# Development of New Empirical Relationship between Shear Wave Velocity and Standard Penetration Resistance for All Soils of Mandalay City

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

Abstract

Shear wave velocity resulted from microtremor H/V ratio is an important input parameter to calculate seismic response analysis of soil. For present study, 187 microtremor measurements and 50 borehole points were investigated at different sites of Mandalay city. But considering 50 pairs of data, a new empirical relationship between SPT-N and shear wave velocity to a depth of 30m has been conducted for all soils of Mandalay city by using regression analysis. In the present area, this empirical correlation equation has not been reported in the literature. Thus, a new correlation equation between SPT-N value and Vs was established for all soils. Based on the statistical observed data, the new empirical equation developed for the correlation between Vs and SPT-N values of the study area is $\mathbf{Vs=100.49N^{0.2801}}$ and the coefficient determination **($R^2$) is 0.9672** .According to coefficient determination ($R^2$) value, the present equation is a strong correlation for all soils. The relationship proposed in this present research is important as this can be used for a part of engineering site selection and the seismic microzonation of the study area.

**Keywords**: Standard penetration test blow count number (SPT-N), shear wave velocity (Vs), microtremor horizontal to vertical spectral ratio (H/V ratio), regression analysis, coefficient determination **($R^2$)**

## Introduction

For present research, surface wave method as microtremor SMAR-6A3P test is commonly used for determining the near surface shear wave velocity to a depth of 30m (Vs30). Shear wave velocity of the study area can be easily obtained by microtremor SMAR-6A3P test at sites where drillings may be disallowed such as dumping ground, great distance sites requiring rapid evaluation and being hard subsurface sites. But sometimes microtremor survey is not easy to measure Vs in all the locations of the research area such as noisy environments. At this condition, standard penetration test is better than microtremor survey. Moreover, SPT test provides indirect measure of the soil resistance (N value) as well as disturbed drive samples. It can be performed in a wide variety of soil types. 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 correlation equation between shear wave velocity and SPT- N value has to needs for Mandalay city. This correlation can be developed by using linear regression analysis. The present result is helpful for estimating an earthquake site response, engineering purposes such as land used planning, site classification and soil density.

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## Methodology

Subsurface soil conditions of the study area were explored by means of borings and microtremor surveying. For site classification, 50 boreholes for geotechnical investigations and 187 microtremor SMAR-6A3P survey points (Fig.1) for geophysical investigations have been conducted in the study area. 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. Therefore, for the present study, the boreholes and microtremor measurements were possibly performed to a depth of 30 m. For the SPT, hand released hammer mechanism was used. Soil samples for the laboratory tests were collected from different depths at 50 borehole sites using SPT method. Shear wave velocity was calculated based on N value and H/V ratio data. For the empirical correlation equation of the study area, 50 data pair based on 50 microtremor point nearly selected 50 boreholes (Fig. 2) were employed to develop new empirical correlation for all soils by using regression analysis for Mandalay city.

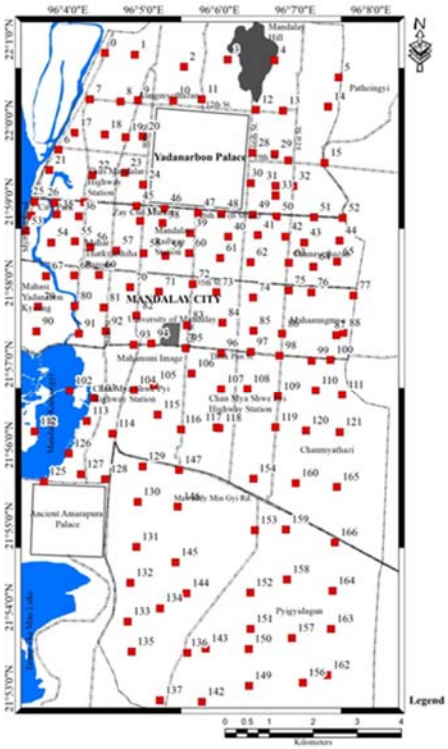


Figure (1). 187-Microtremor survey points of Mandalay city

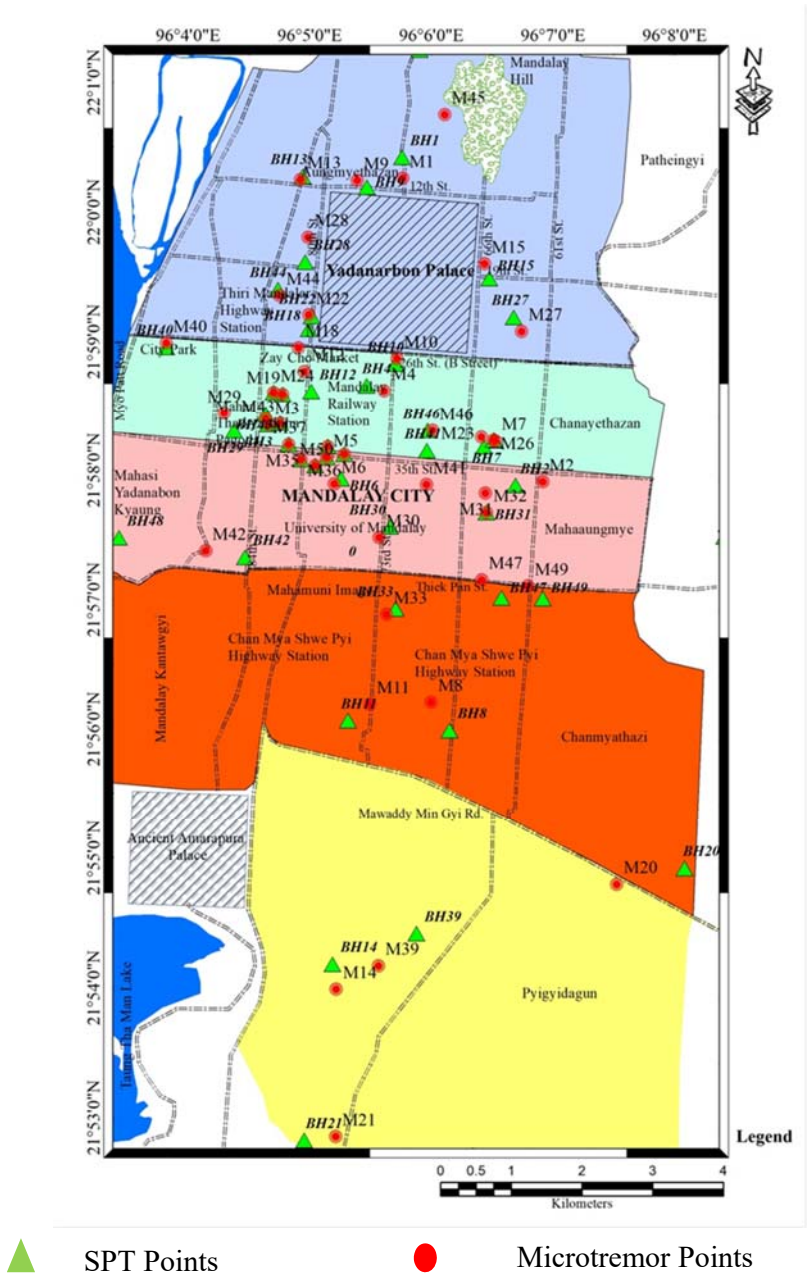


Figure (2). 50-Data Pair (SPT& Microtremor) Positions of Mandalay City.

**Calculation Method for Vs30 Using SMAR 6A3P Measurement Data**

Shear wave velocity is an important parameter for estimation of the dynamic properties of soil in the shallow subsurface. In the present study, empirical equation have been used for the estimation of shear wave velocity $V_{s,d}$ is computed for different depths (CEN, 2004):

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

Where d is the depth in meters, and $h_i$ and $V_i$ denote the thickness and shear wave velocity of the i-$^{th}$ layer based on microtremor measurements, for a total of N layers (Bessason,B., and Erlingsson,S.,2011).The average shear wave velocity of the top 30m (Vs30) model is shown in figure (4) which 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, hi and vi denote the thickness (m) and shear wave velocity of the i-$^{th}$ layer, in a total of N, existing in the top 30m, Vs30 (Dobery *et al*. 2000, Sebetta & Bommer 2002; Seco e Pinto 2002).

## Results and Discussions

The present correlations Vs and SPT-N were determined based on previous literature and observed data using regression analysis as shown in table (1). The predicted correlation in the form of a power-law relationship between Vs and SPT resistance can be used as the following equation.

$$Vs = a\ Nb$$

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 all soils of other researchers (Modified after Marto et al, 2013& Kirar et al, 2016)

| Researcher | All Soils ( $ms^{-1}$) |
|---|---|
| **Hanumantharao and Ramana** | $Vs= 82.6N^{0.430}$ |
| **Ohba and Toriumi** | $Vs=84N^{0.310}$ |
| **Imai** | $Vs=91N^{0.340}$ |
| **Ohta and Goto** | $Vs=85.35N^{0.348}$ |
| **Jafari et al** | $Vs=121.0N^{0.270}$ |
| **Seed and Idriss** | $Vs=61N^{0.500}$ |
| **Athanasopoulos** | $Vs=107.6N^{0.360}$ |
| **Hasancebi and Ulusay** | $Vs=90N^{0.309}$ |
| **Uma Maheswari et al** | $Vs=95.64N^{0.301}$ |

We considered the average range of SPT-N values are 2 to 20 and Vs ranges >110 to <400 $ms^{-1}$ to obtain the present empirical correlations. Fig (3) shows the graphical validation of the regression analysis for all soil based on comparison of previous researchers and observed data. This correlation ($Vs=90.9N^{\wedge 0.352}$) was compared with nine researchers in table (1). The coefficient of determination ($R^2$) is 0.9898 which is a strong correlation between SPT-N and Vs value as seen in Fig (3). According to Fig (3), the equation for all soil is

similar to Imai (1977), and Hasancebi and Ulusay (2007). Fig (4) shows the empirical correlation between Vs and SPT-N for all soil based on observed data of the study area using regression analysis. By this result, a new equation developed for correlation between SPT-N values and Vs of the present area is $Vs=100.49N^{\wedge 0.2801}$as shown in Fig (4). The coefficient of determination ($R^2$) is 0.9672. Thus, the new correlation equation is validated good prediction performance for all soil.

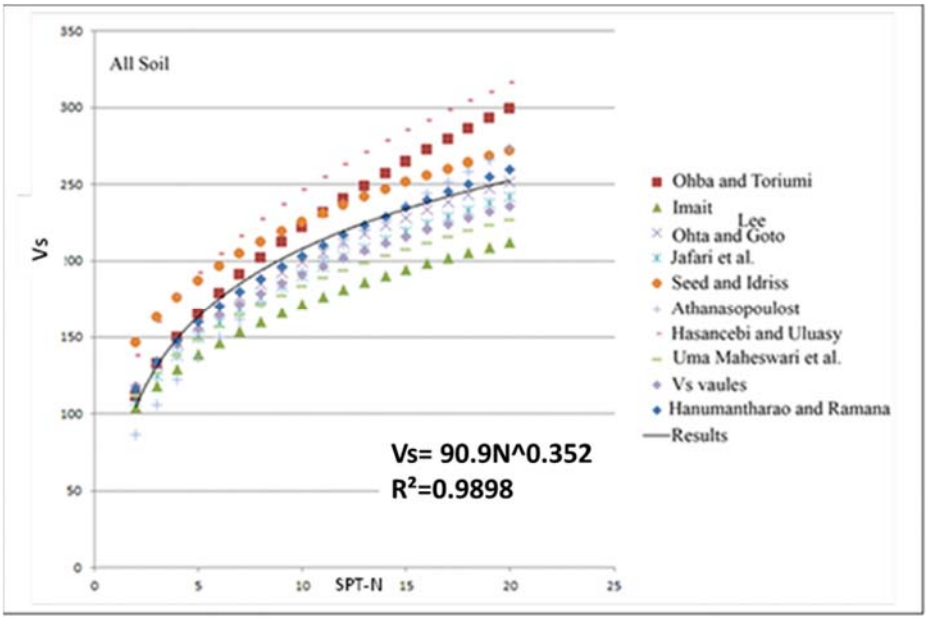


Figure (3). Comparable with the previous equations of other researchers from all over the world and observed data between predicted SPT-N and Vs value for all soils.

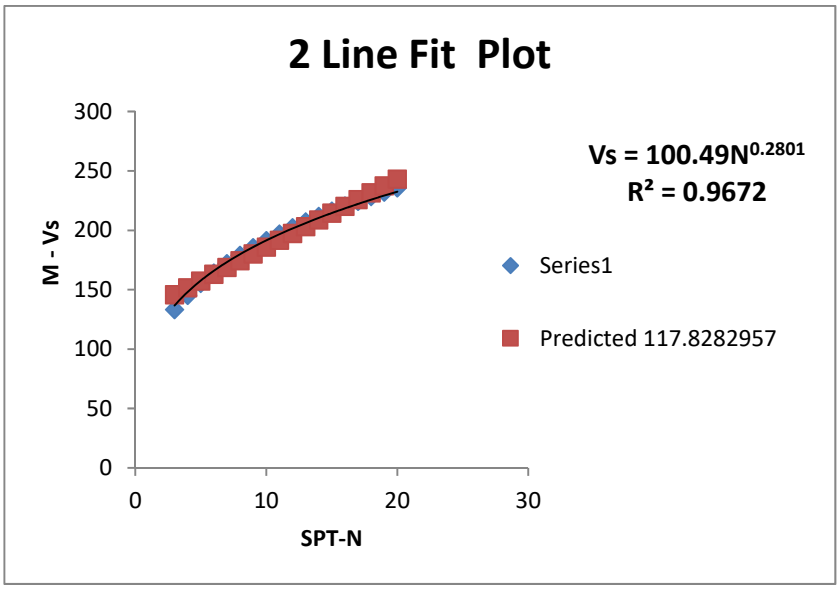


Figure (4). New Correlation between Vs and SPT-N for all soils based on observed data.

## Conclusions

New empirical relationship between SPT-N and Vs of all soils has been determined based on considering 50 pairs-data of different sites by using regression analysis. The new correlation for all soils taken together is almost at average values of observed data and comparable with the previous equations of other researchers from all over the world. The coefficient of determination ($R^2$) is used to analyze how difference in two variable such as input and output results. $R^2$ range must be 0 to 1 i.e, 0% to 100% probability of the two sets of variables. According to coefficient of determination ($R^2$) value, the new regression equations give good prediction performances for all soils of the study area. The present correlations are reliable as other relations in different countries. Our present equation can easily be used to find shear wave velocity (Vs) if often N values are readily available. Moreover, the present results can be effectively used for evaluating earthquake related hazard especially liquefaction potential analysis of the study area.

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## 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