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DYNAMIC PROPERTIES MEASUREMENT OF ROORKEE USING GEOPHYSICAL METHODS

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ABSTRACT

In the designing of structures, slopes, bridges and earthen dams it is very much essential to measure the dynamic properties of subsurface soil. The geophysical methods for the evaluation of dynamic properties over the other conventional methods are more advantageous by providing continuous data and requires less time for subsurface investigation. Multichannel analysis of Surface Waves (MASW) is one of the most widely used seismic survey method to determine the stiffness of soil in the field of geotechnical earthquake engineering. In this method, surface waves generated from different sources are measured and then shear wave velocity profile (i.e. v_s versus depth) is estimated using inversion technique.
The study area for the present paper is the subsurface soil of Roorkee (situated at the foothills of Himalayas). Himalayan region is one of the most seismically active zones lying close to the Indo Gangetic plain having deep alluvium deposits. The dynamic properties are delineated by carrying out MASW survey with nine geophones at an interval of 2m using a 10kg hammer in different parts of the city. The survey points are selected in such a way so as to represent the entire city. The estimated dynamic properties from MASW and those obtained from the available bore hole data shows a good match. Hence, this method can be used to determine dynamic properties of soil for designing of structures considering cyclic loading with lesser time.
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Keywords: MASW; Stiffness; Indo-Gangetic plain

1. INTRODUCTION

In the present scenario, the use of geophysical methods has been tremendously increased in several applications of problems in earthquake geotechnical engineering. In the field of site response studies and microzonation, geophysical methods have been employed. The important advantage of these methods is that large areas can be covered in lesser expenses and drilling boreholes is not required. The subsurface information can be easily obtained by earthquake engineers. In order to measure the shear wave velocity of soil and dynamic properties, the use of Multichannel Analysis of Surface waves (MASW) can be of great help. MASW can be widely used for geotechnical site characterization for subsurface material properties (Miller et. al, 1999; Xia et. al, 1999).

The existence of surface waves was first predicted by Lord Rayleigh (1885). The development of noninvasive techniques for the characterization of subsurface materials properties is based on these surface waves. The basic principle in this technique is to analyze the surface wave's geometric dispersion for getting the properties of the underlying medium and solving an inversion problem for identification of parameters (Robert and Wride, 1997).

The soil characterization is carried out by the several tests is based on the applied stress in cyclic loading conditions. The broad category of these tests is geophysical field tests and laboratory tests. In laboratory tests, field conditions are implemented on the soil sample, but, in geophysical field tests

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undisturbed soil sample is tested having the real effective stresses. In geophysical methods, at the source, impulsive stress waves are created with the help of sledgehammer or by source vibrator and the arrival time of the waves are recorded at the different receivers located at some distance from one another. Figure 1 represents different methods of application of stress waves (Kramer, 1996). The shear strains induced by the geophysical methods is less than 10^{-4} %. The measured shear wave velocity (V_S) can be used to determine the G_{max} from the following relation:

$$G_{max} = \rho V_s^2 \tag{1}$$

where ρ is the density of soil.

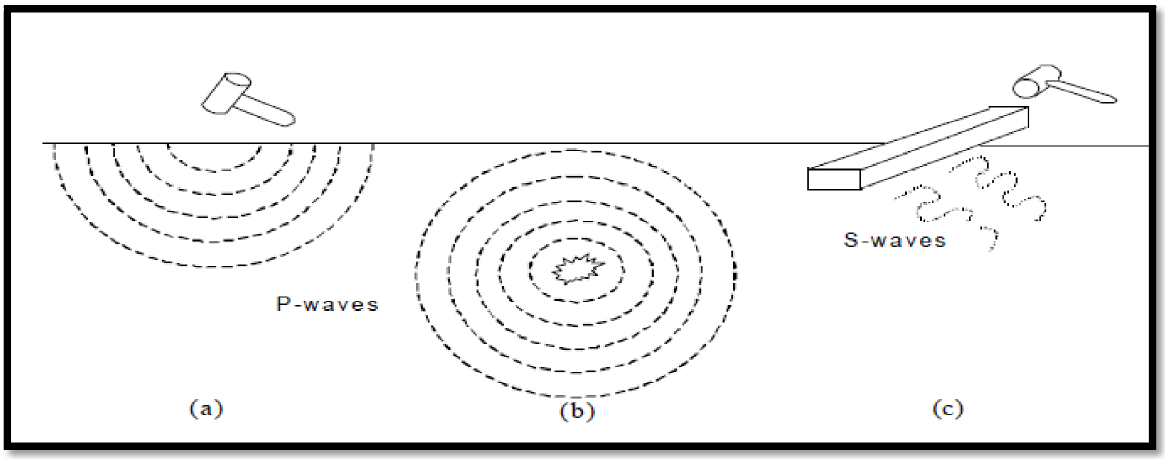

Figure 1. Generation of impulse waves (a) Vertical Impact Method (b) Explosive Method and (c) Horizontal Impact Method (Kramer, 1996)

In the present paper, an attempt has been made to practically use the geophysical methods i.e MASW to provide us the required dynamic properties as compared to other available conventional methods which are more time consuming. Although these methods shows the requirement of number of information of the soil as compared to the other drilling boreholes methods. However, continuous data or three dimensional images can be obtained from the geophysical methods. The inferred dynamic properties are very much useful in structural design in dynamic loading conditions, assessment of liquefaction at a particular site of interest and site response analysis.

2. STUDY REGION: ROORKEE (UTTARAKHAND)

In the present study, the region selected for site characterization is Roorkee attributing to its high seismicity and having local site characteristics of soil. Roorkee is situated at latitude 29° 51’ and longitude 77° 54’ is a city in the state of Uttarakhand. It is located around 30 km from Shiwaliks range which can lead the city to experience strong ground motion if a moderate earthquake occurs on Main Boundary Thrust or on Main Central Thrust. Moreover, Himalayan Frontal Thrust lies very close to Roorkee and to the south of Main Boundary Thrust and Main Central Thrust. As per the seismic zoning map of India as incorporated in Indian Standard Criteria for Earthquake Resistant Design of Structures: General Provisions and Buildings, Roorkee lies in seismic Zone IV (IS: 1893-Part I; 2002). Indian Meteorological Department has reported that numerous earthquakes of medium to large size have occurred in the study region as per the data obtained from historical and instrumental records. The major earthquakes reported are (i) The Kangra earthquake (1905) of magnitude 8.0 (ii) The Kinnaur earthquake (1975) of magnitude 7.0 (iii) Bihar-Nepal border earthquake (1980) of magnitude 6.1 (iv)The Uttarkashi earthquake (1991) of magnitude 6.6 and (v) The Chamoli earthquake of

(1999) of magnitude 6.8.

In the present study, six sites of Roorkee are selected for the evaluation of shear wave velocity profile of the city using MASW tests. These sites were located at a distance of about 2-3 km from each other. The surface wave data that was obtained from the MASW test was analyzed for shear wave velocity at different depths of soil strata. Figure 2 shows the division of Roorkee city namely, as, Roorkee East, Solani River and Roorkee West which is based on the professed existing soil conditions in each area. In Roorkee East, it is expected to be consisting of hardest sub soil while, on the other hand, Roorkee West was expected to have the less hard sub soil. The Solani River was expected to have the soft sub soil conditions. In Roorkee East, three sites are taken within the IIT Roorkee campus which includes Department of Earthquake Engineering (S1), Lal Bahadur Shastri Stadium (S2) and IIT Roorkee Hospital Ground (S3). In Roorkee West, two sites are chosen are the Roorkee Railway Station (S4) and Nehru Stadium Ground (S5). The sixth site that was selected for the study was Solani River (S6).

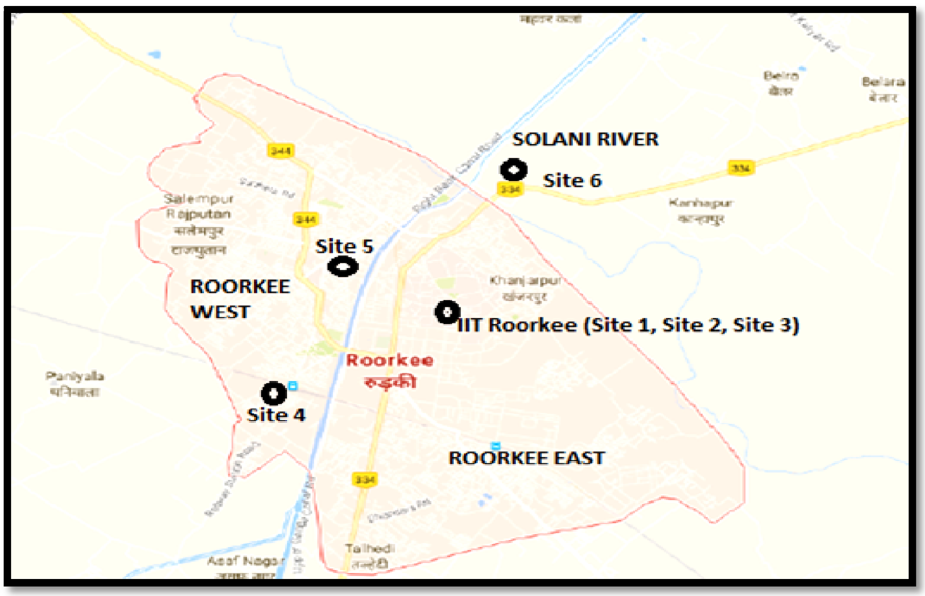

Figure 2. Sites selected for MASW test in the study region (Roorkee)

3. METHODOLOGY: MULTI CHANNEL ANALYSIS OF SURFACE WAVES (MASW)

The set up used for investigating the subsurface materials is 9-channel MASW setup. For many applications, such as, microzonation and dynamic response analysis of sites, Multichannel Analysis of Surface wave (MASW) is increasingly being used in earthquake geotechnical engineering. It is generally used for the estimation of shear wave velocity and dynamic properties. Moreover, subsurface material boundaries identification and spatial variations of shear wave velocity can also be measured. The basic steps include, firstly, the recorded Rayleigh waves are transformed into the frequency domain from the time domain using the Fast Fourier Transform (FFT) techniques. Secondly, the corresponding phase difference [$\Delta\Phi(f)$] between each receiver pair of channels is computed for every component of frequency measured. The travel time $\Delta(t)$ between receivers is computed using the following relation:

$$\Delta t(f) = \Delta\Phi(f)/2\pi f \qquad (2)$$

The distance between each pair of receivers $\Delta d = d_2 - d_1$ is known which can be used in estimation of the Rayleigh wave phase velocity [$V_R(f)$] as follows:

$$V_R(f) = \Delta d / \Delta t(f) \tag{3}$$

After the estimation of Rayleigh velocity, the wavelength (λ_R) is determined as

$$\lambda_R(f) = V_R(f)/f \tag{4}$$

Finally, a dispersion curve can be plotted between V_R-λ or V_R-depth.

4. EXPERIMENTAL SET UP

In the field stet up, in order to characterize the sites of the present study, active MASW consisting of Soil Spy Rosina (Micromed S. p. A., 2008a) is the hardware and software platform of multichannel digital system for carrying out active and passive seismic surveys was used. The setup consisted of nine sensors with 2m inter-geophone spacing. For setting out a trigger, first geophone from the source was used. Figure 3 shows the systematic experimental setting up of MASW method.

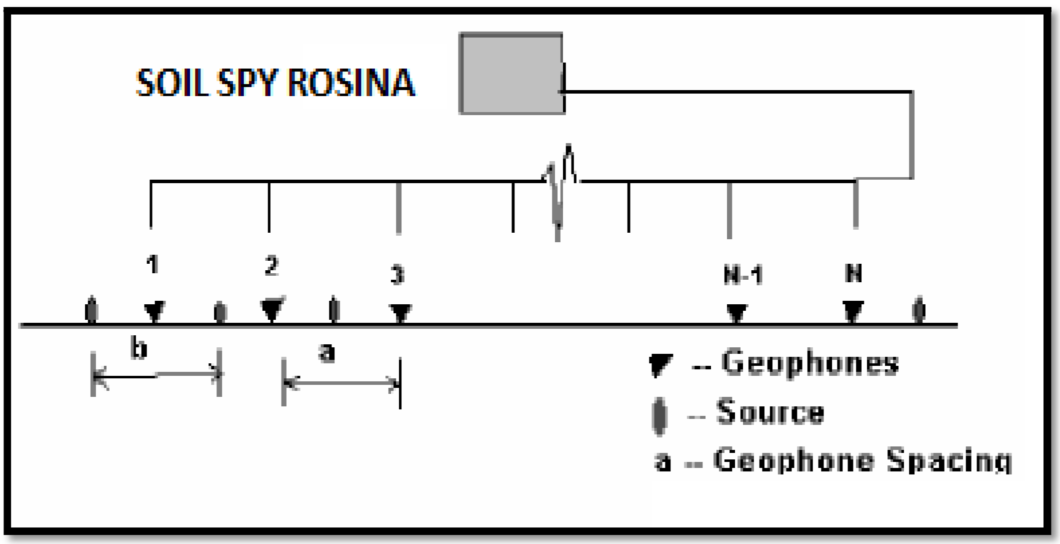

Figure 3 Systematic representation of the MASW method.

The data recorded from the Soil Spy Rosina is then used to prepare the dispersion curve. The dispersion curve shows the plot between the phase velocity and material frequency. Grilla (Micromed S. p. A., 2008b) software is used for the analysis of the data recorded in the field using Soil Spy Rosina. This software is used to plot the dispersion curve from the records obtained from Soil Spy Rosina which are quite useful for the estimation of shear wave velocity profiles of shallow soil. The dispersion curve is best fitted by setting up an initial synthetic model from estimated shear wave velocity profile having high impedance contrast of half space. The depth is estimated from the lowest frequency that is in the dispersion curve. Figure 4 shows the experimental dispersion curve obtained for all the six sites and the dotted curve represents the theoretical curve. The lowest frequency is around 3 Hz and the largest frequency is about 50 Hz. A shear wave velocity profile is generated using this dispersion curve as input using an inversion technique.

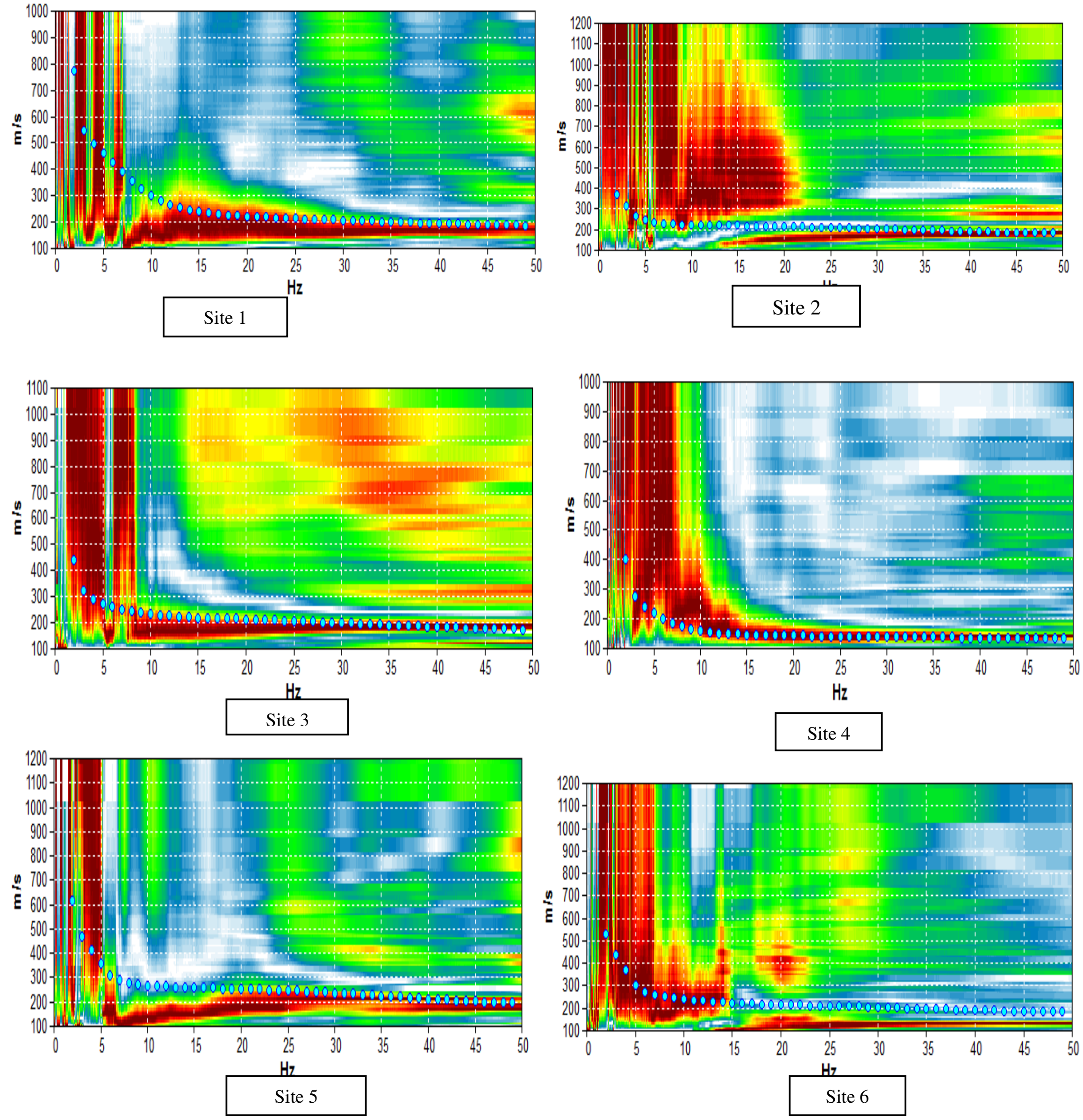

Figure 4. Experimental dispersion curves and the dotted line represent the theoretical dispersion curves for all the six sites.

5. EVALUATION OF DYNAMIC PROPERTIES FROM MASW

The dispersion curve obtained from the record is used to estimate shear wave velocity of the soil by the inversion technique. In the inversion technique, least square approach is employed (Xia et al. 1999) and the shear wave velocity is updated after every iteration. Figure 5 shows the shear wave velocity profiles of all the six sites obtained from the inversion technique. It can be seen from the Figure that at Site 1, the estimated shear wave velocity up to 9m is 190m/s and upto 20 m, it is found to be 250m/s. At Site 2, the topmost 9m has shear wave velocity of 180m/s which increases to 240m/s up to 20m. Similarly at Site 3, the top 9m of soil is having shear wave velocity of 192m/s, which then increases to 260m/s upto 20m depth. At Site 4, the top 2m has shear wave velocity of 186m/s and 300m/s up to 30m. At Site 5, it is seen that the top 2m soil layer is having shear wave velocity of

145m/s which increases to 280m/s up to 26m depth. Finally at Site 6, it is seen that the top 2m soil layer is having shear wave velocity of 186m/s which increases to 300m/s up to 26m depth. It is observed that for Site, Site 2 and Site 3, shear wave velocity profiles are very close to each other as the site are located at a distance of about 1.5 km from each other and with a hard subsoil conditions. On the other hand, Site 4 and Site 5 (Roorkee West) are located on less hard sub soil and also at such a place, where, heavy traffic passes and caused hindrance in the data collection. Site 6 is located on soft soil very near to Solani River and thus a variation is seen in the shear wave velocity profiles among other sites.

Shear wave velocity is an important parameter for understanding the dynamic behavior of soil. Moreover, it can be used for the determination of shear modulus (G) of soil as well as for the site characterization applications of geotechnical earthquake engineering. At low strains, dynamic properties can be evaluated using the shear wave velocity obtained from MASW test. Thus, the shear modulus of the soil layers can be obtained. In order to estimate the Poisson's ratio, in each layer constant distribution of Poisson's ratio is assumed and with the variation in depth V_P model is well matched with the V_S model. The value of Young' modulus is obtained from the estimated Poisson's ratio. Table 1 shows the estimated dynamic properties of the soil from the measured shear wave velocity.

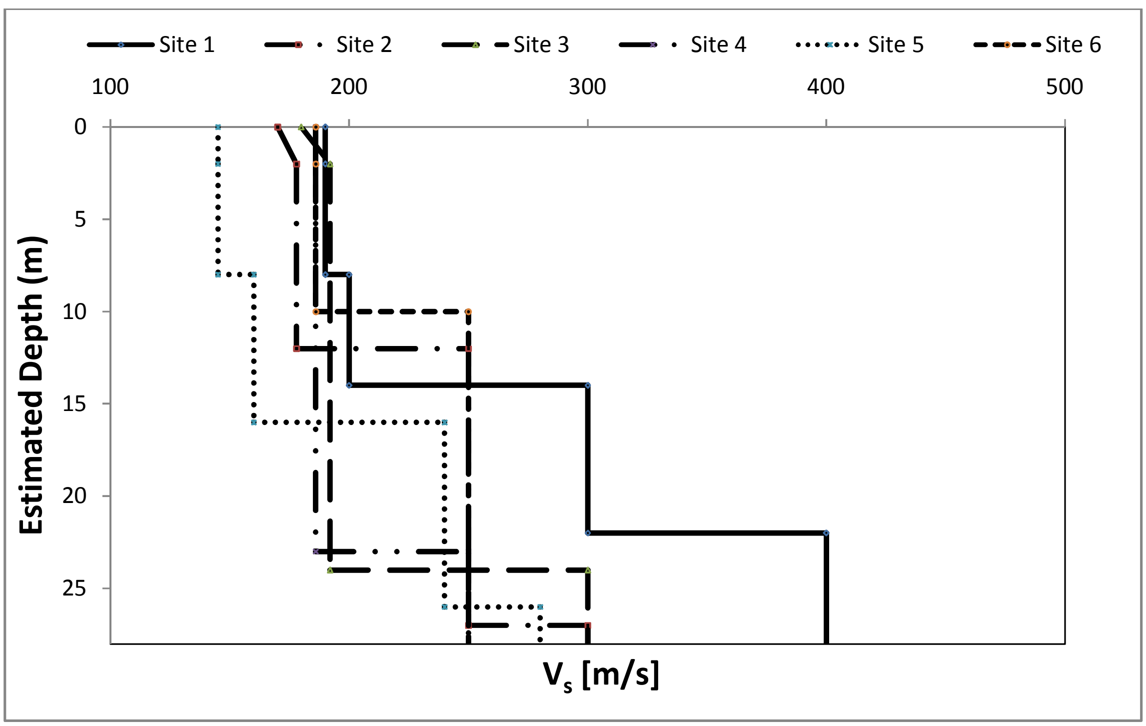

Figure 5 Shear wave velocity profiles of all the sites

The sites are selected in such a way that the whole city soil characteristics can be represented. It can be observed from Figure 5 that shear wave velocities of all the six sites upto depth of 28m is estimated. Moreover, shear wave velocity varies from 150m/s to 400m/s and the compressional wave velocity varies from 322m/s to 590m/s upto a depth of 28m measured below the ground level. The dense soil was observed at a depth of 20m with shear wave velocity of more than 360m/s. Table 1 shows the dynamic properties evaluated from the at low strain from the shear wave velocity profiles. From Table 1, it can be inferred that for Roorkee Soil, the shear modulus varies from 72 MN/m^2 to 289 MN/m^2. The Young's Modulus varies from 187 MN/m^2 to 694 MN/m^2 for Roorkee soil. Hence this method can be used for evaluation of dynamic properties in a lesser span of time.

Table 1. Evaluation of Dynamic properties

Depth (m)	Shear Wave velocity (V_S)	Density (ρ) (g/cc)	Shear Modulus(G) (MN/m^2)	Poisson's Ratio (ν)	Young's Modulus (E) (MN/m^2)
0-9	200	1.80	72	0.3	187
9-20	250	1.90	119	0.3	309
>20	380	2.00	289	0.2	694

6. CONCLUSIONS

The paper presents the geophysical method application in geotechnical earthquake engineering. At low strains, multichannel analysis of surface waves (MASW) can be used to evaluate the dynamic properties of soil by using the shear wave velocity profiles obtained by inversion technique. This method is advantageous over other conventional methods of obtaining subsurface material properties. Moreover, with the help of this method of determination of dynamic properties, engineers are able to decide the relevant equipment or method of construction on preliminary basis in a short time. Thus, measured dynamic properties for the study region are useful for design of structures in case of cyclic loading.

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