Comparison between Results of Dynamic Properties of Soil for Different Site Conditions Based on Seismic Cross hole test and SPT

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Abstract. The relationship between Standard Penetration Tests (N) and Shear wave Velocity (Vs) was investigated at different Power Plant sites located in West Bengal, Bihar, Andhra Pradesh and Bangladesh**.** This paper presents a development of correlation for all soils between shear wave velocity (Vs) and Standard penetration Test (N).

A total of minimum 30 numbers of boreholes at each site were drilled to a maximum depth of 30.0m with SPT measurements. A total 2 number of Seismic cross hole tests per site were performed. The shear wave velocity was measured through Cross hole test. It was proven that the developed correlation falls within the range of other relations, developed by different researchers worldwide at various sites. A comparison with available relation are also presented. Their validation confirms the relevancy of the results carried though statistical assessment of data.

Keywords: Shear Wave Velocity, Standard Penetration Test, Cross hole Test

1 Introduction

Under dynamic load for the design of Geotechnical structures, the shear wave velocity determined from different geophysical methods play an important role. The shear wave velocity is considered as most reliable predictor for the seismic action study at the site. In particular, the shear wave velocity (Vs) obtained from Seismic cross hole test are used to obtained dynamic soil properties for seismic design and seismic performance evaluation.

The Geotechnical design codes recommend a combination of In-situ Penetration resistance Test and Laboratory Tests allowing for wide range of correlations. This present paper deals with the comparison of shear wave velocity obtained from Seismic cross hole test and Standard Penetration Test (N).

The first attempts to correlate shear wave velocity with SPT N value started in early 70s and were based on several datasets from different site with different soil conditions of Japan [10, 23, 29, 7, 24, and 11]. A careful analysis of available empirical correlations in the technical literature has been carried out. Table 1 reports the empirical equations relating SPT N value v/s Shear wave velocity.

Table 1. Significant features of existing empirical correlations between Vs and N

Reference	Material type	Formula	a	b	c
Imai and Yoshimura (1970)	All Soil	$Vs=aN^b$	76	0.330	
Ohba and Toriumi (1970)	All soils	$Vs=aN^b$	84	0.310	
Fujiwara (1972)	All soils	$Vs=aN^b$	92.1	0.337	
Ohsaki and Iwasaki (1973)	All soils	$Vs=aN^b$	81.4	0.390	
	All soils	$Vs=aN^b$	91	0.337	
Imai (1977)	Sand	$Vs=aN^b$	80.6	0.331	
	Clay	$Vs=aN^b$	102	0.292	
	All soils	$Vs=aN^b$	85.35	0.342	
Ohta and Goto (1978)	Sand	$Vs=aN^b$	88.40	0.333	
	Clay	$Vs=aN^b$	86.90	0.333	
Seed and Idriss (1981)	All soils	$Vs=aN^b$	61.40	0.50	
	All soils	$Vs=aN^b$	97	0314	
Imai and Tonouchi (1982)	Sand	$Vs=aN^b$	87.8	0.314	
	Clay	$Vs=aN^b$	107	0.274	
Jinan (1987)	All soils	$VS = a(c+N)^b$	116.1	0.202	
	Sand	$Vs=aN^b$	57.40	0.490	
Lee (1990)	Silt	$Vs=aN^b$	105.6	0.320	
	Clay	$Vs=aN^b$	114.0	0.310	
Yokota et al. (1991)	All soils	$Vs=aN^b$	121.0	0.270	
	Sand	$Vs=c+aN$	4.74		157.1
Lee (1992)	Silt	$Vs=a(N+1)^b$	104	0.334	
	Clay		138.4	0.242	
	All Soil		76.2	0.240	
Kalteziotis et al. (1992)	Sand/Silt	$Vs=aN^b$	49.1	0.502	
	Clay		76.55	0.445	
	All Soil		107.6	0.360	
Athanasopoulos (1994)	Sand	$Vs=aN^b$	85.30	0.420	
	Clay		121.7	0.330	
	Loose sand		123.0	0.290	
Raptakis et al. (1995)	Medium Sand	$Vs=aN^b$	100.0	0.240	
	Soft Clay		105.7	0.330	
	Stiff Clay		184.2	0.170	
Iyisan (1996)	All Soil	$Vs=aN^b$	51.50	0.516	
Pitilakis et al. (1999)	Sand/Silt	$Vs=aN_{60}^b$	145.0	0.178	
	Clay		132.0	0.271	

Jafari et al. (2002)	All Soil	$Vs=aN^b$	19	0.850
	Silt		22	0.770
	Clay		27	0.730
Hasançebi and Ulusay (2007)	All Soil	$Vs=aN^b$	90	0.309
	Sand		90.82	0.319
	Clay		97.89	0.269
Hanumantharao and Ramana (2008)	All Soil	$Vs=aN^b$	82.60	0.430
	Sand		79.0	0.434
	Silt		86.0	0.420
Koçkar and Akgün (2008)	All Soil	$Vs=aN^b$	56.94	0.428
Dikmen (2009)	All Soil	$Vs=aN^b$	58	0.390
	Sand		73	0.330
	Clay		44	0.480
	Silt		60	0.360
Maheswari et al. (2010)	All Soil	$Vs=aN^b$	95.64	0.301
Tsiambaos and Sabatakakis (2011)	All Soil	$Vs=aN_{60}^b$	105.7	0.327
	Sand		79.7	0.365
	Clay		112.2	0.324
	Silt		88.8	0.370
Present Study	All Soil	$Vs=aN^b$	79.95	0.361

Imai and Tonouchi (1982) [12] conducted about 1650 experimental points in Japan, revealing that shear wave velocity in clayey soil is higher than sands. In early 80s similar experiments were conducted in USA to evaluate the liquefaction susceptibility of marine and alluvial sand in California [28, 30, 31, 27, and 5].

In the last decade, for micro zonation study, increased the availability of shear wave velocity (Vs) measures according to the geographic location and soil type in Greece [18, 1, 26, 32, 13, 16, 8, 17, 6, 2, 9, 21, 3, 15]. Most of the empirical laws used for the data regression were power type, such as:

$$Vs= a*N^b \tag{1}$$

Where, Vs is the shear wave velocity at a specific depth and N is the number of blows of SPT at the same depth.

2 Geotechnical Investigation

The geotechnical investigations were carried out using standard penetration tests (SPT) according to IS 2131 and laboratory tests of the samples collected from all the Power plant sites located in West Bengal, Bihar, Andhra Pradesh and Bangladesh.

A comprehensive study was carried out to investigate the dynamic properties of soil. A total of minimum 30 numbers of boreholes at each site were drilled to a maximum depth of 30.0m with SPT measurements at every 1.0m to 1.5m depth.

The soil stratification in West Bengal and Bihar consists of thick clay deposit of depth 25.0m followed by dense sand. In Andhra Pradesh Power plant project the sub soil profile consist of Silty sand of depth 4.30m followed by Clay of depth 19.0m followed by Silty sand. In Bhola Project at one location the subsoil profile consists of Silty soil of depth 10.5m followed by Clay layer and at other location subsoil profile consists of Silty Sand soil up to depth of exploration. In Bibiyana South project the subsoil consists of soft clay of depth 9.0m followed by Sand. In Bibiyana III Project the subsoil consists of soft clay of depth 5.0m followed by Silt of depth 10.0m followed by Silty Sand and Soft clay of depth 5.0m and 4.0m, respectively.

Variation of SPT N value with depth for different sites is as shown in **Fig. 1**.

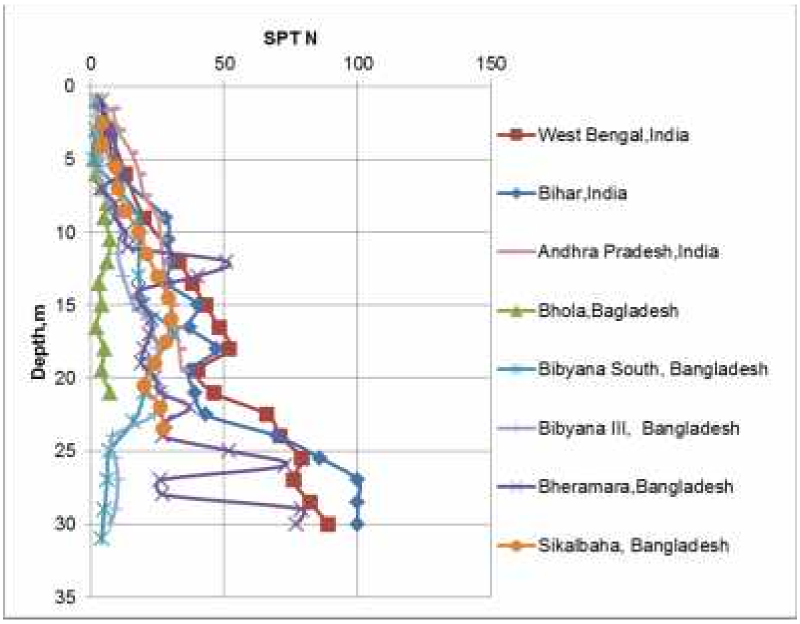

Fig. 1. Variation of Standard penetration test (N) with Depth for all sites

3 Geophysical Investigation

In order to estimate the strength of soil, SPT was found to be more popular among Geotechnical engineers. The Seismic cross hole method allows in-situ measurement of shear wave velocity with depth.

This test was carried out in accordance with ASTM D-4428 [4] to establish the dynamic elastic properties of soil and rock. In this test, the seismic waves are to be picked up in two adjacent receiver boreholes. The spacing of boreholes kept was about 3.0m. In each receiver borehole multiple geophones were provided at 2m interval (with starting depth as 1m below ground level) to cover the depth and various strata as specified. Intensity of the waves shall be recorded by multiple channel seismograph.

According to ASSHTO Guidelines for Seismic Design of Highway Bridges, soil is classified into six classes, A, B, C, D, E and F with reference to shear wave velocity.

Class A represents hard rock with measured VS> 600 m/s, while E and F classes represent soft to very soft soil with measured elastic properties for estimating the behavior of soil and rock under foundations

A total of two number of Cross hole tests per site were carried out. Variations of shear wave velocity (Vs) with depth for all the sites are shown in **Fig. 2**.

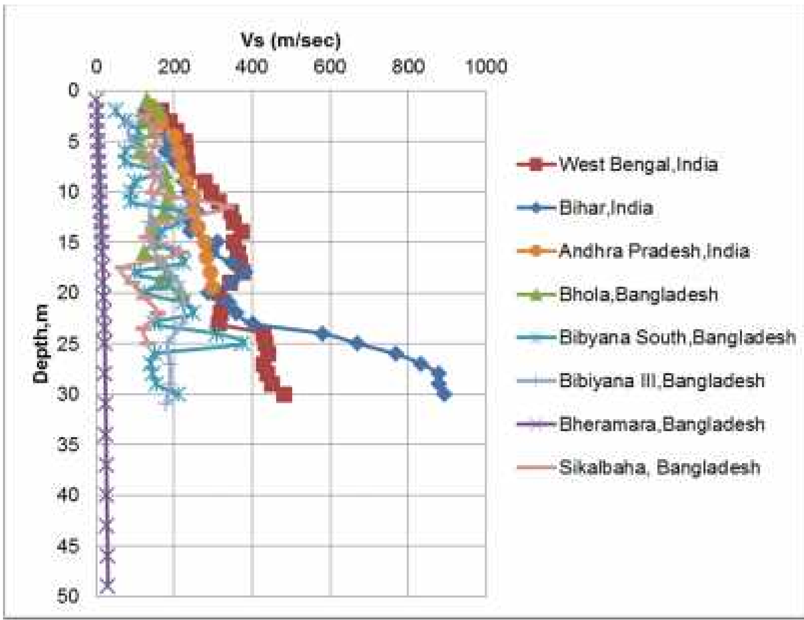

Fig. 2. Variation of Shear wave velocity (Vs) with Depth for all sites

4 Test Results and Discussion

For assessment, 3 locations from India and 5 locations from Bangladesh, in total 40 data pairs (Vs and N) were employed. In this study, using simple regression analysis the correlation between shear wave velocity (Vs) and Standard Penetration Test (N) was developed.

Fig. 2 shows the proposed correlation between Vs and N for all Soils.

$$Vs = 79.951 \text{ x } N^{0.3611} \quad (2)$$

This proposed relation has correlation coefficient R^2= 0.5221 which is reasonably a good value.

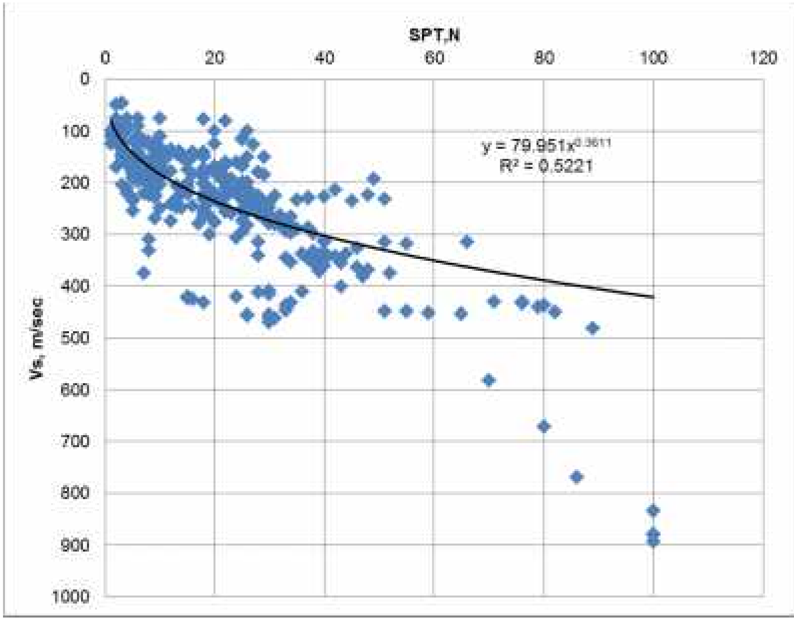

Fig. 3. Correlation between shear wave velocity (Vs) and Standard penetration test (N) for all Soils

The comparisons of the present study results were made with the equations developed by other researchers, as shown in **Table 1**. **Fig. 4**, **Fig. 5**, **Fig. 6**, **Fig. 7** and **Fig. 8** shows the comparison between the results obtained by Present study, Field test and results obtained by other researchers for different mentioned sites. It can be observed that the curve obtained from present study matches fairly well with the results obtained from field test.

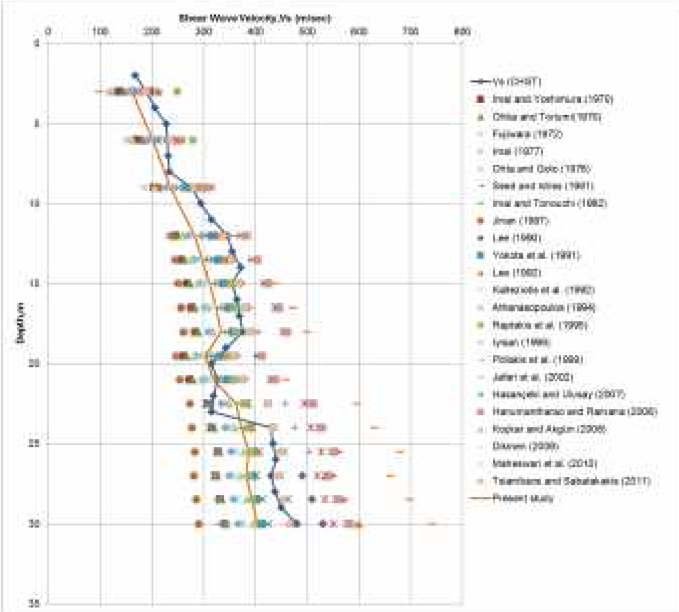

Fig. 4. Comparison of shear wave velocity and SPT N for West Bengal Power plant site

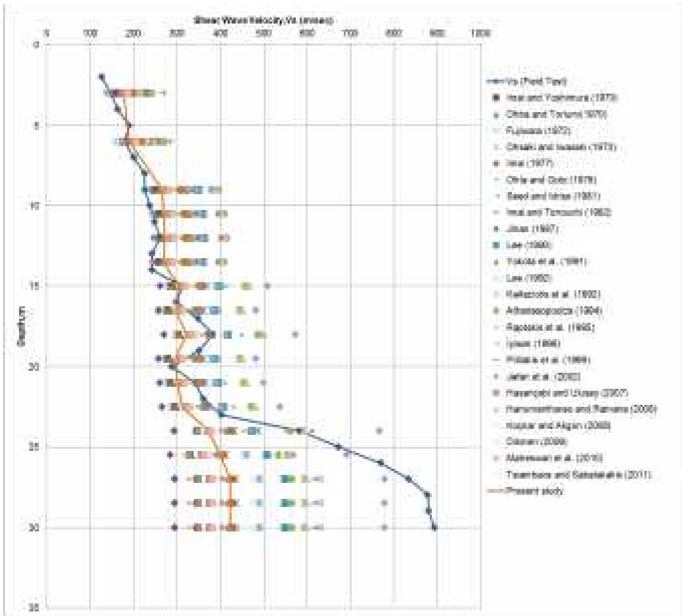

Fig. 5. Comparison of shear wave velocity and SPT N for Bihar Power plant site

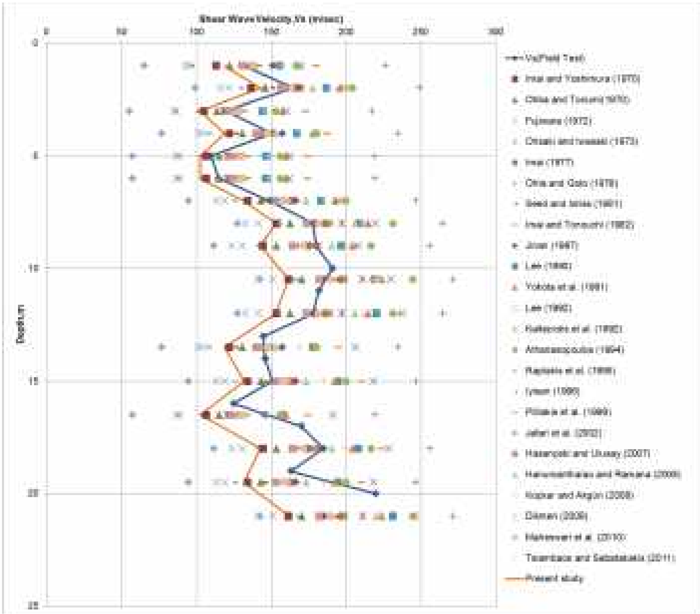

Fig. 6. Comparison of shear wave velocity and SPT N for Bhola, Bangladesh

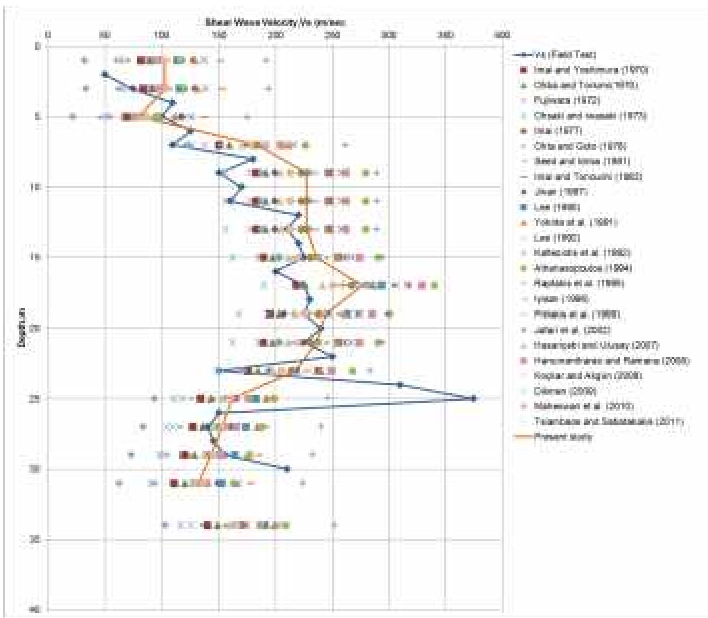

Fig. 7. Comparison of shear wave velocity and SPT N for Bibiyana South, Bangladesh

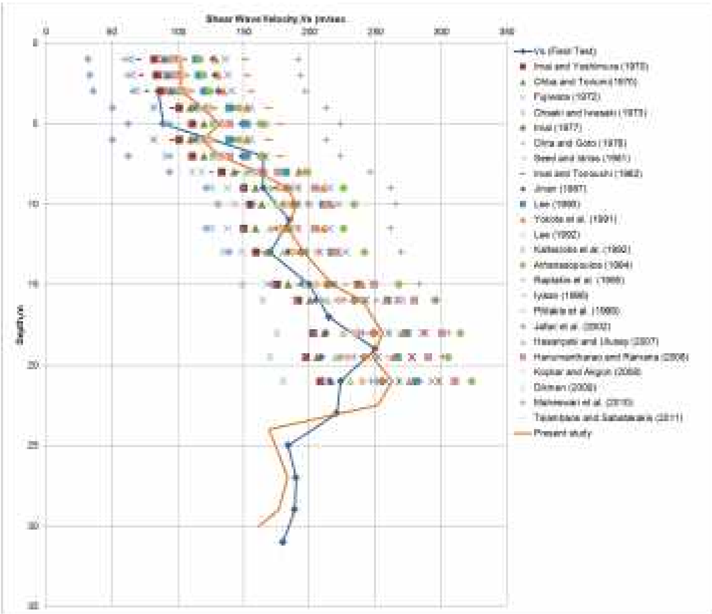

Fig. 8. Comparison of shear wave velocity and SPT N for Bibiyana III, Bangladesh

The comparison between the Shear wave velocities obtained from Seismic Cross hole test (CHST) and from Present study is shown in **Error! Reference source not found.**, **Table 3** and **Table 4** for different sites.

Table 2. Comparison of Shear wave Velocities obtained from CHST and Present Study for West Bengal and Bihar, India

West Bengal, India				Bihar, India			
Depth,m	Vs, m/sec		% Error	Depth,m	Vs, m/sec		% Error
	CHST	Present Study			CHST	Present Study	
3.0	189.0	161.43	14.59	3.0	155.0	176.77	14.04
6.0	230.0	201.87	12.23	6.0	220.0	190.05	13.61
9.0	278.0	235.84	15.16	9.0	240.0	266.31	10.96
12.0	346.0	282.59	18.33	10.5	245.0	269.71	8.32
13.5	355.0	297.36	16.24	12.0	261.0	273.03	4.61
15.0	355.0	310.93	12.41	13.5	288.0	269.71	6.35
16.5	364.0	323.53	11.12	15.0	312.0	302.92	2.91
18.0	375.0	333.02	11.19	16.5	338.0	294.51	12.87

19.5	343.0	302.92	11.69	18.0	382.0	321.08	15.95
21.0	326.0	318.60	2.27	19.5	350.0	294.51	15.85
22.5	319.0	362.96	13.78	21.0	341.0	300.16	11.98
24.0	430.0	372.66	13.33	22.5	360.0	310.93	13.63
25.5	440.0	387.31	11.98	24.0	582.0	370.76	36.30
27.0	430.0	381.93	11.18	25.5	672.0	399.37	40.57
28.5	450.0	392.56	12.77	27.0	834.0	421.72	49.43
30.0	481.0	404.34	15.94	28.5	878.0	421.72	51.97
				30.0	893	421.72	52.77

Table 3. Comparison of Shear wave Velocities obtained from CHST and Present Study for Andhra Pradesh, India and Bhola, Bangladesh

Andhra Pradesh, India				**Bhola, Bangladesh**			
Depth,m	**Vs, m/sec**		**% Error**	**Depth,m**	**Vs, m/sec**		**% Error**
	CHST	**Present Study**			**CHST**	**Present Study**	
1.5	140.0	169.41	21.00	1.0	132.0	118.88	9.94
3.0	165.0	183.62	11.29	2.0	165.0	142.96	13.36
4.5	202.0	212.57	5.23	3.0	120.0	102.69	14.43
6.0	211.0	227.04	7.60	4.0	151.0	118.88	21.27
7.5	220.0	235.84	7.20	5.0	110.0	102.69	6.65
9.0	233.4	255.63	9.53	6.0	115.0	102.69	10.70
10.5	248.6	259.28	4.30	7.0	149.0	131.89	11.48
12.0	249.2	262.84	5.47	8.0	178.0	152.69	14.22
13.5	261.8	266.31	1.72	9.0	180.0	142.96	20.58
15.0	279.4	273.03	2.28	10.5	191.0	161.43	15.48
16.5	282.7	279.47	1.14	12.0	182.0	152.69	14.22
18.0	293.5	282.59	3.72	13.5	178.0	118.88	18.01
19.5	297.1	285.65	3.85	15.0	145.0	131.89	12.65
				16.5	146.0	102.69	17.85
				18.0	151.0	142.96	22.72
				19.5	125.0	131.89	19.08
				21.0	170.0	161.43	26.62

Table 4. Comparison of Shear wave Velocities obtained from CHST and Present Study for Bibiyana South and Bibiyana III, Bangladesh

Bibiyana South, Bangladesh				**Bibiyana III, Bangladesh**			
Depth,m	**Vs, m/sec**		**% Error**	**Depth,m**	**Vs, m/sec**		**% Error**
	CHST	**Present Study**			**CHST**	**Present Study**	
1.0	75.0	102.69	36.92	3.0	85.0	102.69	20.81
3.0	89.0	102.69	15.38	5.0	89.0	131.89	48.20
5.0	100.0	79.95	20.05	7.0	165.0	131.89	20.06
7.0	156.0	183.62	17.71	9.0	165.0	183.62	11.29
9.0	175.0	227.04	29.74	11.0	185.0	183.62	0.75
11.0	180.0	227.04	26.13	13.0	170.0	196.12	15.36
13.0	210.0	227.04	8.11	15.0	200.0	217.59	8.79
15.0	225.0	235.84	4.82	17.0	215.0	255.63	18.90
17.0	225.0	276.28	22.79	19.0	250.0	248.05	0.78
19.0	225.0	244.10	8.49	21.0	224.0	262.84	17.34
21.0	225.0	235.84	7.20	23.0	221.0	251.89	13.98
23.0	180.0	217.59	20.88	25.0	184.0	176.77	3.93
25.0	350.0	161.43	53.88	27.0	190.0	183.62	3.36
27.0	140.0	152.69	9.07	29.0	189.0	176.77	6.47
29.0	155.0	142.96	7.77	31.0	180.0	161.43	10.32
31.0	210.0	131.89	37.19				

5 CONCLUSION

In the present paper, an attempt has been made to develop a new reliable relationship between shear wave velocity (Vs) and Standard penetration test (N) for All Soils based on the extensive seismic cross hole tests. For this, Field test i.e. Seismic Cross hole and Standard penetration test were conducted for different power plant sites. The data collected are discussed in this paper.

The shear wave velocity obtained from the proposed equation matches fairly well with field tests and results of few researchers. The proposed equation can be used effectively for estimating shear wave velocity for All Soils.

The relationship developed in this paper is important for development seismic hazard maps for microzonation. The results obtained from this study are useful for site response studies of sites, where site specific shear modulus and N correlation is not available and only SPT N with soil type data are available.

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