Shallow Sub-surface Characterization Using Integrated Geophysical Methods: An Implication to Seismic Data Processing

Abul Aas[1], Satish Kumar Sinha
[1]Email: pgp19001@rgipt.ac.in, Rajiv Gandhi Institute of Petroleum Technology

Abstract

Insufficient information about near-surface layers may lead to the misrepresentation of geological features in processed seismic sections. Therefore identifying near-surface variation is important for seismic data processing. Integrated geophysical methods namely electrical resistivity tomography (ERT), multi-channel analysis of surface wave (MASW), and ground penetrating radar (GPR) have been used to study the shallow subsurface variation in the Bundelkhand region of India. ERT, MASW, and GPR were acquired along the same profile and it was processed using ZondRes2D, winMASW, and RADAN7 software to obtain the subsurface images. It is inferred from the subsurface image produced by MASW and GPR methods that the current study site consists of mainly two layers: (i) alternate layers of soil up to a depth of 15 m, and (ii) weathered/fractured rock beyond 15 m depth. The ERT resistivity section shows the high value of resistivity (1600 ohm-m) at depth of 7 m and a horizontal distance of 46 m, which indicates the presence of rock mass/boulder. The same feature is observed in the GPR section also, showing a bulge at depth of 15 m and a horizontal distance of 48 m. Both the ERT and GPR sections show highly fractured rock at depth of 14 m and a horizontal distance of 20 m. Due to low resistivity (2.5 ohm-m) at position (20 m, 14 m) in the ERT section, it can be inferred that fractured rock is filled with water. When assessing the depth of geological features, there is always some uncertainty, which can be reduced by using an integrated geophysical approach. These shallow subsurface information will be useful for developing an appropriate near-surface velocity model and can be utilized in national seismic projects for correcting the near-surface velocity model and improving the static correction during seismic data processing.

Introduction

The reflection seismic method is generally used for mapping the subsurface geological features such as faults, folds, etc. Inadequate information of the shallow subsurface layers and physical properties may give an incorrect image or false location of the hidden geological features (Yilmaz, 2015). It arises due to complexity in near-surface layers. There are various causes of complexity in the near subsurface. The most significant are variations in the thickness and properties of weathered layers. Other factors include complex topography, faults, karst, buried channels, water table, etc. They can all result in incorrect static correction computation and degrade the quality of a seismic image (Docherty, 1992; Mrlina, 2016; Telford et al., 1990). It is therefore necessary to have adequate information about the shallow subsurface during seismic data processing.

Integrated geophysical methods can be used to characterize the shallow subsurface (Foti et al., 2018; Yilmaz, 2015). Different geophysical techniques are now being used to map the subsurface all over the world. Some geophysical tools require external energy to energize the ground to measure subsurface response, while others do not and measure the natural ground response directly. Geophysical methods are selected based on the target depth of investigation and the resolution of the subsurface section. ERT, MASW, and GPR the proven geophysical tools capable of detecting shallow subsurface variation (Lowrie, 2007). Each technique has its specific benefits, dimensions, and limitations in which it is appropriate to employ. When one geophysical method does not provide sufficient information to build a holistic picture of the subsurface environment, integrated geophysical methods are used. The detected near-surface homogeneity could be utilized for correcting the near-surface velocity model and improving the static correction.

In the present work, we have selected the Mahoba district in the Bundelkhand region to study shallow subsurface variation using integrated geophysical methods such as ERT, GPR, and MASW. Geophysical data acquisition was carried out using these three techniques and data were subjected to processing for a better understanding of the shallow subsurface environment.

Data Acquisition

Geophysical data acquisition was carried out in Mahoba, Bundelkhand region (Fig. 1) for shallow subsurface characterization by using integrated geophysical methods (i.e. ERT, MASW, and GPR). ERT is carried out with multi-electrode with constant spacing, connected to multi-core cable and resistivity meter system. A control unit is used to automatically choose the active electrodes for each measurement. In the present survey Wenner-Schlumberger configuration is used for subsurface imaging with 48 electrodes and 2m electrode spacing (Fig. 2a). With this arrangement spread length will be 94 m and that will give information about the subsurface up to approximately 20 m. Resistivity reading was taken along one ERT line (AB) (Fig.1b).

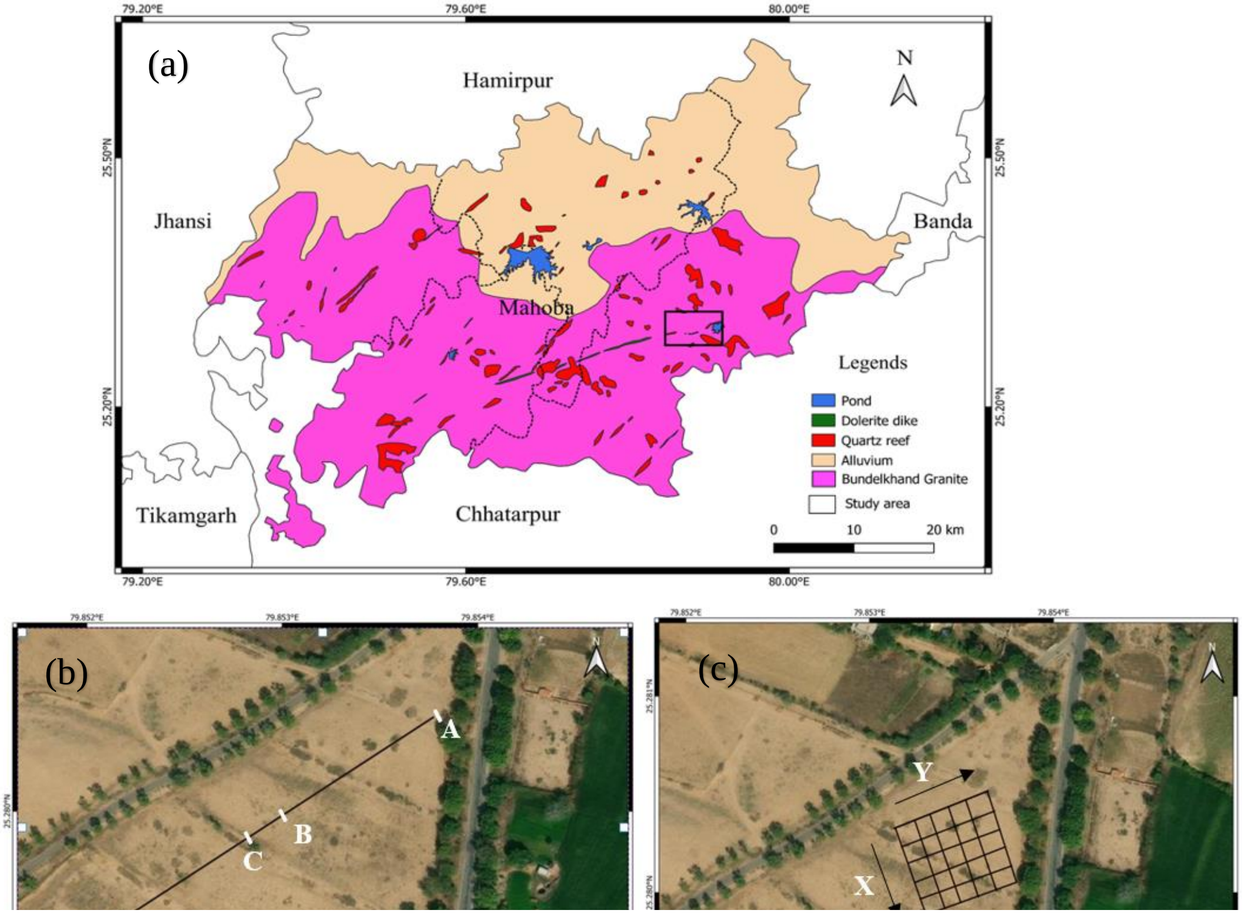

Figure 1: Study area map with (a) geology, (b) survey profile (ERT-AB; MASW-AC; and Bi-static GPR-AA'), and (c) survey Profile (Mono-static GPR).

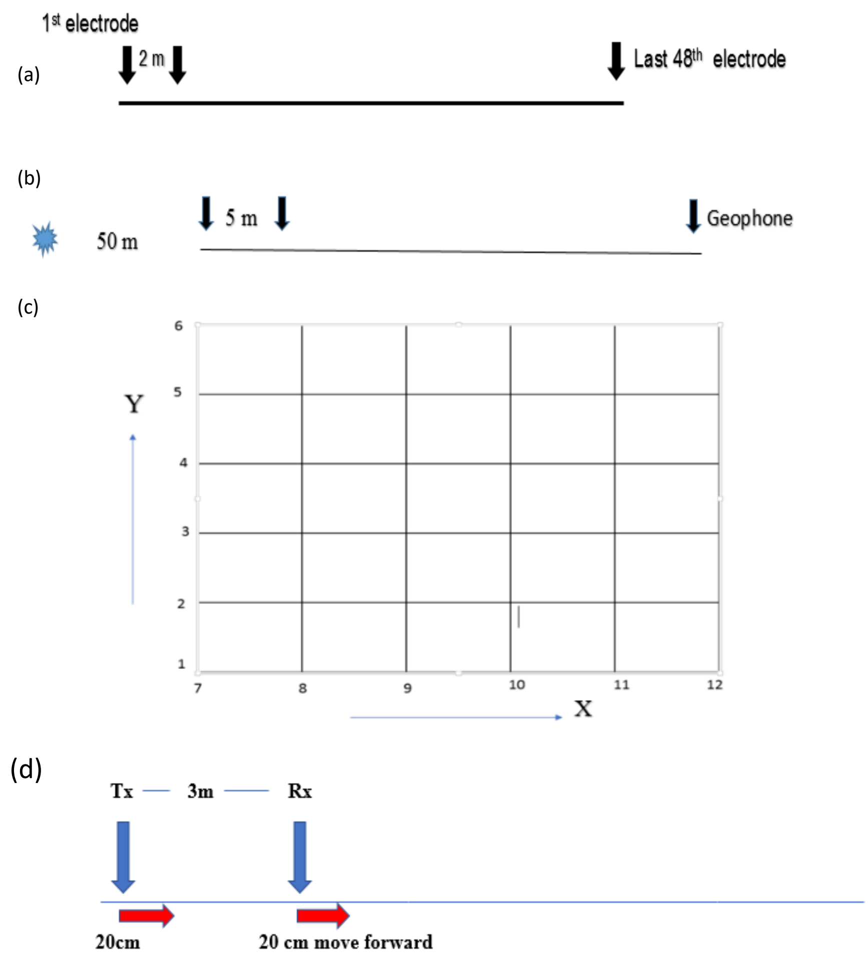

Figure 2: : Survey design using (a) ERT (b) MASW and (c) Mono-static and (d)Bi-static GPR

MASW survey was carried out along survey line AC (Fig. 1b) using 24 channel seismographs with 5 m geophone spacing and one shot was given at 50 m offset (Fig. 2b). Shot gather traces were recorded for the single shot.

GPR is a non-destructive geophysical method that utilizes high-frequency electromagnetic waves to scan shallow subsurface structures. For mapping shallow subsurface up to 10 m depth, Monostatic GPR was used and the survey was carried out along a gridded profile (Fig. 1c and Fig. 2c). i.e. 6 lines along the x direction and six lines along y direction of length 50 m and line spacing 10 m. For measuring deeper subsurface response Bi-static GPR reading was taken along line AA' (Fig.1b) with 3m spacing between transmitter and receiver, 20 cm increment, and a total 200 m profile length (Fig. 2d).

Data Processing

Seismic shot-gather traces were processed to evaluate the shear wave velocity (Vs) profile using winMASW software. The processing involves three steps: (i) transforming the seismic shot gather traces (Fig. 3a) into phase velocity and frequency domain (dispersion curve) (Fig. 3b) (ii) extracting the dispersion curve (dotted points in Fig. 3b), and (iii) inversion of dispersion curve to obtain shear wave velocity profile (Fig. 3c).

Processing steps were applied to the GPR data to obtain better subsurface images (Fig. 3d and 3e) using RADAN7 software. Processing steps include geometrical merging, vertical calibration, horizontal calibration, filtering, and gaining.

ERT data were inverted to obtain subsurface resistivity structure (Fig. 3f) by utilizing ZONDRES2DINV software. Processing steps involve (i) data cleaning, (ii) calculating the initial model by observing ERT data, and (iii) inversion of experimental data.

Results

Data were acquired by using all three geophysical techniques and processing steps were applied for studying the shallow subsurface environment. The processed image of the subsurface produced by all three geophysical methods is shown in fig. 3. It is observed from the shear wave velocity profile(Fig. 3a) that up to a depth of 15 m, Vs varies from 160 to 400 m/s, which indicate the alternate layers of soil. Beyond 15 m depth Vs drastically increases to 530 m/s, which suggests the presence of rock mass/boulder.

The GPR section (Fig. 3d and 3e) shows a low amplitude signal up to a depth of 15 m, which indicate the presence of soil. Around 15 m depth there is a strong reflection and also showing bulge (indicated by the white circle in fig. 3e) at depth of 13 m. This suggests the presence of weathered/fractured rock and the bulge is indicating the rock mass or the boulder. Beyond 15 m depth and a horizontal distance of 20 m in the GPR section (indicated by an arrow in Fig. 3e), multiple dipping reflections can be seen, which is attributed to highly fractured rock.

It is observed from the resistivity section (Fig. 3f), that the top layer of the subsurface up to 2 m depth shows high resistivity values (25-70 Ohm-m), which indicate the presence of hard soil. Around 2-3 depth (Fig. 3f, indicated by arrow), a low resistivity value (2.5 to 10 ohm-m) can be seen, which indicates the water-saturated soil. A very low resistivity value (< 7 ohm-m) can be observed at a depth from 6 to 14 m, which indicates the possibility of groundwater (Fig. 3f).The same feature is also displayed in the GPR section at depth of 15 m. A very high resistivity value(~1600 ohm-m) in the mid of the ERT section can be seen, which indicates the rock mass/boulder. This rock mass can also be seen in the GPR section but at depth of 13 m. By integrating the results of GPR and ERT, it can be concluded that: (i) at depth of 14 m, there is a highly fractured rock filled with water, and (ii) rock mass or boulder at depth of 7 m or 13 m.

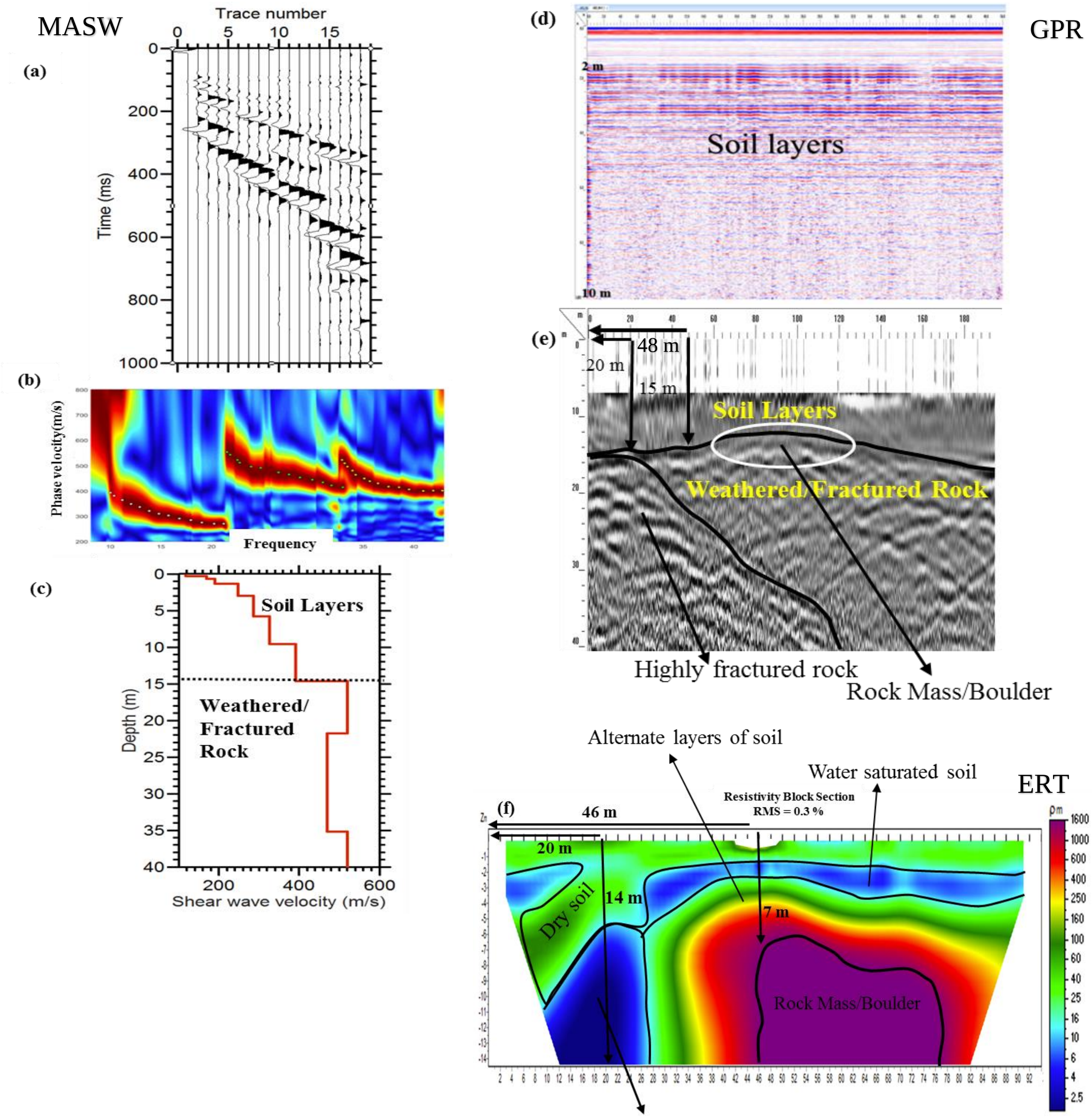

Figure 3: (a) Seismic shot gather traces, (b) Dispersion curve obtained from shot gather traces, (c) Vertical shear wave velocity profile, (d) Mono-static GPR section along a single line, (e) Mapped shallow subsurface image by bi-static GPR technique, and (f) ERT subsurface resistivity section.

Conclusion

The main objective of the current study was to understand the near-surface variation by using integrated geophysical methods for generating an appropriate shallow subsurface velocity structure. By combining the results of all three geophysical methods it can be concluded that the current study site consists of soil layers and weathered/fractured rock. But there is uncertainty in locating the depth of rock mass by using ERT and GPR methods. It can be resolved by making some additional depth corrections while doing GPR and ERT data processing. There is always some uncertainty in locating the depth of geological features, which can be minimized by using an integrated geophysical approach.

Acknowledgment

The work presented here is a part of the SEG Field Camp (2021) funded by the SEG foundation to the student chapter at RGIPT. We acknowledge all the students who were part of the field camp. We also thank the Director of RGIPT for supporting the field trip.

References

Docherty, P., 1992. Solving for the thickness and velocity of the weathering layer using 2-D refraction tomography. Geophysics 57, 1307–1318. https://doi.org/10.1190/1.1443198

Foti, S., Hollender, F., Garofalo, F., Albarello, D., Asten, M., Bard, P.Y., Comina, C., Cornou, C., Cox, B., Di Giulio, G., Forbriger, T., Hayashi, K., Lunedei, E., Martin, A., Mercerat, D., Ohrnberger, M., Poggi, V., Renalier, F., Sicilia, D., Socco, V., 2018. Guidelines for the good practice of surface wave analysis: a product of the InterPACIFIC project, Bulletin of Earthquake Engineering. https://doi.org/10.1007/s10518-017-0206-7

Lowrie, W., 2007. Fundamentals Of Geophysics, Second Edition, Cambridge University Press.

Mrlina, J., 2016. Near-Surface Characterization for Seismic Exploration Based on Gravity and Resistivity Data *, in The 12th Middle East Geosciences Conference and Exhibition March 7-10, 2016, Manama, Bahrain.

Telford, W.M., Geldart, L.P., Sheriff, R.E., 1990. Applied Geophysics. Cambridge University Press.

Yilmaz, Ö., 2015. Engineering Seismology with Applications to Geotechnical Engineering, Investigations in Geophysics. Society of Exploration Geophysicists. https://doi.org/doi:10.1190/1.9781560803300