ESTEEM Academic Journal
Vol. 19, March 2023, 91-100

Resistivity Determination of Railway Track's Subgrade

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ARTICLE HISTORY	ABSTRACT

Received
20 January 2023

Accepted
15 March 2023

Available online
31 March 2023

The conventional geotechnical investigation method using borehole drilling and sampling was usually performed for subsurface exploration. However, it is -time-consuming, invasive and requires the closing of railway lanes that disrupts the train service. To avoid this problem, a geophysical method is an alternative that can be proposed to assess the conditions of the soil subgrade under the railway track. Electrical resistivity is one of the geophysical methods that study the nature of the electricity flow in the soil by injecting the electric current into the soil and measuring the generated potential difference. The field investigation was conducted at two different locations using electrical resistivity methods to identify the properties of the soil. Two railway track site locations selected were Pinang Tunggal, Pulau Pinang (KM 23), and Alor Setar, Kedah (250 m from the station in the north direction). ABEM Terrameter LS was used in field work that applied two configurations of an array,the Wenner and Schlumberger arrays, to infer the subsurface soil layer. The results concluded that the apparent resistivity data need to be inverted into an actual resistivity data set using Resistivity 2D Inversion (RES2DINV) software. The analysis found that the soil properties are both classified as soft soil with electrical resistivity values ranging from 0 - 100 Ω-m.

Keywords: *borehole, railway track, soil subgrade, electrical resistivity, geophysical.*

1. INTRODUCTION

One of the earliest transportation networks in Malaysia is the railway transport system [1]. The track substructure consists of layers of ballast, sub-ballast and subgrade, in which its behaviour has a major effect on the stability and performance of the track superstructure of rail since it supports the structure [2]. The subgrade is also the most variable and probably the weakest of track components. The inaccessibility of the subgrade renders it and challenging to determine its condition, diagnose a problem, and confidently administer or enforce a solution [2]. Failure in subgrade usually occurs when it cannot resist the stress from a load of embankments on top of it.

The failure in subgrades under railway tracks can be divided into three leading causes. Firstly, repeated loading triggers progressive shear failure, excessive plastic deformation, mud pumping, and liquefaction. Next, the weight of track structures, subgrades and trains will cause massive shear and consolidation settlement failure. Finally, the failure can also be caused by environmental factors such as frost, swelling, slope erosion and soil collapse [3]. Monitoring

p-ISSN 1675-7939; e-ISSN 2289-4934

subgrade conditions is most important for preparing suitable protective measures [4]. Geotechnical methods such as soil investigation (SI) by borehole drilling and sampling are usually used to monitor the subgrade conditions. However, it is laborious, costly, time consuming and invasive [5], [6]. In addition, these approaches lack reliability and practicality in the rapid evaluation of soil parameters to compute factor of safety (FOS) [7].

In order to avoid this problem, geophysical methods can be used to assess the properties of the soil subgrade under the railway track. Geophysics requires using non-invasive procedures without having to engage in destructive excavation to assess subsurface anomalies [8]. Geophysical methods, especially electrical resistivity surveys, have become widely known in engineering site characterisation [5]. Geophysical measurements do not require drilling and excavation with no preparation of access roads for transferring instruments to the site as geophysical instruments are easily portable. In order to save cost, time and energy, the electrical resistivity method can be used as an alternative method that can provide a fast and rapid evaluation of the soil under the surface without causing any soil disturbance as it can save time and resources [9].

Electrical resistivity is one of the geophysical methods that study the nature of the electricity flow in the soil by injecting the electric current into the soil and measuring the generated potential difference [10]. Generally, the electrical resistivity of the subsurface varies depending on moisture content/water saturation, mineral presence, mineral ionisation, type of formation, porosity, temperature, and others [4]. The distribution of soil resistivity will vary depending on the water content and lithology [11]. Electric Resistivity Tomography (ERT) is one of the geophysical imaging methods most widely used in subsurface imaging. ERT maps subsurface geological features, locate groundwater sources, and monitor groundwater pollution [12].

Although a few researchers worldwide have conducted studies on the electrical resistivity of railway tracks, there is yet no study on this problem in Malaysia. Therefore, more study must be done to determine the importance of soil subgrade under railway tracks and the effectiveness of geophysical investigation primarily electrical resistivity as the exploration method. The present study attempts to identify the railway track soil subgrade physical properties and develop and analyse the subsurface soil profile under the railway track using the electrical resistivity method.

2. GEOLOGY OF THE AREA

The study region was near Pinang Tunggal Kepala Batas, Pulau Pinang, and Alor Setar, Kedah. According to a geological map [13], the region around Alor Setar primarily comprises Quaternary marine and continental deposits, including clay, silt, sand, peat, and a small amount of gravel. Early Pleistocene-aged basalt is found in the Kuantan region. The soil types at Kepala Batas, Pulau Pinang, where Pinang tunggal is located, are covered by Tertiary deposits. Shale, sandstone, conglomerate, and minor coal seams are among the Late Tertiary deposits in these isolated continental basins. Volcanic activity is found at Segamat.

3. METHODOLOGY

ERT was conducted at two sites of railway tracks located at (KM 23) Pinang Tunggal and (KM 90) Alor Setar Stations. Both sites were selected due to the track settlement issues at these locations. Track settlement could be observed at both lines of rail track location, as shown in

p-ISSN 1675-7939; e-ISSN 2289-4934

Figure 1 and Figure 2. The railway line at Pinang Tunggal area, as shown in Figure 1 is surrounded by paddy field (green line) indicating the origin of soft soil subgrade, possibly the main reason for the railway track's settlement problem. Meanwhile, Alor Setar town was also built on alluvial soil, as reported by [14], and this explains the possible reason for track settlement in certain areas along the track. Although the track's settlement on site is not critical, daily inspection is required to monitor the track defect and conduct proper maintenance when necessary.

Electrical imaging is provided through Electrical Resistivity Tomography (ERT) technology, widely used to analyse subsurface soil. This method has been used during the past several decades along with advancements in geoelectrical imaging, particularly in the data quality. ERT imaging is capable of high-resolution lithological variation mapping, which is widely used to provide information and trace the location of the boulder, bedrock/formation, and overburdened materials [15], in addition to improving the accuracy of subsurface mapping on rugged terrain [16].

The electrical resistivity field surveys were performed using ABEM Terrameter LS equipment. NS40 portable battery type was used as current sources generator to ensure the sufficient capacity current supply during testing and a whole arrangement of the electrical resistivity imaging (ERI) components with the overview instrument placement on site as shown in Figure 2. It has two cable rolls (100 m each), a battery, 41 steel electrodes, and 43 transmitter/jumper cable numbers. The acquisition line set in the resistivity test comprised two longitudinal spread lines (red line) performed at both track sides, as shown in Figure 3. Each line contained two continuous rolled cables connected to 41 electrodes with 5m of electrode spacing via 43 jumpers. The cable was spread a longitudinal at one side of the track for both test locations. The test was conducted during the active operating system. The steel electrodes were placed at a straight distance of 200 m with equal spacing of 5 m apart along the railway track. The exact location for the test was selected near the track settlement. The placement of electrodes at the site was challenging because most areas are covered by ballast aggregate, which can compromise data accuracy due to the contact failure of electrodes to the subgrade.

Figure 1: Railway track at Pinang Tunggal (KM 23) Pulau Pinang [17]

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Figure 2: Railway track at Alor Setar KTMB Station (KM 90)

The electrical resistivity method was used to infer the subsurface soil layer by using two configurationsan , the Wenner and Schlumberger arrays. These arrays were selected depending on the type of structure to be mapped, the sensitivity of the resistivity meter, and the background noise level. The images are presented in the form of 2D resistivity profiles to provide a clear view of the distribution of layers of subgrade. The results obtained found that the apparent resistivity data need to be inverted into an actual resistivity data set by using Resistivity 2D Inversion (RES2DINV) software to determine where the soil moisture is changing at various locations throughout the profile.

Figure 3: Electrical resistivity conducted at KM 23 Pinang Tunggal and KM 90 Alor Setar station.

3. RESULTS AND DISCUSSION

A total of two geophysical surveys were conducted in both study areas. Table 1 below summarises the location, array, survey line length, maximum depth, and RMS error. The imaging data obtained from RES2DINV software for Wenner and Schlumberger arrays at both locations are presented in Figure 4, Figure 5, Figure 6, and Figure 7, respectively. At Pinang Tunggal, the result indicated that most subgrade resistivity values were below 300 Ω-m for both arrays. Meanwhile, at Alor Setar, the result indicated that most subgrade resistivity values were below 90 Ω-m ad 45 Ω-m for Wenner and Schlumberger arrays, respectively.

p-ISSN 1675-7939; e-ISSN 2289-4934

Table 1: Summary of the location, array, length of a survey line, maximum depth and RMS error

Location	Array	Length of a survey line (m)	Maximum depth (m)	RMS error (%)
Pinang Tunggal	Wenner	200	28.7	9.8
Pinang Tunggal	Schlumberger	200	28.7	9.5
Alor Setar	Wenner	200	32.8	8.8
Alor Setar	Schlumberger	200	28.7	7.6

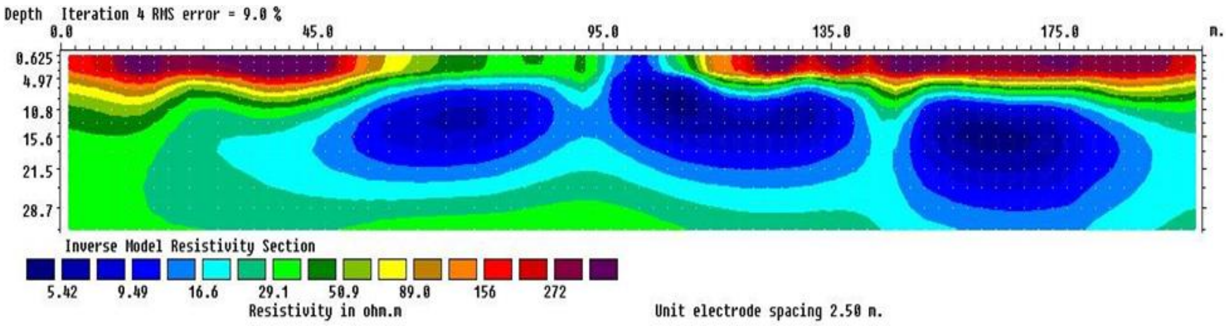

Figure 4: Electrical resistivity using Wenner array protocol at Pinang Tunggal

The top layer of the profile had a zone of high resistivity (>300 Ω-m), which corresponded to the layer of dry railway ballast, according to the inverse model resistivity section by Winner array in Figure 4. Moreover, most earth materials had a low resistivity (10 Ω-m) between around 10.8 m and 28.7 m in depth. The soil minerals were identified as soft clay with low electrical resistivity values between 1 and 100 Ω-m [18]. The low resistivity valuemay also point to a high groundwater potential zone beneath the research region.

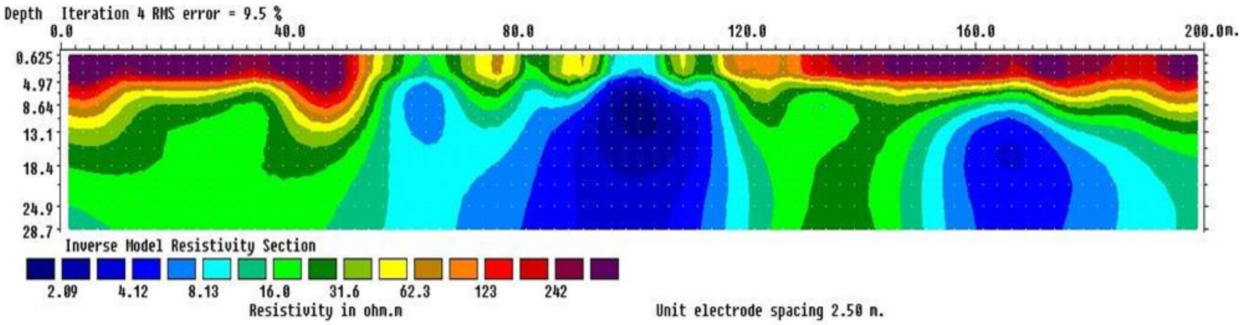

Figure 5: Electrical resistivity using Schlumberger array protocol at Pinang Tunggal

The top layer of the soil profile also contained a high resistivity zone (>300 Ω-m) nearly identical to the value of electrical resistivity obtained by using the Wenner array, as shown in the analysis of the inverse model resistivity section by using the Schlumberger array in Figure 5. The top layer was a formation of ballast, which typically consists of granite (>5000 Ω-m) or basalt (>600 Ω-m), according to the high resistivity values. Moreover, most of the materials exhibited a low resistivity zone (16 Ω-m) between 8.64 m and 28.7 m of depth. This value may indicate the existence of clay (1-100 Ω-m), alluvium (10-800 m), and groundwater (10-100 Ω-m) [18].

p-ISSN 1675-7939; e-ISSN 2289-4934

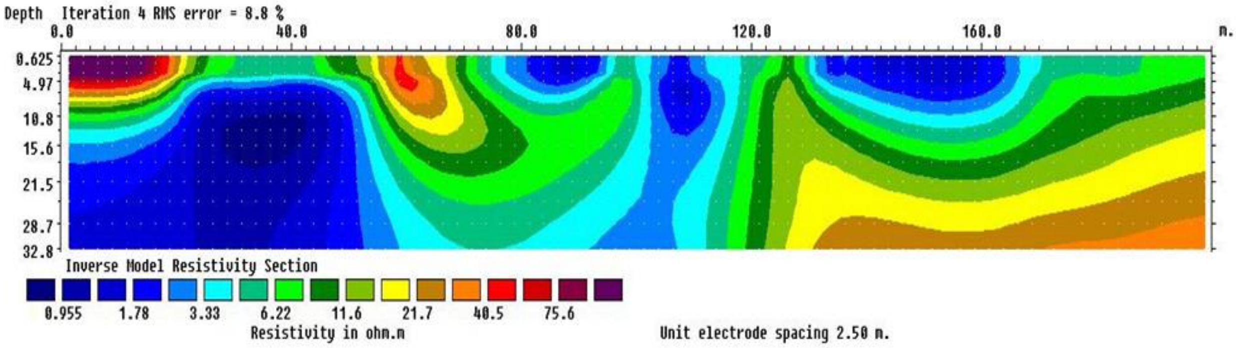

Figure 6: Electrical resistivity using Wenner array protocol at Alor Setar

The maximum resistivity value achieved for theresistivity value achieved for the Alor Setar subgrade using the inverse model resistivity section with Wenner array was 90 m, as shown in Figure 6. The dominance of the low resistivity zone in the top layer profile (>6.22 Ω-m) indicated the presence of clay (1-100 Ω-m), alluvium (10-800 Ω-m), and groundwater (10-100 Ω-m). Besides this, most of the materials possessed a low resistivity zone (approximately 11.6 Ω-m) at a depth of 10.8 to 32.8 m. Furthermore, this indicated the presence of clay (1-100 Ω-m), alluvium (10-800 Ω-m), and groundwater (10-100 Ω-m). The higher rainfall intensity inin the study area may cause the subgrade's lower electrical resistivity.

Figure 7 shows that the inverse model resistivity section produced a low resistivity zone in the subsurface using the Schlumberger array. The measurements' depth assessments ranged from 0 m to 28.7 m. Also, the results of the resistivity analysis up to 45 Ω-m were regarded as low resistivity zones. The low resistivity result may suggest a high groundwater level under the research region, which supports the classification of the soil subgrade as soft soil. This is a possible reason for the low resistivity value. Since the research area is situated in a region with unconsolidated layers of clay and silt, as explained in the section on the physical characteristics of the subgrade, this state is consistent with the lithology of the region.

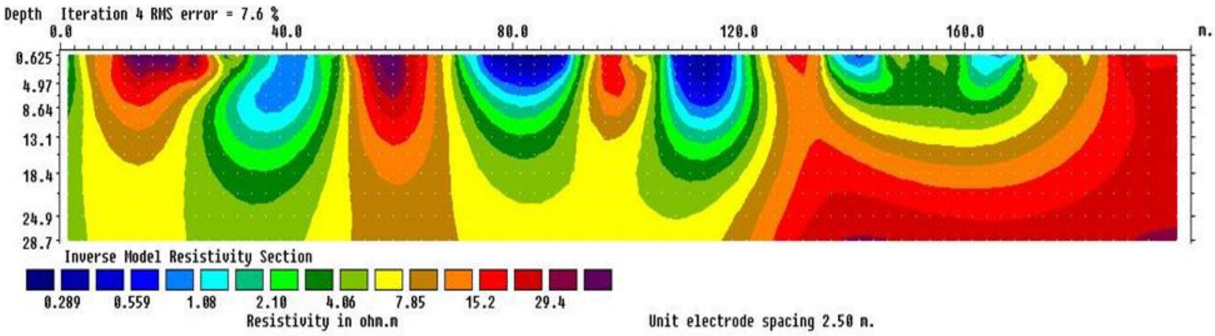

Figure 7: Electrical resistivity using Schlumberger array protocol at Alor Setar

Schlumberger array reads more data points than the Wenner array during the testing. This indicated that Schlumberger array is more accurate compared to the Wenner array. The difference in the results from both Wenner and Schlumberger arrays is due to the difference ofin the results from both Wenner and Schlumberger arrays due to the data points taken. The results of the electrical resistivity survey of the subgrade under the railway track varied depending on moisture content/water saturation, mineral presence, mineral ionisation, type of

p-ISSN 1675-7939; e-ISSN 2289-4934

formation, porosity, temperature, and others. From the data analysis, the value of resistivity of both locations differed due to the presence of groundwater.

After acquiring the resistivity value of the surveyed line, the soil type within the subsurface can be anticipated using the resistivity value shown in Table 2 [19]. To further confirm the soil types in area comparison was made with previous study publications. The range of electrical resistivity values for both sites indicated a soft ground with higher moisture content.

Table 2: Type of material according to resistivity value [19]

Material	Resistivity (Ω -m)
Groundwater (fresh)	10 to 100
Soft clay	50
Silt alluvium	20 to 100
Clayey sand	50 to 500
Shale	$20 – 2 \times 10^3$
Limestone	$50 – 4 \times 10^3$
Granite	5000 - 1000000

The results from the electrical resistivity imaging show that subsurface's condition on the railway track site had a relatively high resistivity at Pinang Tunggal compared to low resistivity at Alor Setar. The low resistivity value indicated that there might be high groundwater level beneath the ground study area. The visual observation at KM 23 Pinang Tunggal site showed that the box culvert under the railway track could be seen. The culvert was provided to allow water discharge circulation/drainage system. As the study area is in the area which consists of unconsolidated layers of clay and silt, as had been discussed earlier, this condition correlates with the lithology of the area where the type of soil is soft soil which has high water content.

4. SUBGRADE PHYSICAL PROPERTIES

The physical properties of soil near the location were determined from the data collected from articles and journal reviews by past researchers. Based on the analysis of the data collected, it can be concluded that the soil subgrade near both locations is soft soil as the primarysignificant soil type, which mainly consists of soft clay and sandy silt. The data collected from the test results are tabulated in Table 3.

Table 3. Previous studies of soil properties at Alor Setar and Pinang Tunggal

References	Location	Test	Type of soils
[20]	Alor Setar	Particle size distribution	Clayey silt
[14]	Alor Setar	Particle size distribution	Alluvial soil
[21]	Tasek Gelugor to Pinang Tunggal	Particle size distribution	Very soft to soft clay
[21]	Pinang Tunggal to Sungai Petani	Particle size distribution	Sandy silt

The electrical resistivity measurements at Pinang Tunggal, which ranged from 0 to 300 Ω-m for both Wenner and Schlumberger arrays, showed minimal to no fluctuation. At Alor Setar, the values of 0 - 90 Ω-m and 0 - 45 Ω-m for Wenner and Schlumberger arrays showed a slight discrepancy. The research region may have a high groundwater level which supports the classification of the soil subgrade as soft soil. The low resistivity value may imply that the earth's constituents are clay or alluvium. Soft soil is commonly unsuitable for engineering work

p-ISSN 1675-7939; e-ISSN 2289-4934

as it has low shear strength and high-water content, which can cause defects such as settlement, flooding and damage to the structure [22]. Higher water content can affect the value of the electrical resistivity of the soil.

5. CONCLUSION

The electrical resistivity values indicate minimal or no variation at Pinang Tunggal, which fluctuate between 0 - 300 Ω-m for both Wenner and Schlumberger arrays. However, at Alor Setar, the values indicate, a minor difference of 0 – 90 Ω-m and 0 - 45 Ω-m for Wenner and Schlumberger arrays, respectively. The low resistivity value may indicate that the earth material consists of clay or alluvium, and there might be high groundwater level beneath the study area, which validates the classification of the soil subgrade as soft soil.

In conclusion, the results have shown that the type of soil subgrade under the railway track at Pinang Tunggal and Alor Setar can be classified as soft soil. From the analysis by past researchers, it was found that the average density of the soil around the location is 1.7 g/cm^3. In addition, 2 electrical resistivity surveys have been conducted at the railway track located at Pinang Tunggal, Penang and Alor Setar, Kedah. Based on the obtained data, the electrical resistivity values indicate little or no variation at Pinang Tunggal,, ranging from 0 - 300 Ω-m for both Wenner and Schlumberger arrays. However, at Alor Setar, the value indicates a minor difference with 0 – 90 Ω-m and 0 - 45 Ω-m for Wenner and Schlumberger arrays, respectively. The low resistivity value may indicate a high groundwater level beneath the study area, which validates the classification of the soil subgrade as soft soil. Hence, this study has successfully achieved both objectives, which are to identify the physical properties of the railway track soil subgrade and to develop and analyse the subsurface soil profile under the railway track by using the electrical resistivity method.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Ministry of Higher Education Malaysia (MOHE) because this research work was financially supported under the FRGS scheme (600-IRMI/FRGS 5/3 (302/2019)). Besides, the authors are grateful to the Research Management Centre (RMC) and School of Civil Engineering, UiTM Cawangan Pulau Pinang and Shah Alam, and Keretapi Tanah Melayu Berhad (KTMB) for providing facilities and assistance that helped this research to be completed.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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