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Investigating Linkages between Electrical Resistivity and Physical Characteristics of Unsaturated Soils

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Abstract—*Proper understanding of the relationships between the physical factors influencing the engineering properties of soils and their measurable electrical parameters provides a methodology by which the engineering behaviour of soils can be predicted non-intrusively. This paper presents the preliminary results of an ongoing research on correlations of electrical resistivity with index and engineering properties of blends of shedi soil, a problematic soil locally available throughout the Konkan area, with river sand. The unsaturated soil, which is composed of soil particles, water and air, exhibit more complex properties due to negative pore water pressure and matric suction when compared to saturated soils. Digital multimeters, a resistivity box and a dc power source are utilised to measure the electrical resistivity of the unsaturated soil samples. This paper presents how the physical factors like water content and dry density influence the electrical resistivity and also the effects of degree of saturation on the resistivity for different gradations of the soil.*

1. INTRODUCTION

The unsaturated soil, which is composed of soil particles, water and air, exhibit more complex properties due to negative pore water pressure and matric suction when compared to saturated soils. The outcomes of the study would provide proper understanding about the influence of fundamental physical characteristics of unsaturated soils on their electrical responses. The paper presents the preliminary results of an ongoing research on the correlations of electrical resistivity with index and engineering properties of blends of shedi soil- (a lithomargic clay and a problematic soil present at depths of 1-3 meters below the top lateritic outcrops throughout the Konkan area) with river sand. Digital multimeters, a dc power supply and a resistivity box with stainless steel electrodes were used to measure the electrical resistivity of compacted unsaturated soil samples.

Bai[2] conducted a laboratory study on the effects of physical properties on electrical conductivity of lateritic soils. Studies on electrical resistivity of sand-siltmixtures[7]compacted clays[1], [5], marine clays[6]and expansive soils[8] have also been conducted. However, the laboratory studies of electrical resistivity on unsaturated dispersive type of soils such as, shedi soil and its blends with river sand are rarely reported.

2. TEST MATERIALS

Shedi soil is the name given to the locally available whitish, pinkish or yellowish lithomargic soils. These soils are characterized by high silt content, and low strengths [4]. Shedi soil in the current study was collected from Padapanambur, which is located in Dakshina Kannada district near to Mangalore. Locally available river sand was used in the present study. River sand, used for blending with shedi soil, was collected from Kulur river site.

For the present study, soil samples were collected and were investigated for geotechnical and electrical resistivity studies by adding different percentage of river sand to them. The river sand was added to shedi soil at rates,of 0, 10, 20, 30, 40 and 50% by weight of dry soil. The results of the geotechnical tests conducted as per the IS specifications are presented in Table 1.

Table1: Basic geotechnical parameters of the soil samples.

Parameter	Percentage of river sand added					
	0 %	10%	20%	30%	40%	50%
G	2.58	2.58	2.60	2.61	2.61	2.62
PL (%)	33.90	31.42	30.50	29.90	27.10	25.30
LL (%)	47.00	44.50	40.60	39.40	37.70	34.40
PI (%)	13.10	13.08	10.10	9.50	10.60	9.10
OMC (%)	26.80	24.07	20.90	19.00	17.00	13.30
Γdmax (g/cc)	1.48	1.56	1.62	1.72	1.80	1.87
Clay size (%)	36.60	26.90	28.90	23.40	19.40	15.20
Silt size (%)	52.60	50.80	39.60	32.10	28.30	24.00
Sand size (%)	10.80	22.30	31.50	44.50	52.30	60.80

G- Specific Gravity, PL- Plastic Limit, LL- Liquid Limit, OMC- Optimum Moisture Content, γ_{dmax}- maximum dry density

3. TEST APPARATUS

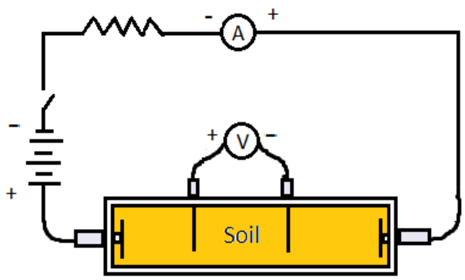

Fig. 1: Circuit diagram showing the connections for the setup.

4. MEASUREMENT OF RESISTIVITY

4.1 Calibration of the equipment

Standard solutions of NaCl and KCl, with different molarities(0.2 to 1.0 M) were used for standardizing the test setup. Thus a calibration factor was obtained.

4.2 Measurement of soil electrical resistivity

The soil was filled in the resistivity box by compaction. The stainless steel electrodes of the resistivity box were connected to the multimeters and the dc power source as shown in the Fig. 1. The resistance of the soil thus obtained is multiplied with the calibration factor and a geometric factor (A/L) of the resistivity box to obtain the apparent resistivity, where 'A' is the cross sectional area of the current electrode and 'L' is the separation between the current electrodes.

5. RESULTS AND DISCUSSION

5.1 Effect of moisture content on electrical resistivity

It was observed that soil resistivity decreased almost linearly up to moisture content around 25% for all soil samples at fixed dry density. The average rate of reduction in soil resistivity was 926.43 Ohm-m for the increase of moisture from 9% to 20%. Of these, maximum variation was observed in the sample of shedi soil with 40% river sand. However, it was found that soil resistivity results were almost constant after 35% to 40% moisture content. The observed soil resistivity ranged from 19.91 to 45.11 Ohm-m at 50% moisture content in the soil samples. The variations of resistivity with moisture content of soil samples at fixed dry density are presented in Fig. 2. The R^2 values vary from 0.90 to 0.97.

The discontinuity of pore water causes an extremely high resistivity in the materials. The continuity of pore water can be obtained for water content higher than the plastic limits which is almost 'adsorbed water content'. This results in a relatively lower resistivity value at higher water content[3].

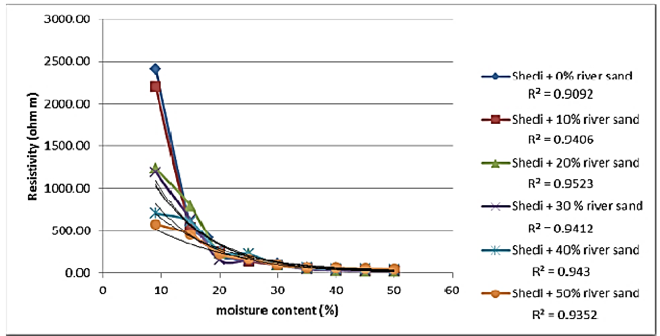

Fig. 2: Variations of resistivity with moisture content of soil samples at fixed dry density.

5.2 Effect of moisture content and dry density on soil Resistivity

The variation of resistivity with dry density at fixed moisture content of studied soil samples are presented in Fig. 3. It was found that soil resistivity decreased with increase of density for all types of soil samples. Soil resistivity decreased almost linearly with an average reduction of 433.1Ohm-m for an increase of dry density from 1.3 to 1.45 g/cc at 9% moisture content for the six samples. The least variation in soil resistivity was observed in soil sample consisting of shedi soil with 50% river sand for the same condition. Soil resistivity decreased at an average reduction of 83.74Ohm-m at 18% moisture content with an increase of dry density from 1.3g/cc to 1.45g/cc. Whereas, the average reduction in soil resistivity was only 24.91Ohm-m at 30% moisture content. Therefore, the variation in soil resistivity with density was not substantial at high moisture content. However, soil resistivity did not show remarkable changes for further increase in dry density at the three moisture contents for any of the samples.

An increase in density is associated with an increase in degree of saturation. More pronounced bridging occurs between the particles at higher degree of saturation. In addition, increase of density is associated with remoulding of clay clods, elimination of interclod voids and reorientation of particle. Therefore, soil resistivity decreases with the increase of density[1].

The average rate of reduction in soil resistivity with the increase of dry density from 1.30 to 1.45 g/cc is presented in Table 2.

It was observed that soil resistivity decreased with increase of moisture content and density. However, test results showed that soil resistivity was more sensitive to moisture content compared to density. It is seen that soil resistivity decreased with increase in moisture content and density.

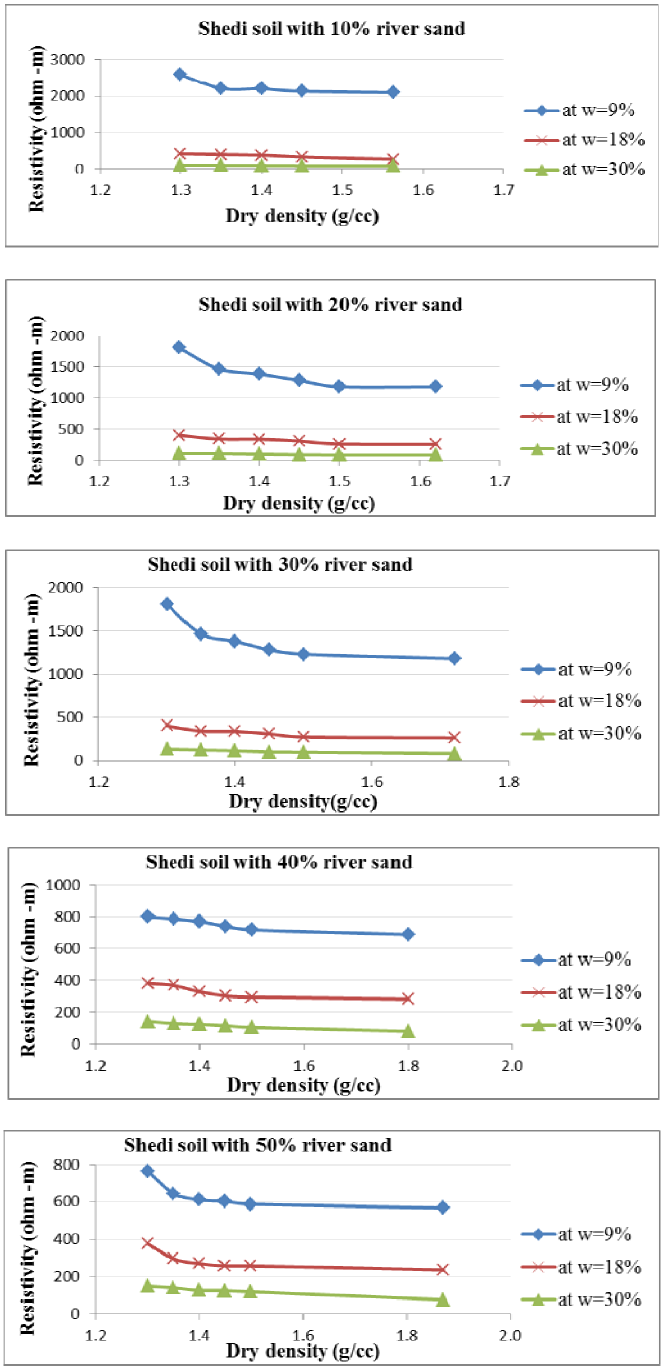

Fig. 3: Comparison of the effect of moisture content and density with soil resistivity for Shedi soil with 0%, 10%, 20%, 30%, 40%, 50% river sand.

Table 2: Summary of Average Reduction Rate of Soil Resistivity.

Moisture Content (%)	Reduction Rate of Resistivity (Ohm-m per g/cc)
9	2887.31
18	558.27
30	166.06

The rate of reduction was found to be high at 9% moisture content and decreased with increase of moisture content. Thus, soil resistivity was sensitive to density at low moisture content. However, rate of reduction decreased to 166.06 Ohm-m per g/cc at 30% moisture content. Therefore, soil resistivity was more sensitive to moisture content compared to density at higher moisture content.

Under applied electrical field, electrical conduction occurs through the pore space by conductive ions in the water solution. Thus, electrical conduction in soil mainly depends on moisture content.

5.3 Effect of degree of saturation on soil resistivity

The water content and density of soil can be combined to a single geotechnical parameter called degree of saturation. The variation of soil resistivity with degree of saturation is presented in Fig. 4 for all the soil samples. It was observed that soil resistivity decreased with increase of degree of saturation with R^2 value ranging from 0.699 to 0.941. Degree of saturation increases with the increase of water content or dry density[1]. Average soil resistivity was 1363.3Ohm-m at 30% degree of saturation. However, average soil resistivity decreased to 168.54Ohm-m at 90% degree of saturation.

Increase in degree of saturation yields changes in clay clods, reduction in interclod macro voids and orientation of clay particles. Therefore, soil resistivity decreased with the increase in degree of saturation.

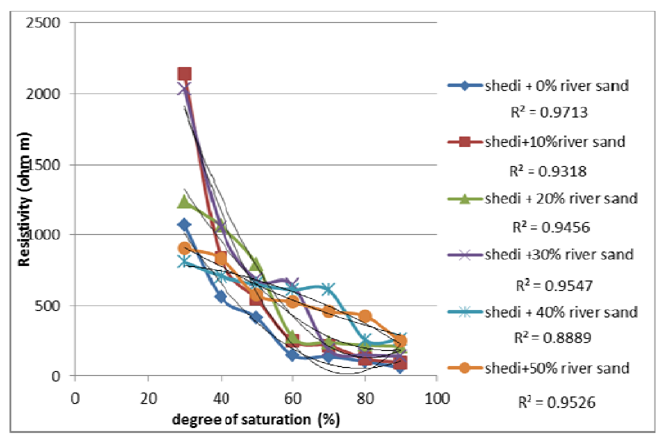

Fig. 4: Comparison of variation of soil resistivity with degree of saturation for Shedi soil with 0%, 10%, 20%, 30%, 40%, 50% river sand.

5.3.1 Effect of degree of saturation on electrical resistivity on increase in percentage of fine content.

Soil resistivity tests were conducted on all the soil samples at 9%, 18% (partially saturated) and 30% moisture content (fully saturated) and 1.3 g/cc dry density. Test results showed that soil resistivity was dependent on fine fraction for the soil samples as presented in Figures 5 & 6. It was observed that soil resistivity decreased with increase of percent fines at 9% and 18% moisture contents for a dry density of 1.3 g/cc.

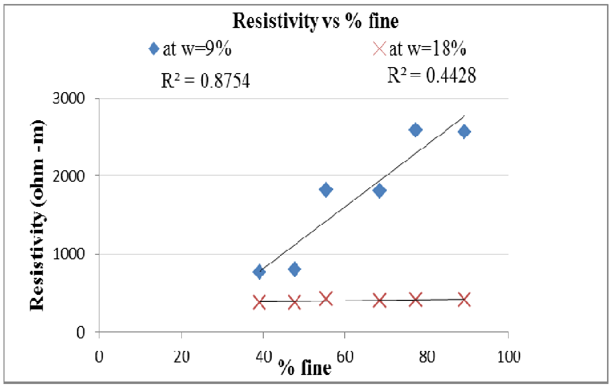

Fig. 5: Correlation between percent fines and soil resistivity for shedi soil and their blends at 9% and 18% moisture contents.

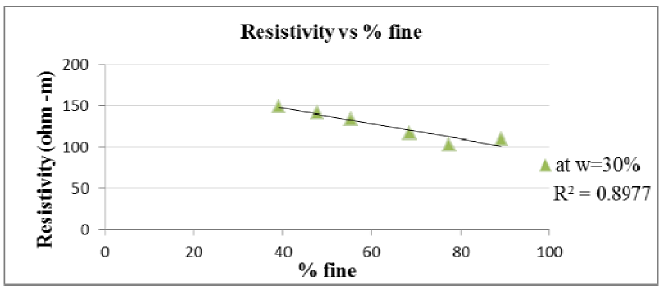

Fig. 6: Correlation between percent fines and soil resistivity for shedi soil and their blends at 30% moisture content.

Test results showed that the resistivity increased from 764.8 to 2564.27Ohm-m at 9% moisture content for an increase in percent fines from 39.16% to 89.27% whereas, soil resistivity increased from 375.01 to 424.77 Ohm-m at 18% moisture content. At this stage, all the soil samples are partially saturated. Specific surface area of soil particles increases as percent fines increases. As the surface area increases, more water is required to make the soil saturated or for the formation of continuous water film around fine particles. In the absence of continuous water film, bridging between soil particles is not possible to occur. In addition, even though conductive clay content is present, ionic conduction does not take place without proper water bridging between soil particles. Hence at undersaturated conditions, the increase of fine percentage would result in increase in electrical resistivity as a result of greater specific surface area.

However, there was a decrease in soil resistivity from 148.97 to 103.37 to Ohm-m at 30% moisture content and 1.3 g/cc dry density with an increase in percent fines. At this stage all the soil samples are fully saturated. Soils with high percentage of fine content are often composed of more conductive clay particles[1]. Therefore, soil resistivity may decrease with increase in fine content at fully saturated conditions, since continuous film of water will be maintained along the inter aggregate voids which facilitate ionic conduction. However, the most influential factor for soil resistivity is moisture content and density.

6. CONCLUSIONS

- Soil resistivity decreased with increase of moisture content. The average reduction in soil resistivity was 1006.42Ohm-m for an increase in moisture content from 9% to 20%. It was observed that soil resistivity was almost independent after 35-40% moisture content. Enhanced electrical conduction due to the presence of moisture might cause the reduction in soil resistivity with the increase of moisture.
- Soil resistivity decreased at an average reduction of 433.1Ohm-m, 83.74Ohm-m and 24.91Ohm-m at moisture contents of 9%, 18% and 30% respectively for an increase in dry density from 1.3g/cc to 1.45g/cc. Hence, the variation in soil resistivity with density was not substantial at higher moisture contents. However, this variation was comparatively less for further increase in dry density at the same moisture content. Reduction of interclod pores and better particle-to-particle contact might cause reduction in soil resistivity with the increase of dry density.
- It was also concluded that the effect of moisture content on soil resistivity was more pronounced than the effect of dry density.
- It can be generalized that, as the percentage of fine particles in the soil sample is increased at partially saturated conditions, the concept of specific surface area comes into role, resulting in the increase of electrical resistivity. But at saturated conditions, presence of water bridging alleviates electrical conduction, and hence electrical resistivity reduces as the percentage of fine particles is increased.

7. SCOPE

Electrical resistivity measurements can be done quickly and economically compared to conventional geotechnical testing methods. This study would enhance the knowledge on how the physical factors influence the electrical responses of soils at undersaturated conditions compared to saturated conditions. Since the fundamental physical properties of soil play a key role in its engineering behavior, the linkages between these basic properties and its electrical properties would furnish a way to develop a methodology for quantifying the engineering and index properties of the soils using a comparatively cost-effective, less time consuming and easier method.

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