3 (1988) 3

Indian Geotechnical Conference (IGC-88), Allahabad, December 1988, Vol. I

Model Studies on Electrical Resistivity of Soils

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SYNOPSIS: With advancement in technology, Geotechnical engineers have well realised the importance of electrical resistivity sounding method for subsurface explorations. However, there is a need to varify the reliability of interpretation techniques commonly practiced. This is only possible through laboratory model studies on layered soil systems under controlled conditions. The model studies conducted herein presents the results of electrical resistivity of two soils under controlled conditions of density and layer thicknesses by using both Wenner's as well as Schlumberger's circuit arrays. A comparison has also been made between the interpreted values of resistivity and thickness with their true values. The results are very much encouraging.

1 INTRODUCTION

With advancement in technology, Geotechnical engineers have well realised the importance of Geophysical methods for subsurface explorations. Electrical resistivity is one such non-destructive technique which is now being increasingly used as a complementary to direct method of exploration due to its simplicity, low cost and quick output.

Resistivity soundings at a field location provide the values of apparent resistivities (ρ_a) at different depths of subsurface strata beneath. The apparent resistivity upto any particular depth is a function of true resistivities (ρ) and thickness (t) of various strata through which the current passes. Unless one interprets ρ_a to derive ρ it is not possible to identify various strata in subsurface profile.

There are number of interpretation techniques available for evaluating ρ and t of each of the stratum from the resistivity sounding data. To understand the reliability of various interpretation techniques, attempts were made by Kate and Khichchu Mal (1983) to compare results of interpreted resistivity (ρ_i) and thickness (t_i) of different subsurface strata obtained by various interpretation techniques from resistivity sounding data with the true values of ρ and t obtained from actual bore hole data in the field. It was observed that the interpreted data was not comparable with the actual bore hole data. This indicated the need to develop a suitable method to interpret resistivity sounding data on the basis of experimental studies under controlled conditions.

In the light of this, as a preliminary approach towards the above goal, present laboratory investigation was planned in which model studies on electrical resistivity of soils were conducted under controlled conditions. The studies were conducted on two soils namely Delhi silt and Yamuna sand.

An attempt has also been made to interpret the laboratory electrical resistivity sounding results by using different interpretation techniques. The interpreted values have been compared with the true values observed in the laboratory.

2 ELECTRICAL RESISTIVITY SOUNDINGS

2.1 Circuit arrays

Two circuit array arrangements are commonly used for conducting electrical resistivity soundings in the field. These are Wenner's circuit array and Schlumberger's circuit array. In Wenner's array the electrodes are spaced at equal spacings, the resistivity ρ_a is calculated by using the following equation.

$$\rho_a = 2\pi a_1 R \quad \ldots (1)$$

In which a_1 is the electodes spacing and R is the resistance i.e. the ratio between potential difference(E) and current(I). The depth of current penetration in this case is equal to a_1.

In Schlumberger's array, the seperations between adjacent electrodes are not equal but current electrodes are spaced much farther apart than the potential electrodes. The resistivity ρ_a is obtained from:

$$\rho_a = \pi R(a_2^2 - b^2)/2b \quad \ldots (2)$$

Where $2a_2$ is spacing between current electrodes and b is the spacing between potential electodes. The depth of current penetration into the ground for the arrangement is a_2.

2.2 Interpretation

The log of subsurface profile can only be prepared when the following informations are available. These are (i) each and every stratum comprising the profile in identified (ii) Their thicknesses, sequence and depth below ground is known and (iii) the depth of ground water table if exists, within the depth explored is known. The electrical resistivity soundings data is capable of furnishing all the above information provided it is interpreted correctly. The commonly used interpretation techniques are Moore's Cumulative plot (Moore, 1961), Hummel's extension (Hummel, 1931). Direct slope (Baig, 1980), Inverse slope (Sankar Narayan and Ramanujachary, 1967), Barnes layer method (Barnes, 1954) and Master or Standard curve matching (compagnie General de Geophysique, 1963).

3 EXPERIMENTAL PROGRAMME

The present study was planned only on dry soil having very high resistivities; the electrical instruments used were highly sensitive.

3.1 Instruments

Unit power : The 'unit power instrument' having capacity to stabilize the voltage ranges from 0 - 40 volt, was used for constant Direct Current supply through laboratory mains. It was connected with the outer electrodes through micro Ammeter as shown in Fig.1

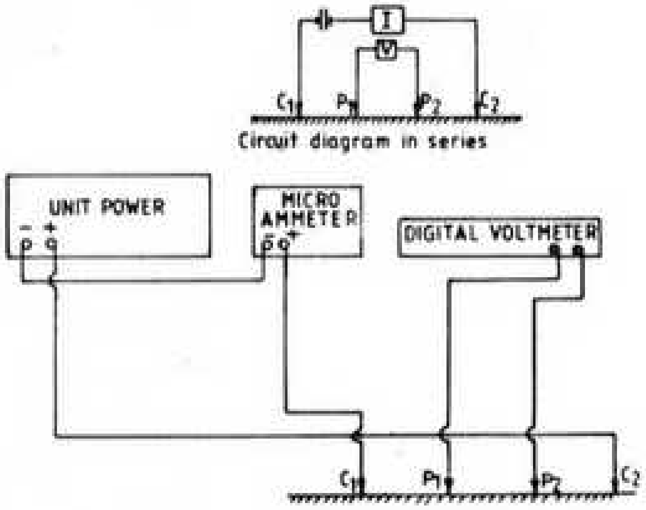

Fig.1 Schematic arrangement for measuring soil resistivity in laboratory.

Micro Ammeter : The 150B micro ammeter range (0.3-300 A-nano amperes) was used to measure the current very precisely.
Digital Voltmeter : The digital voltmeter having range of 100 millivolts to 1000 volts was used to measure the potential difference developed between the potential electrodes.

3.2 Accessories

Wooden tank : A wooden tank of dimension 244 cm x 30 cm x 83 cm was fabricated out of water proof 12 mm thick ply wood and was well stiffened by wooden stiffeners. The soils were compacted at desired densities in the tank to study their electrical resistivities under various conditions. A wooden leveller with handle was used to level the soil at each stage during compaction.
Compaction device : Compaction device was specially fabricated to have the uniform compaction of soils. It consists of a m.s. base plate with steel collar in the centre and handles to lift it. While compacting the soil the standard proctor hammer was to be placed inside the collar and the required blows were then given so that the blows are transferred to the soil through the base plate.
Wooden scale : A wooden scale of width 10 cm and length equal to that of wooden tank was fabricated. The holes of 6 mm diameter at 2.5 cm intervals were drilled in the centre along the length of the scale. These holes facilitate driving of electrodes into the soil at calculated spacings. The distances were also marked with the paint on this scale.
Electrodes : Four copper rods each of 6 mm diameter and 22.5 cm length were used as electrodes. The clips were used to connect the electrodes to the measuring instruments through the wires.

3.3 Soils studied

In the present investigation two soils namely Delhi silt and Yamuna sand were used.Delhi silt has sand, silt and clay percentages of 29, 57 and 14 respectively. It has liquid limit, plasticity index and shrinkage limit of 33%, 10% and 21% respectively. It is classified as silt, sandy with low plasticity (ML). Yamuna sand has 100% sand particles and it's maximum and minimum densities are 1.67 and 1.35 g/cc respectively. The angle of shearing resistance of this sand is around 44° at compacted density.

3.4 Experimental Procedure

The dry soils were compacted in the wooden tank at desired dry density and thickness in layers of 10 cm thick. The soil surface was levelled and a wooden scale was placed above it in the centre of tank along it's length. The electrodes were pushed through the scale holes into the soil for about 15 cm deep. The electrodes were arranged as per circuit array. The electrical connections between electrodes and the instruments were made as indicated in Fig.1. The perspective view of the complete set up is shown in Fig.2. The power unit was switched on and the

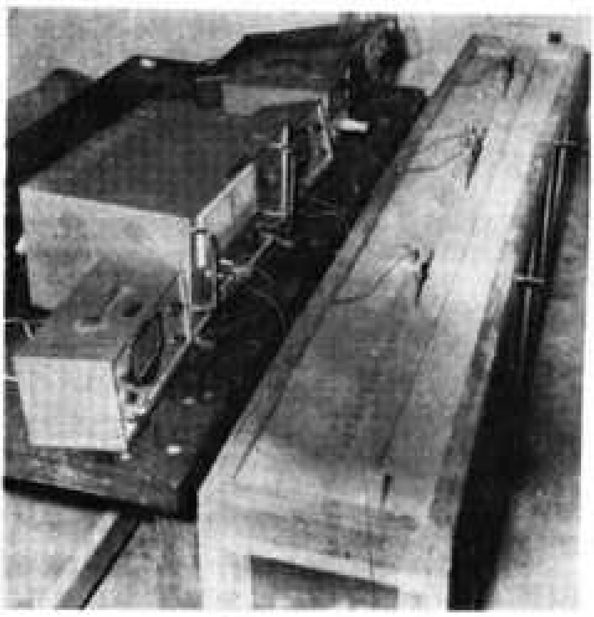

Fig.2 Perspective view of the complete set-up.

observations for current and potential difference were recorded. The electrode spacings were then changed. The procedure was repeated for different electrode spacings and circuit arrays. In Wenner's array the electrode spacings (a_1) were increased by 5 cm whereas Schlumberger's array the spacings between the potential electrodes (2b) were kept constant at 5 cm and current electrode spacing ($2a_2$) were increased till the desired depth of current penetration was reached. The Equation 1 and 2 were used to calculate the resistivity by Wenner's & Schlumberger's array respectively.

3.5 Parameters studied

All the experiments were conducted by using both Wenner's and Schlumberger's circuit array arrangement as per the following programme :

(i) Delhi silt as one single layer of maximum thickness 80 cm. The observations of E and I were taken during the compaction of layers thicknesses 20 cm, 40 cm, 60 cm and 80 cm. The dry densities varied were 1.35 g/cc, 1.4 g/cc, 1.45 g/cc and 1.5 g/cc.

(ii) Yamuna sand as one single layer of maximum thickness 80 cm. The observations of E and I were taken during the compaction of layers thicknesses 20 cm, 40 cm, 60 cm and 80 cm. The dry densities varied were 1.5 g/cc, 1.6 g/cc and 1.7 g/cc.

4 PRESENTATION AND DISCUSSION

4.1 Delhi silt

The variation between the electode spacings and the corresponding resistivity is shown in Fig.3 and 4 for compaction densities of 1.35 g/cc and 1.5 g/cc which corresponds to the density at loosest and densest state respectively obtained from Wenner's circuit array.

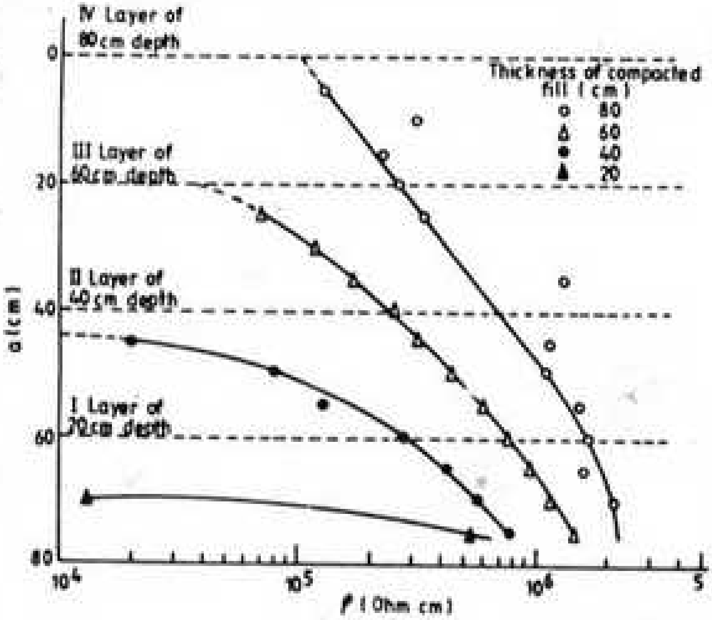

Fig.3 Resistivity variation with electrode spacings for density of 1.35 g/cc.

These figures also show the variation of electrodes spacing with resistivity for observations taken when the thickness of compacted fill were 20 cm, 40 cm, 60 cm and 80 cm. Referring to Fig.3 it can be seen that with increase in electodes spacing the electrical resistivity also increases as shown. This is true for all the compacted layers studied, e.g. for the thickness of soil layer is 80 cm the electrical resistivity increases from 1.3 x 10^5 ohm. cm to 244 x 10^5 ohm. cm, when the electrodes spacing increases from 5 cm to 70 cm respectively, same trend has been observed for the observations for all other compacted layers. The depths of current penetration have been corrected to identify the same existing layer for which resistivity observation corresponds e.g. the current penetration of the top layer of 10 cm for the observation layer of 20 cm becomes the 70 cm depth of current penetration for the observation layer of 80 cm thickness.

It is very much interesting to note that although the soil is same even then there is a variation in electrical resistivity with electrodes spacing. This may be due

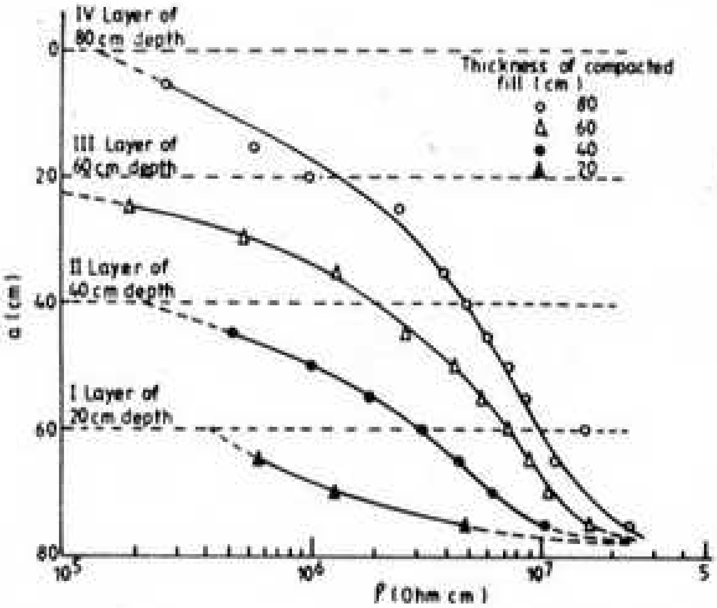

Fig.4 Resistivity versus electode seperation for density of 1.5 g/cc.

to the changes in densities of the lower layers during compaction. If it is possible to achieve the uniform density throughout, then for the same soil and for the same initial compaction density there would have been no variation in density values even if the electrodes spacing have been changed (Kate 1978).

It can also be seen at the layer 10 cm above the bottom, the electrical resistivity observed are 5.4 x 10^5 ohm.cm, 7.9 x 10^5 ohm. cm, 15 x 10^5 ohm. cm and 23 x 10^5 ohm. cm for the measurement taken at the compaction height of 20 cm, 40 cm, 60 cm and 80 cm respectively for the initial compaction density 1.35 g/cc. Similar trend in electrical resistivity has been observed at all other soil layers for different initial compaction densities studied herein. It is again interesting to note from Fig.4 that all the four curves are converging near bottom most layer indicating that the maximum possible dry density has been already reached and there may not be any more change in electical resistivity value beyond this. The resistivity in this case is around 2.8 x 10^7 ohm.cm. Similar trends have been also seen when the studies were conducted by using Schlumberger's circuit array.

In the present study the experiments were conducted on fully dry soil without any moisture. To understand the effect of density on electrical resistivity the variation between initial compaction dry density and resistivity for Delhi silt is shown in Fig.5. The values of resistivities at different electrodes spacings have been obtained for the case of total compacted thickness of 80 cm for different compaction densities. The figure shows the range of electrical resistivity with density. .t can be seen that the resistivity ranges are 1 x 10^5 ohm.cm to 23 x 10^5 ohm. cm, 1.1 x 10^5 ohm. cm to 38 x 10^5 ohm.cm, 1.2 x 10^5 ohm.cm to 66 x 10^5 ohm. cm and 1.4 x 10^5 ohm.cm to 150 x 10^5 ohm. cm for the densities of 1.35 g/cc, 1.4 g/cc, 1.45 g/cc and 1.5 g/cc respectively. The average values of resistivity corresponding to each dry density have been plotted by a firm line curve which indicates increase in density with increasing resistivity. Referring back to Chauhan and Kate (1983), they have indicated reverse trend i.e. decreasing resistivity with increase in dry density. Although in both

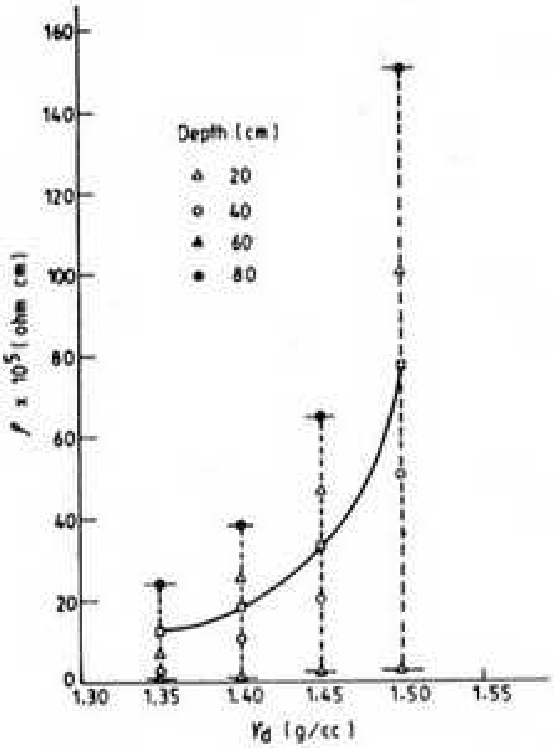

Fig.5 Resistivity variation with dry density.

the cases the plots are between dry density and electrical resistivity. However in case of former there was initial moisture content in remoulded samples, whereas in the latter the initial moisture content was zero. This clearly pointed out the facts of presence of initial moisture content in changing the electrical resistivity even for the same dry density and can be explained as below :

It is well known that current follows the path of least resistance. Water has very low resistivity in comparison to the soil, whereas in wet soil flow of current will be through the moisture present in the voids. This view is further strengthened by the fact that dry soils are almost non-conductive to the flow of electric current.

Keeping the above idea in mind it can be anticipated that the path of current flow at lower densities would be tortuous due to less contact among soil particles and air voids.

The Fig.6 and Fig.7 by Wenner's and Schlumberger's circuit array respectively show the variation between the electrodes spacing and the electrical resistivity for the densities for the observations taken at surface of 80 cm thick soil. It can be seen from these figures the high compaction density curve exhibits increase in resistivity as electrode spacing increases i.e. increase in resistivity with increasing depth this also explain the effect of compaction on the resistivity at similar depth, there is not significant change in resistivity for the corresponding change in density. Similar variation has been observed in Fig.7 in case of Schlumberger.

4.2 Yamuna sand

As illustrated for Delhi silt, similar studies using Wenner's and Schlumberger's circuit arrays, changes in densities etc. were conducted on Yamuna sand compacted upto a maximum thickness of 80 cm.

The results of electrodes spacing versus resistivity have been shown in Figs 8 and 9. They show the obser-

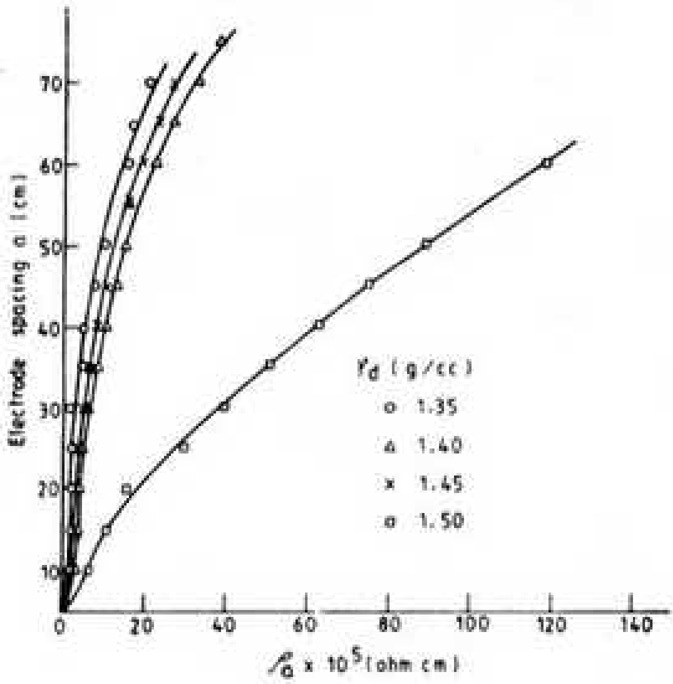

Fig.6 Variation of resistivity with electrode **seperation** by Wenner's array.

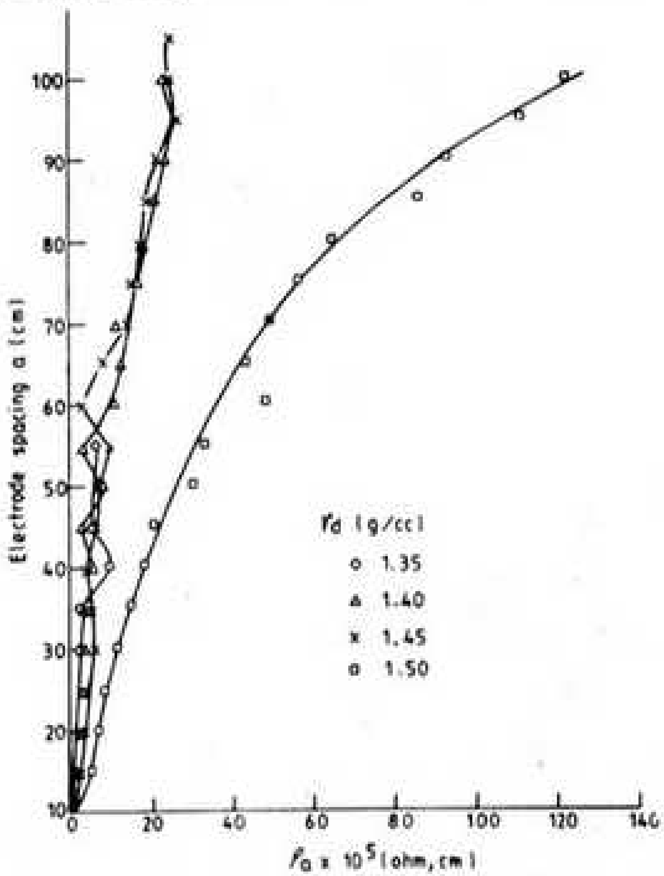

Fig.7 Resistivity variation with electrode spacings by Schlumberger's array.

vation at various layers during compaction for the densities of 1.6 g/cc and 1.7 g/cc by using Wenner's circuit array. These figures show this variation as similar to that observed in case of Delhi silt i.e. the effects of heavy compaction on the bottom layers exhibited by high values of resistivity. Similar result has been observed for density of 1.5 g/cc i.e. at the loosest state and also for Schlumberger's circuit array.

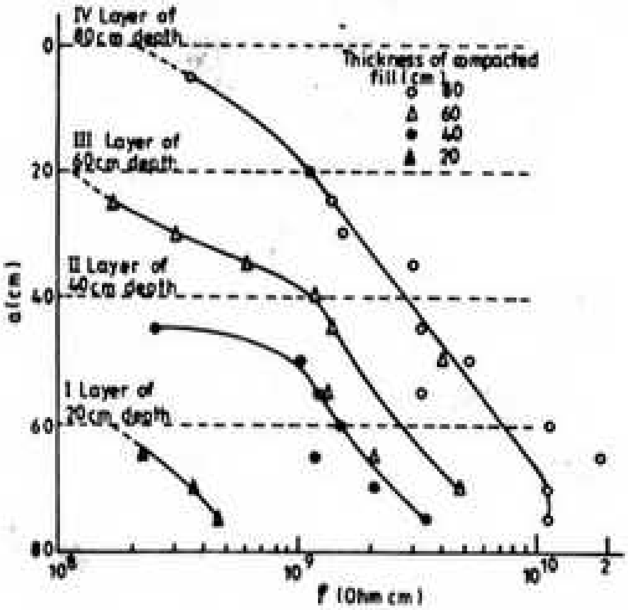

Fig.8 Electrical resistivity versus electrode spacings for density of 1.6 g/cc.

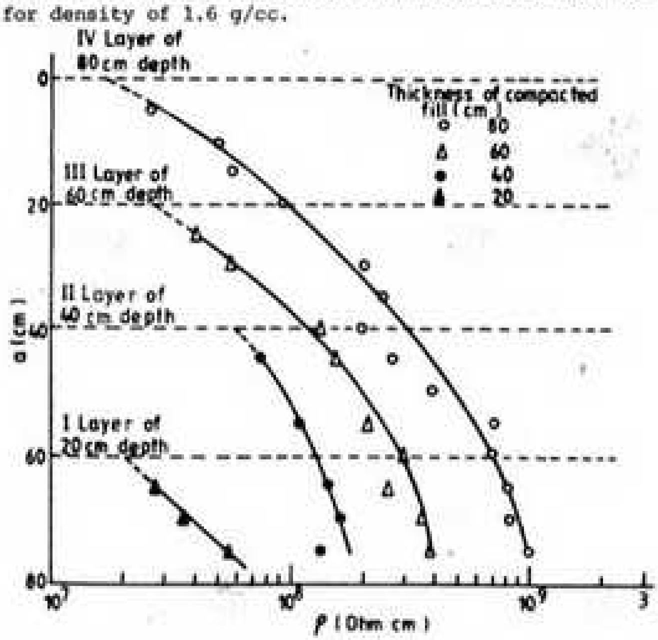

Fig.9 Variation of resistivity with electrode seperation for density of 1.7 g/cc.

The Fig.10 shows the variation between the electodes spacing and the resistivity for different densities by Wenner's array. The observation were taken at surface of 80 cm thick soil. It can be seen from this figure that on an average the resistivity for the losest density of 1.5 g/cc also remains constant upto certain depth. However, for the higher compaction density the curve exhibits increase in resistivity as the electrodes spacing increases i.e. increase in resistivity with increasing depth. This also explained the effect of compaction on the resistivity at similar depth; there is no significant change in resistivity for the corresponding change in density. Similar variations have been observed in case of Schlumberger's circuit array.

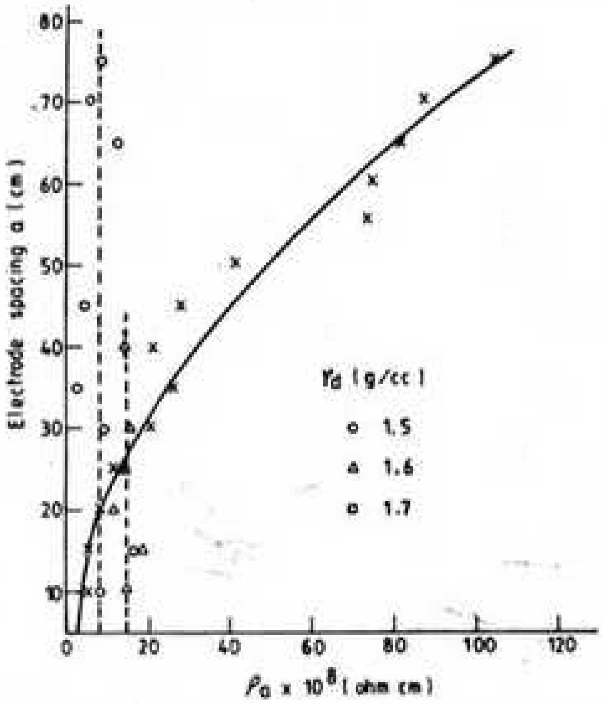

Fig.10 Resistivity versus electrode seperation for different densities.

4.3 Interpretation techniques - a comparative study: Herein an attempt has been made to varify the reliability of various interpretation techniques as mentioned earlier for laboratory resistivity soundings data under controlled conditions. The interpreted values of resistivity (ρ_i) and thickness (t_i) have been presented in Table 1 as obtained by various interpretation techniques. In the present laboratory study, it was not possible to use Master curve technique because of small thickness of each layers. The Table also shows the values of true resistivities (ρ) of Delhi silt and Yamuna sand obtained in the present laboratory experiments at different thicknesses (t). The comparison of these results indicate significant deviations of interpreted values from the true values. Which means, a caution needs to be exercised while selecting the interpretation technique. This also suggests the need for developing a reliable method.

5 CONCLUSIONS

On the basis of laboratory model studies on soils under control conditions, the following main conclusions have been arrived :

(i) For both the dry soils studied, the resistivity increases with increase in initial compaction density.

(ii) The Wenner array and Schlumberger array provides nearly the same trend for all the variations studied. However there are marginal differences in resistivity values observed for the same condition.

(iii) The laboratory studies under control conditions indicate that the available methods of interpretation has much more limitations to provide the correct values of true resistivity and thickness of each of the layer.

The studies indicate that there is a plenty of scope to extend this work with a view to suggest a rational method for electrical resistivity sounding data interpretation for shallow depth.

Table 1 Comparison of layer thicknesses and resistivities obtained from different techniques.

Soil Type	Moore's with Hummel's Extension		Direct Slope		Inverse Slope		Barne's Layer		True Resistivity Values	
	t_i cm	ρ_i Ohm cm	t_i cm	ρ_i Ohm cm	t_i cm	ρ_i Ohm cm	t_i cm	ρ_i Ohm cm	t cm	ρ Ohm cm
Delhi silt	20	3.6×10^6	20	3×10^7	25	4.4×10^5	20	2.9×10^6	20	14.0×10^5
	40	22×10^6	40	25×10^7	41.5	12.5×10^5	40	8.1×10^6	40	50.0×10^5
	60	64×10^6	59	70×10^7	60	25.0×10^5	-	15.7×10^6	60	100.0×10^5
	-	165×10^6	-	230×10^7	-	8.8×10^5			-	240×10^5
Yamuna sand	28	*		*		0.3×10^9		*	20	1.7×10^9
	52	*		*		7.5×10^9		*	40	1.8×10^9
	60	*		*		*		*	60	15.5×10^9

* Not possible to interpret

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