.0      | 468              | 19      | Very Stiff  | Gravelly Sandy Clay |
| 16.5      | 346              | 50      | Hard        | Coarse Slightly Sandy Silt |
| 18.0      | 305              | 50      | Hard        | Coarse Slightly Sandy Silt |

Based on Figure 8, no positive correlations are detected between N value and resistivity value. The first 3m depth show inconsistence results of resistivity even though the N value is increased. The zone was highlighted in pink zone. The graphs show large yellow zones which revealed that layer which has a high resistivity values will masked or shielded the lower resistivity material underneath as a result higher resistivity values is detected. This phenomenon can be seen at depth 9m. At 13.5m depth, the N value drop from 27 to 19 but then increased to 50 where it masked.

**N Value (BH3) & Resistivity (SILC3)**

![Figure 8. SPT N Value and Resistivity (Ωm) versus depth (m) for BH3 at SILC3.](image)
3.4 SILC4
Survey line SILC4 are shown in Figure 9, the resistivity image indicate that SILC4 are made up of materials with resistivity value of 60 Ωm -1750 Ωm. This area is covered with silt clay and sand. Low resistivity zones with value <225 Ωm were found at depth 4.5m-6m depth while high resistivity are detected at depth 1.5m and 10.5m with resistivity value 1733Ωm and 1457Ωm respectively. Resistivity image show the present of boulder and saturated zones. Data obtained from the Borehole BH3 is not completely matched with the resistivity results.

![Resistivity image showing boulders and saturated zones.](image)

**Figure 9. Inversion model resistivity of SILC4 with BH3.**

Based on borehole description in Table 4, clay materials is detected from ground to 1.5m, 4.5m to 7.5m, 10.5m and 15m depth but the resistivity does not in the standard range of clay except for 4.5m to 7.5m. The N values slowly increase from ground to the depths of 10.5m, but then slightly decrease until 16.5m depth. The transition of clay to silt shows increase in both resistivity and N values. However, resistivity value identified big range in the same material of either clay or silt.

In order to clearly identify the relationship, the chart consist of N value, resistivity and depth is plotted at Figure 10. A zone of positive correlations at depth 9m to 13.5m. The last 5.5m depth show inconsistence results of resistivity even though the N value is slowly increased. The zone was highlighted in pink zone. In the transition of clay material to silt at a few depth (3m, 9m and 15m), the resistivity value does not show exactly the range value of the material. Clay materials have slightly high value compare to silt for example at 1.5m depth.

![Chart showing N value and resistivity versus depth.](image)

**Figure 10. SPT N Value and Resistivity (Ωm) versus depth (m) for BH3 at SILC4.**
3.5 SILC5

Result for SILC5 survey line were present in Figure 11, it is clear that SILC5 survey line can be divided into three part, upper part with (300 Ωm - 5000 Ωm) with the existences of boulders at the first 10m depth, middle part of 40m depth with resistivity value of 0 Ωm - 300 Ωm while some saturated zones are detected and lastly the lower part of 300 Ωm to 3000 Ωm. The interpretation result of the survey line shows a deep image of about 60m depth into the ground. This area is made up of clay, silt and sand. This line has resistivity for borehole range from 30 Ωm - 300 Ωm, this line has the lowest range of borehole resistivity value compare to others survey line. Low resistivity zones with value <225 Ωm was detected at as known as clay materials at depth. Borehole data was not completely match with the given resistivity value. From borehole description in Table 5, clay materials is detected from ground to 6m, 10.5m-12m and 15m, the result for resistivity give a good range for clay.

![Figure 11. Inversion model resistivity of SILC5 and BH4.](image)

### Table 5. Resistivity Data and Borehole Descriptions for BH4.

| Depth (m) | Resistivity (Ωm) | N value | Consistency | Soil Description               |
|-----------|------------------|---------|-------------|--------------------------------|
| 1.5       | 200              | 8       | Stiff       | Slightly Gravelly Slightly Sandy Clay |
| 3.0       | 256              | 11      | Stiff       | Slightly Gravelly Slightly Sandy Clay |
| 4.5       | 129              | 6       | Firm        | Slightly Gravelly Slightly Sandy Clay |
| 6.0       | 60               | 6       | Firm        | Slightly Gravelly Slightly Sandy Clay |
| 7.5       | 31               | 9       | Stiff       | Slightly Sandy Silt            |
| 9.0       | 34               | 8       | Stiff       | Slightly Gravelly Silt         |
| 10.5      | 48               | 10      | Stiff       | Slightly Sandy Clay            |
| 12.0      | 75               | 11      | Stiff       | Slightly Gravelly Silt         |
| 13.5      | 115              | 10      | Stiff       | Slightly Gravelly Silt         |
| 15.0      | 166              | 12      | Stiff       | Gravelly Sandy Clay            |
| 16.5      | 48               | 15      | Stiff       | Gravelly Sandy Clay            |
| 18.0      | 62               | 50      | Hard        | Silty Very Gravelly Sand       |
| 19.5      | 75               | 50      | Hard        | Slightly Sandy Silt            |
| 21.0      | 81               | 50      | Very Dense  | Silty Sand                    |
| 22.5      | 100              | 50      | Very Dense  | Silty Sand                    |
| 24.0      | 115              | 50      | Very Dense  | Slightly Gravelly Silty Sand   |
| 25.5      | 129              | 50      | Very Dense  | Slightly Gravelly Silty Sand   |
| 27.0      | 166              | 50      | Very Dense  | Slightly Gravelly Silty Sand   |
Based on Table 5, N values are not consistence but give a low value. Clearly seen that in the same material zone, with same N value at depth 4.5m-6m the resistivity value detected are 129Ωm and 60Ωm respectively. The transition of clay to silt shows decrease in both resistivity and N values at depth 6m but opposite value at 10.5m depth. Furthermore, the transition of silt to clay (9m and 13.5m) both give increased in resistivity and N value. At 18m depth and above, the N value is masked to 50. Thus, the chart consist of N value, resistivity and depth is plotted at Figure 12 to clearly search for their relationship. The chart of N value and resistivity was plotted in Figure 12.

![Figure 12. SPT N Value and Resistivity (Ωm) versus depth (m) for BH4 at SILC5.](image)

Based on Figure 12, Positive correlation specify in green colour can be found at depth 1.5m-4.5m and 13.5m-18m. Zone with yellow colour was identified at depth 4.5m-13.5m in which the ups and down of both resistivity value and N value has no specific patterns. The transition of material does not give any significant change in both value detected. Lastly when the material are masked, the N value are constantly 50 while there is increased of the resistivity value. The resistivity value does not give clear and unique relationship with N value.

4. Discussion

Generally high resistivity zones will shows a high N values that represent a positive correlations and vice versa. However, some regions show dissimilar patterns between these parameters. The reduced level between resistivity data and borehole data need careful considerations in the data interpretations. Result of the resistivity values and N values are divided by different color zone which is green, yellow and pink zone. Green indicates positive correlation which high N value represent high resistivity zone and vice versa. This results is in agreement with study by Gallage [10] Yellow zones revealed that layer which has a high resistivity values will masked or shielded the lower resistivity material underneath as a result higher resistivity values is detected. This is in agreement with Seokhoon[5].However, in pink zone shows different inconsistent patterns between the N values and resistivity values. This is consistent with the finding of Sudha[13]. The relationship between SPT N-value and resistivity is not possible to obtain in standard and unique relationship for all different type of materials or lithology.
5. Conclusion
Generally, the results of resistivity survey and borehole data are interpreted simultaneously to understand the state of the core material and to identify the relation between the two properties. The findings show that the resistivity and SPT N values show positive, negative and inconsistent correlated pattern as expected. That is, zones showing low resistivity value generally have low N value with higher production rate and vice versa. But, some distinctive traits from the combined analysis are established. It may be inaccurate to say that the low resistivity value always means the unstable or disturbed material conditions which lead to low N value, and easy to be excavate. Instead, we can find some regions where the resistivity value is somewhat high, but the SPT N value is very low, which appeared as an anomalous group. Therefore, conclusion can be made on the core material in the normal condition does not signify a correct resistivity value. Some regions with high resistivity value may be in a severe condition. However, with only resistivity survey, it is very difficult to differentiate it whether the material has a normal or a troubled condition, because highly resistive zones are not always explain troubled zones. Of course, by comparing to near regions, it is still a good way to observe the zone with irregularly low or high resistivity value. As a result, it is recommended to apply various geophysical methods like seismic velocity test or other approaches to reduce the ambiguity of interpretation. Same procedure can be implies to different type of materials or weather condition to observe the correlations. Overwhelming analysis for the relationship should be keep away; it should be considered that this result is based only on the biased and non-unique inversion result, because of the limitation of resolution and imperfectness of inversion.

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