5 CURVE BREAK METHOD

5.1 General

The ambiguities in the resistivity data interpretation and the frequent unsatisfactory results obtained when theoretical methods are adopted have encouraged the use of several empirical methods and guidelines in interpreting the resistivity curves. For successful siting of borewells in areas underlain by crystalline formations, the presence of hard rock aquifers must be identified by means of some parameter. From the results obtained by correlation studies of borewell yields with geoelectrical parameters such as resistivity, longitudinal conductance etc, it is clear that the presence of hard rock aquifers cannot be identified by evaluating these geoelectrical characteristics. Therefore, a method has to be evolved in order to identify water bearing zones from VES curves so that successful borewell sites can be located. With this objective in view the sounding curves were studied along with their respective borewell logs.

5.2 Concept of Curve Break

The inflection points in a sounding curve have been used to identify changes in sub-surface lithology. A distinct lowering of apparent resistivity values from one electrode separation to the next in a sounding curve may indicate a thin horizontal layer of comparatively better conductivity.
in the parent rock. Van Nostrand and Cook (87) refer to these curve breaks and point out that when they correlate with vertical resistivity contrasts they may be caused by effects not taken into account in the assumption of an ohmic flow of current. Further, they note that "...Although such breaks are completely outside the bounds of present theory, it must be said in defence of the empirical school that some excellent results have been obtained with this method". Amalendhu Roy (3) while developing his theorem for direct current regimes points out that a thin conducting horizontal layer buried in a resistive medium will help to produce a negative resistivity anomaly at the surface by contributing less than normal to the measured potential, since the potential difference along this conducting body is negligible. The water bearing fractures/joints (hard rock aquifers) can be considered as essentially horizontal discontinuities at least on a local scale. These zones of weakness will be highly weathered in nature and hence their resistivity will be very much lower than that of the overlying and underlying rock material. This comparatively conducting layer may therefore generate a resistivity low anomaly at the surface and may be recognized in a sounding curve.

A comparative study of the sounding curves and the depths at which water bearing zones are encountered in borewells has shown that in majority of cases, the hard rock aquifers are reflected in the VES curves as breaks,
i.e., an appreciable lowering of apparent resistivity is observed at electrode separations comparable to aquifer depths. This correlation is clearly evident in case of sounding curves obtained with Schlumberger electrode configurations, though it is observed in Wenner curves also to a limited extent. However, in a number of instances, these breaks were not confirmed by a water-bearing zone in borewells. It is therefore necessary to discern and distinguish breaks in the sounding curves which are indicative of horizontal discontinuities.

Although the curve breaks have been used by many workers to identify horizontal geological discontinuities, a detailed study of these horizontal discontinuities on the VES curves has not been undertaken under controlled conditions. Therefore, a tank model study was taken up to investigate this aspect by examining the effects of horizontal and vertical discontinuities on the VES curves under laboratory conditions.

5.3 Tank Model Experiment

5.3.1 Description of Tank Model

A masonry tank of 3.1 x 3.1 x 1.1 metres size was constructed with brick and mortar (Plate-1). The side walls of the tank have a thickness of 25 cm in the front and 15 cm on the other three sides. A glass plate of
1.5m x 0.75m x 0.015m was fixed at the center of the front wall to afford a view of the materials in the tank. The tank was constructed on a cement concrete foundation and was filled with uniformly graded red soil, slightly moist, free from stone pebbles and other extraneous materials. The soil in the tank was well packed by tamping during filling. A cross sectional view of the tank, showing the directions of electrode spread and the placement of horizontal as well as vertical discontinuities embedded in the soil, is shown in Fig. 5.1. The entire structure was covered by asbestos cement sheets to minimize evaporation from the soil.

5.3.2 Equipment

A direct current resistivity meter with a constant current control was used for taking potential measurements. Copper electrodes of 2 cm length and 5 mm diameter were used as current electrodes. Porous pots of 2 cm length and 5 mm outside diameter, fitted with copper electrode and filled with saturated copper sulphate solution were used as potential electrodes (Plate-2). Cylindrical plastic pipe with proper electrode contacts was used for measuring the true resistivities of the soil and clay materials used in the experiments (Plate-3).

5.3.3 Methodology

The tank was filled with uniformly graded and homogeneous soil having a resistivity of 160 ohm-metres. Vertical
NO - HORIZONTAL DISCONTINUITY
VO - VERTICAL DISCONTINUITY

RG. 5-1 CROSS SECTIONAL VIEW OF TANK MODEL

HD - HORIZONTAL DISCONTINUITY
VD - VERTICAL DISCONTINUITY

FIG. 5-1 CROSS SECTIONAL VIEW OF TANK MODEL
PLATE - 2 CURRENT AND POTENTIAL ELECTRODES
PLATE -3 MEASUREMENT OF RESISTIVITY OF MATERIAL SAMPLES
electrical soundings were carried out in two electrode spread directions, perpendicular to each other, keeping the centre of the tank as the centre of electrode spread. Schlumberger electrode configuration with a fixed potential electrode separation of one centimeter (MN = 1 cm) was used. The least current electrode separation was fixed as 8 cm (AB = 8 cm) and soundings were carried out to a maximum of AB = 100 to 120 cm. This upper limit was fixed considering the boundary effect on the measured potentials. Three types of conducting medium have been used viz, mild steel plate of 1.0 cm thickness, clay mixed with saline water having a resistivity of 3 ohm-metres and plain wet clay having a resistivity of 10 ohm-metres. These were buried within the soil medium at different depths in the form of thin horizontal layers of limited dimensions (40 x 30 cm) at the centre of the model to simulate water bearing zones in hard rock. Vertical electrical soundings have been carried out for different conditions with these three materials. Soundings were also carried out across and parallel to conducting as well as resistive dyke-like bodies (mild steel plate and glass sheet) buried in the soil medium. The various geological conditions for which vertical electrical soundings were carried out are shown in Table 5.1.
### TABLE 5.1: VARIOUS GEOLOGICAL CONDITIONS FOR WHICH EXPERIMENTS WERE CARRIED OUT IN THE TANK MODEL

<table>
<thead>
<tr>
<th>Type of Discontinuity</th>
<th>Material Used</th>
<th>Mild Steel Plate</th>
<th>Salty Clay Layer</th>
<th>Wet Clay Layer</th>
<th>Glass Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td></td>
<td>Z = 12 and 18 cm</td>
<td>Z = 15 cm</td>
<td>Z = 10, 17 cm</td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td></td>
<td>X = 20 and 40 cm</td>
<td></td>
<td>X = 20 and 40 cm</td>
<td>Y = 20 cm</td>
</tr>
</tbody>
</table>

X = distance between the centre of electrode spread and the vertical discontinuity

Y = distance between the electrode spread line and vertical discontinuity

Z = depth to horizontal discontinuity

5.3.4 Results and Discussion

5.3.4.1 Soundings over Homogeneous Soil Medium

Vertical electrical soundings were carried out over the soil medium in two electrode spread directions, perpendicular to each other. The VES curves obtained are given in Fig. 5.2 (A and B). It is seen that the sounding curves are more or less horizontal in nature, though a slight
APPARENT RESISTIVITY IN OHM-METRES

ELECTRODE SEPARATION (AB / 2) IN CENTIMETRES

FIG. 5.2 RESULTS OF TANK MODEL STUDIES - VES CURVES OVER HOMOGENEOUS SOIL
increase in the apparent resistivity values is observed from $\overline{AB}/2 = 4$ cm to 20 cm. The measured apparent resistivity values over the homogeneous soil are found to vary between 40 and 60 ohm-metres for the two VES curves. However, in later experiments, the value of apparent resistivity was found to go upto 120 ohm-metres and still, the measured apparent resistivity values were lower than the true resistivity of the soil (160 ohm-metres) which is probably due to the slight moist conditions at the potential electrode zone, created by the copper sulphate solution used in the non-polarizing electrodes.

5.3.4.2 M.S. Plate Buried at the Centre

The two sets of VES curves shown in Fig. 5.3 have been obtained when a mild steel plate (40 x 30 x 1.0 cm) was buried at the centre of the tank at depths of 12 and 18 cm respectively. The apparent resistivity values are seen to increase gradually until the current electrode separation ($\overline{AB}$) reaches twice the depth at which the plate is buried. At this electrode separation, the VES curves show a marked change in their slope as the apparent resistivity values decrease sharply. The downward trend of the slope of the curve is more pronounced when the electrode spread direction is along the longer axis of the m.s. plate than when it is along the shorter axis. When the conducting layer is nearer to the surface the gradient of the curve slope is
FIG. 5-3 RESULTS OF TANK MODEL STUDIES - VES CURVES FOR HORIZONTAL DISCONTINUITY (M.S. PLATE)
more steep as well as more persistent than when the conducting bed is at greater depths. This is because of the fact that as the depth of the burial of the conducting bed increases, its effect on the total measured potential relatively decreases. From the two sets of VES curves it is also clear that the depth of investigation, in this case, is equal to half the current electrode separation ($\frac{A}{2}$).

5.3.4.3 Saline Clay Layer

The m.s. plate was replaced with a saline clay bed of $40 \times 30 \times 3$ cm size having a resistivity of 3 ohm-metres. The material was prepared by mixing a solution of common salt with clay. This layer was buried at a depth of 15 cm from the surface and the VES curves obtained are given in Fig. 5.4. As can be seen from the figure, a sharp downward trend is observed in the slope of the curve beginning at electrode separation $\frac{A}{2} = 15$ cm. The downward trend in the slope is more pronounced when the longer axis of the clay layer coincides with the electrode spread direction than when it is along the shorter axis. In this case also, the depth of investigation is observed to be approximately equal to half the current electrode separation.
Fig. 5.4 Results of tank model studies: VES curves for horizontal discontinuity (salty clay bed)
5.3.4.4 Clay Layer

Plain wet clay having a resistivity of 10 ohm-metres was used in another series of measurements. It was buried in the form of a horizontal layer of 40 x 30 x 2 cm dimensions in the soil medium at depths of $Z = 10, 17$ and 22 cm. Before the horizontal discontinuity was introduced, soundings were carried out over the homogeneous soil and the resulting VES curves are given in Fig. 5.5. The curves in this figure show a slight variation in their slope from those obtained earlier (Fig. 5.2), in that, the apparent resistivities show a clear increasing trend from the first electrode separation till $AB/2 = 25$ cm after which they assume a near horizontal trend. The increase in slope observed in these curves as compared to those in Fig. 5.2 is probably due to the slightly changed moisture content and material compaction. When the clay layer is buried at a depth of 10 cm from the surface, the VES curves obtained show a clear change in their slope at $AB/2 = 10$ cm as can be seen from Fig. 5.6. The lowering of the curve slope is more pronounced and persistent when the electrode spread direction is along the longer axis of the clay bed. When the electrode spread direction is along the shorter axis of the clay layer, the sounding curve assumes its former slope after a break between $AB/2 = 10$ cm and $AB/2 = 12$ cm. The VES curves obtained when the clay bed is buried at depths of 17 cm and 22 cm also clearly show breaks in curve
FIG. 5.5 RESULTS OF TANK MODEL STUDIES - VES CURVES OVER HOMOGENEOUS SOIL
APPARENT RESISTIVITY IN OHM-METRES

ELECTRODE SEPARATION (AB/2) IN CENTIMETRES

FIG. 5-6 RESULTS OF TANK MODEL STUDIES: VES CURVES FOR HORIZONTAL DISCONTINUITY (CLAY BED)
slopes at $\overline{AB}/2 = 17$ cm and $\overline{AB}/2 = 22$ cm respectively (Fig. 5.6). In both cases, the original trend of the sounding curves is maintained after the occurrence of breaks. These VES curves are observed to be very much similar to majority of the field sounding curves obtained in hard rock areas. The depth of investigation once again is seen to be approximately equal to half the current electrode separation.

5.3.4.5 Conducting Lateral Inhomogeneity

The effect of a conducting dyke-like body, creating a vertical discontinuity, on the VES curves was examined by placing a metal plate of 120 x 30 x 1.00 cm size in the soil medium, 20 cm away from the centre of the tank and buried 2 cm below surface. Soundings were carried out with this discontinuity at 20 cm and 40 cm away from the centre of the electrode spread ($X = 20$ cm and 40 cm). From the VES curves obtained (Fig. 5.7) it is clearly seen that when the current electrode is very near to the discontinuity, the apparent resistivity declines sharply and continues to do so for a few more spacings after which it regains its original slope. For example, as can be seen in the figure, when the discontinuity is 20 cm from the centre of electrode spread, a break in the slope of the apparent resistivity sounding curve is observed between electrode separations $\overline{AB}/2 = 20$ to 32 cm. When the electrode spread direction is
FIG. 5.7 RESULTS OF TANK MODEL STUDIES: VES CURVES FOR CONDUCTING VERTICAL DISCONTINUITY
parallel to that of the lateral inhomogeneity, its effect on the sounding curve slope does not appear to be appreciable as can be seen from the figure. However, there appears to be a significant reduction in the values of apparent resistivity when the conducting vertical discontinuity is parallel to the electrode spread direction.

5.3.4.6 Resistive Lateral Inhomogeneity

To study the effect of a resistive lateral inhomogeneity, a glass plate measuring 75 x 40 x 1.5 cm was placed 20 cm away from the centre of the tank in a vertical plane and buried 2 cm below the surface. The results of vertical electrical soundings carried out are shown in Fig. 5.8. Two vertical soundings were carried out by keeping the plate at distances of 20 cm and 40 cm away from the centre of electrode spread. It is seen from the figure that a break in the slope of the VES curve is formed when the current electrode is very near to the resistive inhomogeneity. The VES curves gradually tend to become horizontal after a few more electrode spacings. When compared to the breaks formed due to conducting lateral inhomogeneities, these breaks are observed to be less pronounced in their change of slope. The effect of this lateral inhomogeneity on the VES curve slope when the electrode spread direction is parallel to it is not appreciable.
FIG. 5-8 RESULTS OF TANK MODEL STUDIES: VES CURVES FOR RESISTIVE VERTICAL DISCONTINUITY
5.4 Conclusions

During the tank model experiments it was observed that the measured apparent resistivity values tend to vary when the sounding is repeated. This anomaly is probably due to changes in moisture content of the soil and also due to the compactness of material, particularly near potential electrodes. Even minor changes in the physical conditions of the medium near potential electrodes have been observed to affect the measured values significantly. However, the profiles of the sounding curves remain same for two sounding measurements for a given arrangement and this aspect is more relevant than the values since the studies relate to the changes in the slope of the curve.

The results of tank model studies clearly indicate that horizontal and vertical discontinuities of limited extent produce a downward trend - break - in the slope of VES curve. The breaks caused by a wet clay bed of limited dimensions buried in soil medium are comparable to the breaks observed in field VES curves. The results also indicate that the depth of investigation is approximately equal to half the current electrode separation \((\frac{AB}{2})\) in case of Schlumberger electrode configuration. Therefore, it can be asserted that the hard rock aquifers may give rise to 'breaks' in VES curves and hence can be of use in their identification and location of sites for the construction of borewells.