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M Balamaheswari and K Premalatha

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Establishing the Correlations between Electrical Resistivity and SPT N in Sandy Soils.

Balamaheswari M[1 [0000-0003-4605-9553]] and Premalatha K[2[0000-0002-5893-1495]]

[1] National Engineering College, Kovilpatti 628503, TamilNadu
[2] College of Engineering Guindy, Anna Universityi, Chennai 600025, TamilNadu
lncs@springer.com

Abstract. Conventional field tests such as the Standard Penetration test, Cone Penetration test, Pressuremeter test, and Dilatometer test are being used for subsurface explorations. Geophysical tests are also becoming popular in subsurface investigations by adopting in combination with conventional methods. Electrical Resistivity is one of the geophysical methods which measure the apparent resistivity of soils. From the literature review, it is understood that there is a scope to establish the correlation between SPT N value and electrical resistivity for different types of soil. Establishing these correlations by detailed study in subsurface investigations will help for the construction of common residential buildings since the cost of conducting an electrical resistivity test is lesser than the conventional Standard Penetration Test. This article focuses on establishing the correlation between the apparent electrical resistivity and the Standard penetration number with the depth of the soil strata from the collected data of three sites. The average apparent electrical resistivity values of the three different sites are compared with the different boreholes nearer to the test location of electrical resistivity. The boreholes show the presence of sandy soils. The average apparent electrical resistivity values are compared with the SPT N values for the three sites and the variation between the apparent electrical resistivity and standard penetration number with depth is linear. The coefficient of correlation values shows a positive trend for site 1 and negative trend for site 2 and site 3. The reason for the lower values of coefficient of correlation in site 2 and site 3 is due to the transition of the the soil profile. This correlation has been compared with the field data for different soil layers of other researchers.

Keywords: Electrical Resistivity, Standard Penetration Number, Geophysical Methods

1 Introduction

Soil investigations are carried out in the site to acquire information about the physical characteristics of the geomaterials underlying the site area as an initial step in the construction of any structures. In geotechnical engineering, conventional field tests are performed to get the data about the soils. As the cost to conduct these tests is expensive, a limited number of tests are carried out in the field to obtain the subsoil profile at selected locations. The geophysical methods act as a tool to interpolate or extrapolate along with the available data from the geotechnical investigations to give more promising results. The electrical resistivity method and seismic refraction survey are the more common geophysical methods adopted in the site. The efforts to correlate the apparent electrical resistivity values with the geotechnical properties of the soil are limited.

Braga et al. [1] established the correlation between geoelectric properties and standard penetration number N for different materials which could be used in areas with similar lithology. Philippe et al. [2] has observed a fair correlation between the different water contents and inverted electrical resistivity values since other geotechnical data are limited. Mohammed et al. [3] show that the geotechnical properties such as density, liquid limit & plastic limit have a better correlation with the electrical resistivity values when it is more than 400 Ohm-metre. Yulong et al. [4] has observed that the electrical resistivity values decrease at decreasing rate with consolidation pressure. Liu et al. [5] have reported that the electrical resistivity values decrease with the increment of heavy metal concentrations in the contaminated soils.

Melo, Laura et al. [6] have found that the relationship between soil moisture content and soil resistivity values gets affected by the degree of soil compaction. The increase in fine contents led to a decrement in the electrical resistivity values by carrying out the soil compaction tests reported by Marwa et al. [7]. Olawale and Michael [8] have shown that where the budget is limited, geotechnical investigation spots cannot be established at closer grid intervals. Further, the maps and 3D section developed using the electrical resistivity method helps as a guide to choose points for geotechnical investigations based on the heterogeneity of the subsurface. Bandar et al. [9] developed a model using an artificial neural network to establish the correlation between geotechnical properties and electrical resistivity, which shows the distinguished exponential negative relationship between them.

Based on the literature review, it is clear that a deep understanding of the electrical resistivity values with the geotechnical properties has to be established. This can be achieved by conducting laboratory investigations for different soil materials and validating the results by comparing them with the field data. The main focus of this paper is to establish correlations between standard penetration number N and electrical resistivity values with the depth of the soil strata from the collected data of three sites.

2 Materials and Methods

2.1 Field Data Collection

The soil investigation reports of three adjacent sites are collected whose general sub-soil profile for two sites is indicated in figure 1. The general subsoil profile for site 1 consists of well-graded sandy soil for a depth up to 4 m followed by sandy clay up to 9 m below which exists very poor –hard rock. The general subsoil profile for site 2 consists of well-graded sandy soil along with silty soil up to 6.5 m followed by sandy clay up to 9.5 m below which exists poorly graded gravel up to 15 m followed by poor-hard rock. The general subsoil profile for site 3 consists of well-graded sandy soil with fine contents of silts up to 6.5 m followed by sandy clay up to 14 m below which exists fair-excellent hard rock.

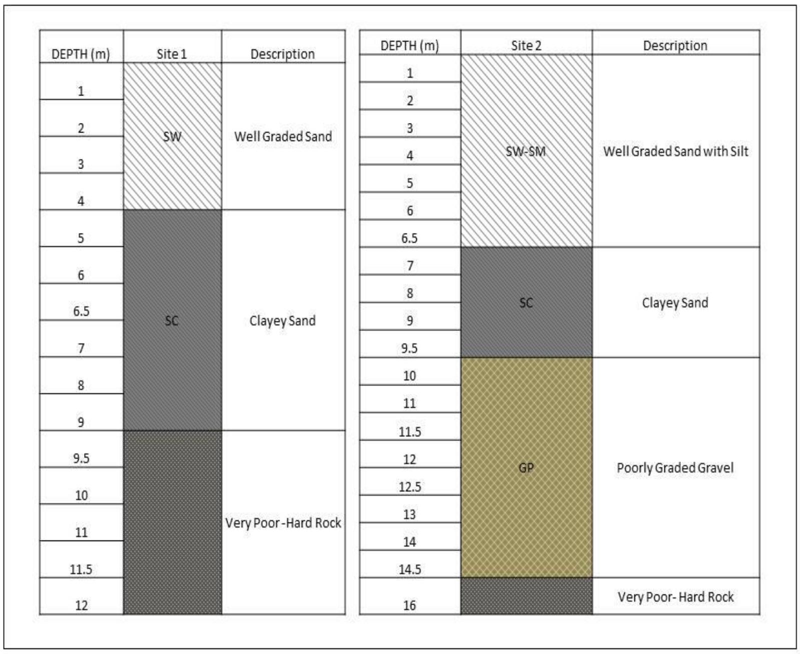

Fig.1 Description of subsoil profile for Site 1 and Site 2

2.2 Soil Boring and Standard Penetration Test

The rotary drilling technique is adopted in all the boreholes to the required depth in all the sites. The sides of boreholes were protected by using bentonite slurry and casing pipes. Standard penetration tests were conducted at specified intervals according to the standards IS 2131:1981[10]. The disturbed samples collected from the boreholes are used for visual identification and sent to the laboratory for the classification of soils. Core samples were obtained by using a double tube core barrel of NX size.

2.3 Determination of Electrical Resistivity

The apparent electrical resistivity of the soil can be determined by conducting an electrical resistivity test. The four-electrode method of Wenner Configuration is conducted in the field as per the standards IS 15736:2007 [11]. The spacing between the electrodes is fixed based on the depth of investigations. The test is carried up to 20 m depth in all the site locations. The direct current is passed through current electrodes whereas the potential drop is measured employing the potential electrodes. The electrical resistivity test is conducted in all the site locations in both the directions North-South and East-West. The average apparent electrical resistivity is taken into consideration for further establishing the correlations.

The average apparent resistivity value of 215 ohm-m is found at 4 m depth for the site 1 location and the value decreases till 12 m depth up to 27.72 ohm-m. An average value of around 30 ohm-m is observed for the depth of 13 m to 20 m. Similarly, for site 2, the average apparent resistivity value of 278.5 ohm-m is found at the depth of 6 m with a further decrease in the apparent electrical resistivity value until the depth of 20 m. For the site 3 location, the average apparent resistivity value of 112.5 ohm-m is observed at 4 m depth with a further decrease in the apparent electrical resistivity value to 8.58 ohm-m at 20 m depth. The electrical resistivity values for different materials are given according to the code IS 15736:2007 [11] in Table 1,

Table 1. Resistivity values for some materials [11]

Material	Resistivity Ohm-m
Igneous and Metamorphic rocks	
Granite	5×10^3 -10^6
Basalt	10^3 -10^6
Marble	$10^2 – 2.5 \times 10^8$
Sedimentary rocks	
Sandstone	$8 – 4 \times 10^3$
Shale	$20 – 2 \times 10^3$
Limestone	$50 – 4 \times 10^2$
Soils	
Clay	1-100
Alluvium	10-800

3 Results and Discussions

3.1 Soil Boring and Standard Penetration Test

The boreholes adjacent to the electrical resistivity test (ERT) location are identified for all the three sites. For the site 1, two borehole locations adjacent to the ERT spot is taken whose standard penetration number N versus depth is plotted in the fig.2. Similarly for the site 2 and site 3, four boreholes are identified adjacent to the ERT spot and three boreholes are identified adjacent to the ERT spot, respectively. The SPT N versus depth is plotted for the site 2 and site 3 which is shown in fig.3 and fig.4 respectively.

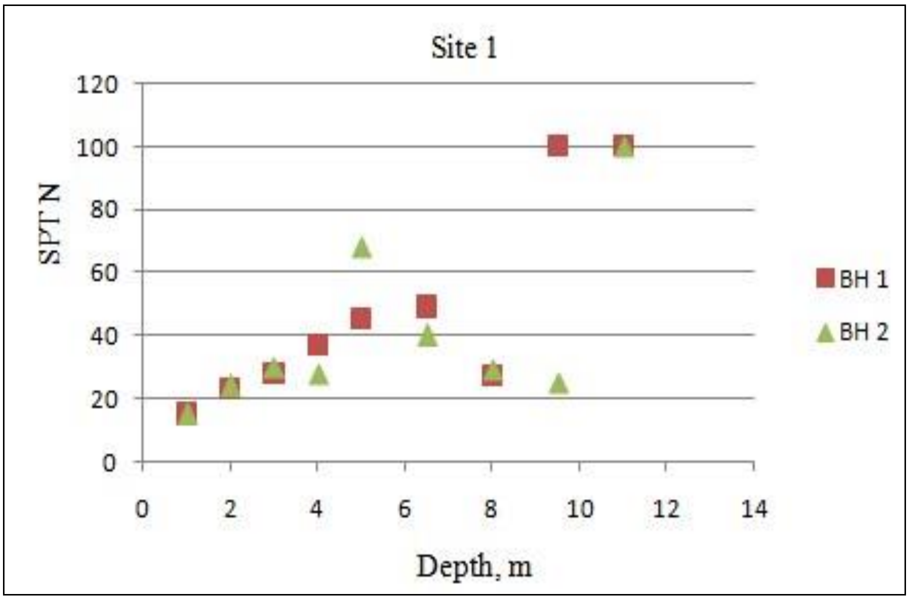

Fig.2 SPT N versus depth for Site 1

The variation of SPT N with depth is given for all three sites. From fig.2, it is seen that the SPT N value differs from 15 to 100 for 11 m depth in site 1 since it consists of a well-graded sandy layer up to 4.0 m followed by sandy clay below which the presence of very poor hard is observed. In Site 2, much lower SPT N values are observed due to the presence of filled-up soil and sandy soil with silt content at the initial depth up to 4 m reaching higher SPT N at greater depths which is indicated in fig.3. Similarly, for site 3, BH 1 shows a deviation in SPT N value compared to BH2 and BH3 which are almost similar due to the presence of sandy soil with fine content of silts followed by sandy clay where excellent hard rock exists at greater depths.

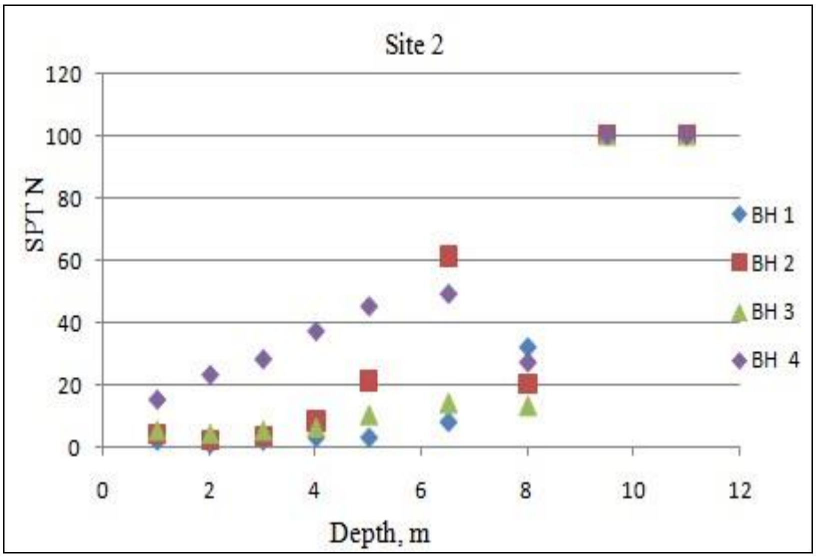

Fig.3 SPT N versus depth for Site 2

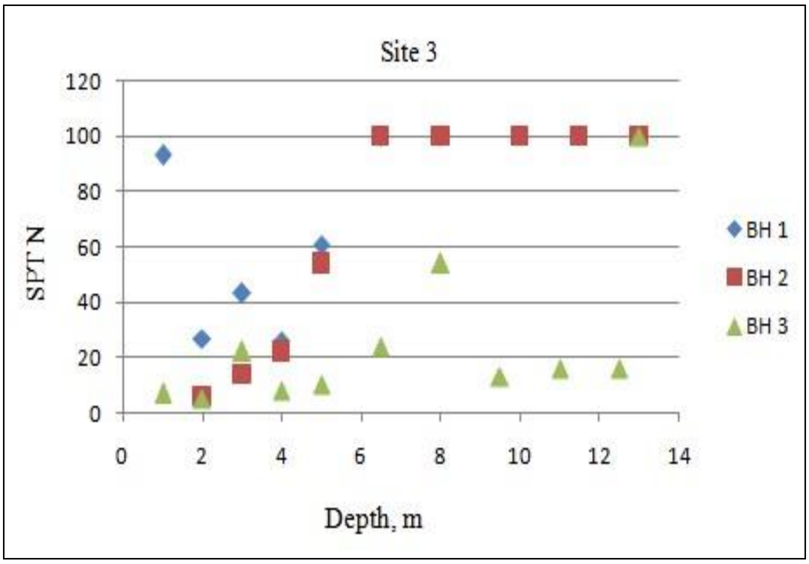

Fig.4 SPT N versus depth for Site 3

3.2 Standard Penetration Number (N) versus Electrical Resitivity

The average apparent electrical resistivity values calculated are correlated with standard penetration number for all three sites. The variation of apparent electrical resistivity value with the SPT N in site 1 is shown in Fig.5. Similarly, for site 2 and site 3, the graph is plotted between SPT N versus apparent electrical resistivity presented in fig.6 and fig.7

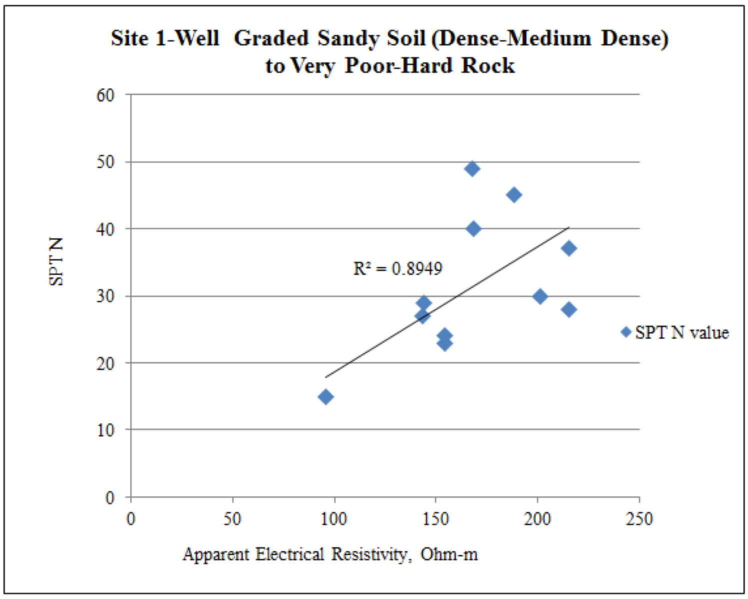

Fig.5 Change of apparent electrical resistivity with SPT N for Site 1

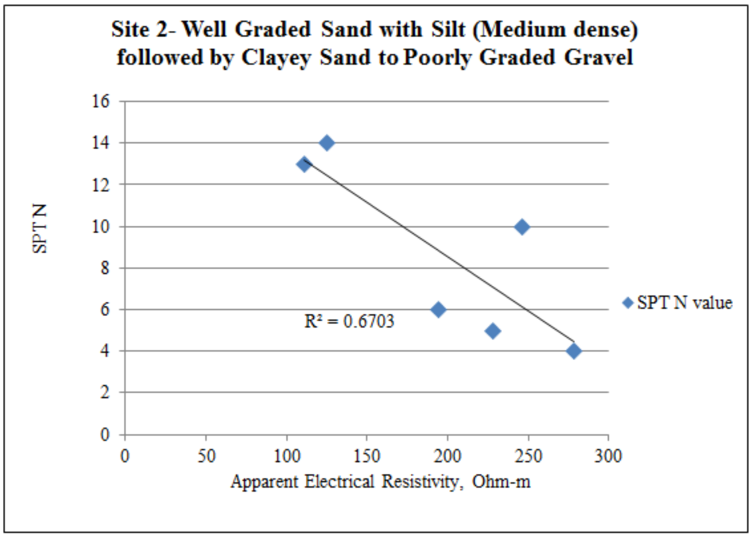

Fig.6 Change of apparent electrical resistivity with SPT N for Site 2

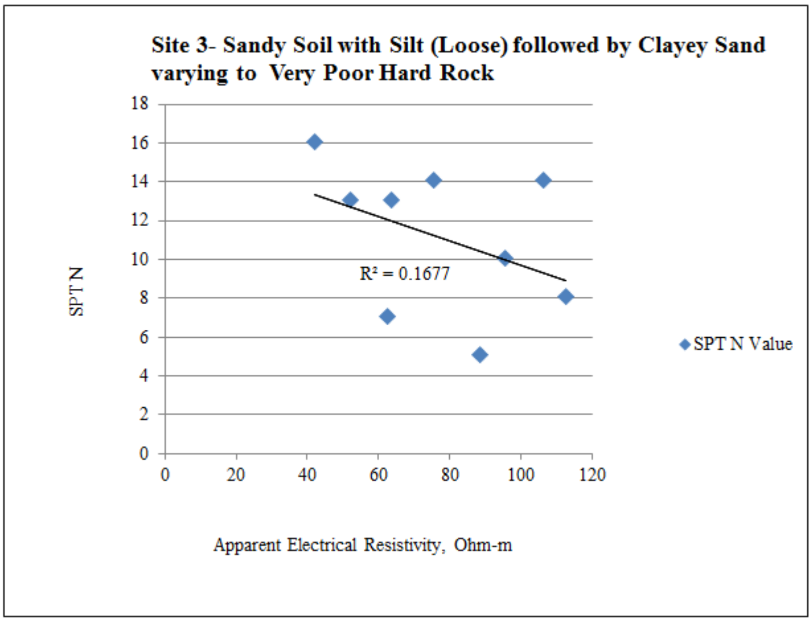

Fig.7 Change of apparent electrical resistivity with SPT N for Site 3

From the fig.5, the coefficient of correlation, R^2 value is 0.8949, which shows that the correlation between apparent electrical resistivity and standard penetration number values is linear for site 1. Khairul et al [12] obtained the correlation between inverted values of 1D resistivity versus SPT N showing a linear relationship with R^2 value of 0.9007. For site 2 in fig.6 and site 3 in fig.7, the correlation between apparent electrical resistivity and standard penetration number values shows a linear relationship with a negative trend. The reason for negative trend in the fitting slope is due to the presence of sandy soil with silts in the upper zone of the site 2 and site 3. Juliana et al [13] explained the reason for negative trend in the fitting slope is due to the transition in the materials. In their research, the software RES2Dinv is used to obtain the inverted resistivity data values utilizing the technique of Gauss-Newton least-square inversion techniques. Table.2 shows the coefficient of correlation given by the researcher for different types of soil.

Table 2. Coefficient of Correlation, R2 for different types of soil, Juliana et al [13]

Soil Description	Coefficient of correlation, R^2
Sandy silt with gravel	0.83
Sandy silt with gravel and fragments of rock	0.97
Sandy silt with clay	0.77
Sandy silt with clay and sandstone fragments	0.90
Silty clay and weathered shale	0.82
Clayey silt with rock fragments	0.95

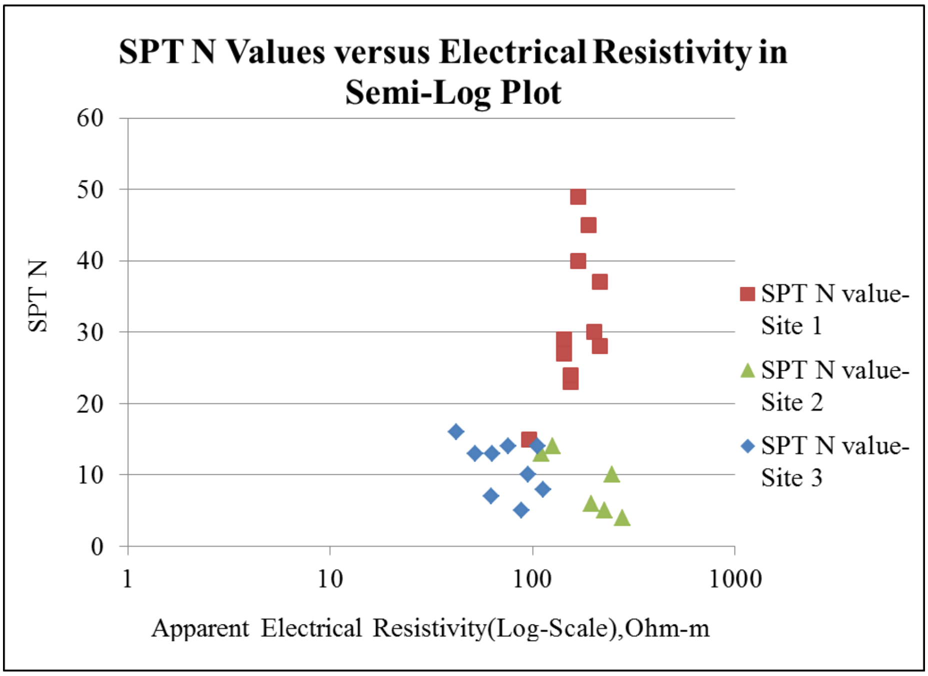

Fig.8 Variation of Apparent Electrical Resistivity in Log-Scale with SPT N for all the sites

From the fig.8, it is observed that the lower values of SPT N are observed for the site 2 and site 3 which implies that the relative density of the soil is very loose to medium whereas the relative density of the soil in site 1 is in dense state.This attempt was made to study the correlation between the average apparent electrical resistivity value with standard penetration number which shows clearly that inverted resistivity values have a good correlation with SPT N rather than the average apparent electrical resistivity values. The inverted resistivity value is calculated by using computing software or inversion techniques to obtain a higher accuracy value explained by Shrey and Gunjan [14]. According to Sudha et al [15].the coefficient of linear fit are different due to the site showing varying soil matrix under different geological conditions. Hence the relationships are site-specific which needs a detailed study to validate the results for different soil types based on the geological site conditions.

4 Summary

In the present study, Geotechnical investigations for three sites are considered to obtain the correlation between the average apparent resistivity value and Standard penetration number shows a linear relationship in all three sites. The coefficient of correlation values for site 1, site 2, and site 3 are 0.8949, 0.670, and 0.167. The reason for lower value for site 2 and site 3 is due to the transition in the soil layers. The actual average apparent resistivity values are considered for obtaining the correlation whereas the researchers used data inversion techniques in predicting the linear relationship. The data used in the present study can be inverted by using modeling software to give higher accuracy results. There is a unique linear relationship between the inverted resistivity data and standard penetration number explained in various researches. This will be validated considering the electrical resistivity data for different sites and different types of soil. Further, the electrical resistivity test data alone is not sufficient to predict the failure zones in slope stability analysis. The dual combination of electrical resistivity data with standard penetration test data plays a major role in predicting the unstable slope zone reported by Zainal et al.[16] Geophysical surveys give in-depth information about the sites compared which can be obtained quickly. The cost of investigation for conducting geophysical survey is economical compared with other conventional methods.

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