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Geotechnical Site Characterization Using Surface Waves

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ABSTRACT

Soil behaviour under cyclic loading or dynamic conditions is of interest for a wide range of problems, from foundation vibrations to site response during earthquake. Geotechnical investigation normally requires in situ strength, stiffness and permeability of the ground. Stiffness measurements are critical in the case of buildings, tunnels, excavations etc., so that ground movement before and after construction can be calculated. In this regard both laboratory and in situ tests have a great importance. Laboratory techniques include resonant column test, ultrasonic pulse test, cyclic simple shear test, cyclic triaxle compression test, cyclic torsional simple shear test. Field measurements of shear wave velocity include continuous surface wave system (CSWS), cross-hole test (CHT), down-hole test (DHT), suspension logging, seismic reflection, seismic refraction and spectral analysis of seismic waves (SASW). The objective of the present study is to conduct CSWS test at different locations on IIT Kharagpur campus and find out shear modulus and shear wave velocity profile of respective sites. SASW tests are also conducted for comparing the results obtained from CSWS tests. Shear-wave velocity and shear modulus profiles obtained, using the CSWS, showed reasonably good correlations with profiles determined using the SASW method.

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I.INTRODUCTION

Nowadays, there has been a move towards the use of field techniques for the measurement of stiffness because laboratory methods are subject to sampling disturbance and to unrepresentative sampling. Geophysical techniques, like the seismic surface wave technique, offer a nonintrusive and non-destructive way of performing geotechnical properties measurements. Moreover, geophysical approaches such as this provide a cost effective way to investigate conditions on a test site. Surface wave methods make use of dispersive nature (i.e. Velocity of surface waves depends on its frequency) of the Rayleigh waves in layered media. Three types of surface wave methods are generally used namely spectral analysis of surface wave (SASW), continuous surface wave system (CSWS) and multichannel analysis of surface wave (MASW). The main difference between SASW and CSWS are that the CSWS uses a ground vibrator as the source of energy while SASW uses an impact source (usually a sledge hammer). CSWS system can be used for determine stiffness-depth profile to a depth of upto 10m in clays and 30m in granular soils and weak rocks.CSWS system typically measures the penetration depths between 2 and 3 times that of the SASW system. It provides on-line data processing such that the stiffness-depth profile may be viewed as the test is in progress. This allows the operator to assess the quality of the data before moving to another location.

Shear modulus and shear wave velocity are the two important parameter used for evaluation of the dynamic behavior of soil as well as the characterization of the soil profile. Surface wave methods such as Continuous Surface Wave System (CSWS) and Spectral Analysis of Surface Wave (SASW) can be effectively used for determining these parameters.

II. SURFACE WAVE METHODS

Surface wave methods offer a non-intrusive and economical approach for determining V_s profiles for many geotechnical earthquake engineering applications. According to the energy sources used, surface wave methods can be categorized into: active-source and passive-source methods. Active-source methods measure surface waves generated by dynamic sources such as sledge hammers, drop weights, bulldozers and vibrator, while passive-source methods utilize ambient vibrations caused by natural (ocean wave activity, wind) and man-made (traffic, construction, factories) activities.

In this study, two active-source methods, the Continuous Surface Wave System (CSWS) and the Spectral Analysis of Surface Waves (SASW), are utilized for determining stiffness profile.

Both CSWS and SASW system works on the same fundamental principal, that Rayleigh waves (surface waves) can be generated at a source and the measured on the ground using geophones. The difference between the systems is that the CSWS system uses a ground vibrator as the source ofthe energy, and the SASW uses an impact source (usually a sledge hammer). Basic procedures that are used in both the methods are same.

III. RESULTS AND DISCUSSION

SASW tests were carried out at two locations where CSWS tests were conducted before. Variations of shear modulus and shear wave velocity with depth are plotted and compared with CSWS results. Shear wave velocity and shear modulus profiles obtained using the CSWS, showed reasonably good correlation with profiles determined using the SASW method.

From Figs. 3.1 through 3.4, it is observed that depth of penetration achieved using CSWS test is more than that obtained using SASW test. In Tata Sports Complex site, a penetration depth of 13.5m was achieved with CSWS test while SASW test provided a penetration depth of 7.5m. In St. Agnes School site, a penetration depth of 10m was achieved with CSWS test while SASW test provided a penetration depth of 6m. The maximum depth of penetration that can be achieved using the surface wave method depends on the lowest frequency for which reliable data may be obtained. The lower frequencies correspond to longer wavelength Rayleigh waves and these waves provide information about the soil at greater depth. Energy source also plays an important role in surface wave testing. SASW test uses a hammer of 7.5kg while CSWS test uses a vibrator of 64kg. Stronger sources are always preferred for deeper material investigations. This is one of the reasons for larger penetration depth obtained in CSWS tests than SASW test.

Of the two approaches to surface-wave testing, SASW may at first sight appear to be more attractive due to the simplicity and cost effective of the sources used. However restricted range of and the lack of control over the frequencies generated by impact-type sources impose a serious limitation on the SASW method. The use of a vibrator source with the CSWS method overcomes these problems since in which frequency range can be set by a PC laptop connected to control unit. Moreover, since a vibration source produces, in essence, mono-frequency signals, unwanted noise are easily filtered from the data, giving more accurate stiffness-depth profiles. Both the method took almost 1 to 2 hours for completion of experiment at one site. CSWS tests provided about 50 stiffness measurements for different depths while SASW tests provided about 150 stiffness measurements for different depth at a given location.

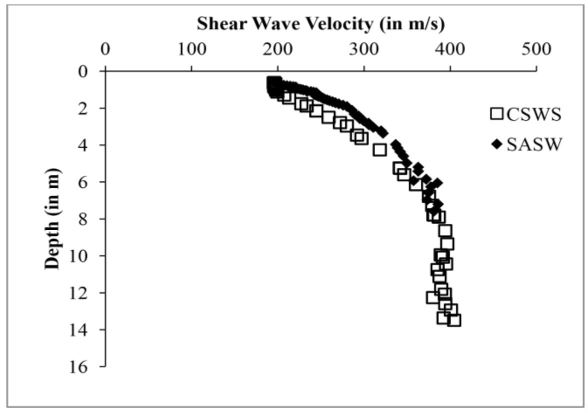

Fig. 3.1 Variation of Shear Wave Velocity with Depth at Tata Sports Complex

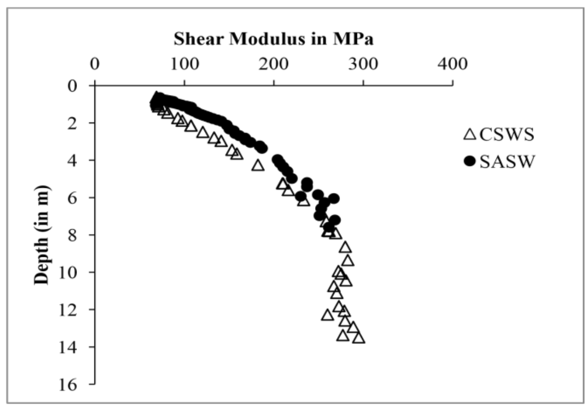

Fig. 3.2 Variation of Shear Modulus with Depth at Tata Sports complex

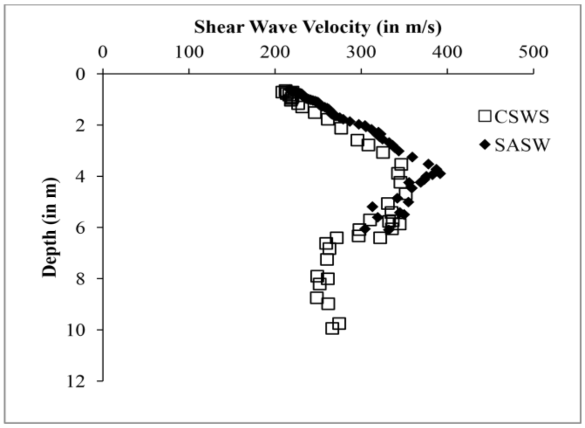

Fig. 3.3 Variation of Shear Wave Velocity with Depth at St. Agnes School

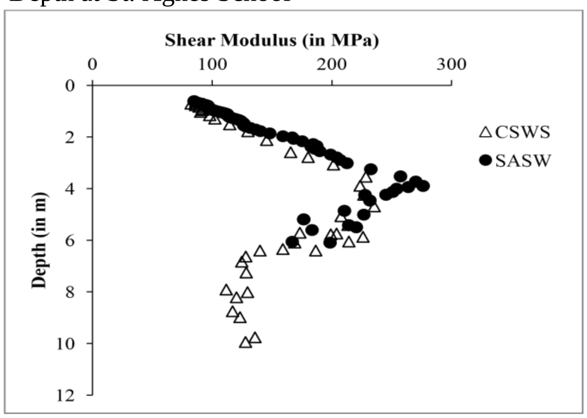

Fig. 3.4 Variation of Shear Modulus with Depth at St. Agnes School

IV. CONCLUSIONS

CSWS tests were performed to determine the shear wave velocity and shear modulus profile at two locations of IIT Kharagpur Campus and SASW tests were carried out at two locations where CSWS tests already had been conducted. Based on the results obtained, the Shear-wave velocity and shear modulus profiles obtained, using the CSWS, showed reasonably good correlations with profiles determined using the SASW method. At Tata Sports Complex, it is observed that the shear wave velocity and shear modulus increases with depth which indicates the non-existence of soft layer at those sites. At St. Agnes School, it is observed that shear wave velocity and shear modulus increased with depth up to 3.5m depth and after 3.5m it is reduced significantly which indicates the presence of soft soil below 3.5m. It is noticed that seismic wave penetration depth was varying for different sites. The penetration depth is dependent on the soil profile and local site conditions. The surface-wave method provides a rapid means of determining stiffness-depth profiles in near surface soil and rock without the need for boreholes. Both CSWS and SASW tests were completed within 1 to 2 hours at a given location. CSWS test will usually give about 50 stiffness measurements at different depths while SASW test will usually give 150 stiffness measurements at different depths at a given location. On this basis surface wave testing is considered to be very cost effective for relatively shallow investigations, when compared with some other site investigation methods. Shear modulus profile of greater depth has been achieved using CSWS test compared to SASW test. The maximum depth of penetration that can be achieved using the surface wave method depends on the lowest frequency for which reliable data may be obtained. Because of restricted range of and the lack of control over the frequencies generated by impact-type sources, depth of penetration has been found to be less in SASW test. In surface wave testing the energy source also plays an important role.

While borehole drilling must never be entirely replaced by geophysical techniques in geotechnical site investigations, a combination of borehole drilling supplemented by geophysical investigation may prove to be cost-effective. This approach has the potential to reduce the amount of intrusive investigation, such as the number of boreholes.

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