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Development of Subsurface Profile Using Geophysical Test Data

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Abstract: Site characterization is a basic activity towards the proper analysis, design, construction and long term performance of all types of geotechnical structures, ranging from substructures, excavation, earth dams, embankments, seismic hazards, environmental issues, tunnels, and offshore structures. In view of this, it is essential to understand the soil characteristics before making a final decision on the analysis, design and construction of a structure. This paper presents the development of one- and two-dimensional (1D and 2D) subsurface profiles in IITM campus and Surat city. In the multichannel analysis of surface waves (MASW) test, concepts of refraction analysis, time term method and tomographic inversion are used to calculate the shear wave velocity with respect to depth for a few selected locations in the IITM campus and Surat City.

Keywords: *Site characterization, Spectral Analysis of Surface Wave, multichannel analysis of surface waves, and Shear Wave Velocity*

1. Introduction

Site characterization includes an evaluation of subsurface features, subsurface material types and their properties. The overall performance of a structure founded on geologic material depends on the subsurface conditions, ground surface features, and construction. The field and laboratory studies are required to be carried out for obtaining the necessary information regarding the subsoil characteristics.

This paper outlines the seismic site characterization carried out for the Indian Institute of Technology Madras (IITM) campus and Surat city. Multi-Channel Analysis of Surface Wave (MASW) tests were conducted at 10 locations for Surat city and 12 locations for IITM campus. The site characterization activity was divided into two categories. The first one was the geophysical seismic testing, which included multichannel analysis of surface waves (MASW) and the second category was the conventional geotechnical testing, which included geological surveys, standard penetration test. In early stage of surface wave analysis, the Spectral Analysis of Surface Wave (SASW) method was widely used for shallow shear wave velocity personation ([5], [6], [7], and [4]). The MASW test [6] as an extension to the SASW method and it is commonly employed to estimate shallow S-wave structure. The MASW method is commonly used to indirectly measure the shear velocity profile of the subsurface medium in site characterization and hence provides the variation of stiffness along the depth of the geologic medium.

The purpose of this study is to demonstrate a methodology for determine the soil parameter which is applicable in areas with limited subsurface information. In this situation requires many input parameters related to subsurface conditions, many of which are difficult to obtain through geotechnical and geophysical investigations. Multichannel analysis of surface waves is one of the most widely used techniques in geotechnical engineering for the measurement of dynamic soil properties, identification of subsurface material boundaries and spatial variations of shear wave velocity. The MASW test is a non-destructive seismic method used to evaluate thickness and shear wave velocity of the soil strata.

2. Field Testing Elements and Procedure

Type An imaginary centerline for the receiver array is selected and multiple receivers are then placed on the ground surface. In this MASW test, contains an array of 24 low frequency vertical geophones (e.g. 4.5 Hz) placed in a linear array and typically at equidistant spacings is along with a seismic cable, seismograph, laptop computer, seismic source and trigger wire. To survey at greater depths a higher energy source, such a weight drop or accelerated weight drop or a controlled vibrating source can be used and the steps of Acquisition, inversion and Processing are as follows.

2.1. Acquisition

A vertical impulse is applied to the ground by means of a hammer. A major portion of the various types of stress waves generated by the impulse propagates as surface waves of various frequencies. Impulses are delivered several times, and the signals are averaged together. Selection of seismic source and geophone spacing is based on depth of investigation and velocity-depth distribution. For deep bedrock sites where anticipated depth of investigation is in the range of 10 meters, a geophone separation of 2 meters is generally adequate. The seismic source is located off the end, and co-linear. The geophone array of an MASW setup is presented in Figure 1.

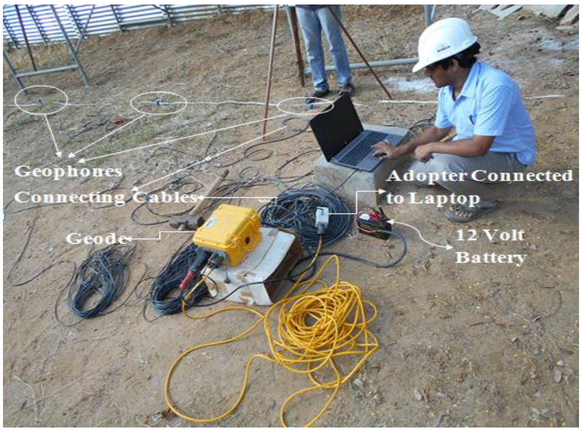

***Figure 1** Single geode test setup and sources at different position*

2.2. Processing

The collected MASW data would be first processed to remove any bad records, such as a geophone with poor response. Data can also be time filtered to remove any spurious noise on the seismic records at times before or after the source energy, to reduce their effect on the calculated phase velocities. Some processing techniques transform the whole data set from the time-offset domain where it has been acquired into domains where the energy is mapped as a function of other parameters, such as frequency, slowness, and wavenumber. Traditionally, the inversion process consists of adjusting a Vs profile until its theoretical dispersion curve for the fundamental mode coincides with the experimental dispersion curve assumed to represent the fundamental mode. The processing step has to estimate the dispersive characteristics from the acquired raw data and from the records of the particle motion at different positions; the processing algorithms infer the dispersion curve. The data are then processed in the frequency domain through analysis of the phase spectrum. There is common method to generate a dispersion curve, through frequency-wavenumber plots and the field data are processed to estimate the experimental dispersion curve, which is the relationship between phase velocity and frequency [2].

2.3. Inversion

The inversion is the last step of the seismic wave method, and it is the step that produces the final result. After finishing the dispersion analysis, the inversion algorithm is applied to characterize the soil profiles from the dispersion curves. Inversion of Rayleigh wave dispersion curve is a process for determining the shear wave velocity profile from frequency-phase velocity dispersion relationship. It consists of estimating the parameters of a layered model from the dispersion curve measured, and the data used for the inversion are the dispersion characteristics extracted by the processing from the acquired traces. Finally the inversion analysis is carried out to obtain the 1D S- and P-wave velocity profiles.

3. Data Analysis

Following are the steps involved in the data analysis:

1) Data monitoring: Gathering data and noisy traces were filtered out.
2) Selection of first arrivals: First arrivals of traces were selected and travel time curves were picked.
3) Assigning the Layers: Layer assignments were made based on the dominant slope travel time curve segments (as shown in Figure 2).
4) Time term inversion: A linear Least-Squares approach is used to define Time term inversion assumes that the subsurface is vertically stratified, On the basis of the points assigned for different layers, a layered model is generated. The depth is calculated and interpolated and the layered model from the time term inversion is generated [9].
5) Tomographic inversion: The tomographic method, involves the creation of an initial velocity model, and then iteratively tracing rays through the model, comparing the calculated travel times to the measured travel times, modifying the model, and repeating the process until the difference between calculated and measured times is minimized. Stated that tomographic inversion method is able to resolve velocity gradients and lateral velocity changes and can be applied in settings where conventional refraction techniques don't work. For example, the method can be applied in areas of compaction.

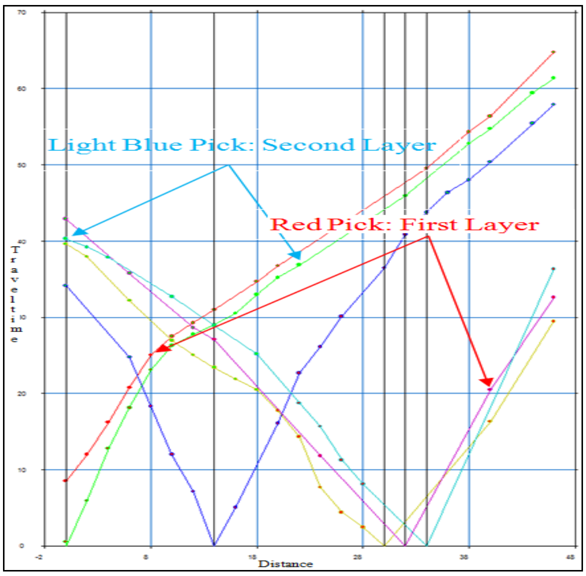

***Figure 2** Travel time curve and layer assignments for B-type quarters*

4. Result and Analysis

4.1. 1D Shear and Primary Waves Velocity Profiles

Figure, The MASW tests were conducted at 12 different locations in the IIT Madras campus, with 24 receivers with a spacing of 2 meters over a total spread of 22 to 48 meters. The MASW test results for the 1D Primary (P) and Shear (S) wave velocities for the B-type quarters are furnished in the subsequent sections. For the purpose of presentation, the MASW test results of B-type quarters are only given in this paper.

For B-type quarters the survey Line 9 (L9) is chosen from study area with bearing of 34'12" N. Totally five sets of data were collected by performing the MASW test with 15 receivers (array length = 28 m). These five sets of data came from the five positions of the active impact source at -2 m, zero meter (near to the first receiver i.e., first geophone), 14 m from the first receiver, 28 m (near to the last receiver), and 30 m (i.e., 2 m way from the last receiver).

The description of each layer has been obtained based on the average shear wave velocity for each of the layers as per [9] site classification. The data analyzed is for the B-type quarters and the subsurface identified is the medium to dense soil. Figure 3(a, b, c, d and e) shows the shear wave velocity corresponding to this soil varies from 220 to 400 m/s and the compressional wave velocity varies from 400 to 700 m/s (460 to 915 m/s as per [1]) up to a depth of 10 m from the ground level (GL). From 5 m depth onwards, the dense soil and/or weathered rock is identified which has shear wave velocity more than 300 m/s. In this location a completely weathered rock (shear wave velocity more than 700 m/s) is not found even up to a depth of 30 m from the ground level (GL).

Source Position at -2 m (Line 9)

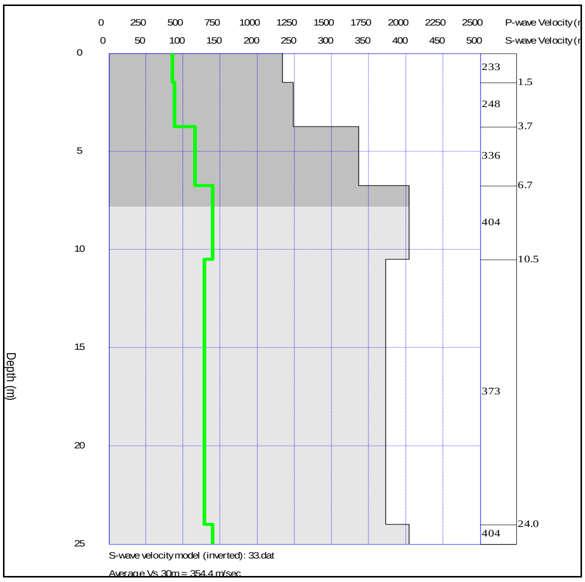

Figure 3a *Inversion for P- and S-wave velocity profiles*

Source Position at Zero m (Line 9)

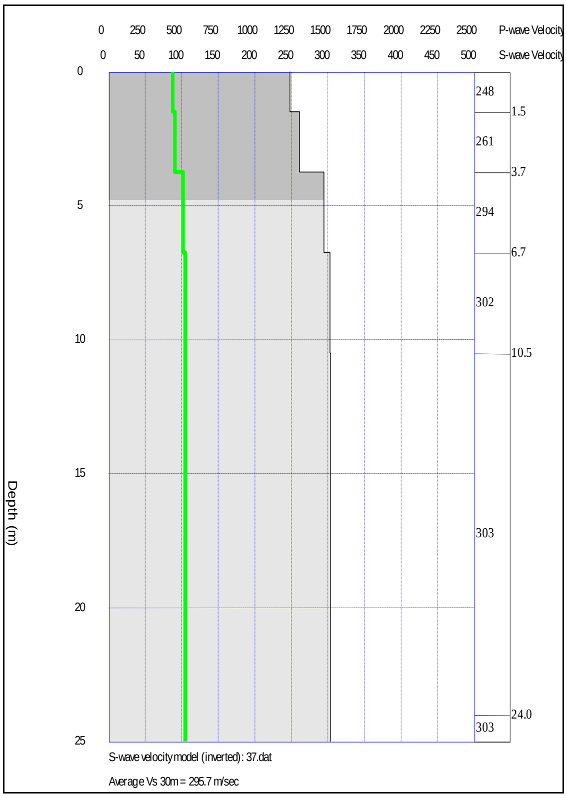

Figure 3b *Inversion for P- and S-wave velocity profiles*

Source Position at 14 m (Line 9)

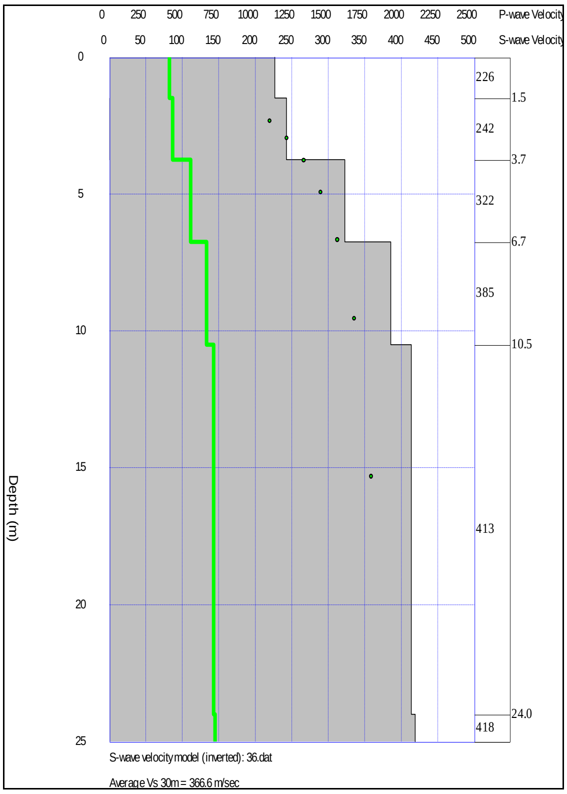

Figure 3c *Inversion for P- and S-wave velocity profiles*

Source Position at 28 m (Line 9)

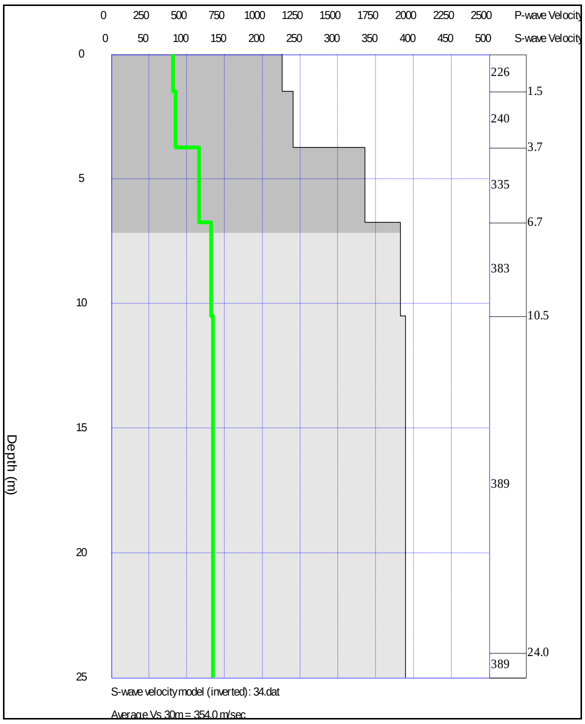

Figure 3d *Inversion for P- and S-wave velocity profiles*

Source Position at 30 m (Line 9)

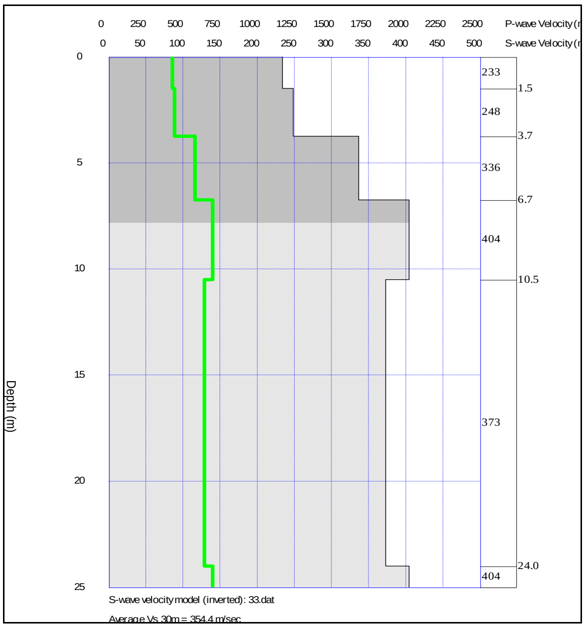

Figure 3e *Inversion for P- and S-wave velocity profiles*

5. Conclusions

Overall, the MASW test has been carried out at 12 locations in the IIT Madras campus as part of the development of 2D subsurface profile and 10 locations in Surat city. The 1D P- and S-waves analyses show that the compressional/primary wave velocity varies from 400 to 700 m/s (460 to 915 m/s as per [1] and shear wave velocity varies from 220 to 400 m/s up to a depth of 10 m from the ground level. The soil deposit up to 5 m depth from the ground level is residual soil and from 5 to 10 m depth it is a weather rock. From the value of Vs30 for the IITM campus soil, the soil can be classified as "site class D" and in some places "site class C" as per the NEHRP classification.

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