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Shear Wave Velocity as a Function of Standard Penetration Number and Depth in Dhaka City, Bangladesh

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Abstract: *Shear wave velocity (Vs) is widely used by earthquake and geotechnical engineers for seismic behavior modeling of the sites. This paper attempts to propose general correlation between shear wave velocity and standard penetration resistance and depth in Dhaka City based on geophysical test which had been established worldwide. PS Logging Test was performed using down-hole method to determine shear wave velocity (V_s) and Standard Penetration Test was performed to determine standard penetration resistance value (N value) along seventeen locations of Dhaka City. From multi regression analysis, considering V_S as the dependent variable, depth and the SPT N value as the independent variable a correlation was obtained for any kind of soil sand silt or clay.*

Keywords: *PS Logging Test, Standard Penetration Test, Shear Wave velocity, SPT N Value.*

I. Introduction

The ground motion characteristics of the site are significantly affected by the presence of soil deposits during an earthquake. The ground motion characteristics at the surface are evaluated by simplified site classification method or by carrying out rigorous site specific ground response analysis. Shear wave velocity is the fundamental geotechnical characteristic, which acts as the main input of quantitative earthquake engineering and the main controller of site response. In most cases determination of Vs by geophysical testing may not be feasible due to comparatively high cost of Down-hole and Cross-hole tests and/or other considerations. On the other hand, Standard Penetration Test (SPT) is the most common in-situ geotechnical test which is almost carried out in every geotechnical investigation program. So, different researchers tried to correlate Vs in terms of various soil indexes including depth, soil type and SPT-N value. In this research work, shear wave velocity and SPT N value was determined using PS Logging test and Standard Penetration Test in seventeen locations of Dhaka City. Using the 189 values of seventeen locations, a correlation was developed for Dhaka city.

II. Worldwide Correlation

Shear wave velocity is a basic engineering tool required to define dynamic properties of soils. In many instances it may be preferable to determine Vs indirectly by common in-situ tests, such as the Standard Penetration Test. Many empirical correlations based on the Standard Penetration Test are broadly classified as regression techniques shear wave velocity (Vs) is a principal geotechnical soil property for site response analysis. A summary of established correlation in half of the past century is given in *Table 1*. The published regression was divided into three groups, namely all soil types, cohesionless soil and cohesive soil.

III. Test Sites and Field data

Dhaka is situated in the centre of Bangladesh, between longitude 90°20' E and 90°30' E and latitude 23°40' N and 23°55' N. The present area of the city is 256 square kilometers, bounded by the Demra in the east, the Turag River in the west, the Tongi Khal in the north and the Burhiganga River in the south. In and around the city, an area of 280 square kilometers has been mapped. Dhaka City is almost flat, with many depressions, bounded by rivers on all four sides topographically. The surface elevation of the city ranges between 1.7 and 14 meters above mean sea level, but is generally around 6.5 meters. The average depth of the groundwater table is 3 meters. The main part of the city lies either on Madhupur Clay, old natural levees, high flood plains, or filled-in gullies. The Madhupur Clay, with its average thickness of 8 meters, consists of over-consolidated clayey silt

and is underlain by the Plio-Pleistocene Dupi Tila Formation.PS Logging Test and Standard Penetration Test was performed in seventeen locations of Dhaka city. Different test sites are given in table 2. The test sites are shown as map in figure 1. Figure 2 shows SPT Test at site 8 and figure 3 shows PS Logging Test at site 7.Field investigation results are given in Table 3 and also presented as graphical from in figure 4 to figure 6.

Table 1 Correlation of Vs = ANB (After Jafari *et al.* (2002); Hanumantharao and Ramana (2008); Uma Maheswari *et al.* (2010); Kuo *et al.* (2011); Akin *et al.* (2011); Anbazhagan *et al.* (2012)

Year	Researcher	All soil	Cohesionless soil	Cohesive soil
1966	Kanai	$Vs = 19N^{0.6}$	-	-
1970	Ohba and Toriumi	$Vs = 84N^{0.31}$	-	-
	Shibata		$Vs = 32N^{0.5}$	-
	Imai and Yahimura	$Vs = 76N^{0.33}$		-
1972	Ohta et al		$Vs = 87N^{0.36}$	-
	Fujimara	$Vs = 92.1N^{0.337}$		-
1973	Ohsaki and Iwasaki	$Vs = 81.4N^{0.39}$	$Vs = 59.4N^{0.47}$	-
1975	Imai and Yoshimura	$Vs = 92N^{0.329}$	-	-
	Imai et al	$Vs = 89.9N^{0.341}$	-	-
1977	Imai	$Vs = 91N^{0.337}$	$Vs = 80.6N^{0.331}$	$Vs = 102N^{0.292}$
1978	Ohta and Goto	$Vs = 85.35N^{0.348}$	$Vs = 88N^{0.34}$	
1980	JRA		$Vs = 80N^{0.33}$	$Vs = 100N^{0.33}$
1981	Seed and Idriss	$Vs = 61.4N^{0.5}$	-	-
1982	Imai and Tonouchi	$Vs = 97N^{0.314}$	-	-
1983	Seed et al	-	$Vs = 56.4N^{0.5}$	-
	Sykora and Stokoe	-	$Vs = 100.5N^{0.29}$	-
1989	Okamoto et al	-	$Vs = 125N^{0.3}$	-
1990	Lee	-	$Vs = 57.4N^{0.49}$	$Vs = 114.43N^{0.31}$
	Imai and Yoshimura	$Vs = 76N^{0.33}$	-	-
1991	Yokota et al	$Vs = 121N^{0.27}$	-	-
1992	Kalteziotis et al	$Vs = 76.2N^{0.24}$	$Vs = 49.1N^{0.50}$	$Vs = 76.6N^{0.45}$
1995	Raptakis et al		$Vs = 100N^{0.24}$	$Vs = 184.2N^{0.17}$
	Athanasopoulos	$Vs = 107.6N^{0.36}$	-	-
	Sisman	$Vs = 32.8N^{0.51}$	-	-
1996	Iyisan	$Vs = 51.5N^{0.516}$	-	-
1997	Jafari et al	$Vs = 22N^{0.85}$	-	-
2000	Chien et al	-	$Vs = 22N^{0.76}$	-
2001	Kiku et al.	$Vs = 68.3N^{0.292}$	-	-
2002	Jafari et al	$Vs = 22N^{0.85}$	$Vs = 19N^{0.85}$	$Vs = 27N^{0.73}$
2007	Hasancebi and Ulusay	$Vs = 90N^{0.309}$	$Vs = 90.82N^{0.319}$	$Vs = 97.89N^{0.269}$
2008	Hanumantharao and Ramana	$Vs = 82.6N^{0.43}$	$Vs = 79N^{0.434}$	
2008	Lee and Tsai	$Vs = 137.153N^{0.229}$	$Vs = 98.07N^{0.305}$	$Vs = 163.15N^{0.192}$
2009	Dikmen	$Vs = 58N^{0.39}$	$Vs = 73N^{0.33}$	$Vs = 44N^{0.48}$
2010	Brandenberg et al			
	Uma Maheswari et al.	$Vs = 95.64N^{0.301}$	$Vs = 100.53N^{0.265}$	$Vs = 89.31N^{0.358}$
2011	Tsiambaos and Sabatakakis	$Vs = 105.7N^{0.327}$	$Vs = 79.7N^{0.365}$	$Vs = 88.8N^{0.370}$
2012	Anbazhagan et al	$Vs = 68.96N^{0.51}$	$Vs = 60.17N^{0.56}$	$Vs = 106.63N^{0.39}$

Table 2 Different Test Site Locations

Test Site	Location	Test Site	Location
1	BUET JIDPUS	10	RHD, Tejgaon
2	MIST, Mirpur	11	Mehernagar, Uttara
3	Hazaribag	12	Jubok Project, Ashulia
4	Gulshan 2	13	Mirpur-1, Avenue-2
5	Kamrangichor	14	Akash Nagar, Mohammadpur, Beribadh
6	Dakhin Kafrul	15	United City Project, Beraidh
7	Maniknagar	16	East Nandipara
8	Aftabnagar	17	Asian City, Dokhinkhan
9	Lake City Concord, Khilkhet		

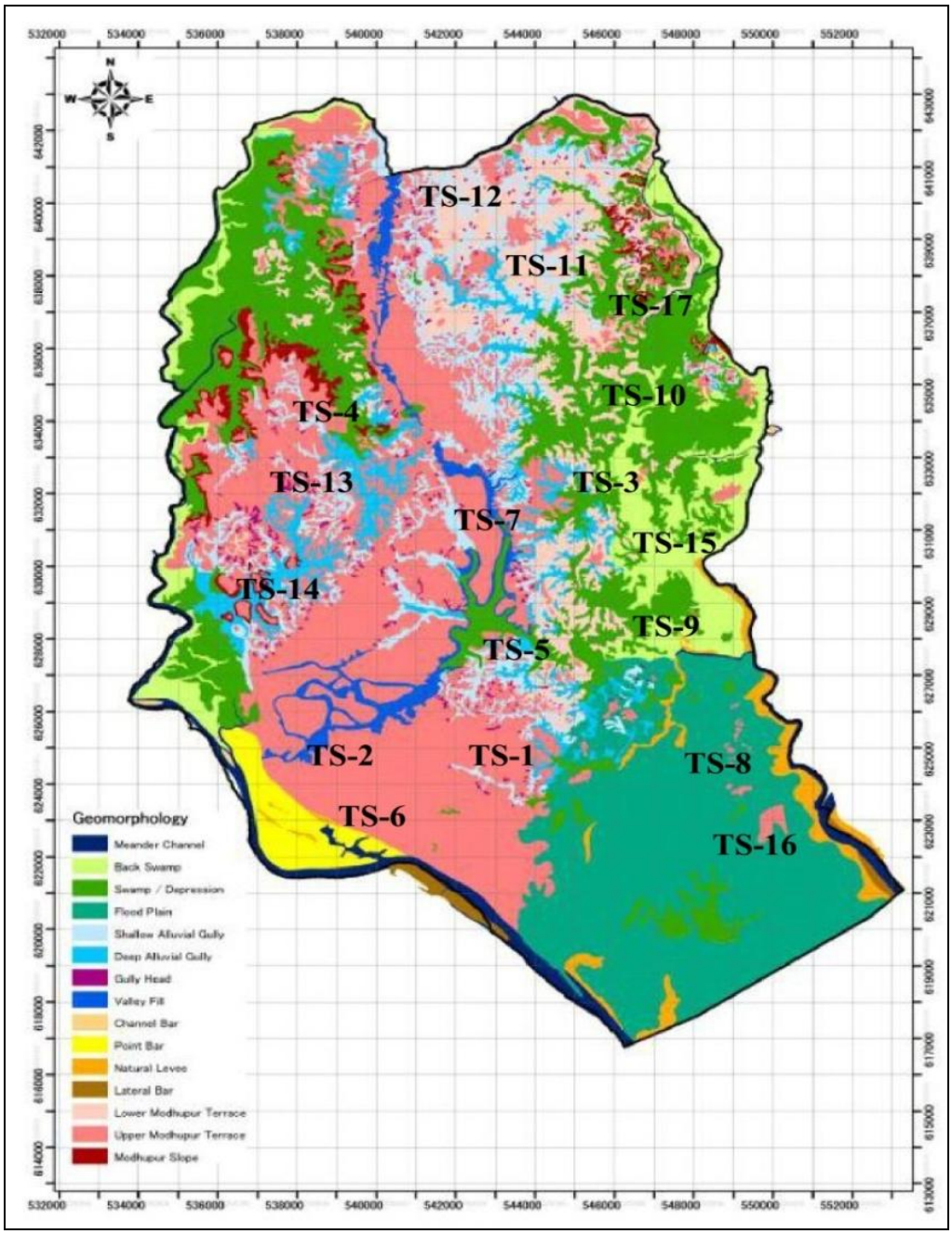

Figure 1 Test Site Map of Dhaka City

Table 3 Field data of shear wave velocity and SPT N of different locations

TS-1			TS-2			TS-3			TS-4			TS-5			TS-6		
Depth ft	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**
5	3	136	10	1	284	8	18	665	8	5	561	10	18	773	8	11	661
10	6	433	15	1	346	13	9	797	13	3	480	15	13	597	13	12	845
15	15	758	20	2	450	18	9	654	18	2	801	20	8	497	18	12	791
20	18	1316	25	2	405	23	12	1256	23	3	722	25	7	756	23	14	831
25	8	295	30	4	472	28	14	732	28	3	838	30	17	897	28	17	831
30	9	1324	35	8	722	33	15	644	33	4	1158	35	25	1184	33	23	833
35	11	1041	40	11	424	38	15	401	38	4	410	40	30	1499	38	25	753
40	15	1572	45	6	1469	43	24	1348	43	4	730	45	30	1631	43	30	666
45	14	656	50	12	449	48	27	620	48	4	447	50	29	1826	48	34	742
50	20	1366	55	16	992	53	27	507	53	4	1050	55	29	2486	53	32	954
55	19	821	60	18	687	58	28	457	58	6	1056	60	30	2488	58	30	833
60	19	533	65	16	1277	63	28	428	63	5	1274	65	28	1671	63	28	909
65	25	703	70	17	1140	68	27	512	68	5	840	70	26	1767	68	28	1111
70	19	731	75	20	1280	73	26	739	73	4	1121	75	25	1696			
75	17	1286	80	22	1225	78	25	1326	78	5	1311						
80	11	1339				83	24	831									

TS-7			TS-8			TS-9			TS-10			TS-11			TS-12		
Depth ft	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**

9	16	532	9	3	364	8	4	317	8	5	343	10	2	561	10	1	285
14	13	799	14	3	305	13	7	406	13	9	669	20	3	495	20	2	236
19	14	605	19	5	256	18	8	285	18	7	412	30	2	502	30	4	400
24	32	776	24	8	488	23	6	280	23	8	616	39	4	758	39	2	410
29	28	1332	29	13	410	28	5	509	28	9	630	49	10	820	49	1	361
34	28	909	34	14	554	33	6	387	33	9	967	59	21	830	59	11	948
39	36	1100	39	17	848	38	6	408	38	9	752	69	20	1122	69	18	731
44	34	1150	44	21	622	43	9	399	43	9	781	79	25	1332	79	15	712
49	29	1012	49	23	728	48	10	427	48	10	667	89	27	1056	89	25	1000
54	28	507	54	21	941	53	7	567	53	20	551	98	17	1706	98	26	1246
59	29	1041	59	17	1005	58	8	466									
64	28	1220	64	18	1100												

TS-13			**TS-14**			**TS-15**			**TS-16**			**TS-17**					
Depth ft	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**	**Depth ft**	**Corrected SPT N**	**Shear Wave Velocity ft/s**			
10	3	302	10	12	676	10	3	462	10	6	413	10	53	1309			
20	10	610	20	22	1109	20	5	312	20	15	790	20	38	2037			
30	10	633	30	18	1168	30	1	305	30	9	1096	30	24	1200			
39	14	626	39	16	1302	39	1	430	39	22	1410	39	16	1174			
49	14	984	49	18	1214	49	1	492	49	24	1345	49	15	656			
59	14	840	59	13	1394	59	1	443	59	12	1102	59	13	649			
69	16	774	69	16	1050	69	22	804	69	12	1220	69	21	886			
79	15	912	79	18	1050	79	5	1000									
89	15	754															

Figure 2 SPT Test at Site 8

Figure 3 PS Logging Test at Site 7

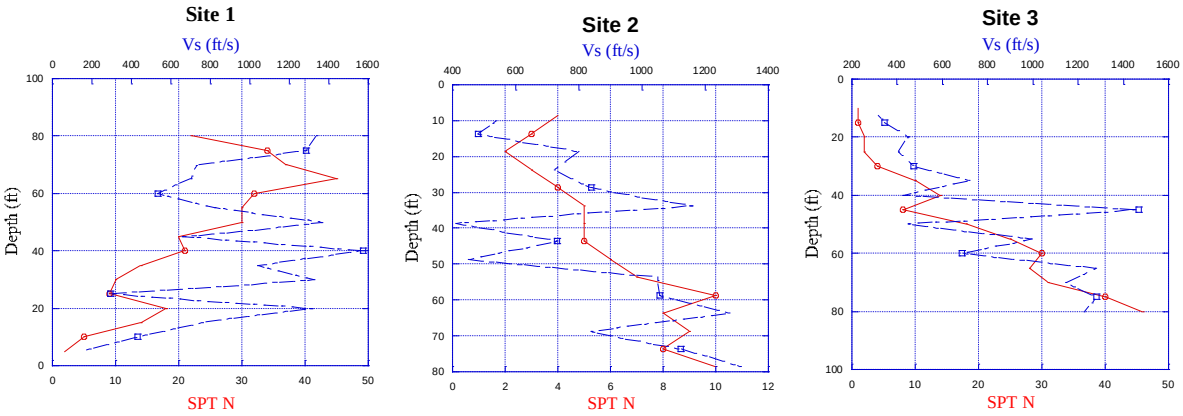

Figure 4 Field Investigation Results of Site 1 to Site 3

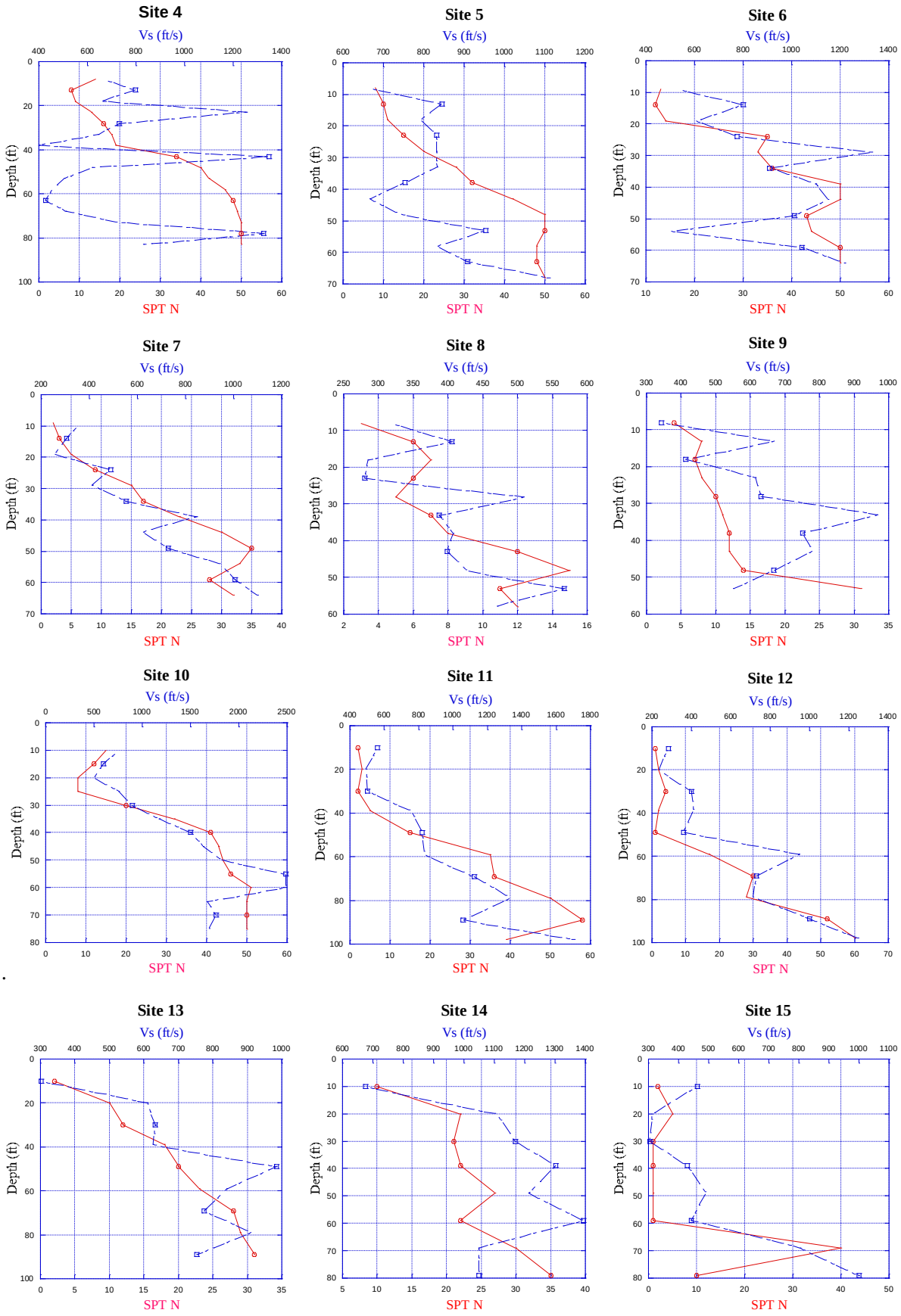

Figure 5 Field Investigation Results of Site 4 to Site 15

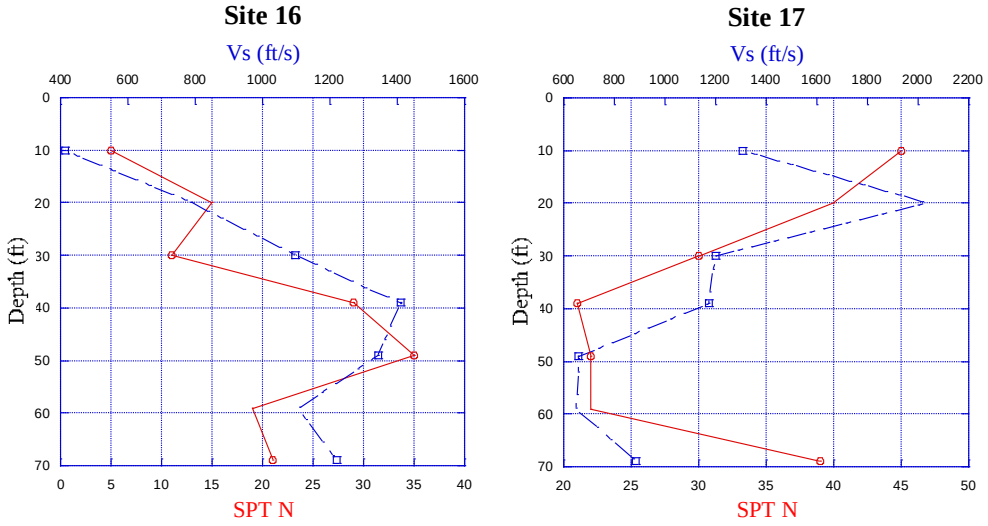

Figure 6 Field Investigation Results of Site 16 and Site 17

IV. Proposed Correlation

A correlation equation was developed using 189 data of depth, SPT N value and shear wave velocity. Considering V_S as the dependent variable and depth and the SPT N value as the independent variable following correlation was obtained for any kind of soil sand silt or clay. Figure 7 shows graphs between the V_s and depth and V_s and SPT N value.

$$\mathbf{V_s = 169 * N^{0.2638} * D^{0.2396}\ (ft/s)\ (r\text{^}2=0.45)}$$

Here,
Vs = Shear wave velocity in ft/sec
N = Corrected Standard penetration Number
D = Depth in ft.

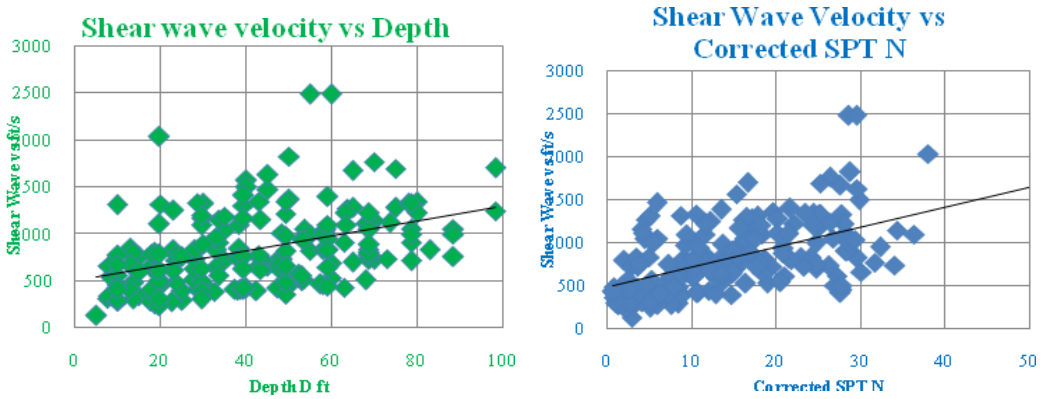

Figure 7 (a) Graph of Shear Wave Velocity (Vs) and Depth; **(b)** Graph of Shear Wave Velocity (Vs) and Corrected SPT N

V. Conclusion

Correlation between shear wave velocity and SPT N is very rarely developed in Bangladesh. In this research work, only 189 data of seventeen locations were analyzed to determine correlation equation. So the regression coefficient was too low, that is 0.45. If more and more data was used then better value may be obtained. So, many tests should be performed to determine shear wave velocity and SPT N value in Dhaka City. Using the tested result and adding the research data of this paper more precise equation should be developed.

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