J. Myanmar Acad. Arts Sci. 2020 **Vol. XVIII. No.5A**

CORRELATION OF SHEAR WAVE VELOCITY (Vs) AND SPT-N VALUE OF VARIOUS SOIL DEPOSITS FOR CHANAYETHARZAN TOWNSHIP IN MANDALAY DISTRICT

Tun Tun Win[1], Myo Thant[2], Than Than Nu[3], Pyi Soe Thein[4], Tin Naing Tun[5] & Win Min Than[6]

Abstract

The research area, Chanayethazan Township is a main population center in Mandalay District and lies in near the seismically active Sagaing fault. Nowadays, geotechnical and geophysical techniques are widely used for evaluating dynamic soil properties and seismic hazard analysis. The dynamic loading of soil in the present area are evaluated by shear wave velocity (Vs) using geotechnical (mainly SPT) and geophysical (mainly microtremor HVSR) methods. At some places obtaining only SPT data or only Vs value, we are difficult to predict the true correlation. The purpose of this paper is to establish the new formulas for the shear wave velocity (Vs) and SPT-N values relationships of the various soil types. Fifteen data pairs were employed to assess relation between Vs and SPT-N values. Although most correlations of other areas are comparable and in good trend, these correlations for the present area are directly disallowed because of different practice of SPT and shear wave investigation works. Thus, present research based on previous literature and observed data was attempted to establish new correlations between Vs and SPT-N for various soil types of the study area. The proposed data will be aid for seismic hazard analysis and engineering purposes of Chanayethazan Township.

Keywords: shear wave velocity (Vs), numbers of blows from standard penetration test (SPT-N) value, microtremor horizontal vertical spectral ratio (HVSR).

Introduction

The research area, Chanayethazan Township is a main population center of Mandalay District and lies in near the seismically active Sagaing fault. The hazardous effects of earthquake are significantly affected by the local site effects of soil under dynamic loading. Nowadays, geotechnical and geophysical techniques are widely used for evaluating dynamic soil properties and seismic hazard analysis. The dynamic properties of soil in the present area can be estimated using shear wave velocity (Vs) resulted from both borehole (SPT-N values) data and microtremor horizontal vertical spectral ratio (MHVRs) data.

Shear wave velocity (Vs) can be also used for various applications such as liquefaction potential analysis, earthquake site response, foundation stiffness assessment and soil compaction (Park, B, C., et al, 1997). Thus, average shear wave velocity to a depth of 30 m (Vs_{30}) is essential for evaluation of seismic site characteristic in the study area. Now, standard penetration tests blow count number (SPT-N) value and the shear wave velocity (Vs)are the most common methods for determining the earthquake related hazards all over the world. Thus, many attempts in worldwide have been made to correlate values of Vs with available soil parameters (SPT- N value). Although the empirical correlations of previous researchers between SPT-N and Vs is

[1] Lecturer, Department of Geology, University of Mandalay
[2] Professor, Department of Geology, University of Yangon
[3] Professor, Department of Geology, University of Mandalay
[4] Lecturer, Department of Geology, Yadanabon University
[5] Assistance Lecturer, Department of Geology, University of Mandalay
[6] Assistance Lecturer, Department of Geology, University of Mandalay

convincing with notably worldwide agreement, these correlations are directly disallowed because of different practice of SPT and shear wave investigation works due to various geological conditions. In the present area, the own empirical correlations of SPT-N & Vs for the different soil types have not been reported in the literature. Therefore, Vs–N relationship for various soil types of Chanayethazan Township in Mandalay district has been investigated. Sometimes microtremor survey is not easy to obtain Vs value in all the locations of the research area because of noisy conditions. At this condition, standard penetration test is better than microtremor survey. On the other hand, sometimes the penetration test cannot be performed conveniently and reliably at all depths and in all soils such as those with large grain size, i.e., gravelly soils these sites may give unrealistic high N-value. Thus, a new correlation between SPT-N and Vs needs to establish for research area.An empirical relation (Vs & SPT-N) applicable to all the fifteen-pair sites was evaluated based on the existing correlations of previous researchers and observed data. By using empirical regression analysis, the present research was established the new formulas for SPT-N and Vs values relationships of the various soil types i.e. all soils, sandy soils and clayey soils for estimation of seismic hazard analysis.

Site Investigations

The site investigations were carried out using both geotechnical mainly standard penetration test (SPT) and geophysical mainly microtremor survey. In the present research, 15 boreholes and 40 microtremor investigation points are used to conduct subsurface survey in the study area. Among them, all the 15 pair sites was evaluated for empirical relation SPT-N & Vs .The laboratory tests of sample were collected from all these sites. The locations of the fifteen-pair points are shown in Fig. 1.

Figure 1 Location map of investigation sites

Methodology

Subsurface investigations of the present area were carried out by using 40 microtremor points and 15 drilled boreholes. For the study area, 15 data pairs were employed to develop empirical relations between Vs &SPT-N values for different soils using regression analysis. The site investigations at 15 boreholes points of the study area were examined about 30 m depth of surface layer. N value was obtained from geotechnical field data as SPT method. Vs profiles resulted from SPT-N values were presented seven layers and Vs models obtained from microtremor HVSR data were constructed four layers. The combination of the two Vs model profiles are shown in Fig. 2.

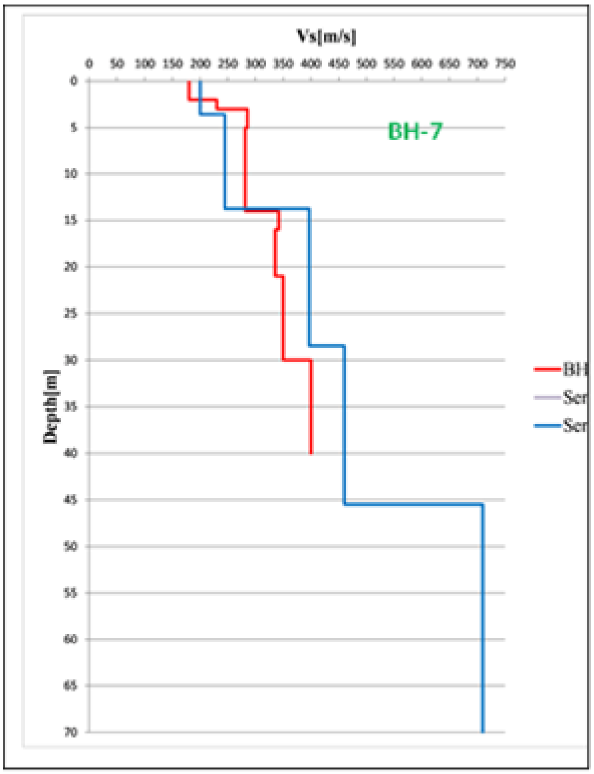

Figure 2 Comparison of Vs profiles resulted from SPT-N (red line) and microtremor (HVSR) data (blue line)

Estimation of shear wave velocity to a depth of 30m using SPT data

The SPT dataset is used to develop subsurface describing the distribution of time-averaged shear wave velocity, Vs30, across the study area .Target profile depths of 5, 10, 20, 30 m were considered to allow for an assessment of the distributions of soil stiffness with depth across the region. Vs30 values are computed for each target depth. The evaluated Vs30 for each site of the study area are calculated in the following equation.

$$Vs30 = \frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum \frac{d_i}{vs_i}}$$

Where v_{si} is shear wave velocity, d_i thickness of i th layer and t_i one way travel time in i th layer

Estimation of shear wave velocity to a depth of 30m using MHVRs method

Shear wave velocity is an important parameter for estimation of the dynamic properties of soil in the shallow subsurface. In the present study, Vs30 is calculated as the following equation;

$$V_{S\,30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{V_i}}$$

Where, Vs^{30} is the shear wave velocity of upper 30m, h_i and V_i denote the thickness (m) and shear wave velocity of the i-th layer, in a total of N, existing in the top 30m.

Regression analysis

For the regression analysis of the present area, N values were estimated above suitable depth of SPT borehole and the shear wave velocity profile was developed based on the layer formations observed from SPT and MHVRs testing by using 15 pair data.Many researchers as listed in table (1) were proposed their own empirical correlation between Vs and SPT-N value for various categories of soil (i.e. all soils, sand and clay) at different locations. The present correlations Vs and SPT-N were examined based on previous literature and observed data using regression analysis. The predicted correlation in the form of a power-law relationship between Vs and SPT resistance can be used as the following equation.

$$Vs = a\, N^{b}$$

where Vs is shear wave velocity, N is SPT-N value, *a* and *b* are coefficients varying for different locations and types of soil.

Table 1 Vs-N correlations given by other researchers

Researchers	All soil(ms^{-1})	Sand(ms^{-1})	Clay(ms^{-1})
Hanumantharao and Ramana	$Vs= 82.6N^{0.430}$	$Vs=79.0N^{0.434}$	-
Maheshwari et al.	-	$Vs=95N^{0.300}$	-
Ohba and Toriumi	$Vs=84N^{0.310}$	-	-
Imai	$Vs=91N^{0.340}$	$Vs=80.6N^{0.331}$	$Vs=80.2N^{0.292}$
Ohta and Goto	$Vs=85.35N^{0.348}$	$Vs=88.0N^{0.340}$	-
Jafari et al	$Vs=121.0N^{0.270}$	$Vs=88.0N^{0.330}$	$Vs=100.0N^{0.330}$
Seed and Idriss	$Vs=61N^{0.500}$	-	-
Lee	-	$Vs=57.4N^{0.490}$	$Vs=114.4N^{0.310}$
Sykora and Stokoe	-	$Vs=100.5N^{0.290}$	-
Okamoto et al	-	$Vs=125.0N^{0.300}$	-
Pitilakis et al	-	$Vs=162.0N^{0.170}$	$Vs=165.7N^{0.190}$
Athanasopoulos	$Vs=107.6N^{0.360}$	-	-
Raptakis et al	-	$Vs=123.4N^{0.290}$	$Vs=184.2N^{0.170}$
Hasancebi and Ulusay	$Vs=90N^{0.309}$	$Vs=90.8N^{0.319}$	$Vs=z97.9N^{0.269}$
Uma Maheswari et al	$Vs=95.64N^{0.301}$	$Vs=100.53N^{0.265}$	$Vs=89.31N^{0.358}$
Esfehanizadeh et al	-	$Vs=107.2N^{0.34}$	-
Fatehnia et al	-	$Vs=77.1N^{0.355}$	$Vs=77.1N^{0.355}$

Results and Discussion

For the present area, the observed data for estimating the best relationships were also used in the above power function equation. By result data, range of SPT-N values is 2 to 20 and average range of Vs is >120 to <400 ms^{-s}. This analysis is almost performed by computer program. The newequations developed for the correlation between Vs and SPT-N values of the study area are shown in table (2). The coefficient of determination (R^2) is used to analyze how difference in two variable. R^2 range is 0 to 1 i.e, 0% to 100% probability of the two sets of variables.

Table 2 Summary of the proposed relationships in Chanayetharzan Township

Type of soil	correlation	R^2
All soils	**$Vs=90.9N^{0.352}$**	0.9874
Sandy soil	**$Vs= 97.6N^{0.325}$**	0.9894
Clayey soil	**$Vs= 113.55N^{0.28}$**	0.9918

All Soil

Fig (3) shows the graphical validation of the regression analysis for all soil based on comparison of previous researchers and observed data. N values were placed ≤ 20 for regression analysis. This correlation was compared with nine researchers such as Hanumantharao and Ramana(2008),Ohba and Toriumi(1970), Imai(1977), Ohta and Goto(1978), Jafari et al(2002), Seed and Idriss(1981), Athanasopoulos(1995), Hasancebi and Ulusay(2007), and Uma Maheswari et al(2009)**.** According to research data, the new regression equation for all soil is similar to Imai (1977), and Hasancebi and Ulusay (2007). Fig (3) shows the empirical correlation between Vs and SPT-N for all soil based on observed data of the study area using regression analysis and the proposed relation is $Vs=90.9N^{0.352}$.The coefficient of determination (R^2) is 0.9874 which is a strong correlation between SPT-N and Vs value.

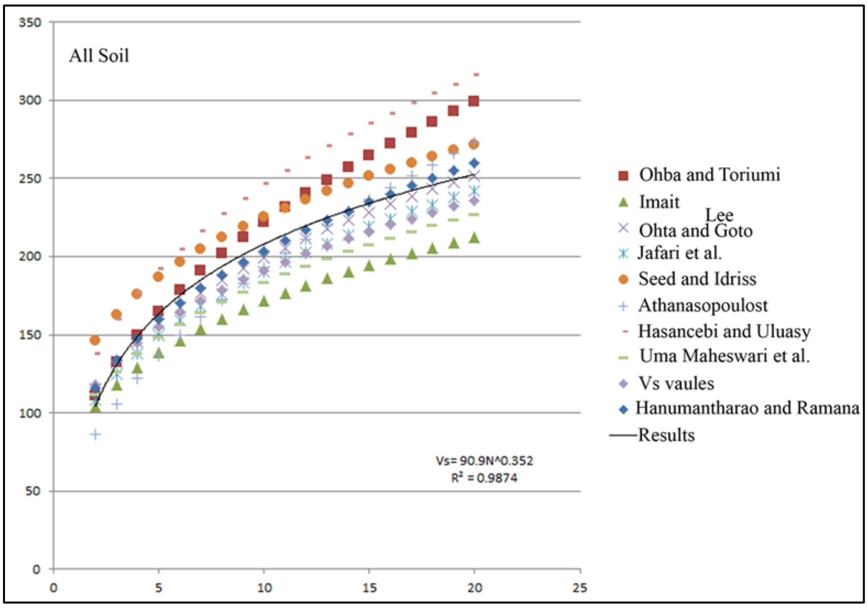

Figure 3 Comparison of the proposed regression formula with current correlations between SPT-N and Vsvalue for all soil types based on other worldwide relations and observed data

Sandy Soil

The predicted correlation between SPT value and shear wave velocity for sandy soil is compared with the existing correlations given by other researchers as shown in Fig (4). The comparisons of the results of the present study are made with the equations recommended by fourteen other researchers as shown in table (1). Fig (4) shows correlation between Vs and N for sandy soils and proposed relationship of sandy soil is $Vs=97.6N^{0.325}$. The coefficient of determination obtained (R^2) was 0.9894 which is a good correlation between SPT-N and Vs.There is a considerable more scatter below the fitted (results) line. According to fig (4), the new regression equation for sandy soil is similar to Sykora and Stokoe.

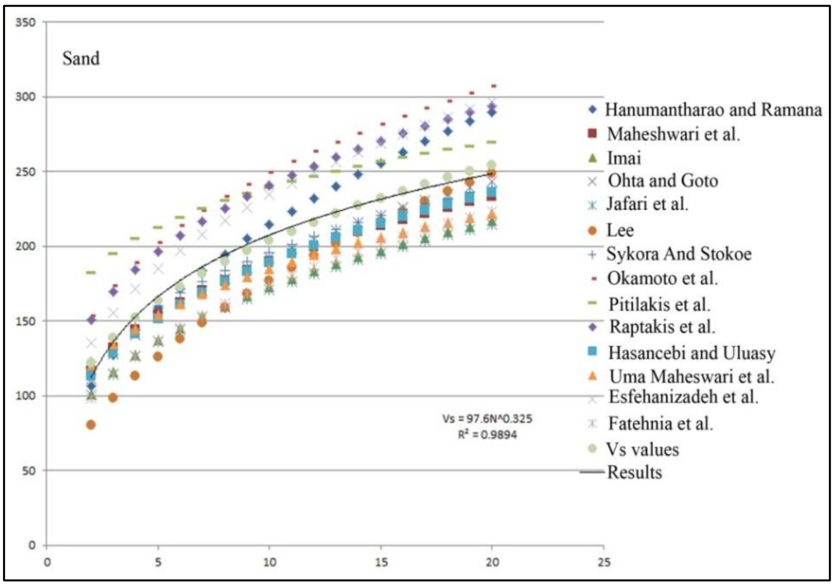

Figure 4 Comparison of the proposed regression formula with current correlations between SPT-N and Vsvalue for sandy soil

Clayey Soil

Similar to other soil types, the correlation was developed using a simple regression analysis for the existing database. In Fig. 5, the proposed relationship of Vs and SPT-N for clayey soils is compared with the equations recommended by eight other researchers as shown in table (1). Fig (5) shows comparison between uncorrected Vs and uncorrected N for clayey soils is developed and the proposed relation is $Vs=113.55N^{0.28}$. The coefficient of determination is R^2=0.9918 which is quite high value as compare to that for other soil types. Therefore, the relationship for clayey soils is bit different than other soils (table.2). It can be observed that the result of the present study is closed to that of Jafari et al.

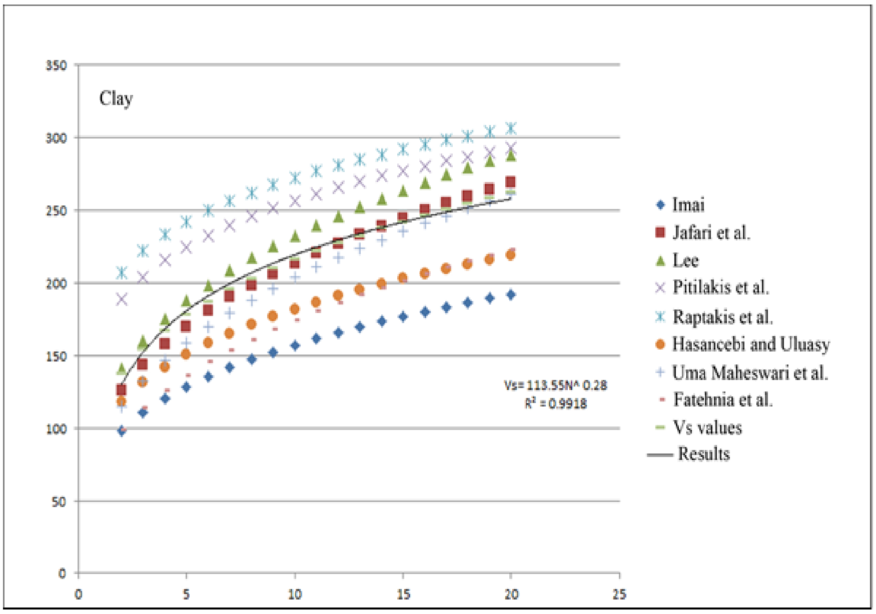

Figure 5 Comparison of the proposed regression formula with current correlations between SPT-N and Vs value for clayey soil

Conclusions

For the study area, 15 data pairs were employed to develop empirical relations between Vs &SPT-N values for different soils using regression analysis. By result data, range of SPT-N values is 2 to 20 and average range of Vs is >120 to <400 ms^{-s}. Direct measurement of Vs is time consuming and costly, therefore many researchers have been trying to update empirical relationships between Vs and other geotechnical properties of soils such as SPT Blow count, SPT-N.

All of present results obtaining from SPT and Vs are to assess the dynamic properties of soil. Although most of the previous correlations are comparable and in good trend, direct application to other regions are disallowed because of different practice of SPT and shear wave investigation works. The differences exist in the earlier predicted correlations because of the site investigation error and chance in geological conditions or soil strata in the study area. Such relationships are not reported previously for the present area. Hence, present researcher were attempted to establish new correlations between Vs and SPT-N for various soil types of the study area such as all soils, sandy soils and clayey soils. The present correlations Vs and SPT-N were examined based on previous literature and observed data using regression analysis. According to our result data, the present correlations are reliable with other relations. By the coefficient of determination (R^2) values, the new regression equations of the present area give good prediction performances. Hence, the present results can be effectively used for studying the seismic site response and engineering properties of soil in the study area.

Acknowledgements

We would like to thank Professor Dr. Myo Min, Department of Geology, University of Mandalay for his valuable suggestions and advices in preparation for the research paper. We are deeply thankful to Professor Hiroshi Kawase, Tokyo University in Japan for his constructive suggestions and supporting the microtremor machine to measure geophysical survey for the study area.

References

Athanasopoulos, G.A. (1995), "Empirical correlations Vso-NSPT for soils of Greece": a comparative study of reliability, *Proceedings of the 7th International Conference on Soil Dynamics and Earthquake Engineering Computation Mechanics Publications, Southampton, Boston*, pp 19–25

Boore, D.M., Joyner, W.B and Fumal, T. E. (1997), Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes: A Summary of recent Work, *Seismological Research Letters*, Vol. 68, No. 1, 128-153.

Bour,M., Fouissac,D., Dominique,P and Martin, C.1998. "On the Use of Microtremor Recordings in Seismic Microzonation", *Soil Dynamics and Earthquake Engineering, Vol*. 17, No. 7-8, pp. 465-474

Esfehanizadeh, M., Nabizadeh, F., Yazarloo, R. (2015), Correlation between Standard Penetration (NSPT) and Shear Wave Velocity (Vs) for Young Coastal Sands of the Caspian Sea, *Arab J Geosci 8:7333–7341.*

Fatehnia, M., Hayden, M and Landschoot, M. (2015),"Correlation between Shear Wave Velocity and SPT-N values for North Florida Soils", *Elec J Geotech Eng 20:12421–12430 Int. J. of Geosynth and Ground Eng. (2016) 2:9 pp.* 11 of 11 9123.

Hanumantharao, C & Ramana, G.V. (2008),"Dynamics Soil Properties for Microzonation of Delhi, India". *J Earth Syst Sci 117(S2):*719–730

Hasancebi, N& Ulusay, R. (2007), Empirical Correlations between Shear Wave Velocity and Penetration Resistance for Ground Shaking Assessments, Bull Eng Geol Environ 66:203–213

Imai, T. (1977), P- and S-wave Velocities of the Ground in Japan, Proc IX Int conf Soil Mech Found Eng 2:127–132

Jafari, M.K., Shafiee, A & Razmkhah, A. (2002), Dynamic Properties of Fine Grained Soils in South of Tehran. Soil Dyn Earthq Eng 4(1):25–35

Jhinkwan, H & Jain,P. K. (2016), "Prediction of Shear Wave Velocity Using SPT-N Value" *TROI*, Vl.3, Issue 7.

Kirar, B., Maheshwari, B. K & Muley, P. (2016), Correlation between Shear Wave Velocity (Vs) and SPT Resistance (N) for Roorkee Region, *Int. J. of Geosynth, Ground Eng. 2016.2-9.*

Krammer, S.L. (1996). Geotechnical Earthquake Engineering, *Prentice-Hall Civil Engineering and Engineering Mechanics Series, Upper Saddle River, NJ:* Prentice Hall,| c1996, 1.

Lee S, H, H. (1990), Regression Models of Shear Wave Velocities in Taipei Basin. J Chinese Inst Eng 13:519–532

Maheshwari, B.K., Mahajan, A.K., Sharma, M.L., Paul, D.K., Kaynia, A.M., Lindholm, C. (2013), Relation between Shear Velocity and SPT Resistance for Sandy Soils in the Ganga Basin, Int J Geotech Eng 7(1):63–70

Nakamura, Y. (1989), A Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface,Quarterly Report of the Railway Technology Research Institute.

Ohta, Y& Goto, N. (1978), Empirical Shear Wave Velocity Equations in Terms of Characteristics Soil Indexes. Earthq Eng Struct Dyn 6:167–187

Pitilakis, K.D., Anastasiadis, A & Raptakis, D. (1992), Field and Laboratory Determination of Dynamic Properties of Natural Soil Deposits, *In Proceedings of the 10th world conference on earthquake engineering, Rotterdam*, pp 1275–1280.

Raptakis, D.G., Anastasiadis, S.A.J., Pitilakis, K.D & Lontzetidis, K.S. (1995), Shear Wave Velocities and Damping of Greek Natural Soils, *In Proceedings of the 10th European conference on earthquake engineering, Vienna,* pp 477–482.

Seed, H. B., Tokimatso, K & Harder, L. F. (1985), The Influence of SPT Procedures in Soil Liquefaction Resistance Evaluation, *Geotechnical engineering, ASCE, No.111, Vol.12*.

Sykora, D. E & Stokoe, K. II. (1983), Correlations of In situ Measurements in Sands of Shear Wave Velocity, Soil Dyn Earthq Eng 20(1–4):125–136

Uma Maheswari, et al. (2010),Use of Surface Waves in Statistical Correlations of Shear Wave Velocity and Penetration Resistance of Chennai soils, Geotech Geol Eng 28:119–137