6. APPLICATION OF CURVE BREAK METHOD IN FIELD INVESTIGATIONS

6.1 Application of Curve Breaks

The tank model studies have shown that a thin, comparatively conducting layer buried in a resistive medium gives rise to a break in VES curves at electrode separations comparable to the depth of burial of the discontinuity. The hard rock aquifers may be compared to thin conducting layers embedded in a resistive rock medium. These hard rock aquifers can, therefore, be expected to give rise to deviations in the slope of VES curves and hence could be identified. However, it is seen from the results of tank model studies that the presence of lateral inhomogeneities also causes a downward deviation in the slope of sounding curves. A proper methodology is, therefore, necessary to successfully use the curve break method for identifying hard rock aquifers in order to locate borewell sites. Field investigations carried out to examine this problem and the application of curve break method to field data are discussed in this chapter.

6.2 Field Layout

A careful examination of field data have shown that a proper field layout and instrumentation are required for successfully applying the curve break method. The Schlumberger electrode configuration has been found to be advantageous for carrying out vertical electrical soundings in areas underlain by hard rocks, particularly when the
curve break technique is employed for interpretation. Electrode arrays where potential electrodes are shifted to expanded spacings for every current electrode separation expansion during soundings are not reliable since a certain amount of error is introduced into the measurements due to lateral inhomogeneities and also due to possible inaccuracies in potential electrode placement. These errors and anomalies may result in a break in the sounding curve leading to erroneous interpretation. A proper layout of electrode spacings is also found to be necessary for successful use of curve break method. During the present study, the expansion of electrode spacings was in steps of six metres i.e., $AB = 3, 6, 12, 18, 24, 30, 36 \ldots 66, 72 \ldots$ metres with appropriate potential electrode separations as given in Section 2.3. Accurate measurements of electrode spacings are essential, particularly for small electrode separations.

It is necessary to have a control for providing constant current to avoid the effects of possible non-ohmic current flow. The magnitude of current must be maintained constant throughout a vertical sounding. The ground surface over the entire electrode spread zone should be reasonably flat as changes in elevation introduces certain anomalies in the measured values (31).

6.3 Data Presentation

For the study of curve breaks, the VES curve is drawn in its field form without any smoothening of the curve.
Double logarithmic plotting is preferable as this affords easier comparison of different VES curves. The amplitude of log cycle should be wide enough to clearly show the minor deviations in the apparent resistivity values. In the present study double log sheets of 83 mm amplitude per log cycle were used with apparent resistivity on ordinate and current electrode separation on abscissa.

6.4 Depth of Investigation

In an empirical evaluation, use of a simple ratio between electrode separation and depth of investigation is advantageous. The depth of investigation can be defined as that depth from which a dominant portion of the measured signal is generated for a given electrode separation (1). Based on this criterion, Roy and Appa Rao (4) have computed the depth of investigation as 0.35 L for two-electrode array, 0.125 L for Schlumberger array and 0.11 L for Wenner array, L being the distance between the two outermost active electrodes. Theoretically, computed depths to sub-surface layers are often inaccurate as discussed in Section 4.7. A practical method of determining depth to interface is to use geological controls in interpreting the inflection points in a sounding curve. The general sub-surface lithology in hard rock area is a surface layer of soil and decomposed material, underlain by weathered rock. The transition from overburden material to rock layer is indicated by an inflection point (minima) in the VES curve.
and the current electrode separation at which the minima occurs can be empirically related to the depth at which rock layer begins. From the data studied, it is observed that the current electrode separation at which the minima occurs is approximately double the depth to rock layers, that is, the depth of investigation is more or less equal to half the current electrode separation ($\frac{A_3}{2}$). The results of tank model studies have also shown that this ratio is quite reliable in determining depth to layers and therefore, this empirical ratio is used in this investigation. A few sounding curves, both Wenner and Schlumberger, along with their respective litho-logs are given in Fig. 6.1 and 6.2 to illustrate the validity of this empirical ratio. However, it is to be noted that under some geoelectrical conditions such as a highly resistive surface layer, saline waterbearing formations and sandy zones, this relation may not hold good. An example is given from lateritic region in Fig. 6.3 from which it can be seen the actual depth to rock layers is very much less than those obtained by theoretical as well as empirical analysis. In many VES curves, the minima may not be well defined (Fig.6.4) or they may be distorted due to the effects of lateral inhomogeneities (Fig.6.5) and under such conditions it may not be possible to apply the empirical ratio. In majority of cases, however, the relation appears to be valid. This
FIG. 6-1 ELECTRODE SEPARATION AND DEPTH OF INVESTIGATION (SCHLUMBERGER CURVES)
FIG. 6-2 ELECTRODE SEPARATION AND DEPTH OF INVESTIGATION (WENNER SOUNDING CURVES)
FIG. 6: ELECTRODE SEPARATION AND DEPTH OF INVESTIGATION: EFFECT OF HIGHLY RESISTIVE SURFACE LAYER

ELECTRODE SEPARATION ($AB/2$) IN METRES

APPEARANT RESISTIVITY IN OHM-METRES

- LATERITE
- LATERITE-CLAY
- WEATHERED GNEISS
- HARD GNEISS
- DOLERITE
- MINIMA

RESISTIVITY IN OHM-METRES

FI1?! LATERITE
LATERITE-CLAY
WEATHERED GNEISS
HARD GNEISS
P??! DOLERITE
4M MINIMA

500 - 200
FIG. 8-4 VES CURVES WITH ILL-DEFINED MINIMA

APPARENT RESISTIVITY IN OHM-METRES

ELECTRODE SEPARATION (AB/2) IN METRES

FIG. 6-4 VES CURVES WITH ILL-DEFINED MINIMA
FIG. 6.5 ELECTRODE SEPARATION AND DEPTH OF INVESTIGATION: EFFECT OF LATERAL INHOMOGENEITIES
is clearly indicated by the Figs. 6.6 and 6.7 in which the depths to rock layer have been plotted against $\frac{AB}{2}$ at which the minima occur. The correlation coefficient obtained is 0.96 in case of Schlumberger curves and 0.94 for Wenner curves.

6.5 VES Profiling

VES profiling is an exercise where a few soundings are carried out close to each other with a common electrode spread direction to identify the presence of horizontal discontinuities which probably are water bearing zones. The results obtained in a field investigation are shown in Fig. 6.8. Four soundings were carried out along a straight line, with the centres of electrode spread close to each other. A clear break is observed between $\frac{AB}{2} = 33$ and 36 metres in all the four sounding curves while another break between $\frac{AB}{2} = 27$ and 30 metres is noticed in curve D and between 24 and 27 metres in curves A and C. From the borewell drilled near station D, it is observed that two aquifers were encountered at depths of 28 to 29 metres and 34 to 35 metres yielding 2.7 m$^3$/hr and 13.6 m$^3$/hr respectively. It is clear from the above that the curve breaks caused by horizontal discontinuities, which probably are hard rock aquifers, repeat in VES curves of closely spaced stations, essentially at the same electrode separation, thus facilitating their identification.
Fig. 6.6 Correlation of curve minima with depth to rock (Schlumberger curves)

\[ X = 11.5 \]
\[ Y = 11.5 \]
\[ \sigma_X = 6.0 \]
\[ \sigma_Y = 6.0 \]
\[ r_{XY} = 0.96 \]
FIG. 6. 7 CORRELATION OF CURVE MINIMA WITH DEPTH TO ROCK (WENNER CURVES)
APPARENT RESISTIVITY IN OHM-METRES

OVERBURDEN

WEATHERED GNEISS

HARD GNEISS

AQUIFER WITH YIELD

"CURVE BREAKS"

FIG. 6-8 "CURVE BREAKS" AS INDICATORS OF HARD ROCK AQUIFERS
6.6 Curve Breaks Due to Lateral Inhomogeneities

In Section 3.6 it was shown that the presence of lateral inhomogeneities also cause a lowering of apparent resistivity resulting in curve breaks which has been further confirmed by tank model studies. It is, therefore, necessary to identify such breaks in order to use the curve breaks as indicators of hard rock aquifers. The methods suggested for identifying and locating lateral inhomogeneities from VES curves (Section 3.6.2) can be applied to distinguish breaks caused by horizontal discontinuities from those caused by lateral heterogeneities.

6.7 Correlation of Curve Breaks with Drilling Results

170 sounding curves have been analysed to examine the validity of the curve break method. The depths at which the aquifers are met with are plotted against half the current electrode separation at which the breaks are observed in the respective VES curves (Fig. 6.9). In plotting Fig. 6.9, breaks which can be identified as due to lateral heterogeneities (Fig. 6.10) as well as aquifers present without a corresponding break in VES curves have been ignored. Such anomalies are less than 20 percent of the total sample analysed. A good correlation, with a correlation coefficient of 0.94, is evident from the plot. This significant correlation indicates that the method can be successfully employed under favourable geoelectric
FIG. 6.9 CORRELATION OF CURVE BREAK WITH AQUIFER
FIG. 6.10 VES CURVES WITH BREAKS DUE TO LATERAL INHOMOGENEITIES
conditions to identify hard rock aquifers. A few field VES curves with their respective litho-logs are given in Figs. 6.11 and 6.12 to illustrate the usefulness of the concept.

6.6 Forecasting borewell yield

It has been shown that the curve breaks do indicate the presence of hard rock aquifers. In an effort to quantify the groundwater that may be available from such aquifers, an attempt was made to correlate the magnitude of curve break deviation with yields obtained in the respective aquifer. However, no such relation could be established as the correlation coefficient was found to be as low as 0.015.

6.9 Limitations

The curve breaks as indicators of hard rock aquifers can be used only for shallow investigations extending to a depth of about 50 metres. The method is not very effective beyond this depth as observed from the field results. This limitation is mainly due to the difficulty experienced in distinguishing the nature and cause of breaks at larger electrode separations. Also, as hard rock aquifers have a limited vertical thickness, their effect on surface potential decreases as their depth of burial increases; hence their presence may not be recognized from a VES curve. However, since a majority of the water-bearing zones are found within a depth of 40 metres, this method can be advantageously adopted.
FIG. 6.11 VES CURVES WITH BREAKS AND BOREWELL SECTIONS SHOWING AQUIFERS
FIG. 6-12 VES CURVES WITH BREAKS AND BOREWELL SECTIONS SHOWING AQUIFERS
6.10 Discussion

The curve break method is an empirical exercise to identify water bearing zones from VES curves. The tank model studies have shown the usefulness of the method and field results have corroborated the concept. Since the presence of water bearing zones cannot be ascertained by theoretical evaluation of VES curves and in the absence of a more positive solution, the suggested empirical method can be advantageously used for depths up to 50 metres.