INTEGRATED SITE INVESTIGATION OF SHALLOW BEDROCK SITES FOR SEISMIC SITE RESPONSE STUDY

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ABSTRACT

Study of seismic hazard and site response are essential and has become mandatory for the design of important structures. Subsurface investigation is an important step, from where input parameters for site response studies like shear wave velocity (Vs), density, thickness and damping characteristics etc are obtained. Most of the site response studies at shallow bedrock site are usually carried out by using Standard penetration test (SPT) N values and Vs from Multichannel Analysis of Surface Waves (MASW) with assumption that soil layers are horizontal, uniform and homogeneous. These assumptions are not completely true in shallow bedrock region due to heterogeneous soil deposits. The objective of this study is to generate subsurface profiles at shallow bedrock region using integrated site investigation testing. In this study drilling of borehole with SPT N value measurement, seismic testing of MASW and Electrical Resistivity Tomography (ERT) has been carried out at selected locations in Hampi, Karnataka, India. SPT gives soil type and density, MASW gives shear wave velocity and resistivity testing gives layer thickness. Integrated subsurface profiles are generated and are used to understand variation of subsurface layers in shallow bedrock sites and validate 1-D site response study assumptions. These subsurface profiles may be further used to understand difference of 1-D and 2-D site response.

KEYWORDS

Subsurface investigation, soil profiling, SPT, MASW, electrical resistivity.

INTRODUCTION

Southern India once considered as a stable continent has experienced many earthquakes recently indicating that it has become moderately seismically active region. Site specific site response studies are essential and have become one of the mandatory steps for the design of important structures. The input parameters for site response studies like shear wave velocity (Vs), density, thickness and damping characteristics etc are obtained from the detailed subsurface investigation of the site. Hence subsurface exploration is an important step in the site response analysis. Most of the site response studies at shallow bedrock site are one dimensional and usually carried out by using Standard Penetration Test (SPT) N values and Vs from Multichannel Analysis of Surface Waves (MASW) with the assumptions that soil layers are horizontal, uniform and homogeneous (Anbazhagan et al. 2007; Umut, 2004). These assumptions are not completely true in shallow bedrock region due to heterogeneous soil.

The use of Electrical resistivity tomography (ERT) provides the electrical image of subsurface soil and has become an important tool for the electrical characterization of soil in 2D where it is possible to extract the continuous and special variability of soil layer properties and thickness (Sudha et al. 2009; Braga et al. 1999). Various attempts have been made in literatures to characterize the subsoil using ERT (Samoulelian et al. 2005; Cosenza et al. 2006; Gay et al. 2006). The objective of this study is to generate subsurface profiles at shallow bedrock region using integrated site investigation testing. In this study drilling of borehole with SPT N value measurement, seismic testing of MASW and Electrical Resistivity Tomography (ERT) has been carried out at selected locations at Hampi, Karnataka, India. SPT tests gives soil type and density, MASW gives shear wave velocity and resistivity testing gives layer thickness. Integrated subsurface profiles are generated and are used to understand variation of subsurface layers in shallow bedrock sites and validate 1-D site response study assumptions. These subsurface profiles may be further used to understand difference of 1-D and 2-D site response.

STUDY AREA AND METHODOLOGY

Study area selected for this work was Hampi, Karnataka, India. Hampi is an important archaeological site in India which is at the northern part of Karnataka state. SPT N value measurement, seismic testing by MASW and Resistivity imaging has been carried out at selected locations at Hampi. ERT survey lines were selected based on the availability of space and borehole data. Both SPT and MASW tests were conducted at the same location in such a way that these tests comes over the ERT survey line. Spatial variation of soil layer thickness is arrived from resistivity imaging. MASW test results are used to map the shear wave velocity (Vs) variation with depth. SPT test gives soil type and density values and also used to crosscheck the other two geophysical test results. The combined test results of SPT, MASW and Resistivity imaging used to map the final 2-D subsurface profiles which can be further used for the 2D site response analysis.

Standard Penetration Test (SPT)

The standard penetration test is a widely used in situ test in a borehole to evaluate the dynamic properties of soil. 150 mm dia/Nx size boreholes were drilled in all kinds of soil/weathered strata using rotary drilling by wash boring method as per IS: 1892 (1979). The SPT was conducted as per IS: 2131(1981) at various depths in the boreholes. A split spoon sampler with external and internal diameter of 50.8 and 38 mm respectively and 650 mm long was driven into the soil under the impact of a 63.5 kg hammer from a height of 0.75 m. The number of blows required by the sampler to penetrate the 300 mm of depth is called the N-SPT value. Typical Borehole drilled at a location along with SPT-N value is shown in Figure 1. Whenever the N-SPT value exceeds 50 for 300 mm penetration, it was treated as refusal or rebound (R) and further N-SPT values were not measured for that depth. Disturbed and undisturbed samples were collected at possible depths as per IS: 2132 (1986). The physical properties were measured in the laboratory using disturbed soil samples as per IS: 1498 (1970) and used for soil classification in this paper. N-SPT values and soil profiles were recorded in the field itself.

BH No 1

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Depth Below GL(m)	Soil Description	Thickness of Strata (m)	Legend	Details of Sampling		SPT N Value
				Type	Depth (m)	
0 1 2	Clayey silt	2m		SPT	1.5	11 (4,5,6)
3 4 5 6 7	Clayey silty sand	5m		SPT	3.0	9 (3,4,5)
				SPT	4.5	15 (5,7,8)
8	Disintegrated weathered rock	1m		SPT	7	23 (8,9,14)
9 10	Hard rock	Below 8m		SPT	8	50R for no penetration

Note:

SPT Standard Penetration Test R Rebound

Figure 1. Typical borelog at location 6 with SPT-N values

Multichannel Analysis of Surface Wave (MASW) method

MASW is a geophysical method, which generates a shear wave velocity profile (ie., Vs versus depth) by analyzing Raleigh-type surface waves. MASW system used for this study consists of 24 channel geode seismograph with 24 geophones of 4.5Hz capacity. The MASW spread length was selected in such a way that the midpoint of the MASW spread length matches with the SPT borehole points. All tests have been carried out with geophone interval of 1 m. Source has been kept on both side of the spread and distance to source from the first and last receiver have been varied from 5 m, 10 m and 15 m to avoid the near-field and far-field effects. The seismic waves were created by impulsive source of 10 pound sledge hammer with 1'x1' size hammer plate with 10 shots; these waves were captured by geophones (Park et al. 1999). The captured surface waves were analyzed by a software package of Surfseis. The typical shear wave velocity profile at a test location in Hampi is shown in Figure 2. Even though MASW gives Vs which is required for site response analysis, but it is difficult to identify layer type and thickness.

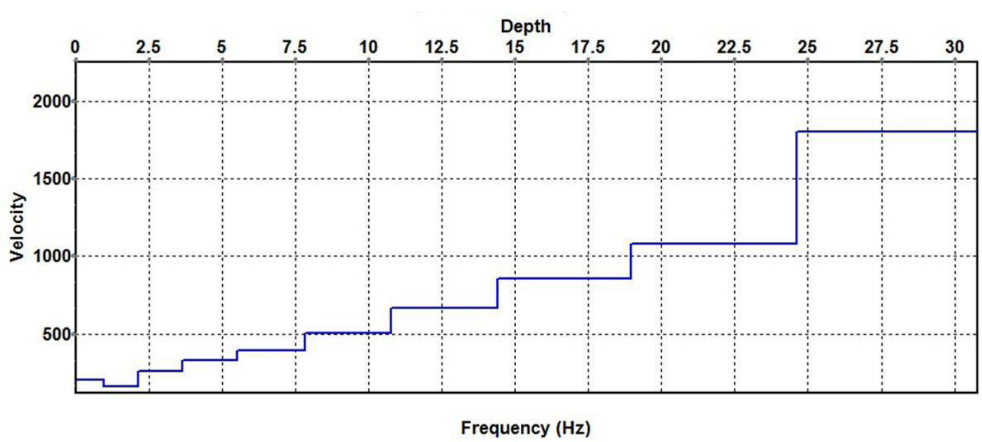
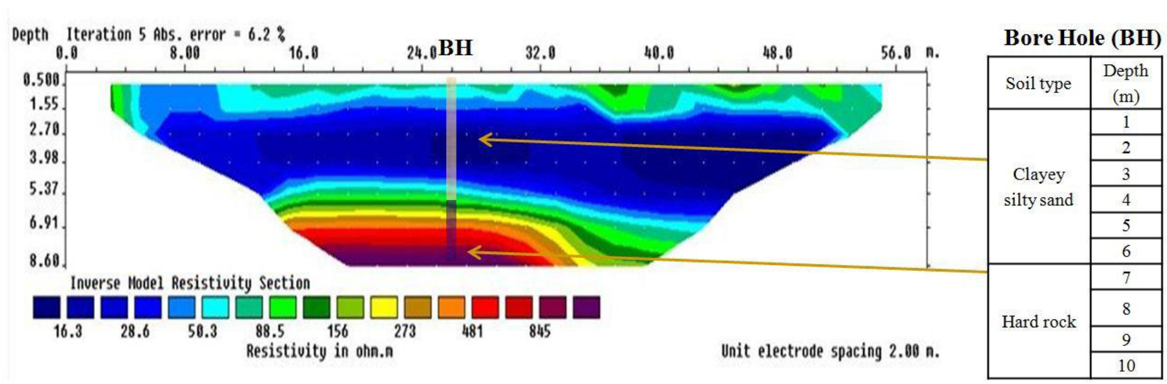


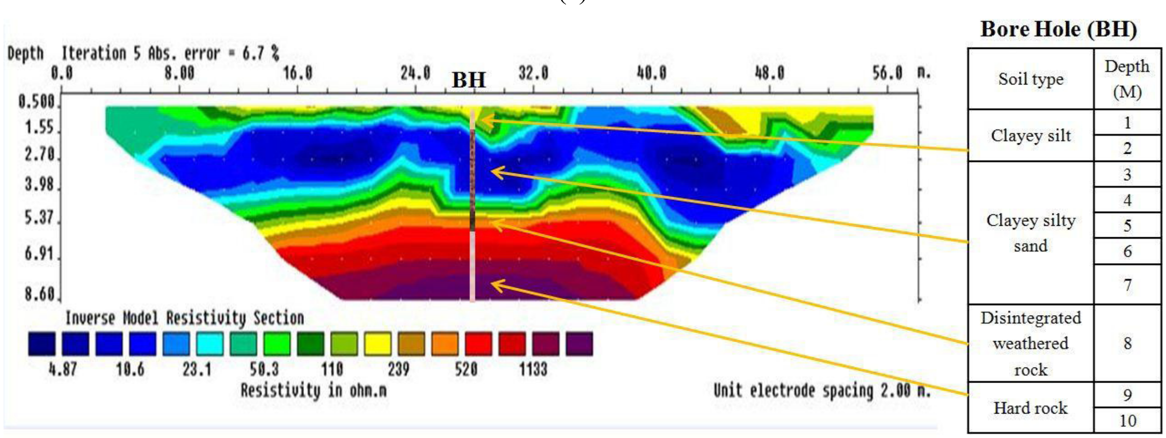
Figure 2. Typical Vs profile for the site Hampi

Electrical Resistivity Tomography (ERT)

Electrical resistivity tomography (ERT) was carried out using multi electrode system. The instrument used for the study was GD-10 Series, DC Digital Resistivity Meter from WTS Limited,China. GD-10 Series is a new-state-of-the-art Multi-Electrode Resistivity Imaging System, which can automatically measure and store primary voltage (Vp), current (Ip), apparent resistivity (Ro), etc and is capable of conducting 1D VES/SP/IP Sounding & 2D & 3D Resistivity/IP Imaging function. It is widely applied in hydrology and engineering explorations as groundwater detection, inspecting reservoir base and level for incipient fault, as well as in metal and nonmetal resources exploration, civil geophysical prospecting, railway and geothermal application. Based on the availability of space for aligning the survey line the number of electrodes, electrode spacing and the total length of the survey line varies. The data using Schlumberger–Wenner sequence with either 30 or 60 combination of electrodes were deployed along the profile line at an inter-electrode spacing which varied from 2m to 5m. The total length of each profile line varied from 58 m to 295 m. RES2DINV code (Loke and Barker, 1996; Loke, 1997) was used for the processing and inversion of resistivity image profile data. The method uses a finite difference scheme for solving the 2-D forward problem and blocky inversion method for inverting the processed ERT data and it (RES2DINV) generates the inverted resistivity depth image for each profile line. Soil layer thickness and layer properties were interpreted from the resistivity profiles by cross checking with the conventional borehole data. Interpretations show that the resistivity profiles match well with the borehole data. Typical resistivity profiles at location in Hampi are shown in Figure 3.



(a)

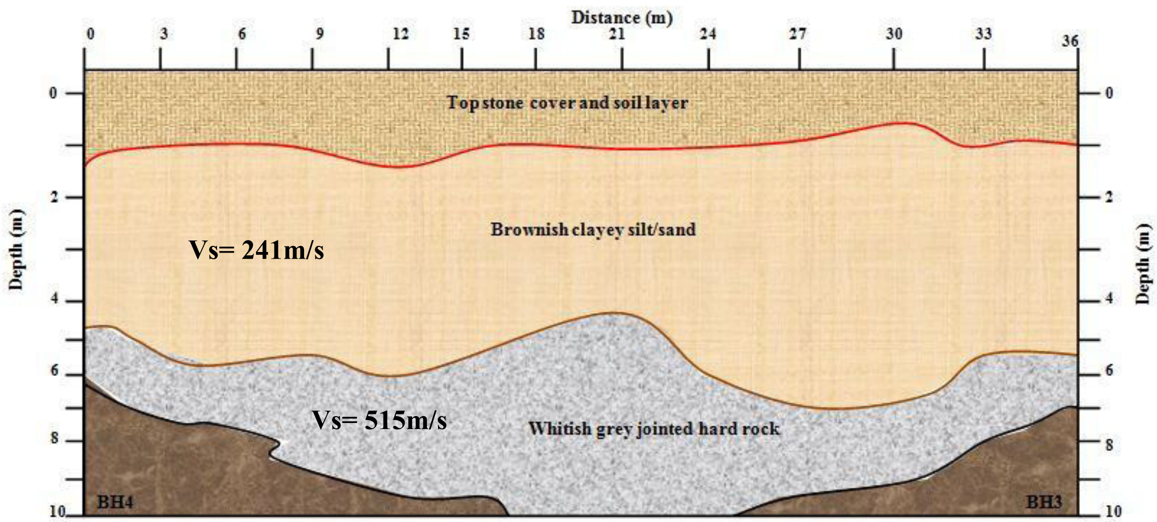


(b)

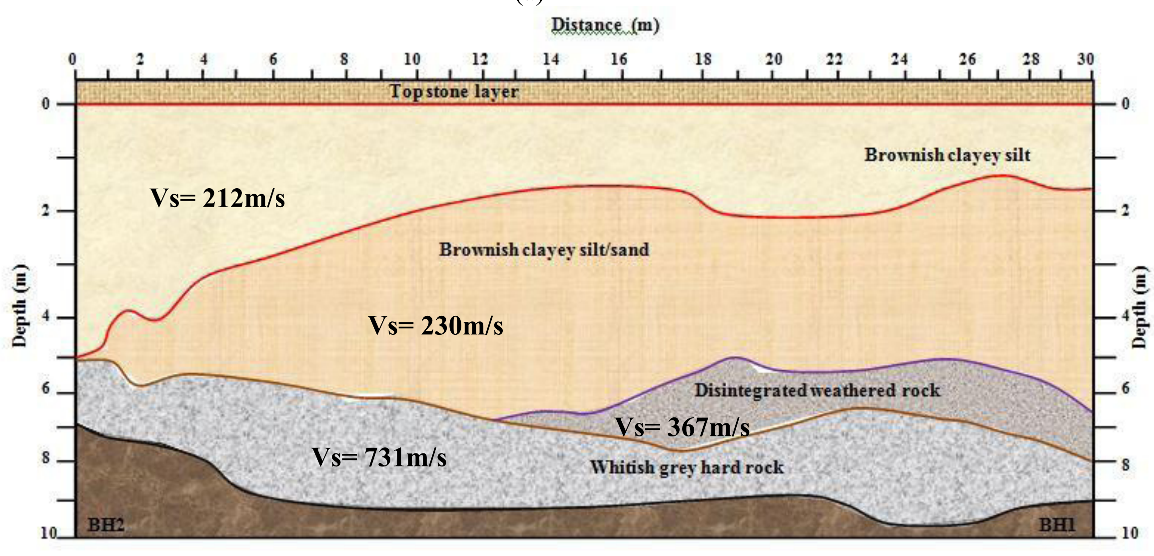
Figure 3. (a), (b) Typical Electrical Resistivity Tomography (ERT) profiles at Hampi

RESULTS AND DISCUSSIONS

SPT and MASW tests were conducted at different points over ERT survey lines. MASW test gives the variation of Vs with depth and SPT give soil type, density and thickness. However it is difficult to capture spatial variation using these two methods. These actual undulations in the soil layer thickness and property in the site was captured by Electrical Resistivity Tomography (ERT). So combining these three methods (ERT, SPT and MASW) it is possible to generate the detailed 2D subsurface profile of the site which shows the spatial variation of the layer thickness (from ERT), soil type (from SPT) and the Vs value of each layer (from MASW). Typical 2D subsurface profiles are shown in Figure 4. From these profiles it is possible to distinguish the clear variation of layer thickness, soil type and corresponding shear wave velocity values. This can be further used for the 2-D site response analysis and numerical simulations. Integrated subsurface investigations using SPT, MASW and ERT can give detailed subsurface profiling which are useful for 2D site response and other numerical simulations.



(a)



(b)

Figure 4. (a), (b) Typical 2D subsurface profiles generated by combining the three methods ie, ERT, SPT and MASW

CONCLUSIONS

Geotechnical and geophysical investigations have been carried out at different test locations in Hampi. The SPT was conducted at various depths in the boreholes and the soil type and layer thickness was estimated. MASW along with the software Surfseis has been used to calculate the shear wave velocity of soil profile in all the borehole locations. But both MASW and SPT fail to give the actual variation of layer properties and thickness. This is achieved by conducting ERT. Resistivity surveys has been conducted at the selected locations and with the help of RES2DINV code the continuous spatial variation of soil, the layer thickness and properties were interpreted by comparing with the borehole data. By combining and correlating the geotechnical and geophysical data final 2-D subsurface profiles were generated. This study shows that the assumption that soil layers are horizontal and are of uniform thickness is not valid in the shallow bedrock site investigated. Integrated subsurface investigation will give more reliable subsurface profiling. These reliable subsurface profiles may be further used for the 2-D site response analysis and numerical simulations. It can also be used to understand difference of 1-D and 2-D site response. The mapping of soil profile by combining the methods ERT, MASW and SPT is efficient, fast and economic in comparison to the single (SPT or MASW) method.

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