DEVELOPMENT OF EMPIRICAL CORRELATION BETWEEN SHEAR WAVE VELOCITY AND STANDARD PENETRATION RESISTANCE IN SOILS OF CHENNAI CITY

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ABSTRACT :

During an earthquake, the ground motion characteristics of the site are significantly affected by the presence of soil deposits. The ground motion characteristics at the surface are evaluated by simplified site classification method or by carrying out rigorous site specific ground response analysis. In all these methods, the shear wave velocity (V_s) is the most important parameter which represents the stiffness of the soil layers and it is related to the amplification of the ground. The shear wave velocity profile is usually obtained by carrying out wave propagation tests in the field. But it is often not economically feasible to conduct these tests at all the sites. Therefore, a reliable empirical correlation between V_s and SPT-N would be a considerable advantage. This paper presents a development of reliable regression equation between V_s and SPT-N based on the shear wave velocity measurement carried out by Multi channel Analysis of Surface Wave (MASW) test at various sites in Chennai city.
In Chennai city, the soil formation mainly consists of soft marine clay, stiff clay and loose sand with thickness varies from a few meters to 50 m. The Multichannel Analysis of Surface Wave (MASW) tests has been carried out at thirty sites distributed spatially for which SPT-N value profiles are available. Geometrics make 24 channel - seismic recorder with 4.5 Hz geophones were used to receive the wavefields. The acquired surface wave data were processed to develop shear wave velocity profile of the site. Based on the statistical assessments, an empirical correlation between V_s and SPT-N was developed. The regression equation developed in this study exhibits good prediction performance and it can be used for sites which predominantly consist of very soft to very stiff clay and very loose to dense sand.

KEYWORDS: Site characterization, Shear wave velocity, Stiffness, Standard penetration resistance, MASW test

1. INTRODUCTION

Recent seismic events throughout Indian sub-continent have made engineers review their analysis and design approaches seriously. Strong motions locally observed at a specific site induced by a large earthquake are well known as the site effect caused by the weakness in physical properties of surficial soft sediments. The major factor which controls the site effect is shear wave velocities of the surficial sediments. Knowledge of accurate and realistic dynamic characteristics such as shear wave velocity and other related dynamic soil properties like shear modulus, damping ratio etc. is an essential requirement in the analysis of seismic wave propagation. Prediction of the ground shaking response at soil sites requires knowledge of the stiffness of the soil, expressed in terms of shear wave velocity (V_s), which is measured at small strain levels by in-situ seismic methods as well as laboratory test methods. While it is preferable to determine V_s directly from field tests, it is often not economically feasible at all sites. For this reason, a reliable correlation between V_s and penetration resistance would be a considerable advantage, reducing the number of field verifications required. Though a quite number of empirical correlations between V_s and SPT-N values are available, but they are region specific and cannot be applicable to all regions.

In this study, which is an integral part of a research study on soil amplification in Chennai city, an attempt has been made to develop a reliable correlation between V_s and SPT-N for soils of Chennai. The shear wave velocity has been measured by Multichannel Analysis of Surface Wave (MASW) tests carried out at thirty spatially distributed sites, where SPT-N value profiles are available. The seismic crosshole test was also conducted at a typical site to support the accuracy of MASW test results. The regression equation developed for the study area was compared with the regression equations suggested in the literature in order to evaluate the prediction capability of the developed equation.

2. GENERAL GEOLOGY OF THE STUDY AREA

Chennai city is located between 12.75° - 13.25° N and 80.0° - 80.5° E on the southeast coast of India and in the northeast corner of Tamil Nadu. It is the India's fourth largest metropolitan city covering an area of 1,177 km². The general geology of the city comprises of mostly sandy, clay, shale and sandstone as shown in Figure 1. Sandy areas are found along the river banks and coasts. Igneous/metamorphic rocks are found in the southern area; marine sediments containing clay-silt sands and Charnockite rocks are found in the eastern and northern parts and the western parts are composed of alluvium and sedimentary rocks. Clayey regions cover most of the city. The thickness of soil formation ranges from a few meters in the southern part to as much as 50 m in the northern and central parts.

It is well known that the average shear wave velocity in the upper 30 m of the ground is an important factor for ground characterization (Dobry et al. 2000). Therefore, for the present study, the boreholes were planned to penetrate to a depth of 30 m if possible. Nearly thirty spatially distributed sites were considered in and around Chennai for geotechnical and geophysical seismic investigations as shown in Figure 2.

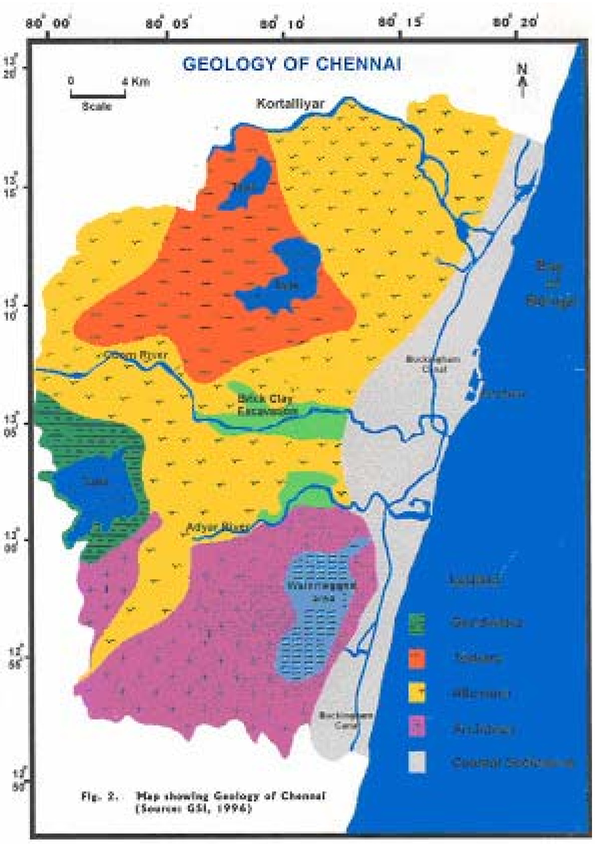

Figure 1. Geological map of the study area

Figure 2. Locations of geotechnical and geophysical seismic investigations

3. SURFACE WAVE METHOD

The most commonly used seismic method for shear wave velocity profiling is the surface wave method. The recent surface wave geophysical method provides a rapid, cost-effective, noninvasive approach for solving a variety of geotechnical engineering problems. Surface based techniques use surface receivers to measure the travel times of seismic waves with distance along the surface. Surface wave methods offer advantages over other surface-based in-situ seismic techniques which include the ability to measure both shear wave velocity and material damping profiles with depth and the ability to detect low velocity features underneath higher velocity layers, allowing for more accurate site characterization. Rayleigh waves are considered for site characterization and it is characterized by relatively low velocity, low frequency and high amplitude. For a given mode, longer wavelength surface waves will penetrate deeper into the earth than shorter wavelengths.

Nazarian et al. (1983) introduced a surface wave method called spectral analysis of surface waves (SASW) to produce near surface shear wave velocity profiles. The main disadvantage of SASW test includes the time consumption for field survey due to single pair of receivers. Later on, a four-phase research project team from Kansas Geological Survey developed an efficient and accurate method to estimate near surface shear wave velocity from ground roll using multichannel seismic data from Multichannel analysis of surface wave (MASW) test. The surface wave method, used to produce a shear wave velocity profile, involves three steps: acquisition of ground roll, construction of dispersion curve (phase velocity vs. frequency) and back calculation (inversion) of the V_s profile from the calculated dispersion curve (Park et al. 1999).

In the current study, MASW tests were carried out using Geometrics make 24 channels Geode seismic recorder with Single Geode Operating System (SGOS) operating software. Twenty four numbers of 4.5 Hz vertical geophones were used to receive the wavefields generated by the active source of 8 kg sledgehammer. Geophones were arranged in a linear pattern at 1m interval with the nearest source to geophone offset in the range of 5 to 15 m as recommended by Xu et al. (2006) to meet the requirement of different types of soil. All geophones and seismic source were connected to the Geode seismic recorder as shown in Figure 3. The seismic wave signals from all geophones were detected simultaneously and analyzed using SURFSEIS software. Raw field data was transformed into the f-k domain where phase velocities of Rayleigh waves were calculated to produce a dispersion curve with high signal to noise (S/N) ratio. The typical dispersion curve with S/N of 0.9 is shown in Figure 4. Then the calculated dispersion curve was inverted to estimate the V_s profile. The typical blow count along with the shear wave velocity variation for typical site is shown in Figure 5. It is clearly seen from the figure that the shear wave velocity profiling well matches with the variation of SPT-N values with depth. The two dimensional shear wave velocity profiling for typical site is shown in Figure 6. This figure clearly indicates the occurrence of low shear wave velocity layer underneath the stiffest soil deposit.

Figure 3. Field configuration of MASW test

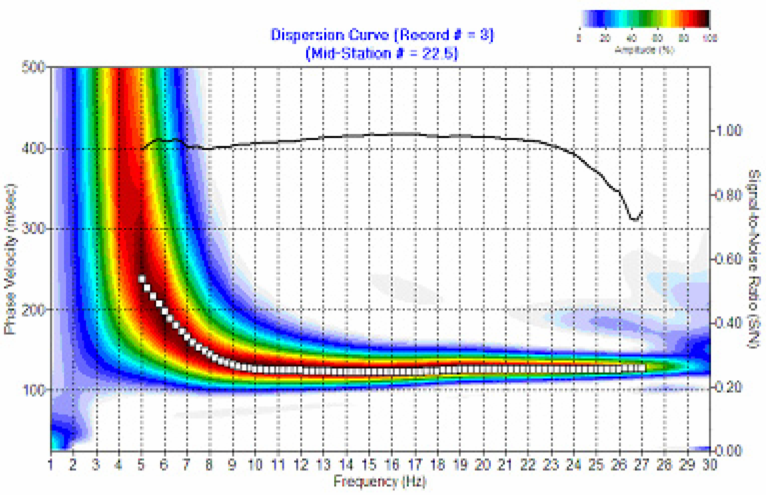

Figure 4. Typical dispersion curve (Egmore Site)

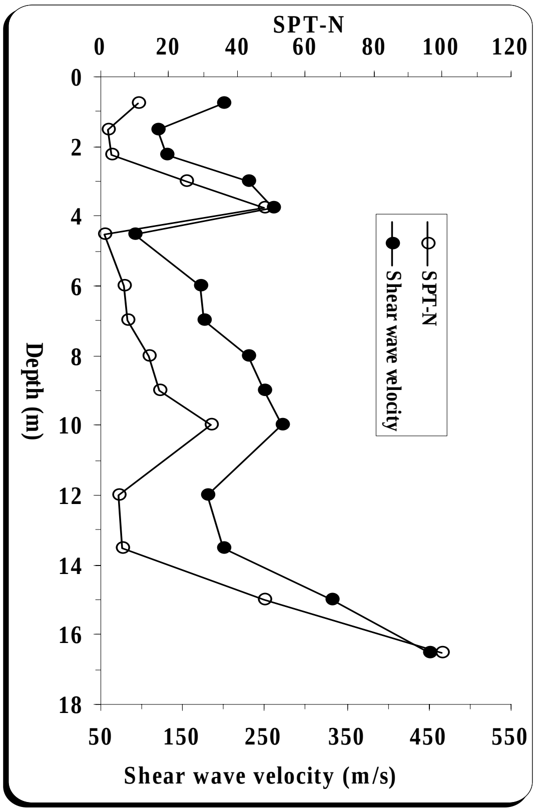

Figure 5. Variation of V_s and SPT-N with depth (Egmore Site)

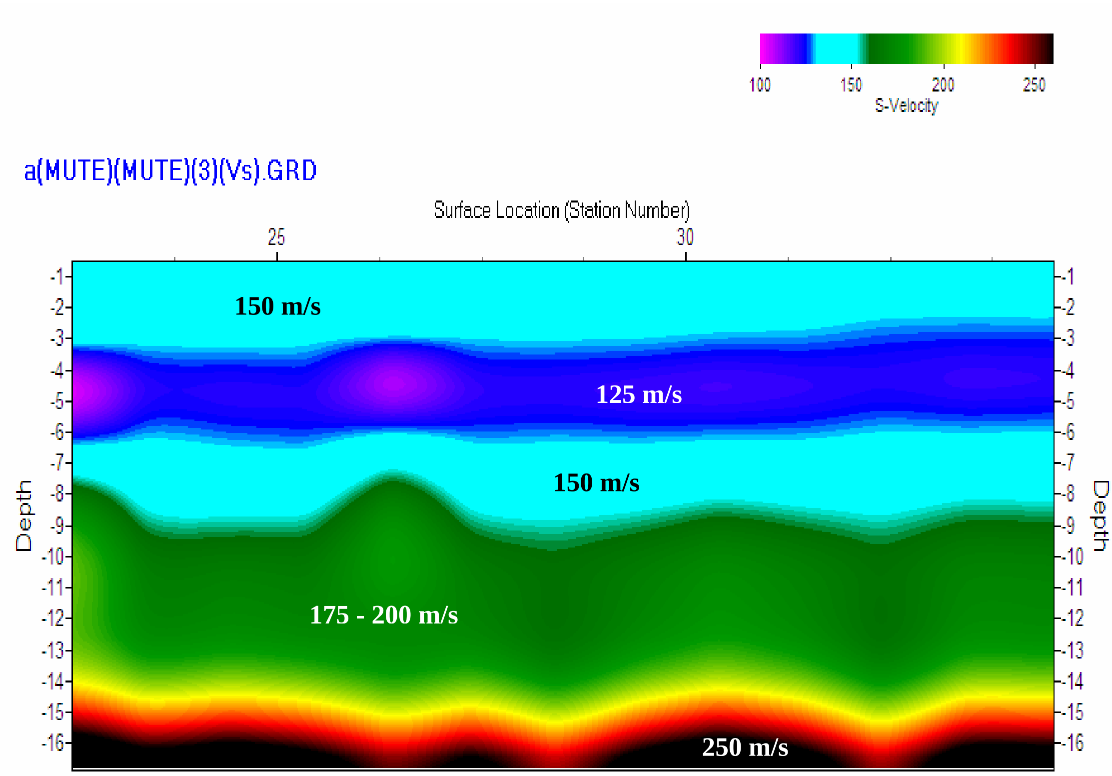

Figure 6. Typical 2D shear wave velocity profiling (Egmore Site)

The seismic crosshole test was conducted as per ASTM D4428 / D4428M (2007) at a typical site (Adyar) to compare the shear wave velocity values obtained from field Multichannel Analysis of Surface wave (MASW) tests. The tests were carried out using two receiver boreholes with spacing of 3 m. The recorded wave traces are shown in Figure 7. The shear wave velocity of the soil layer at a depth of 0.5 m is found to be about 188 m /s. The shear wave velocity profile obtained from MASW test carried out at the same site as shown in Figure 8 shows that the shear wave velocity measured by both methods is practically the same.

In addition to the above, the shear velocity measurements using bender element tests have also been carried out on the undisturbed samples collected from the typical sites in the study area (Uma Maheswari et al. 2007) and these test results confirm the accuracy of MASW test results.

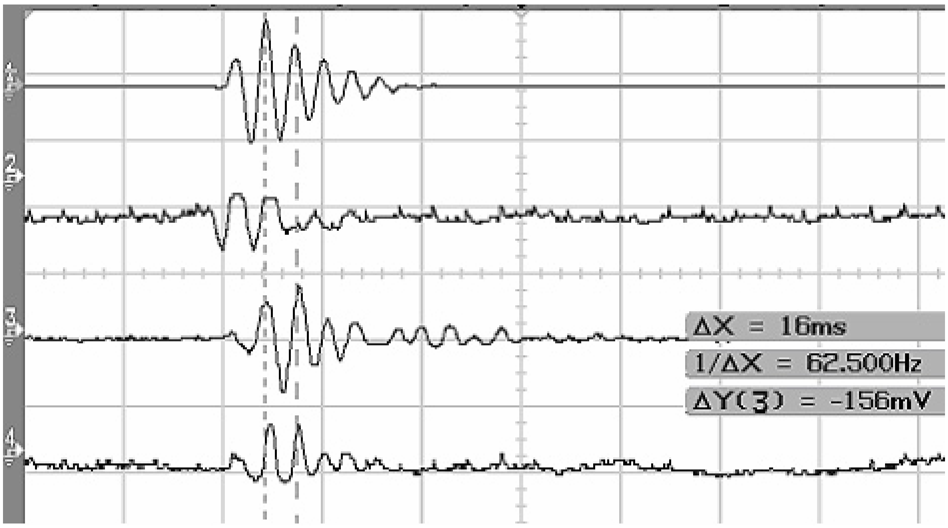

Figure 7. The typical receiver signal obtained at Adyar

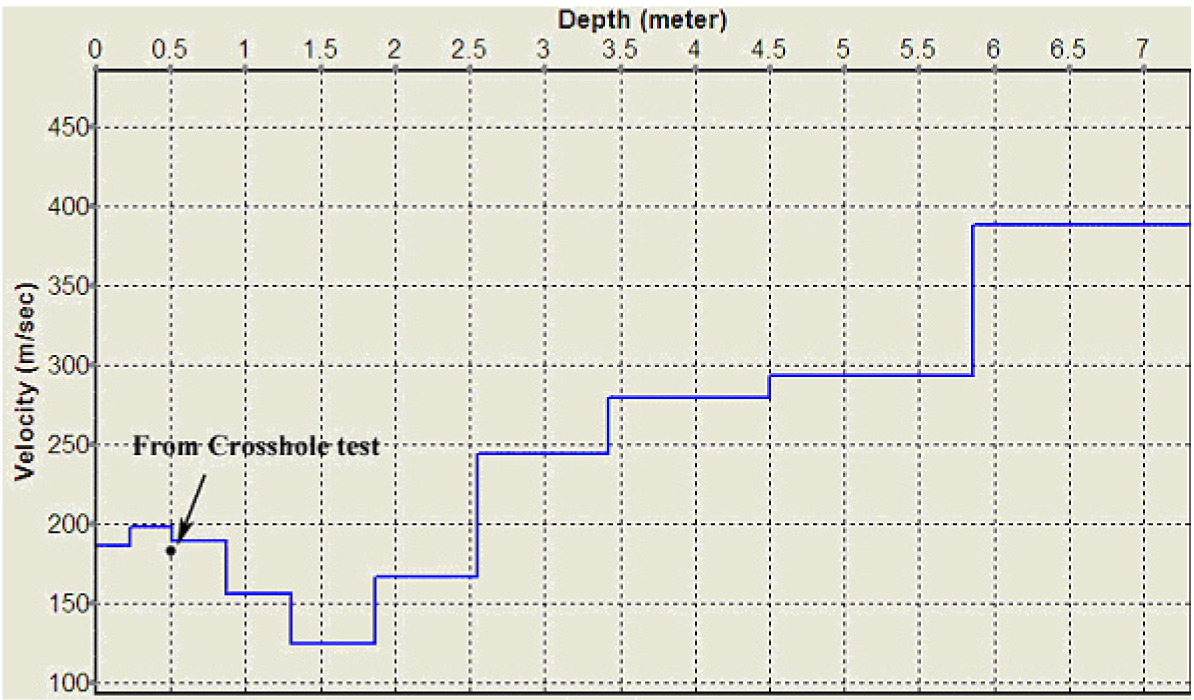

Figure 8. Results from MASW and crosshole tests at Adyar

4. DEVELOPMENT OF EMPIRICAL REGRESSION EQUATION FOR SHEAR WAVE VELOCITY

While it is preferable to determine shear wave velocity directly from field tests, it is often not economically feasible to make V_s measurements at all locations. Many correlations between V_s and penetration resistance have been proposed for different soils based on uncorrected SPT-N values. Sykora and Stokoe (1983) suggest that geological age and soil type are not important parameters in determining V_s, while the SPT-N value is of prime importance. In this study, 200 data pairs (V_s and SPT-N) were employed in the assessments. The measured data points are shown in Figure 9. The correlation developed between V_s (m/s) and corresponding SPT-N for all soils by a simple regression analysis is shown in Figure 9. The developed correlation equation is given below.

$$V_S = 95.64(N)^{0.301} \; (r^2 = 0.83) \tag{4.1}$$

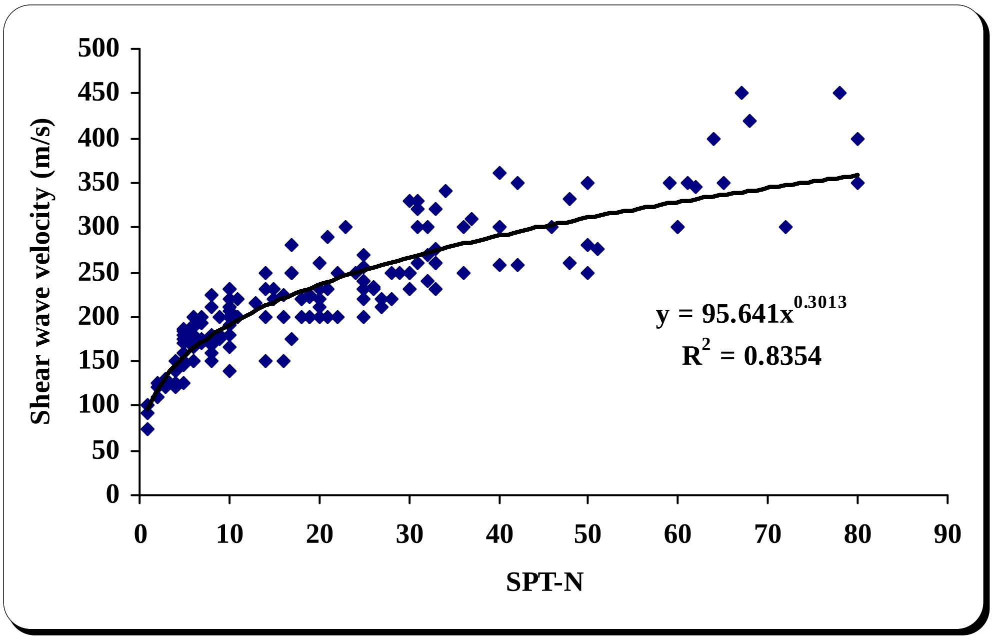

Figure 9. Developed Correlation between V_s and SPT-N

The variation of shear wave velocity with SPT-N value obtained from the equations (4.2) and (4.3) proposed by other investigators are plotted in Figure 10 along with the proposed regression equation (4.1).

$$V_s = 84N^{0.31} \quad \text{Ohba and Toriumi (1970)} \tag{4.2}$$

$$V_s = 97N^{0.314} \quad \text{Imai and Tonouchi (1982)} \tag{4.3}$$

It is clearly seen from Figure 10 that the V_s versus SPT N curve based on the proposed correlation equation lies between the curves obtained using equations (4.2) and (4.3). It is important to note that the equation (4.3) proposed by Imai and Tonouchi (1982) is based on about 1,600 dataset collected from all over Japan.

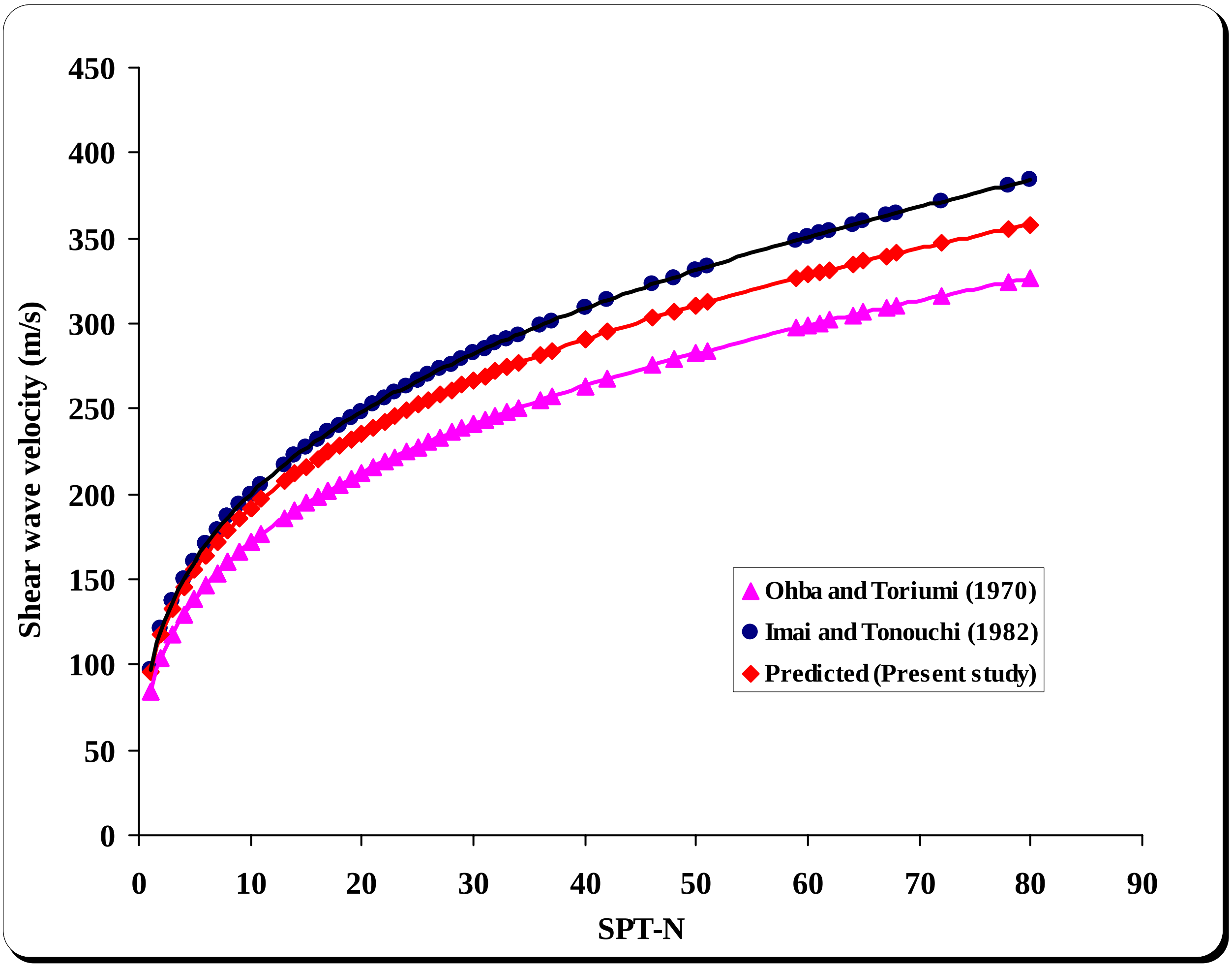

Figure 10 Comparisons between proposed and previous correlations for V_s and SPT-N for all soils

5. CONCLUSIONS

In this study, based on the results of geotechnical and geoseismic tests carried out for typical sites of Chennai city confirms the accuracy of the MASW test for the estimation of shear wave velocity. The geophysical surface wave test also predicts the loose sand / soft clay deposit underneath the stiffest soil deposit. In order to have a confidence on the results of in-situ tests, seismic crosshole test was conducted and the results from both methods match well. It is to be noted that based on the results of in-situ experimental programme, it can be concluded that MASW test can be effectively used for the determination of shear wave velocity.

Based on the extensive MASW tests carried out at various sites in Chennai a regression equation is developed to correlate shear wave velocity with SPT N. The shear wave velocity curve obtained from the proposed equation lies between those obtained from Ohba and Toriumi (1970) and Imai and Tonouchi (1982). The proposed equation can be effectively utilized for the estimation of shear wave velocity of soil for the sites predominantly comprises of very soft to very stiff clay and very loose to dense sand in Chennai city. The regression equation developed provides a viable alternative to actual field measurements by way of estimating V_s from SPT blow count for development of Seismic hazard maps for microzonation.

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