J. Ind. Geophys. Union (October 2012)
Vol.16, No.4, pp. 169-174

Delineating uneven bedrock topography by Continuous Seismic Refraction Study

Ch. Subba Rao and M.S. Chaudhari
Central Water and Power Research Station, Khadakwasla, Pune 411024

ABSTRACT:
For designing and deciding the level of foundation for heavy civil structures, information on depth to rock and its quality are pertinent. Information on rock quality and its topography can be obtained from boreholes at discrete locations. However, information gathered covers a small volume around the hole. Interpolation of geological information between boreholes in areas of uneven weathering could be erroneous and misleading. Continuous seismic refraction study along with the information from a few boreholes can overcome these limitations and provide the required information reliably. The efficacy of the method is illustrated through a study conducted at Indira Gandhi Center for Atomic Research (IGCAR), Tamil Nadu. Continuous refraction study was carried out along 24 line km in the form of 20 m grid in two mutually perpendicular directions to decipher subsurface stratigraphy including rock topography, to infer its quality and to check anisotropy in rock velocities, if any. Special efforts were made to ensure good coupling of explosives with dry sand in shot holes and also of geophones with loose sand on surface, for generating and efficient recording of seismic waves in windy conditions near the sea coast.

Seismic depth sections revealed two to three layers viz., loose sand, compact sand/ weathered rock and good quality charnockite rock. The rock topography was very uneven indicating differential weathering pattern. The depth to rock varied from 5.9m to 25.8m and the rock velocity ranged between 4000 m/sec and 5800 m/sec, which for charnockite rock indicated good quality. However, a few zones in bedrock having lower wave velocity (< 3500 m/sec), corresponding to inferior quality rock, were inferred and their lateral extent delineated. The seismic velocities obtained in the two mutually perpendicular directions were comparable and did not show any anisotropy in rock. The study showed that at the sites with uneven weathering, only boreholes at discrete locations are not enough to define rock topography and quality precisely. Instead, continuous seismic refraction study in conjunction with limited borehole data provided optimum coverage economically.

INTRODUCTION

Department of Atomic Energy (DAE), Government of India, proposed to develop integrated Fast Reactor Fuel Cycle Facilities (FRFCF) at Kalpakkam near Chennai, Tamil Nadu. The FRFCF site comprises two rectangular areas 400m X 200m and 1060m X 420m (Fig 1). To decide the founding levels for civil structures to be constructed for FRFCF and to design their foundations, continuous refraction survey using explosives as source was carried out in the form of 20 m grid in North-South (N-S) and East-West (E-W) directions, totaling 24 line km to decipher subsurface stratigraphy including rock topography and to infer its quality.

GEOLOGY

The FRFCF site consists of loose sand, which is followed by compact saturated sand/ stiff clay, as inferred from the borehole data. The overburden strata are underlain by weathered rock and hard rock (Charnockite) respectively.

METHOD EMPLOYED

Seismic refraction method utilizes the existence of a recognizable difference in the velocities with which elastic (seismic) waves are transmitted through various subsurface layers. (Dobrin, 1976; Sjogren, 1984). Continuous profiling technique was used

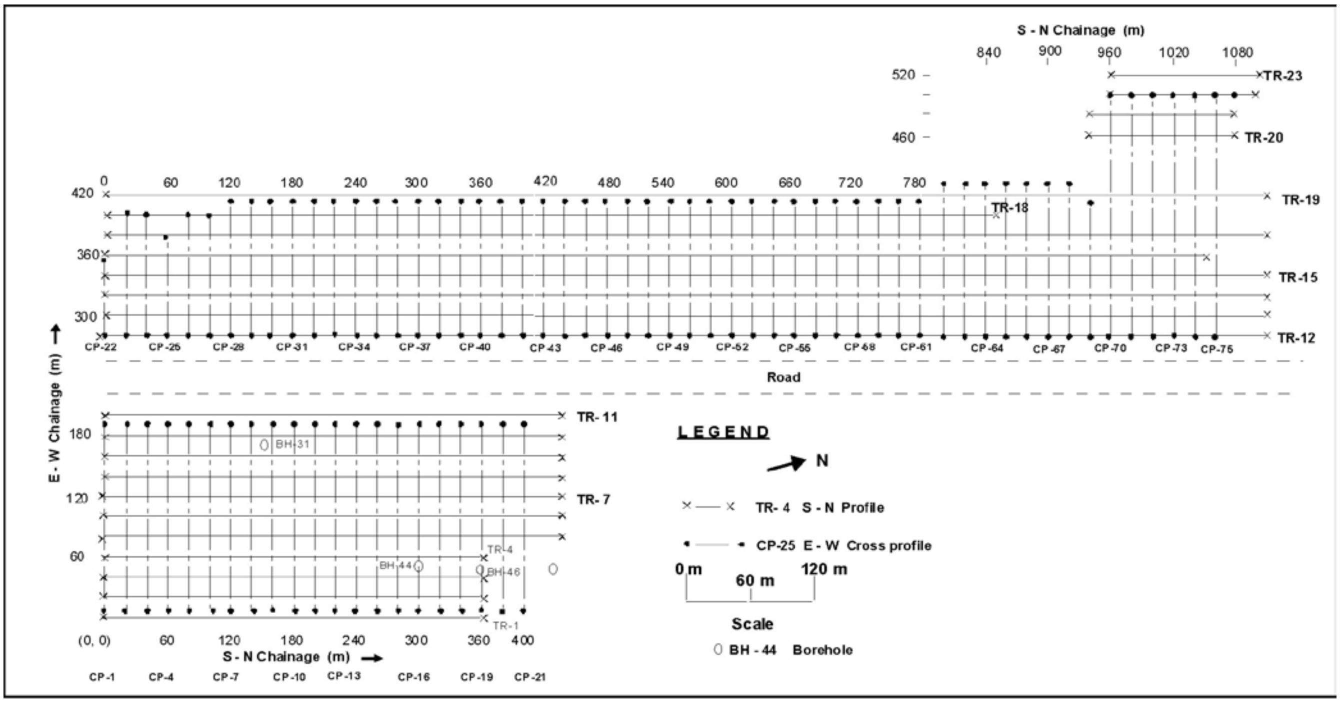

Figure 1. Location plan of seismic profiles at FRFCF site

for field data collection and 'Reciprocal method' was adopted for interpretation. 'Reciprocal method' enables to evaluate depths to subsurface layers below all geophones along a traverse. A number of shots are recorded both inside and outside of a geophone spread which is of small length (geophones are kept at 5m interval).

DELAY TIME:

The determination of depths to refractors below geophones in 'Reciprocal method' is based on the concept of the "delay time" (also called time-depth). For a two layer earth of velocities V_1 and V_2 of the top and bottom layers, the "delay-time" is the time delay associated with the critically refracted ray in travelling between the refractor and the surface (Fig 2).

$$\Delta T_A = \frac{AB}{V_1} - \frac{A'B}{V_2}$$

The delay time (ΔT_G) at a geophone location in a reversed seismic profile is given by

$$\Delta T_G = \frac{1}{2}(t_{AG} + t_{DG} - T_t)$$

Where 't_{AG}' and 't_{DG}' are the arrival times for a geophone from shot points 'A' and 'D' and 'T_t' is the reciprocal time or total time (time of travel from shot A to shot D). The depth of the refractor is calculated from the delay-time at a geophone using equation (Hawkins,1961)

$$h_G = \frac{\Delta T_G V_1}{\mathrm{Cos}(\mathrm{Sin}^{-1}\frac{V_1}{V_2})}$$

For a multi layered earth, when the study of individual layers within the overburden is not important, as in engineering surveys, depth to the important refractor i.e. rock is evaluated by the 'Depth Conversion Factor' (DCF), given by

$$DCF = \sum_{a=1}^{n-1} \frac{2\,h_a}{T_{n,n-1}}$$

where 'h_a' is the thickness of each individual layer below shot-point and '$T_{n,n-1}$' is the intercept-time for the refractor of interest and 'n' is the total number of layers (Hawkins and Whiteley,1973; Redpath, 1973).

The depth (h_G) to the important refractor at a geophone station 'G' is evaluated using the equation

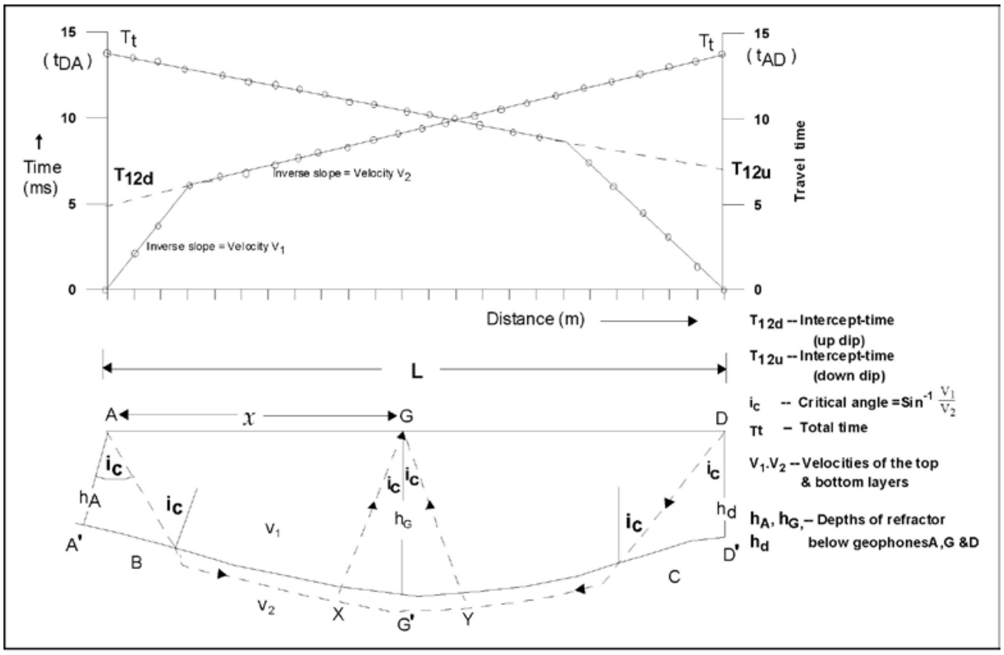

Figure 2. Reverse day paths and time-distance curve used for delay-time evaluation (After Hawkins and Whiteley, 1973)

$$h_G = DCF \cdot \Delta T_G$$

Here 'Δt_G', is the delay-time to the important refractor at the geophone location and 'DCF' is the corresponding depth conversion factor. Depths to important refractor (bed rock) are evaluated at all geophone locations and refractor topography defined with a resolution equal to the geophone spacing.

DATA ACQUISITION:

The arrivals of the direct and refracted elastic waves produced by the explosion of a gelatin charge placed at the bottom of a shot-hole of about 1.5 m depth, are picked-up by a set of detectors (geophones) having 8 Hz natural frequency placed on the ground at known intervals in line with the shot-hole. These direct and refracted arrivals are then amplified and recorded. The travel times of arrivals of the waves are measured from the refraction record on which a time scale is maintained. A 24-channel signal enhancement seismograph was employed to record the data.

The survey area was close to the sea coast and is covered by loose dry sand. Shallow pits, 5-10 cm deep were made and geophones were planted in them along the seismic profiles. This not only ensured good coupling of the sensors with the ground but also reduced the wind effect on the recording of seismic waves.

Seismic refraction study was conducted on a 20 m grid along twenty-three North-South and seventy-five East-West profiles of lengths varying from 138m to 680m and from 138m to 225m respectively. For continuous refraction survey along 138 m long profile, geophones were placed at 6 m interval and the shots were fired at 30m/ 42m interval to generate seismic waves. For profiles of lengths greater than 138m, geophones were kept at 5m interval and shots to generate seismic waves were fired at 30m/ 50m interval. To achieve desired lengths of the long profiles, two geophones were kept overlapping while moving from one spread to the next.

RESULTS AND DISCUSSION:

The rock depths evaluated from seismic study compared well with those obtained from the data of a few boreholes drilled in the study area. The Rock Quality Designation (RQD) values of 60 percent and above have correlated with the Charnockite rock (Fig 3). Refraction survey revealed that the subsurface comprises two to three layers in the area covered. Depending on the velocities of the layers and the geological data of a few boreholes, the three subsurface layers were interpreted as loose sand, compact saturated sand/ weathered rock and good

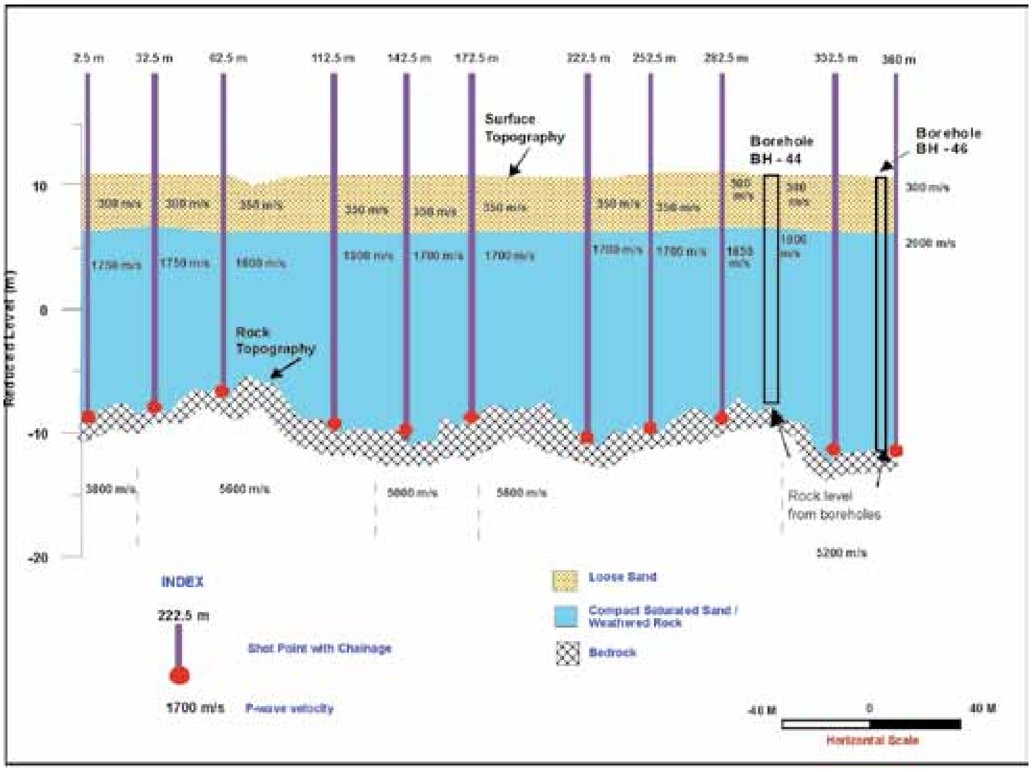

Figure 3. Depth - Section along Taverse - 4 (Ch. 0-360 m) illustrating matching between seismic and borehole rock depths

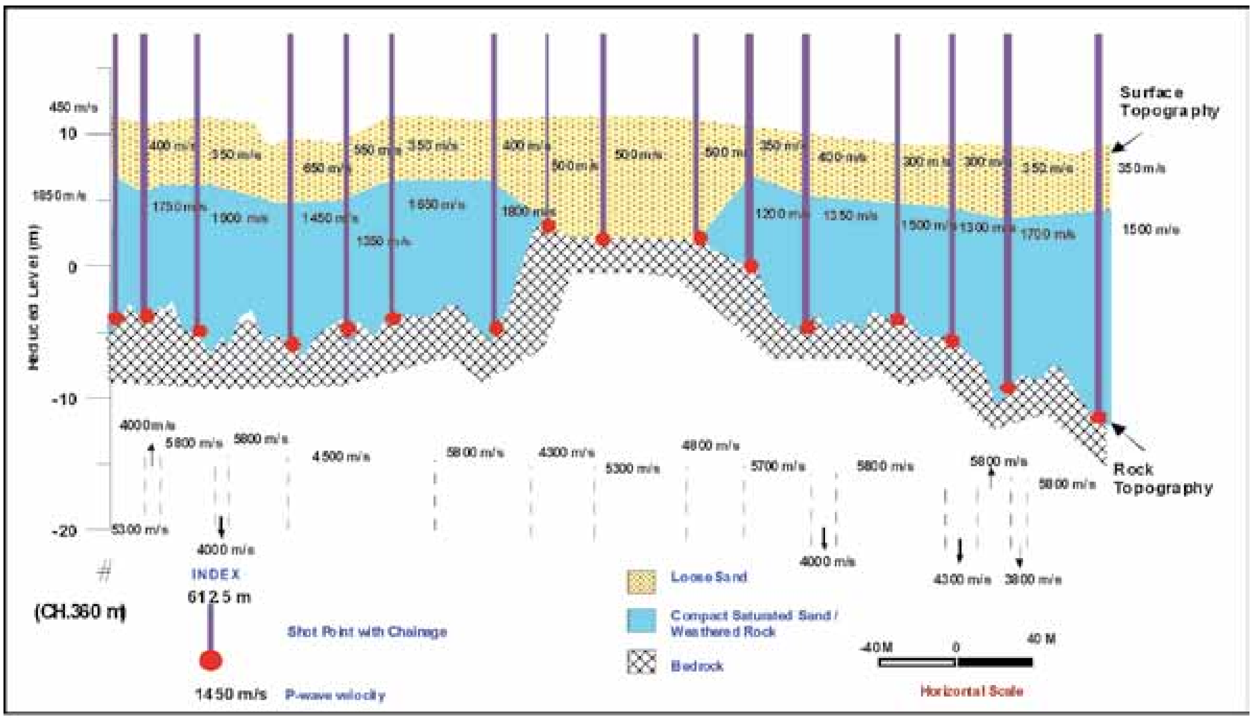

Figure 4. Depth - Section along N-S Profile-16 (515 - 1055 m) showing undulating rock topography and variation in the number of Overburden layers

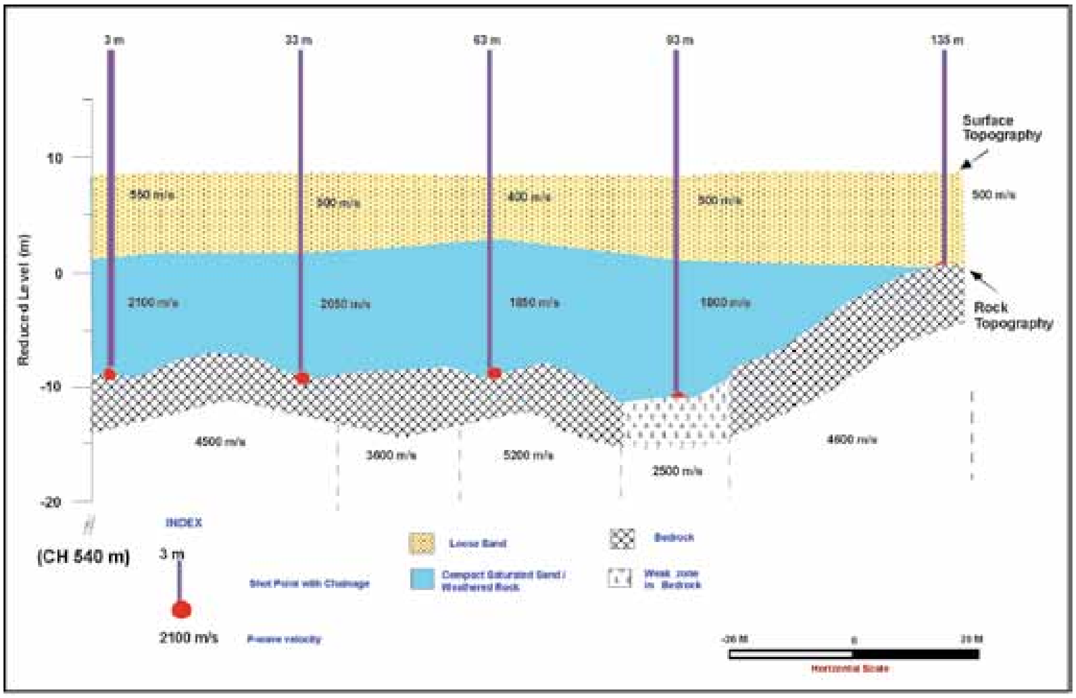

Figure 5. Depth - Section along N-S Profile-23 (966 - 1104 m) showing a weak zone in bedrock

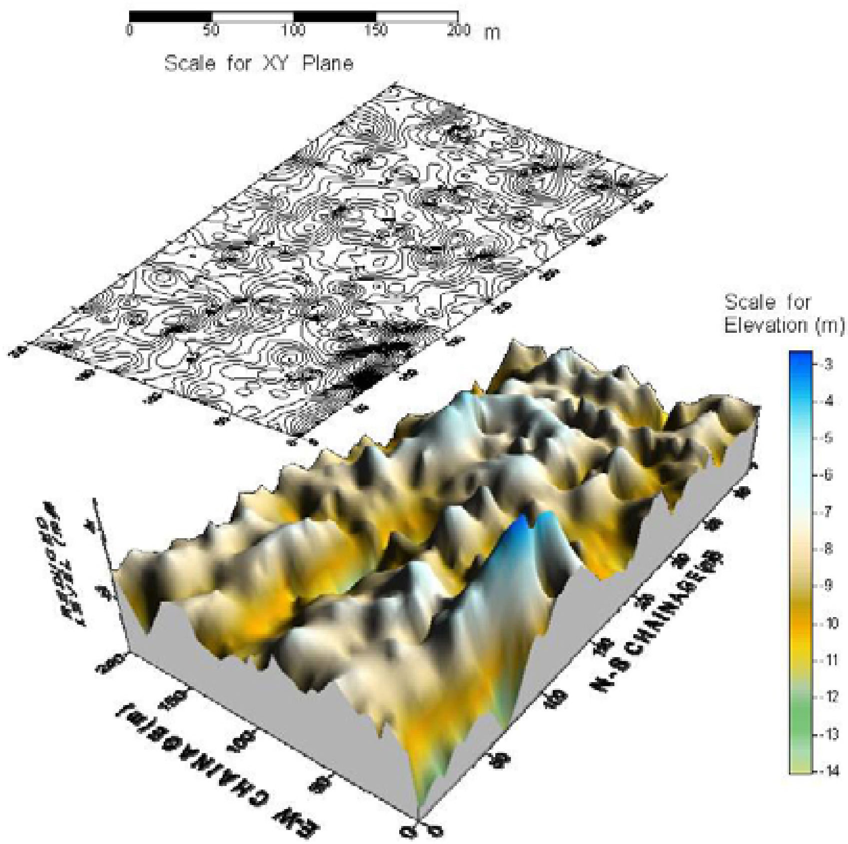

Figure 6. Topographic undulations in bed rock (East side of road)

quality rock. However, at locations where only two subsurface layers were inferred, from the velocities of the layers, it was observed that the middle layer i.e. compact saturated sand/ weathered rock was absent (Fig 4) and the rock was found to occur at shallower depths as compared to the locations where three subsurface layers were inferred.

The top layer velocity was evaluated to be between 300m/sec and 600m/sec which was interpreted to be loose sand. The second layer velocity varied from 1100m/sec to 2000m/sec. The lower end of velocity range (1100m/sec) may represent partially saturated sand and the velocity 1500m/sec and above corresponds to compact/ saturated sand/ weathered rock. The rock velocity ranged between 4000m/sec and 5800 m/sec, which for charnockite indicates good quality. However, a few zones in bedrock having lower wave velocity (< 3500m/sec), which represent inferior quality rock (weak zone) were inferred from the velocity analysis of data. Lateral extent of these zones was marked in the depth-section (Fig 5). However, the vertical extent of weak zones could not be established by refraction survey because of insufficient velocity contrast between weak zone and good quality rock. The seismic velocities of bed rock evaluated along N –S and E-W directions were in the same range showing that there is no anisotropy in rock velocities (Fig 4 & 5).

The depth to rock from the ground surface varied from 5.9m to 25.8m in both the study areas. The rock was found to be at shallower depth, where two subsurface layers were inferred. The rock was deeper (15m to 25m), where three subsurface layers were inferred. The large variations in rock depths at the site are indicative of uneven weathering in the rock (Fig 6).

CONCLUSIONS

Depth and quality of rock obtained from boreholes at discrete locations covers a small volume around the hole and interpolation of geological information between boreholes could be erroneous and misleading particularly so in areas of uneven weathering. This information required for locating and for deciding the level of foundation for civil structures is obtained reliably and economically by continuous seismic refraction study along with the information from a few boreholes. Seismic refraction study conducted in 20 m grid in two mutually perpendicular directions at the FRFCF site, Kalpakkam was able to delineate the uneven bed rock topography, decipher its relative quality, locate the lateral extent of weak zones in rock and confirm the absence of anisotropy in seismic velocities of rock.

ACKNOWLEDGEMENTS

Authors are grateful to Dr. I.D. Gupta, Director, Central Water and Power Research Station, Pune for constant encouragement and for permission to publish the paper. The help and co-operation extended by project authorities during collection of data is thankfully acknowledged.

REFERENCES

Dobrin M.B., 1976, Introduction to Geophysical Prospecting, McGraw-Hill Book Company, New York

Hawkins, L.V., 1961, The Reciprocal method of routine shallow seismic refraction investigations, Geophysics, Vol.26.

Hawkins, L.V., and Whiteley, R.J., 1973, Shallow seismic refraction methods in exploration and engineering, University of New South Wales, Australia.

Redpath, B.B, 1973, Technical report E-73-4 Seismic refraction exploration for engineering site investigations, U.S Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Livermore, California

Sjogren, B., 1984, Shallow refraction seismics; Chapman and Hall Ltd., London.