Procedural Assessment of Multichannel Analysis of Surface Waves (MASW) Test

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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. Several geotechnical and geophysical methods are employed to obtain the subsurface profile and corresponding properties. In the present study, an attempt is made to use the Multichannel Analysis of Surface Waves (MASW) tests to develop the one- and two-dimensional (1D and 2D) subsurface profiles for the IIT Madras campus, Chennai. The MASW test is commonly used in geotechnical engineering profession for obtaining dynamic soil properties for microzonation and site response studies. In the MASW test, shear wave velocity (Vs) is obtained and it is related to different soil layers of the subsurface. The shear wave velocity of the soil can be related to shear modulus.

Keywords – Multichannel Analysis of Surface Waves, shear wave velocity, geophysical methods and subsurface profile

I. INTRODUCTION

In characterizing the soil stratum, there are several methods being adopted by geotechnical engineers. Among the noninvasive techniques, the geophysical methods are the most robust methods that can be performed without physically accessing the stratum. These methods provide the profiles of continuous sections. A few of the techniques can also provide stiffness variation of the subsurface which is useful for the static and dynamic soil-structure interaction studies. Geophysical techniques also help in locating cavities, backfilled mine shafts and subsurface geological features such as faults and discontinuities. Currently, Multichannel Analysis of Surface Waves (MASW) test is used in the geotechnical engineering profession for the evaluation of dynamic properties, soil profiling, microzonation and site response studies. In particular, the MASW test is widely used in the measurement of shear wave velocity (Vs), identification of interface between the strata and spatial variation of soil layers, etc. Another advantage of the MASW test is that it is a noninvasive, low cost, and rapid. Moreover, the MASW test consistently provides reliable shear wave velocity profiles. The MASW test is used for near surface materials for getting stiffness data needed in earthquake analysis of geotechnical structures and also for liquefaction assessment.

II. LITERATURE REVIEV

A number of geophysical methods have been proposed for surface and subsurface characterization. Borehole logging and spectral analysis of surface waves (SASW) are generally considered to be the standard methods of obtaining shear wave velocity (V_s) with depth. The determination of V_s can also be carried out in boreholes, using down-hole, up-hole and cross-hole techniques. In the early stage of the surface wave methods, the SASW method was widely used for determining the shallow shear wave velocity (Nazarian et al., 1983; Tokimatsu et al., 1991; Ganji et al., 1997), in which only one pair of receivers were used for different spacing. The travel time between the receivers was calculated from phase differences this method was widely used in geotechnical projects as a geophysical test; its liability being the sensitivity to noise. The interference of different wave types may also easily lead to misinterpretation of phase velocities. Hence, it requires repeated measurements in the field (Kanli et al., 2006). All these disadvantages are overcome by Multichannel Analysis of Surface Wave (MASW) method (Park et al., 1999). In this method, the field work is easier and the measurement time is reduced.

III. MULTICHANNEL ANALYSIS OF SURFACE WAVE TEST

Shear wave velocity (V_s) is an essential parameter for evaluating the dynamic properties of soil in the shallow subsurface. A number of geophysical methods have been proposed for near-surface, subsurface characterization and measurement of shear wave velocity by using processing techniques and inversion algorithms. The most widely used technique is Multichannel Analysis of Surface Waves (MASW). The MASW method was first introduced in geophysics by Park et al. (1999). It is a very conventional mode of survey using an active seismic source (e.g., a sledge hammer) and a linear receiver array. Data is collected in a roll-along mode. The MASW has been found to be an efficient method for unraveling the shallow subsurface properties. In particular, the MASW test is used in geotechnical engineering for the measurement of shear wave velocity, which will then used in the estimation of shear modulus.

The MASW is a geophysical method, which generates a shear wave velocity profile (i.e., V_s versus depth) by analyzing Rayleigh surface waves on multichannel geophones. The identification leads to an optimum field configuration that assures the highest signal-to-noise ratio (S/N). Effectiveness in signal analysis is then further enhanced by the data processing step. The MASW test is also used to generate the 1D and 2D shear wave velocity profiles.

The MASW test setup consists of number of geophones (usually more than twelve) which are placed along a linear array with equal spacing. The seismic waves are created by an impulsive source i.e., a sledge hammer. These waves are captured by the geophones/receivers. The captured Rayleigh wave is further analyzed using suitable software to generate V_s data. This is being done in three steps: (i) Preparation of a multichannel record, (ii) Dispersion curve analysis, and (iii) Inversion. The term “Multichannel record” indicates a seismic data set acquired by using geophones with more than one channel using geode seismograph. The MASW test has been effectively used with highest signal-to-noise ratio of surface waves.

3.1 METHODOLOGY

The following methodology is adopted for the present study:

1. Case study - IITM, Chennai campus:

   A whole of IITM campus is selected for the study. The SPT data is collected from the Engineering Unit of the IIT Madras, Chennai.

2. Multichannel analysis surface wave (MASW) test:

   The MASW test is conducted at a few selected locations where borehole investigations were previously conducted by the IIT Madras authorities.

3. Processing of MASW test data by:

   (a) Obtaining the dispersion curves of Rayleigh wave phase velocity from the recorded data.

   (b) Determining the V_s profiles from which the $(V_s)^{30}$ values are calculated using SeisImager/2D^{TM} software.

3.2 MASW TEST PROCEDURE

Multichannel analysis of surface waves method (Xia et al., 1999; Miller et al., 1999) utilizes pattern recognition techniques made possible by the multichannel recording and processing approaches. The MASW method is widely used in seismology as well as in refraction surveying for oil exploration, etc. Rayleigh-wave energy is defined as signal in the MASW analysis and needs to be enhanced during both the data acquisition and processing steps. In all kinds of surface seismic surveys using vertical sources, ground roll takes more than two thirds of the total generated seismic energy and usually appears with the most prominence on the multichannel records. Therefore, generation of ground roll is easiest among all other types of seismic waves. Field records of various geophones measured using a 24 channel seismograph associated with linear survey. The MASW data is collected using a 2 m geophone spacing along with seismic sources at a different locations. The field setup of the MASW test is shown schematically in Figure 1.

The method first requires the measurement of seismic surface waves generated from seismic sources at different locations along the survey line. In the present study, sledge hammer is used to generate the seismic energy. The propagation velocities of those surface waves is analyzed, and finally the shear wave velocity (V_s) variations below the survey line is evaluated though the inversion process.

1) Data Acquisition

The MASW data are being collected from linear array in the IITM campus at a particular location using single Geode and 24-channel of geophones with a spacing of 2 m between them with the natural frequency of 4.5 Hz. The offset distances i.e., distance between the source and the nearest geophone is fixed to 2 m at both ends. The source is shifted among first, last and midway between the geophones (Figure 2d). These configurations are used for all the survey lines. The length of the survey line is varied from 22 to 48 m. Seismic energy is generated using a sledge hammer of 8 kg which is manually impacted on 150 cm^2 metal plate. The source is shifted every time from the first, last and midway between the geophones. A total of 5 shots are made at each location. Trigger is used to initialize the recording immediately after the shot. The generated Rayleigh wave data is recorded at all the shot points. Data for each shot is digitally recorded and saved in a computer through software called seismic controller and the data is recorded in the SEG-2 format. Figure 2 shows the typical test program in the field and a few data files.

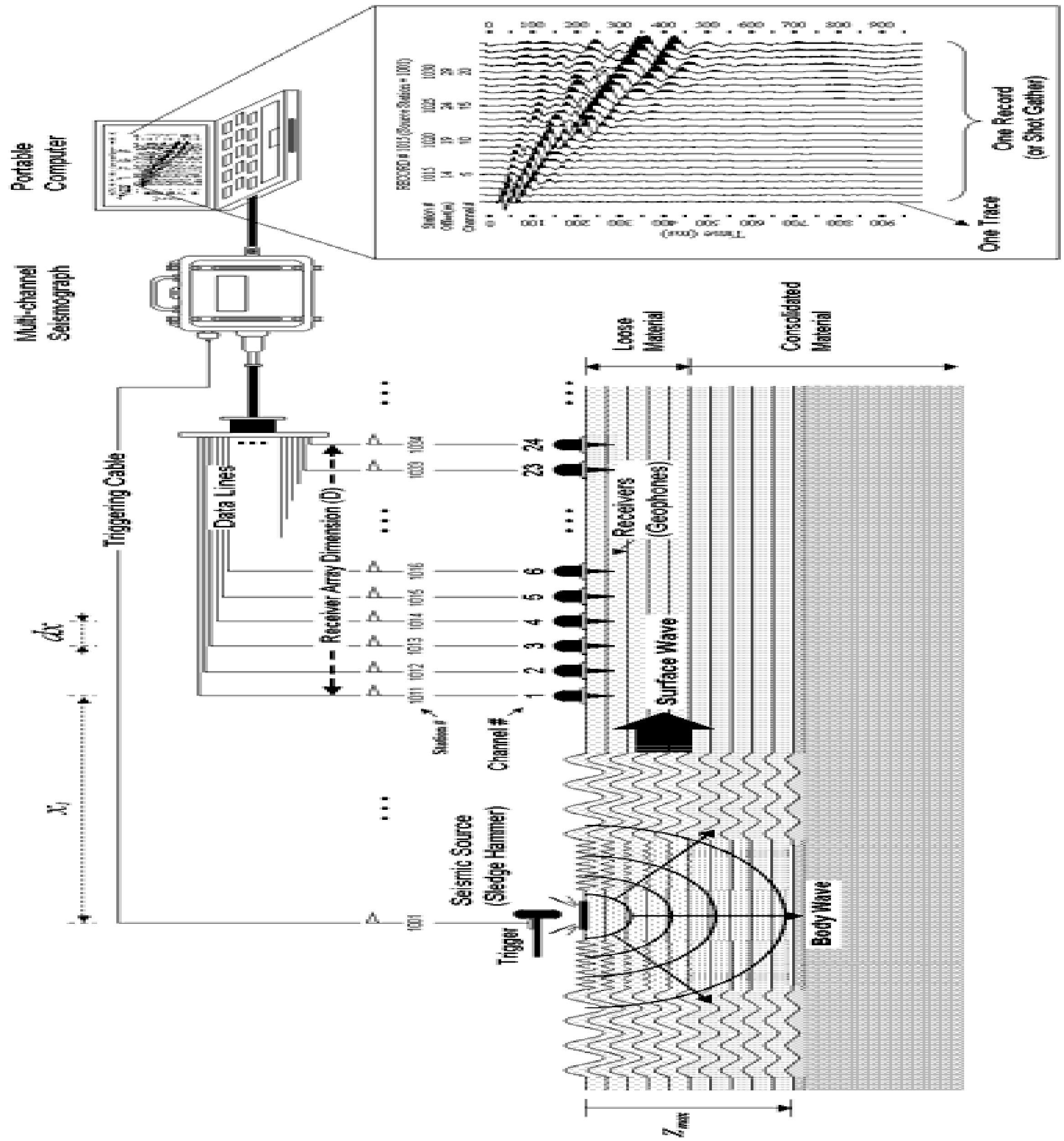
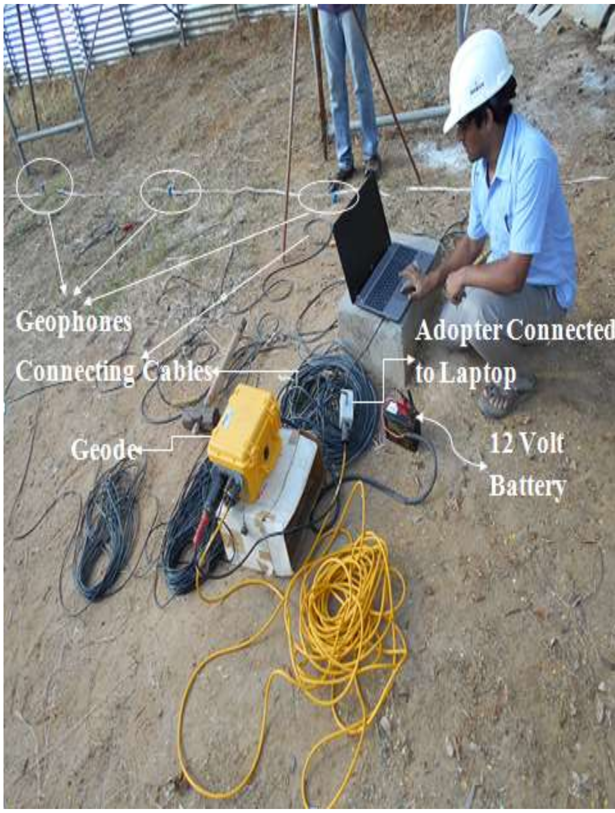


Figure 1. Schematic illustration of a typical field configuration of the MASW test

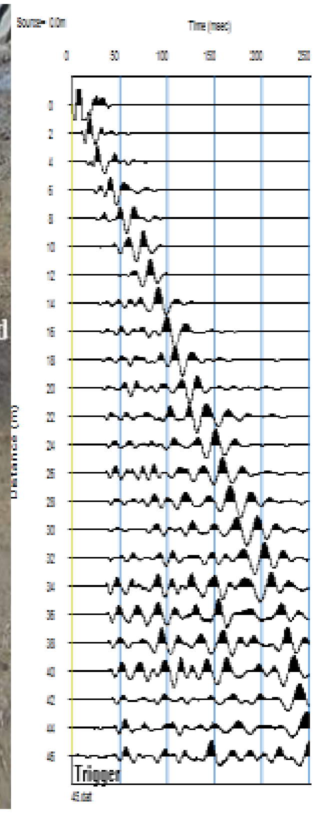
2) Instruments for MASW Test and Data Acquisition Parameters

The following is the list of instruments and data acquisition parameters of the MASW test: (i) Digital seismograph: DMT summit 24-channels, (ii) Adopter connected to laptop, (iii) 24 Geophones of natural frequency 4.5

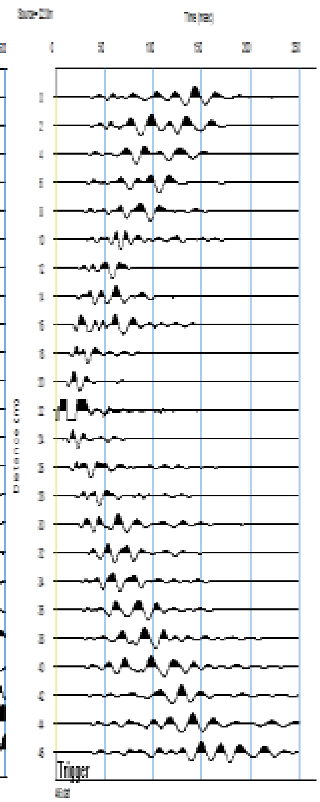
Hz, (iv) Sledge hammer, (v) Metal plate to drop weight from sledge hammer (8 kg) (vi) 12 volt battery, (vii) Sampling rate of 0.125 ms (viii) Record length of 0.25 s, (ix) Offset distance 2 m, (x) Geophones linear with 2 m spacing, (xi) Stack mode average.



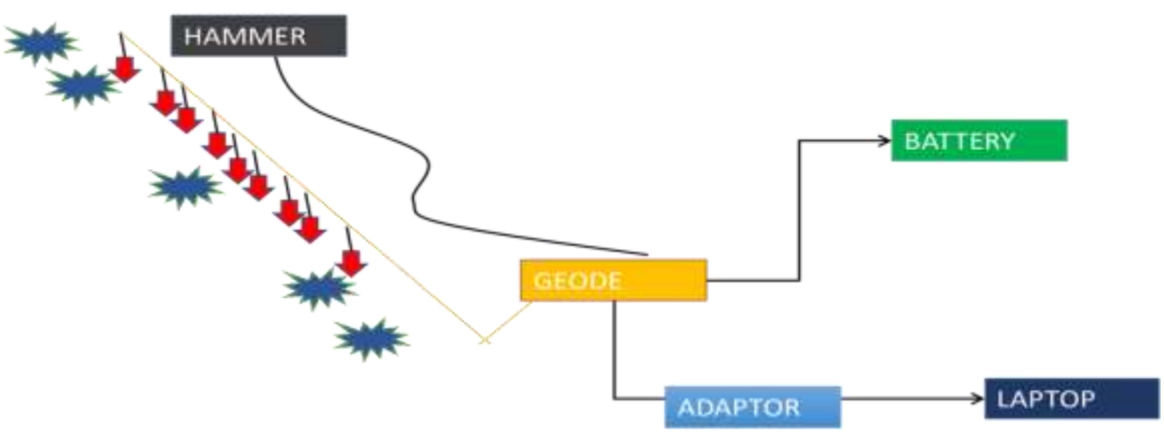
(a) MASW test accessories



(b) Data file for source at 0 m



(c) Data file for source at centre



(d) Single geode test setup and sources at different positions

Figure 2. MASW test accessories in the field and data files

IV.1D SHEAR AND PRIMARY WAVES VELOCITY PROFILES: RESULTS

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 given in this research.

For B-type quarters the survey Line 9 (L9) is chosen. 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 data were collected and corresponding wiggle plots are shown Figures 3 (a),. The shear and primary wave velocities are presented in Tables 1. The description of each layer has been obtained based on the average shear wave velocity for each of the layers as per NEHRP site classification. The data analyzed is for the B-type quarters and the subsurface identified is the medium to dense soil. 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 ASTM D-5777-95) 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).

The source of impact was at a distance of -2 m from the first geophone of the survey line. The resulting profile indicates the presence of a low velocity layer near the surface underlain by approximately 10 meters of sediments having shear wave velocity approximately equal to 416 m/s as shown in Figure 3(d). Table 1 presents the results of average S- and P-wave velocities for the identified layers.

Table 1 Calculated S- and P -wave velocities for a site near B-type quarters (source at -2 m from the first receiver)

Depth (m)	S-wave velocity (m/s)	P-wave velocity (m/s)
0 - 1.5	248.12	448.86
1.5 - 3.75	260.80	467.57
3.75 - 6.75	326.29	564.48
6.75 - 10.5	416.25	720.11

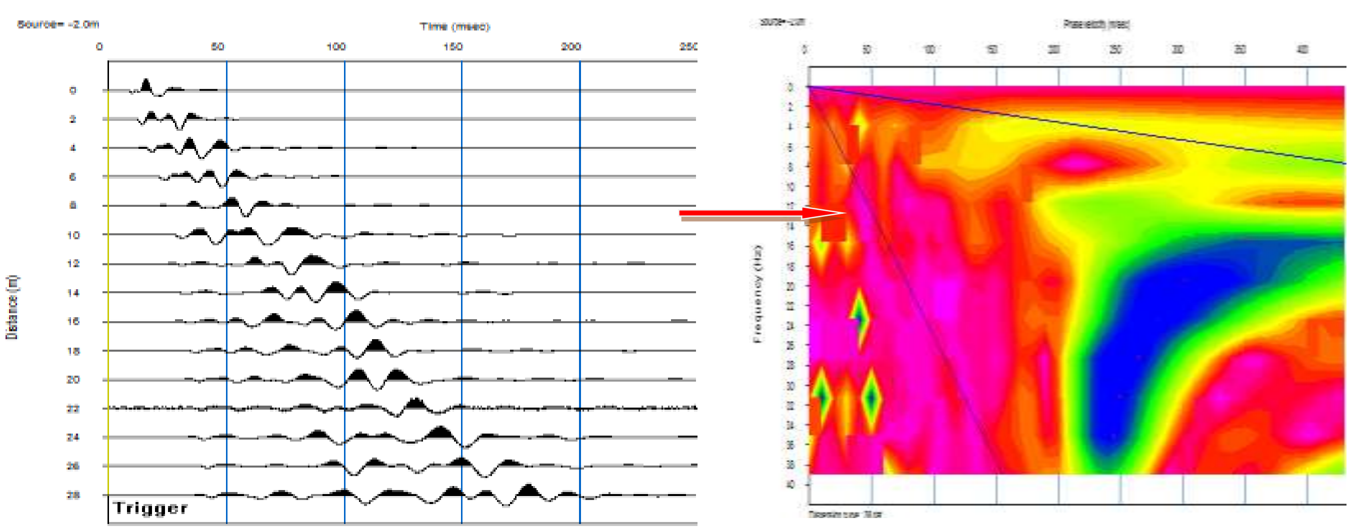


Figure3(a). Data acquisition

Figure3 **(b)** Dispersion analysis (velocity-frequency) with identification of the fundamental mode (red dots)

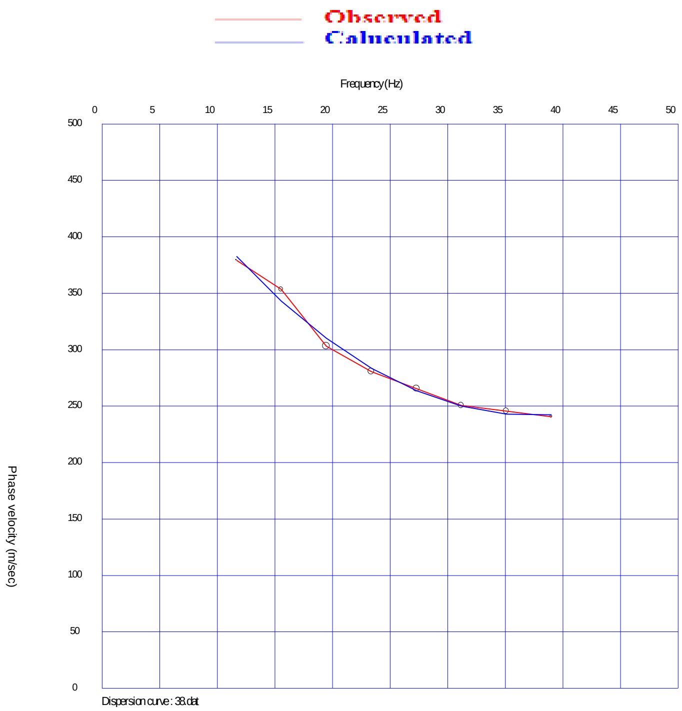


Figure3 **(c)** Dispersion curve

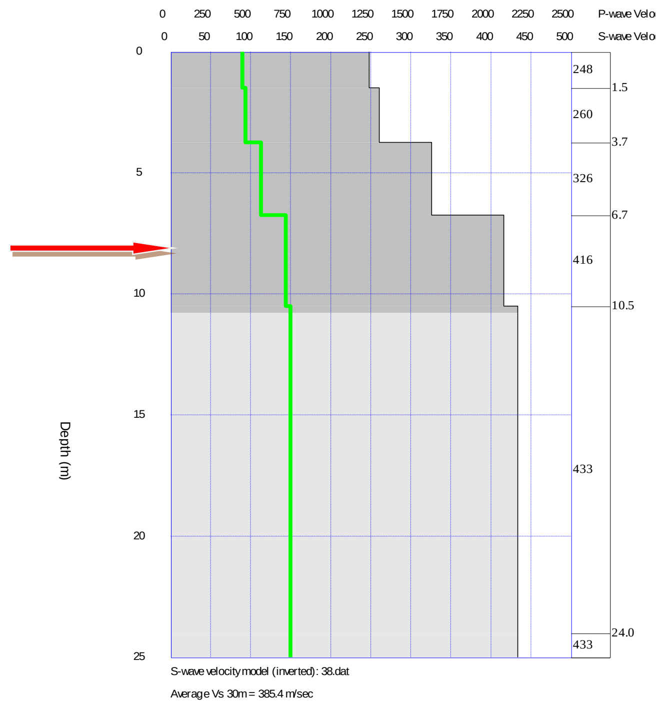


Figure3 **(d)** Inversion for P- and S-wave velocity profiles

V.CONCLUSION

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. 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 ASTM–D-5777-95) 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 V_s^{30} 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. A fairly good match is obtained between the measured shear wave velocity profiles by MASW tests and those evaluated from the predictive equation developed for *all soils* of the Chennai city.

REFERENCES

[1] Angadi S., Hiravennavar A., Desai M.K., Solanki C.H., Dodagoudar G.R. (2019) Development of Gutenberg–Richter Recurrence Relationship Using Earthquake Data. In: Drück H., Pillai R., Tharian M., Majeed A. (eds) Green Buildings and Sustainable Engineering. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore

[2] Angadi, S., Desai, M.K., Huded, P.M., Chatra, A., Dodagouder, G.R.: Review on Variation of Seismic Hazard Parameters at Different Places of India, Indian Geotechnical Conference (IGC2016). IITM, Madras (2016)

[3] ASTM D 5777-95 (1996). Standard guide for using the seismic refraction method for subsurface investigation. West Conshohocken, PA, USA, pp. 1-14.

[4] Building Seismic Safety Council (2004). NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, FEMA-450. Washington, D.C, pp. 1-385

[5] Miller, R.D., Xia, J., Park, C.B. and Ivanov, J., (1999). "Multichannel analysis of surface waves to map bedrock." *The Leading Edge*, Vol. 18(12), pp. 1392-1396.

[6] Park, C. B., Xia, J. and Miller, R. D. (1998). "Imaging dispersion curves of surface waves on multi-channel record." *Expanded Abstracts, 68th Annual Meeting of Society of Exploration Geophysicists*, pp. 1377-1380.

[7] Park, C. B., Miller, R. D. and Xia, J. (1999), "Multi-channel analysis of surface wave (MASW)." *Geophysics*, Vol. 64(3), pp. 800-808.

[8] SeisImager/2D™ (2009). A manual http://www.geometrics.com.

[9] Sitharam, T. G. and Samui, P.(2007). "Geostatistical modelling of spatial and depth variability of SPT data for Bangalore." *Geomechanics and Geoengineering: An International Journal*, Vol.2, pp. 307-316.

[10] Shivamanth Angadi, Desai M.K., Solanki C.H., Dodagoudar G.R. (2016). Development of Subsurface Profile Using Geophysical Test Data, International Journal of Earth Sciences and Engineering ISSN 0974-5904, Vol. 09, No. 03, June, 2016, pp. 161-164

[11] Angadi, Shivamanth & Desai, M.K. & Solanki, C.H. & Dodagoudar, G.. (2017). Characterization of ground profile using multichannel analysis of surface wave at somnath temple. International Journal of Civil Engineering and Technology. 8. 969-976.

[12] Uma Maheshwari, R., Boominathan, A. and Dodagoudar, G. R. (2010). “Use of surface waves in statistical correlations of shear wave velocity and penetration resistance of Chennai soils.” *Geotechnical and Geological Engineering*, Vol. 28, pp. 119-137.

[13] Xia, J., Miller, R. D., Park, C. B., Hunter, J. A., Harris, J. B. and Ivanov, J. (2002). “Comparing shear-wave velocity profiles from multichannel analysis of surface wave with borehole measurements.” *Soil Dynamics and Earthquake Engineering*, Vol. 22(3), pp. 181-190.