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COMPUTERISED RESISTIVITY METER FOR SUBSURFACE INVESTIGATIONS

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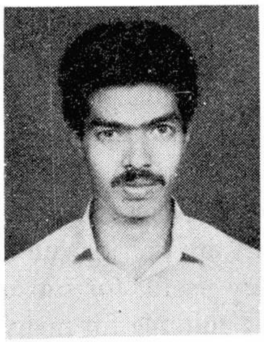

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ABSTRACT:

Geophysical investigations are useful for the selection of suitable sites for foundation of bridges, dams, tunnels etc. There are four types of geophysical methods employed for the solution of various civil engineering problems. They are electrical methods, seismic methods, gravity methods and magnetic methods. But electrical methods are widely used because of their easy operation, less cost and the principle suitable for many problems. Electrical resistivity methods are being successfully used to findout soil thickness, rock layers, depth to basement, subsurface structures and groundwater.

When current is passed through the two current electrodes, it is conducted through the soil, rock and mineralised water and the potential difference is received through the two potential electrodes. This is the resistance and apparent resistivity is obtained by multiplying the resistance with the geometric factor.

The commonly used electrode arrangements are 1. Wenner and 2. Schlumberger. Two types of field procedures are in common use, resistivity sounding and resistivity profiling.

Many instruments are available in India and abroad for geoelectrical survey. Aquameter-CRM is a modern version of earth resistivity meter, which makes use of advanced technology of microprocessors. The operation procedures, available facility in the instrument and its uses in various field conditions are explained in this paper.

The data obtained from the field can be processed by using either curve matching techniques or computer inversion techniques. Applications and results of geoelectrical survey in various lithological conditions are also presented. The use of geoelectrical survey for the selection of suitable sites for bridge are presented.

Results obtained from electrical survey should be correlated with the results of direct methods of exploration, as there are some limitations in this method.

1. INTRODUCTION:

Before undertaking any design work for a project, a civil engineer must have full information about the earth material on which the structure is to be founded, constructed with or in which the construction is to be carried out. This will necessiate a preliminary examination of the work site before detailed designs are prepared. Otherwise disastrous may result and almost always with consequent monetary loss. Many such losses for bridges, dams and tunnels have been reported in the past due to improper investigations {4}.For subsurface exploration , exploratory drillings and borings are carried out normally. This involves high cost and labour. Geophysical surveys are very useful for subsurface exploration because of its lesser cost, easy operation and the principle suitable for many problems. The suitability of geoelectrical surveys for various geologic problems have been reported by many earlier workers {1}.

Geophysical methods are of four types viz., 1. Electrical methods, 2. Seismic methods, 3. Magnetic methods and 4. Gravity methods. But electrical methods are widely used for many civil engineering and geologic problems, because of high contrast of electrical resistivity exists between the subsurface formations. Many electrical resistivity instruments are available in the market. But Aquameter CRM 20 is the only available computerised resistivity meter in India for subsurface investigation.

2. INSTRUMENTATION

Aquameter CRM 20 (Computerised Resistivity Meter) is a computerised earth resistivity meter, which make use of advanced technology of microprocessors. In conventional resistivity meters, the transmitter and amplifier are housed in seperate enclosures because of interference and electromagnetic coupling. The CRM is housed in a single casing-possible because of incorporation of modern electronic principle. Aquameter CRM 20 is shown in plate 1.

The generator circuit in Aquameter CRM 20 is so designed to maintain the current flowing through the ground at preset level, irrespective of variations in the soil and contact condition. The current passes through the C_1 C_2 electrodes in the ground and the potential generated across V_1 V_2 electrode is sensed by the instrument. The instrument is capable of detecting even a very low signal riding on a noisy background. The noise elimination takes place at various stages of amplification and the filtered signal is then processed to derive the resistance information. For excessively noisy condition the averaging mode is provided externally in addition to the internal built-in averaging. This facilitates geophysical prospecting even in difficult terrain {3}.

The microprocessor based circuit always ensure the proper functioning of the instrument. Any malfunction such as low battery voltage, a poor contact at the current setting etc, is immediately detected and conveyed to the operator through LCD display. This eliminates the possibility of any erraneous readings.

A seven position switch is provided to select the appropriate current. The current ranges are 0.2, 0.5, 1.0, 2.0, 5.0, 10 and 20 mA. Accuracy of the result will be higher, the higher the value of current. The Aquameter is provided by a rechargeable high power battery of 12V. The generator circuit inside the Aquameter coverts the 12V DC into a high voltage supply of 150 V DC which is made to alternate at regular intervals. This constant current genetator circuits sends out the current through the C_1C_2 electrodes and maintain it at the preset value throughout the measurement.

By selecting the number of cycles depending on the ground noise, one can get noise free readings. The available cycles are 1, 4, 16 and 64. Using the range switch it is possible to select the resistance range 10 Ohm, 100 Ohm, 10 K Ohm or 1 M Ohm depending on soil resistivity. Normally the lowest range is very suitable for accurate readings. Self potential(SP) cancellation is done automatically by the instrument itself. There is no need of using non-polarising electrodes. But when SP values are required they can be measured in the voltage mode through the use of non polarising electrodes. There are only 5 controls of the instrument. They are (i) On/Off switch, (ii) 7 position generator current selection switch, (iii) 6 position range selector switch, (iv) 4 position cycle switch and (v) measure start/push button.

3. PRINCIPLES OF REISTIVITY

The pattern of electric current flows in the ground is dependent on the sub-surface variation in conductivity. The electric potential distribution in the surface is thus related to the subsurface geology. The electrical resistivity of different materials beng different from each other, it is possible to distinguish them by their resistivity.

The matrix minerals in rocks are insulators. In rocks containing fluids, current is conducted electrolytically by the interstitial fluids and resistivity is controlled by porosity, water content as well as quantity of dissolved salts. Clay minerals are capable of storing electrical charges and current conduction in clay minerals is electronic and electrolytic {10}.

Resistivity is a physical property of a substance. It is defined as the resistance offered for the flow of electric current by unit cube of the substance when voltage is applied across the opposite faces. The resistivity is expressed in Ohm-meters. The inverse of resistivty is termed as the conductivity.The resistance for a substance is a function of the resistivity, size and shape. The resistance (R) offered by the substance with regular shapes such as cylinders, cubes etc can be determined with the formula

$$R = \frac{\rho L}{A}$$

Where

ρ is the resistivity of the substance,
L is the length of the substance and
A is the area of cross section of the substance

4. RESISTIVITY SOUNDING VERSUS RESITIVITY PROFILING

Two basic types of field procedures are in common use, resistivity sounding and resistivity profiling. In resistivity sounding, the electrode spacing interval is changed while maintaining a final location for the center of the electrode spread. Since depth of investigation increases in a general way with increasing electrode spacing, resistivity sounding will be preferred if the aim is to determine the vertical variation of formations (like thickness of rock layers and depth to basement). In resistivity profiling, the location of the spread is changed while maintaning a fixed electrode spacing interval, for example to locate the boundary of a gravel deposit.

Measurement of resistivity

Four electrodes are required for measuring the resistivities of the subsurface formations. A current of electrical intensity " I " is introduced between one pair of electrodes, called current electrodes C_1C_2. The potential difference produced as a result of current flow is measured with the help of another pair of electrodes called potential electrodes P_1P_2. Fig 1 shows the electrical resistivity method of subsurface investigation. Let " ΔV "represents the potential difference, the apparent resistivity measure (ρa) is

$$K \times \frac{\Delta V}{I}$$

A comprehensive of 25 electrode arrangements are available for various geological investigations {8}, of which Wenner and Schlumberger arrangements are being widely adopted for civil engeineering and groundwater problems.

Wenner array has four collinear equi-spaced point electrodes as shown in Fig 2a. The four electrodes C_1,C_2,P_1 and P_2 are placed at the surface of the ground along a straight line symmetrically about a central point, so that $C_1P_1 = P_1P_2 = P_2C_2 = a$, where " a " can be called as interelectrode separation. The configuration factor 'K'(also called as geometric factor) for this array is $2\pi a$ and therefore the apparent resistivty (ρa) for this array becomes

$$\rho a = 2 \pi a \left(\frac{\Delta V}{I}\right)$$

Schlumberger Array is shown in Fig 2b. This array also uses four collinear point electrodes, but measures the potential gradient at the mid-point by keeping the measuring electrodes close to each other. The configuration factor for Schlumberger array is

$$K = \pi \ MN \left(\frac{L^2}{MN} \quad \frac{1}{4}\right)$$

5. RESISTIVITY SOUNDING INTERPRETATION

The reading obtained from Aquameter is the resistance and apparent resistivity is obtained by multiplying resistance with geometric factor. After the apparent resistivity is calculated , it is important to findout the true resistivity. Many theoretical curves {5,9} and computer inversion programs {2,6} are available to calculate the true resistivity with layer details.

Types of sounding curves:

The form of the curves obtained by sounding over a horizontally stratified medium is a function of resistivities and thickness of the layers as well as of the electrode configuration. If the ground is composed of a single homogeneous and isotropic layer of infinite thickness and finite resistivity then, irrespective of the electrode array used, the apparent resistivity curve will be a horizontal line.

If the ground is composed of three layers of resistivities $_1$, ρ_2 and ρ_3 and thickness h_1, h_2 and $h_3 = \infty$, the geoelectric section is described according to the relation between the values of ρ_1, ρ_2 and ρ_3. There are four possible combination between the values of ρ_1, ρ_2 and ρ_3. They are

$\rho_1 > \rho_2 < \rho_3$	H type sections
$\rho_1 < \rho_2 < \rho_3$	A type sections
$\rho_1 < \rho_2 > \rho_3$	K type sections
$\rho_1 > \rho_2 > \rho_3$	Q type sections.

Fig 3 shows the model master curves of H,A,K and Q type sections for Schlumberger sounding data. Electrode spacings (AB/2) are plotted in abcissa and apparent resistivity (ρa) is plotted in ordinate. True resistivities for first, second and third layer are given in the figure for the H,A,Q and K type curves as ρ1, ρ2 and ρ3 respectively. "H" type curves are found in place where top soil of high resistivity with water saturated or clay layer as the second layer and underlain by con act hard rock. "A" type curve results if the formations are resistive continuously towards the th. "K" type occur if the cental layer has low resistivity then the overlying and underlying trata. " Q " type curve results if the resistivity is decreasing towards depth.

If the ground is composed of more than three horizontal layers to resistivities ρ_1,ρ_2, ρ_3....ρ_n and thicknesses h_1, h_2, h_3....hn = ∞, the geoelectric section is described in terms of relationship between the resistivities of the layer, and the letters H,A,K and Q are used in combination, to indicate the variation of resistivity with depth. In four layer geoelectric sections, there are eight possible relation between ρ_1,ρ_2,ρ_3 and ρ_4.

$\rho_1 > \rho_2 < \rho_3 < \rho_4$	HA type sections
$\rho_1 > \rho_2 < \rho_3 > \rho_4$	HK type sections
$\rho_1 < \rho_2 < \rho_3 < \rho_4$	AA type sections
$\rho_1 < \rho_2 < \rho_3 > \rho_4$	AK type sections
$\rho_1 < \rho_2 > \rho_3 < \rho_4$	KH type sections
$\rho_1 < \rho_2 > \rho_3 > \rho_4$	KQ type sections
$\rho_1 > \rho_2 > \rho_3 < \rho_4$	QH type sections
$\rho_1 > \rho_2 > \rho_3 > \rho_4$	QQ type sections

For five layer sections there are 16 possible relationships between ρ_1,ρ_2,ρ_3,ρ_4 and ρ

Interpretation by curve matching:

Curve matching technique is widely used for the assessment of layers thickness and layers resistivity. Apparent resistivity values are plotted in ordinate and electrode spacings are plotted in abcissa in a tracing paper superimposed on double log sheet. A smooth curve should be drawn to connect all the points. This is the field curve which may be two, three or four layer case. If the field curve matches a three layer theoretical master curve, then that three layer curves should be used for interpretation.

Three layer master curve should be selected and the field curve should be superimposed on the master curve. Move the transparent sheet (field curve) horizontally or vertically over the master curves keeping the corresponding axes parallel, till the field curve matches with one of the master curves. Trace the master curves origin on transparent sheet and note down the h2/h1, $\rho 2/\rho 1$ and $\rho 3/\rho 1$ values corresponding to the master curve which matched with the field curve. Origin traced on the field curve will yield $\rho 1$ and h1. Then the other parameters $\rho 2$, $\rho 3$ and h2 can be deduced automatically.

Computer Inversion Techniques:

Some errors may occur in manual curve matching methods. Computer inversion programme RESIST87 is available for accurate interpretation {6}. The results obtained from curve matching method can be given in this programme as input for getting effective result. Otherwise some arbitrary values for the field curve can be given by experience and by iteration method the true resistivity and layer thickness can be obtained form this program.

Limitation of this method:

From these methods only we can get a geoelectric section. This is because the resistivity method is governed only by the resistivity contrast between various subsurface layers which need not always correspond to the geological boundaries. Geoelectric and geological boundaries coincide only when there is a pronounced contrast between geologic layers. But if the resistivity values and layer thicknesses are correlated with the existing neigbhour borewell or electric logs or with the old data, one can get effective result and this will save much cost.

6. CONCLUSION

Subsurface prediction from geophysical survey is indirect and such prediction must be checked by actual penetration of subsurface, either by exploratory boring and sampling of the soil or by excavation of small shaft or adits, which will also yield samples of materials for later testing in laboratories. Geologic structures like fold and fault may be undetected by exploratory boring and other direct methods because of the random sampling ,but they can be easily detected by geoelectrical survey. Caerful examination of geoelectrical sounding curves with actual exploratory boring will be very useful for larger areas where it is not possible to go for exploratory boring densely. The exploratory boring will be carried out frequently for shallow depths. But geoelectrical survey can be carried out for 500 m depth with high accuracy. This survey can also be carried out rapidly for many locations and if anamolies in subsurface is found then one can go for exploratory boring. This reduces the cost and time of exploratory boring.

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