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Application of Shallow Seismic Studies for Civil Engineering Applications: A case study from Chennai city, Tamilnadu

G.S. Srinivas, P.Shiva Shankar, K. Satish Kumar*, S.Trupti, P.Pavan Kishore, K.N.S.S.S.Srinivas and T. Seshunarayana

CSIR-NGRI, Uppal Road, Hyderabad-500007, India.
*Corresponding Author: satish_marine777@yahoo.co.in

ABSTRACT

Shear wave (V_S) and P-wave (V_P) velocities were estimated for the evaluation of the sub-surface structure along four profiles at CSIR-SERC Campus in Chennai city to aid in the structural design for a proposed high rise building. These velocities are essential parameters for determining the dynamic properties of soil in the shallow subsurface. Dynamic properties, thickness of soil, depth to basement and the associated in-homogeneities such as fractures, joints, voids and shear zones, play a very important role in design and construction of civil structures. Multichannel analysis of surface waves (MASW) and refraction methods were used for the estimation of V_S and V_P respectively to decipher the subsurface structure in detail. From the Seismic velocity-depth sections, the near surface distribution of rocks, soils and their physical properties were determined to characterize the site conditions. The results indicate a three layered structure with P-wave velocities of 400-500 m/s, 2700-3100 m/s and 5300-5500 m/s and S-wave velocities of >200 m/s, 200 to 300 m/s and >400 m/s up to a depth of 30 m. The obtained results are well correlating with the available borehole lithological data. These results are helpful in civil engineering applications in estimation of elastic properties, depth to bedrock and useful in planning of high rise structures.

Key words: Shear wave velocity, P wave velocity, bedrock, MASW and Structures.

INTRODUCTION

Several geophysical methods have been suggested for shallow near-surface characterization and in-situ measurement of P- and S- wave velocities using different configurations, processing techniques and inversion algorithms. The frequently used techniques are seismic refraction, spectral analysis of surface waves (SASW) and multichannel analysis of surface waves (MASW). MASW is a non-destructive and economical geophysical method, mostly used in geotechnical engineering for the measurement of shear wave velocity, evaluation of dynamic properties, subsurface structure and related studies. (Park et al., 1998,1999; Xia et al., 1999, 2000, 2002; Miller et al., 1999; Kanli et al., 2006).

Damage due to seismic waves depends on local ground conditions/soil type and its thickness apart from the type of constructions. The soft deposits (clay and sands along the coast and rivers) generally amplify ground motion thereby increasing the damage during an earthquake. Hence, the geotechnical characteristics of (V_P and V_S of soils, rocks and pavement) shallow material and its impact on seismic wave propagation are of great importance in groundwater, geo technical engineering, seismic hazard assessment and microzonation studies. The most challenging part of these investigations is to collect the data needed with the minimum expenditure and time (Oyedele et al., 2012).

The primary objective of this study is the identification of bedrock depth, which is the solid rock that lies below loose material, such as sand, top soil, gravel, or clay. It is very much essential to identify the bedrock depth, in order to estimate the impact of local site conditions in the event of an earthquake. In general, the soil cover over the bedrock may attenuate or amplify the earthquake motion depending upon geotechnical characteristics, their depth and composition of the soil. Usually the younger soft soil tends to amplify the ground motion as compared to the older, more competent soils or bedrock. The P wave Seismic refraction method is used to decipher the structure of the underlying bedrock. In refraction, seismic wave velocity is computed based on the first arrival times. These velocities can assist in the interpretation of geological layers as well as estimation of bed rock. Seismic refraction is a quantitative technique to determine the bedrock depth and lithological characteristics. MASW is very effective in delineation of subsurface features, any stratigraphic changes as well as the top rock and the associated features. In the present study, seismic refraction and MASW methods are used for the identification of bedrock depth and characterize the subsurface.

GEOLOGY OF THE AREA

The study area falls between 12° 59′ 12.12′′N to 12° 59′ 13.37′′N latitude and 80° 14′ 44.24′′N to 80° 14′ 46.18′′N longitude along the SE coast of India and in the NE corner of Tamil Nadu. The sea coast is flat and comprises of sandy structures for about one kilometre from the shore. Many parts of the city in the east and southern regions comprise of shallow bedrock (which is crystalline in nature) while some other areas towards west and north have Gondwana deposits below the alluvium (Ballukraya and Ravi, 1994). Most of the area is covered by Pleistocene/Recent alluvium, which has been deposited by the two rivers in the area, Coovum and Adyar. The alluvium mostly comprises of clay, sand, sandy clay and boulder/gravel zones occasionally. In general, sand is found along the river banks and coasts. The southern part of the study area has occurrences of Igneous / metamorphic rocks. The eastern and northern parts of the study area have marine sediments comprising of clay-silt sands and charnockites. The western part of the area is seen to be having alluvium and sedimentary rocks, along with a thin layer of laterite at some locations. Small boulders and rounded pebbles are seen at several locations at different depths. Thus, in general, It is observed that, the eastern side of the coastal zone is predominantly sandy, while the north western side is predominantly clayey in nature (Boominathan et al., 2008).

DATA ACQUISITION AND PROCESSING

Seismic refraction survey and MASW tests were conducted along four profiles. Two profiles (No-1 & 2) were laid in "E-W" another two profiles (No-3 & 4) were laid in "S-N" direction. The data was acquired using 24-channel seismograph with the following acquisition parameters:

For refraction survey, number 4.5 Hz geophones; 24; Geophone interval: 5m; spread length:115m; number of shots:5 (all in line shots, 2 far offset shots at 30m on either side, 2 near offset shots at 5m on either side and 1 shot at the middle of the spread): Sampling interval: 0.25m sec; Record length: 0.5sec.

The data processing involves picking the first arrival times from the time traces recorded from all shot points. From these arrival times the Time-Distance Curve is generated for each profile. The Time-Term inversion method, a standard inversion iterative method is a linear Least-Squares approach to determine the best discrete-layer solution to the data set (Bath, 1978). The time term inversion technique is applied to the travel time to estimate the velocities of different layers and the corresponding depths of the layers. It is a simple travel-time inversion enveloped by Scheidegger and Willmore (1957) and has been used widely for seismic refraction studies in the 1960–70s (Willmore and Bancroft, 1960; Berry and West, 1966; Meru, 1966; Yoshii and Asano, 1972).

MASW data was processing using "SurSeis software package" (Kanas Geological Society Make). The data has been subjected to following standard processing steps: (i) conversion of the field (SEG-2) data of Kansas Geological Society data format (ii) removal of bad traces through muting procedure (iii) generation of dispersive curve from filtered data (iv) extraction of dispersive curve (vii) Inversion of each dispersion curve for 1D shear wave velocity and finally staking of each 1D shear wave velocity curves for 2D shear wave velocity with depth.

RESULTS

The obtained P- and S- wave velocities with depth of four profiles are presented in Figure 1 to 4. P- and S- wave velocity depth sections of profile 1 in E-W direction shown in Figure 1. The P-wave velocity depth section of profile 1 shows the three (Figure 1a) different velocity layers. The average thickness of first layer is 3 m with a velocity of 500 m/s, the second layer is spreading between 3 m to 11 m with a velocity of 2700 m/s and the third layer velocity is 5400 m/s. It is also inferred from that the shear wave velocity depth section (Figure 1b), that the thickness of top layer is around 3 m with a velocity of < 200 m/s, depth to the second layer is 3 m with a velocity of 200 m/s to 500 m/s and depth to the third layer is 12 m with a velocity of >500 m/s.

It is observed from the P- and S- wave velocity depth sections of profile 1, top soil is present up to a depth of 3 m below that weathered charnockite is presented up to the depth of 12 m. Moderately weathered charnockite is extended up to the depth of 30 m. Further, fractured/ moderately the weathered charnockite is also seen (Figure 1b) from the shear wave velocity section.

Figure 2 shows the P- and S- wave velocity depth sections of profile 2 in E-W direction. The P-wave velocity depth section of profile 2 is also showing the three layers (Figure 2a). The average thickness of first layer is around 4 m with a velocity of 500 m/s, the second layer is between 4 m to 12 m with a velocity of 3100 m/s and the third layer velocity is 5500 m/s. It is also inferred from the shear wave velocity depth section (Figure 2b), that the thickness of top layer is around 5 m with a velocity of < 200 m/s, depth to the second layer is 5 m and extending up to the depth of 20 m with a velocity of 200 m/s to 500 m/s and third layer is extended up the depth of 30 m with a velocity of >500 m/s, which may be moderately weathered charnockite.

It is observed from the P- and S- wave velocity depth sections of profile 2, top soil is observed up to the depth of 4 m below that weathered charnockite is seen up to the depth of 20 m. It is observed from the shear wave velocity section moderately/fractured weathered charnockite is present in some parts up to the depth of 30 m.

It is inferred from the E-W profiles that the top soil, weathered charnockite and fractured/moderately charnockite extended up to the depth of 30 m sequentially. Further fractured/moderately weathered charnockite is seen in some part of the profiles.

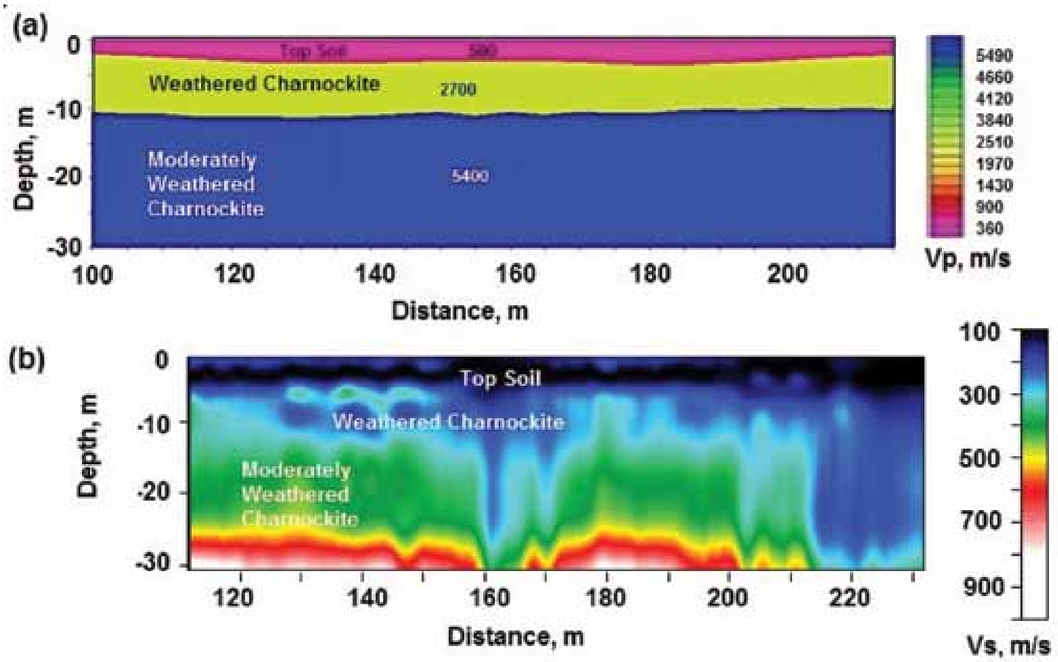

Figure 1. shows a) P-wave velocity depth section of profile 1, b) Shear wave velocity depth section of profile 1.

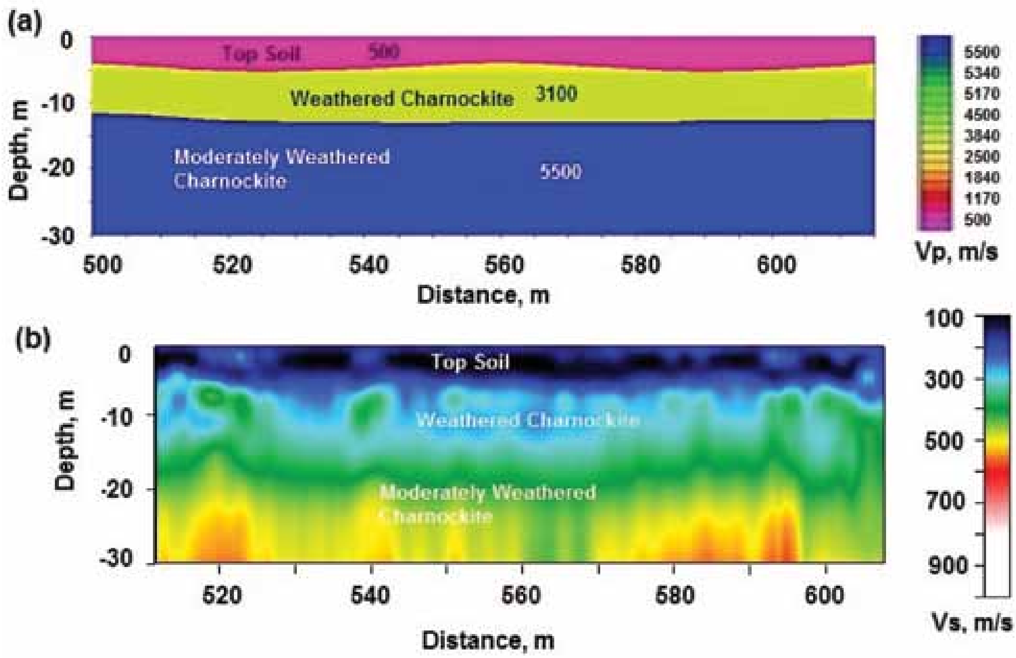

Figure 2. shows a) P-wave velocity depth section of profile 2, b) Shear wave velocity depth section of profile 2.

Figure 3 shows the P- and S- wave velocity depth sections of profile 3 in N-S direction. The P-wave velocity depth section of profile 2 is also showing the three layers (Figure 3a). The average thickness of first layer is around 3 m with a velocity of 400 m/s, the second layer is seen between 4 m to 11 m with a velocity of 2800 m/s and is third layer velocity is 5500 m/s. It is also inferred from the shear wave velocity depth section (Figure 3b), the average thickness of top layer is around 3 m with a velocity of < 200 m/s, depth to the second layer is 3 m and extending up to the depth of 18 m with a velocity of 200 m/s to 500 m/s and third layer is extended up the depth of 30 m with a velocity of >500 m/s.

It is observed from the P- and S- wave velocity depth sections of profile 3, top soil is present at up to the depth of 3 m below that weathered charnockite is presented

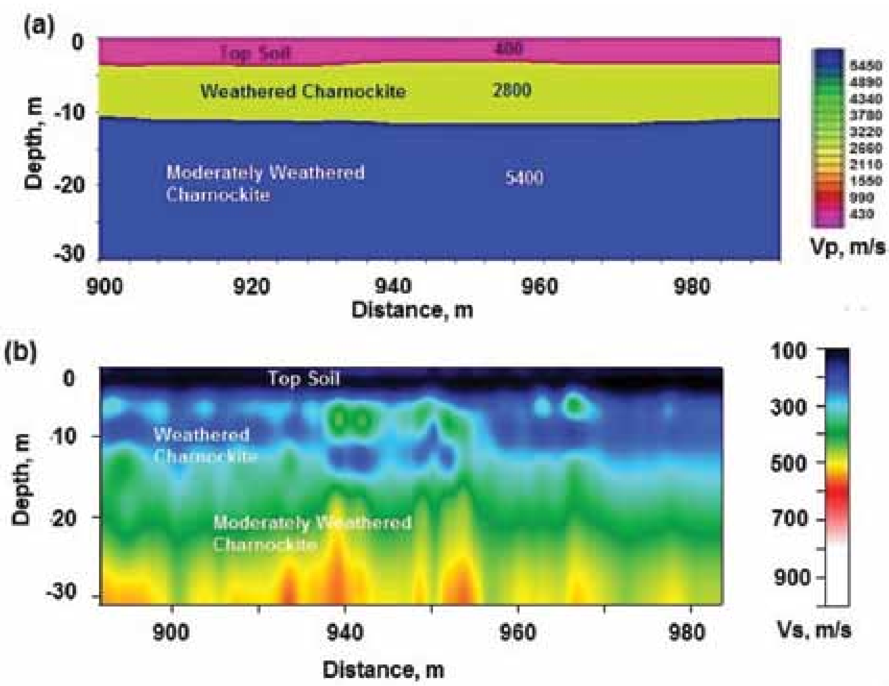

Figure 3. shows a) P-wave velocity depth section of profile 3, b) Shear wave velocity depth section of profile 3.

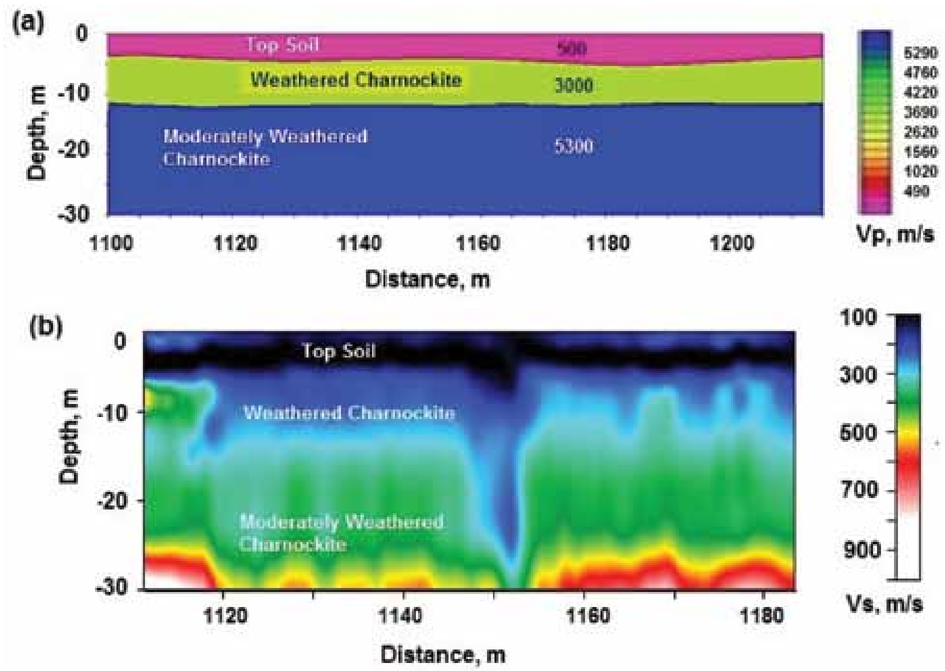

Figure 4. shows a) P-wave velocity depth section of profile 4, b) Shear wave velocity depth section of profile 4.

up to the depth of 18 m. The depth to the fractured/ moderately weathered charnockite is 18 m. Further, a patch of fractured/moderately weathered charnockite is seen in the central portion of the profile at a depth of 5 m (Figure 3b).

Figure 4 shows the P- and S- wave velocity depth sections of profile 4 in N-S direction. The P-wave velocity depth section of profile 4 shows the three layers (Figure 4a). The average thickness of first layer is around 3 m with a velocity of 500 m/s, the second layer is present between 4 m to 12 m with a velocity of 3000 m/s and depth to the bottom most layer is around 12 m with a velocity of 5300 m/s. It is also inferred from the shear wave velocity depth section (Figure 4b), the average thickness of top layer is around 3 m with a velocity of < 200 m/s, depth to the second layer is 5 m and extending up to the depth of

15 m with a velocity of 200 m/s to 500 m/s and third layer with a velocity of >500 m/s.

It is seen from the P- and S- wave velocity depth sections of profile 4, top soil is presented at up to the depth of 5 m below that weathered charnockite is presented up to the depth of 15 m. The depth to the fractured/ moderately weathered charnockite is 15 m. Further, a patch of fractured/moderately weathered charnockite is seen in the central portion of the profile at a depth of 5 m and extended up the depth of 30 m (Figure 4b).

It is inferred from the N-S profiles of the study area, top soil, weathered charnockite and fractured/moderately weathered charnockite extended up to the depth of 30 m sequentially. Further weathered charnockite is presented in central part of the profiles in shallow levels.

The interpreted rock strata from the present analysis are correlated with the nearby borehole information (GMCL, 2013) and it is observed from the borehole sections that soil with clay is present up to the depth of 9 m, where as highly weathered to slightly weathered Charnockitic rock is present up to the depth of 15 m. The interpreted depth strata from the present analysis are well correlated with the borehole results and provided the depth information up to the depth of 30 m in terms of P- and S- wave velocities for site evaluation for construction of high rise building at SERC complex.

CONCLUSIONS

The MASW and Seismic refraction studies at CSIR-SERC complex in Chennai city clearly shows the presence of top soil, weathered charnockite, and fresh charnockite sequentially up to the depth of 30 m.

P-wave velocities of 400-500 m/s, 2700-3100 m/s and 5300-5500 m/s are estimated for top soil, weathered charnockite, and fresh charnockite respectively using refraction technique.

S-wave velocities of >200 m/s, 200 to 300 m/s and >400 m/s are estimated for top soil, weathered charnockite, and fresh charnockite respectively using MASW technique.

Seismic velocities are obtained in the two mutually perpendicular directions with limited borehole information are provided the optimum coverage economically to understand the soils and basement characteristics. These results are helpful in civil engineering applications in estimation of elastic properties, depth to bedrock and planning of high rise structures in the study area.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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