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Correlation of electrical resistivity of soil with geotechnical engineering parameters at Wattar area district Nowshera, Khyber Pakhtunkhwa, Pakistan

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Abstract

Geo-electrical survey is an alluring tool for defining subsurface properties without upsetting soil. A systematic investigation of amalgamating geophysical and geotechnical engineering parameters for subsoil evaluation is adopted at Wattar area near Nowshera, Khyber Pakhtunkhwa, Pakistan, in order to figure the shallow subsurface. A field electrical resistivity survey of 52 m is conducted using Schlumberger configuration. Soil samples are collected from the available exposure for conducting geotechnical investigation in the laboratory. Sieve analysis, Hydrometer analysis, moisture content, Atterberg's laboratory tests (liquid and plastic limits) are performed on these soil samples. Correlation between lithology of layers and electrical resistivity is resolved by correlating the apparent resistivity values with the accepted defined values of resistivity. From the data investigation, momentous correlations have been obtained for electrical resistivity with moisture content, lithology and thickness of a layer. The field observations show that the top and bottom layer in the area is dominated by gravely sand and clayey sand respectively. The results of sieve analysis and vertical electrical sounding also proved these lithologies. The result shows a strong correlation of electrical resistivity with moisture content, lithologies and thickness of a layer. Relationship between moisture content and apparent resistivity values testify non-linear logarithmic correlation. The trend line of the curve between moisture content and apparent resistivity shows an inverse relation.

Keywords: Electrical resistivity; Geotechnical properties; Apparent resistivity; Correlation

1. Introduction

The study area (Wattar) lies in north-east direction of Nowshera District coordinated as latitude of 34° 00' 27.4"N to 34° 00' 27.4"N, and longitude of E 72°04' 06.1"E to 72° 04' 04.1"E. The studied outcrop is exposed near Wattar area at a distance of 6.17 km from Nowshera District and 46.60 km from Peshawar city. The outcrop encompasses of upper unconsolidated gravely sand materials and a lower clayey sandy layer. The total thickness of outcrop calculated through measuring tape was 7.6m as shown in Figure 1.

There has been a lot of research work done by different geoscientist using the connected approach of geophysical and geotechnical methods in other parts of the world. Siddiqui and Osman (2012) conducted a research study to correlated the different geotechnical index properties with geophysical methods in Malaysia. Cosenza et al. (2006) correlated the geotechnical and electrical data at Garchy in France. Sastry and Gautam (2007) studied geotechnical site characterization through geotechnical and electrical data in India. Bhatt and Jain (2014) worked on the correlation between electrical resistivity and water content of sand in Bhopal, India. Bery and Saad (2011) characterized the geotechnical site using approach of electrical resistivity method in Malaysia. Akintorinwa and Adesoji (2009) worked on application of geophysical and geotechnical analysis in engineering site evaluation in Nigeria. Akintorinwa and Abiola (2011) evaluated subsoil for pre-foundation study using geophysical and geotechnical assessment in Nigeria. Faleye and Omosuyi (2011) interrogated geophysical and geotechnical delineation of foundation beds at Kuchiyaku, Kuje Area, Abuja, Nigeria. Abu zeid et al. (2014) calculated expansive soil properties by electrical resistivity in Egypt.

The main target of this research is the determination of geotechnical index properties of soil by employing geophysical and geotechnical techniques. It complements a well-planned, cost-effective drilling and testing program, and may provide a volumetric image of the subsurface rather than a point assessment. All engineering structures (buildings, bridges, airport, runways, and roadways) reside directly or indirectly on the ground. Hence, the strength of the foundation and the mega structures held up by the foundation depends on the bearing capacity of the geologic components underlying the site (Oyedele, 2009).These studies should include determination of depth to the bedrock, the geotechnical integrity of the bedrock, and the physical abilities of foundation (Venkatranmaiah, 2006).

2. Methodology

2.1. Geotechnical Methods

For geotechnical investigation various tests in the laboratory were performed i.e., Sieve analysis, Hydrometer analysis, Moisture content, Specific gravity, Atterberg Limits for soil classification. For sieve and hydrometer analysis two samples were taken in the field, Wt. 1 from the lower Clayey sand layer and the Wt. 2 was taken from the upper, Gravelly sand layer, as shown in Figure 1.

The grain size distribution analysis was conducted according to the ASTM Standard Test Method for Particle-Size Analysis of Soils (D 422-63(2007)).The hydrometer analysis was performed using 50 g of material finer than 0.075 mm. The water content test is designated as D 2216-98 in ASTM test. The specific gravity (Gs) was determined according to the ASTM Standard Test Method for Specific Gravity of Soil Solids (D 854- 06). Liquid Limit, Plastic Limit and Plasticity Index analysis tests were conducted according to the ASTM Standard Test Method (D 4318-05).

2.2. Geo-electrical Method

Resistivity soundings are used to interrogat ground resistivity. Schlumberger configuration is used to take the apparent resistivity (ρa) measurements in which the current electrode (AB/2) moved after every reading and the potential electrode (MN/2) is remained at the fixed position of 0.3m. The position of the potential electrode (MN/2) is changed from 0.3m to 1.0m after taking 19th reading. This is due the reason of potential drop which will fall below the reading accuracy of the voltmeter. The condition of MN ≤ 1/5AB is also satisfied by changing the MN spacing. The total spread length of the survey is 52m.According to the MN/2 of the survey, the total depth of the coverage at least 25m. The resistivity values are determined by using ABEM SAS 4000 Terrameter. The subsurface resistivity value is comparable to the true earth resistivity only if the earth is homogeneous. (Kelly and Mares, 1993; Khalil, 2013).

3. Results and Conclusions

3.1 Soil Investigation Results

Table 1 gives the geotechnical index properties of the samples collected from Wattar area. The specific gravity of Wt. 1 was 2.9. Moisture content of Wt. 1 ranges from 9-10% and Wt. 2 ranges from 4-5. Figure 2 gives the grain size distribution of the investigated soil samples. All of the samples were found to be well-graded. The combine graph of sieve analysis and hydrometer analysis of sample from lower layer i.e., clayey sand, is constructed on a semi logarithmic graph. The percent finer is plotted on the linear scale and grain size is plotted on a log scale as shown in Figure 3.

3.2 Electrical resistivity measurement results

The data obtained from ABEM SAS 4000 Terrameter is processed by IPI win 2 software and converted into curves form that are known as resistivity curves, shown in Figure (4a). The values of current electrode spacing (AB/2) and apparent resistivity are plotted at x-axis and y-axis respectively. The general trend (black line) is given in the software by adding the values of resistivity. Layers are determined by matching the general trend of the data with the help of blue line that will fit the red lines in to best possible curve form. At start the blue line is the straight, when it moves to match the trend of black line into curve; it splits in to pieces. The blue line is moved in every direction to match the curve. At each time when blue line is split, it gives a new layer in the resistivity layer table. Based on the resistivity values, the software has interpreted the data into three distinct layers as shown in Figure (4b). The layer (1) having a thickness of 3.45 m from surface has an average apparent resistivity of 213 Ωm. For layer (2) (12.4 m thick) the average apparent resistivity value decreased to54.6 Ωm. The layer (3) has apparent resistivity value of 232 Ωm.

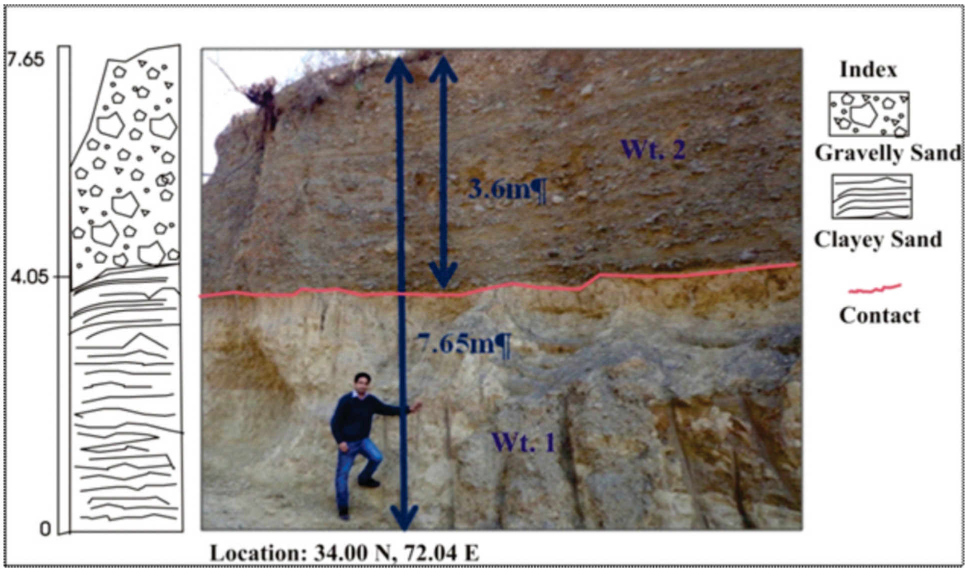

Fig. 1. Outcrop section of field area.

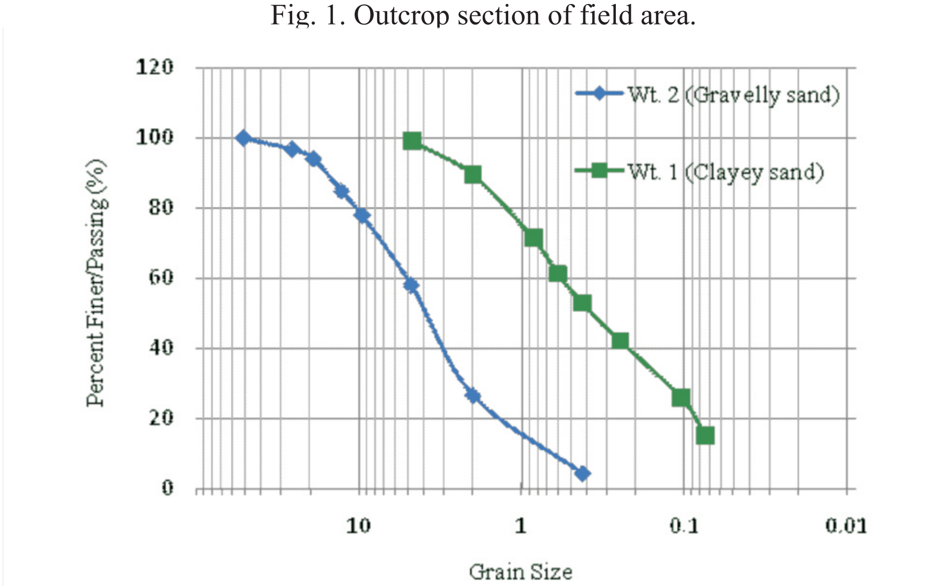

Fig. 2. Grain size distribution of soil sample Wt.1 and Wt.2.

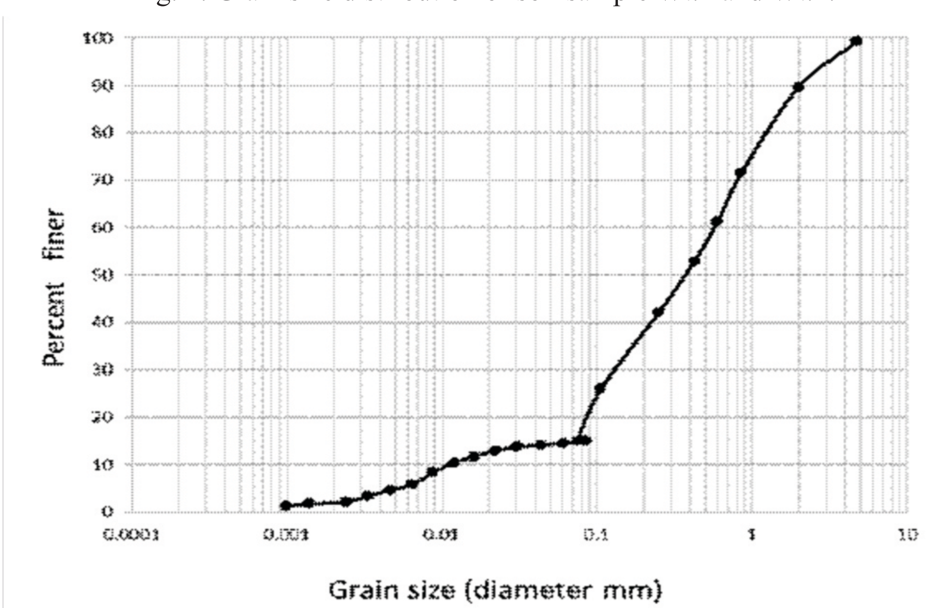

Fig. 3. Combine Grain size Distribution curve of both sieve and Hydrometer analysis of sample Wt. 1 (clayey sand).

3.3 Correlations of Geotechnical and Resistivity Data

The results from electrical resistivity tests and soil characterization tests were analysed together to understand the interrelation between electrical resistivity and soil properties. Correlation between the layer lithology and vertical electrical sounding is achieved by correlating the resistivity values with the standard values of resistivity as shown in Table 2.The field observation and sieve analysis results show that the upper layer is gravely sand and lower layer is clayey sand. The standard range of resistivity values for the sand clay/clayey sand and sand and gravel is 30-215 Ωm and 30-225 Ωm respectively. So the average apparent resistivity value of layer (1) lies in the range of sand and gravel and the average apparent resistivity value of the layer (2) lies in the range of sand clay/clayey sand.

The total thickness of the outcrop measured at the study area is 7.65 m and the contact was marked between the gravely sand and clayey sand at 3.6 m from the centre as shown in Figure (1). The thickness of the upper layer obtained by resistivity values is 3.45 m from the top as shown in resistivity curve.

Electrical resistivity decreases with increasing moisture content in soils as reported in various literatures (Cosenza et al., 2006; Pozdnyakova et al., 2002; Kalinski et al., 1993; Ozcep et al., 2009; Ozcep et al., 2010; Giao et al., 2003). Conduction of electrical current through shifting of ions in pore water is facilitated mainly by greater moisture content. The electrical conductivity is related to the movability of the ions present in the fluid filling the pores. Electrical conductivity depends upon the viscosity and the concentration of the water (Scollar et al., 1990). The estimation of the water content by resistivity measurements requires knowledge of the concentration of dissolved ions.

Moisture content values were correlated with electrical resistivity (Ωm) and the following results were obtained as shown in the form of curve.

In order to create relationship between electrical resistivity and several soil properties, simple regression analysis technique was used. Relationship between moisture content and resistivity values demonstrates non-linear logarithmic correlation with high regression co-efficient R2 = 0.96. The trend of the curve shows that the higher moisture content declines the value of resistivity as shown in Figure 5.

Table 1. Summary of geotechnical index properties.

Property	Wt. 1(Clayey Sand)	Wt. 2(Gravelly Sand)
Gs	2.9	2.5
Liquid Limit (%)	30.17	—
Plastic Limit (%)	20.2	—
Plasticity Index (%)	9.97	NP
4.750mm (%)	99.3	58.14
0.074mm (%)	15	1.69
D10 (mm)	—	0.65
D30 (mm)	0.14	2.4
D60 (mm)	0.6	5
Cc*	—	0.73
Cu**	—	7.69
USCS Symbol***	SC	SP

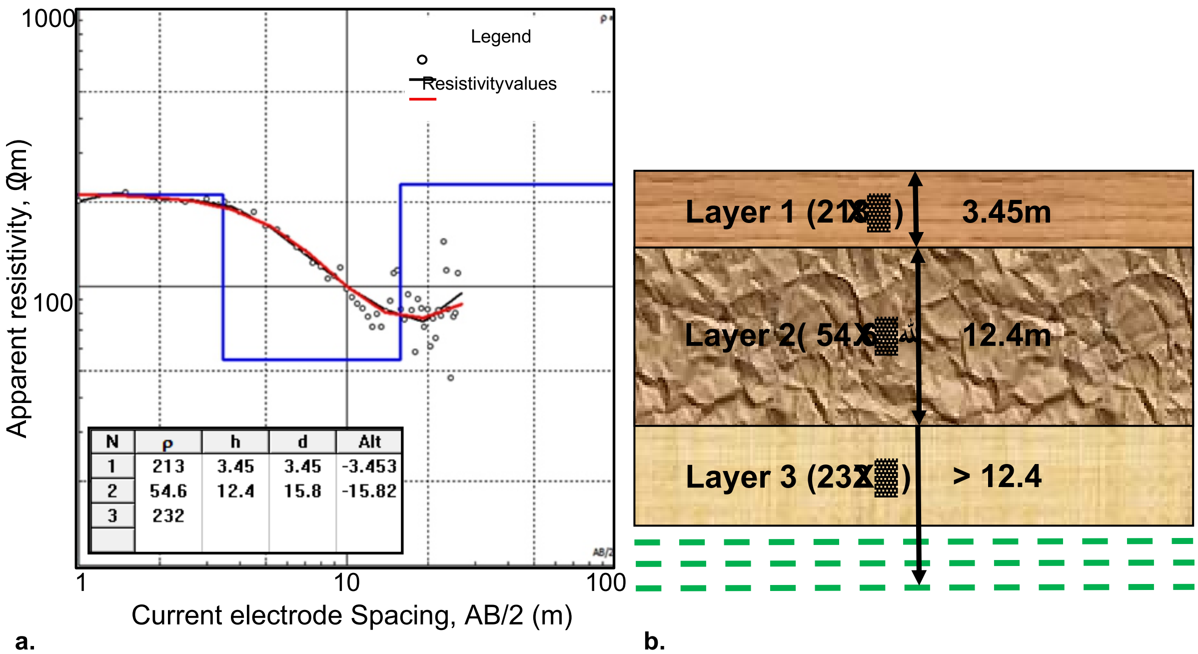

Fig. 4.a. Resistivity curve of vertical electrical sounding. b. Generalized sketch of layers according the resistivity values.Where = resistivity (Ωm), h = height of each layer (m), d = layer depth from the surface (m), Alt = altitude from datum (m).

Table 2. Resistivity of common geologic materials.

Materials	Nominal resistivity(Ωm)
Ash	4
Laterite	800-1500
Lateritic soil	120-750
Gravel (Dry)	1400
Gravel (saturated)	100
Dry sandy soil	80-1050
Sand clay/clayey sand	30-215
Sand and gravel	30-225
Saturated landfill	15-30
Glacier ice (temperate)	2×10^6-1.2 X 10^8
Glacier ice (polar)	5×10^4-3 X 10^5 *
Permafrost	10^3-> 10^4

.* - 10°C to - 60°C, respectively; strongly temperature-dependent. Based on Telford et al.(1990); Reynolds (1987);Reynolds and Paren(1980; 1984).

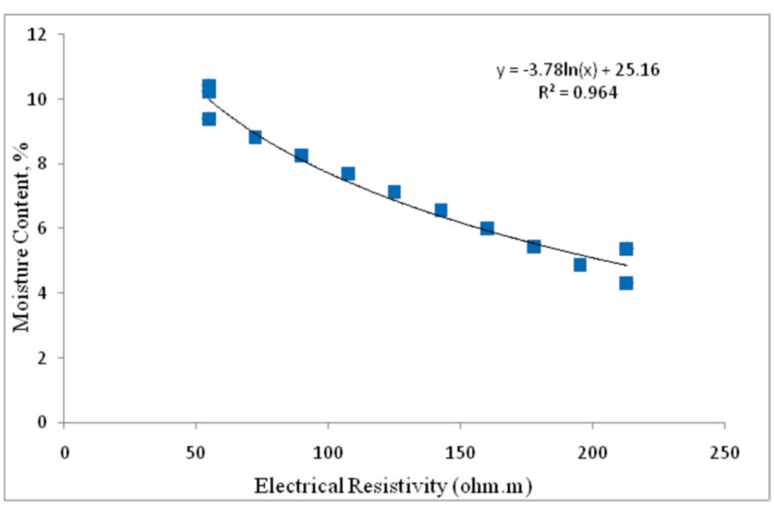

Fig. 5. Correlation of electrical resistivity with moisture content.

4. Conclusions

Electrical resistivity values are successfully correlated with geotechnical propertiesof sandy and silty soils in the study area. Significant quantitative and qualitative correlations have been obtained between the resistivity and lithologies, thickness of layers and moisture content. Relationship between moisture content and resistivity values demonstrates non-linear logarithmic correlation with good regression co-efficient R2 = 0.96. The trend of the curve shows that the higher moisture content decreases the value of resistivity. However, further detailed research work is required to develop such relationships in different types of soils at varying moisture contents.

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