Empirical Correlation between Shear Wave Velocity (V_s) and Uncorrected Standard Penetration Resistance (SPT-N) for Dinajpur District, Bangladesh

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Keywords

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Abstract

In seismic analysis, shear wave velocity (V_s) is a valuable parameter for measuring the site effect of earthquake microzonation. Various methods have been explored to measure this key factor directly. Since measuring shear wave velocity directly is time consuming and expensive, researchers in various regions have been attempting to update empirical relationships between shear wave velocity (V_s) and other soil geotechnical properties such as SPT blow count, depth, vertical effective stress and so on. Geophysical tests associated with direct methods are not feasible in developing countries like Bangladesh, so the indirect method is more important. Due to the location of a fault line nearby, the Dinajpur district has previously undergone anomalous earthquakes. As a result, site characterization is important for enhancing seismic design considerations. Focused on an indirect approach, this paper mainly aims to propose a general correlation between shear wave velocity and standard penetration number in 13 upazilas of Dinajpur district for four soil categories ("all soils", sand, clay, and silt). Finally, an approach was developed to find the overall correlations for the Dinajpur district by combining all of the data. The regression coefficient (R^2) values were observed to vary in between 0.04416-0.6134 for "all soils", 0.0593-0.668 for sand, 0.5911-0.7149 for clay and 0.5547-0.6794 for silt. The correlations obtained in this study can be used for seismic hazard analysis in both the study region and other areas with identical soil strata.

1. Introduction

Shear wave velocity (V_s) is the key parameter for determining the interaction of soil dynamic properties. It also aids in the identification of a site and the investigation of subsurface conditions. Direct field measurement of such a parameter is extremely complex, costly and time-consuming. Shear wave velocity (V_s) is estimated directly in field study and laboratory investigation by using empirical correlations. Of all the approaches, indirectly determining shear wave velocity through empirical correlations between V_s and SPT-N value is the most efficient [1].

The correlation of shear wave velocity (V_s) and SPT-N value began in the early 1970s, based on a variety of data sets obtained throughout Japan. Empirical relations were established using about 300 data obtained from characterization of alluvial deposits in Japan, taking into account all four indices: SPT-N, depth from the ground surface, geological age, and soil content [1]. The best relationships were achieved using uncorrected SPT-N values [2]. Majority of the relations have used uncorrected SPT-N values for regression correlation study [3].

Empirical regression equations have been used all around the world. Before applying to the design purposes, this proposed equation needs to be validated first because they are especially site dependent. Convenience, performance, and cost savings are three major benefits of analytical regression equations [4].

Several Bangladeshi researchers have suggested various sets of regression correlations between SPT-N values and V_s for different seismically active regions. They also attempted to correlate V_s with different soil indices such as depth, soil type, and SPT-N value, among others [5,6].

In this current study, eight borehole profiles from each upazila have been collected, representing a total of 104 borehole profiles. A set of correlation equations have been developed for 13 upazilas of the Dinajpur district as well as the Dinajpur district of Bangladesh between the shear wave velocity (V_s) and SPT-N values of various categories of soils.

2. Study area and methodology

The Dinajpur district is situated in Bangladesh's northwestern province (between 25°10' and 26°04' north latitudes and 88°23' and 89°18' east longitudes). The district is one of the largest in the sixteen northern districts of Bangladesh. The topography of the area is typically level, with a gentle southerly slope toward which the major rivers, such as the Dhepa, Punarbhava, and Atrai, flow. Since Dinajpur is in the Terai basin, the soil is sandy in nature, with a much higher ratio of sand and silt than clay. Since there are many fault lines nearby (Bogra fault, Tripura fault, Sub Dauki fault, Shillong fault and Assam fault), this area is extremely vulnerable to earthquakes.

A map of the Dinajpur district is shown in Fig. 1. It is divided into 13 upazilas and is a part of the Rangpur Division. Kaharole, Khansama, Ghoraghat, Chirirbandar, Dinajpur Sadar, Nawabganj, Parbatipur, Fulbari, Biral, Birampur, Birganj, Bochaganj and Hakimpur are among these places. Birganj is the largest of Dinajpur's 13 upazilas.

Geotechnical investigation reports were collected from various government bodies, including the Local Government Engineering Department (LGED), the Public Works Department (PWD), and the Education Engineering Department (EED) in Dinajpur, Bangladesh, as well as private organizations, for this research. The aim of this study is to establish statistical relationships between shear wave velocity and standard penetration number for distinct upazilas of Dinajpur district. To meet the target, eight borehole profiles were collected from each upazila, for a total of 104 borehole profiles.

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

Author (s)	Shear Wave Velocity, V_s (m/s)			
	All soils	Sand	Clay	Silt
Kanai (1996) [7]	$V_s=19N^{0.6}$			
Imai and Yoshimura (1970) [8]	$V_s=76N^{0.33}$			
Ohba and Toriumi (1970) [9]	$V_s=84N^{.31}$			
Fujiwara (1972) [10]	$V_s=92.1N^{.337}$			
Ohsaki and Iwasaki (1973) [11]	$V_s=81.4N^{.39}$	$V_s=59.4N^{0.47}$		
Imai et al. (1975) [12]	$V_s=89.9N^{.341}$			
Imai (1977) [13]	$V_s=91N^{.337}$	$V_s=80.6N^{.331}$	$V_s=102N^{.292}$	
Ohta and Goto(1978) [1]	$V_s=85.35N^{.348}$	$V_s=88N^{.34}$		
Seed and Idriss (1981) [14]	$V_s=61.4N^{.5}$			
Imai and Tonouchi (1982) [15]	$V_s=97N^{.314}$			$V_s=97N^{.314}$
Jinan (1987) [16]	$V_s=116.1(N+.3185)^{.202}$			$V_s=116.1(N+.3185)^{.202}$
Yokota et al. (1981) [17]	$V_s=121N^{.27}$			
Kalteziotis et al (1992) [18]	$V_s=76.2N^{.24}$	$V_s=49.1N^{.5}$	$V_s=76.6N^{.45}$	
Athanasopoulos (1995) [19]	$V_s=107.6N^{.36}$		$V_s=76.55N^{.445}$	
Sisman (1995) [20]	$V_s=32.8N^{.51}$			
Iyisan (1996) [21]	$V_s=51.5N^{.516}$			
Jafari et al. (1997) [30]	$V_s=22N^{.85}$			
Kiku et al. (2001) [22]	$V_s=68.3N^{.292}$			
Hasancebi and Ulusay (2007) [2]	$V_s=90N^{.309}$	$V_s=90.82N^{.319}$	$V_s=97.89N^{.269}$	
Hanumantharao and Ramana (2008) [4]	$V_s=82.6N^{.43}$	$V_s=79N^{.434}$		
Dikmen (2009) [23]	$V_s=58N^{.39}$	$V_s=73N^{.33}$	$V_s=44N^{.48}$	$V_s=60N^{.36}$
Fumal and Tinsley (1985) [24]	$V_s=(5.3N+134)$	$V_s=(5.1N^{0.27}+152)$		
Uma Maheswarier al. (2010) [25]	$V_s=95.641N^{.3013}$	$V_s=100.53N^{.265}$	$V_s=89.31N^{.358}$	
Anbazhagan et al. (2012) [26]	$V_s=68.96N^{.51}$	$V_s=60.17N^{.56}$	$V_s=106.63N^{.39}$	
Sitharam and Anbazhagan(2013)[27]	$V_s=78(N_{60})^{.4}$			
Imai and Yoshimura (1976) [28]	$V_s=92N^{.329}$			
Lee and Tsai (2008) [29]	$V_s=137.153N^{.229}$			
Tsaimbaos and Sabatakakis (2011) [3]	$V_s=105.7N^{.327}$			$V_s=99.45N^{.364}$
Jafari et al. (1997) [30]	$V_s=121N^{.270}$			
Shibata[31]		$V_s=32N^{.5}$		
Ohta et al. (1978) [1]		$V_s=87N^{.36}$		
JRA (1980) [32]		$V_s=80N^{.33}$	$V_s=100N^{.33}$	
Seed et al. (1981) [14]		$V_s=56.4N^{.5}$		
Sykora and Stokoe (1983) [33]		$V_s=100.5N^{.29}$		
Okamoto et al. (1989) [34]		$V_s=125N^{.3}$		
Lee (1990) [35]		$V_s=57.4N^{.49}$	$V_s=144.43N^{.31}$	$V_s=105.6N^{.32}$
Raptakis et al. (1995) [36]		$V_s=100N^{.24}$	$V_s=184.2N^{.17}$	
Chien et al. (2000) [37]		$V_s=22N^{.76}$		
Tsaimbaos and Sabatakakis (2011) [3]		$V_s=79.7N^{.365}$	$V_s=88.8N^{.37}$	
Lee and Tsai (2008)[29]		$V_s=98.07N^{.305}$	$V_s=163.15N^{.192}$	
Pitilakis et al. (1999) [38]		$V_s=145N^{.178}$	$V_s=132(N_{60})^{.271}$	
Pitilakis et al. (1992) [39]		$V_s=162N^{.17}$		
Kayabali (1996) [40]		$V_s=175+3.5N$		
Jafari et al. (2002)[41]		$V_s=19N^{.85}$	$V_s=27N^{.73}$	$V_s=22N^{.77}$
Ohsaki and Iwasaki (1973)[11]		$V_s=59.4N^{.47}$		
Imai (1977) [42]		$V_s=80.6N^{.331}$	$V_s=102N^{.292}$	
Ohta and Goto (1978)[1]		$V_s=88N^{.34}$	$V_s=100N^{.33}$	
Kalteziotis et al. (1992) [18]		$V_s=49.1N^{.5}$	$V_s=76.6N^{.45}$	
Chatterjee and Choudhury (2013) [43]				$V_s=58N^{.455}$
Lee (1988) [44]				$V_s=135.67+9.11N$
Lee (1988) [44]				$V_s=100N^{.38}$

When it comes to determine shear wave velocity and related geotechnical parameters, the following power equation model is commonly used [4].

$$V_s = AN^B \dots\dots\dots (1)$$

In equation (1), 'A' is a constant controlling the amplitude, 'N' is the uncorrected SPT value, 'B' is another constant depending on curvature relationship. Other variables that may affect the equation, such as depth, overburden pressure, fine content, geologic age and soil types, were not included in this analysis.

From a large number of correlations between shear wave velocity and SPT-N value, fifty-one correlations were chosen for this study. Researchers have provided correlations for four distinct categories: "all soils", sand, clay and silt as shown in Table 1. Uncorrected SPT-N values were used to establish all of these correlations.

With the support of Microsoft Excel 2010, eight borehole profiles from each region were used to create a graphical presentation of current relationships. To define and verify the consistency of the equations for "all soils", sand, clay and silt as a power law model ($V_s = AN^B$), regression analysis in terms of R squared (R^2) value was carried out for each upazila. Then, for Dinajpur district, all of the SPT-N values (which range from 1 to 57) were used to develop correlatio

Figure 1. Map of the study area

3. Results and discussions

Table 1 summarizes the existing correlations and reveals four soil classifications: "all soils", sand, clay and silt. Applying the correlations, the following graphs are plotted using collected bore log SPT data for Birampur upazila on the basis of four distinct categories. The correlations between V_s and SPT-N value for Birampur upazila are shown in Fig.2.

Figure 2. Shear wave velocity (V_s) and SPT-N value correlations for Birampur Upazila

For Birampur upazila of Dinajpur district, the graphical representation depicts the shear wave velocity-SPT-N value relationship for "all soils," sand, clay, and silt type soil. $V_s = 76.042N^{0.3756}$ has an R^2 value of 0.5377 and is the governing equation for "all soils". The governing equation for sandy soil is $V_s = 75.655N^{0.3769}$, with an R^2 value of 0.6212. Governing equation for clay soil category is $V_s = 91.573N^{0.3591}$ and corresponding R^2 value is 0.6666. $V_s = 75.655N^{0.3769}$, is the governing equation for silt soil category, with an R^2 value of 0.6212.

Correlations between shear wave velocity and SPT are also carried out in the same way for other soil profiles in other upazilas, as shown in Table 2.

Table 2. Shear wave velocity equation and corresponding R^2 value for 13 upazilas of Dinajpur district

Study Area	Type of Soil	Equations	R^2 value
Birampur	All soils	$V_s = 76.042N^{0.3756}$	0.5377
	Sand	$V_s = 75.655N^{0.3769}$	0.6212
	Clay	$V_s = 91.573N^{0.3591}$	0.6666
	Silt	$V_s = 68.007N^{0.444}$	0.6305
Birganj	All soils	$V_s = 76.066N^{0.3752}$	0.5158
	Sand	$V_s = 75.649N^{0.3768}$	0.6061
	Clay	$V_s = 91.573N^{0.3591}$	0.6542
	Silt	$V_s = 67.89N^{0.4445}$	0.619
Bochaganj	All soils	$V_s = 76.054N^{0.3753}$	0.5335
	Sand	$V_s = 75.637N^{0.3769}$	0.6186
	Clay	$V_s = 91.573N^{0.3591}$	0.6628
	Silt	$V_s = 67.853N^{0.4448}$	0.6315
Biral	All soils	$V_s = 76.281N^{0.3743}$	0.5611
	Sand	$V_s = 75.816N^{0.3761}$	0.637
	Clay	$V_s = 91.573N^{0.3591}$	0.685
	Silt	$V_s = 68.815N^{0.4402}$	0.6499
Chirirbandar	All soils	$V_s = 75.985N^{0.3757}$	0.5308
	Sand	$V_s = 75.568N^{0.3773}$	0.6162
	Clay	$V_s = 91.573N^{0.3591}$	0.6748
	Silt	$V_s = 67.606N^{0.4465}$	0.6357
Dinajpur Sadar	All soils	$V_s = 75.97N^{0.3761}$	0.588
	Sand	$V_s = 75.526N^{0.3778}$	0.6529
	Clay	$V_s = 91.573N^{0.3591}$	0.7229
	Silt	$V_s = 67.634N^{0.4476}$	0.6813
Fulbari	All soils	$V_s = 75.623N^{0.3772}$	0.4478
	Sand	$V_s = 75.269N^{0.3786}$	0.5493
	Clay	$V_s = 91.573N^{0.3591}$	0.619
	Silt	$V_s = 66.137N^{0.4533}$	0.5739
Ghoraghat	All soils	$V_s = 76.591N^{0.3729}$	0.6134
	Sand	$V_s = 76.044N^{0.3751}$	0.668
	Clay	$V_s = 91.573N^{0.3591}$	0.7149
	Silt	$V_s = 70.159N^{0.4335}$	0.6794
Hakimpur	All soils	$V_s = 75.749N^{0.3768}$	0.5139
	Sand	$V_s = 75.364N^{0.3783}$	0.5987
	Clay	$V_s = 91.573N^{0.3591}$	0.6741
	Silt	$V_s = 66.675N^{0.4514}$	0.6285
Kaharole	All soils	$V_s = 76.265N^{0.3745}$	0.5904
	Sand	$V_s = 75.798N^{0.3763}$	0.6566
	Clay	$V_s = 91.573N^{0.3591}$	0.7069
	Silt	$V_s = 68.764N^{0.441}$	0.6735
Khansama	All soils	$V_s = 76.024N^{0.3752}$	0.4416
	Sand	$V_s = 75.629N^{0.3768}$	0.5493
	Clay	$V_s = 91.573N^{0.3591}$	0.5911
	Silt	$V_s = 67.675N^{0.4448}$	0.5547

Study Area	Type of Soil	Equations	R ² value
Nawabganj	All soils	$V_s = 76.279N^{0.3744}$	0.5635
	Sand	$V_s = 75.809N^{0.3762}$	0.6388
	Clay	$V_s = 91.573N^{0.3591}$	0.6918
	Silt	$V_s = 68.823N^{0.4405}$	0.6554
Parbatipur	All soils	$V_s = 75.813N^{0.3764}$	0.4925
	Sand	$V_s = 75.432N^{0.3779}$	0.5887
	Clay	$V_s = 91.573N^{0.3591}$	0.6442
	Silt	$V_s = 66.885N^{0.4497}$	0.6067

As shown in the table above, the regression coefficient values for Dinajpur sadar and Ghoraghat upazila are higher in all categories. Whereas, the regression coefficient values in Khansama and Fulbari upazilas are smaller. This may be due to a lack of data pairs, as well as other variables that could influence the equation, such as depth, overburden pressure, fine content, geologic age and soil types, which were not taken into account in this study.

Table 3. Shear wave velocity equation and corresponding R² value for Dinajpur District

Name of the Area	Types of Soil	Correlations	Value of R ²
Dinajpur District	All soils	$V_s = 76.285N^{0.3746}$	0.6246
	Sand	$V_s = 75.772N^{0.3768}$	0.6755
	Clay	$V_s = 91.573N^{0.3591}$	0.7478
	Silt	$V_s = 68.951N^{0.4493}$	0.7031

Since there aren't any established correlates or field measurement results, comparisons are made with statistical correlations from other parts of Bangladesh[5,6]. For each soil condition, the consistency of newly formed correlations is portrayed. The established correlations for distinct upazilas, as well as the R² value, could provide a fair picture of the dynamic characteristics of subsurface soil deposits for estimating site effects.

Finally, graphs are plotted to determine general relationships for the Dinajpur District, taking into account all uncorrected SPT-N values (from 104 Borehole profiles) obtained from 13 distinct upazilas. Now, using the correlations listed in Table 1, graphs are plotted based on the four distinct categories mentioned earlier. For Dinajpur District, Table 3 shows the relationship between shear wave velocity and SPT-N value.

4. Conclusions

The newly established statistical correlations are focused solely on the SPT data collection that is currently available. Just three of the 52 correlations had an R² value of less than 0.50, according to regression analysis. This reflects the findings' accuracy. The following are some of the findings of this study:

- In the Dinajpur district, the highest correlation is observed for clay, with an R² value of 0.7478. With the exception of clay, the coefficient of regression value for the other types of soil ("all soils", sand, and silt) ranges from 0.6246 to 0.7031.
- In order to estimate shear wave velocity, the number of borehole data sets is vitally important. The more borehole datasets there are, the more accurate the regression curves would be. Owing to a shortage of data, number of equations used and other factors, some coefficients were smaller.
- By estimating V_s from SPT blow count, the regression equation produced provides a feasible alternative to actual field measurements, which can be used for preliminary seismic microzonation and seismic site response for the study area.

- Just the 13 upazilas and Dinajpur district are covered by the proposed equations. It may also be applied to areas with identical soil strata to the current one.

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Nomenclature

V_s: Shear wave velocity

G: Shear modulus

ρ: Density

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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