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Electrical Resistivity Interpretation Method & Resistivity Profile for Investigations on Selected Case Studies

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Abstract-- Electrical resistivity has been previously reviewed with interpretation of presented earlier in a case study,it is known that resistivity surveys are all based on the method of Wenner. A current, I, is passed into the earth through one point electrode and returns to the apparatus through a second. The potential difference between two points on the earth's surface, V, is measured. The profile based on the 'VES' interpretation on an extended review of a previous publication from a landslide filled site adjacent to a dumpsite from Abule-Egba Area and environ in Lagos was presented here.

Keywords-- *Apparent resistivity, Electrodes, VES, Dumpsite, Landslide.*

I. INTRODUCTION

Electrical resistivity surveys are all based on the method of Wenner. A current, I, is passed into the earth through one point electrode and returns to the apparatus through a second. The potential difference between two points on the earth's surface, V, is measured.

Then R can be related to the resistivity of the earth and the electrode spacing. Usually the four electrodes used are spaced in a straight line, and frequently a symmetrical arrangement is used. If the distance between the current electrodes is 2r and between the potential electrodes is 2αr for a symmetrical arrangement, it is easily shown[2]that, for a homogeneous earth, the resistivity ρ is given by (1) below.

If the earth is not homogeneous, the value of ρ obtained from (2) will vary with a. This variation will be related to the nature of the earth, and hence the usefulness of the method.

The resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground. It utilizes direct currents or low frequency alternating currents to investigate the electrical properties (resistivity) of the subsurface. A resistivity contrast between the target and the background geology must exist.

II. EFFECTIVE APPARENT RESISTIVITY

A. Theory

Data from resistivity surveys are customarily presented and interpreted in the form of values of apparent resistivity ρ_a. Apparent resistivity is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential difference for a particular arrangement and spacing of electrodes. An equation giving the apparent resistivity in terms of applied current, distribution of potential, and arrangement of electrodes can be arrived at through an examination of the potential distribution due to a single current electrode. The effect of an electrode pair (or any other combination) can be found by superposition. Consider a single point electrode, located on the boundary of a semi-infinite, electrically homogeneous medium, which represents a fictitious homogeneous earth. If the electrode carries a current I, measured in amperes (a), the potential at any point in the medium or on the boundary is given by:

$$U = \rho \frac{1}{2\pi R} \qquad (1)$$

where

U = potential, in V,
ρ = resistivity of the medium,
r = distance from the electrode.

The mathematical demonstration for the derivation of the equation may be found in textbooks on geophysics, such as Keller and Frischknecht (1966).

For an electrode pair with current I at electrode A, and -I at electrode B (figure 1), the potential at a point is given by the algebraic sum of the individual contributions:

$$U = \frac{1}{2\pi r_A} - \frac{1}{2\pi r_B} = \frac{\rho I}{2\pi}\left[\frac{1}{r_A} - \frac{1}{r_B}\right], \qquad (2)$$

where

r_A and r_B = distances from the point to electrodes A and B

Figure 1 illustrates the electric field around the two electrodes in terms of equipotentials and current lines. The equipotentials represent imagery shells, or bowls, surrounding the current electrodes, and on any one of which the electrical potential is everywhere equal. The current lines represent a sampling of the infinitely many paths followed by the current, paths that are defined by the condition that they must be everywhere normal to the equipotential surfaces.

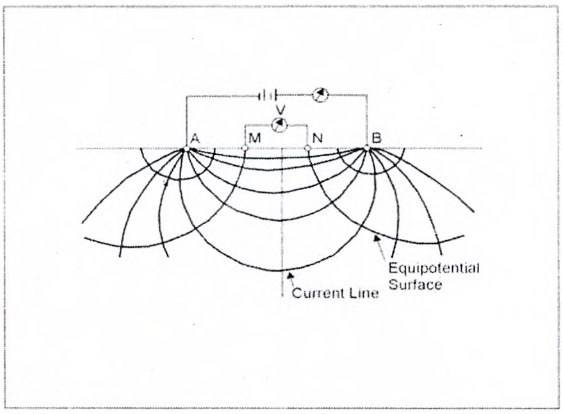

Figure 1: Equipotentials and current lines for a pair of current electrodes A and B on a homogeneous half space.

In addition to current electrodes A and B, figure 1 shows a pair of electrodes M and N, which carry no current, but between which the potential difference V may be measured. Following the previous equation, the potential difference V may be written

$$V = U_M - U_N = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right], \qquad (3)$$

where

U_M and U_N = potentials at M and N,
AM = distance between electrodes A and M, etc.

These distances are always the actual distances between the respective electrodes, whether or not they lie on a line. The quantity inside the brackets is a function only of the various electrode spacings. The quantity is denoted 1/K, which allows rewriting the equation as:

$$V = \frac{\rho I}{2\pi}\frac{1}{K} \qquad (4)$$

where

K = array geometric factor.

Equation (2) can be invrted to deduce ρ, and to obtain:

$$\rho = 2\pi K\frac{V}{I} \qquad (5)$$

The resistivity of the medium can be found from measured values of V, I, and K, the geometric factor. K is a function only of the geometry of the electrode arrangement.

***: geometric factors**

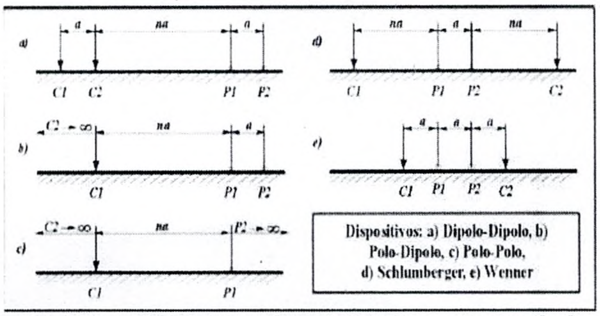

Figura 1. Diferentes Dispositivos usados en Tomografía Geoeléctrica para relevamientos 2D y 3D

Figure 2: based on extract

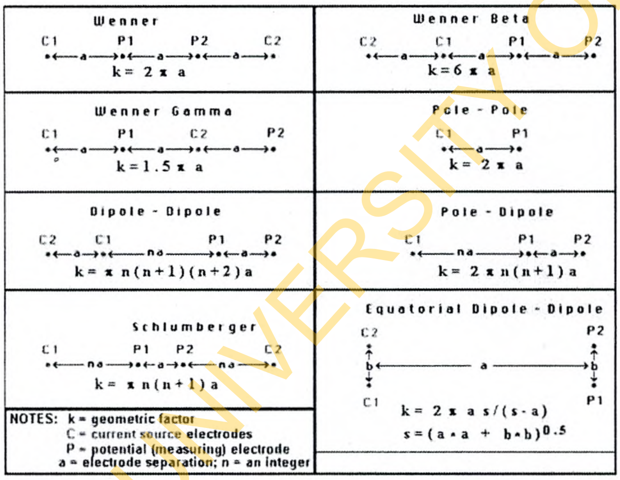

Figure 3: Geometric factors for the arrangements in extract of Figura

B. Apparent Resistivity

Wherever these measurements are made over a real heterogeneous earth, as distinguished from the fictitious homogeneous half-space, the symbol ρ is replaced by ρ_a for apparent resistivity. The resistivity surveying problem is, reduced to its essence, the use of apparent resistivity values from field observations at various locations and with various electrode configurations to estimate the true resistivities of the several earth materials present at a site and to locate their boundaries spatially below the surface of the site.

An electrode array with constant spacing is used to investigate lateral changes in apparent resistivity reflecting lateral geologic variability or localized anomalous features. To investigate changes in resistivity with depth, the size of the electrode array is varied. The apparent resistivity is affected by material at increasingly greater depths (hence larger volume) as the electrode spacing is increased. Because of this effect, a plot of apparent resistivity against electrode spacing can be used to indicate vertical variations in resistivity.

The types of electrode arrays that are most commonly used (Schlumberger, Wenner, and dipole-dipole) are illustrated in figure 2. There are other electrode configurations that are used experimentally or for non-geotechnical problems or are not in wide popularity today. Some of these include the Lee, half-Schlumberger, polar dipole, bipole dipole, and gradient arrays. In any case, the geometric factor for any four-electrode system can be found from equation 3 and can be developed for more complicated systems by using the rule illustrated by equation 2. It can also be seen from equation 3 that the current and potential electrodes can be interchanged without affecting the results; this property is called reciprocity.

C. Schlumberger Array

For this array (figure 2a), in the limit as a approaches zero, the quantity V/a approaches the value of the potential gradient at the midpoint of the array. In practice, the sensitivity of the instruments limits the ratio of s to a and usually keeps it within the limits of about 3 to 30. Therefore, it is typical practice to use a finite electrode spacing and equation 2 to compute the geometric factor (Keller and Frischknecht, 1966). The apparent resistivity (r) is:

$$\rho_a = \pi\left[\frac{s^2}{a}-\frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2-\frac{1}{4}\right]\frac{V}{I}, \qquad (6)$$

In usual field operations, the inner (potential) electrodes remain fixed, while the outer (current) electrodes are adjusted to vary the distance s. The spacing a is adjusted when it is needed because of decreasing sensitivity of measurement. The spacing a must never be larger than 0.4s or the potential gradient assumption is no longer valid. Also, the a spacing may sometimes be adjusted with s held constant in order to detect the presence of local inhomogeneities or lateral changes in the neighborhood of the potential electrodes.

D. Wenner Array

This array (figure 2b) consists of four electrodes in line, separated by equal intervals, denoted a. Applying equation 2, the user will find that the geometric factor K is equal to a , so the apparent resistivity is given by:

$$\rho_a = \pi\left[\frac{s^2}{a}-\frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2-\frac{1}{4}\right]\frac{V}{I}, \qquad (7)$$

Although the Schlumberger array has always been the favored array in Europe, until recently, the Wenner array was used more extensively than the Schlumberger array in the United States. In a survey with varying electrode spacing, field operations with the Schlumberger array are faster, because all four electrodes of the Wenner array are moved between successive observations, but with the Schlumberger array, only the outer ones need to be moved. The Schlumberger array also is said to be superior in distinguishing lateral from vertical variations in resistivity. On the other hand, the Wenner array demands less instrument sensitivity, and reduction of data is marginally easier.

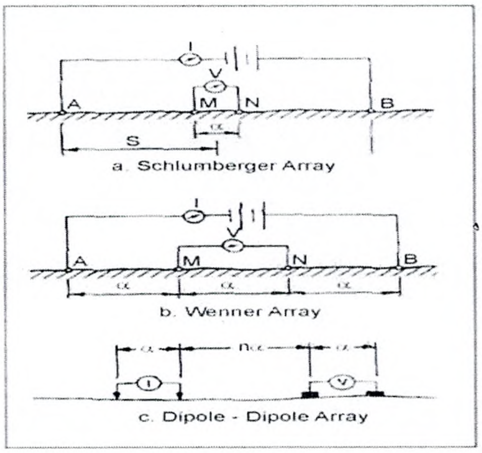

Figure 4: Electrode array configurations for resistivity measurements.

E. Dipole-dipole Array

The dipole-dipole array (figure 2c) is one member of a family of arrays using dipoles (closely spaced electrode pairs) to measure the curvature of the potential field. If the separation between both pairs of electrodes is the same a, and the separation between the centers of the dipoles is restricted to a(n+1), the apparent resistivity is given by:

$$\rho_a = \pi a n(n+1)(n+2)\frac{V}{I}, \qquad (8)$$

This array is especially useful for measuring lateral resistivity changes and has been increasingly used in geotechnical applications.

III. DEPTH OF INVESTIGATION

To illustrate the major features of the relationship between apparent resistivity and electrode spacing, figure 3 shows a hypothetical earth model and some hypothetical apparent resistivity curves. The earth model has a surface layer of resistivity $\rho 1$ and a basement layer of resistivity ρn that extends downward to infinity (figure 3a). There may be intermediate layers of arbitrary thicknesses and resistivities. The electrode spacing may be either the Wenner spacing a or the Schlumberger spacing a; curves of apparent resistivity versus spacing will have the same general shape for both arrays, although they will not generally coincide.

For small electrode spacings, the apparent resistivity is close to the surface layer resistivity, whereas at large electrode spacings, it approaches the resistivity of the basement layer. Every apparent resistivity curve thus has two asymptotes, the horizontal lines $\rho_a = \rho_1$ and $\rho_a = \rho_n$, that it approaches at extreme values of electrode spacing. This is true whether ρ_n is greater than ρ_1, as shown in figure 3b, or the reverse. The behavior of the curve between the regions where it approaches the asymptotes depends on the distribution of resistivities in the intermediate layers. Curve A represents a case in which there is an intermediate layer with a resistivity greater than ρ_n. The behavior of curve B resembles that for the two-layer case or a case where resistivities increase from the surface down to the basement. The curve might look like curve C if there were an intermediate layer with resistivity lower than ρ_1. Unfortunately for the interpreter, neither the maximum of curve A nor the minimum of curve C reach the true resistivity values for the intermediate layers, though they may be close if the layers are very thick.

There is no simple relationship between the electrode spacing at which features of the apparent resistivity curve are located and the depths to the interfaces between layers. The depth of investigation will always be less than the electrode spacing. Typically, a maximum electrode spacing of three or more times the depth of interest is necessary to assure that sufficient data have been obtained. The best general guide to use in the field is to plot the apparent resistivity curve (literature revealations)* as the survey progresses, so that it can be judged whether the asymptotic phase of the curve has been reached.

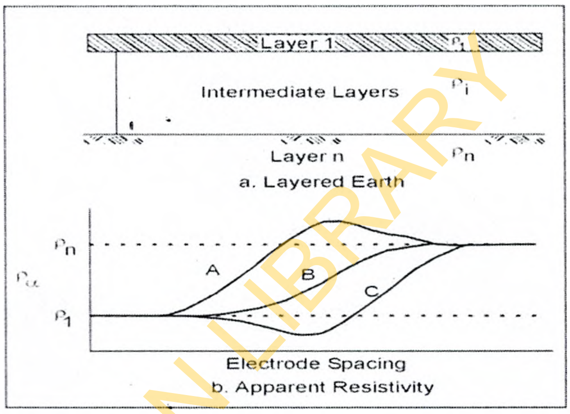

Figure 5: Asymptotic behavior of the apparent resistivity curves at very small and very large electrode spacings.

A. Instruments and Measurements

The theory and field methods used for resistivity surveys are based on the use of direct current, because it allows greater depth of investigation than alternating current and because it avoids the complexities caused by effects of ground inductance and capacitance and resulting frequency dependence of resistivity. However, in practice, actual direct current is infrequently used for two reasons: (1) direct current electrodes produce polarized ionization fields in the electrolytes around them, and these fields produce additional electromotive forces that cause the current and potentials in the ground to be different from those in the electrodes; and (2) natural Earth currents (telluric currents) and spontaneous potentials, which are essentially unidirectional or slowly time-varying, induce potentials in addition to those caused by the applied current. The effects of these phenomena, as well as any others that produce unidirectional components of current or potential gradients, are reduced by the use of alternating current, because the polarized ionization fields do not have sufficient time to develop in a half-cycle, and the alternating component of the response can be measured independently of any superimposed direct currents. The frequencies used are very low, typically below 20 Hz, so that the measured resistivity is essentially the same as the direct current resistivity.

In concept, a direct current (I), or an alternating current of low frequency, is applied to the current electrodes, and the current is measured with an ammeter. Independently, a potential difference V is measured across the potential electrodes, and, ideally, there should be no current flowing between the potential electrodes. This is accomplished either with a null-balancing galvanometer (old technology) or very high input impedance operational amplifiers. A few resistivity instruments have separate "sending" and "receiving" units for current and potential; but in usual practice, the potential measuring circuit is derived from the same source as the potential across the current electrodes, so that variations in the supply voltage equally and do not affect the balance point.

IV. APPLICATION AND DATA ACQUISITION

A. Vertical Electrical Sounding (VES) - 1D Imaging

Either the Schlumberger or, less effectively, the Wenner array is used for sounding, since all commonly available interpretation methods and interpretation aids for sounding are based on these two arrays. In the use of either method, the center point of the array is kept at a fixed location, while the electrode locations are varied around it. The apparent resistivity values, and layer depths interpreted from them, are referred to the center point.

In the Wenner array, the electrodes are located at distances of a/2 and 3a/2 from the center point. The most convenient way to locate the electrode stations is to use two measuring tapes, pinned with their zero ends at the center point and extending away from the center in opposite directions. After each reading, each potential electrode is moved out by half the increment in electrode spacing, and each current electrode is moved out by 1.5 times the increment. The increment to be used depends on the interpretation methods that will be applied. In most interpretation methods, the curves are sampled at logarithmically spaced points. The ratio between successive spacings can be obtained from the relation

$$\frac{a_i}{a_{i-1}} = 10^{1/n} \qquad (9)$$

where n = number of points to be plotted in each logarithmic cycle.

For example, if six points are wanted for each cycle of the logarithmic plot, then each spacing a will be equal to 1.47 times the previous spacing. The sequence starting at 10 m would then be 10, 14.7, 21.5, 31.6, 46.4, 68.2, which, for convenience in layout and plotting, could be rounded to 10, 15, 20, 30, 45, 70. In the next cycle, the spacings would be 100, 150, 200, and so on. Six points per cycle is the minimum recommended; 10, 12, or even more per cycle may be necessary in noisy areas.

VES surveys with the Schlumberger array are also made with a fixed center point. An initial spacing s (the distance from the center of the array to either of the current electrodes) is chosen, and the current electrodes are moved outward with the potential electrodes fixed. According to Van Nostrand and Cook (1966), errors in apparent resistivity are within 2 to 3 percent if the distance between the potential electrodes does not exceed 2s/5. Potential electrode spacing is, therefore, determined by the minimum value of s. As s is increased, the sensitivity of the potential measurement decreases; therefore, at some point, if s becomes large enough, it will be necessary to increase the potential electrode spacing. The increments in s should normally be logarithmic and can be chosen in the same way as described for the Wenner array.

For either type of electrode array, minimum and maximum spacings are governed by the need to define the asymptotic phases of the apparent resistivity curve and the needed depth ofinvestigation. Frequently, the maximum useful electrode spacing is limited by available time, site topography, or lateral variations in resistivity. For the purpose of planning the survey, a maximum electrode spacing of at least three times the depth of interest may be used, but the apparent resistivity curve should be plotted as the survey progresses in order to judge whether sufficient data have been obtained. Also, the progressive plot can be used to detect errors in readings or spurious resistivity values due to local effects. Sample field data sheets are shown in literatures (Smith & Booker, 1991, Rodi & Mackie, 2001).

In a normal series of observations, the total resistance, R = V/I, decreases with increasing electrode spacing. Occasionally, the normal relationship may be reversed for one or a few readings. If these reversals are not a result of errors in reading, they are caused by some type of lateral or local changes in resistivity of the soil or rock. Such an effect can be caused by one current electrode being placed in a material of much higher resistivity than that around the other, for instance, in a pocket of dry gravel in contact with a boulder of highly resistive rock or close to an empty cavity. Systematic reversals might be caused by thinning of a surface conductive stratum where an underlying resistant stratum approaches the surface because it dips steeply or because of surface topography. In hilly terrains, the line of electrodes should be laid out along a contour if possible. Where beds are known to dip steeply (more than about 10 deg), the line should be laid out along the strike. Electrodes should not be placed in close proximity to boulders, so it may sometimes be necessary to displace individual electrodes away from the line. The theoretically correct method of displacing one electrode, e.g., the current electrode A, would be to place it at a new position A' such that the geometric factor K is unchanged. This condition would be satisfied (see Equation 10) if

$$\frac{1}{AM} - \frac{1}{AN} = \frac{1}{A'M} - \frac{1}{A'N} \qquad (10)$$

If the electrode spacing is large as compared with the amount of shift, it is satisfactory to shift the electrode on a line perpendicular to the array. For large shifts, a reasonable approximation is to move the electrode along an arc centered on the nearest potential electrode, so long as it is not moved more than about 45□ off the line.

The plot of apparent resistivity versus spacing is always a smooth curve where it is governed only by vertical variation in resistivity. Reversals in resistance and irregularities in the apparent resistivity curve, if not due to errors, both indicate lateral changes and should be further investigated. With the Wenner array, the Lee modification may be used to detect differences from one side of the array to the other, and a further check can be made by taking a second set of readings at the same location but on a perpendicular line. Where the Schlumberger array is used, changing the spacing of the potential electrodes may produce an offset in the apparent resistivity curve as a result of lateral inhomogeneity. Such an offset may occur as an overall shift of the curve without much change in its shape (Zohdy, 1968). Under such conditions, the cause of the offset can often be determined by repeating portions of the sounding with different potential electrode spacing.

B. Horizontal Profiling - 1D Imaging

Surveys of lateral variations in resistivity can be useful for the investigation of any geological features that can be expected to offer resistivity contrasts with their surroundings. Deposits of gravel, particularly if unsaturated, have high resistivity and have been successfully prospected for by resistivity methods. Steeply dipping faults may be located by resistivity traverses crossing the suspected fault line, if there is sufficient resistivity contrast between the rocks on the two sides of the fault. Solution cavities or joint openings may be detected as a high resistivity anomaly, if they are open, or low resistivity anomaly if they are filled with soil or water.

Resistivity surveys for the investigation of aerial geology are made with a fixed electrode spacing, by moving the array between successive measurements. Horizontal profiling, per se, means moving the array along a line of traverse, although horizontal variations may also be investigated by individual measurements made at the points of a grid. If a symmetrical array, such as the Schlumberger or Wenner array, is used, the resistivity value obtained is associated with the location of the center of the array. Normally, a vertical survey would be made first to determine the best electrode spacing. Any available geological information, such as the depth of the features of interest, should also be considered in making this decision, which governs the effective depth of investigation. The spacing of adjacent resistivity stations, or the fineness of the grid, governs the resolution of detail that may be obtained. This is very much influenced by the depths of the features, and the achievable resolution diminishes with depth. As a general rule, the spacing between resistivity stations should be smaller than the width of the smallest feature to be detected, or smaller than the required resolution in the location of lateral boundaries.

Field data may be plotted in the form of profiles or as contours on a map of the surveyed area. For a contour map, resistivity data obtained at grid points are preferable to those obtained from profile lines, unless the lines are closely spaced, because the alignment of data along profiles tends to distort the contour map and gives it an artificial grain that is distracting and interferes with interpretation of the map. The best method of data collection for a contour map is to use a square grid, or at least a set of stations with uniform coverage of the area, and without directional bias.

With the improving of the performance of instrument hardware system and the designing thoughts, especially applying GPS to the time synchronization of signal acquisition, Magnetotelluric sounding method (referred to as MT) field data collection makes remote reference technology into reality and greatly improved the quality of field data (Chen, Lin & Wang, 1989). In the aspect of data processing and interpretation, The introduction of Robust statistical methods (Sutarno & Vozoff, 1989), perfecting and maturity of one-dimensional and two-dimensional inversion method as well as development of three-dimensional forward and inversion method continuously improving the accuracy of data interpretation (Bostick, 1986).

Occasionally, a combination of vertical and horizontal methods may be used. Where mapping of the depth to bedrock is desired, a vertical sounding may be done at each of a set of grid points. However, before a commitment is made to a comprehensive survey of this type, the results of resistivity surveys at a few stations should be compared with the drill hole logs. If the comparison indicates that reliable quantitative interpretation of the resistivity can be made, the survey can be extended over the area of interest.

When profiling is done with the Wenner array, it is convenient to use a spacing between stations equal to the electrode spacing, if this is compatible with the spacing requirements of the problem and the site conditions. In moving the array, the rearmost electrode need only be moved a step ahead of the forward electrode, by a distance equal to the electrode spacing. The cables are then reconnected to the proper electrodes, and the next reading is made. With the Schlumberger array, however, the whole set of electrodes must be moved between stations.

C. Detection of Cavities

Subsurface cavities most commonly occur as solution cavities in carbonate rocks. They may be empty or filled with soil or water. In favorable circumstances, either type may offer a good resistivity contrast with the surrounding rock since carbonate rocks, unless porous and saturated, usually have high resistivities, whereas soil or water fillings are usually conductive, and the air in an empty cavity is essentially nonconductive. Wenner or Schlumberger arrays may be used with horizontal profiling to detect the resistivity anomalies produced by cavities, although reports in the literature indicate mixed success. The probability of success by this method depends on the site conditions and on the use of the optimum combination of electrode spacing and interval between successive stations. Many of the unsuccessful surveys are done with an interval too large to resolve the anomalies sought.

V. INTERPRETATION OF VERTICAL ELECTRICAL SOUNDING DATA

The interpretation problem for VES data is to use the curve of apparent resistivity versus electrode spacing, plotted from field measurements, to obtain the parameters of the geoelectrical section: the layer resistivities and thicknesses. From a given set of layer parameters, it is always possible to compute the apparent resistivity as a function of electrode spacing (the VES curve). Unfortunately, for the converse of that problem, it is not generally possible to obtain a unique solution. There is an interplay between thickness and resistivity; there may be anisotropy of resistivity in some strata; large differences in geoelectrical section, particularly at depth, produce small differences in apparent resistivity; and accuracy of field measurements is limited by the natural variability of surface soil and rock and by instrument capabilities. As a result, different sections may be electrically equivalent within the practical accuracy limits of the field measurements.

To deal with the problem of ambiguity, the interpreter should check all interpretations by computing the theoretical VES curve for the interpreted section and comparing it with the field curve. The test of geological reasonableness should be applied. In particular, interpreted thin beds with unreasonably high resistivity contrasts are likely to be artifacts of interpretation rather than real features. Adjustments to the interpreted values may be made on the basis of the computed VES curves and checked by computing the new curves. Because of the accuracy limitations caused by instrumental and geological factors, effort should not be wasted on excessive refinement of the interpretation. As an example, suppose a set of field data and a three-layer theoretical curve agree within 10 percent. Adding several thin layers to achieve a fit of 2 percent is rarely a better geologic fit.

All of the direct interpretation methods, except some empirical and semi-empirical methods such as the Moore cumulative method and the Barnes layer method, which should be avoided, rely on curve matching in some form to obtain the layer parameters. Because the theoretical curves are always smooth, the field curves should be smoothed before their interpretation is begun to remove obvious observational errors and effects of lateral variability. Isolated one-point spikes in resistivity are removed rather than interpolated. The curves should be inspected for apparent distortion due to effects of lateral variations.

Interpretation from a land slide filled site based on 'VES'

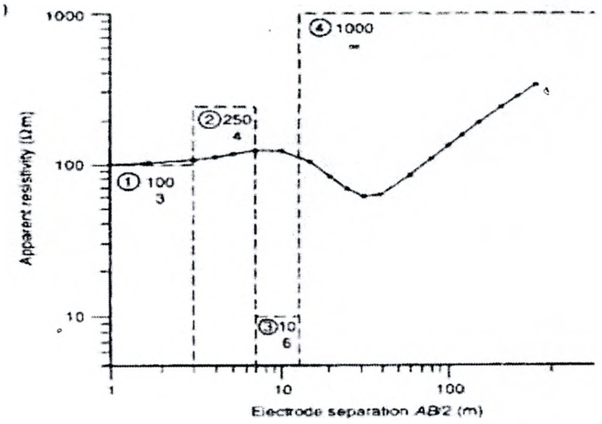

Figure 6: 'VES' interpretation from a landslide filled site adjacent to a dumpsite from Abule- Egba Area in Lagos.

Case study:

For sewer construction wanted to avoid having to blast into sandstone bedrock.

CST profiling with Wenner array at 10 m spacing and 10 m station interval used to map bedrock highs from South Wales.

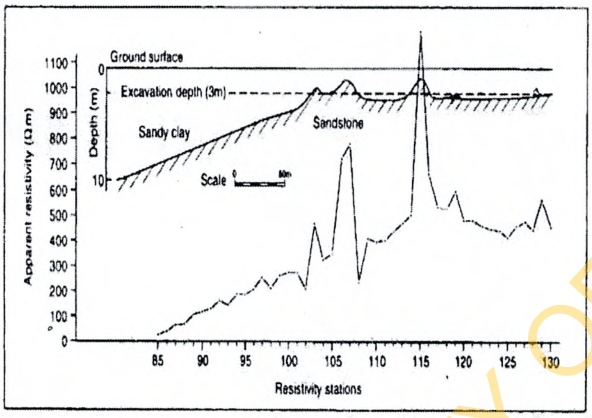

Figure 7: A case study from 'South Wales'

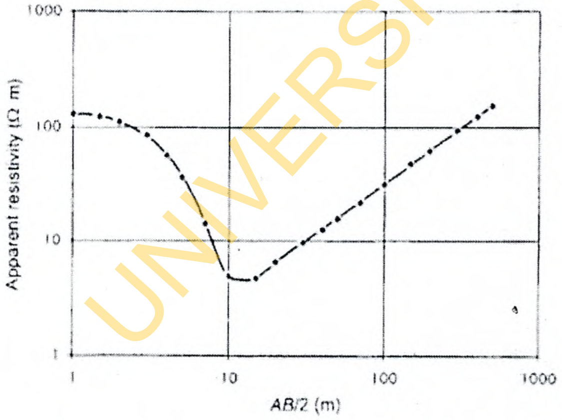

Figure 8: Resistivity profile plot based on 1000 m spacing

Comparison with theoretical multilayer curves is helpful in detecting such distortion. The site conditions should be considered; excessive dip of subsurface strata along the survey line (more than about 10 percent), unfavorable topography, or known high lateral variability in soil or rock properties may be reasons to reject field data as unsuitable for interpretation in terms of simple vertical variation of resistivity.

The simplest multilayer case is that of a single layer of finite thickness overlying a homogeneous half-space of different resistivity. The VES curves for this case vary in a relatively simple way, and a complete set of reference curves can be plotted on a single sheet of paper. Standard two-layer curves for the Schlumberger array are included in figure 2a. The curves are plotted on a logarithmic scale, both horizontally and vertically, and are normalized by plotting the ratio of apparent resistivity to the first layer resistivity (ρa/ρ1) against the ratio of electrode spacing to the first layer thickness (a/d1). Each curve of the family represents one value of the parameter k, which is defined by:

$$k = \frac{\rho_2-\rho_1}{\rho_2+\rho_1} \qquad (11)$$

The apparent resistivity for small electrode spacings approaches ρ_1 and for large spacings approaches ρ_2; these curves begin at $\rho_a/\rho_1 = 1$, and asymptotically approach $\rho_a/\rho_1 = \rho_2/\rho_1$.

Any two-layer curve for a particular value of k, or for a particular ratio of layer resistivities, must have the same shape on the logarithmic plot as the corresponding standard curve. It differs only by horizontal and vertical shifts, which are equal to the logarithms of the thickness and resistivity of the first layer. The early (i.e., corresponding to the smaller electrode spacings) portion of more complex multiple-layer curves can also be fitted to two-layer curves to obtain the first layer parameters ρ1 and d1 and the resistivity ρ2 of layer 2. The extreme curves in figure 3 correspond to values of k equal to 1.0 and -1.0; these values represent infinitely great resistivity contrasts between the upper and lower layers. The first case represents a layer 2 that is a perfect insulator; the second, a layer 2 that is a perfect conductor. The next nearest curves in both cases represent a ratio of 19 in the layer resistivities. Evidently, where the resistivity contrast is more than about 20 to 1, fine resolution of the layer 2 resistivity cannot be expected. Loss of resolution is not merely an effect of the way the curves are plotted, but is representative of the basic physics of the problem and leads to ambiguity in the interpretation of VES curves.

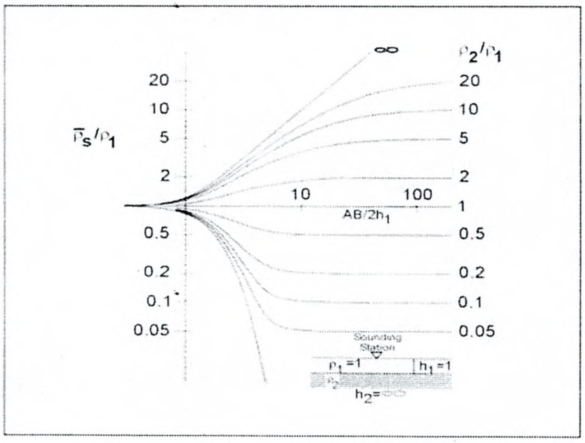

Figure 9: Two-layer master set of sounding curves for the Schlumberger array. (Zohdy 1974a, 1974b)

Where three or more strata of contrasting resistivity are present, the VES curves are more complex than the two-layer curves. For three layers, there are four possible types of VES curves, as shown in figure 8, depending on the nature of the successive resistivity contrasts. The classification of these curves is found in the literature with the notations H, K, A, and Q. These symbols correspond respectively to bowl-type curves, which occur with an intermediate layer of lower resistivity than layers 1 or 3; bell-type curves, where the intermediate layer is of higher resistivity; ascending curves, where resistivities successively increase; and descending curves, where resistivities successively decrease. With four layers, another curve segment is present, so that 16 curve types can be identified: HK for a bowl-bell curve, AA for a monotonically ascending curve, and so on.

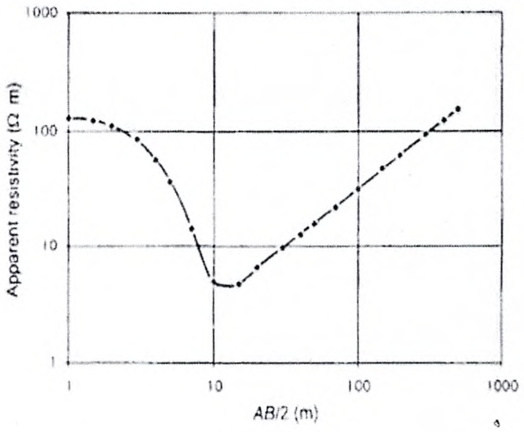

Figure 10:

CONCLUSION

Electrical resistivity surveys are all based on the method of Wenner. A current, I, is passed into the earth through one point electrode and returns to the apparatus through a second. The potential difference between two points on the earth's surface, V, is thus measured.

Effective apparent resistivity is correspondent to the modulus of magnetotelluric response impedance tensor matrix (Groom & Bailay, 1991, DeGroot – Hedlin & Constable, 1991). It is a invariable under the coordinate rotation. Under one dimensional (1-D) condition, It is equal to the normal apparent resistivity ρa, when to two dimensional condition, it is the geometry average of apparent resistivity of TE mode (ρTE) and TM mode (ρTM), which has the dimensional its reduction property.

The profile based on the 'VES' interpretation from a landslide filled site adjacent to a dumpsite from Abule- Egba Area in Lagos was presented here.

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