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Development of Empirical Correlations Between Shear Wave Velocity and Standard Penetration Value: A Case Study of Rajshahi District, Bangladesh

Md Ashikuzzaman[1, 3, *], Md Shakil Ar Salan[2], Md Ashikur Rahman[3], Md Mahmudul Hasan[3]

[1]Department of Civil Engineering, Zhejiang University, Hangzhou, China,

[2]Urban Planner, Committed Development Limited (CDL), Rajshahi, Bangladesh

[3]Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Email address:

ashik.amjr120116@gmail.com (Md Ashikuzzaman), shakil.ruet@hotmail.com (Md S. Ar Salan), ashikurrahmanruet13@gmail.com (Md A. Rahman), mahmudulhp13@gmail.com (Md M. Hasan)

[*]Corresponding author

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Abstract: In seismic response investigation, shear wave velocity, Vs shows a vigorous role as an input factor. Enormous methodologies have been developed and tested to directly determine this key factor. Direct measurement of V_s is time-consuming as well as highly expensive. As a result, researchers from different regions have tried to reduce the difficulties associated with the measurement and developed empirical relationships between V_S and other geotechnical characteristics of the soil, such as SPT calculation, depth, vertical effective pressure, etc. In this paper, the empirical correlation between shear wave velocity and standard penetration number (SPT-N) has been investigated for several soil categories: all soils, sand, silt and clay-type soils. Study area selected for this analysis are Bagha, Bagmara, Charghat, Durgapur, Godagari, Paba, Puthia, Tanore and Rajshahi City Corporation (RCC) area consisting of 36 borehole dataset. Combining all the data, an approach is made to correlate the Vs with the SPT-N. The square value of the coefficient (R^2) of correlation shows good agreement with the subsoil. Regression analysis is used to propose an empirical relation for this zone which would be helpful for foundation engineers to have the idea on earthquake response analysis of subsoil.

Keywords: Standard Penetration Test (SPT)-N, Shear Wave Velocity, Regression Analysis

1. Introduction

Shear wave velocity (Vs) is the significant parameter for the dynamic characterization and analysis of subsurface. Field measurement of such parameter is expensive as well as time consuming. Vs is estimated as field study and laboratory investigation by using empirical correlations. Laboratory investigation is worked out to determine shear wave velocity with SPT-N value. SPT-N value is locally and internationally available and can be determined very easily in the field.

In the current study, a set of correlation equations between standard penetrations tests (SPT-N values) and shear wave velocity (Vs) for different groups of soils is established for Rajshahi district, Bangladesh. Rajshahi District located in north-western part of Bangladesh beside Padma River. It is a part of the Rajshahi Division and third largest city of Bangladesh. Rajshahi district is divided into 9 Upazila named: Bagha, Bagmara, Charghat, Durgapur, Godagari, Paba, Puthia, Tanore and Rajshahi City Corporation (RCC). Study area selected for this analysis are shown in figure 1.

Empirical correlations have three different advantages i.e., convenience, efficiency and economy. Empirical correlations have been used worldwide but before using it should be checked against validation because these equations are site dependent and some researchers have tried to formulate the equations which may be applicable for all region [1, 2]. This analytical research deals with the development of empirical correlations between Vs and SPT-N for different upazillas of Rajshahi and finally for Rajshahi District (RD) collecting four borehole profile from each Upazila, a total of 36 borehole profile.

2. Development of Empirical Correlations

For evaluation of shear wave velocities and associated geotechnical parameters, the following a power-equation model is practiced widely:

$$V_S = AN^B \tag{1}$$

Where, A is a constant controlling the amplitude, N is the uncorrected SPT value and B is another constant depending on curvature relationship. Also, it is to be noted here, other factors such as depth, overburden pressure, geological age, fine content and soil types which may also govern or modify the relationships has-not been included in this study.

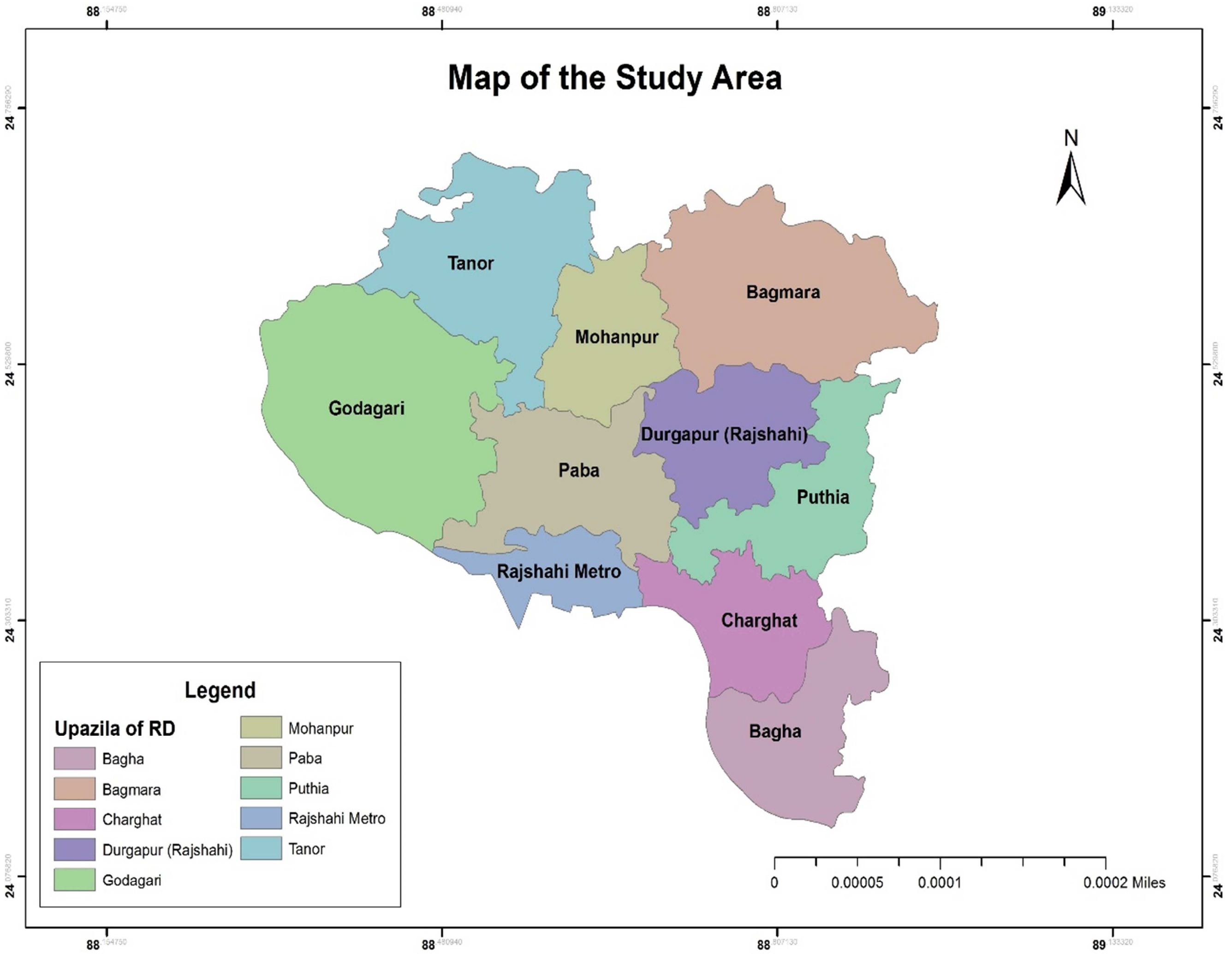

Figure 1. *Study Area (Rajshahi District).*

In the present world, Earthquake hazards is one of the crucial issue and Vs in this issue has intensive power to evaluate assessment of any area. Four borehole profiles from each areas in total 36 were utilized for the graphical presentation of existing relations (table 1) with the help of Microsoft Excel 2013. Regression analysis in terms of R squared value is carried out to establish and check the accuracy of the equation for every selected areas for all soils, sands, clays and silts as a power law form (Vs= AN^B). Then, taking all the SPT-N values from these areas (varies from 1 to 49) were plotted for Rajshahi District.

Table 1. *Existing correlations between shear wave velocity and standard penetration number (SPT-N).*

Author(s)	**Shear Wave Velocity, Vs**			
	All Soils	**Sands**	**Clays**	**Silts**
Ohba and Toriumi (1970) [3]	V_s= $84N^{0.31}$	--	--	--
Imai and Yoshimura (1970) [4]	V_s= $76N^{0.33}$	--	--	--
Fujiwara (1972) [5]	V_s= $92.1N^{0.337}$	--	--	--
Ohsaki and Iwasaki (1973) [6]	V_s= $82N^{0.39}$	V_s= $59.4N^{0.47}$	--	--
Imai and Tonouchi (1982) [7]	V_s= $91N^{0.337}$	V_s= $80.6N^{0.331}$	V_s= $80.2N^{0.292}$	--
Ohta and Goto (1978) [8]	V_s= $85.35N^{0.348}$	V_s= $88N^{0.34}$	--	--
Seed and Idriss (1981) [9]	V_s= $61N^{0.5}$	--	--	--
Imai and Tonouchi (1982) [7]	V_s= $97N^{0.314}$	--	--	--
Sykora and Stoke (1983) [10]	--	V_s= $100.5N^{0.29}$	--	--
Jinan (1987) [11]	V_s= $116.1\ (N+0.3185)^{0.202}$	--	--	--
Lee (1990) [12]	--	V_s= $57.4N^{0.49}$	V_s= $114.43N^{0.31}$	V_s= $105.6N^{0.32}$
Sisman (1995) [13]	V_s= $32.8N^{0.51}$	--	--	--
Iyisan (1996) [14]	V_s= $51.5N^{0.516}$	--	--	--
Jafari et al. (1997) [15]	V_s= $22N^{0.85}$	--	--	--
Kiku et al. (2001) [16]	$68.3N^{0.292}$	--	--	--
Jafari et al. (2002) [17]	--	V_s= $19N^{0.85}$	V_s= $27N^{0.73}$	V_s= $22N^{0.77}$
Kanai (1996) [18]	V_s= $19N^{0.6}$	--	--	--
Shibata (1970) [19]	--	V_s= $32N^{0.5}$	--	--
Ohta et al. (1972) [20]	--	V_s= $87N^{0.36}$	--	--
Dikmen (2009) [21]	V_s= $58N^{0.39}$	V_s= $73N^{0.33}$	V_s= 44N0.48	V_s= $60N^{0.36}$
Athanasopoulos (1995) [22]	V_s= $107.6N^{0.36}$	--	V_s= $76.55N^{0.445}$	--
Okamoto et al. (1989) [23]	--	V_s= $125N^{0.3}$	--	--
Kalteziotis et al. (1992) [24]	V_s= $76.2N^{0.24}$	--	V_s= $76.6N^{0.45}$	--
Hanumanthrao and Ramana (2008) [25]	V_s= $82.6N^{0.43}$	V_s= $86N^{0.42}$	--	--
Hasancebi and Ulusay (2007) [26]	V_s= $90N^{0.309}$	V_s= $90.82N^{0.319}$	V_s= $97.89N^{0.269}$	--
Tsiambaos and Sabatakakis (2010) [27]	--	--	--	V_s= $99.45N^{0.364}$
Chatterjee and Choudhury (2013) [28]	--	--	--	V_s= $58N^{0.455}$
Lee (1988) [29]	--	--	--	V_s= 135.67+9.11N
Lee (1988) [29]	--	--	--	V_s= $100N^{0.38}$
Uma Maheswari et al. (2010) [30]	V_s= $95.641N^{0.3013}$	V_s= $100.53N^{0.265}$	V_s= $89.31N^{0.358}$	--
Pitilakis et al. (1992) [31]	V_s= $162N^{0.17}$	--	V_s= $165.7N^{0.19}$	--
JRA (1980) [32]	--	V_s= $80N^{0.33}$	V_s= $100N^{0.33}$	--
Fatehnia et al. (2015) [33]	--	V_s= $77.1N^{0.355}$	V_s= $77.1N^{0.355}$	--
Esfehanizadeh et al. (2015) [34]	--	V_s= $107.2N^{0.34}$	--	--
Chien et al. (2000) [35]	--	V_s= $22N^{0.76}$	--	--
Raptakis et al. (1995) [36]	--	V_s= $100N^{0.24}$	V_s= $184.2N^{0.17}$	--
Yokota et al. (1991) [37]	V_s= $121N^{0.27}$	--	--	--
Imai and Yoshimura (1976) [38]	V_s= $92N^{0.329}$	--	--	--
Mhaske and Choudhury (2011) [39]	V_s= $72N^{0.40}$	--	--	--
Sykoro and Stokoe (1983) [10]	V_s= $100.5N^{0.329}$	--	--	--

3. Results and Discussion

It is noticeable from the table that, researchers have given correlations on four distinct category: (a) All soils, (b) Sands, (c) Clay and (d) Silt. Using these correlations given in table 1, following graphs are plotted according to the collected bore log SPT data for Bagha Upazila. Along with graphs, equations and corresponding R^2 value for each category has also been incorporated here.

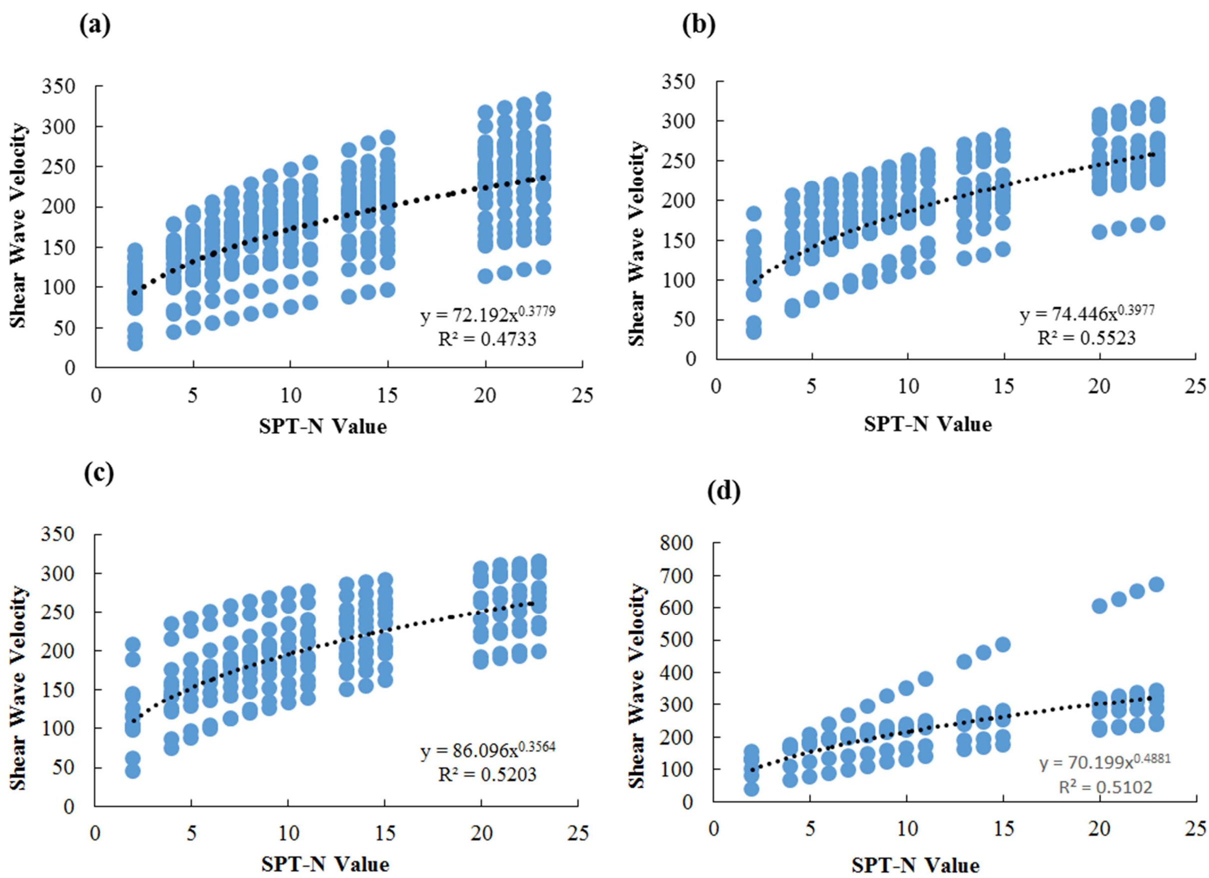

***Figure 2.** Shear wave velocity and SPT correlations for Bagha Upazila.*

Now, same analysis is performed for other soil profile located in other Upazila and their analysis findings are shown in the following table:

***Table 2.** Shear wave velocity equation and corresponding R^2 value for study area.*

Study Area	Type of soil	Equation	R^2 value
Bagha	All soils	$V_s = 72.192N^{0.3779}$	0.4733
	Sands	$V_s = 74.446N^{0.3977}$	0.5523
	Clays	$V_s = 86.096N^{0.3564}$	0.5203
	Silts	$V_s = 70.199N^{0.4881}$	0.5102
Bagmara	All soils	$V_s = 72.189N^{0.3779}$	0.5613
	Sands	$V_s = 74.446N^{0.3977}$	0.6345
	Clays	$V_s = 85.475N^{0.3603}$	0.6092
	Silts	$V_s = 69.61N^{0.4933}$	0.5944
Charghat	All soils	$V_s = 72.198N^{0.3779}$	0.4555
	Sands	$V_s = 74.446N^{0.3977}$	0.5389
	Clays	$V_s = 86.329N^{0.355}$	0.5031
	Silts	$V_s = 70.64N^{0.4851}$	0.4884
Durgapur	All soils	$V_s = 72.211N^{0.3779}$	0.6837
	Sands	$V_s = 74.446N^{0.3977}$	0.7505
	Clays	$V_s = 85.202N^{0.3655}$	0.738
	Silts	$V_s = 70.375N^{0.493}$	0.6877
Godagari	All soils	$V_s = 72.185N^{0.378}$	0.5835
	Sands	$V_s = 74.446N^{0.3977}$	0.6728
	Clays	$V_s = 84.39N^{0.3671}$	0.6553
	Silts	$V_s = 69.1N^{0.497}$	0.6085
Paba	All soils	$V_s = 72.192N^{0.3779}$	0.4796
	Sands	$V_s = 74.446N^{0.3977}$	0.5594
	Clays	$V_s = 86.037N^{0.3567}$	0.5276
	Silts	$V_s = 70.147N^{0.4886}$	0.516

Study Area	Type of soil	Equation	R^2 value
Puthia	All soils	$V_s = 72.199N^{0.3779}$	0.4229
	Sands	$V_s = 74.446N^{0.3977}$	0.4799
	Clays	$V_s = 86.481N^{0.3539}$	0.4491
	Silts	$V_s = 71.033N^{0.4817}$	0.4639
RCC	All soils	$V_s = 72.223N^{0.3778}$	0.5969
	Sands	$V_s = 74.446N^{0.3977}$	0.6467
	Clays	$V_s = 86.593N^{0.3552}$	0.6196
	Silts	$V_s = 71.626N^{0.4811}$	0.6173
Tanore	All soils	$V_s = 72.191N^{0.3779}$	0.5121
	Sands	$V_s = 74.446N^{0.3977}$	0.6007
	Clays	$V_s = 84.726N^{0.3653}$	0.5796
	Silts	$V_s = 69.983N^{0.4902}$	0.5427

From table, taking "all soils" category into account, representative correlation for subsoil of Bagha Upazila is given by the equation $V_s = 72.192N^{0.3779}$ having R^2 value of 0.4733. For the estimated correlations, the co-efficient of determination (R^2) is found to be relatively low; this may be due to limited data pairs. Similarly, among the derived correlations for Bagmara, Charghat, Durgapur, Godagari, Paba, Puthia, RCC and Tanore Upazila, R^2 values are given as 0.5613, 0.4555, 0.6837, 0.5835, 0.4796, 0.4229, 0.5969 and 0.6007 respectively. Also, considering soil profiles as sandy, clayey or silty, derived correlations along with their R^2 value would possibly be an important geological parameter for this zone.

Now, considering all the SPT data (36 Borehole profile) collected from nine different Upazila, graphs are plotted to find overall correlations for Rajshahi District. Using the correlations given in table 1, graphs are plotted on the basis of four distinct category sated earlier. Governing equation along with R squared values are incorporated here also. Analysis results are shown in tabular format below:

Table 3. *Shear wave velocity equation and corresponding R^2 value for Rajshahi District.*

Name of the area	Types of soil	Equation	R squared value
Rajshahi District	All soils	$V_s = 72.202N^{0.3779}$	0.6256
	Sands	$V_s = 74.446N^{0.3977}$	0.7261
	Clays	$V_s = 85.558N^{0.362}$	0.7028
	Silts	$V_s = 69.644N^{0.4956}$	0.6293

4. Conclusions

The developed correlations relating shear wave velocity with SPT value is entirely based on SPT data set available. To quantify liquefaction assessment of the studied area shear wave velocity equations proposed in this study will play a significant role. From the present study, several conclusions can be drawn:

1) The proposed and developed equations are only applicable for the selected areas and Rajshahi District.
2) Number of borehole data set play a dominant role in the estimation of Shear wave velocity. More the number of borehole dataset would give more the accuracy of the regression curves.
3) Using as many equations also give more accuracy curve for the estimation of Vs.
4) The R^2 value shows good agreement with soil type's sand and clay. On the contrary, it also can be shown considering intermediate soil strata.

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