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EVALUATION OF DYNAMIC PROPERTIES AND GROUND PROFILES USING MASW: CORRELATION BETWEEN V_S AND N_{60}

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ABSTRACT

Identification and mapping of soil and rock profiles and evaluation of dynamic properties are very important part in seismic hazard, site response and microzonation studies. Conventionally, the soil and rock profiles are obtained using borelogs by drilling boreholes and engineering properties are evaluated by conducting Standard Penetration Testing (SPT). However SPT test is highly time consuming and discontinuous data with depth. The recent development in geophysical methods, in particular Multichannel Analysis of Surface Wave (MASW) is widely used technique for determining the 1D and 2D shear wave velocity of the subsurface material. An attempt has been made to evaluate dynamic properties (Vs and V_S^{30}) of the ground using MASW survey and cross verification of using SPT bore logs for a site in Bangalore, India. Also the correlation has been generated for shear wave velocity (Vs) versus the SPT corrected "N" value (N_{60}). The site has a dimension of 37.0m x 52.7m and it is located in south eastern side of Bangalore city, right in front of the Bangalore international airport. The five boreholes along with SPT tests at alternative depths of 1.5m, five 1D-MASW and one 2D-MASW surveys have been conducted at the site. The survey points have been selected such a way that the results represent the soil characteristics of the entire site. The soil thickness and classification of sub surface material have been carried out using shear wave velocity obtained from MASW testing. Subsurface ground profiles have been prepared from both the SPT and MASW data. Further Vs for each layer and V_S^{30} to the each bore hole locations are calculated and mapped. The available data has been used to generate the relation between the shear wave velocity (Vs) and corrected "N" values.

Keywords: MASW, SPT, Shear wave velocity, V_S^{30}.

INTRODUCTION

Multichannel Analysis of Surface waves (MASW) is increasing by being applied to earthquake geotechnical engineering problems for the microzonation and site response studies. In particular, MASW is widely used in geotechnical engineering for the measurement of shear wave velocity, evaluation of material properties, material boundaries and variations of ground. MASW is non-intrusive and less time consuming. Multichannel analysis of surface waves is a seismic method that can be used for geotechnical characterization of near surface materials (Park et. al, 1999a; Xia et. al, 1999; Miller et. al, 1999). MASW identifies the each type of seismic waves on a multichannel record based on the normal pattern recognition technique that has been used in oil exploration for several decades. The identification leads to an optimum field configuration that assures the highest signal-to-noise ratio (S/N) possible. Effectiveness in signal analysis is then further enhanced due to the diversity and flexibility in the data processing step (Ivanov et. al, 2001). MASW also generate the 2D shear wave velocity profile.

STUDY AREA

The site is located on southern part of Bangalore city near to the International Airport, having the dimension of 37mx52.7m. The testing point locations of MASW and SPT are marked in the site plan shown in Figure 1.The topography of the site is a flat terrain with two side roads on the northern side and western side of the site.

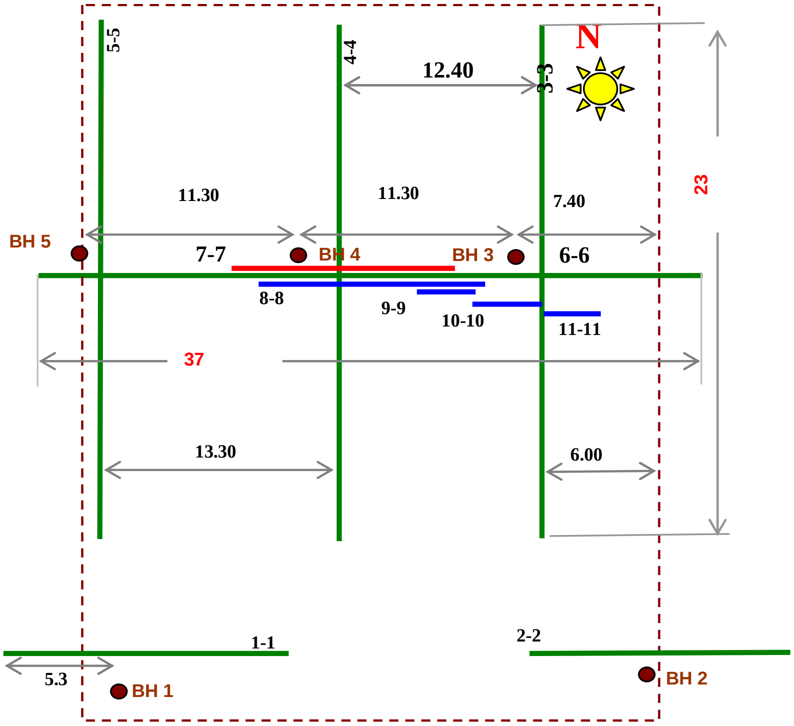


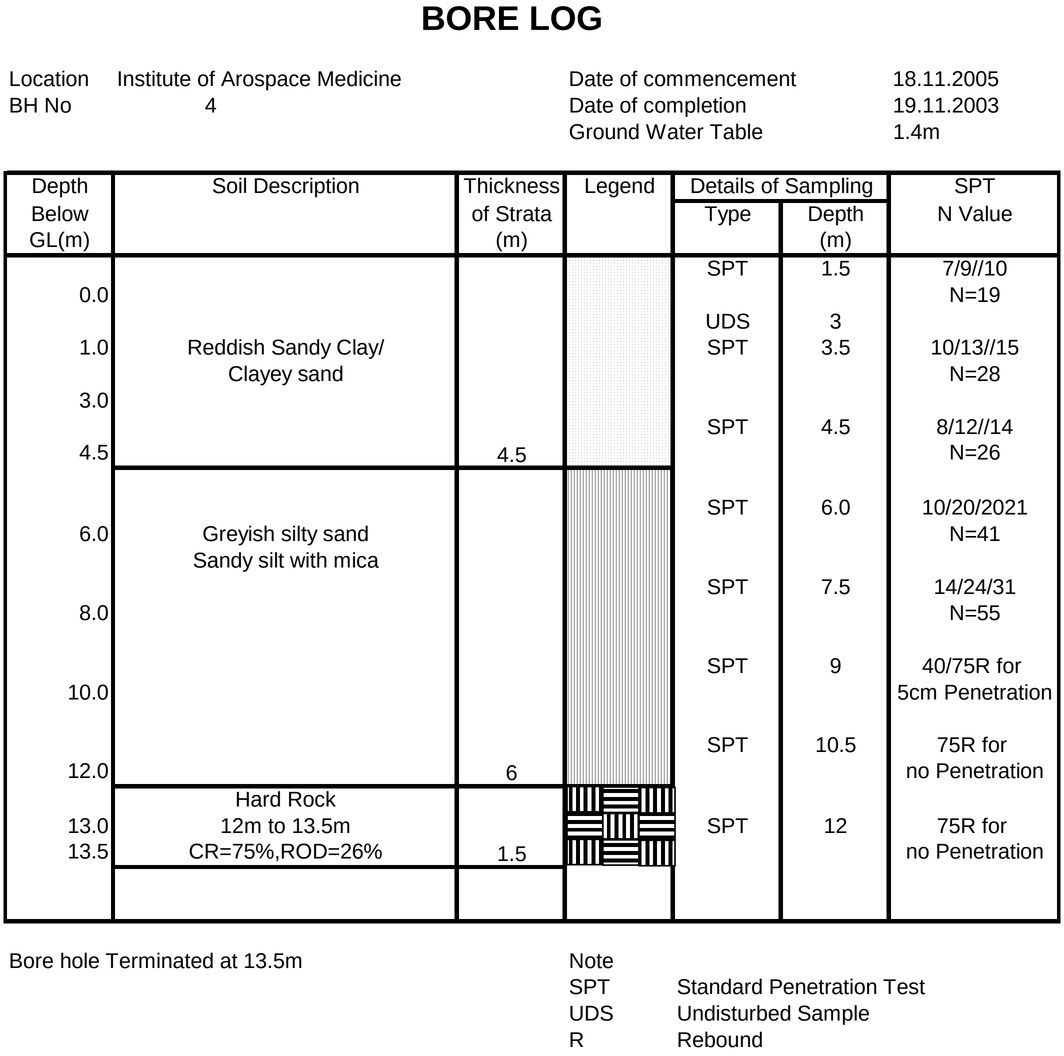
Figure 1: Site Map with Marked Testing Locations

Geotechnical Investigations

The SPT testing was carried out at five locations in such a way that they are distributed through out the construction area and represent the site characteristics (see Figure 1). Five bore holes of 150mm diameter up to the rock depth has been drilled using Rotary hydraulic drilling. SPT testing results shows the general soil profile which consists of a variable thickness of soil overburden. The soil can be classified as filled up soil extending to a depth of 2m to 2.3m in different locations. The field ‘N’ value for the filled up soil layer varies from 8 to 24 at different borehole locations. In the borehole BH-3 to BH-5 clayey sand is present below the filled up soil or at the top itself having a liquid limit of more than 35. Below this layer, a silty sand layer with clay or without clay is present to a depth of 9.0m to 16m. The field ‘N’ value for this silty sand layer varies from 19 to 75. The disintegrated weathered rock exists below the silty sand layer having a refusal strata with N>100. The thickness of the overburden varies from 3.5m to 16.5m from ground level at different borehole locations. Below the disintegrated weathered rock, weathered / hard rock exists. The rock formation is classified as granitic gneiss without faults and fissures. Water table in this area during the investigation is at about 1.5m below the ground level in all the boreholes. Typical bore log is shown in Figure 2. The N values measured in the field using standard penetration test procedure have been corrected for various corrections, such as:(i) Overburden Pressure (C_N), (ii) Hammer energy (C_E), (iii) Bore hole diameter

(C_B), (iv) presence or absence of liner (C_S), (v) Rod length (C_R) and (vi) fines content (C_{fines}) (Seed et al.; 1983, Skempton; 1986, Schmertmann; 1978, Sitharam et. al, 2005).Field "N" is corrected using the following equation and Corrected "N" value i.e., (N60) is obtained:

$$N_{60} = N \times (C_N \times C_E \times C_B \times C_S \times C_R \times C_{fines}) \quad (1)$$



BORE LOG

Location	Institute of Arospace Medicine	Date of commencement	18.11.2005
BH No	4	Date of completion	19.11.2003
		Ground Water Table	1.4m

Depth Below GL(m)	Soil Description	Thickness of Strata (m)	Legend	Details of Sampling		SPT N Value
				Type	Depth (m)	
0.0	Reddish Sandy Clay/ Clayey sand	4.5	░	SPT	1.5	7/9//10 N=19
1.0				UDS	3	
3.0				SPT	3.5	10/13//15 N=28
4.5				SPT	4.5	8/12//14 N=26
6.0	Greyish silty sand Sandy silt with mica	6	▥	SPT	6.0	10/20/2021 N=41
8.0				SPT	7.5	14/24/31 N=55
10.0				SPT	9	40/75R for 5cm Penetration
12.0				SPT	10.5	75R for no Penetration
13.0 13.5	Hard Rock 12m to 13.5m CR=75%,ROD=26%	1.5	▦	SPT	12	75R for no Penetration

Bore hole Terminated at 13.5m

Note
SPT Standard Penetration Test
UDS Undisturbed Sample
R Rebound

Figure 2: Typical Borelog at the selected site.

Table 1: Typical SPT (N_{60}) Calculation

Institute of Aerospace Medicine **Water Table = 1.5 m/18-11-2005**
Bore hole No-BH3

Depth m	Field "N" Value	Density kN/cu.m	T.S kN/sq.m	E.S kN/sq.m	C_N	Correction Factors For				$C.N_1$	F.C %	C.F.C	N_{60}
						Hammer Effect	Bore hole Dia	Rod Length	Sample Method				
1.50	2	20.10	30.15	30.15	1.47	1	1.05	0.75	1	2.31	31	1.796	4
3.00	19	20.10	60.30	45.59	1.33	1	1.05	0.8	1	21.20	41	1.261	27
5.00	39	20.10	100.50	80.88	1.10	1	1.05	0.85	1	38.12	35	1.186	45
6.00	101	20.10	120.60	110.79	0.95	1	1.05	0.85	1	85.93	28	1.128	97
7.50	100	20.10	150.75	136.04	0.86	1	1.05	0.95	1	85.71	22	1.101	94
9.00	100	20.10	180.90	166.19	0.77	1	1.05	0.95	1	76.68	22	1.102	85

T.S - Total Stress

E.S - Effective Stress
C_N – Correction for overburden correction
C_{N1}- Corrected “N” value before applying fine content corrections
F.C – Fines content
C.F.C – Correction for Fines content
N_{60} – Corrected ‘N’ Value

Geophysical Investigations

MASW is a geophysical method, which generates a shear-wave velocity (Vs) profile (i.e., Vs versus depth) by analyzing Raleigh-type surface waves on a multichannel record. MASW has been effectively used for identification of broadband width and highest signal-to-noise ratio (S/N) of surface waves. MASW system used for this investigation consists of 24 channels Geode seismograph with 24 geophones of 4.5 Hz capacity. The seismic waves are created by impulsive source of 10 pound (sledge hammer) with 1’x1’ size hammer plate with ten shots, these wave are captured by geophones/receivers. The captured Rayleigh wave is further analyzed using SurfSeis software. SurfSeis is designed to generate Vs data (either in 1-D or 2-D format) using a simple three-step procedure: i) preparation of a Multichannel record (some times called a shot gather or a field file), ii) dispersion-curve analysis, and iii) inversion. The 1D MASW test has been carried out corresponding to 5 borehole locations (BH-1 to BH-5) with 25 recording points. The spread length locations are shown in Figure 1 as survey line 1-1 to 5-5. The optimum field parameters recommended by Park et al. (1999) (source to first and last receiver, receiver spacing and spread length of survey line) are selected in such a way that required depth of information can be obtained. All the testing has been carried out with geophone interval of 1m and source to first and last receiver is varied from 5m, 10m and15m. Typical recorded surface wave arrivals using source to first receiver distance as 5m with recording length of 1000 milli second (ms) is shown in Figure 3 for the survey line 5-5.

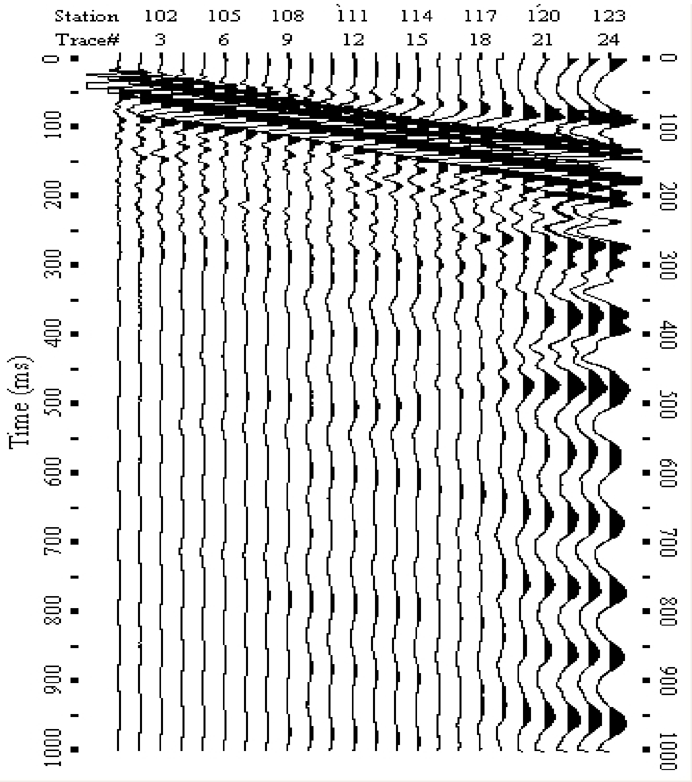


Figure 3: Typical Seismic waves Recorded in Location 5-5

2D velocity profiling has been carried out to verify the rock dipping direction. To get the 2D profile, a multiple number of shot gathers are acquired in a consecutive manner along the survey line by moving both source and receiver spread simultaneously by a fixed amount of distance after each shot. Each shot gather is then analyzed for 1-D shear wave velocity (Vs) profile in a manner previously stated. In this way a multiple number of Vs profiles are generated. The Vs data are assigned into 2-D (x-z) grid. Various types of data processing techniques can be applied to this 2-D Vs data. A countering, a simple interpolation, data smoothing, or combination of these may be applied at this stage. When the Vs data are assigned to the grid, there is ambiguity in the horizontal coordinate (x) to be assigned because each Vs profile was obtained from a shot gather that spanned a distance too large to be considered as a single point. It seems reasonable that the centre of the receiver spread be the most appropriate point because the analyzed Vs profile represents an average property within the spread length (Park et. al, 2005). 2D MASW test has been carried out along survey line 6-6 with 13 recording points, which is shown in the Figure 1 as line 6-6. The results of 2D profile have been presented for the location of line 7-7.

The generation of a dispersion curve is a critical step in all MASW methods. A dispersion curve is generally displayed as a function of phase velocity versus frequency. Phase velocity can be calculated from the linear slope of each component on the swept-frequency record. The lowest analyzable frequency in this dispersion curve is around 4 Hz and highest frequency of 35Hz has been considered. Typical dispersion curve is shown in Figure 4 for the location 5-5, each dispersion curve obtained for corresponding locations has high signal to noise ratio of 80 and above. A Vs profile has been calculated using an iterative inversion process that requires the dispersion curve developed earlier as input. A least-squares approach allows automation of the process (Xia et al., 1999) as inbuilt in SurfSeis. Vs have been updated after completion of each iteration with parameters such as Poisson's ratio, density, and thickness of the model remaining unchanged. An initial earth model is specified to begin the iterative inversion process. The earth model consists of velocity (P-wave and S-wave velocity), density, and thickness parameters. Typical 1D Vs and Vp profile is shown in Figure 5 for the location of 1-1. Velocity calculated at mid point of each survey line is comparable with the borehole location because the survey line mid point is coinciding with the borehole location. The shear wave velocity values obtained from each survey line for the different layers fall within the

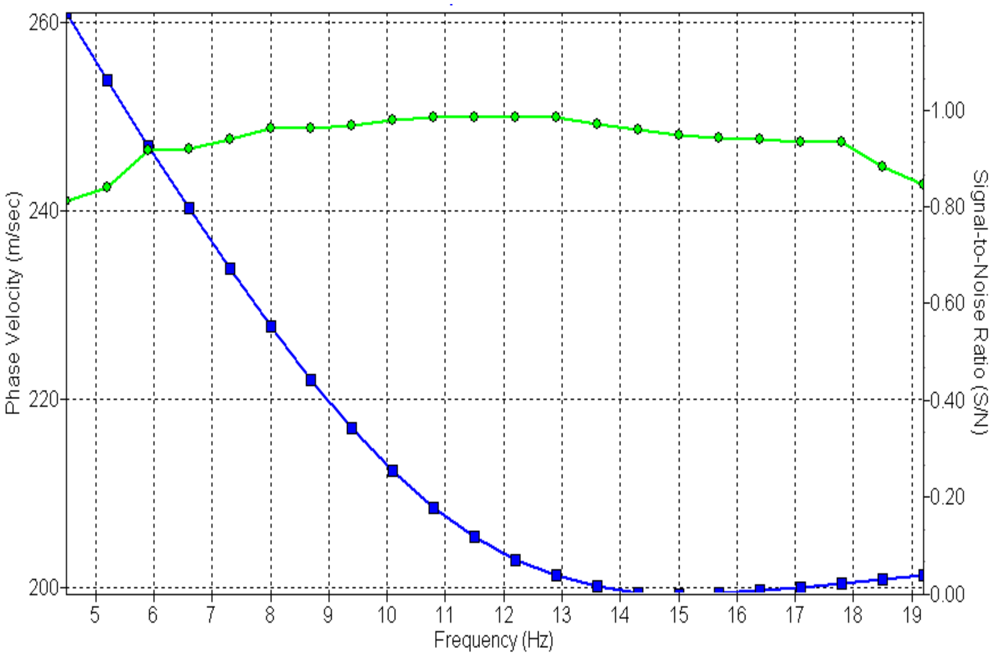


Figure 4: Typical Dispersion Curve obtained from MASW for Line 5-5

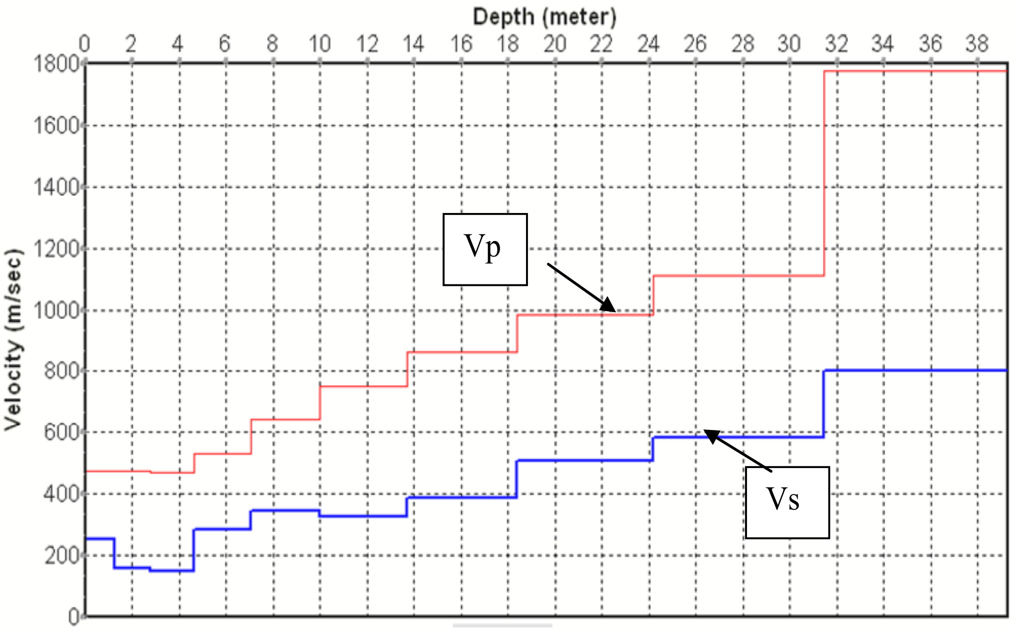


Figure 5: Typical Vs and Vp Plot for Line 1-1

recommendations of NEHRP "Vs"- soil classification of site categories (Martin, 1994) and IBC code site classification (IBC-2000). A layer with a shear wave velocity of more than 360 m/sec is considered as a weathered rock. The 2D velocity profile has been used to find the layer thickness, subsurface anomaly and rock dipping directions. Typical 2D velocity profile for the line 7-7 is shown in Figure 6. The weathered rock velocity ranges are at shallow depth at left side of the line (Eastern side) and at deeper depth on right side (Western side) of line 7-7. The rock dipping observed in MASW test results match well with the SPT borehole observation. The soil profile obtained using MASW shear wave velocity matches well with the drilled bore soil profiles.

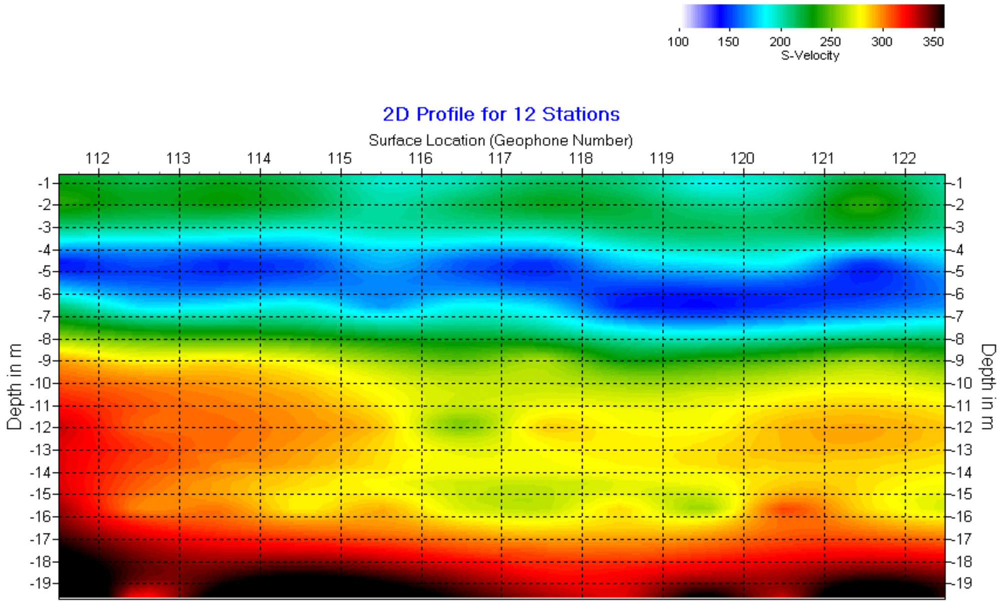


Figure 6: 2D Shear wave velocity Profile obtained for the Location7-7

During last several years, the MASW method has been successfully applied to various types of geotechnical and geophysical projects. These projects include mapping 2-D bedrock surface and shear properties of overburden materials (Miller et al., 1999a), weak spots (Miller et al., 1999b), Poisson's ratio distribution (Ivanov et al., 2000a), generation of shear-wave velocity (Vs) profiles (Xia et al., 2000a), detection of voids (Park et al., 1998a), seismic evaluation of pavements (Ryden et al., 2001; Park et al., 2001a; 2001b), and seismic characterization of sea-bottom sediments (Park et al., 2000a; Ivanov et al., 2000b).

DYNAMIC PROPERTIES FROM MASW SURVEY

Dynamic behaviour of soil has been evaluated form the shear wave velocity, which is an important parameter for seismic site characterization and determination of shear modulus. A dynamic property at low strain level for site soil layers has been determined using shear wave velocity from MASW. The shear wave velocity as obtained from the MASW test has been used to evaluate shear modulus for the soil. Poisson's ratio was estimated by assuming a constant distribution of Poisson's ratio for a layer by ensuring Vp model matches with the Vs model with depth. From the above value of Poisson's ratio, Young' modulus was calculated. Soil and rock layer dynamic properties has been estimated for locations (1-1 to 5-5) corresponding to borehole locations of (BH1 to BH5). Typical results are shown in Table 2.

The seismic site characterization for calculating seismic hazard is usually carried out based on the near surface shear wave velocity values. The average shear wave velocity for the top 30m of soil is referred to as V_S^{30}. The average shear wave velocity of the upper 30 m (V_S^{30}) should be computed in accordance with the following expression:

$$V_s^{30} = \frac{30}{\sum_{i=1}^{N} \left(h_i / v_i \right)} \qquad (2)$$

where hi and v_i denote the thickness (in meters) and shear-wave velocity (at a shear strain level of 10^{-5} or less) of the i^{th} formation or layer, in a total of N, existing in the top 30 m. V_S^{30} was accepted for site classification in the USA (NEHRP) by the UBC (Uniform Building Code) in 1997 (Dobry et al. 2000, Kanli et. al, 2004). To characterize the site the V_S^{30} has been calculated and mapped, distribution of V_S^{30} shown in Figure 7. Figure 7 shows that the location near to line 2-2 and 3-3 has the average shear wave velocity of more than 360m/sec, which is very dense and soft rock as per UBC classification matches well with bore log information.

Table 2: Typical Dynamic properties of soil layers

Depth m	Vs m/sec	Density g/cc	Shear Modulus MN/m2	Poisson Ratio	Young's Modulus MN/m2
0-10.5	220	1.90	92	0.30	239
10.5-23	320	2.00	205	0.20	492
>23	520	2.20	595	0.20	1428

CORRELATION BETWEEN N_{60} AND V_S

For the seismic site characterizations, microzonation and site response study the important parameter is shear wave velocity, which can be determined experimentally or using empirical equation. Soil characteristics in the five bore logs are silty sand material, representing residual soil of Bangalore area. Figure 8 Shows relation between the corrected "N" values to measured shear wave velocity. The predicted correlation is given in equation 3 as shown below;

$$Vs = 50{N_{60}}^{0.41} \qquad (3)$$

Power regression fitting gives the highest R squared value of 0.90. Figure 8 also shows the observed Vs value with predicted Vs values using equation 3.

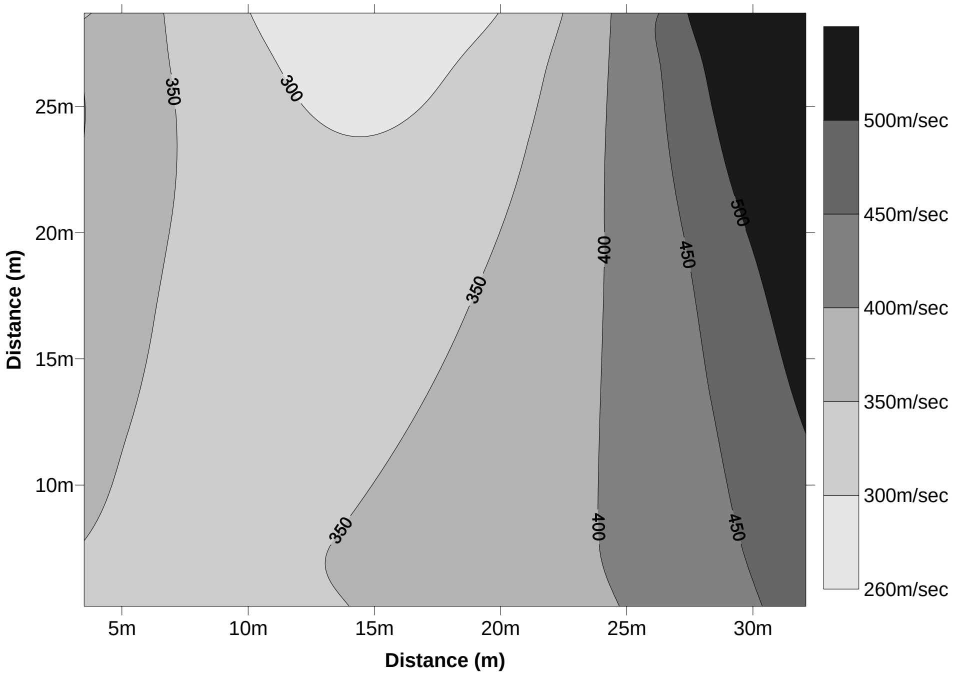


Figure 7: Vs^{30} Map Using MASW system Measurements in the portion selected site (37mx52.7m).

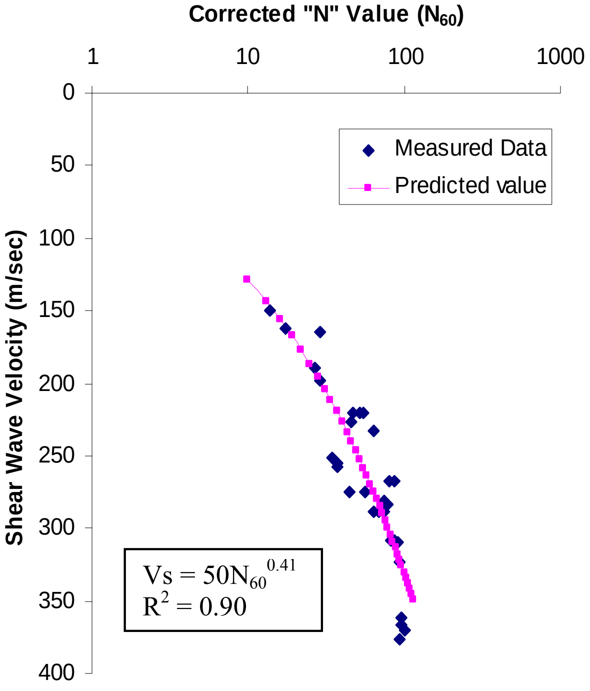


Figure 8: Correlation between Corrected “N” Value (N_{60}) and Measured Vs value.

CONCLUSIONS

Soil layers and rock depth has been identified and mapped using MASW surveys, which is also cross verified using SPT bore logs. The depth of soil/rock layer identified using MASW data matches well with bore log information. MASW technique can be effectively used for seismic site characterization, microzonation and site response studies. MASW can also be used for calculation of dynamic properties of the site soil. V_S^{30} is evaluated for each survey line and mapped for the site. For the eastern side of site, V_S^{30} is more than 360m/sec, indicating the dense soil/ weathered rock at shallow depth. The correlation between corrected "N" values to measured shear wave velocity at low strain level has been developed. From our study, it is conformed that the MASW can be used effectively for the soil layer profiling and identification rock depth and measurement of dynamic properties, with a short time and minimum cost.

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