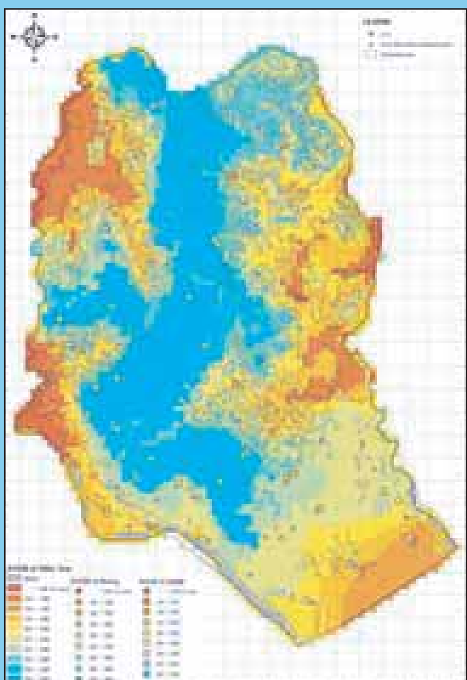
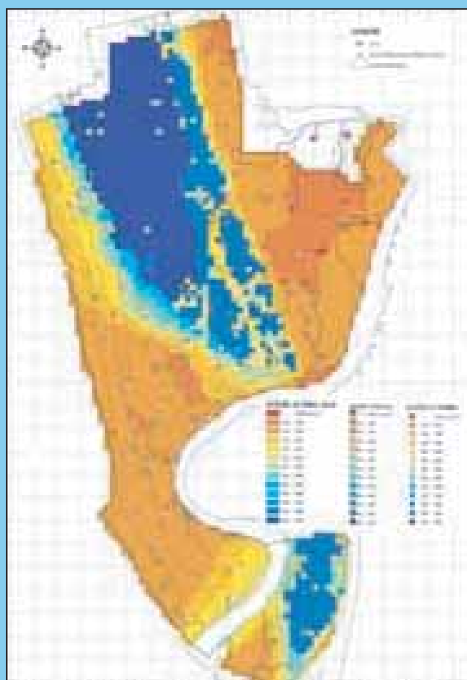
Engineering Geological Mapping of Dhaka, Chittagong And Sylhet City Corporation Area of Bangladesh





June 2009

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Engineering Geological Mapping of Dhaka, Chittagong And Sylhet City Corporation Area of Bangladesh

Comprehensive Disaster Management Programme (CDMP)
Ministry of Food and Disaster Management (MoFDM)
Government of the People's Republic of Bangladesh

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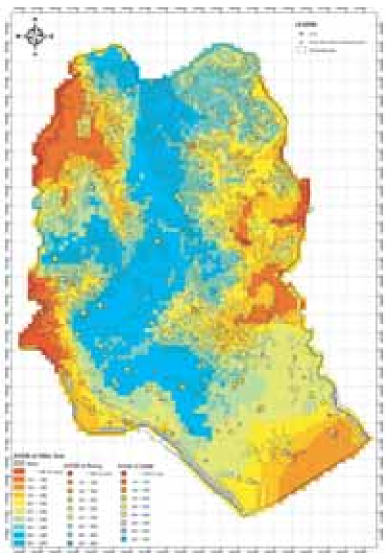

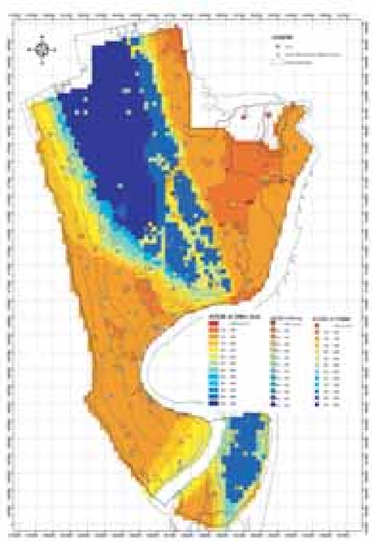

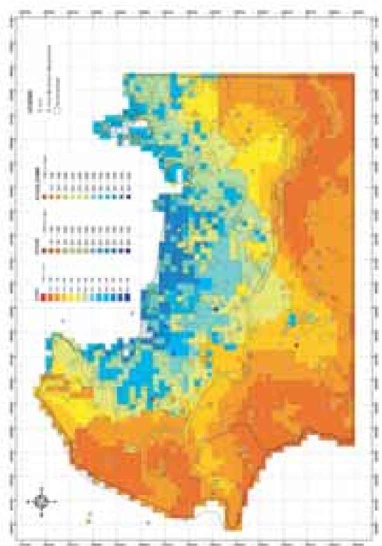

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Comprehensive Disaster Management Programme (CDMP)
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Engineering Geological Map
for
Seismic Hazard
and Vulnerability Assessment
of
Dhaka, Chittagong and Sylhet
City Corporation Area

26 May 2009

Asian Disaster Preparedness Center

OYO International Corporation

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Executive Summary

In order to obtain geological / geotechnical data as basic information for analysis of the seismic hazard assessment, geomorphic survey (Chapter 1), geotechnical investigation (Chapter 2) and geophysical exploration (Chapter 3) were carried out in Dhaka, Chittagong and Sylhet.

In geotechnical investigation, 139 soil borings (4,099 m in drilling length), 2,720 times of standard penetration test (SPT), 19 points of PS logging, 9 points of cone penetration test (CPT) and laboratory tests were conducted.

In geophysical exploration, 126 points of multi-channel analysis of surface wave and small scale microtremor measurement, 22 points of array microtremor measurement, and 257 points of single microtremor measurement were conducted.

In this study, we could use the reliable data derived from the above mentioned surveys carried out by ADPC under CDMP and TAG supervision, consequently, amount of available data had limitation. Hence, empirical method that point source data is expanded to analyzing area was applied for the analysis of soil amplification in order to examine area-wide analysis.

Based on the results of the above surveys, AVS 30 map (Chapter 4), which 250 m grid has average S-wave velocity of ground in the top 30 m depth, was presented as an engineering geological map and this map was provided for the seismic hazard assessment.

1. Geomorphic Survey

Geomorphic surveys in 3 cities were carried out by Geological Survey of Bangladesh (hereinafter referred to as “GSB”). Detailed report of the geomorphic survey was submitted by GSB to CDMP. In here, tabulations of the Quaternary stratigraphic succession and geomorphic maps in each city on the basis of the report are shown in Table 1-1.

Table 1-1 Quaternary Stratigraphic Succession in each City

[Dhaka]

Chronostratigraphy		Formation	Member	Bed	Lithologic Description	Thickness (m)
Series	Sub-Series					
HOLOCENE	Sub-Atlantic	Basabo Silty-clay	Matuail Clay	Silty-Clay	Pale olive very sticky silty clay with modern soil on top	2 to 5
	Sub-Boreal			Clayey Silt	Light yellowish brown very sticky clayey silt, containing plenty of plant roots and iron concretions.	
	Atlantic		Gulshan Sand	Silty Clay	Yellow red silty-clay.	
	Boreal			Clayey Silt	Pale yellow clayey silt, containing wood fragments, plants' roots and iron concretions.	
	Pre-Boreal			Sand	Light bluish grey sand-silt-clay to sand. It contains roots, wood fragments and iron concretions.	
PLIOSTOCENE	Middle	Madhupur Clay and Sand	Kalsi Bed	1	Pale yellowish brown with light brown spotted sandy clay	12 to 15
			Dhaka Clay	2	Yellowish brown very sticky silty-clay, containing iron concretions.	
				Upper	Red with reddish yellow reduction spots. It is highly weathered and powdery. It contains iron concretions, pipe stems, calcareous nodules, plants' roots and manganese spots.	
	Lower		Mirpur Siltyclay	Middle	Light brown sandy clay to clayey sand with moderate reddish brown spots, containing iron concretions, pipe-stems, plants' roots and manganese spots.	
			Bhaluka Sand	Lower	Pale yellowish brown silty-sand to sand. It is highly micaceous and cross bedded, contains Mn-spots. Micas are biotitic and highly oxidized. It has intraformation or intercalated silty-clay layers.	
L. Pleistocene (Pliocene?)		Dupi Tila			Oxidized reddish brown fine grained to coarse asnd. It contains silicified wood fragment and peaty wood fragments. It has primary sedimentary structures, such as cross bedding, ripple marks etc. There are some intraformational yellwish brown and bluish silty clay layers having hickness of about 1 to m. The sediments are highly oxidized. The main characteristic is that the sediments have colour bands. The boundary between Madhupur and Dupi Tila Formation is represented by smooth quartz-chalcedony gravel beds.	2500

[Chittagong]

(after Mominullah, 1978)

Epoch	Group	Formation	Lithologic Description	Thick-ness (m)
Recen		Alluvium	Dark clay, silt and sand	
Pleistocene		Dihing	Sandstone, ill sorted, pebbly and mottled clay	
Plio/ Pleistocene		Dupi Tila	Yellowish brown medium grained sandstone with subordinate slty shale or clay layer.	200
Miocene	Tipam	Girujan Clay	Shale and silty-shale with calcareous bands.	200
		Tipam	Yellowish brown medium to fine grained sandstone with subordinate silty shale layers. Cross bedded.	800
	Surma	Bokabil	Sandstone, siltstone and shale. Sandy shale with subordinate massive sandstone. Cross bedded, ripple marks and thickly bedded.	500
		Bhuban	Fine gained sandstone with subordinate sandy shale and siltstone (upper). Greyish coloured sandy shale with subordinate buish grey laminated silty shale.	450

[Sylhet]

Age	Group	Formation	Lithologic Description
Holocene			Very coarse sand, silt, clay, alluvium
Pleistocene		Dupitila	Sandstone with minor shale and clay beds, having colour bands.
Pliocene	Tipam	Tipam Sandstone	Predominantly cross bedded sandstone with minor shale and clay beds.
Mio-Pliocene	Surma	Bokabil	Alternating shale and sandstone with minor siltstone. Sand dominated
Miocene		Bhuban	Alternating sandstone and shale with minor siltstone. Shale dominated
Oligocene	Borail	Renji	Sandstone with minor shale
		Jenam	Predominantly shale with minor siltstone and sandstone

Geomorphic units of each city were classified / defined by GSB as shown in Table 1-2 and Figure 1-1. The results are used for the seismic hazard assessment.

Table 1-2 Tabulation of Geomorphic Unit in each City

	Dhaka	Chittagong	Sylhet
Lowland	Meander Channel Back Swamp Swamp / Depression Flood Plain Shallow Alluvial Gully Deep Alluvial Gully Gully Head Valley Fill Channel Bar Point Bar Natural Levee Lateral Bar Lower Modhupur Terrace Upper Modhupur Terrace Modhupur Slope	Active Channel Depression Sandy Beach Clayey Beach Lower Tidal Flat Estuarine Tidal Flat Inter Tidal Flat Supra Tidal Flat Younger Point Bar Ancient Point Bar Natural Levee Sand Dune Deep Valley Fill Gully Fill River Tidal Flat Fluvio Tidal Plain Alluvial Fan	Abandoned Channel Meander Scar Back Swamp Swamp / Depression Floodplain Point Bar Natural Levee Lateral Bar Alluvial Fan Gully Fill
Hilly Area		Hill Slope Level Hill Piedmont Plain Rounded Top Highly Dissected Hill Sharp Crest Highly Dissected Hill Sharp Crest Slightly Dissected Hill Isolated Valley	Valley Piedmont Plain Level Hill Ridge Isolated Hills

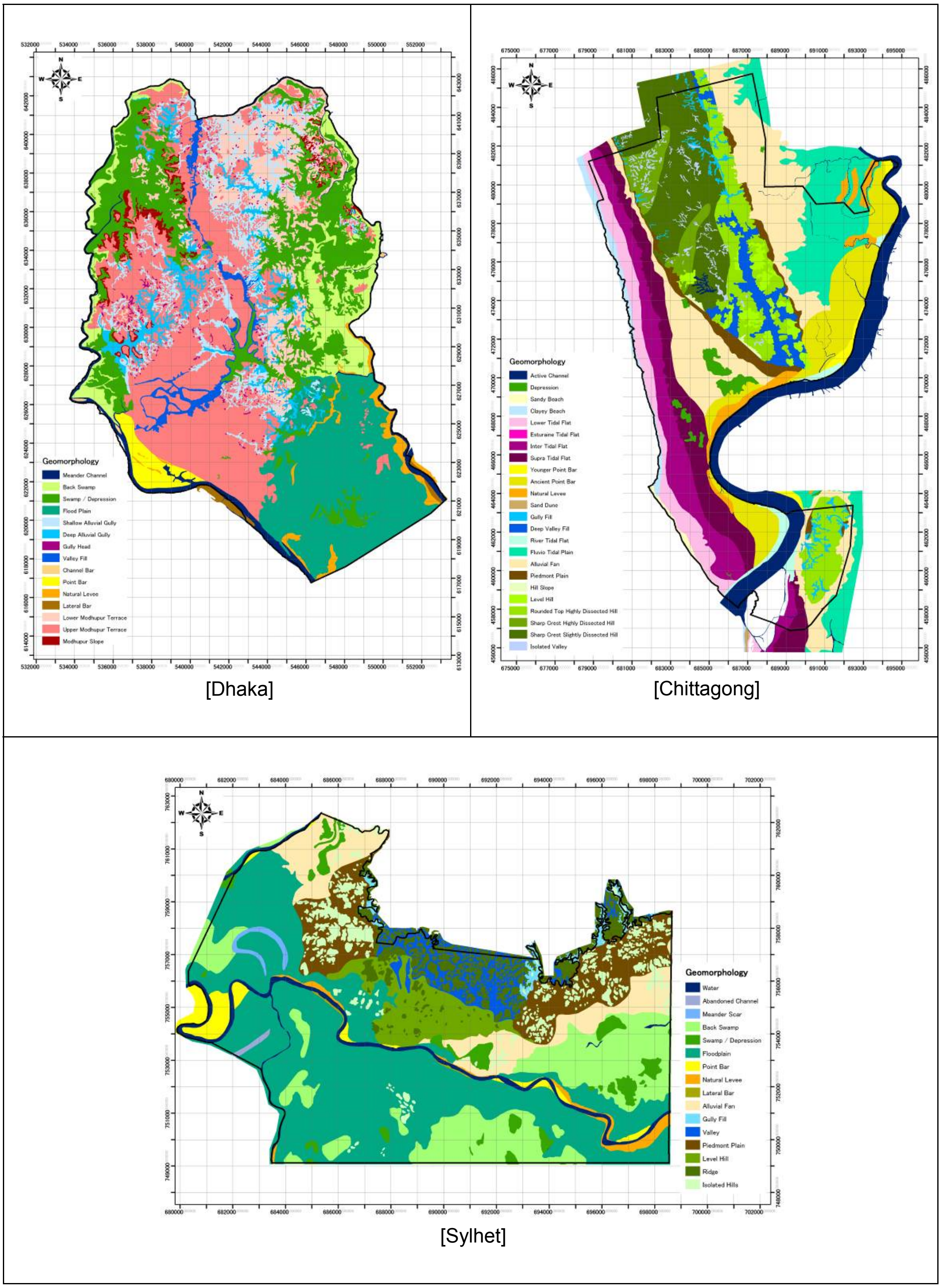


Figure 1-1 Geomorphic Map in each City

2. Geotechnical Investigation

2.1. Boring with Standard Penetration Test and Laboratory Test

(1) Boring with Standard Penetration Test

Investigation borings with standard penetration test (hereinafter referred to as “SPT”) were conducted in order to know vertical geological conditions / groundwater level, to take geotechnical characteristics and to carry out PS logging.

The borings with SPT were carried out at 53 points in Dhaka, at 48 points in Chittagong and at 38 points in Sylhet (total 139 points) by Asian Disaster Preparedness Center (hereinafter referred to as “ADPC”, 85 points) and GSB (54 points). Table 2-1 shows basic information of the borings and the SPT in each city.

Table 2-1 Summary of Boring and SPT

[Dhaka]

Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Dhk_01	543326.921	639885.898	Uttar Khan Collegiate School, Dhaka	6.8	ADPC	31.5	21	Lower Modhupur Terrace
Dhk_02	543376.105	621458.480	Dhup khola DCC field, Dhaka	6.0		30.0	20	Upper Modhupur Terrace
Dhk_03	550687.573	623127.326	Demra Ghat, Dhaka	6.0		30.0	20	Flood Plain
Dhk_04	543419.417	637327.450	Asian City, Dakhin khan, Dhaka	4.5		33.0	22	Deep Alluvial Gully
Dhk_05	545603.314	638709.462	Meher Nagar (Uttara), Dhaka	2.0		33.0	22	Lower Modhupur Terrace
Dhk_06	537030.393	641213.024	Asulia (Jubak Project), Dhaka	1.8		33.0	22	Swamp / Depression
Dhk_07	535839.846	632035.635	Mirpur-1, Avenue-2, Section-1, Dhaka	14.3		33.0	22	Upper Modhupur Terrace
Dhk_08	535484.452	628074.969	Akkas Nagar, Turag City, Mohammadpur,(Bheribadh), Dhaka	5.2		34.5	23	Swamp / Depression
Dhk_09	546532.200	625777.363	East Nandipara, Mothertek, Dhaka	5.0		34.5	23	Upper Modhupur Terrace
Dhk_10	546545.398	631924.450	Beraid United City Project, Dhaka	1.9		34.5	23	Back Swamp
Dhk_11	537885.386	622550.343	Kamrangir Char	5.8	GSB	28.5	19	Point Bar
Dhk_12	538449.420	623412.903	Hazaribagh Girl's High School	5.8		30.0	20	Upper Modhupur Terrace
Dhk_13	539212.062	624091.499	Agroni School & College, Azimpur, Dhaka	8.0		30.0	20	Upper Modhupur Terrace
Dhk_14	543787.064	627948.675	Bank of Rampura Khal (Aftab Nagar), Dhaka	5.8		30.0	20	Deep Alluvial Gully
Dhk_15	546267.801	631123.967	Sun Valley Project, Dhaka	2.7		30.0	20	Swamp / Depression
Dhk_16	548501.530	631684.808	Neptune Project (Beraid, Badda), Dhaka	3.0		30.0	20	Upper Modhupur Terrace
Dhk_17	546282.102	635521.810	Dumni, Dhaka	1.5		30.0	20	Lower Modhupur Terrace
Dhk_18	549679.509	634764.180	Ichapur (Near Balu River), Dhaka	2.6		30.0	20	Back Swamp
Dhk_19	551367.994	621269.109	Rasulbagh, Demra, Dhaka	3.5		30.0	20	Flood Plain
Dhk_20	547143.988	622700.284	Matuail, Dhaka	2.8		30.0	20	Flood Plain
Dhk_21	544049.881	625273.913	North Bashabo, Dhaka	6.0		30.0	20	Upper Modhupur Terrace

Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Dhk_22	541835.945	631382.021	Bank of Banani Lake, Dhaka	7.0		30.0	20	Upper Modhupur Terrace
Dhk_23	542752.243	634307.125	Nikunja-1, Dhaka	6.3		30.0	20	Shallow Alluvial Gully
Dhk_24	539372.339	638115.516	Bounia/Dolipara (New Airport), Dhaka	4.0		30.0	20	Shallow Alluvial Gully
Dhk_25	540158.180	640331.941	Uttara, Section-11, Dhaka	7.0		30.0	20	Upper Modhupur Terrace
Dhk_26	537796.560	634974.463	Mirpur-12, Dhaka	7.7		30.0	20	Shallow Alluvial Gully
Dhk_27	537132.080	629283.366	Kallayanpur, Dhaka	5.0		30.0	20	Deep Alluvial Gully
Dhk_28	544802.623	629058.890	East Badda (Graveyard), Dhaka	2.0		30.0	20	Lower Modhupur Terrace
Dhk_29	540012.645	621887.187	Muslim bag, Kamrangir char, Dhaka	6.7	ADPC	30.0	20	Point Bar
Dhk_30	537251.312	624212.582	Hazaribagh, Bhuyian Housing Estate, Dhaka	5.5		30.0	20	Point Bar
Dhk_31	538385.375	629766.609	Agargoan, Dhaka	0.8		30.0	20	Upper Modhupur Terrace
Dhk_32	538594.907	635280.650	Pallabi, Dhaka	1.2		30.0	20	Swamp / Depression
Dhk_33	536272.230	634302.618	Eastern Housing, Pallabi, Dhaka	1.8		30.0	20	Modhupur Slope
Dhk_34	546042.619	618894.671	Pagla, Dhaka	0.8		30.0	20	Flood Plain
Dhk_35	545583.954	621460.646	Kazla, Dhaka	3.7		30.0	20	Flood Plain
Dhk_36	545193.435	626097.174	East Goran, Dhaka	0.6		30.0	20	Deep Alluvial Gully
Dhk_37	541583.654	623635.279	Phulbaria, Dhaka	3.7		30.0	20	Upper Modhupur Terrace
Dhk_38	538537.681	625718.273	Dhanmondi, Dhaka	7.8		30.0	20	Upper Modhupur Terrace
Dhk_39	539424.733	641648.101	Ranavola, Uttara, Dhaka	7.3		30.0	20	Upper Modhupur Terrace
Dhk_40	546755.248	620173.641	Rayerbag, Dhaka	2.6		30.0	20	Flood Plain
Dhk_41	534707.013	636900.280	Birulia, Dhaka	3.6		30.0	20	Back Swamp
Dhk_42	539861.822	635008.868	Balughat Bazar, Manikdi, Dhaka	5.9		30.0	20	Lower Modhupur Terrace
Dhk_43	546001.183	624015.105	Manda, Dhaka	2.0		30.0	20	Swamp / Depression
Dhk_44	538455.075	631081.218	East Shewrapara, Dhaka	7.5		30.0	20	Upper Modhupur Terrace
Dhk_45	536010.634	626431.552	Bashila, Dhaka	1.1		30.0	20	Back Swamp
Dhk_46	547379.066	635489.770	Pink City, Dumni, Dhaka	4.4		30.0	20	Swamp / Depression
Dhk_47	537745.941	641488.616	Uttaran Abashik Prakalpa, Dhaka	3.9		30.0	20	Upper Modhupur Terrace
Dhk_48	546481.069	641160.514	Teromukh, Uzampur, Dhaka	2.4		30.0	20	Lower Modhupur Terrace
Dhk_49	550146.733	624520.859	Naraibag, Demra, Dhaka	4.7		30.0	20	Natural Levee
Dhk_50	541657.054	638301.250	Uttara, Sector-4, Dhaka	7.5		30.0	20	Upper Modhupur Terrace
Dhk_51	547661.889	635503.001	Dumni, Fakirbari, Dhaka	4.4		30.0	20	Swamp / Depression
Dhk_52	540194.154	633499.907	Bhashantek (east), Dhaka	4.7		30.0	20	Deep Alluvial Gully
Dhk_53	548533.328	620405.182	Signboard (Matuail), Dhaka	2.1		30.0	20	Swamp / Depression

[Chittagong]

Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Ctg_01	687262.441	482968.025	Fatehabad, West Chowdhury hat, Chittagong	6.6	ADPC	30.0	20	Alluvial Fan
Ctg_02	692302.309	477812.344	CDA, Mohara, Chandgaon, Chittagong	2.0		34.5	23	Fluvio Tidal Plain

Boring No.	Coordinates		Location	Eleva -tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Ctg_03	686637.122	476958.631	Baizid Bostami Road, Nasirabad, Chittagong	13.5		30.0	20	Deep Valley Fill
Ctg_04	690708.755	472006.065	Meah Khan Nagar Road, Kalameah Bazar, Chittagong	4.7		34.5	23	Ancient Point Bar
Ctg_05	682792.234	474055.025	North Katalli, Cornel hat, Chittagong	5.4		30.0	20	Alluvial Fan
Ctg_06	681637.968	473669.259	Rail Road & Embankment, North Katalli, Chittagong	2.7		30.0	20	Inter Tidal Flat
Ctg_07	683556.576	473294.991	A.K. Khan Gowdan, Alankar, Chittagong	6.5		31.5	21	Alluvial Fan
Ctg_08	684137.761	465045.336	Ali Sha Para, South Halishahar, Cornel hat, Chittagong	3.5		30.0	20	Supra Tidal Flat
Ctg_09	685344.885	459827.026	Pool Chari Patenga, chittagong	4.5		30.0	20	Inter Tidal Flat
Ctg_10	687367.456	460247.986	East side of the Airport, South Patenga, Chittagong	5.0		30.0	20	Ancient Point Bar
Ctg_11	692463.690	480709.222	Kaptai Road, Burischar,Chittagong	4.2	GSB	28.5	19	Natural Levee
Ctg_12	693283.780	476873.950	CJM High School,Kalurghat, Chittagong	3.0	GSB	30.0	20	Natural Levee
Ctg_13	691467.931	475651.640	Nuruzzaman Nazir Road, Chandgaon, Chittagong	2.7	GSB	30.0	20	Fluvio Tidal Plain
Ctg_14	690512.694	474224.766	Badurtala, Chittagong	2.5	GSB	30.0	20	Alluvial Fan
Ctg_15	690654.226	474349.557	Bahaddarhat, Chittagong	3.0	GSB	30.0	20	Alluvial Fan
Ctg_16	688990.821	474667.608	Topkhana Road, Muradpur, Chittagong	6.3	GSB	30.0	20	Piedmont Plain
Ctg_17	687330.097	474770.523	Baizid Bostami Road, Nasirabad, Chittagong	9.5	GSB	30.0	20	Deep Valley Fill
Ctg_18	686873.193	477072.221	Tular Godown, Nasirabad, Chittagong	15.5	GSB	30.0	20	Deep Valley Fill
Ctg_19	688980.442	477866.845	Yar Ali Govt. Primary School, Panchlaish, Chittagong	5.7	GSB	30.0	20	Alluvial Fan
Ctg_20	689177.688	471070.611	Public Library, Chittagong	10.7	GSB	31.5	17	Deep Valley Fill
Ctg_21	685419.332	471855.908	Saraipara, Pahartoli, Chittagong	6.0	GSB	30.0	13	Alluvial Fan
Ctg_22	685270.750	469916.111	Chotopul, Halishahar, Chittagong	3.3	GSB	30.0	20	Alluvial Fan
Ctg_23	684203.583	470610.963	Halishahar "G" Block, Chittagong	3.5	GSB	30.0	20	Alluvial Fan
Ctg_24	684058.462	468363.614	Dhopa Dighir Par, Halishahar, Chittagong	3.4	GSB	30.0	20	Supra Tidal Flat
Ctg_25	683185.038	467184.359	Dhompara, Chittagong	3.5	GSB	33.0	22	Inter Tidal Flat
Ctg_26	683769.791	466145.344	EPZ, Chittagong	3.2	GSB	30.0	20	Inter Tidal Flat
Ctg_27	682404.353	467851.952	Anandabazar, Chittagong	5.0	GSB	36.0	24	Inter Tidal Flat
Ctg_28	683618.460	474110.919	Colonelhat, Chittagong	10.0	GSB	15.0	10	Piedmont Plain
Ctg_29	681216.137	477448.033	T & T Corner, Solimpur, Chittagong	4.5	ADPC	30.0	20	Supra Tidal Flat
Ctg_30	682270.078	476854.378	South silimpur (East side of the brickfield), Chittagong	9.0	ADPC	31.5	20	Piedmont Plain
Ctg_31	682674.482	470442.189	Abbas para , north of Rail Line, Chittagong	3.5	ADPC	30.0	20	Supra Tidal Flat
Ctg_32	684343.061	462208.441	Muslimbag, Patenga, Chittagong	4.5	ADPC	28.5	19	Lower Tidal Flat
Ctg_33	690425.054	475537.284	Chandgaon, R/A, Chittagong	3.5	ADPC	30.0	20	Fluvio Tidal Plain
Ctg_34	688054.229	472622.805	WASA, Chittagong	14.2	ADPC	30.0	20	Deep Valley Fill
Ctg_35	690027.779	473868.122	Kapasgola, Chittagong	3.7	ADPC	30.0	20	Alluvial Fan
Ctg_36	690384.660	462231.756	Buddhist Temple, KEPZ, Chittagong	10.5	ADPC	30.0	20	Gully Fill
Ctg_37	692193.121	460940.339	Bara Uthan, Anwar Ali Khan Road, Chittagong	5.8	ADPC	30.0	20	Alluvial Fan
Ctg_38	689309.704	458782.497	Rangadia, KAFCO, Chittagong	2.5	ADPC	30.0	20	Inter Tidal Flat
Ctg_39	685524.439	485768.536	Kulalpara Primary High School, Fatehpur	8.3	ADPC	30.0	20	Alluvial Fan

Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Ctg_40	686096.668	482410.228	Fateyabad College Gate, Fateyabad	11.5		30.0	20	Piedmont Plain
Ctg_41	693678.734	478852.061	Wasa Colony, North Mehera	2.0		30.0	20	Ancient Point Bar
Ctg_42	687570.804	477804.739	Kulgaon Residential Area (Oxygen)	9.9		30.0	20	Deep Valley Fill
Ctg_43	685661.086	472955.435	Shegun Bagan, Pahartali	21.2		30.0	20	Deep Valley Fill
Ctg_44	686397.780	471887.667	Batali Hill, Tigerpass Railway Colony	10.9		21.0	14	Piedmont Plain
Ctg_45	686381.715	469651.213	Jamburi Math, Agrabad	3.3		30.0	20	Depression
Ctg_46	679223.119	480418.758	Bhatiari, Ship Breaking Yard	4.5		21.0	14	Lower Tidal Flat
Ctg_47	687577.191	461640.288	Charbasti, Airport Colony	3.7		21.0	14	Ancient Point Bar
Ctg_48	690002.846	456661.894	Baktiar Para, Anwara	2.5		30.0	20	Supra Tidal Flat

[Sylhet]

Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Syl_01	689914.742	751662.222	Patan para , Sylhet	10.3	ADPC	30.0	20	Floodplain
Syl_02	686392.558	753445.131	Makoor High School, Sylhet	10.0		28.5	19	Floodplain
Syl_03	691242.788	752665.359	Naogoan Sadipur-2, Sylhet	10.5		30.0	20	Alluvial Fan
Syl_04	692495.512	753621.425	Mirapara (Near the Greenlad Kinder Garten) , Sylhet	10.2		30.0	20	Alluvial Fan
Syl_05	692354.667	756066.014	Agricultural University, Sylhet	18.7		30.0	20	Ridge
Syl_06	689404.721	755471.145	Amberkhana, Sylhet	18.0		30.0	20	Level Hill
Syl_07	686698.627	755920.374	Ansar VDP Madina Market, Sylhet	11.7		30.0	20	Floodplain
Syl_08	684676.399	756243.887	Kumargaon, Sylhet	10.5		30.0	20	Isolated Hills
Syl_09	685190.275	756638.539	Shahajalal University School, Sylhet	10.0		30.0	20	Piedmont Plain
Syl_10	693626.720	752427.852	Mirer Chak, Sylhet	10.0		30.0	20	Floodplain
Syl_11	695213.477	751554.705	West Muradpur, Sylhet	10.6	GSB	30.0	20	Floodplain
Syl_12	697030.546	753910.240	Surma valley abashik procolpo	8.0		30.0	20	Back Swamp
Syl_13	697635.829	756719.466	Khidirpur Khadim, Sylhet	13.0		22.5	15	Piedmont Plain
Syl_14	693151.163	752066.655	Mierer Chalk, Khadimpara, Sylhet	11.0		30.0	20	Point Bar
Syl_15	692650.620	753971.345	Borahanuddin road, Mirapara Sylhet	10.5		27.0	18	Alluvial Fan
Syl_16	692223.749	756396.546	Notun Bazar Uttar balur char, Sylhet	25.7		21.0	14	Valley
Syl_17	686878.571	755276.577	Shamimabad Abashik Area Bagbari, kansail road, Sylhet	9.8		30.0	20	Floodplain
Syl_18	688937.519	754829.551	Alia Madrasa, Sylhet	13.5		18.0	12	Ridge
Syl_19	688925.962	757427.928	West pir mohallah Jalalabad Residential area, Sylhet	24.0		18.0	12	Ridge
Syl_20	689099.384	757754.669	Lakkatura Tea Garden, Sylhet	20.5		18.0	12	Ridge
Syl_21	685722.036	757784.321	Shahajalal Science and Technology University Campus, Sylhet	15.0		25.5	17	Piedmont Plain
Syl_22	684103.021	757147.079	Nayabazar, Sylhet	10.0		30.0	20	Floodplain
Syl_23	683195.778	758304.328	West Muradpur, Sylhet	8.3		28.5	19	Floodplain
Syl_24	691266.300	750566.900	Sonargaon Abashik Area (R/A), Fenchuganj Road, Lalmatia, Sylhet	8.3		30.0	20	Back Swamp
Syl_25	688273.483	751787.411	South Surma Degree College, Pirijpur, Sylhet	9.5		30.0	20	Floodplain
Syl_26	687016.317	753401.274	Neyamatpur, Sylhet	10.3		30.0	20	Floodplain
Syl_27	684972.464	755096.954	Shuklampur, Sylhet	9.5		27.0	18	Floodplain

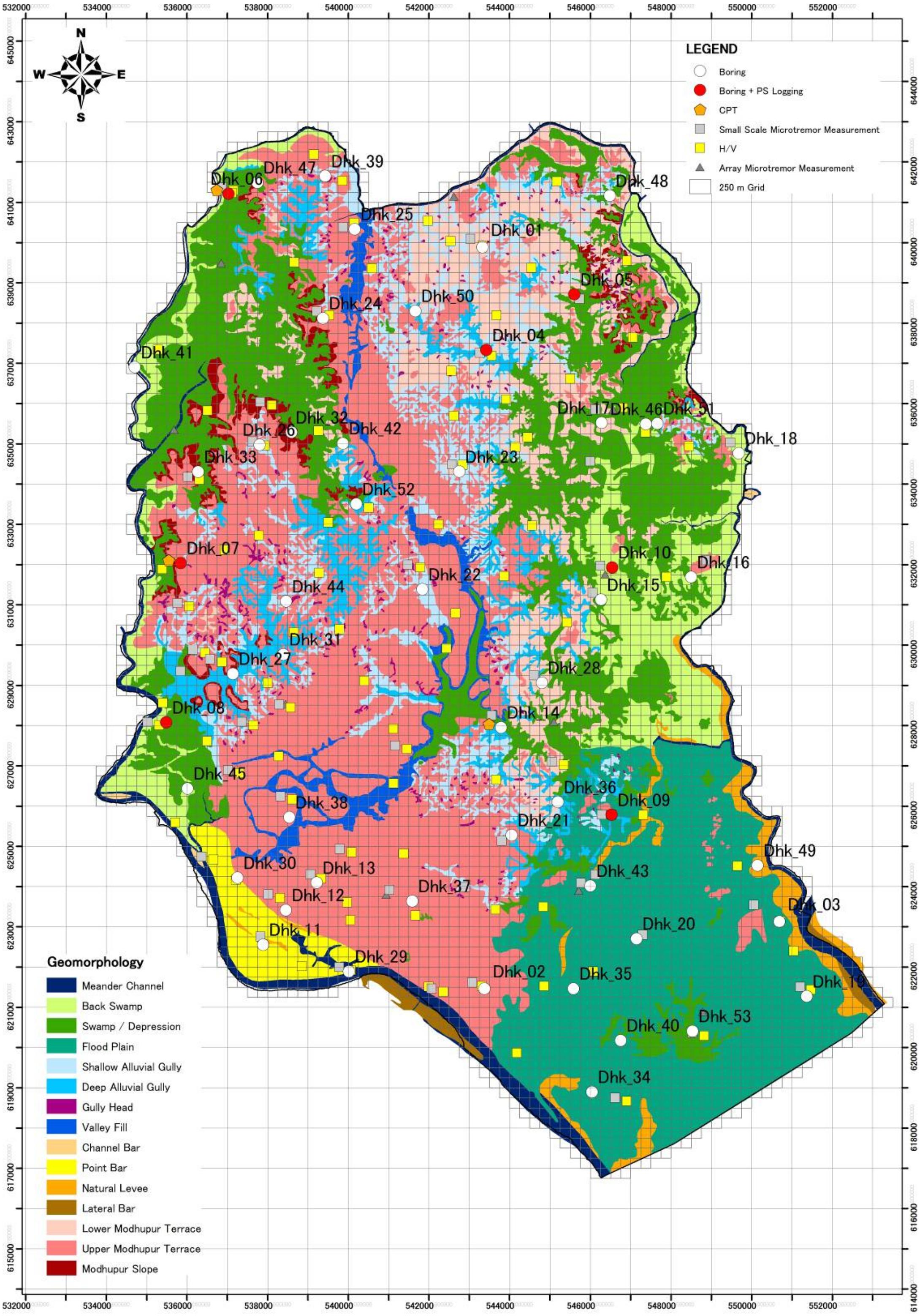
Boring No.	Coordinates		Location	Eleva-tion (m)	Execution Organization	Drilling Depth (m)	SPT (Times)	Geomorphic Unit
	Easting	Northing						
Syl_28	689336.137	753642.240	Sylhet Pilot High School, Sylhet	12.5		21.0	14	Floodplain
Syl_29	689606.238	750414.717	Chandi Telipara (infront of deep tubewell), south joinpur, Sylhet	8.5	ADPC	30.0	20	Isolated Hills
Syl_30	686571.463	750597.957	Ahmedpur, behind BRAC office, close to Dhk- Syl -sunamgong junction, Sylhet	9.5		30.0	20	Floodplain
Syl_31	695170.839	750640.094	Uttarbagh, just south end of 3 no Surma bridge, Sylhet	10.5		30.0	20	Floodplain
Syl_32	681733.925	754859.933	Basirpur (beside house of nurul hoque), Sylhet	9.6		30.0	20	Point Bar
Syl_33	683268.855	760776.368	Noagaon, East of Singra khal bridge, Sylhet	9.0		30.0	19	Floodplain
Syl_34	681793.748	759885.887	West of Badaghat Bazar (in front of sand stack), west of Singra khal bridge, Sylhet	8.0		30.0	20	Swamp / Depression
Syl_35	682058.180	757079.845	North of ghopal Bazar (north of hanif mia house), Sylhet	9.5		30.0	20	Back Swamp
Syl_36	697088.564	755739.114	BKSP, Sylhet	11.8		30.0	20	Alluvial Fan
Syl_37	688164.002	753841.585	Sheikh ghat colony, Sylhet	11.5		31.5	21	Level Hill
Syl_38	685073.666	758212.554	Dolia, dolia housing project, Behind (north) SUST boundary, Sylhet	10.3		30.0	20	Piedmont Plain

Boring density for the study area is 1 borehole in 8.4 square kilometer in Dhaka, in 6.1 square kilometer in Chittagong and in 4.2 square kilometer in Sylhet as shown in Table 2-2, and Figure 2-1 to Figure 2-3 show the boring location in each city.

Factual report of the boring is submitted by ADPC as an annex for this report.

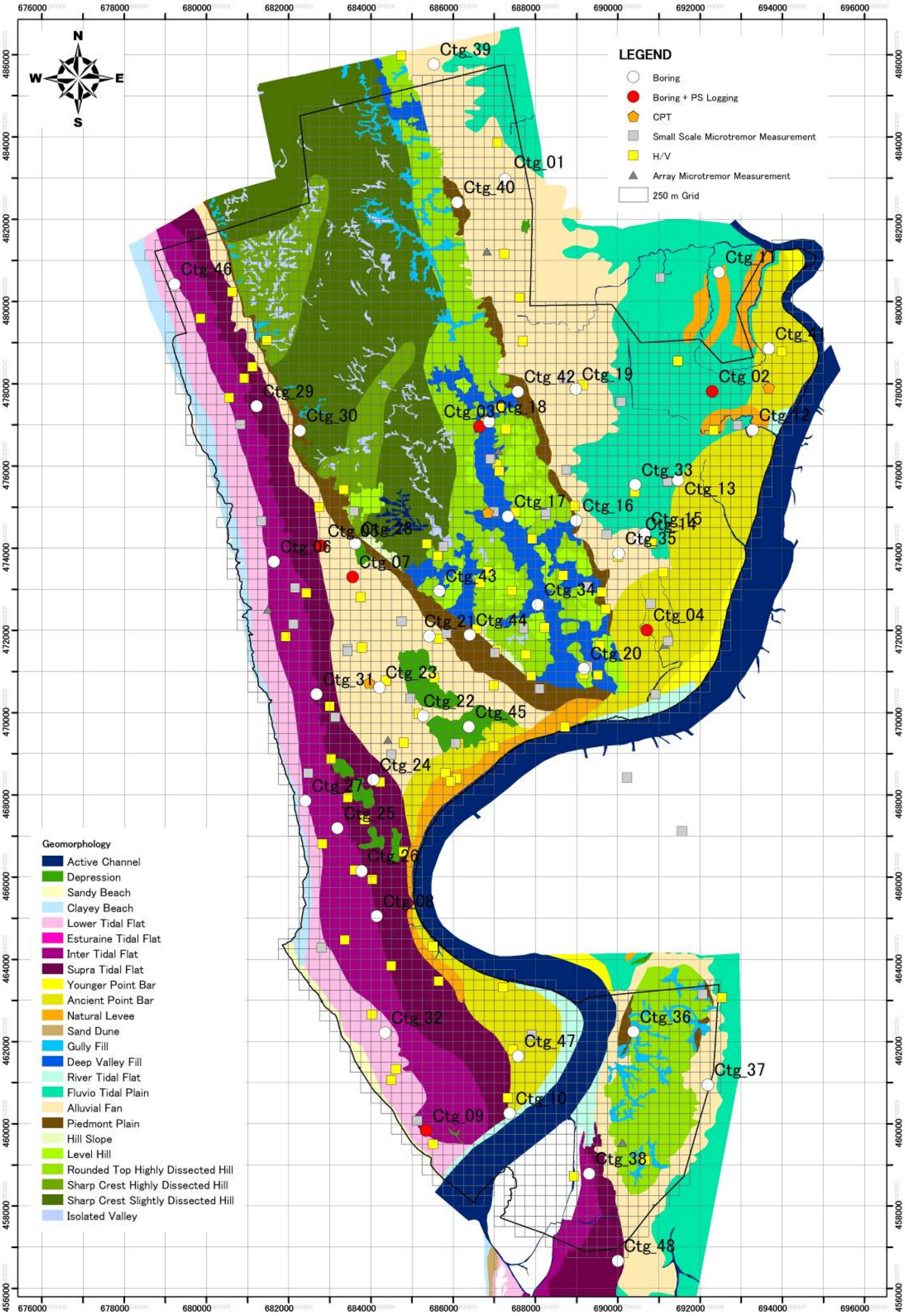
Table 2-2 Boring Density in each City

City	Number of Boreholes	Study Area (km^2)	Density	
			Area (km^2) covered by 1 borehole	Number of 250 m grid covered by 1 borehole
Dhaka	53	321	6.1	97 grids
Chittagong	48	233	4.9	78 grids
Sylhet	38	160	4.2	67 grids



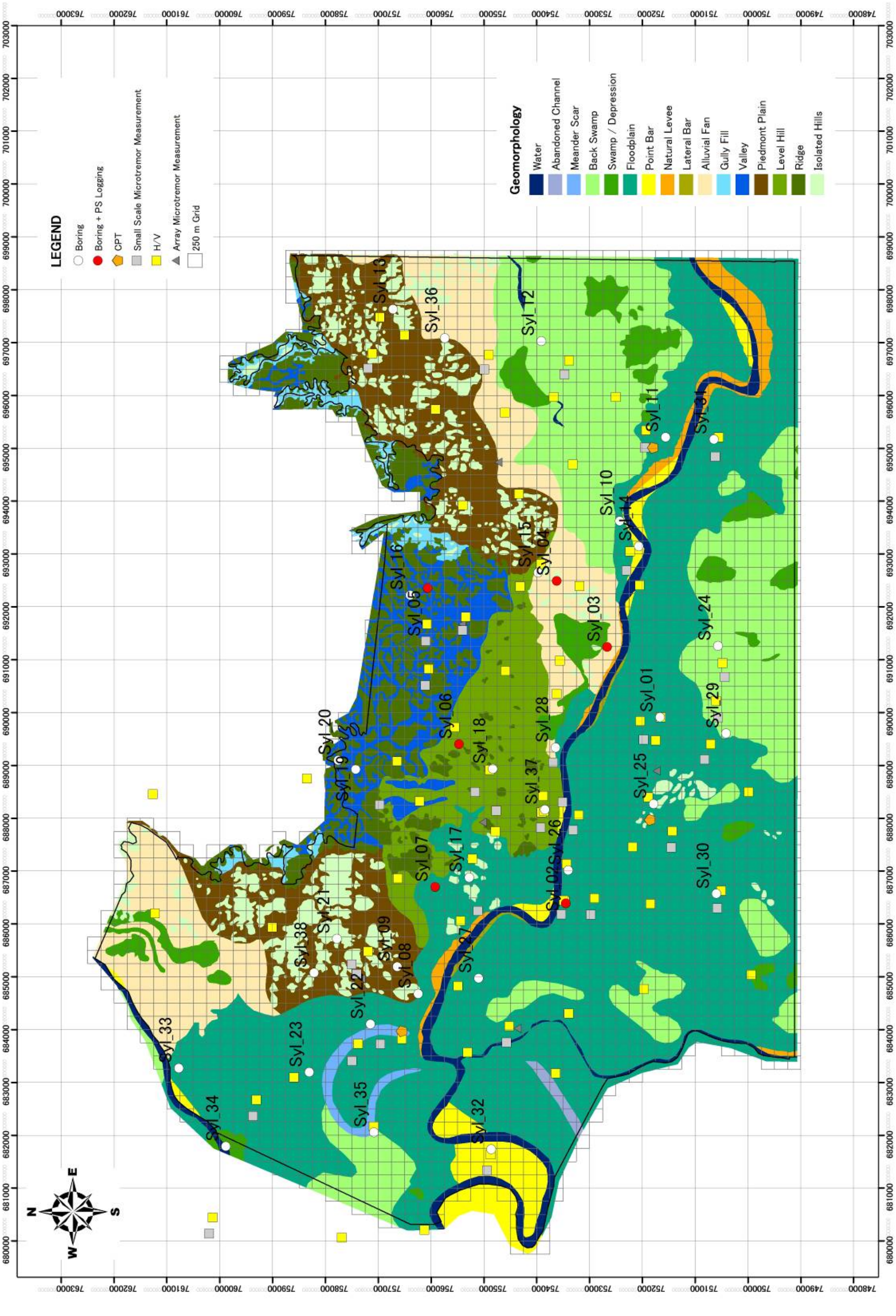
[Background: geomorphic map edited by GSB]

Figure 2-1 Boring Location in Dhaka



[Background: geomorphic map edited by GSB]

Figure 2-2 Boring Location in Chittagong



[Background: geomorphic map edited by GSB]

Figure 2-3 Boring Location in Sylhet

(2) Laboratory Test

Laboratory test was performed in order to know basic characteristics of soil for the geological classification. Results of the physical tests, and the mechanical tests were used for the soil classifications in the boring logs / clarification of the soil characteristics, and for the setup of the geotechnical properties (shear strength) for the landslide analysis.

The laboratory test of physical tests and mechanical tests were carried out using disturbed samples by SPT and undisturbed samples, respectively. Table 2-3 shows work quantities of the laboratory test.

Table 2-3 Work Quantities of Laboratory Test

Test Item		Execution Organization	Dhaka	Chittagong	Sylhet	Total
Physical Test	Grain Size Analysis	ADPC	446	246	178	870
		GSB	190	195	185	570
		Sub-total	636	441	363	1,440
	Specific Gravity	ADPC	167	157	53	377
		GSB	54	54	53	161
		Sub-total	221	211	106	538
	Natural Moisture Contents	ADPC	43	73	59	175
		GSB	9	11	9	29
		Sub-total	52	84	68	204
	Atterberg Limit	ADPC	34	46	29	109
		GSB	16	14	12	42
		Sub-total	50	60	41	151
Mechanical Test	Dry / Bulk Density	ADPC	32	18	23	73
		GSB	9	11	9	29
		Sub-total	41	29	32	102
	Unconfined Compression Test	ADPC	48	34	37	119
		GSB	10	11	9	30
		Sub-total	58	45	46	149
	Direct Shear Test	ADPC	49	46	43	138
		GSB	18	18	17	53
		Sub-total	67	64	60	191
	Consolidation Test	ADPC	5	9	17	31
		GSB	7	6	6	19
		Sub-total	12	15	23	50
	Tri-axial Test	ADPC	11	11	5	27
		GSB	4	2	4	10
		Sub-total	15	13	9	37

Factual report of the laboratory test is submitted by ADPC as an annex for this report.

2.2. PS Logging

(1) Outline

PS logging was conducted in order to directly obtain S-wave velocity.

Asian Institute of Technology (hereinafter referred to as "AIT") under ADPC was carried out PS logging at 7 points in Dhaka, 6 points in Chittagong and 6 points in Sylhet, and their location is shown in Figure 2-1 to Figure 2-3 (refer to circle marked out by red color in the figures).

Table 2-4 shows reference of number alignment between boring code and PS logging code.

Table 2-4 Number Alignment between Boring Code and PS Logging Code

Dhaka		Chittagong		Sylhet	
Boring Code	PS Code	Boring Code	PS Code	Boring Code	PS Code
Dhk_04	D2	Ctg_02	C2	Syl_02	S5
Dhk_05	D7	Ctg_03	C5	Syl_03	S4
Dhk_06	D1	Ctg_04	C3	Syl_04	S1
Dhk_07	D5	Ctg_05	C6	Syl_05	S2
Dhk_08	D4	Ctg_07	C4	Syl_06	S3
Dhk_09	D6	Ctg_09	C1	Syl_07	S6
Dhk_10	D3				

Factual report of PS logging is submitted by ADPC as an annex for this report, and more detail data is provided by the report.

(2) Procedure of Field Work and Analysis

1) A wooden plank with an approximate dimension of 0.15 m x 0.15 m x 1.5 m is fixed to the ground. Sand bags are placed on the top. The wooden plank is placed about 3 m from the borehole as shown in Figure 2-4.

Figure 2-4 Wooden Plank as the Vibration Source

2) A trigger is fixed to the hammer as shown in Figure 2-5. The trigger starts data

acquisition when an excitation exceeds a certain threshold.

Figure 2-5　Trigger fixed to the Hammer

3) Cables are wired from the geophone (Figure 2-6) and the trigger to the data acquisition unit (Figure 2-7). Signals in the vertical, radial and transverse directions are recorded by the data acquisition unit.

Figure 2-6　Geophone

Figure 2-7　Data Acquisition Unit

4) The geophone is lowered into the borehole as shown in Figure 2-8. Then, air is pumped into the air bag to fix the geophone to the casing (PVC pipe) at 1 m interval in depth basically.

Figure 2-8　Geophone in the Borehole

5) Excitations are generated by hitting the wooden plank in three directions by the hammer.

Figure 2-9 Direction of Excitations

6) Data is recorded in the data acquisition unit. Figure 2-10 illustrates a typical dataset in obtaining the arrival time of S-wave. Hitting the wooden plank in opposite directions generates signals as shown in the figure. The time that two curves begin to separate is the arrival time of shear wave. By doing the same analysis for every depth, S-wave profiles are obtained throughout the depth of the borehole.

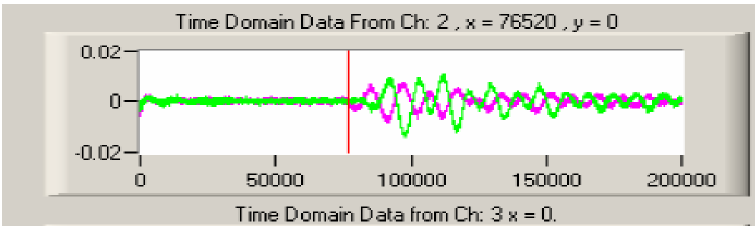
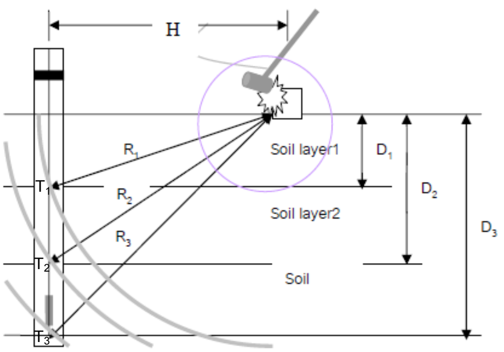


Figure 2-10 Determination of the Arrival Time of S-wave

7) Using the raw data of the test depth (Di), the shortest pass (Ri) and the recorded arrival time of S-wave (Ti) according to the AIT's report, the travel time at each test depth (TTi) is calculated as shown in Figure 2-11.



TTi = Ti * Di / Ri

where,
TTi: Travel time at depth "i"
Ti: Arrival time
Di: Recorded depth from ground surface
Ri: The shortest path from the plank to the geophone

Figure 2-11 Calculation of the Travel Time

(3) Results

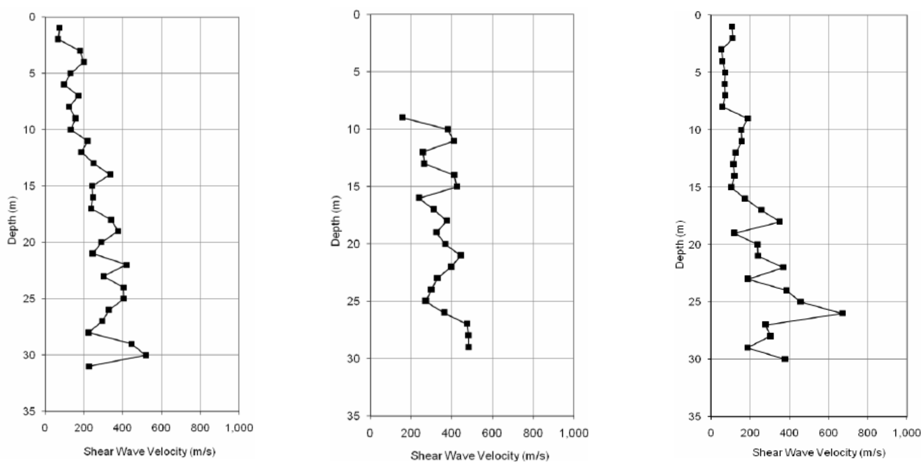
The actual test depth is tabulated in Table 2-5. Work plan of the test depth was 30 m, however, in some locations did not reach the geophone to the 30 m in depth due to adverse conditions of PVC.

Table 2-5 Summary of Test Depth

Dhaka			Chittagong			Sylhet		
Bor. Code (PS Code)	Test Depth (m)		Bor. Code (PS Code)	Test Depth (m)		Bor. Code (PS Code)	Test Depth (m)	
	From	To		From	To		From	To
Dhk_04 (D2)	0.97	30.83	Ctg_02 (C2)	1.02	26.85	Syl_02 (S5)	1.02	23.69
Dhk_05 (D7)	9.00	28.87	Ctg_03 (C5)	0.98	28.90	Syl_03 (S4)	1.01	29.03
Dhk_06 (D1)	1.02	30.25	Ctg_04 (C3)	1.00	30.05	Syl_04 (S1)	1.04	29.86
Dhk_07 (D5)	0.98	23.11	Ctg_05 (C6)	1.00	25.96	Syl_05 (S2)	1.00	29.47
Dhk_08 (D4)	0.98	31.84	Ctg_07 (C4)	1.06	29.92	Syl_06 (S3)	1.00	27.96
Dhk_09 (D6)	1.00	27.70	Ctg_09 (C1)	1.00	29.54	Syl_07 (S6)	1.04	22.59
Dhk_10 (D3)	1.06	25.18						

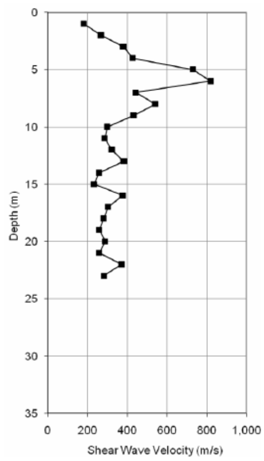
Preliminary results of the PS logging carried out by AIT are as shown in Figure 2-12. In here, dynamic characteristics by each soil layer is required for the amplification analysis, consequently, the travel time is prepared / calculated (see Figure 2-13) for setup of the characteristics, and the detailed procedure of the setup is described in Section 4.2.3.

[Dhaka]

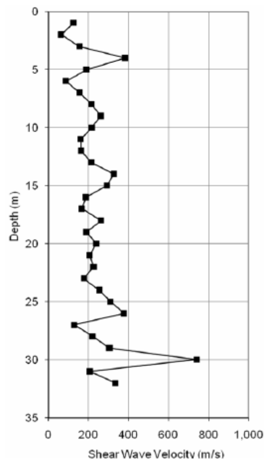


[Dhk_04 (D2)] [Dhk_05 (D7)] [Dhk_06 (D1)]

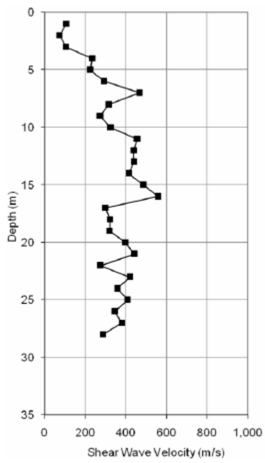
Figure 2-12 Preliminary Results of PS logging



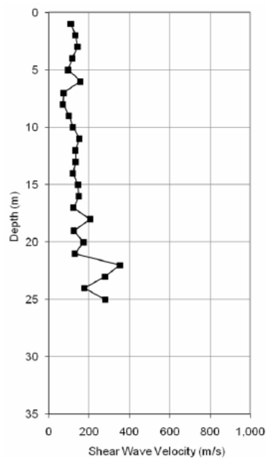
[Dhk_07 (D5)]



[Dhk_08 (D4)]

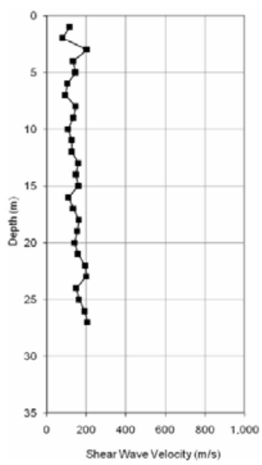


[Dhk_09 (D6)]

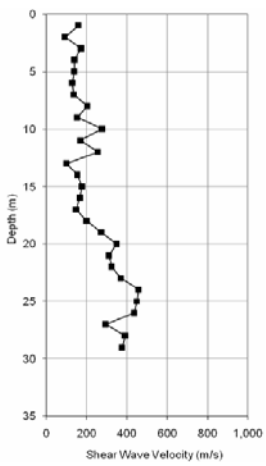


[Dhk_10 (D3)]

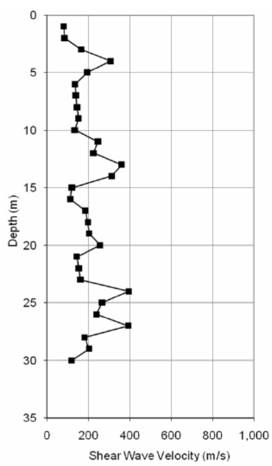
[Chittagong]



[Ctg_02 (C2)]

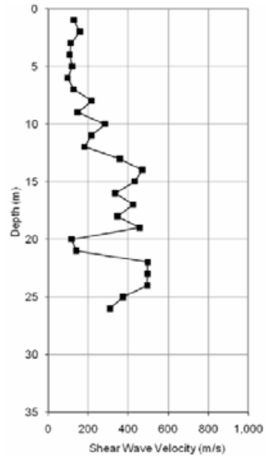


[Ctg_03 (C5)]



[Ctg_04 (C3)]

Figure 2-12 (cont.) Preliminary Results of PS logging



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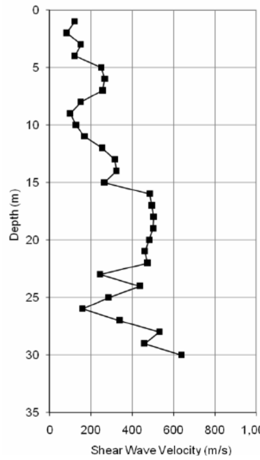
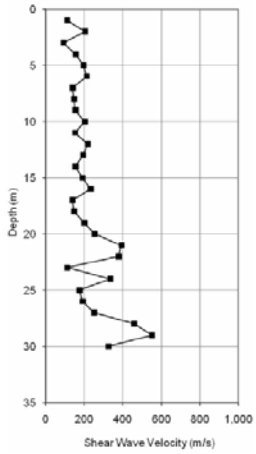
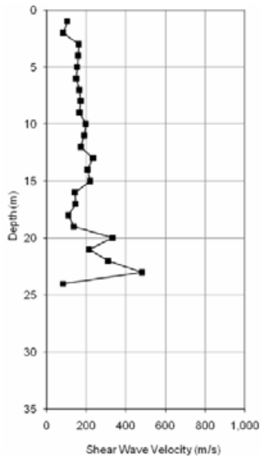


[Ctg_07 (C4)]

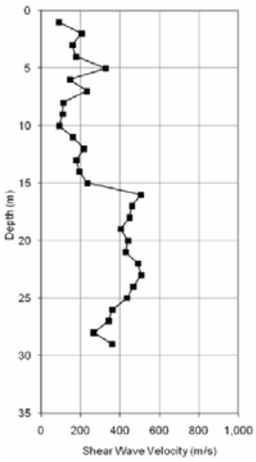


[Ctg_09 (C1)]

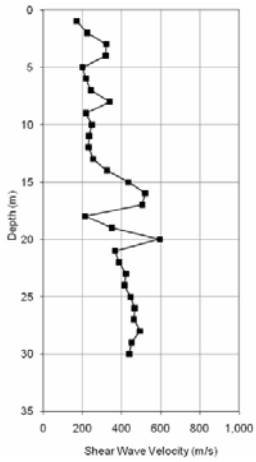
[Sylhet]



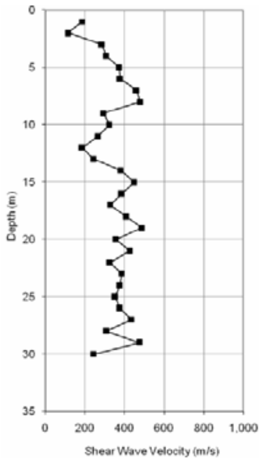
[Syl_02 (S5)]



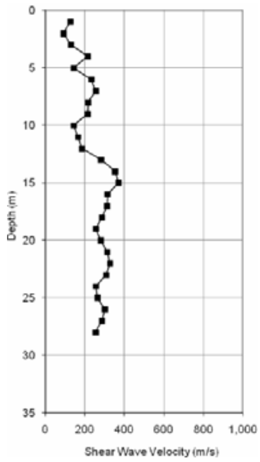
[Syl_03 (S4)]



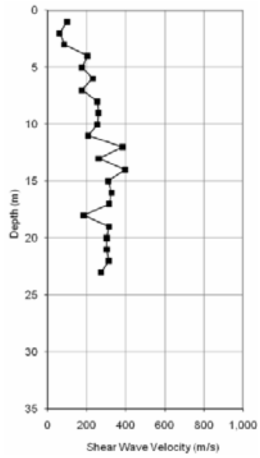
[Syl_04 (S1)]



[Syl_05 (S2)]



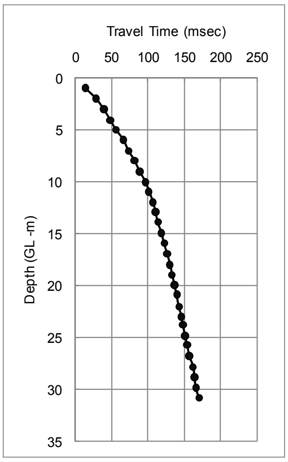
[Syl_06 (S3)]



[Syl_07 (S6)]

Figure 2-12 (cont.) Preliminary Results of PS logging

[Dhaka]



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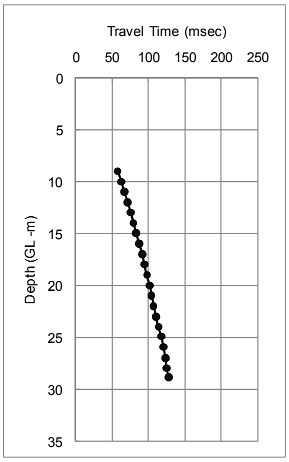
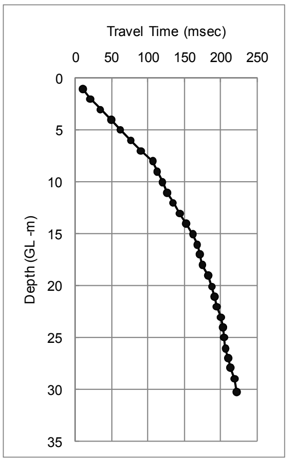
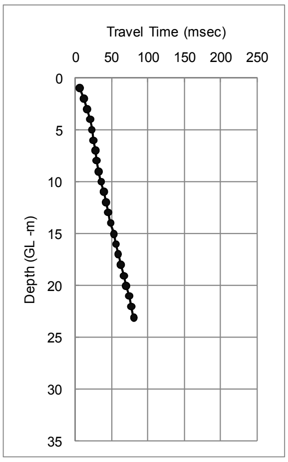


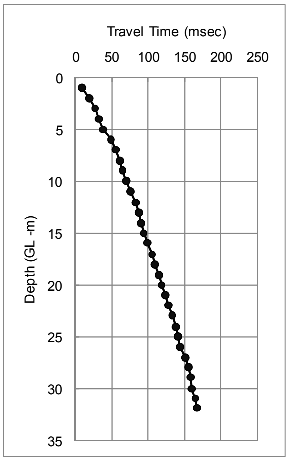
[Dhk_05 (D7)]



[Dhk_06 (D1)]



[Dhk_07 (D5)]



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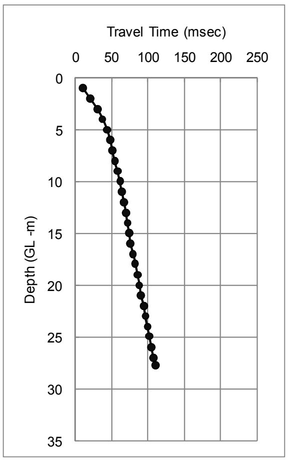

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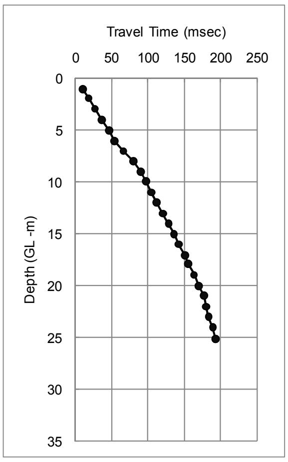
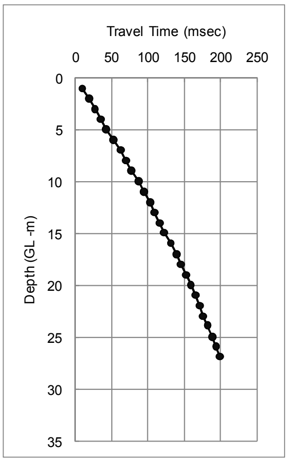


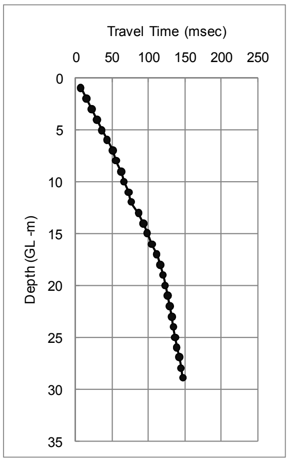
[Dhk_10 (D3)]

Figure 2-13 Graph of Travel Time at each PS Logging Point

[Chittagong]



[Ctg_02 (C2)]



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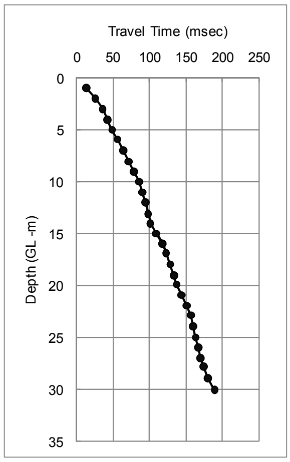

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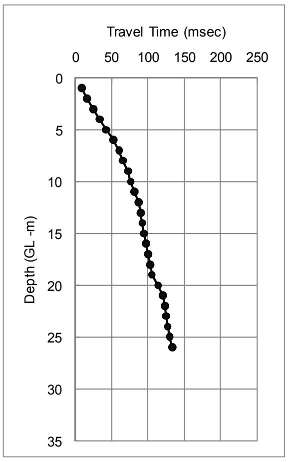
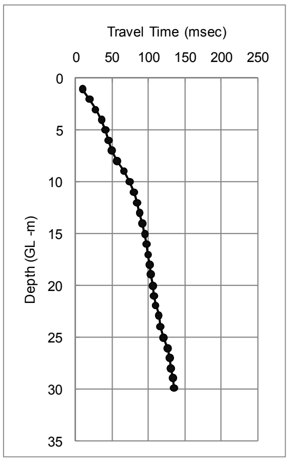


[Ctg_05 (C6)]



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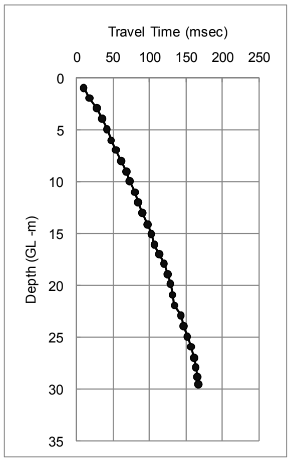
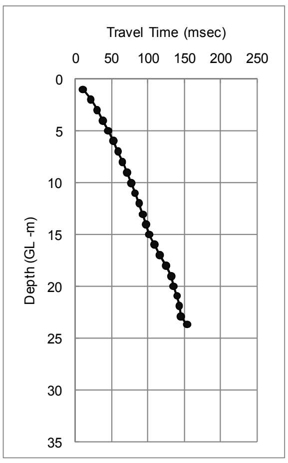
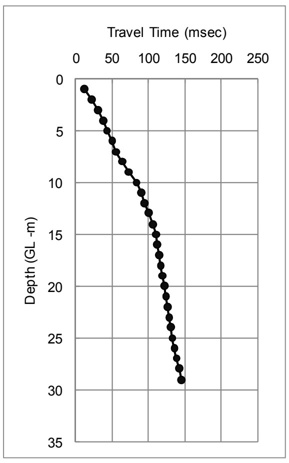


[Ctg_09 (C1)]

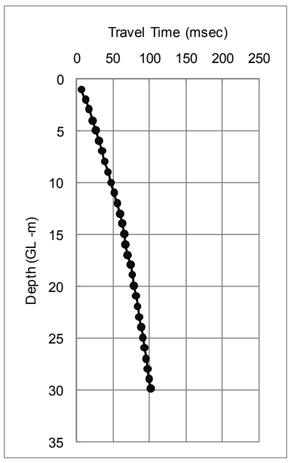
[Sylhet]



[Syl_02 (S5)]

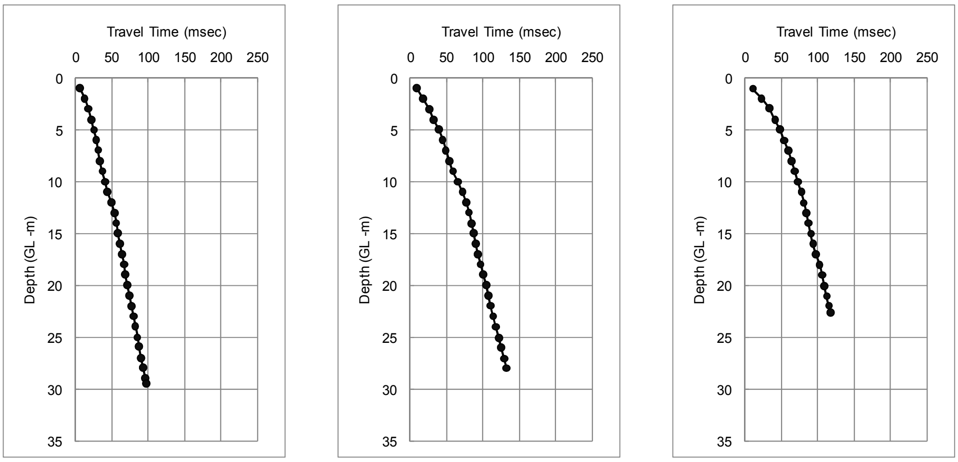


[Syl_03 (S4)]



[Syl_04 (S1)]

Figure 2-13 (cont.) Graph of Travel Time at each PS Logging Point



[Syl_05 (S2)] [Syl_06 (S3)] [Syl_07 (S6)]

Figure 2-13 (cont.) Graph of Travel Time at each PS Logging Point

(4) Recommendation

It should be noted that PS logging results provide key properties, such as S-wave velocity, to analyze subsurface amplification, thus increasing PS logging contributes to be the higher accuracy of the geological model in the future in Bangladesh.

2.3. Cone Penetration Test

Cone penetration test (hereinafter referred to as "CPT") has both advantages and disadvantages. The advantages are that it is possible to get continuous / repeatable data and to be less operator error, while the disadvantages are that it is less populated because of newer technology, soil classification is indirect / included uncertainties due to no soil sample and it is difficult to penetrate in gravels / cobbles. The advantages have not been exceeded in comparison with the disadvantages so far, hence, CPT should be used for the supplemental technique of the existing soil investigations such as the boring / SPT and collection / accumulation of data that is the relationship between CPT results and some geotechnical properties are required to become the reasonable method in the future.

CPT was carried out using 20 ton hydraulic thrust equipment in accordance with ASTM D5778-95 in 3 cities as shown in Table 2-6 and Figure 2-14.

Table 2-6 Summary of CPT in each City

[Dhaka]

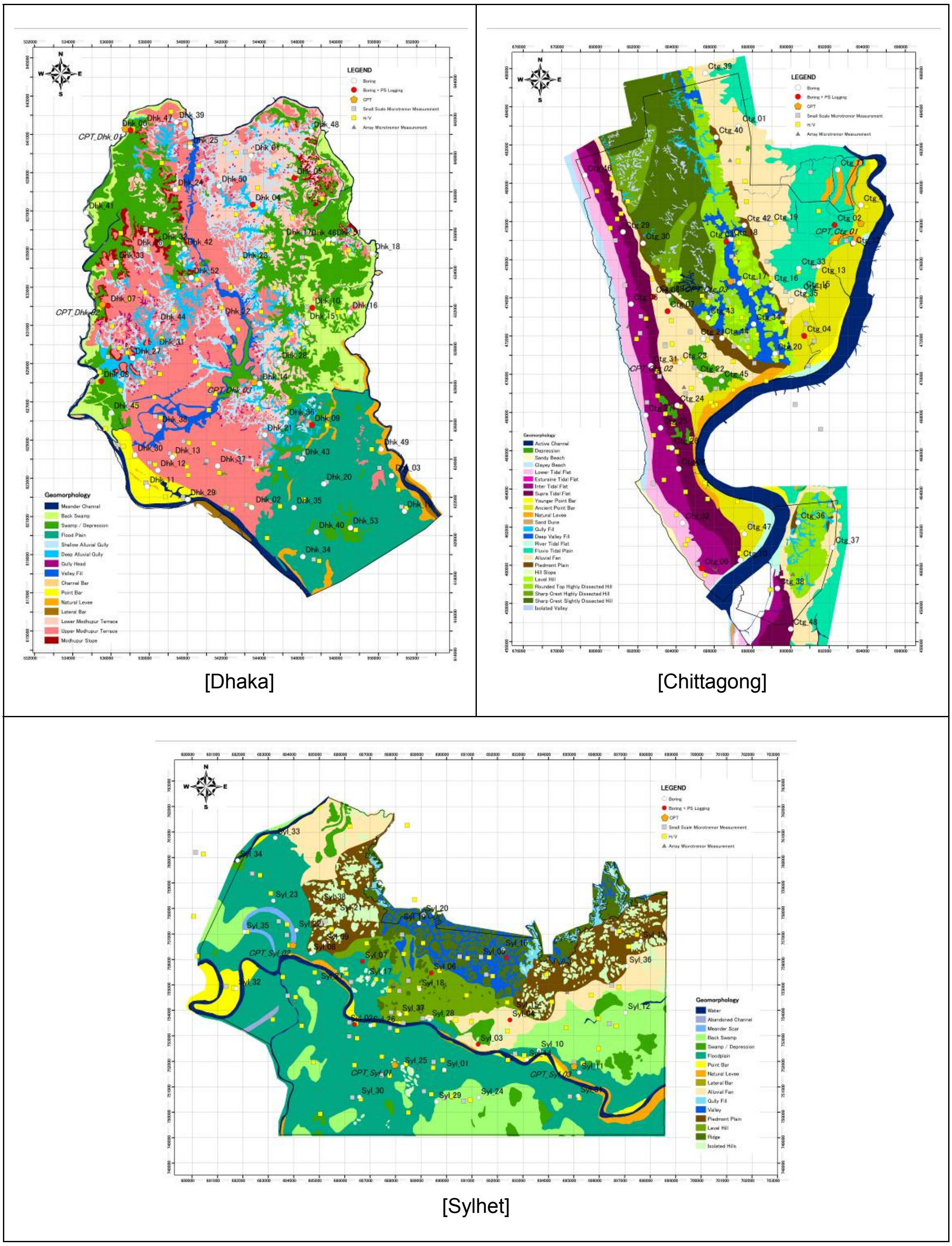
No.	Corresponding Boring No.	Location	Coordinates		Depth (m)	Geomorphic Unit
			Latitude	Longitude		
CPT_Dhk_01	Dhk_06	Ashulia, Dhaka	23^{0}53' 05.1" N	90^{0}21' 39.4" E	30	Flood plain
CPT_Dhk_02	Dhk_07	Mirpur 01, Dhaka	23^{0}48' 06.1" N	90^{0}20'56.58" E	30	Madhupur Terrace
CPT_Dhk_03	Dhk_14	Aftabnagar Project, Dhaka	23^{0}43'26" N	90^{0}25'36.98" E	30	Floodplain

[Chittagong]

No.	Corresponding Boring No.	Location	Coordinates		Depth (m)	Geomorphic Unit
			Latitude	Longitude		
CPT_Ctg_01	Ctg_12	Kalighat, Chittagong	22^{0}23'52.87" N	91^{0}52'54" E	30	Ancient Point Bar
CPT_Ctg_02	Ctg_23	Halishahar, Chittagong	22^{0}20'3.37" N	91^{0}47'11" E	30	Alluvial Fan
CPT_Ctg_03	Ctg_17	Nasirabad, Chittagong	22^{0}22'17" N	91^{0}48'53.6" E	23	Deep Valley Fill

[Sylhet]

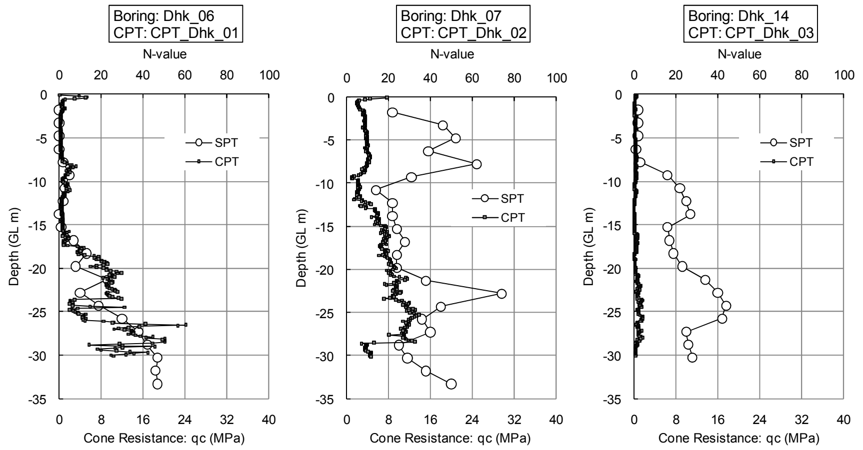
No.	Corresponding Boring No.	Location	Coordinates		Depth (m)	Geomorphic Unit
			Latitude	Longitude		
CPT_Syl_01	Syl_25	South Surma Degree College, Sylhet	24 ^{0}52'20" N	91^{0}51'39" E	30	Floodplain
CPT_Syl_02	Syl_22	Trimukhi, Tukerbazar, Sylhet	24 ^{0}54'54.5" N	91^{0}49'18.8" E	25	Floodplain
CPT_Syl_03	Syl_11	Shahparan Bridge, Muradpur, Sylhet	24 ^{0}52'14.9" N	91^{0}55'49.8" E	24	Floodplain



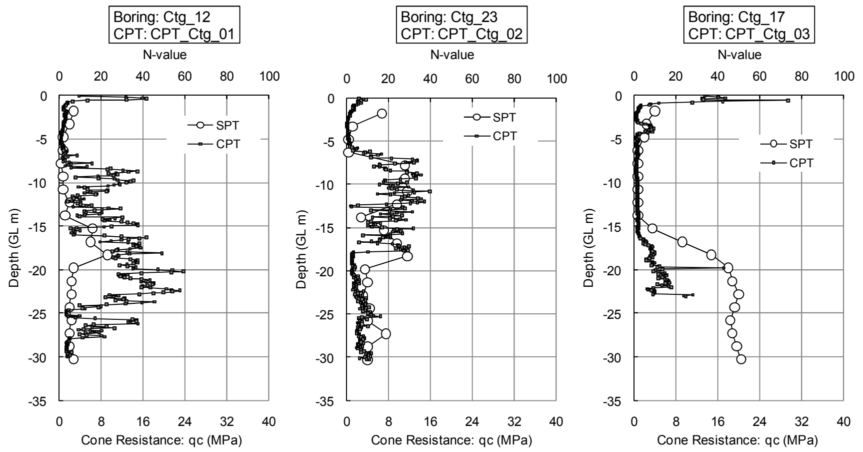
[Background: geomorphic map edited by GSB]

Figure 2-14 CPT Location in each City

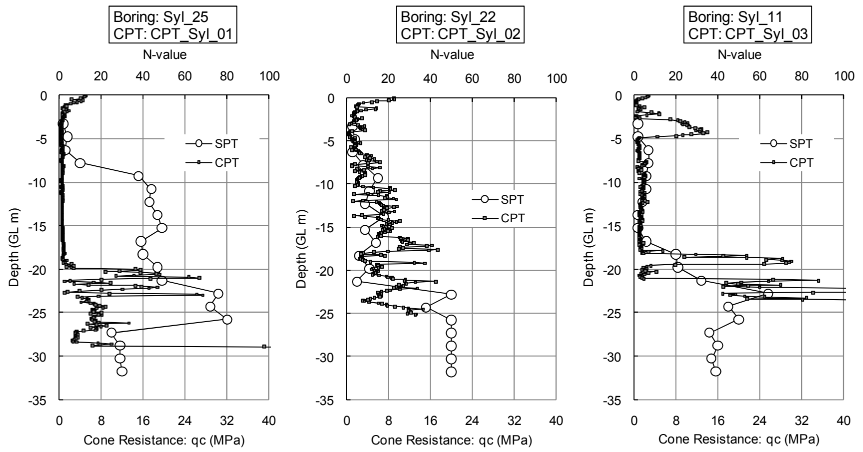
To effectively use the results of CPT, more comparative investigations are required. For instance, SPT N-value and cone resistance (qc) is compared as shown in Figure 2-15 and Figure 2-16.



[Dhaka]

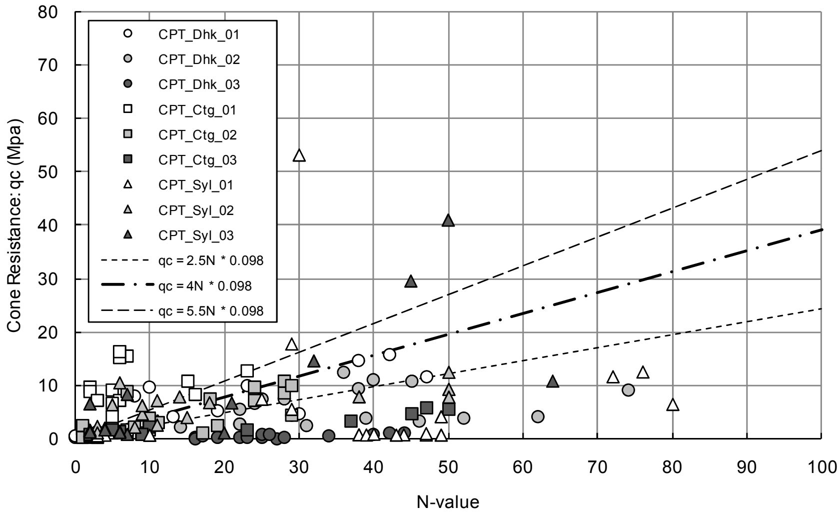


[Chittagong]



[Sylhet]

Figure 2-15 SPT N-value Graph and Cone Resistance Graph of each Location in 3 Cities



* Each line shows Meyerhof (1956) relationships.

Figure 2-16 Relationship between SPT N-value and Cone Resistance (qc)

Cone resistance (qc) tends to be almost lower than general relationship provided by Meyerhof (1956), which is “qc = (2.5 to 5.5) N * 0.098 (MPa)”. One of the reason why obtained data and Meyerhof relationship are different is that CPT locations and their corresponded boring (SPT) locations were not same in this project. Also, other verification studies should be required to clarify the cause of the difference and to get more accurate relationships in Bangladesh.

3. Geophysical Exploration

3.1. Outline of Survey

3.1.1. Purpose

The purpose of the geophysical survey in this project is below.

(1) To provide shear wave velocity data *Vs* for Engineering Geological Model,

(2) To estimate shear wave velocity *Vs* structure in the study area for Seismic Hazard Analysis.

3.1.2. Survey Types

The following four types of surveys are conducted.

(1) Multi-channel Analysis of Surface Wave (MASW)
To check shear wave velocity *Vs* structure at shallower part, and combining with the results by SSMM

(2) Small Scale Micro-tremor Measurement (SSMM)
To estimate average share wave velocity *Vs* up to 30 m (AVS30) combining with the result by MASW

(3) Array Micro-Tremor Measurement (AMT)
To estimate deeper share wave velocity *Vs* structure

(4) Single Micro-Tremor Measurement (Single MT)
To estimate predominant period of the site

3.1.3. Survey Quantity

The number of survey points by survey items is shown in Table 3-1.

Table 3-1 Number of Survey Sites for Geophysical Survey

Item / Location	Shallow Seismic Survey		Deep Survey	H/V
	MASW	SSMM	Array MT	Single MT
Dhaka	50 (49)	50 (49)	10	97 (91)
Chittagong	41 (39)	41 (39)	6	86 (82)
Sylhet	35 (33)	35 (33)	6	74 (66)

Note: ( ) are actually analyzed.

3.1.4. Summary of Technique

Four types of seismic survey technique are used as geophysical survey for this project. These techniques are using surface wave in common. Surface wave is the wave which energy travels along (or near to) the surface, and which motion falls off rapidly with depth from the surface. Surface wave is including mainly Rayleigh and Love waves. To obtain Vs structure, Surface wave survey is developed according to the above feature.

In geophysical survey, Rayleigh wave is used mostly. The particle motion near the surface is elliptical and retrograde (i.e. the particle moves opposite to the direction of propagation at the top of its elliptical path) in the vertical plane containing the direction of propagation. Its amplitude decreases exponentially with depth, and the elastic properties to a depth of about one wavelength determine its velocity. For a Poisson ratio of σ=1/4, the Rayleigh-wave velocity is around 90 % of the S-wave velocity.

The main feature of surface wave is dispersion of wave by frequency. The velocity of surface wave is varied with frequency in the presence of subsurface layer structure. On this feature, the measurement of surface wave can draw the dispersion curve, a plot of phase velocity as a function of frequency. Higher frequency wave corresponds to the velocity of shallower layer, and lower frequency wave corresponds to the velocity of deeper layer, in general. Additionally, since the phase velocity of surface wave is correlated to the *Vs*, *Vs* is estimated from phase velocity simply. Thus, *Vs* structure is analyzed from surface wave measurement.

Surface wave is generated by both artificial and natural sources. Among the four techniques, only MASW uses artificial seismic source, and others use natural source, i.e. microtremor. The exploration depth depends on the frequency of measurement and survey scale, because the low frequency wave has long wave length, survey size is better to be larger than one wave length. General specifications of surface wave survey for this project are shown in Table 3-2.

Table 3-2 General Specification of Geophysical Survey for this Project

Item	Source Type	Target frequencies (sensor)	Survey Scale	Target Depth
MASW	Active (Hammering)	5 ~ 30 Hz Geophone	22 m	1 ~ 15 m
SSMM	Passive (Microtremor)	2 ~ 10 Hz Geophone	60 m	5 ~ 30 m
AMT	Passive (Microtremor)	0.5 ~ 5 Hz Seismometer	125 ~ 500 m	50 ~ 200 m
Single MT	Passive (Microtremor)	0.5 ~ 10Hz Seismometer	point	5~50m

3.2. Shallow Seismic Survey

Shallow seismic survey consists of MASW and SSMM.

3.2.1. Measurement and Analysis Method

(1) Multi-channel Analysis of Surface Wave (MASW)

Multi-channel Analysis of Surface Wave Survey (MASW) is one of the geophysical surveys to detect the distributions of S-wave velocity *Vs* profile. 12 channel seismic sensors (receivers) are installed along a line on the ground surface, and acrylic board is installed between each receiver. When shooting an acrylic board by a big hammer, generated elastic wave including different frequencies is received by receivers. In general the higher frequency elastic wave is influenced by the shallower zone of *Vs* distribution, on the contrary, the lower frequency elastic wave is influenced by the deeper zone of *Vs* distribution. In this principle, the *Vs* distribution section is analyzed.

The measuring procedure in this project is shown as follows:

① To decide the measuring line
② To set receivers along the line at the ground surface. The intervals of each geophone are 2m.
③ To set an acrylic board at a half interval outside the line
④ To shoot it vertically. Then generated elastic waves are recorded by receivers.
⑤ To shift the acrylic board between second receiver and the third receiver, and shoot it vertically. Then generated elastic waves are recorded at receivers.
⑥ To iterate this procedure up to setting the acrylic board at an half interval outside the other side of the line.

The dimension of MASW is as follows:

- Seismic source: hammering (artificial)
- Geophone spacing: 2m
- Number of Geophones: 12
- Measuring line length: 22m
- Shot number: 13 points, 11 between geophones and 2 outside of measuring line.
- Natural frequency of Geophone: 10 Hz
- Sampling rate: 1 msec
- Measurement duration: 2 sec

The investigation depth of MASW of this project can be estimated about 15m, because the target frequencies, receiver spacing and length of measuring line effect the investigation depth. This is not enough depth to determine the average *Vs* between ground surface and 30m depth (*AVS 30*), but, since the source is artificial, this method has the benefit of controlling the seismic source and easiness to separate signal and noise. The purpose of MASW this time is to get shallower *Vs* structure and to get *AVS 30* combining with the SSMM result mentioned below. MASW measurement line is set on the same place as SSMM (Figure 3-1), and the shot-receiver configuration of MASW is shown in Figure 3-2.

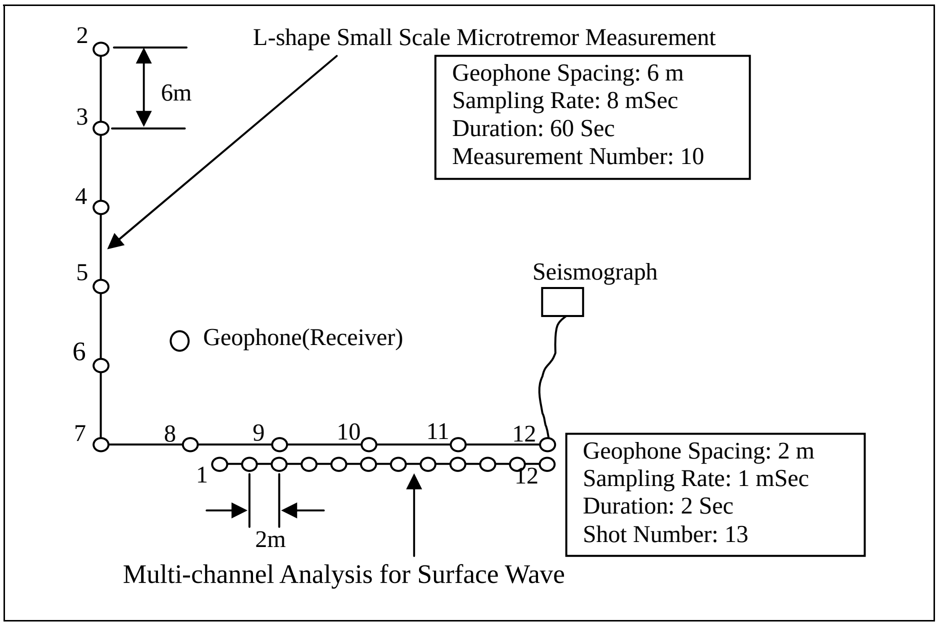


Figure 3-1 Schematic Diagram for Shallow Seismic Survey

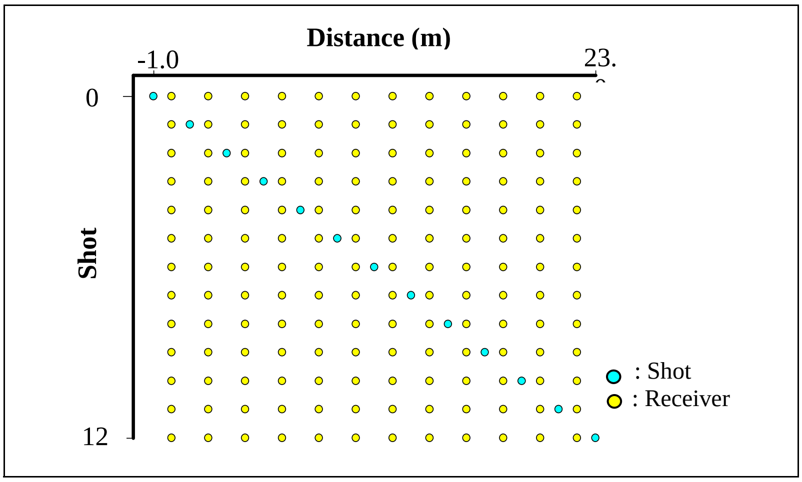


Figure 3-2 Shot-Receiver Configuration for MASW

(2) Analysis of MASW

In the phase velocity analysis, SPAC (Spatial Autocorrelation) method (Okada, 2003) is employed. Okada (2003) shows Spatial Autocorrelation function $\rho(\omega, r)$ is expressed by Bessel function.

$$\rho(\omega, r) = J_0(\omega r / c(\omega)) \quad \text{--------------------(1)}$$

Where, r is the distance between receivers, ω is the angular frequency, $c(\omega)$ is phase velocity of waves, J_0 is the first kind of Bessel function. The phase velocity can be obtained at each frequency using equation *(1)*. Figure 3-3 shows an example the dispersion curve in this survey, in the frequency range between 5 and 30 Hz.

A one-dimensional inversion using a non-linear least square method has been applied to the phase velocity curves. In the inversion, the following relationship between P-wave velocity (Vp) and Vs (Kitsunezaki et. al., 1990):

$$Vp = 1.29 + 1.11Vs \quad \text{-------------------------- (2)}$$

where, Vs is S-wave velocity (km/s), Vp is P-wave velocity (km/s). In order to assume density ρ (g/cm^3) from S-wave velocity, the relationship of Ludwig et al. (1970) is used.

$$\rho = 1.2475 + 0.399Vp - 0.026Vp^2 \quad \text{------- (3)}$$

These calculations are carried out along the measuring line, and the S-wave velocity distribution section was analyzed, then summarized to one dimensional structure, a sample is of which is shown in Figure 3-4.

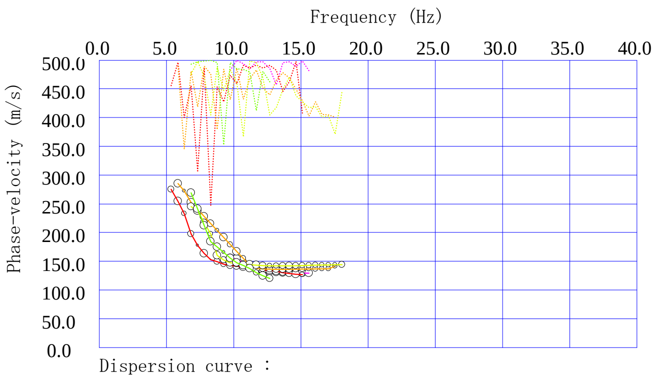


Figure 3-3 Sample of Dispersion Curve (MASW)

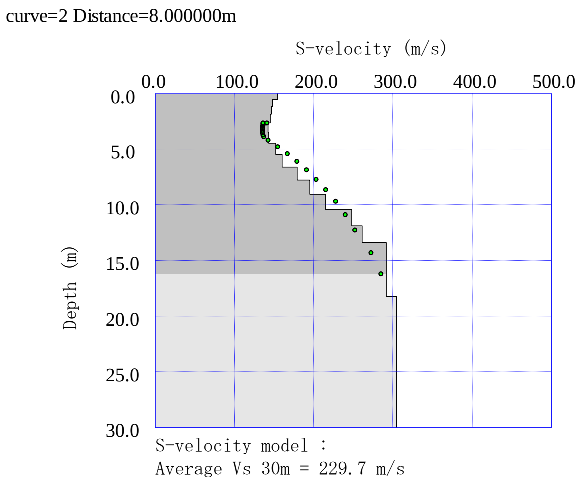


Figure 3-4 An Example of one Dimensional Analysis for MASW

(3) Small Scale Micro-tremor Measurement (SSMM)

S-wave velocity (*Vs*) structure down to 30m is very important in the local site effect during earthquakes. For example, the buried channels filled with alluvial deposits amplify seismic waves and cause stronger ground shaking. Therefore, SSMM is carried out to observe the *Vs* structure down to 30 m on the basis of the passive surface wave method. L shaped arrays with 12 receivers are deployed. A spatial auto-correlation method same as MASW is applied to the vertical component of micro-tremors data.

The dimension of SSMM is as follows:

- Geophone spacing: 6 m
- Number of Geophones: 11
- Geophone configuration: L-Shape (See Figure 2-1)
- Array size: 30 m
- Sampling rate: 8 msec
- Natural frequency of Geophone: 10 Hz
- Measurement duration: 60 sec
- Measurement number: 10 times (total duration is 600 sec)

(4) Analysis of MASW

The different points from MASW analysis method are the source and frequency range etc. For the source, SSMM is natural one of microtremor, and the frequency range is between 2 and 10 Hz due to the scale of measurement. Then, the investigation depth of *Vs* structure by SSMM is down to around 30 m depth. And because of the L shape array, the resultant one-dimensional structures can be interpolated into a three-dimensional structure.

Figure 3-5 shows an example of dispersion curve, and Figure 3-6 phase velocity versus frequency as a sample. A one-dimensional inversion using a non-linear least square method has been applied to the phase velocity curves and one-dimensional S-wave velocity structures down

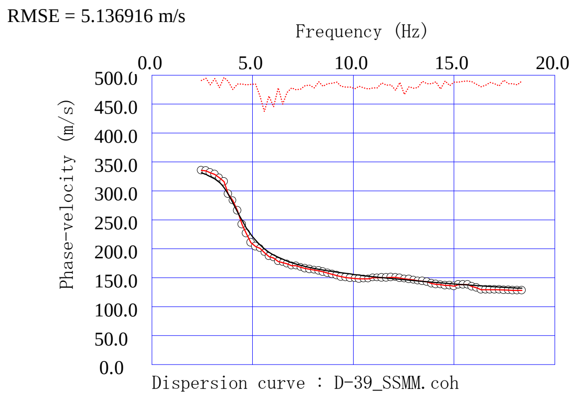


Figure 3-5 An Example of Dispersion Curve (SSMM)

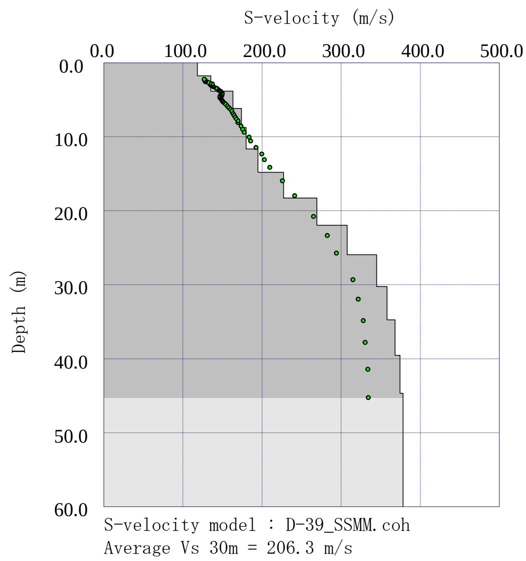


Figure 3-6 Sample of One Dimensional Analysis Result (SSMM)

(5) Calculation of AVS 30

The one dimensional *Vs* structure result of SSMM is finalized combining shallow portion from the MASW result. Then, *AVS30* can be calculated by both SSMM and

MASW results as follows.

$$T_{30} = \sum \frac{Hi}{Vi}$$

$$AVS\ 30 = \frac{30}{T_{30}}$$

Where, Hi : Thickness of i th layer and $30 = \sum Hi$

Vi: S-wave velocity of i th layer

(6) Relationship between Geomorphology and AVS30

The survey result is shown in the following chapter. In this, we mention the relationship between geomorphology and AVS30 (see Figure 3-7). As shown in Figure 3-7, AVS 30 results were classified by geomorphology. However, AVS30 results are scattering results. The reason of scattering data is AVS 30 is affected by not only geomorphology but also the thickness of 1st layer. Therefore, the results should be considered by two parameters, which are morphology and thickness of shallow soils.

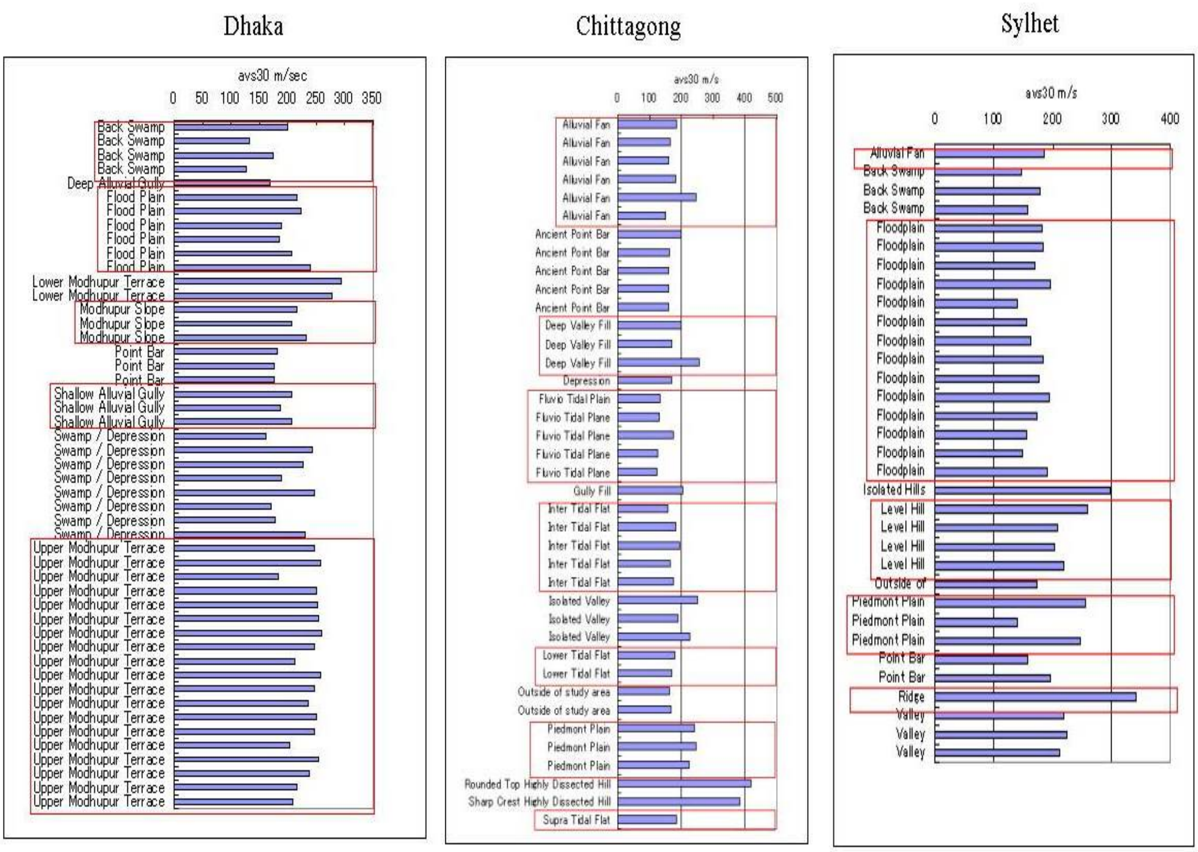


Figure 3-7 Shallow Seismic Results classified by Geomorphology

3.2.2 Survey Result of Shallow Seismic Survey

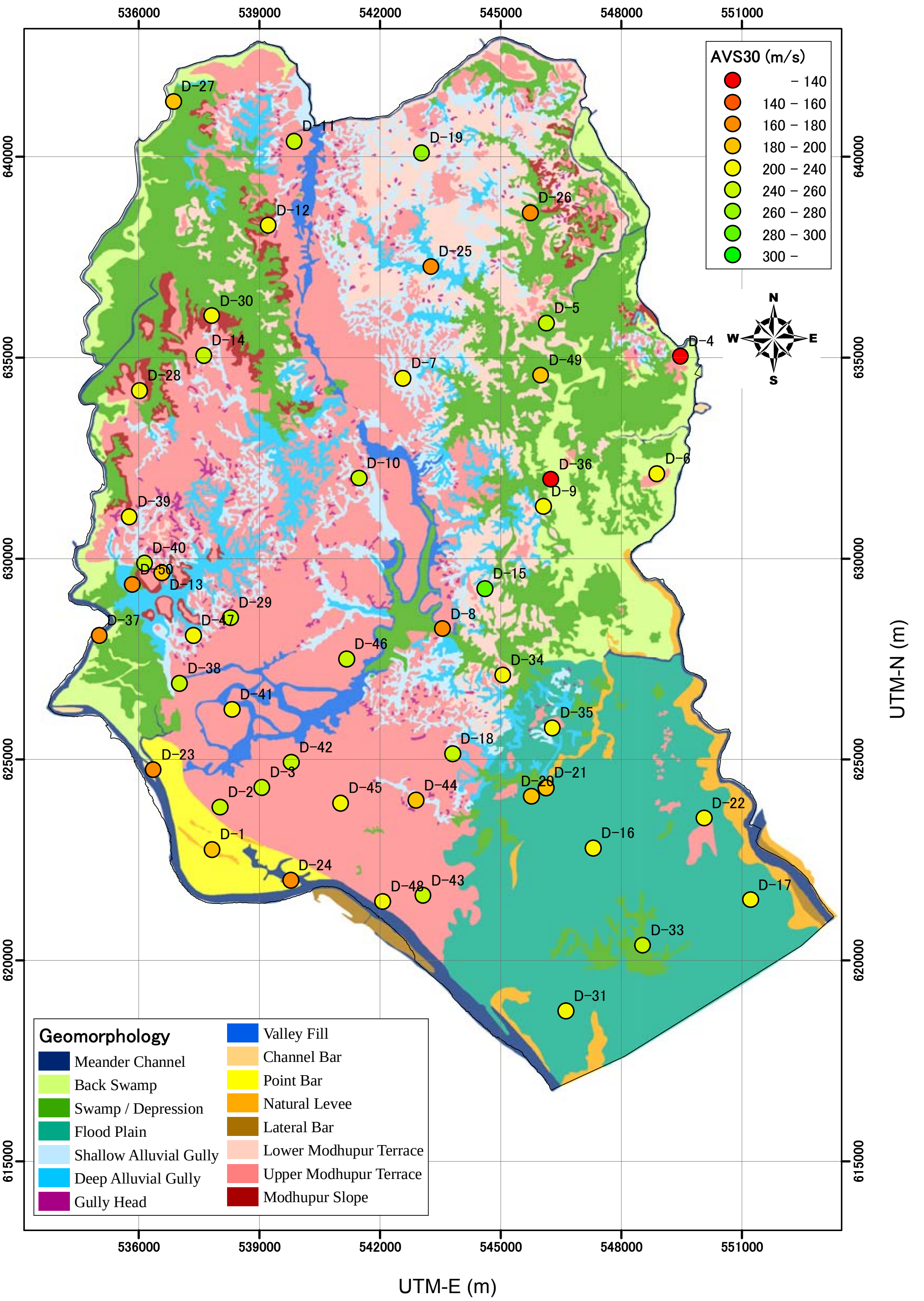
(1) Dhaka

Survey location and survey result (*AVS 30*) in Dhaka are shown in Table 3-3. Figure 3-8 shows the location and result on the geomorphic map.

Table 3-3 Shallow Seismic Survey Result in Dhaka

No	Location	Latitude	Longitude	Geomorphology	AVS30 (m/s)
D-1	Kamrangir Char	23.71722	90.37111	Point Bar	182
D-2	Hazaribagh Park	23.72667	90.37306	Upper Modhupur Terrace	254
D-3	Azimpur Government Quarter	23.73111	90.38333	Upper Modhupur Terrace	246
D-4	Ichhapur	23.82778	90.48583	Back Swamp	127
D-5	Dumni	23.83528	90.45306	Swamp / Depression	246
D-6	Baraid Eidgah Field	23.80139	90.48000	Upper Modhupur Terrace	208
D-7	Nikunja	23.82306	90.41806	Shallow Alluvial Gully	207
D-8	Aftab Nagar	23.76667	90.42750	Swamp / Depression	177
D-9	Sun Valley	23.79417	90.45222	Swamp / Depression	231
D-10	Banani	23.80056	90.40722	Upper Modhupur Terrace	246
D-11	Uttara Sector 11	23.87639	90.39167	Upper Modhupur Terrace	258
D-12	Baunia	23.85750	90.38528	Modhupur Slope	215
D-13	Razia Tower, Kalyanpur	23.77944	90.35903	Upper Modhupur Terrace	183
D-14	Bangladesh Adarsha Shikkha Niketon High School, Mirpur 12	23.82833	90.36944	Upper Modhupur Terrace	251
D-15	East Badda behind Graveyard	23.77567	90.43789	Lower Modhupur Terrace	294
D-16	Matuail	23.71731	90.46414	Flood Plain	215
D-17	Rasulbag (Siddirgang)	23.70550	90.50244	Flood Plain	223
D-18	South Basabo (Central Ideal School and Collage)	23.73856	90.42989	Upper Modhupur Terrace	252
D-19	Uttar Khan	23.87367	90.42278	Lower Modhupur Terrace	277
D-20	Green Model Town, Road No-3	23.72897	90.44911	Flood Plain	189
D-21	Green Model Town, Road No-5	23.73089	90.45269	Flood Plain	185
D-22	Demra	23.72394	90.49117	Flood Plain	207
D-23	Hazaribagh (Gudara ghat)	23.73517	90.35686	Point Bar	175
D-24	Kamrangir Char tower math	23.71028	90.39028	Point Bar	175
D-25	Asian city, Dakhin khan	23.84808	90.42494	Deep Alluvial Gully	168
D-26	Kachkura, Uttar Khan	23.86014	90.44928	Swamp / Depression	161
D-27	Ashulia Deor, Jubok housing	23.88536	90.36217	Back Swamp	200
D-28	Pallabi 2nd phase(Eastern housing)	23.82042	90.35372	Modhupur Slope	206
D-29	Trade fair field(Agargaon)	23.76928	90.37578	Upper Modhupur Terrace	260
D-30	Pallabi DOHS	23.83717	90.37139	Modhupur Slope	232
D-31	Pagla sewarage treatment plant	23.68072	90.45731	Flood Plain	239

No	Location	Latitude	Longitude	Geomorphology	AVS30 (m/s)
D-33	Signboard-Tamirul millat mahila madrasha	23.69533	90.47614	Swamp / Depression	243
D-34	Goran -Banasree	23.75625	90.44219	Swamp / Depression	227
D-35	East nandipara	23.74436	90.45422	Upper Modhupur Terrace	212
D-36	United city, Satarkul	23.80019	90.45408	Back Swamp	133
D-37	Adabar	23.76539	90.34372	Back Swamp	174
D-38	Govt. physical training college, Mahammadpur	23.75458	90.36331	Upper Modhupur Terrace	258
D-39	Mirpur-1, Education board lab. school & college	23.79206	90.35117	Shallow Alluvial Gully	206
D-40	HBRI office, Technical, Mirpur	23.78161	90.35483	Upper Modhupur Terrace	246
D-41	Dhanmondi ladies playing complex	23.74867	90.37608	Upper Modhupur Terrace	236
D-42	Infront of Zia hall, DU	23.73678	90.39050	Upper Modhupur Terrace	250
D-43	Dhupkhola play ground	23.70675	90.42258	Upper Modhupur Terrace	247
D-44	Mohamedan club, motijheel	23.72814	90.42094	Shallow Alluvial Gully	187
D-45	DU campus, Karjon hall	23.72758	90.40253	Upper Modhupur Terrace	204
D-46	Dhaka polytechnic institute , Tejgaon	23.75994	90.40406	Upper Modhupur Terrace	255
D-47	Dhaka resedintial model school & college	23.76536	90.36669	Upper Modhupur Terrace	238
D-48	Zubili school, Bangla bazar	23.70539	90.41272	Upper Modhupur Terrace	215
D-49	Bashundhara housing(L-block)	23.82364	90.45172	Swamp / Depression	189
D-50	Adabar, Shamoly	23.77686	90.35181	Swamp / Depression	171



[Background: geomorphic map edited by GSB]

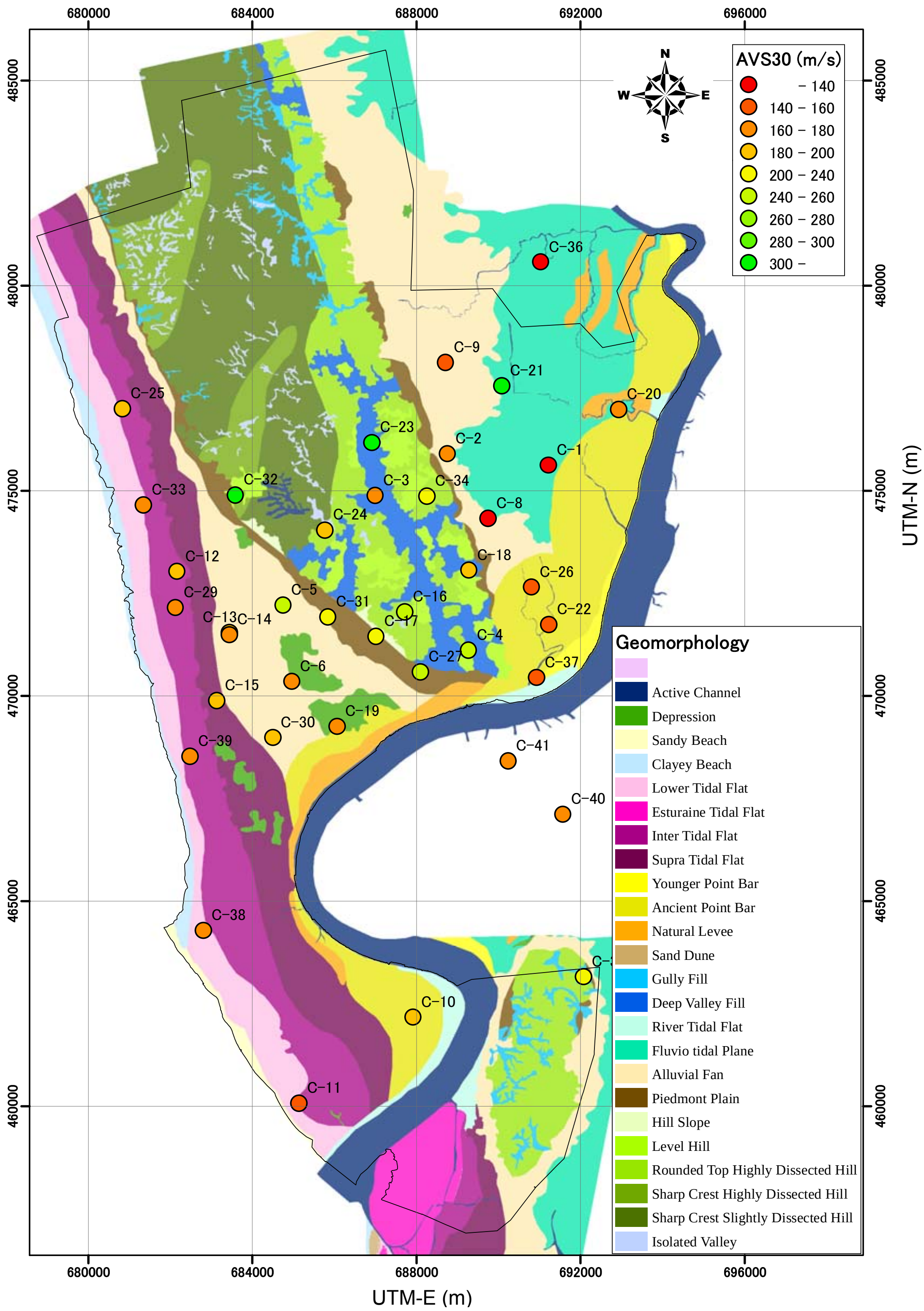
Figure 3-8 Location and AVS 30 of Shallow Seismic Survey in Dhaka

(2) Chittagong

Survey location and survey result (*AVS 30*) in Chittagong are shown in the Table 3-4. Figure 3-9 shows the location and result on the geomorphology map.

Table 3-4 Shallow Seismic Survey Result in Chittagong

No	Location	Latitude	Longitude	Geomorphology	AVS 30 (m/s)
C-1	Khonar para, Chandgaon	22.37778	91.85750	Fluvio Tidal Plane	130
C-2	Hamzarbagh Resident Area	22.38056	91.83361	Alluvial Fan	160
C-3	Nasirabad	22.37153	91.81639	Deep Valley Fill	171
C-4	Public Library	22.33722	91.83806	Deep Valley Fill	256
C-5	Pahartali West Nasirabad (Bacha Miah Road)	22.34769	91.79428	Alluvial Fan	246
C-6	Choto Pul (Chittagong Police Line)	22.33081	91.79614	Depression	170
C-8	Teri Febrics Ltd, BadurTala	22.36622	91.84303	Fluvio Tidal Plane	123
C-9	Nayar Hat, Oxygen	22.40069	91.83347	Alluvial Fan	150
C-10	Chittagong Airport	22.25653	91.82386	Ancient Point Bar	199
C-11	Patenga	22.23794	91.79664	Inter Tidal Flat	156
C-12	Kathtoli Stadium	22.35531	91.76925	Inter Tidal Flat	182
C-13	PDB Coloni	22.34175	91.78142	Alluvial Fan	184
C-14	BDR Camp	22.34128	91.78142	Alluvial Fan	165
C-15	Physical College	22.32681	91.77833	Supra Tidal Flat	183
C-16	M. A. Asis Stadium	22.34583	91.82306	Isolated Valley	252
C-17	Pologround Colony	22.34056	91.81622	Piedmont Plain	240
C-18	Chittagong College	22.35483	91.83833	Deep Valley Fill	199
C-19	Zambori Math Colony	22.32075	91.80669	Ancient Point Bar	163
C-20	Mohora, Chittagong Jute mill, Kalurghat	22.38986	91.87425	Fluvio Tidal Plane	175
C-21	Peda pukurt, Hazirpul, Chandgaon	22.39536	91.84667	Fluvio Tidal Plain	132
C-22	Kalpoloke R/A, Haji Nagar	22.34267	91.85714	Ancient Point Bar	159
C-23	Bangbadik Society, Skatoghar	22.38317	91.81572	Rounded Top Highly Dissected Hill	420
C-24	Vatenary University	22.36403	91.80436	Isolated Valley	190
C-25	TB Hospital, Fonsdarhat	22.39136	91.75678	Inter Tidal Flat	195
C-26	Kamale Iske Mustafa, Madrasha, East Bakalia	22.35092	91.85314	Ancient Point Bar	160
C-27	Chittagong PTI. Ice Factory Road	22.33256	91.82661	Piedmont Plain	247
C-29	Uttar Halighar	22.34736	91.76875	Inter Tidal Flat	164
C-30	Port Colony Stadium	22.31850	91.79144	Alluvial Fan	182
C-31	RHD, Monshurabad	22.34494	91.80489	Piedmont Plain	224
C-32	Firoj Shah R/A, New Monsurabad	22.37200	91.78331	Sharp Crest Highly Dissected Hill	384
C-33	Uttar Kalkuli, Colonel Road, Pahardali	22.37011	91.76147	Lower Tidal Flat	180
C-34	Forest Research Institute	22.37128	91.82864	Isolated Valley	226
C-35	KPPZ	22.26500	91.86431	Gully Fill	205
C-36	Shikarpur, Hathazuri	22.42250	91.85628	Fluvio Tidal Plane	125
C-37	Bakalia Shehid M.N.M.J College	22.33100	91.85406	Ancient Point Bar	160
C-38	South Halighahar, South side of CER2	22.27619	91.77447	Lower Tidal Flat	169
C-39	Middle Halighahar, Dumping Side (North Side)	22.31461	91.77183	Inter Tidal Flat	174
C-40	Shikal Baha (Fahira Wosque)	22.30081	91.85992	Outside of study area	162
C-41	Uttar Chak Lakhya	22.31278	91.84708	Outside of study area	166



[Background: geomorphic map edited by GSB]

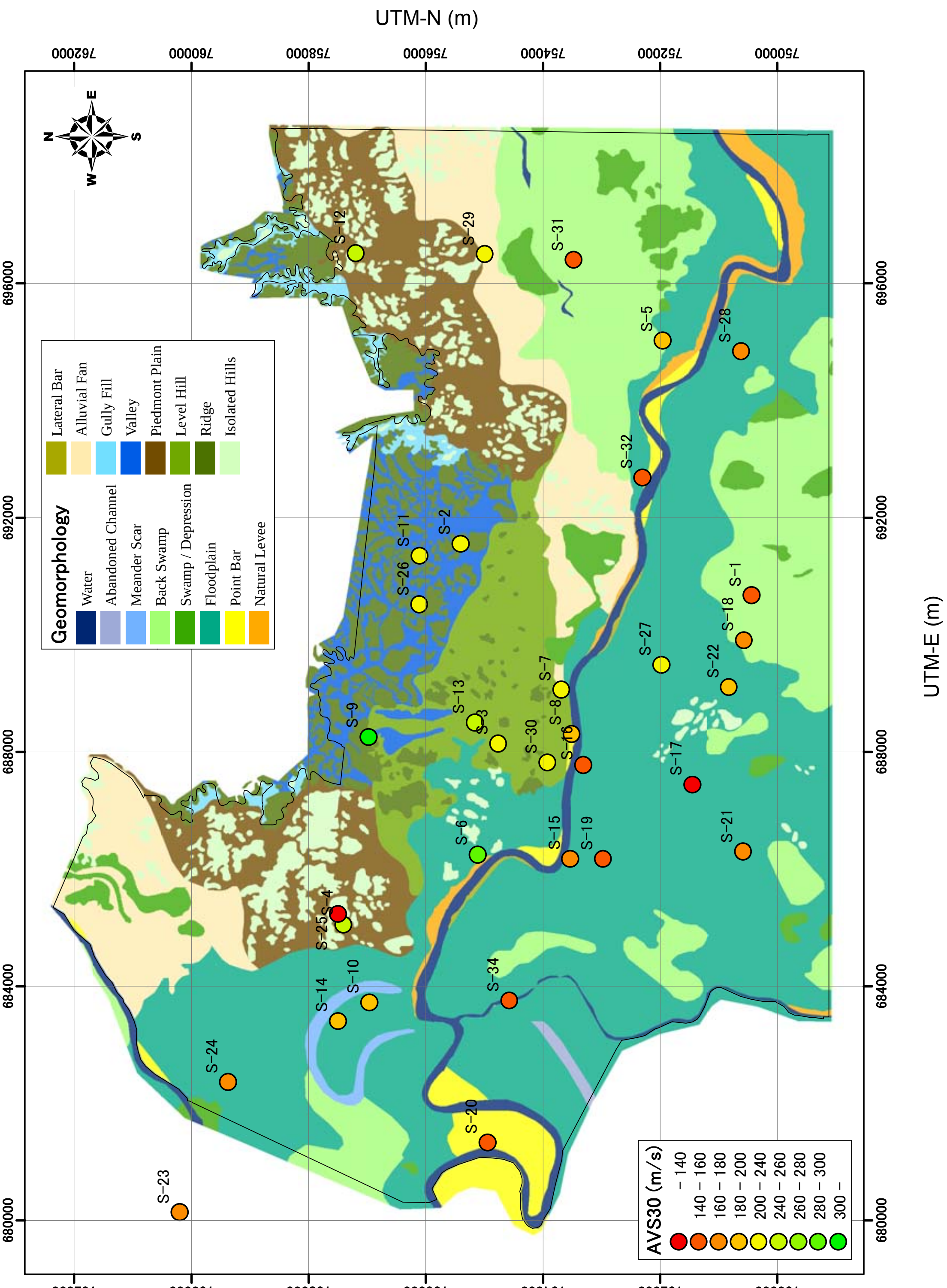
Figure 3-9 Location and AVS 30 of Shallow Seismic Survey in Chittagong

(3) Sylhet

Survey location and survey result (*AVS 30*) in Sylhet are shown in the Table 3-5. Figure 3-10 shows the location and result on the geomorphology map.

Table 3-5 Shallow Seismic Survey Result in Sylhet

No	Location	Latitude	Longitude	Geomorphology	AVS 30 (m/s)
S-1	Sonargaon Housing Project	24.85903	91.88744	Back Swamp	146
S-2	M.C. Collage, Hall ground	24.90372	91.89686	Valley	225
S-3	Sylhet Osmani Stadium	24.89836	91.86297	Level Hill	208
S-4	Shahjalal Engineering University Campus	24.92258	91.83275	Piedmont Plain	246
S-5	Muradpur Road	24.87214	91.93067	Floodplain	190
S-6	Shamima Bagh, Baghmara	24.90178	91.84428	Isolated Hills	298
S-7	Sylhet Govt. Pilot High School	24.88853	91.87192	Level Hill	218
S-8	Mira Para, Muradpur	24.88703	91.86442	Point Bar	196
S-9	Pir Mohalla	24.91831	91.86442	Ridge	341
S-10	Shah Khurrom College, Najiragaon	24.91875	91.81956	Floodplain	182
S-11	Uttar Balur Char (Nafum Bazar)	24.91006	91.89497	Valley	218
S-12	Kidirpur (Datta gram)	24.91925	91.94622	Piedmont Plain	256
S-13	Alia Madrashe Math	24.90194	91.86658	Level Hill	259
S-14	Maiar Char (Tukrarcha Union)	24.92364	91.81650	Floodplain	184
S-15	Makon School	24.88750	91.84339	Floodplain	169
S-16	Polytechnical Institute	24.88531	91.85919	Floodplain	196
S-17	Surma Degree College	24.86856	91.85564	Floodplain	140
S-18	Pathampuae	24.86028	91.87992	Back Swamp	179
S-19	Niyamalpur	24.88244	91.84328	Floodplain	155
S-20	Mastuk Bazar	24.90081	91.79564	Point Bar	157
S-21	Ahamedpur BRAC office	24.86083	91.84419	Floodplain	162
S-22	Jainpur (Fakirpara)	24.86267	91.87206	Floodplain	184
S-23	Mughalgaon Sadar Thana	24.94844	91.78447	Outside of study area	172
S-24	Pran brick field (Nayarpula)	24.94069	91.80639	Floodplain	177
S-25	Sylhet University	24.92344	91.83458	Piedmont Plain	139
S-26	Lakkature Tea Garden	24.91022	91.88667	Valley	212
S-27	Pirijpm Residential Area	24.87303	91.87594	Floodplain	195
S-28	Trigaon, Fulbarn	24.86008	91.92872	Floodplain	172
S-29	B. K. S. P.	24.89936	91.94572	Alluvial Fan	186
S-30	PWDB Office	24.89083	91.85972	Level Hill	202
S-31	Surma Valley	24.88569	91.94456	Back Swamp	158
S-32	Mirorchalk	24.87556	91.90764	Floodplain	155
S-34	Shuklampur	24.89717	91.81956	Floodplain	149



[Background: geomorphic map edited by GSB]

Figure 3-10 Location and AVS 30 of Shallow Seismic Survey in Sylhet

3.3. Array Micro-Tremor Measurement (AMT)

3.3.1. Methodology and Measurement

The purpose of Array Microtremor Survey AMT is to estimate the deeper S-wave velocity (*Vs*) structure.

Array microtremor measurement uses natural seismic source of microtremor as well as SSMM. But the array size is bigger than SSMM. Figure 3-11 shows the schematic diagram of AMT measurement. Since it is difficult to determine the location of seismometer in site, GPS and “Google Earth” are used. Before visiting the site, the locations are prepared on the “Google Earth” map (Figure 3-12). Then, the seismometers were set on the position which is determined on the map.

Detail specification of the measurement is mentioned below.

(1) Number of Seismometer: 10

(2) Seismometer configuration: Triangle

(3) Array size: 125m, 250m and 500 m

(4) Sampling rate: 10 msec

(4) Natural frequency of seismometer: 0.5 Hz

(5) Measurement duration: 60 minutes

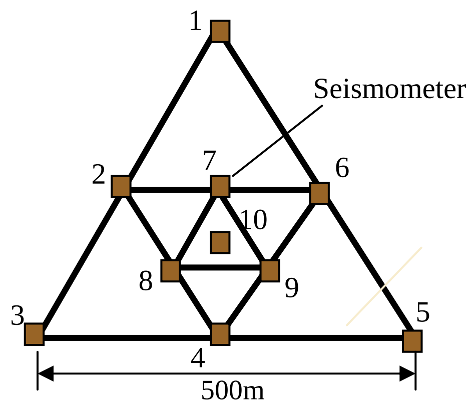
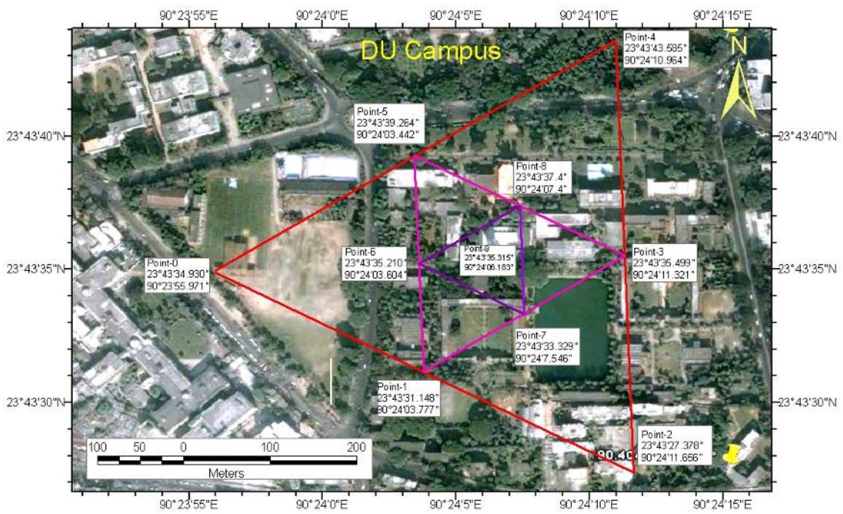


Figure 3-11 Schematic diagram of AMT



[Background: Google Earth]

Figure 3-12 Preparation of Seismometer Position

Basically, the analysis method is the same as SSMM. In this survey, phase velocity curves were calculated in the frequency range between 0.5 and 5 Hz. Figure 3-13 shows the dispersion curve and one dimensional *Vs* structure as a sample. A one-dimensional inversion using a non-linear least square method has been applied to the phase velocity curves and one-dimensional *Vs* structures down to the depth of 200 m are obtained due to array size and seismometer frequency range. The result of one-dimensional *Vs* structures is interpolated into a three-dimensional structure.

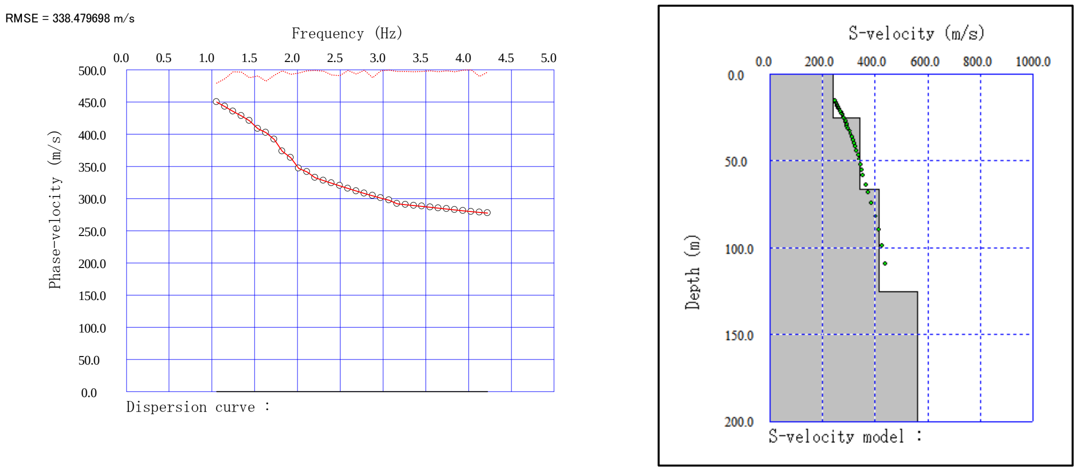


Figure 3-13 An Example of Dispersion Curve (AMT).

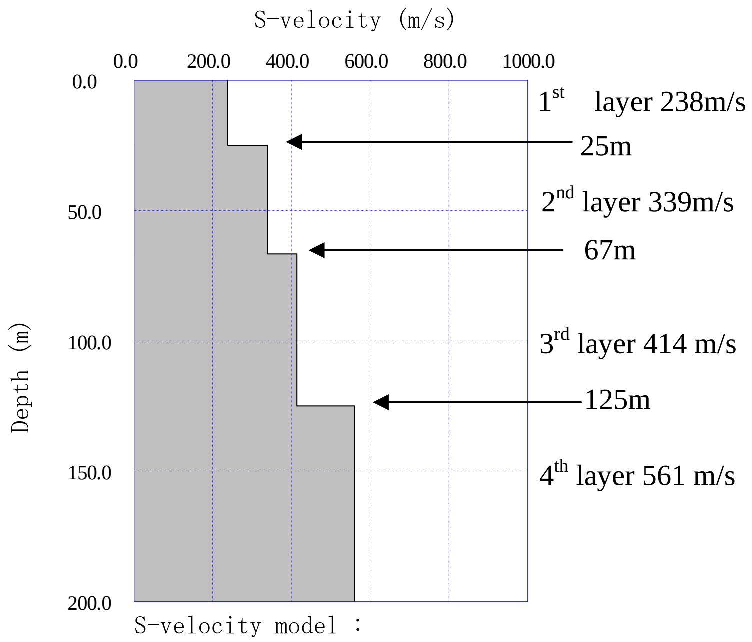


Figure 3-14 Sample of One Dimensional Analysis (AMT)

3.3.2. Survey Result of AMT

Table 3-6 shows the survey location and the estimated depth of the layer which the velocity exceeds 500 m/s in each city. The one dimensional *Vs* structures and the result map on the geomorphology in Dhaka are shown in Figure 3-15 and Figure 3-18, respectively. For Chittagong, the structure and the map are shown in Figure 3-16 and Figure 3-19, and for Sylhet, in Figure 3-17 and Figure 3-20, respectively.

For Dhaka city, the depth with *Vs* more than 500 m/s shows deeper for east-north, for Chittagong and Sylhet shallower in hilly region and deeper in low land region.

Table 3-6 Location and Result of Array Microtremor Measurement.

No	Location	Latitude	Longitude	Geomorphology	Depth of Vs>300	Depth of Vs>400	Depth of Vs>500
DMT-1	Dhaka University	23.72648	90.40172	Upper Modhupur Terrace	25	67	125
DMT-2	Green Model Town	23.72730	90.44860	Flood Plain	25	25	124
DMT-3	United City	23.79821	90.45530	Back Swamp	25	67	124
DMT-4	Uttara Phase 3	23.86835	90.36199	Swamp/Depression	25	67	125
DMT-5	Agargaon Trade Fair Area	23.76938	90.37740	Upper Modhupur Terrace	25	67	124
DMT-6	Pallabi	23.83097	90.35037	Meander Channel	27	50	139
DMT-7	Uttra Khan	23.88317	90.41873	Upper Modhupur Terrace	33	63	175
DMT-8	Aftab Nagar Housing Project, Dhaka	23.76516	90.44269	Swamp/Depression	25	67	124
DMT-9	Sapnali Housing Project, Dhaka	23.83527	90.45738	Lower Modhupur	13	40	160
DMT-10	Matuail, Demra, Dhaka	23.69993	90.47865	Flood Plain	23	60	113
CMT-1	Cittagong Port Colony	22.32169	91.79074	Alluvial Fan	53	99	99
CMT-2	Kalpaluk Project	22.34185	91.85631	Ancient Point Bar	25	67	125
CMT-3	Nagarik Residential Project	22.38494	91.81758	Deep valley Fill	25	66	66
CMT-4	Jaley Para, Halishahar, Chittagong	22.35067	91.76274	Lower Tidal Flat	25	67	125
CMT-5	K. E. P. Z.	22.23258	91.84493	Rounded Top Highly Dissected Hill	10	26	26
CMT-6	Kumar Para	22.42874	91.81553	Alluvial Fan	19	50	93
SMT-1	Shahjalal University of Science & Technology	24.92180	91.83183	Piedmont Plain	15	45	45
SMT-2	MC Collage in Sylhet	24.90381	91.89805	Ridge	23	23	23
SMT-3	Sylhet Stadium (Police Academy)	24.90071	91.86086	Level Hill	25	75	75
SMT-4	Khadimpara, Sylhet Sadar	24.89719	91.92828	Piedmont Plain	19	49	49
SMT-5	Maminkhula, Sylhet	24.87091	91.87002	Flood plain	19	50	94
SMT-6	Suklampur, Dakshin Surma, Sylhet	24.89523	91.82213	Flood plain	19	49	49

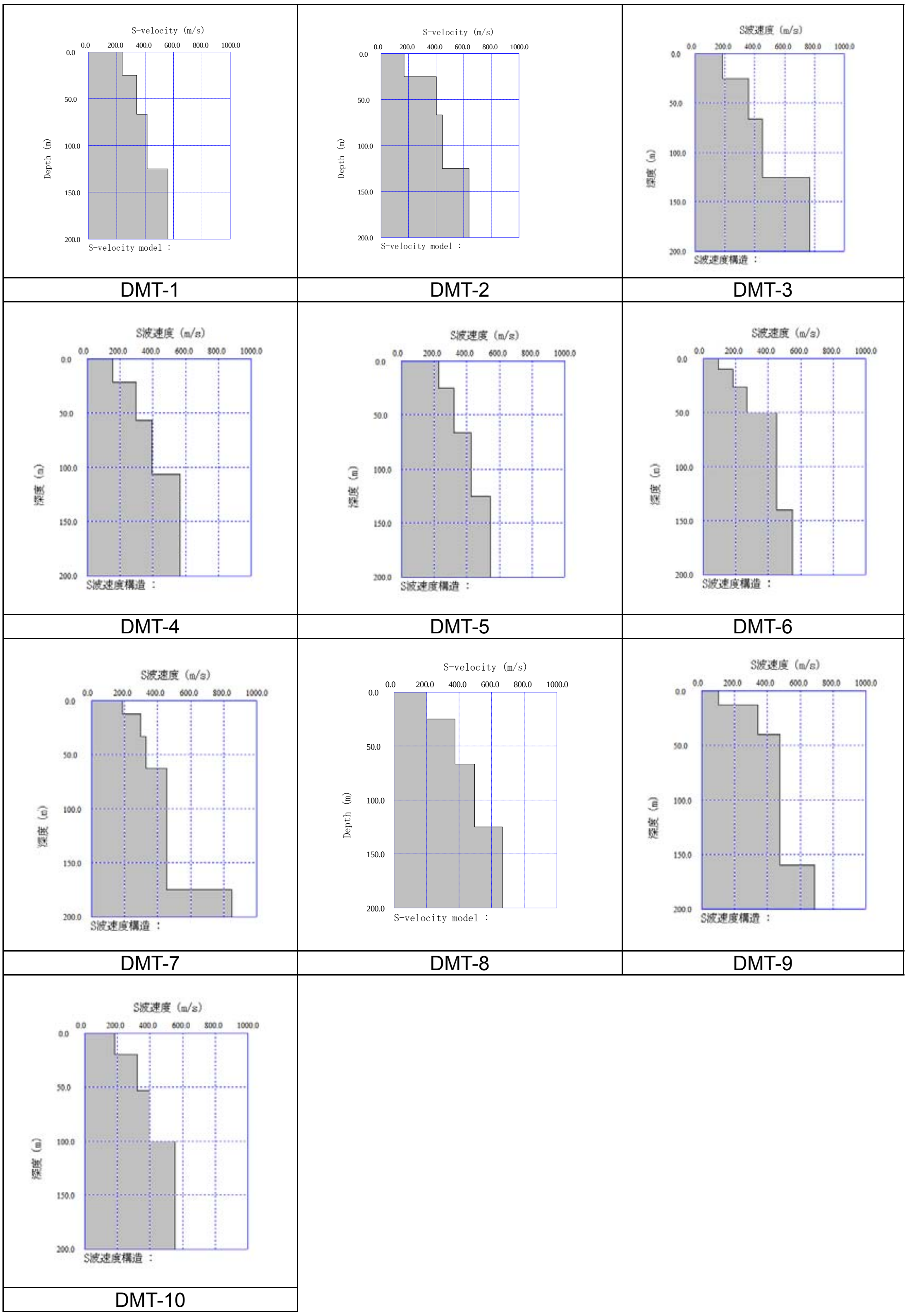
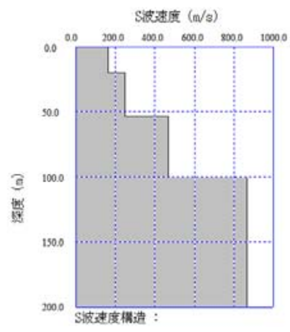
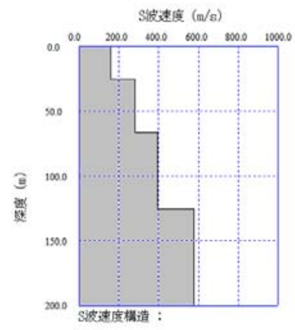


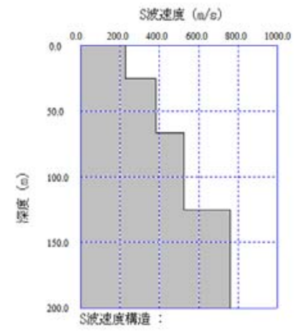
Figure 3-15　AMT Survey Result in Dhaka



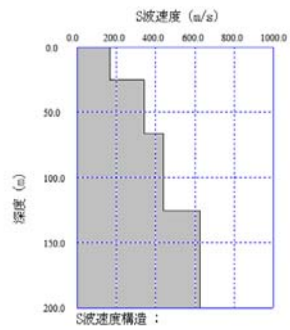
CMT-1



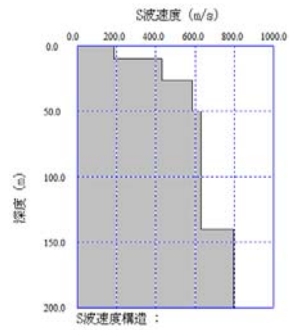
CMT-2



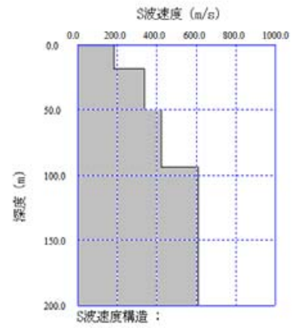
CMT-3



CMT-4

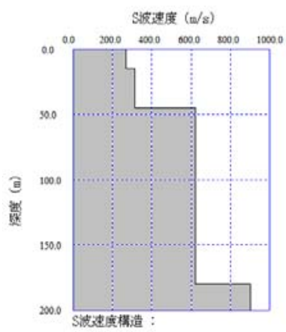


CMT-5

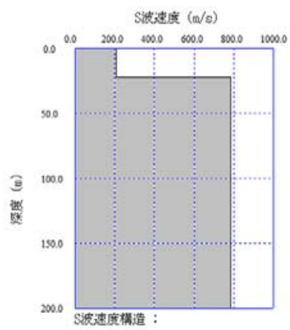


CMT-6

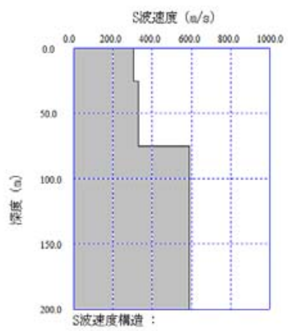
Figure 3-16 AMT Survey Result in Chittagong



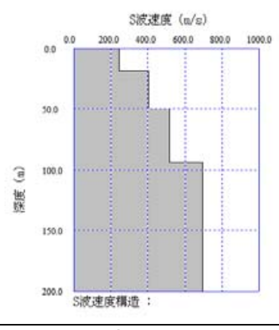
SMT-1



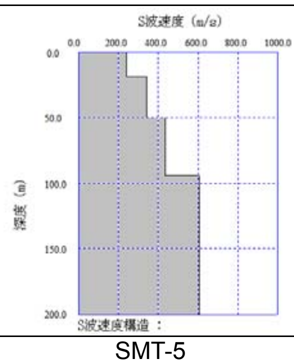
SMT-2



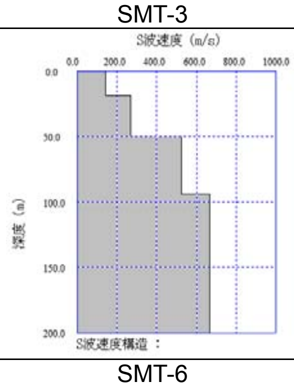
SMT-3



SMT-4

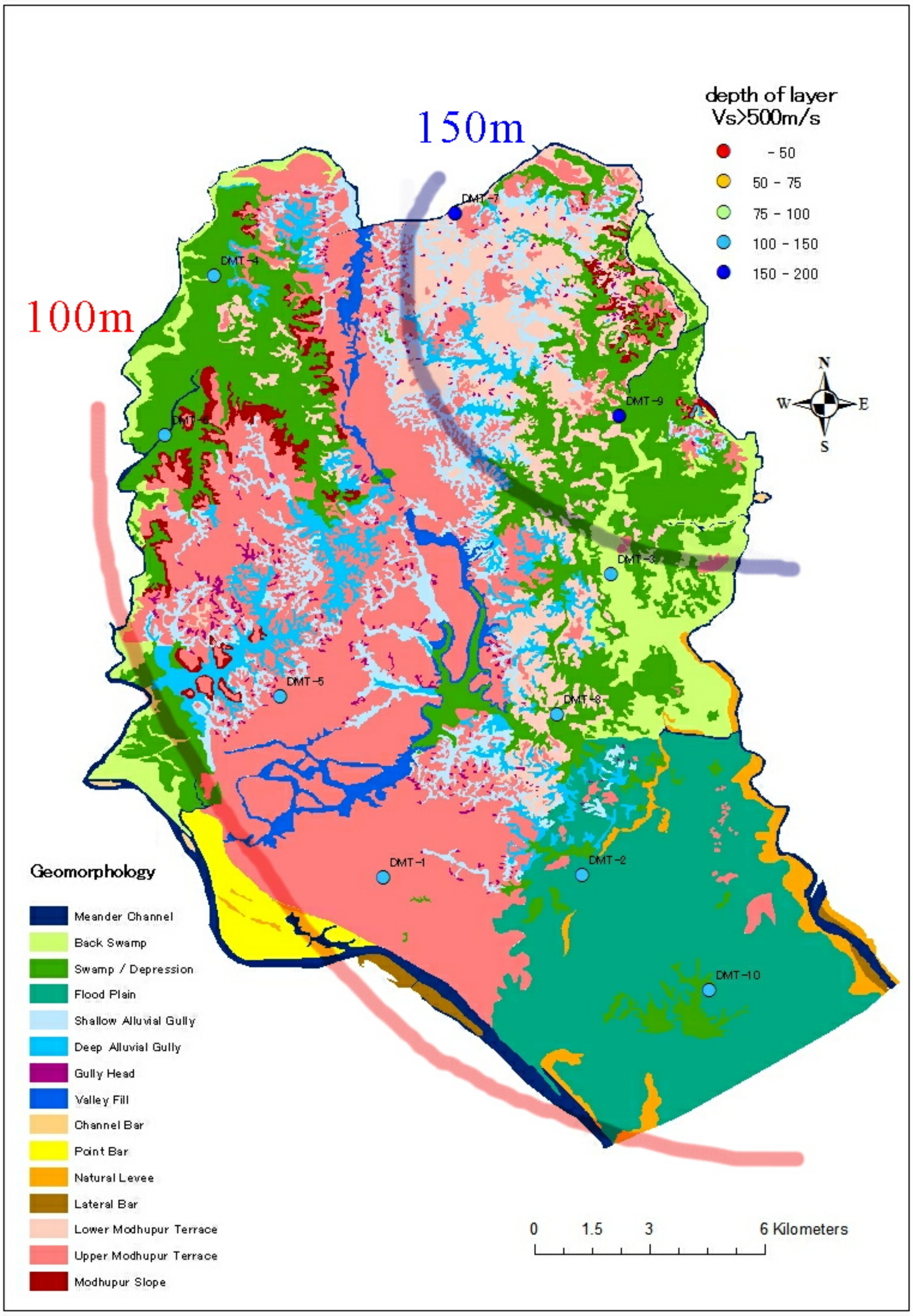


SMT-5



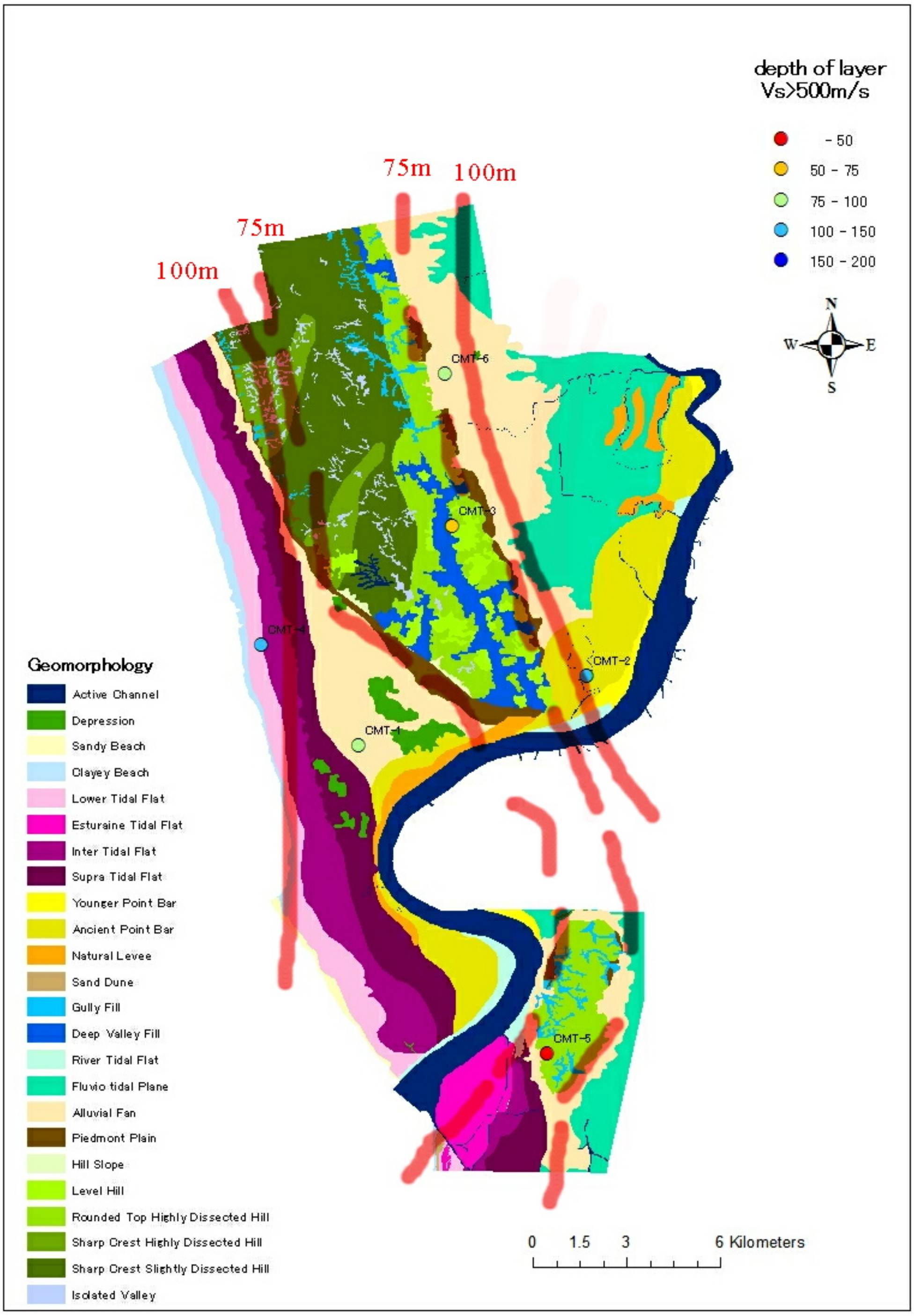
SMT-6

Figure 3-17 AMT Survey Result in Sylhet



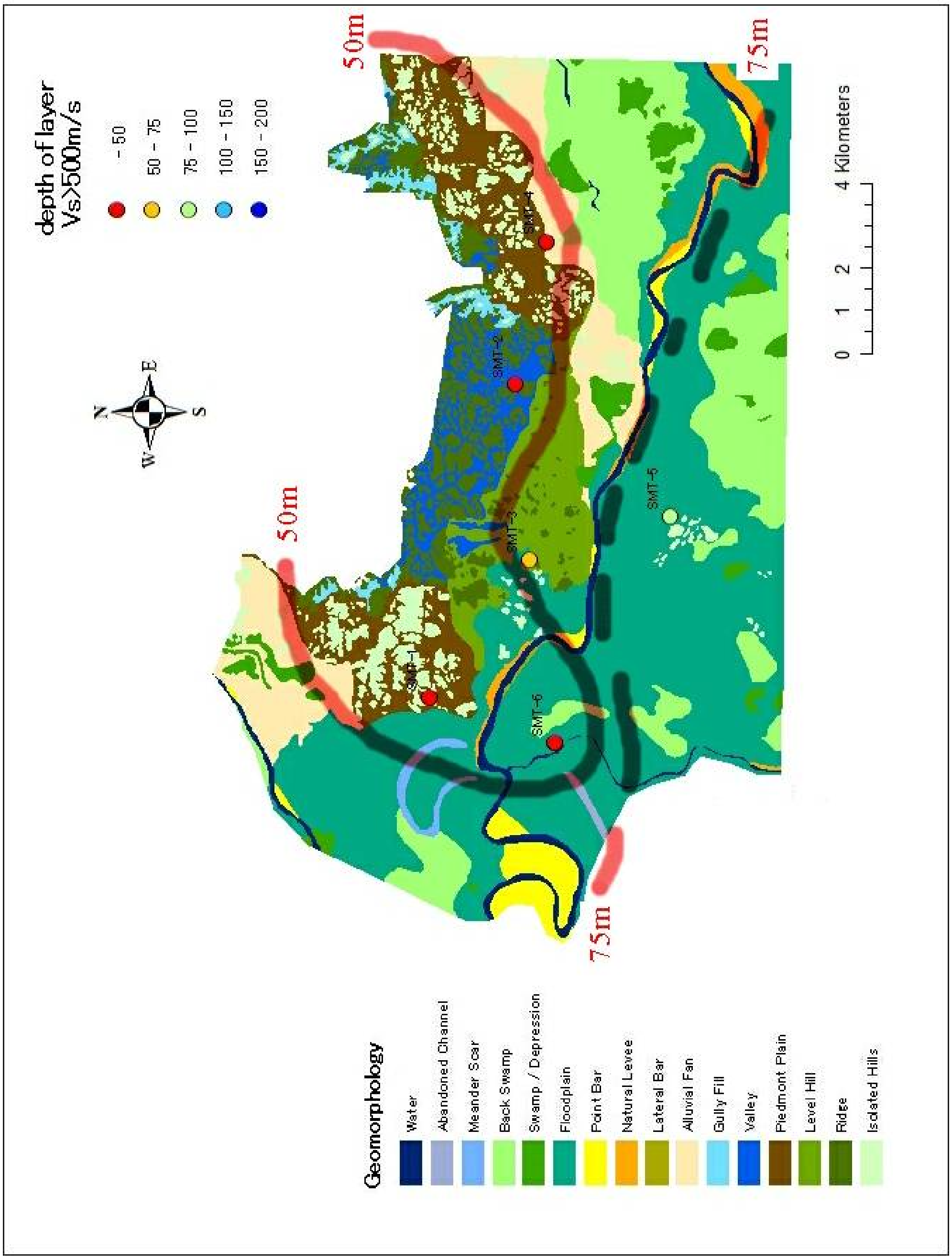
[Background: geomorphic map edited by GSB]

Figure 3-18 Location and Depth (Vs>500m/s) of AMT Survey in Dhaka



[Background: geomorphic map edited by GSB]

Figure 3-19 Location and Depth (Vs>500m/s) of AMT Survey in Chittagong



[Background: geomorphic map edited by GSB]

Figure 3-20 Location and Depth (Vs>500m/s) of AMT Survey in Sylhet

3.4. Single Microtremor Measurement (Single MT)

3.4.1. Methodology of Single Microtremor Measurement

Microtremors are the phenomenon of very small vibrations of the ground surface even during ordinary quiet time as a result of a complex stacking process of various waves propagating from remote man-made vibration sources caused by traffic systems or machinery in industrial plants and from natural vibration caused by tidal or volcanic activities. Observation of microtremors can give useful information on dynamic properties of the site such as predominant period and amplitude. Microtremor observations are easy to perform, inexpensively and can be applied to places with low seismicity as well. Hence, microtremor measurements can be used conveniently for seismic microzonation. More detailed information on *Vs* profile of the site can be obtained from microtremor array observation rather than single microtremor observation.

However, especially for single H/V microtremor measurement, there are various misunderstanding on their characteristics. The first one is that even though microtremor must be the signal not the noise from apparent artificial and natural vibration sources. Then, the most careful and severe wave form sampling for analysis is required avoiding such noises. Also many experts have raised the issue of amplification characteristics between during earthquakes and measured value of H/V spectra. They say sometimes H/V spectral ration cannot be used for amplification of earthquake motion analysis.

3.4.2. Filed Survey

Microtremor observations are performed using portable equipment, which is equipped with a super-sensitive sensor, a wire comprising a jack in one site and USB port in another site, and a laptop computer GEODAS (Geophysical Data Acquisition System) made by Buttan Service Co. Japan (Figure 3-21), is used for the data acquisition.

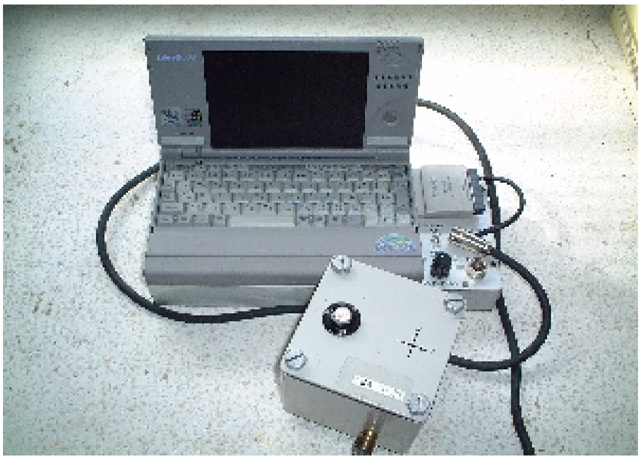


Figure 3-21 Super-Sensitive Portable Seismometer

The microtremor equipment has been set on the free surface on the ground without any minor tilting of the equipment. The N-S and E-W directions are properly maintained following the directions arrowed on the body of the equipment. The sampling frequency for all the measurements is set at 100 Hz. The low-pass filter of 50 Hz is set in the data acquisition unit. Like the seismometer or accelerometer, the velocity sensor used can measure three components of vibration: two horizontal and one vertical. The natural period of the sensor is 2 sec. The available frequency response range for the sensor is 0.5–20 Hz. A global positioning system (GPS) is used for recording the coordinates of observation sites.

Three-components (NS, EW, UD) of microtremors are observed during 20 s.

Note: Quality control of the observation in Japan

(according to "The Society of Exploration Geophysicists of Japan, 2004, Application of Geophysical Methods to Engineering and Environmental Problems, 17 Microtremor")

(1) It is desirable to monitor waveforms of the recorded microtremors during observation, and inspect for the absence of noise, and for the presence of typical-waveforms. Postpone the measurement whenever deemed necessary, since good records may not be expected when it is windy or raining heavily.
(2) When observing microtremors, avoid noise coming from the surrounding local environment, and take detailed note of sources if local noise unavoidably occurs.
(3) At the conclusion of the observation, check if all the data are stable and noise-free for all array stations. Re-measure if poor records are observed.
(4) In order to gain information on the stationary of the microtremor signal, two to three recordings should be obtained with continuous records of for around 5-10 minutes. For observations using longer-period microtremors, the length of record for each observation should be 30-60 minutes.

3.4.3. Data Processing

The following data processing should be conducted for microtremor measurement generally. Unfortunately, in many cases especially for single H/V microtremor measurement, less quality data have been used due to less keeping the followings in Japan (SEGJ, 2004).

(1) Compile the records (analog or digital form) in time-series waveforms for each observation point and each azimuth orientation. Reconfirm the 1ocation, orientation, channel number, gain and filter parameters based on the field notes. Note these parameters on a data sheet.

(2) Choose several contiguous sections with a minimum of unexpected artificial noise from the time-series waveform data, for analysis.

In this project, 3 series of 20 seconds data set are sampled for analysis.

3.4.4. Analysis

After sampling appropriate waveform data for analysis followed above process, the following process is conducted.

(1) The waveform time-series data is normally recorded as variation of voltage. It should be calibrated to velocity/acceleration equivalent as absolute values for vibration.

(2) The essential requirement in analysis of microtremor data is to determine the predominant period of the ground from the peak frequency as recognized on the Fourier spectrum or the power spectrum. In some cases, a more stable predominant frequency can be obtained by averaging spectra from different segments of data or stacking with many data sets.

(3) When microtremor data is acquired at several depths such as at the surface, the boundary of geologica1 1ayers, and the top of the basement formation, spectral-ratio analysis should be included in the processing as consistent with the objective of the investigation.

(4) When single H/V microtremor measurement, two spectra of horizontal components should combined to one representative horizontal component by several methodology (ensemble average, root mean square etc.), and after then divided by vertical component spectra then, H/V spectra can be calculated.

Note: Many analysis conductors consider that in many cases, due to dividing horizontal component by vertical component, noises may be cancelled and less taking into consideration of noises for microtremors. This often provides incorrect analysis results.

(5) When reading predominant periods or frequencies from analyzed spectra, only maximum amplitude is not the factors. It is common in geophysical exploration, the proper interpretation with other information such as geology, geomorphology etc. as well as experts judgment must be required. In many cases only reading the maximum peaks and simply contouring provide often incorrect or strange results. It is usual that several peaks appear in a spectrum, and these peaks are due to the effects of soil layer boundaries. Since, it is not so easy to identify which layer correlates to which peak, comprehensive interpretation is inevitable

Figure 3-22 shows the example of H/V analysis.

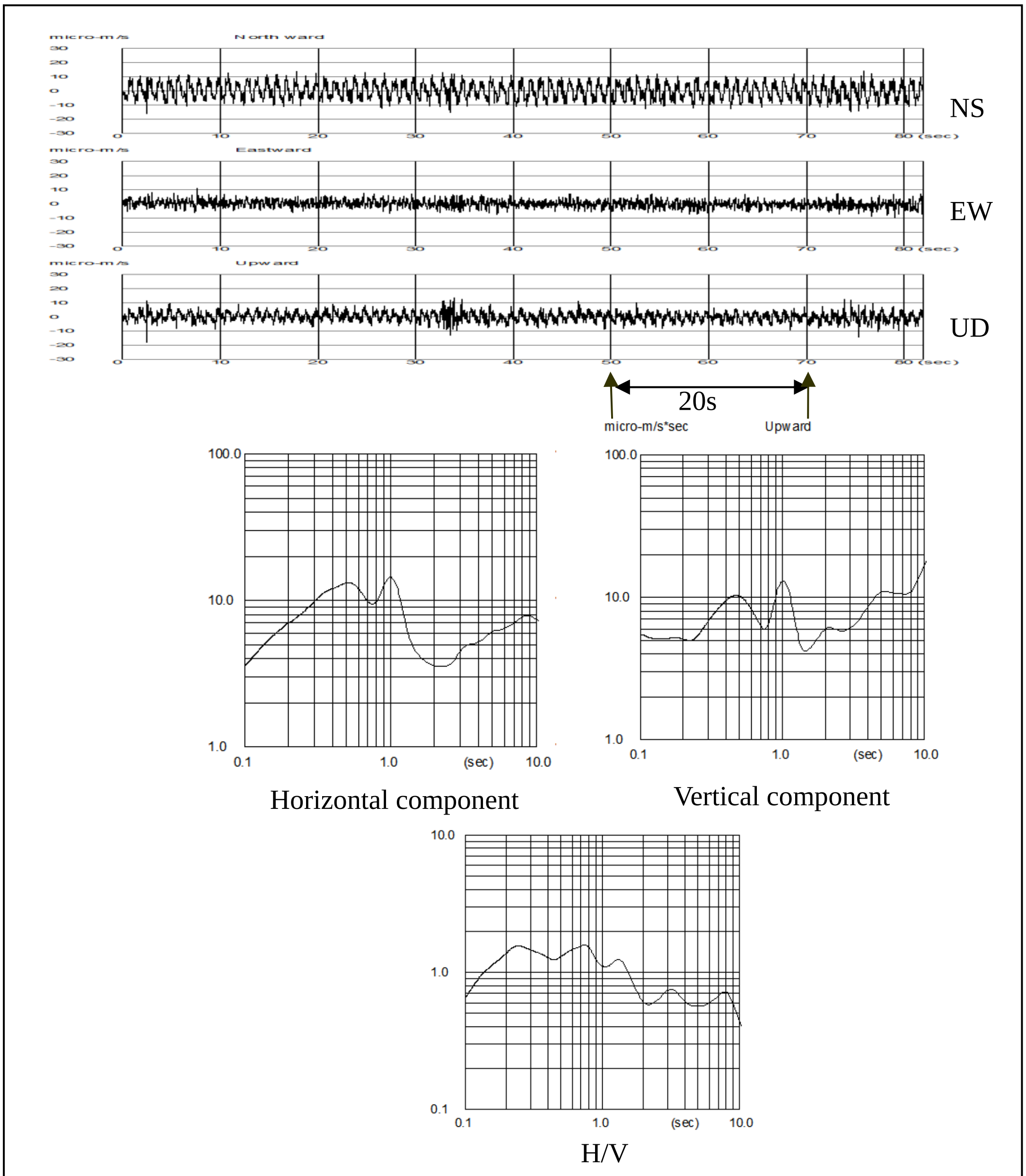


Figure 3-22 Sample of H/V Analysis

3.4.5. Survey Result of Single MT

Table 3-7 to Table 3-9 show the survey locations and the predominant periods in Dhaka, Chittagong and Sylhet. The location and the predominant period map on the geomorphology in Dhaka are shown in Figure 3-23. For Chittagong, the map is shown in Figure 3-24, and for Sylhet, in Figure 3-25.

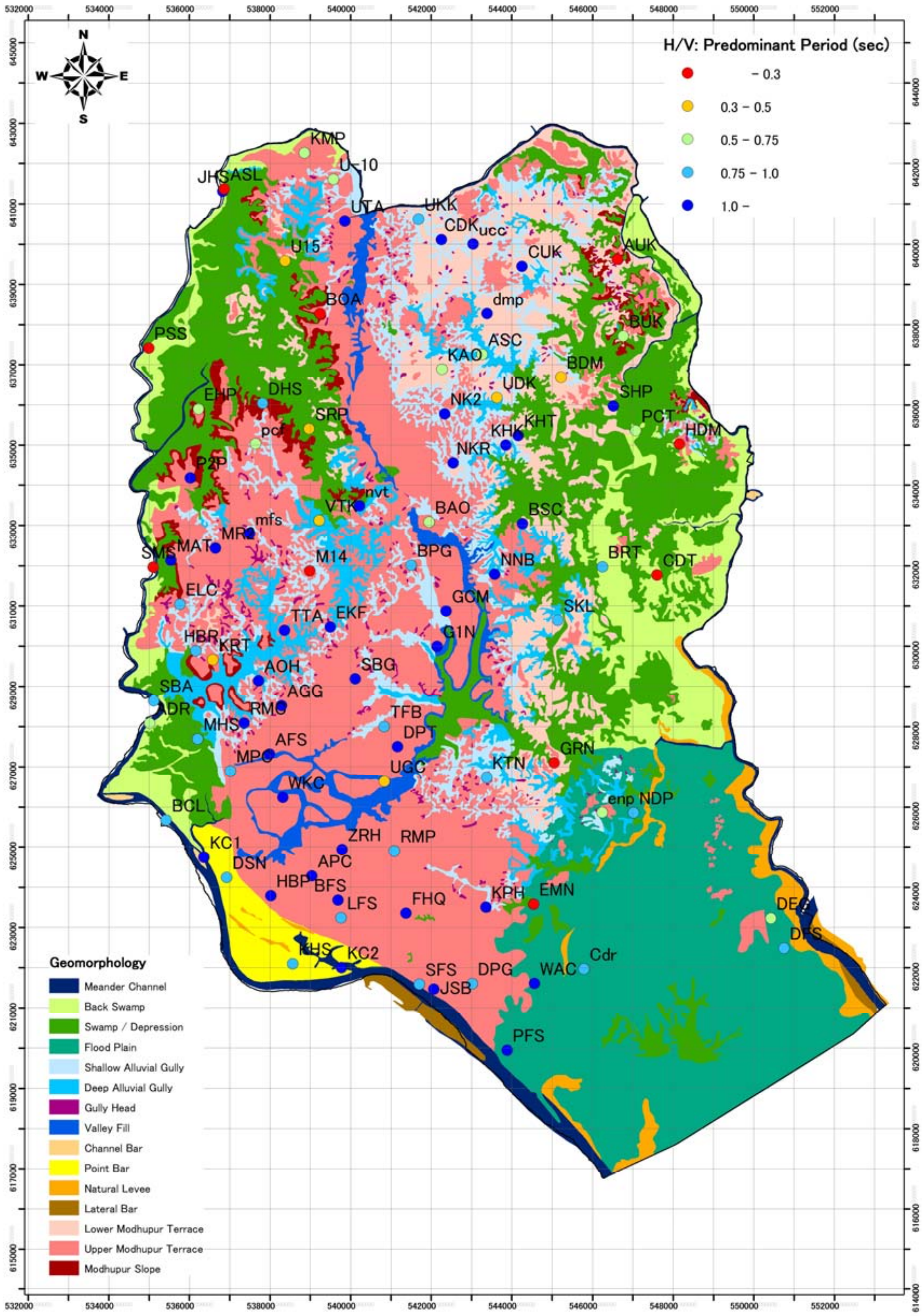
However, these predominant periods are getting from simple reading of maximum peaks in the range of 0.1 to 2 seconds. As far as the observations so far, the waveform for analyses include various apparent artificial noises that should violate the spectra. It leads unreasonable results. Therefore, it is clear that more judgment and analyses is necessary and needs more time for getting reasonable results.

Table 3-7 Location and Result of Single Microtremor Measurement in Dhaka

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
1	Bashila, Mohammadpur	23.74355	90.34765	Meander Channel	BCL	0.975238
2	JUBOK Housing Society, Near Mirpur flood protection Embankment	23.88481	90.36181	Meander Channel	JHS	1.462857
3	Kamrangichar , Gudaraghat	23.73517	90.35686	Meander Channel	KC1	1.28
4	Mohammad, Akkasnagar Housing project	23.76539	90.34372	Back Swamp	ADR	0.731429
5	Ashulia, Deur	23.88536	90.36217	Back Swamp	ASL	0.2048
6	Beraid, United city	23.80019	90.45408	Back Swamp	BRT	0.787692
7	Chandartek, (Baraid)	23.79835	90.46737	Back Swamp	CDT	0.262564
8	Pink City, Dumni	23.83078	90.46233	Back Swamp	PCT	0.682667
9	Prianka Shooting Spot,Birulia	23.84969	90.34369	Back Swamp	PSS	0.235402
10	Sanir Bill, Adabar, MFPE	23.77042	90.34467	Back Swamp	SBA	0.758519
11	Sinnir Tek Millenium Samity, Mirpur-1, Near MFPE	23.80042	90.34464	Back Swamp	SMS	0.262564
12	Basundhara City	23.80992	90.43464	Swamp / Depression	BSC	1.575385
13	Mohommadia, Housing Society	23.76179	90.35539	Swamp / Depression	MHS	0.787692
14	Sagufta Residential Project	23.83139	90.38272	Swamp / Depression	SRP	0.426667
15	Uttara, Section-15	23.86919	90.37694	Swamp / Depression	U15	0.499512
16	Chadnimath,Demra road	23.70985	90.44925	Flood Plain	Cdr	0.853333
17	Demra Ghat	23.72106	90.49481	Flood Plain	DEG	0.682667
18	Demra Fire Service	23.71433	90.49803	Flood Plain	DFS	0.787692
19	East aniknagar	23.72442	90.43708	Flood Plain	EMN	0.288451
20	Nagdarpar,(East Nandipara)	23.74493	90.4615	Flood Plain	NDP	0.930909
21	Postogola Fire Service	23.69164	90.43053	Flood Plain	PFS	1.462857
22	Wapda colony	23.70661	90.43722	Flood Plain	WAC	1.28

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
23	Agargaon Orthopedic Hospital	23.77484	90.37022	Shallow Alluvial Gully	AOH	1.575385
24	Abaya Borobari, Uttar Khan	23.86933	90.458	Shallow Alluvial Gully	AUK	0.265974
25	Chalabon, Dakhin Khan	23.87386	90.41508	Shallow Alluvial Gully	CDK	1.462857
26	Mirpur14, Police station	23.79947	90.38282	Shallow Alluvial Gully	M14	0.273067
27	Nikunjo Residential Project,Uttara	23.83467	90.41575	Shallow Alluvial Gully	NK2	1.706667
28	Nikunja Housing Project-1 Road No-06	23.82364	90.41783	Shallow Alluvial Gully	NKR	1.575385
29	Natun Bazar	23.79864	90.42785	Shallow Alluvial Gully	NNB	1.204706
30	Pallabi Ceramic Industry, Mirpur-12	23.82808	90.36969	Shallow Alluvial Gully	pcf	0.660645
31	Dakkin Kaola, West of Lake City	23.83831	90.4285	Shallow Alluvial Gully	UDK	0.386415
32	Uttar Khan, Faydabad	23.87844	90.40956	Shallow Alluvial Gully	UKK	0.787692
33	Asian City project, Kawla	23.84808	90.42494	Deep Alluvial Gully	ASC	0.525128
34	Uttar Bhasantek	23.81408	90.39494	Deep Alluvial Gully	nvt	1.861818
35	Taltala/West Kafrul	23.78617	90.37659	Deep Alluvial Gully	TTA	1.28
36	West Vasantek, Mirpur	23.81081	90.38508	Deep Alluvial Gully	VTK	0.401569
37	Khilgaon,taltala thana	23.75295	90.42575	Gully Head	KTN	0.758519
38	Dakhin sanatannagar,Hazaribag	23.73063	90.36235	Point Bar	DSN	0.853333
39	Kamrangichar , Towr math	23.71028	90.39028	Point Bar	KC2	1.706667
40	Kamrangichar High school	23.71122	90.37836	Point Bar	KHS	0.787692
41	Baruka, Dumni, East of Jamuna City	23.84289	90.44411	Lower Modhupur Terrace	BDM	0.330323
42	Baukhal, uttar Khan	23.85208	90.45933	Lower Modhupur Terrace	BUK	0.660645
43	Chadpara, Uttar Khan	23.86781	90.43472	Lower Modhupur Terrace	CUK	1.365333
44	Dakhin Khan Miapara	23.85722	90.42617	Lower Modhupur Terrace	dmp	1.077895
45	Matuail, Signboard	23.75625	90.44219	Lower Modhupur Terrace	GRN	0.235402
46	Kaola, Uttara	23.84472	90.41514	Lower Modhupur Terrace	KAO	0.731429
47	Khilkhet	23.82764	90.43064	Lower Modhupur Terrace	KHK	1.575385
48	Khilkhet	23.82974	90.43368	Lower Modhupur Terrace	KHT	1.204706
49	Shornaly Housing Project	23.83638	90.45692	Lower Modhupur Terrace	SHP	1.365333
50	Satarkul	23.78822	90.44313	Lower Modhupur Terrace	SKL	0.890435
51	Uttar Khan Collegiate School	23.87286	90.42283	Lower Modhupur Terrace	ucc	1.575385
52	Asadgate Fire Service	23.75836	90.37283	Upper Modhupur Terrace	AFS	1.575385
53	Agargaon	23.76928	90.37578	Upper Modhupur Terrace	AGG	1.077895
54	Azimpur colony	23.73092	90.38311	Upper Modhupur Terrace	APC	1.575385
55	Baridhara DOHS, Lane-11, ADPC office	23.81033	90.41192	Upper Modhupur Terrace	BAO	0.731429
56	Palashi Fire Service	23.7255	90.38942	Upper Modhupur Terrace	BFS	1.28
57	Banani Lake	23.80067	90.40747	Upper Modhupur Terrace	BPG	0.787692

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
58	Dhupkhula play ground	23.70664	90.42208	Upper Modhupur Terrace	DPG	0.787692
59	Polytechnic	23.75994	90.40406	Upper Modhupur Terrace	DPT	1.28
60	East Kafrul	23.78683	90.38774	Upper Modhupur Terrace	EKF	1.024
61	Dhaka Education Lab. College	23.79206	90.35117	Upper Modhupur Terrace	ELC	0.8192
62	East NandiPara, Sabujbag	23.74503	90.45382	Upper Modhupur Terrace	enp	0.660645
63	Fire Service Head Quarter	23.72253	90.406	Upper Modhupur Terrace	FHQ	1.706667
64	Gulshan 1	23.78244	90.41376	Upper Modhupur Terrace	G1N	1.575385
65	Gulshan central mosque	23.79037	90.41599	Upper Modhupur Terrace	GCM	1.077895
66	Hazaribag park	23.72653	90.37308	Upper Modhupur Terrace	HBP	1.462857
67	Mirpur, Technical, SBRI office	23.78161	90.35497	Upper Modhupur Terrace	HBR	0.787692
68	Dumni, Hajipara	23.82772	90.47297	Upper Modhupur Terrace	HDM	0.20898
69	Jubili school, Banglabazar	23.70539	90.41272	Upper Modhupur Terrace	JSB	1.28
70	Kamarpara,Batulia, Turag Thana.	23.89339	90.38178	Upper Modhupur Terrace	KMP	0.731429
71	KamalapurHat	23.72381	90.42545	Upper Modhupur Terrace	KPH	1.462857
72	Kalyanpur, Razia Tower, Near ACME building	23.77956	90.35908	Upper Modhupur Terrace	KRT	0.330323
73	Lalbag Fire Service	23.72153	90.39017	Upper Modhupur Terrace	LFS	0.890435
74	Mirpur Fire Station	23.80792	90.36817	Upper Modhupur Terrace	mfs	1.137778
75	Mohammadpur physical college	23.75458	90.36331	Upper Modhupur Terrace	MPC	0.975238
76	Mirpur-2 (City Corporation)	23.80467	90.35983	Upper Modhupur Terrace	MR2	1.365333
77	Asad gate, Residential Model college	23.76536	90.36669	Upper Modhupur Terrace	RMC	1.204706
78	Ramna park	23.73643	90.4032	Upper Modhupur Terrace	RMP	0.975238
79	Mohakhali,(Shahinbagh)	23.77523	90.39375	Upper Modhupur Terrace	SBG	1.365333
80	Sadarghat Fire Service	23.70653	90.40922	Upper Modhupur Terrace	SFS	0.758519
81	Tejgoan Fire Service	23.76447	90.40078	Upper Modhupur Terrace	TFB	0.758519
82	Uttara Model Town Section-10	23.88744	90.38878	Upper Modhupur Terrace	U-10	0.731429
83	Beside UGC Office	23.75219	90.40081	Upper Modhupur Terrace	UGC	0.386415
84	Uttara, sector-11, Near Milestone College	23.87806	90.39156	Upper Modhupur Terrace	UTA	1.462857
85	Dhanmondi, Ladies play complex	23.74867	90.37608	Upper Modhupur Terrace	WKC	1.28
86	Zia Hall	23.73678	90.3905	Upper Modhupur Terrace	ZRH	1.462857
87	Baonia, Behind the Air Port	23.85728	90.38547	Modhupur Slope	BOA	0.288451
88	Mirpur DOHS (2nd)	23.83717	90.37139	Modhupur Slope	DHS	0.890435
89	Aludia,Pallobi-2, N of Eastern housing	23.83594	90.35575	Modhupur Slope	EHP	0.585143
90	Mirpur-1, Avenue-02	23.80194	90.34894	Modhupur Slope	MAT	1.365333
91	Duaripara, Pallabi 2nd phase	23.82042	90.35372	Modhupur Slope	P2P	1.575385



[Background: geomorphology map edited by GSB]

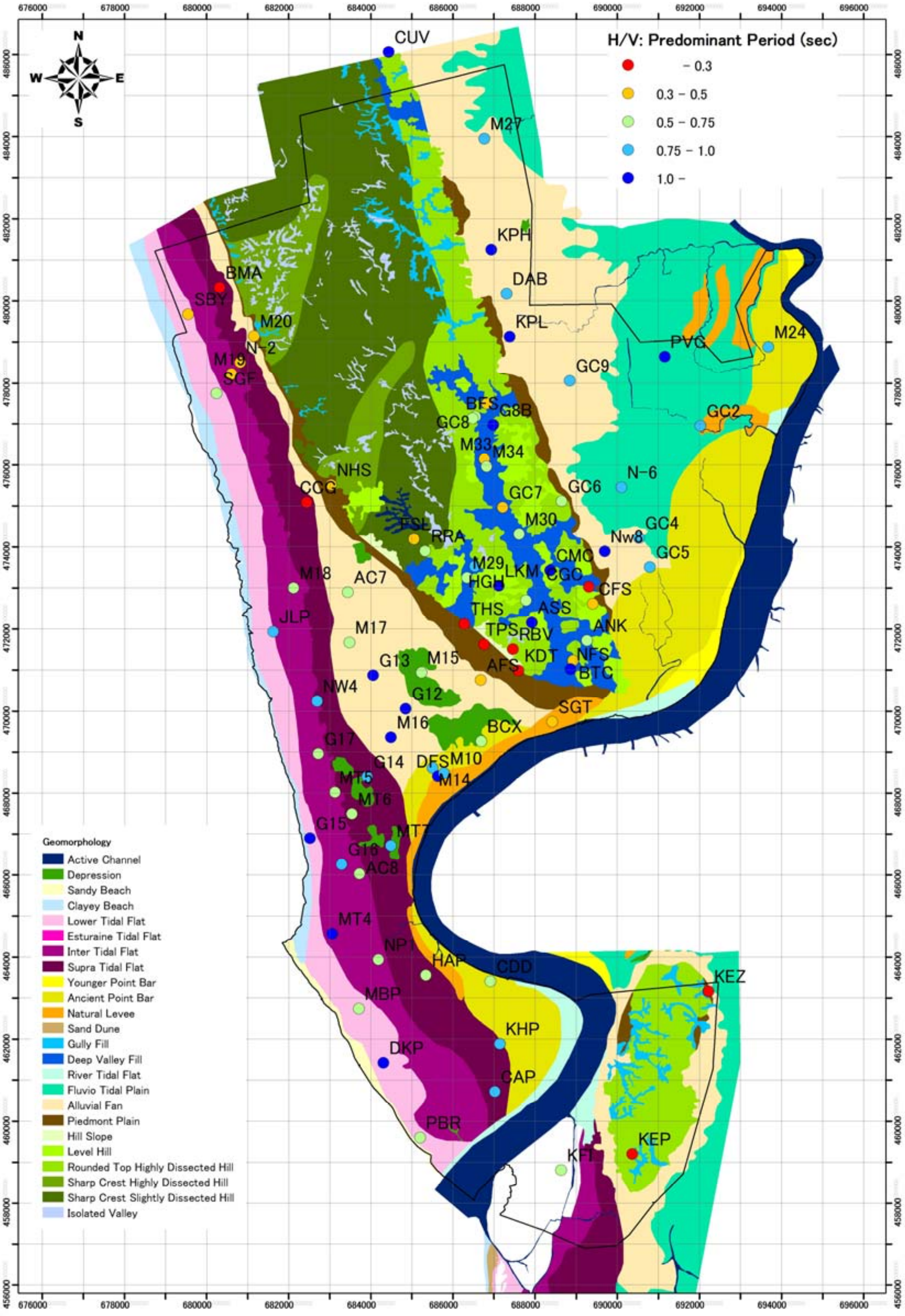
Figure 3-23 Location and Predominant Period of Single Microtremor in Dhaka

Table 3-8 Location and Result of Single Microtremor Measurement in Chittagong

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
1	Golden Road Dakhhin Patenga	22.25022	91.78875	Lower Tidal Flat	DKP	1.86182
2	CEPZ,NEcorner	22.29986	91.772	Lower Tidal Flat	G15	1.70667
3	Jaley Para, Halishahar, CTG	22.3455	91.7639	Lower Tidal Flat	JLP	0.78769
4	Muslembagh, Patenga, CTG	22.26224	91.78313	Lower Tidal Flat	MBP	0.70621
5	Patenga Beach Road	22.23367	91.79725	Lower Tidal Flat	PBR	0.70621
6	Near ship breaking yard	22.41561	91.74467	Lower Tidal Flat	SBY	0.47628
7	Shango gas field	22.39811	91.75119	Lower Tidal Flat	SGF	0.60235
8	K.F.Ins	22.22616	91.83042	Estuarine Tidal Flat	KFI	0.58514
9	Labour colony,Halishahar	22.29192	91.78365	Inter Tidal Flat	AC8	0.60235
10	Right side of entry gate of CEPZ/FS	22.29404	91.77948	Inter Tidal Flat	G16	0.97524
11	Ananda Bazar Subpost office,Halishahar	22.31852	91.77425	Inter Tidal Flat	G17	0.64
12	New Stadium,Kattuli,Hali	22.35505	91.76886	Inter Tidal Flat	M18	0.53895
13	Fauzdaerhat	22.40236	91.75478	Inter Tidal Flat	M19	0.44522
14	CEPZ,SE corner	22.27875	91.77702	Inter Tidal Flat	MT4	1.57539
15	Shilpara,Ananda Bazar,Halishahar	22.30996	91.77809	Inter Tidal Flat	MT5	0.52513
16	Dhurga Mondop Mandir,S Halishahar,RAB HQ	22.27293	91.78788	Inter Tidal Flat	NP1	0.62061
17	B.M.Academy	22.42139	91.75219	Supra Tidal Flat	BMA	0.23011
18	Chitt. AIR PORT	22.24361	91.81503	Supra Tidal Flat	CAP	0.89044
19	Chittagonj city gate	22.37386	91.77214	Supra Tidal Flat	CCG	0.256
20	Middle Halishahar(near big pond)	22.3133	91.78577	Supra Tidal Flat	G14	0.78769
21	Hadipara	22.26942	91.79906	Supra Tidal Flat	HAP	0.70621
22	Hazi Abdul Maium Bari,South Middle Halishahar	22.30512	91.78204	Supra Tidal Flat	MT6	0.55351
23	New Moaring CCT gate	22.29798	91.79112	Supra Tidal Flat	MT7	0.75852
24	After S.G.Field	22.40483	91.75683	Supra Tidal Flat	N-2	0.41796
25	Chowdury para,26No.ward,Hali	22.33007	91.77411	Supra Tidal Flat	NW4	0.93091
26	Banani Complex	22.32081	91.81278	Ancient Point Bar	BCX	0.66065
27	Jamuna Oil	22.26789	91.81428	Ancient Point Bar	CDD	0.62061
28	Kamal Mohajoner hat, CTG	22.2541	91.81633	Ancient Point Bar	KHP	0.75852
29	Nimtala Bosti,Bondor	22.31509	91.80124	Ancient Point Bar	M14	0.85333
30	Mohra	22.40683	91.88186	Ancient Point Bar	M24	0.78769
31	DOC FS (Nim tola bissho road)	22.31326	91.80243	Natural Levee	DFS	1.28
32	IBRAHIM MATCH,cHANGOAN	22.38967	91.86556	Natural Levee	GC2	0.78769
33	Bandar,Postoffice Ghat	22.31389	91.8039	Natural Levee	M10	0.8192

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
34	Sadarghat	22.32494	91.82961	Natural Levee	SGT	0.43575
35	Andar killa Red crecent Hospital	22.3427	91.83807	Deep Valley Fill	ANK	0.73143
36	TNT Office	22.3383	91.83472	Deep Valley Fill	BTC	0.31508
37	C.C	22.35446	91.83869	Deep Valley Fill	CGC	0.16126
38	CMC	22.3582	91.82958	Deep Valley Fill	CMC	1.36533
39	Dampara Army Camp	22.35169	91.82381	Deep Valley Fill	DAC	0.68267
40	Polytechnical	22.37222	91.81853	Deep Valley Fill	GC7	0.38642
41	C.Cantonment, Fire service	22.39228	91.81233	Deep Valley Fill	GC8	0.55351
42	Hill top guest house,Kholsi	22.35935	91.81177	Deep Valley Fill	HGH	0.78769
43	Khulshi	22.35681	91.80992	Deep Valley Fill	M29	0.58514
44	Nasirabad grave yard (2 no.gate)	22.36633	91.82236	Deep Valley Fill	M30	0.53895
45	Cantonment	22.39517	91.81506	Deep Valley Fill	M32	0.49951
46	Baezid Bostami Main Road	22.38289	91.81431	Deep Valley Fill	M33	0.41796
47	Sher Shah colony	22.38128	91.81481	Deep Valley Fill	M34	0.62061
48	Nandon kanon FS (KC dia Road)	22.33646	91.83414	Deep Valley Fill	NFS	1.57539
49	Zia park	22.37633	91.84669	Fluvio Tidal Plain	N-6	0.93091
50	Inst. Of BS campus,Sagorika road,Pahartali	22.35398	91.78168	Alluvial Fan	AC7	0.55351
51	Agrabad FS	22.33427	91.81286	Alluvial Fan	AFS	0.30567
52	Aman Bazar, hathazari, CTG	22.4193	91.8201	Alluvial Fan	DAB	0.78769
53	SK Dewan Ali Jame Mosque,Chotopol,Agrabad	22.32821	91.79502	Alluvial Fan	G12	1.28
54	Abahonir field, Hali	22.33559	91.78744	Alluvial Fan	G13	1.46286
55	Joinal doctors home,Baddarhat,1km	22.36511	91.85067	Alluvial Fan	GC4	0.75852
56	Chittagonj Govt comercial college,Bakulia	22.35864	91.85317	Alluvial Fan	GC5	0.89044
57	Nesam hansa,Noyahat,Bayejit	22.4	91.83478	Alluvial Fan	GC9	0.85333
58	Kumar Para, Hathazari, CTG	22.429	91.8166	Alluvial Fan	KPH	2.048
59	Kulgaon, Panchlaish, CTG	22.4098	91.8207	Alluvial Fan	KPL	1.46286
60	Rangipara,W Agrabad	22.33608	91.79883	Alluvial Fan	M15	0.53895
61	Port Colony.6No.Mosque	22.3219	91.79146	Alluvial Fan	M16	1.28
62	Chuna factory Mor,Artilary road,Hali	22.34288	91.78188	Alluvial Fan	M17	0.60235
63	Fateyabad	22.45344	91.81525	Alluvial Fan	M27	0.78769
64	Badurtola	22.36225	91.84256	Alluvial Fan	Nw8	1.28
65	Bholaganj, Panchlaish, CTG	22.405	91.8573	Alluvial Fan	PVG	1.86182
66	Kadamtali	22.33625	91.82181	Piedmont Plain	KDT	0.25924
67	KEPZ	22.26509	91.86579	Piedmont Plain	KEZ	0.10952

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
68	Latif Nagar	22.41061	91.76022	Piedmont Plain	M20	0.37236
69	Nandon Housing Society (Near new 3)	22.37764	91.778	Piedmont Plain	NHS	0.37236
70	Tiger pass high school	22.34669	91.80911	Piedmont Plain	THS	0.24675
71	Tiger pass primary school	22.34208	91.81375	Piedmont Plain	TPS	0.27676
72	Azizsuper Stadium	22.34681	91.82508	Level Hill	ASS	1.86182
73	Chandon pora fire station	22.35073	91.83955	Level Hill	CFS	0.46546
74	Bayezid bostami FS	22.39194	91.81167	Rounded Top Highly Dissected Hill	BFS	0.62061
75	C.U	22.47278	91.79283	Rounded Top Highly Dissected Hill	CUV	1.70667
76	Baizid Bustami	22.39042	91.81653	Rounded Top Highly Dissected Hill	G8B	1.13778
77	Chittagonj City corporation health care,UPHCP,Sholoshohar	22.37342	91.83253	Rounded Top Highly Dissected Hill	GC6	0.58514
78	Korean EPZ, CTG	22.2295	91.8473	Rounded Top Highly Dissected Hill	KEP	0.21333
79	LalKhan Bazar, CTG	22.355	91.8174	Rounded Top Highly Dissected Hill	LKM	1.46286
80	Railway building valley	22.34097	91.82053	Rounded Top Highly Dissected Hill	RBV	0.15284
81	Foyez lake	22.3655	91.79747	Sharp Crest Slightly Dissected Hill	FSL	0.34712
82	Rose vally Residential area (Near Foyez lake)	22.36281	91.80006	Sharp Crest Slightly Dissected Hill	RRA	0.70621



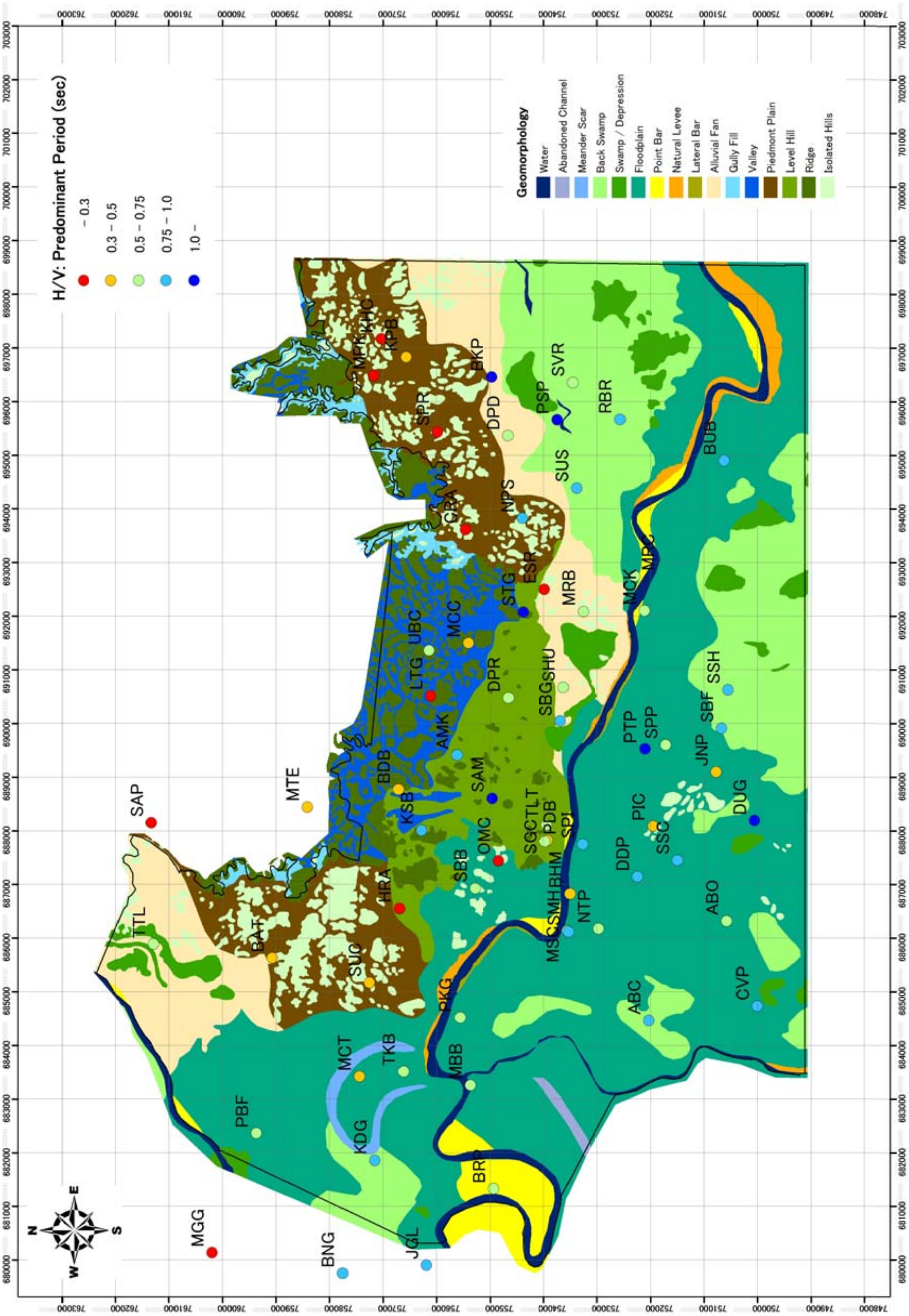
[Background: geomorphology map edited by GSB]

Figure 3-24 Location and Predominant Period of Single Microtremor in Chittagong

Table 3-9 Location and Result of Single Microtremor Measurement in Sylhet

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
1	Suklampur, Dakshin Surma, Sylhet	24.8742	91.8262	Back Swamp	ABC	0.93091
2	Kandigaon	24.92072	91.80111	Back Swamp	KDG	0.75852
3	Panchkuri, ShahParan, Sylhet	24.8882	91.9373	Back Swamp	PSP	1.07790
4	Ruposhi bangla R/project (Jaflong bypass)	24.87761	91.93714	Back Swamp	RBR	0.78769
5	Shib bari brick field (BDB)	24.86119	91.87992	Back Swamp	SBF	0.85333
6	Shah Paran Upashahar, Sylhet	24.8851	91.9246	Back Swamp	SUS	0.89044
7	surma valleyR/project	24.8855	91.94408	Back Swamp	SVR	0.73143
8	Ahmadpur, BRAC office	24.86075	91.84439	Floodplain	ABO	0.60235
9	Boroikandi hafizia madrasa, south surma	24.88714	91.84981	Floodplain	BHM	0.44522
10	Baraia, Uttarbag	24.86008	91.92928	Floodplain	BUB	0.75852
11	Chhoto Betuarpur	24.8558	91.8286	Floodplain	CVP	0.75852
12	Dharadharpur, Dakshin Surma, Sylhet	24.8758	91.8528	Floodplain	DDP	0.85333
13	Dhubaghat, Dakshin Surma, Sylhet	24.85584	91.86283	Floodplain	DUG	1.46286
14	Jangail, sunamgonj road	24.91225	91.78164	Floodplain	JGL	0.85333
15	Jainpur, Shibgonj	24.86222	91.87189	Floodplain	JNP	0.42667
16	Masuk bazar bridge	24.90447	91.81475	Floodplain	MBB	0.73143
17	Moiar char, Toker bazar	24.92317	91.81664	Floodplain	MCT	0.47628
18	Mirer chalk	24.87556	91.90819	Floodplain	MRC	0.73143
19	Mokon high School, kamal gong	24.88772	91.84297	Floodplain	MSC	0.66065
20	Niamotpur	24.88244	91.84328	Floodplain	NTP	0.58514
21	beside Osmani medical college	24.89919	91.85608	Floodplain	OMC	0.24381
22	Pran brick field, Noirpota	24.94069	91.80639	Floodplain	PBF	0.68267
23	PDB office	24.89083	91.85972	Floodplain	PDB	0.49951
24	Pirijpur Ispahani Ali school	24.87303	91.86206	Floodplain	PIC	0.48762
25	Paiker gaon	24.906	91.82722	Floodplain	PKG	0.53895
26	Pathanpara, kadamtoli	24.87422	91.87636	Floodplain	PTP	1.86182
27	Makhon High School	24.88753	91.84281	Floodplain	SMH	0.78769
28	Sylhet Polytechnical Institute	24.88492	91.85892	Floodplain	SPI	0.93091
29	Pathanpara	24.87069	91.87703	Floodplain	SPP	0.58514
30	Dhakin Surma Degree College	24.86897	91.85569	Floodplain	SSC	0.78769
31	Sonargaon Residentail Area	24.86	91.887	Floodplain	SSH	0.78769
32	tuker bazar union complex	24.91569	91.81742	Floodplain	TKB	0.62061
33	Basirpur< Masukbazar	24.90075	91.79558	Point Bar	BRP	0.70621
34	Mirer chalk, bank of Kushiara	24.87397	91.90183	Point Bar	MCK	0.73143

No.	Place	Latitude	Longitude	Geomorphic Unit	Code	Predominant Period (Sec)
35	BKSP	24.89919	91.94536	Alluvial Fan	BKP	1.28000
36	Dhanukandi, Sylhet	24.8966	91.9345	Alluvial Fan	DPD	0.73143
37	East Shaplabagh R/A, Tilagarh	24.89083	91.90603	Alluvial Fan	ESR	0.11907
38	Mirabazar	24.88425	91.90183	Alluvial Fan	MRB	0.73143
39	Sobhani ghat upashar	24.88842	91.88172	Alluvial Fan	SBG	0.75852
40	Shahjalal upashar	24.88781	91.88789	Alluvial Fan	SHU	0.66065
41	Tintila, Sylhet	24.9576	91.8416	Alluvial Fan	TTL	0.56889
42	Chamelibag RA	24.904	91.91725	Piedmont Plain	CRA	0.28444
43	Khadimnagar, Tamabil-Dhaka bypass	24.91358	91.94925	Piedmont Plain	KPB	0.48762
44	Majar potti, Khidirpur, datgram	24.91911	91.94592	Piedmont Plain	MPK	0.26597
45	Shahpara R/A	24.90844	91.93531	Piedmont Plain	SPR	0.20898
46	Amborkhan	24.90594	91.87567	Level Hill	AMK	0.78769
47	Dada pir road, Rainagar, Mirabazar	24.89711	91.88611	Level Hill	DPR	0.73143
48	Kalipara point, Sylhet	24.916	91.8475	Level Hill	HRA	0.22756
49	Alia madrasa	24.90008	91.86761	Level Hill	SAM	1.28000
50	Sheikh ghat colony	24.89128	91.85953	Level Hill	SGC	0.68267
51	Sonargaon Residentail Area	24.89442	91.90186	Level Hill	STG	1.46286
52	Taltola, Telihaor	24.891	91.86258	Level Hill	TLT	0.60235
53	Badam bagicha, airport road	24.91589	91.86947	Ridge	BDB	0.45511
54	Khulapara, Subid Bazar, Sylhet	24.9121	91.8619	Ridge	KSB	0.81920
55	Lakkatura tea garden	24.91022	91.88667	Ridge	LTG	0.19884
56	MC college Hall ground	24.90378	91.89631	Ridge	MCC	0.49951
57	Uttar Baluchar	24.91039	91.89506	Ridge	UBC	0.70621
58	Bhata, Sylhet	24.9376	91.8387	Isolated Hills	BAT	0.44522
59	Khadem chalk gram	24.91775	91.95269	Isolated Hills	KHC	0.29681
60	Nath Para, Sylhet	24.8944	91.9192	Isolated Hills	NPS	0.78769
61	South bagbari, kajalshah	24.90319	91.85103	Isolated Hills	SBB	0.70621
62	Civil engineering Building, SUST	24.92125	91.83392	Isolated Hills	SUC	0.37926
63	Banagaon	24.92642	91.78036	Out of Study Area	BNG	0.78769
64	Mughal gaon	24.94844	91.78447	Out of Study Area	MGG	0.25284
65	malnichara tea garden	24.93133	91.86647	Out of Study Area	MTE	0.37236
66	Airport	24.95769	91.86397	Out of Study Area	SAP	0.14734



[Background: geomorphology map edited by GSB]

Figure 3-25 Location and Predominant Period of Single Microtremor in Sylhet

4. Engineering Geological Map

4.1. Definition of Engineering Geological Map

There are many type of "Engineering Geological Map" depending on intended purpose. For instance, when the target is to know suitable foundation soil layer for a planned building, an engineering geology map should have a property of some geotechnical strength, another case, when it is necessary to know groundwater potential for a water development, a map is created on the basis of permeability of soil as a focal point.

In this study, the target is estimation / evaluation of earthquake phenomenon, and seismic characteristic of soil is required for the engineering geology map to analyze seismic hazard. Basic information for the seismic hazard is ground motion at the ground surface, and the ground motion can be usually calculated using S-wave velocity. Hence, the engineering geological map is created on the basis of S-wave velocity.

It is noted that the seismic ground motion analysis, especially calculation of amplification of soil, is examined by an empirical method that uses average S-wave velocity of ground in the top 30m depth (hereinafter referred to as "AVS 30"), because the limited point data that is boring / PS logging data should be expanded to the study area in order to make ground model. Therefore, "AVS 30 Map" is defined as the "Engineering Geological Map" in this study.

4.2. Geological Subsurface Model

4.2.1. Outline

In order to estimate seismic ground motion at ground surface, geological subsurface model in target area is necessary as well as seismic source model. In this study, AVS 30 at each grid (250 m grid is adopted in this study taking into consideration with Ward area in each City Corporations as shown in Figure 4-1) and AVS 30 Map are created after setup of the geological subsurface model to calculate amplification of subsurface ground. Procedure of the geological subsurface model is shown in Figure 4-2.

Using limited data of geology / geomorphology / boring / soil tests, geological classification, relations between Vs and N-value, AVS 30 at boring sites, Holocene deposit distribution and the relationship between Holocene thickness and AVS 30 are estimated.

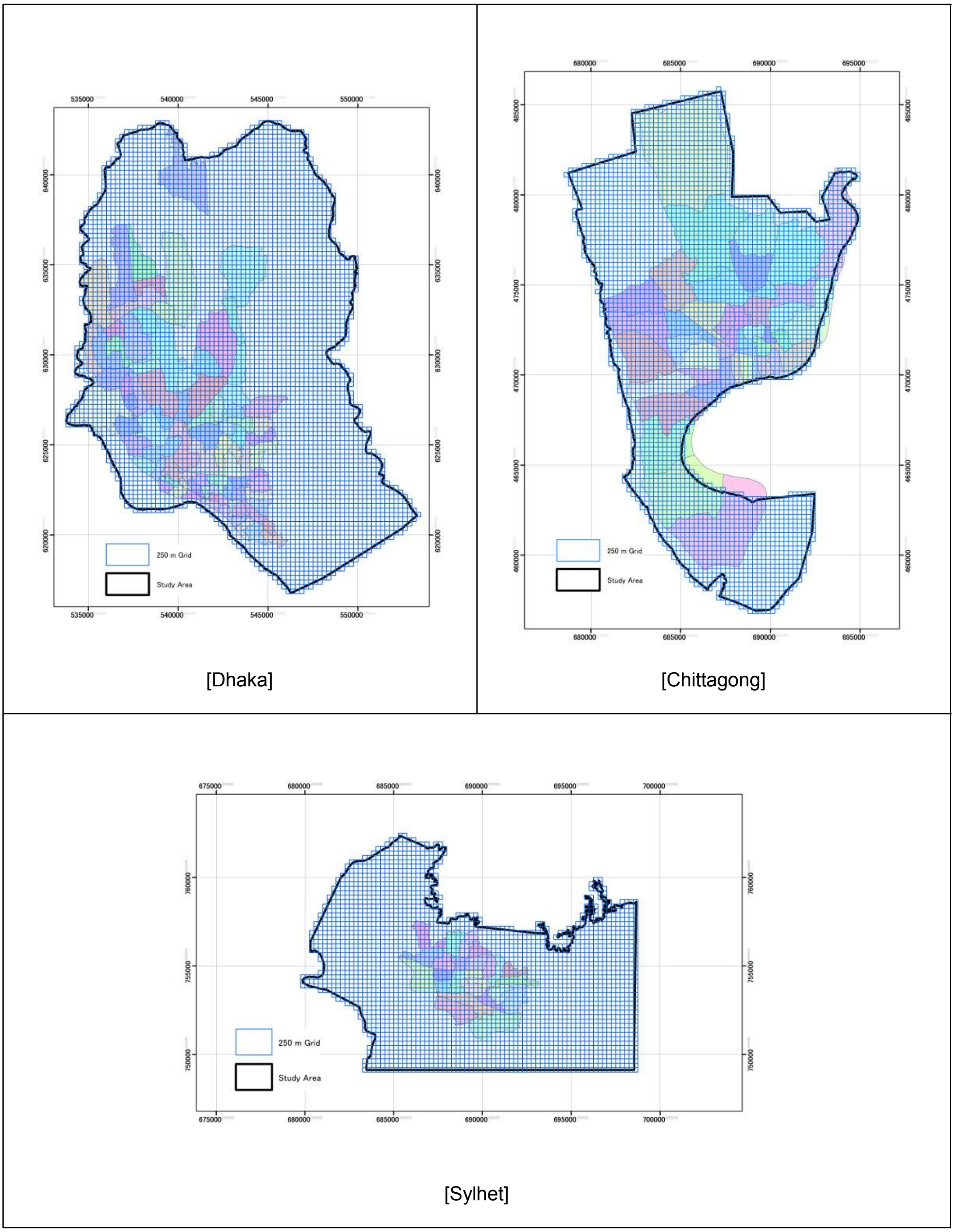


Figure 4-1 250 m Grid in each Study Area with Ward Boundary

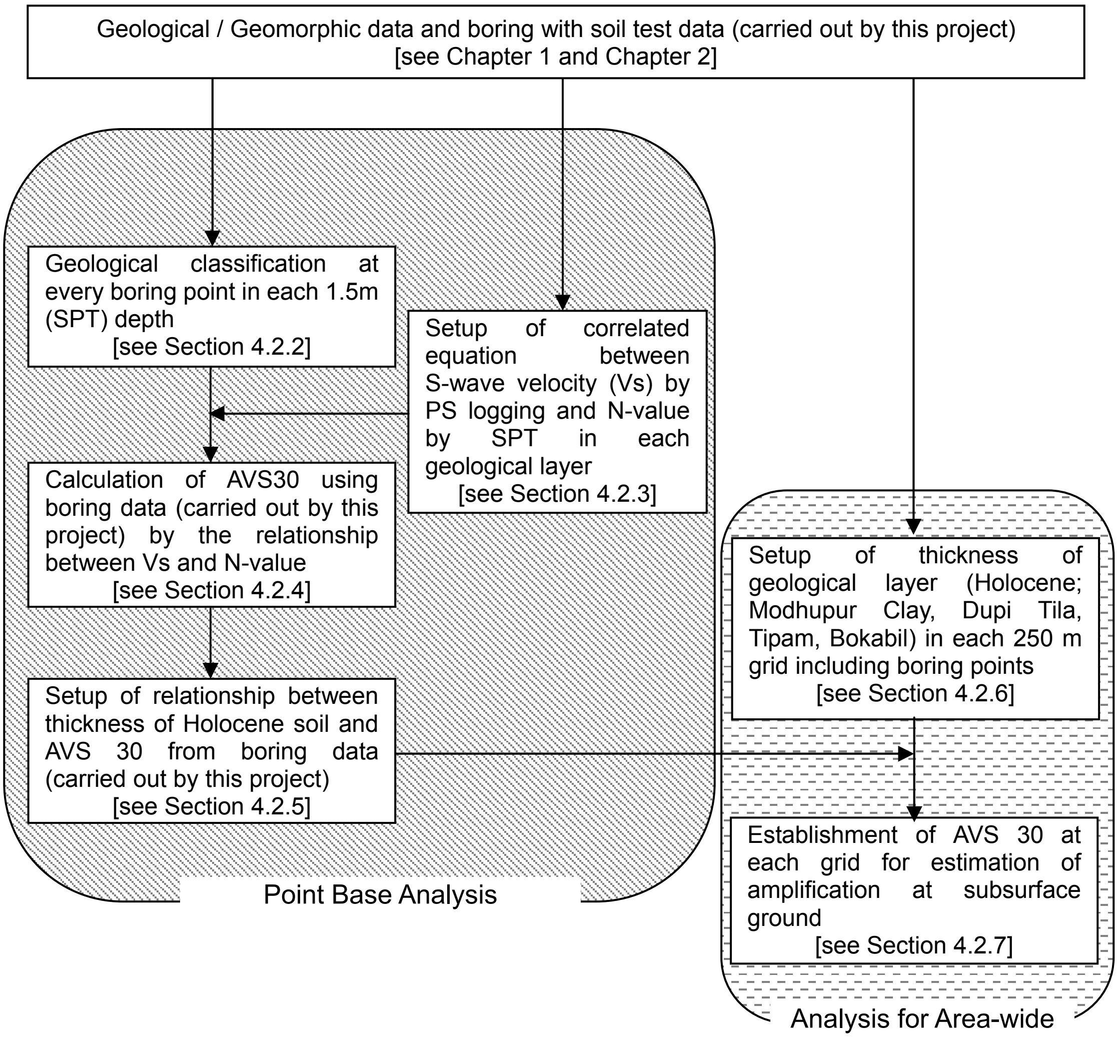


Figure 4-2 Flowchart of Geological Subsurface Model

4.2.2. Geological Classification

Geological layer is classified into 7 types based on soil sample observation and results of the laboratory test as shown in Table 4-1.

Table 4-1 Tabulation of Geological Classification

Geological Classification		Dhaka	Chittagong	Sylhet
Recent	Fill (F)	●	●	●
Holocene	Clayey Soil (H-C)	●	●	●
	Sandy Soil (H-S)	●	●	●
Pleistocene	Modhupur Clay (MC)	●		
Pliocene	Dupi Tila (DT)	●	●	●
Miocene	Tipam (Tp)		●	
	Bokabil (Bk)		●	

Each geological classification has characteristics of N-value as shown in Figure 4-3, and the characteristics reflects S-wave velocity features (refer to Section 4.2.3)

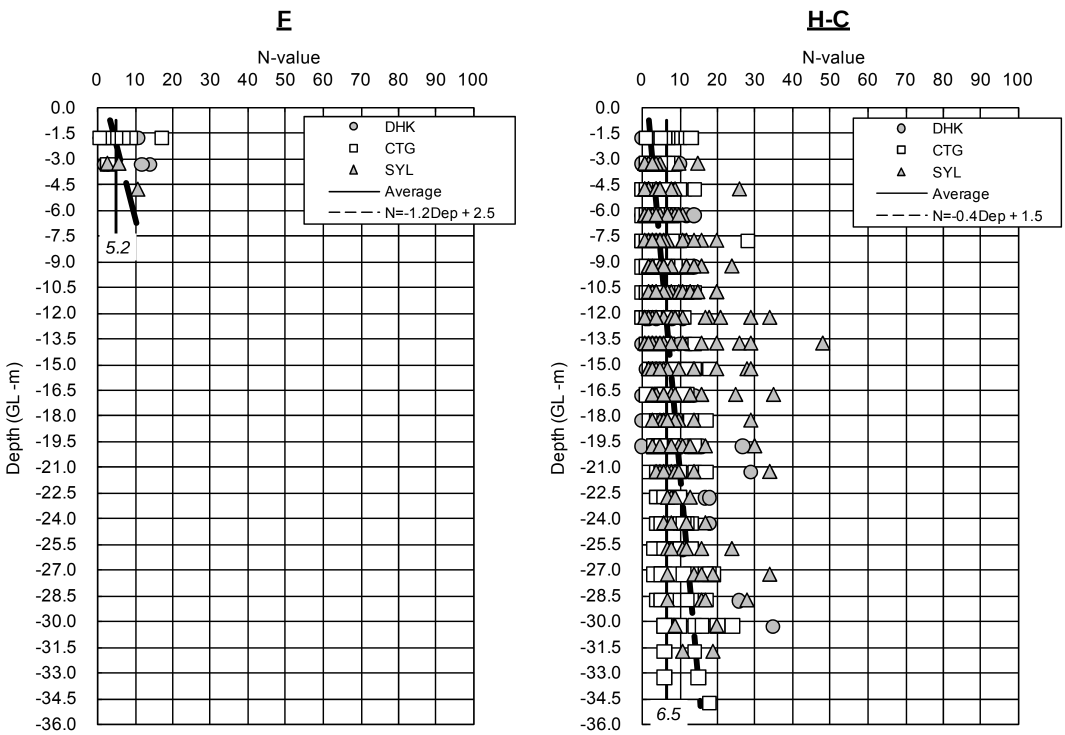


Figure 4-3 N-value Characteristics of each Geological Classification

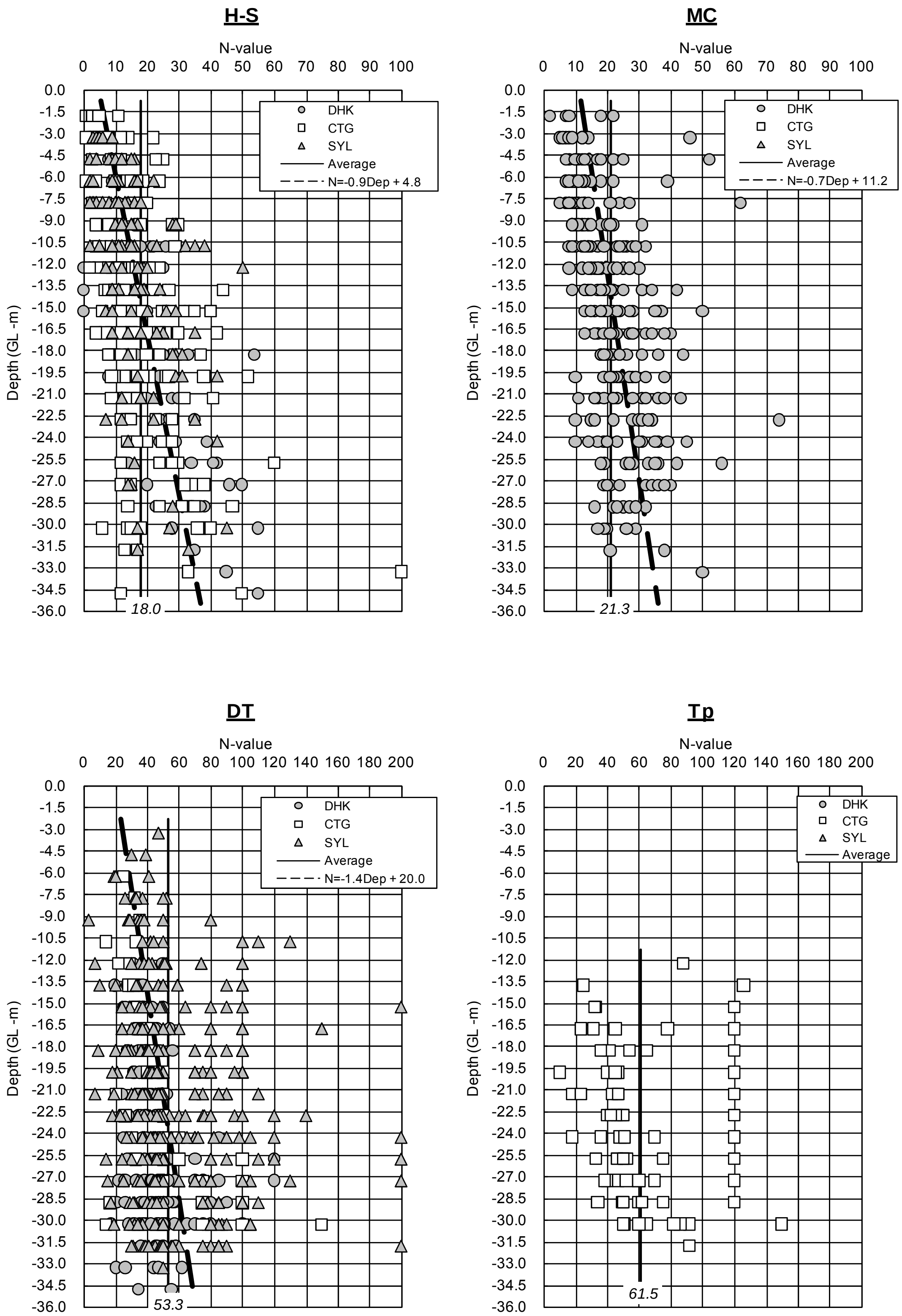


Figure 4-3 (cont.) N-value Characteristics of each Geological Classification

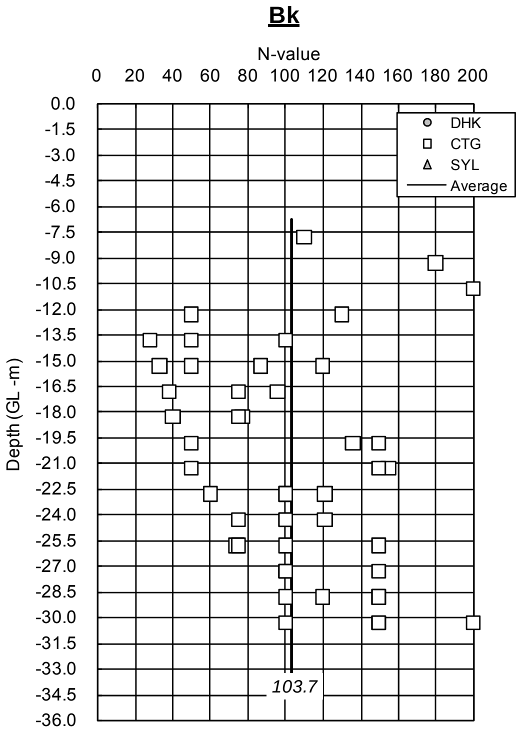


Figure 4-3 (cont.) N-value Characteristics of each Geological Classification

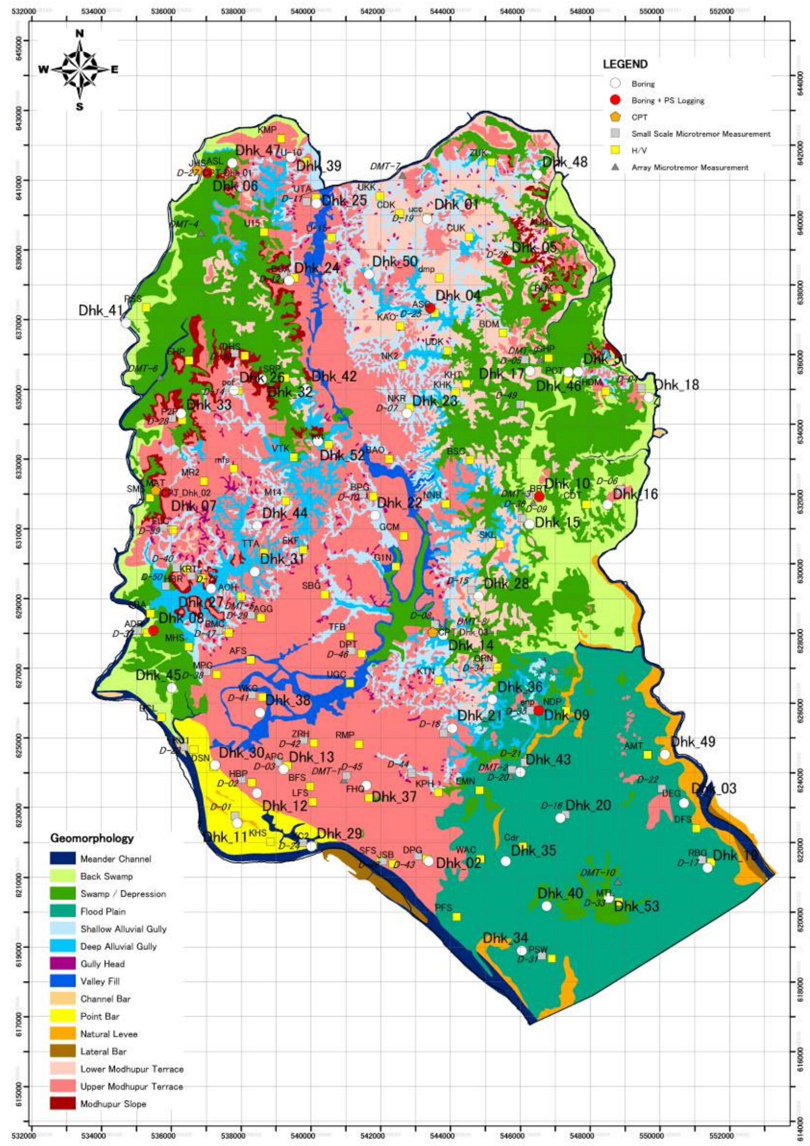
All borings carried out by this project are expressed by the geological classification at every 1.5 m in depth where SPT were conducted as shown in Figure 4-5 (Dhaka), Figure 4-8 (Chittagong) and Figure 4-11 (Sylhet).

At PS logging points, these geological classification are utilized as soil modeling of 1D response analysis (refer to Section 2.2 in Report of “Seismic Hazard Map”).

(1) Dhaka

At subsurface ground in central part of the study area from north to south direction and its surroundings distributes Modhupur Clay and Fill / Holocene soil, respectively, as shown in Figure 4-4.

Fill is located in old wetland / water body and basically made by very loose sand without adequate compaction work, thus it is evaluated that this area is liquefiable induced by a strong seismic motion. Holocene soil consists of loose sandy soil and soft clayey soil with quite complicated distribution, and it is difficult to make a detailed soil modeling due to no horizontal-stratification.



*Red-tinged color shows Modhupur Clay.

[The geomorphic map was edited by GSB]

Figure 4-4 Geomorphic Map with the Investigation Points in Dhaka

Geological strata consist of, from topsoil to downward, Fill, Holocene soil (clayey soil and sandy soil), Modhupur Clay and Dupi Tila as shown in Figure 4-5.

Upper Depth	Dhk_01	Dhk_02	Dhk_03	Dhk_04	Dhk_05	Dhk_06	Dhk_07	Dhk_08	Dhk_09	Dhk_10	Dhk_11	Dhk_12	Dhk_13	Dhk_14	Dhk_15	Dhk_16	Dhk_17	Dhk_18	Dhk_19
1.5	F	MC	F	F	F	H-C	MC	F	F	F	H-S	F	F	H-C	H-C	H-S	H-C	H-C	H-S
3.0	F	MC	H-C	H-C	F	H-C	MC	H-S	MC	F	H-S	MC	MC	H-C	H-C	H-C	H-C	H-C	H-C
4.5	MC	MC	H-C	H-C	MC	H-C	MC	H-C	MC	H-C	H-S	MC	MC	H-C	H-C	H-C	H-C	H-C	H-C
6.0	MC	MC	H-C	H-C	MC	H-C	MC	H-S	MC	H-C	H-S	MC	MC	H-C	MC	H-C	H-C	H-C	H-C
7.5	MC	MC	H-C	H-C	MC	H-C	MC	H-C	MC	H-C	H-S	MC	MC	H-C	MC	MC	H-C	H-C	H-C
9.0	MC	MC	H-C	H-C	MC	H-C	MC	H-C	MC	H-C	H-S	MC	MC	H-S	MC	MC	H-S	H-C	H-C
10.5	MC	MC	H-C	H-S	MC	H-C	MC	H-S	MC	H-C	H-S	MC	MC	H-S	MC	MC	MC	H-C	H-C
12.0	MC	MC	MC	H-S	MC	H-C	MC	H-S	MC	H-S	H-S	MC	MC	H-S	MC	DT	MC	H-C	H-C
13.5	MC	MC	MC	H-C	MC	H-C	MC	H-S	MC	H-S	H-S	MC	DT	H-S	MC	DT	MC	H-C	H-C
15.0	MC	MC	MC	MC	MC	H-C	MC	H-S	MC	H-S	H-S	DT	DT	MC	MC	DT	DT	H-C	H-C
16.5	MC	MC	MC	DT	MC	H-C	MC	H-S	MC	H-C	H-S	DT	DT	MC	MC	DT	DT	H-C	H-C
18.0	MC	MC	MC	DT	MC	H-S	MC	H-S	MC	H-C	H-S	DT	DT	MC	MC	DT	DT	H-S	H-S
19.5	MC	MC	MC	DT	MC	H-S	MC	H-S	MC	H-C	H-S	DT	DT	MC	MC	DT	DT	H-S	H-C
21.0	MC	MC	MC	DT	MC	MC	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	H-S	H-C
22.5	MC	MC	DT	DT	MC	MC	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	H-S	H-C
24.0	MC	MC	DT	DT	MC	MC	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	H-S	H-C
25.5	MC	MC	DT	DT	MC	DT	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	DT	H-C
27.0	MC	MC	DT	DT	DT	DT	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	DT	H-C
28.5	MC	MC	DT	DT	DT	DT	MC	H-S	MC	MC	H-S	DT	DT	DT	MC	DT	DT	DT	H-C
30.0	MC	DT	DT	DT	DT	DT	MC	H-S	DT	MC		DT	DT	DT	MC	DT	DT	DT	H-C
31.5	DT			DT	DT	DT	MC	H-S	DT	MC									
33.0				DT	DT	DT	MC	H-S	DT	DT									
34.5								H-S	DT	DT									

Upper Depth	Dhk_20	Dhk_21	Dhk_22	Dhk_23	Dhk_24	Dhk_25	Dhk_26	Dhk_27	Dhk_28	Dhk_29	Dhk_30	Dhk_31	Dhk_32	Dhk_33	Dhk_34	Dhk_35	Dhk_36	Dhk_37	Dhk_38
1.5	H-C	F	MC	H-C	H-C	MC	H-C	F	H-C	F	H-S	F	H-C	H-C	H-C	F	H-C	F	MC
3.0	MC	MC	MC	H-C	H-C	MC	H-C	H-C	H-C	H-C	H-S	F	H-C	H-C	H-S	F	H-C	H-C	MC
4.5	MC	MC	MC	H-C	H-C	MC	MC	H-C	H-C	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	MC
6.0	MC	MC	MC	MC	H-C	MC	MC	H-C	H-C	H-C	H-C	MC	H-C	H-C	H-C	H-C	H-C	H-C	MC
7.5	MC	MC	MC	MC	H-C	MC	MC	H-C	MC	H-C	H-S	MC	H-C	H-C	MC	MC	H-C	MC	MC
9.0	MC	MC	MC	MC	H-C	MC	MC	H-S	MC	H-C	H-S	MC	H-C	H-C	MC	MC	H-C	MC	MC
10.5	MC	MC	MC	MC	H-C	MC	MC	H-S	MC	H-S	H-S	MC	H-S	H-C	MC	MC	H-C	MC	MC
12.0	MC	MC	MC	MC	H-C	MC	MC	H-S	MC	H-S	H-S	DT	H-S	H-C	MC	MC	H-C	MC	MC
13.5	MC	MC	MC	MC	H-C	MC	MC	DT	MC	H-C	H-C	DT	H-C	H-C	MC	MC	H-C	MC	MC
15.0	MC	DT	MC	MC	H-C	MC	MC	DT	DT	H-S	H-C	DT	MC	H-C	MC	MC	DT	MC	MC
16.5	MC	DT	DT	DT	H-C	MC	MC	DT	DT	H-S	H-C	DT	MC	H-C	MC	MC	DT	MC	MC
18.0	MC	DT	DT	DT	H-C	MC	MC	DT	DT	H-S	H-C	DT	MC	H-C	MC	DT	DT	MC	DT
19.5	MC	DT	DT	DT	H-C	MC	MC	DT	DT	H-S	H-C	DT	MC	H-C	MC	DT	DT	MC	DT
21.0	MC	DT	DT	DT	DT	MC	MC	DT	DT	H-S	H-C	DT	MC	H-C	MC	DT	DT	MC	DT
22.5	MC	DT	DT	DT	DT	MC	MC	DT	DT	H-S	H-S	DT	MC	H-C	MC	DT	DT	DT	DT
24.0	MC	DT	DT	DT	DT	MC	MC	DT	DT	H-S	H-C	DT	DT	MC	MC	DT	DT	DT	DT
25.5	MC	DT	DT	DT	DT	MC	MC	DT	DT	H-S	H-S	DT	DT	MC	MC	DT	DT	DT	DT
27.0	MC	DT	DT	DT	DT	MC	DT	DT	DT	H-S	H-S	DT	DT	DT	MC	DT	DT	DT	DT
28.5	DT	DT	DT	DT	DT	MC	DT	DT	DT	H-S	H-S	DT	DT	DT	MC	DT	DT	DT	DT
30.0	DT	DT	DT	DT	DT	MC	DT	DT	DT	H-S	H-S	DT	DT	DT	MC	DT	DT	DT	DT

Figure 4-5 Geological Classification at the Borings in Dhaka

The strata generally consist of 3 layers, which are Holocene soil including Fill, Modhupur Clay and Dupi Tila, as shown in Figure 4-6. Thickness of Modhupur Clay gradually becomes thin or is disappeared towards boundary of the study area. Dupi Tila distributes whole study area, and surface of Dupi Tila in the central part and its surroundings are encountered in shallow portion (shallower than 20 m in depth from ground surface) and in the deeper portion (deeper than 30 m in depth beside the study area boundary).

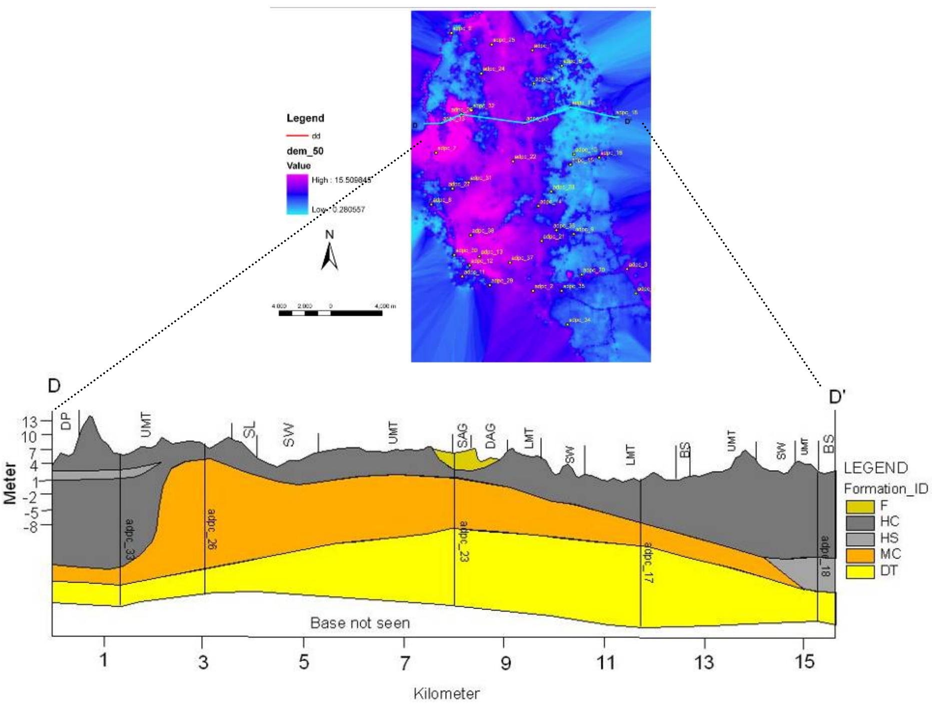
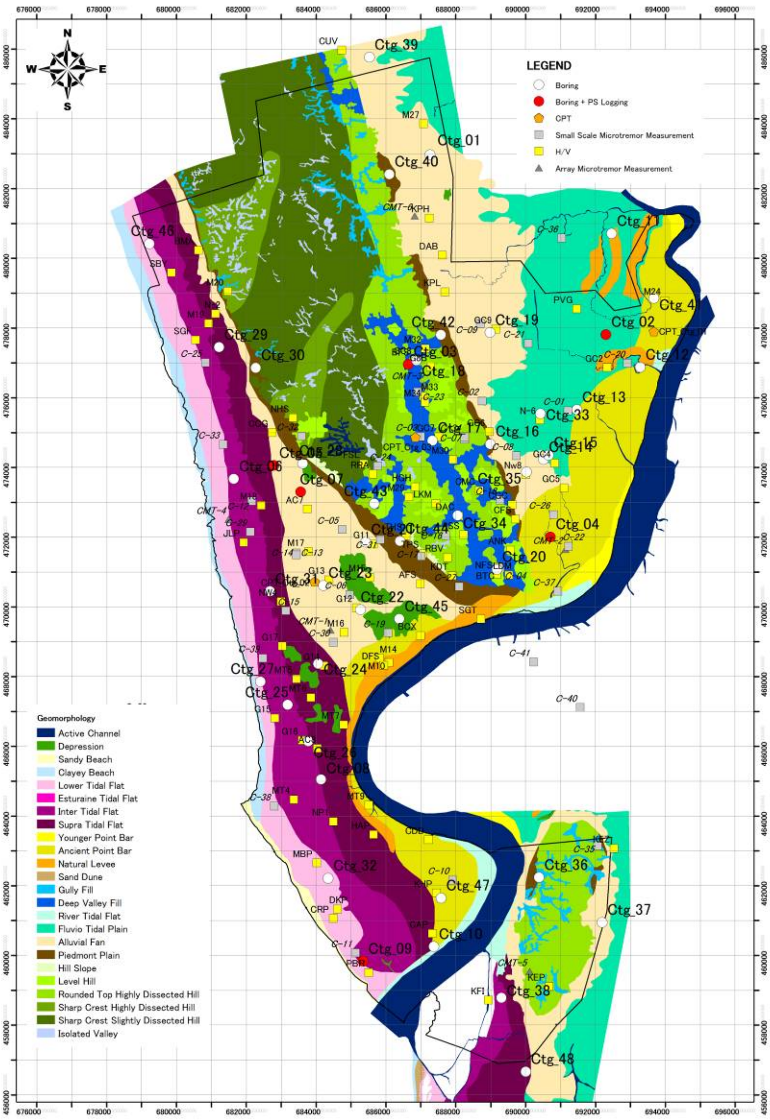


Figure 4-6 Schematic Geological Cross Section in Dhaka

(2)Chittagong

There are hill area and plane area in Chittagong study area. Dupi Tila, Tipam and Bokabil outcrop in the hill area, and Fill / Holocene soil distributes in the plane area as shown in Figure 4-7.

Fill is located in old wetland / water body and basically made by very loose sand without adequate compaction, thus it is evaluated that this area is liquefiable induced by a strong seismic motion. Holocene soil consists of loose sandy soil and soft clayey soil with quite complicated distribution, and it is difficult to make a detailed soil modeling due to no horizontal-stratification.



[The geomorphic map was edited by GSB]

Figure 4-7 Geomorphic Map with the Investigation Points in Chittagong

Geological strata consist of, from topsoil to downward, Fill, Holocene soil (clayey soil and sandy soil), and Dupi Tila / Tipam / Bokabil, which are seismic engineering baserock, as shown in Figure 4-8.

Upper Depth	Ctg_01	Ctg_02	Ctg_03	Ctg_04	Ctg_05	Ctg_06	Ctg_07	Ctg_08	Ctg_09	Ctg_10	Ctg_11	Ctg_12	Ctg_13	Ctg_14	Ctg_15	Ctg_16	Ctg_17	Ctg_18	Ctg_19
1.5	F	F	F	H-S	F	F	F	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	F	H-C
3.0	H-C	H-C	H-C	H-C	H-C	F	H-C	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-C	H-C
4.5	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-C	H-C
6.0	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C
7.5	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-S	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C
9.0	H-C	H-C	H-C	H-C	H-S	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C
10.5	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-S	H-S	H-C	H-C	H-C	H-S	H-C	H-C	H-C	H-C
12.0	H-C	H-C	H-C	H-C	H-C	H-C	Tp	H-S	H-S	H-S	H-S	H-C	H-C	H-C	H-S	H-C	H-C	H-S	H-S
13.5	H-C	H-C	H-C	H-C	H-C	H-C	Tp	H-S	H-S	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	Tp	H-S
15.0	H-C	H-C	H-C	H-S	Bk	H-C	Tp	H-C	H-S	H-C	H-S	H-S	H-C	H-S	H-C	H-C	H-C	Tp	H-C
16.5	H-C	H-C	H-C	H-S	Bk	H-C	Tp	H-C	H-S	H-C	H-S	H-S	H-C	H-S	H-S	H-S	Tp	Tp	H-S
18.0	H-C	H-C	H-C	H-S	Bk	H-S	Tp	H-C	H-C	Tp	H-C	H-S	H-S	H-S	H-C	H-S	Tp	Tp	H-S
19.5	H-C	H-C	H-S	H-S	Bk	H-C	Tp	H-S	H-S	Tp	H-C	H-C	H-S	H-S	H-C	DT	Tp	Tp	H-C
21.0	H-C	H-C	Tp	H-C	Bk	H-S	Tp	H-S	H-S	Tp	H-C	H-C	H-C	H-S	H-C	DT	Tp	Tp	H-S
22.5	H-C	H-C	Tp	H-S	Bk	Bk	Tp	H-C	H-S	Tp	H-C	H-C	H-C	H-C	H-C	DT	Tp	Tp	H-S
24.0	H-S	H-C	Tp	H-S	Bk	Bk	Tp	H-C	H-S	Tp	H-C	H-C	H-C	H-C	H-C	DT	Tp	Tp	H-S
25.5	H-S	H-C	Tp	H-C	Bk	Bk	Tp	H-C	Tp	Tp	H-C	H-C	H-C	H-C	H-C	DT	Tp	Tp	H-C
27.0	H-C	H-C	Tp	H-C	Bk	Bk	Tp	H-S	Tp	Tp	H-C	H-C	H-C	H-C	H-S	DT	Tp	Tp	H-C
28.5	H-C	H-C	Tp	H-C	Bk	Bk	Tp	H-S	Tp	Tp	H-C	H-C	H-C	H-C	H-S	DT	Tp	Tp	H-C
30.0	H-C	H-C	Tp	H-C	Bk	Bk	Tp	H-S	Tp	Tp		H-C	H-C	H-C	H-S	DT	Tp	Tp	H-C
31.5		H-S		H-C			Tp												
33.0		H-S		H-C															
34.5		H-S		H-S															
36.0																			

Upper Depth	Ctg_20	Ctg_21	Ctg_22	Ctg_23	Ctg_24	Ctg_25	Ctg_26	Ctg_27	Ctg_28	Ctg_29	Ctg_30	Ctg_31	Ctg_32	Ctg_33	Ctg_34	Ctg_35	Ctg_36	Ctg_37	Ctg_38
1.5	F	F	H-C	F	H-C	H-C	H-C	H-S	H-S	H-C	H-C	H-S	H-C	H-S	H-S	H-C	H-C	H-S	H-C
3.0	H-C	H-S	H-C	H-C	H-S	H-S	H-C	H-S	H-S	H-C	H-C	H-S	H-C	H-C	H-S	H-C	H-C	H-S	H-C
4.5	H-C	H-S	H-C	H-C	H-C	H-S	H-C	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C
6.0	H-C	H-S	H-S	H-C	H-C	H-S	H-S	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	DT	H-C
7.5	H-C	H-S	H-S	H-C	H-C	H-S	H-S	H-S	BK	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	DT	H-C
9.0	H-C	H-S	H-S	H-S	H-S	H-C	H-C	H-S	BK	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-C	DT	H-C
10.5	H-C	H-S	H-S	H-S	H-S	H-C	H-C	H-S	BK	H-C	H-C	H-C	H-C	H-C	H-C	H-C	DT	DT	H-C
12.0	H-C	H-C	H-S	H-S	H-S	H-S	H-S	H-S	BK	BK	H-C	H-S	H-S	H-C	H-C	H-C	DT	DT	H-C
13.5	H-C	H-S	H-S	H-C	H-C	H-S	H-S	H-S	BK	BK	BK	H-S	H-C	H-S	H-S	H-C	DT	DT	H-C
15.0	H-C	H-S	H-S	H-S	H-S	H-S	H-S	H-S	BK	BK	BK	H-C	H-S	H-S	Tp	H-C	DT	DT	H-C
16.5	H-S	Tp	H-C	H-S	H-S	H-S	H-S	H-C		BK	BK	H-S	H-S	H-S	Tp	H-C	DT	DT	H-C
18.0	H-S	Tp	H-C	H-S	H-S	H-S	H-S	H-C		BK	BK	H-S	H-S	H-C	Tp	H-C	DT	DT	H-C
19.5	H-S	Tp	H-C	H-C	H-S	H-C	H-S	H-C		BK	BK	H-S	H-S	H-S	Tp	H-C	DT	DT	H-S
21.0	Tp	Tp	H-C	H-C	H-C	H-C	H-S	H-C		BK	BK	H-S	H-S	H-S	Tp	H-C	DT	DT	DT
22.5	Tp	Tp	H-C	H-C	H-C	H-C	H-C	H-C		BK	BK	H-S	H-S	Tp	Tp	H-S	DT	DT	DT
24.0	Tp	Tp	H-C	H-C	H-C	H-C	H-C	H-C		BK	BK	H-S	H-S	Tp	Tp	H-S	DT	DT	DT
25.5	Tp	Tp	H-C	H-C	H-S	H-C	H-C	H-C		BK	BK	H-S	H-S	Tp	Tp	H-S	DT	DT	DT
27.0	Tp	Tp	H-C	H-C	H-S	H-C	H-C	H-C		BK	BK	H-S	H-S	Tp	Tp	H-S	DT	DT	DT
28.5	Tp	Tp	H-C	H-C	H-S	H-C	H-C	H-C		BK	BK	H-S	H-S	Tp	Tp	H-S	DT	DT	DT
30.0	Tp	Tp	H-C	H-C	H-S	H-S	H-C	H-S		BK	BK	H-S		Tp	Tp	H-S	DT	DT	DT
31.5	Tp					H-S		H-C			BK								
33.0						H-S		H-C											
34.5								H-C											
36.0								H-S											

Figure 4-8　Geological Classification at the Borings in Chittagong

The strata generally consist of 2 layers, which are Holocene soil and Dupi Tila / Tipam / Bokabil, as shown in Figure 4-9.　Thickness of Holocene soil becomes thick from hill area to sea side (westward) and inland side (eastward), and is more than 30 m in wide area.

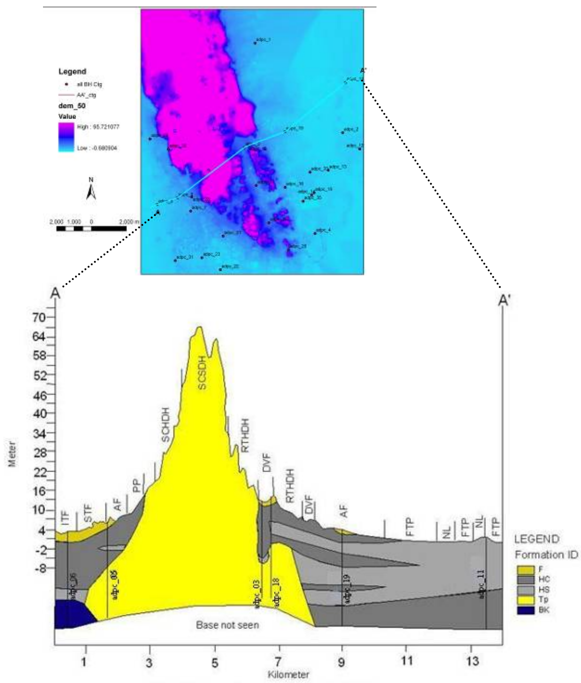
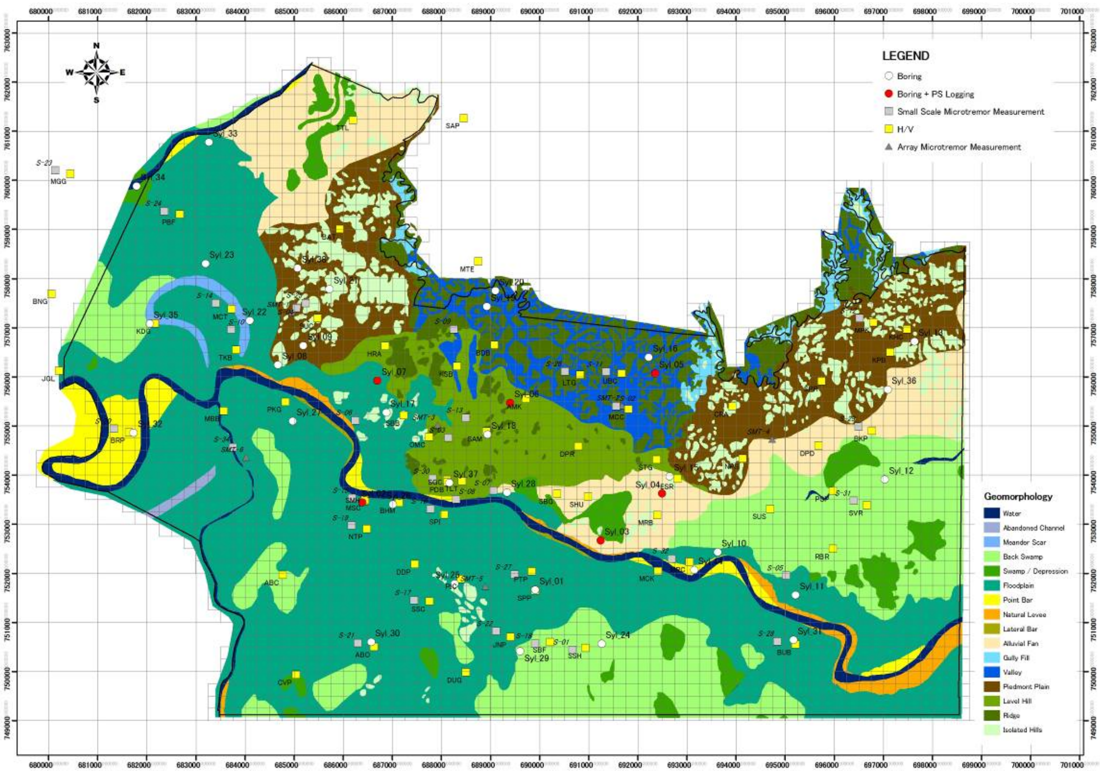


Figure 4-9　Schematic Geological Cross Section in Chittagong

(3) Sylhet

There are hill area and plane area in Sylhet study area. Dupi Tila outcrops in the hill area and Fill / Holocene soil distributes in the plane area as shown in Figure 4-10.

Fill is located in old wetland / water body and basically made by very loose sand without adequate compaction, thus it is evaluated that this area is liquefiable induced by a strong seismic motion. Holocene soil consists of loose sandy soil and soft clayey soil with quite complicated distribution, and it is difficult to make a detailed soil modeling due to no horizontal-stratification.



[The geomorphic map was edited by GSB]

Figure 4-10 Geomorphic Map with the Investigation Points in Sylhet

Geological strata consist of, from topsoil to downward, Fill, Holocene soil (clayey soil and sandy soil), and Dupi Tila, which are seismic engineering baserock, as shown in Figure 4-11.

Upper Depth	Syl_01	Syl_02	Syl_03	Syl_04	Syl_05	Syl_06	Syl_07	Syl_08	Syl_09	Syl_10	Syl_11	Syl_12	Syl_13	Syl_14	Syl_15	Syl_16	Syl_17	Syl_18
1.5	H-C	H-C	H-C	H-C	H-C	F	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	F	H-C	DT
3.0	H-C	H-C	H-C	H-S	H-C	F	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	DT
4.5	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-S	H-C	DT
6.0	H-S	H-C	H-S	H-C	DT	H-C	DT	DT	H-C	H-S	H-C	H-C	H-S	H-S	H-C	H-S	H-S	DT
7.5	H-C	H-C	H-C	H-S	DT	H-S	DT	DT	H-C	H-S	H-C	H-S	H-S	H-C	H-C	H-S	H-S	DT
9.0	H-C	H-C	H-C	H-S	DT	H-S	DT	DT	H-C	H-C	H-C	H-S	H-C	H-S	H-S	H-S	H-S	DT
10.5	DT	H-C	H-C	H-C	DT	DT	DT	DT	H-C	H-C	H-C	H-C	H-S	H-C	H-S	H-C	H-S	DT
12.0	DT	H-C	H-C	H-C	DT	DT	DT	DT	H-C	H-C	H-C	H-C	H-C	H-C	H-S	DT	H-S	DT
13.5	DT	H-C	H-C	H-C	DT	DT	DT	DT	H-C	H-C	H-C	H-C	H-C	H-S	DT	DT	H-S	DT
15.0	DT	H-C	H-S	DT	DT	DT	DT	DT	H-C	H-C	H-C	DT	DT	H-C	DT	DT	H-S	DT
16.5	DT	H-C	DT	DT	DT	DT	DT	DT	H-C	H-C	DT	DT	DT	H-S	DT	DT	H-C	DT
18.0	DT	H-S	DT	DT	DT	DT	DT	DT	DT	H-C	DT	DT	DT	H-S	DT	DT	H-C	DT
19.5	DT	H-C	DT	DT	DT	DT	DT	DT	DT	H-C	DT	DT	DT	H-S	DT	DT	DT	
21.0	DT	H-C	DT	DT	DT	DT	DT	DT	DT	H-C	DT	DT	DT	H-S	DT	DT	DT	
22.5	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	H-S	DT		DT	
24.0	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT		H-S	DT		DT	
25.5	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT		H-S	DT		DT	
27.0	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT		DT	DT		DT	
28.5	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT	DT		DT			DT	
30.0	DT		DT	DT	DT	DT	DT	DT	DT	DT	DT	DT		DT			DT	
31.5																		

Upper Depth	Syl_19	Syl_20	Syl_21	Syl_22	Syl_23	Syl_24	Syl_25	Syl_26	Syl_27	Syl_28	Syl_29	Syl_30	Syl_31	Syl_32	Syl_33	Syl_34	Syl_35	Syl_36	Syl_37	Syl_38
1.5	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-C	H-S	F	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-S
3.0	H-S	DT	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-S
4.5	H-S	DT	H-C	H-S	H-C	H-C	H-C	H-C	H-C	H-C	DT	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-S
6.0	H-S	DT	H-C	H-S	H-C	H-S	H-S	H-C	H-C	H-C	DT	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-C
7.5	DT	DT	H-C	H-S	H-C	H-C	DT	H-C	H-C	H-S	DT	H-C	H-C	H-C	H-C	H-C	H-C	H-S	H-C	H-S
9.0	DT	DT	H-C	H-S	H-S	H-S	DT	H-C	H-C	H-C	DT	H-C	H-C	H-C	H-C	H-C	H-S	H-S	H-C	H-S
10.5	DT	DT	DT	H-S	H-S	H-C	DT	H-C	H-C	DT	DT	H-C	H-C	H-S	H-C	H-C	H-S	H-S	H-C	H-C
12.0	DT	DT	DT	H-S	DT	H-C	DT	H-C	H-C	DT	DT	H-C	H-C	H-S	H-C	H-C	H-S	H-S	H-C	H-C
13.5	DT	DT	DT	H-S	DT	H-C	DT	H-C	H-C	DT	DT	H-C	H-C	H-S	H-S	H-C	H-C	H-S	DT	H-C
15.0	DT	DT	DT	H-S	DT	H-C	DT	H-C	H-C	DT	DT	H-C	H-C	H-S	H-S	H-C	H-C	H-S	DT	H-C
16.5	DT	DT	DT	H-C	DT	H-C	DT	H-C	DT	DT	DT	H-C	H-C	H-S	H-C	H-S	H-C	H-S	DT	H-C
18.0	DT	DT	DT	H-C	DT	H-C	DT	H-C	DT	DT	DT	H-C	H-C	H-C	H-C	H-S	H-C	H-S	DT	DT
19.5			DT	H-C	DT	H-C	DT	H-C	DT	DT	DT	H-C	H-C	H-C	H-C	H-C	H-S	H-S	DT	DT
21.0			DT	DT	DT	H-S	DT	DT	DT	DT	DT	DT	H-S	DT	H-C	H-C	H-C	H-S	DT	DT
22.5			DT	DT	DT	H-S	DT	DT	DT		DT	DT	H-C	DT	H-C	H-C	H-C	H-C	DT	DT
24.0			DT	DT	DT	H-C	DT	DT	DT		DT	DT	H-C	DT	H-C	H-C	H-C	H-C	DT	DT
25.5			DT	DT	DT	H-C	DT	DT	DT		DT	DT	H-C	DT	H-C	H-S	H-C	H-C	DT	DT
27.0				DT	DT	H-C	DT	DT	DT		DT	DT	H-C	DT	H-C	H-S	H-C	DT	DT	DT
28.5				DT	DT	H-S	DT	DT			DT	DT	H-C	DT	H-S	H-S	H-C	DT	DT	DT
30.0				DT		H-S	DT	DT			DT	DT	H-C	DT	H-S	H-S	H-C	DT	DT	DT
31.5																			DT	

Figure 4-11 Geological Classification at the Borings in Sylhet

The strata generally consist of 2 layers, which are Holocene soil and Dupi Tila as shown in Figure 4-12. Thickness of Holocene soil irregularly becomes thick from hill area to south / south-east / south-west side.

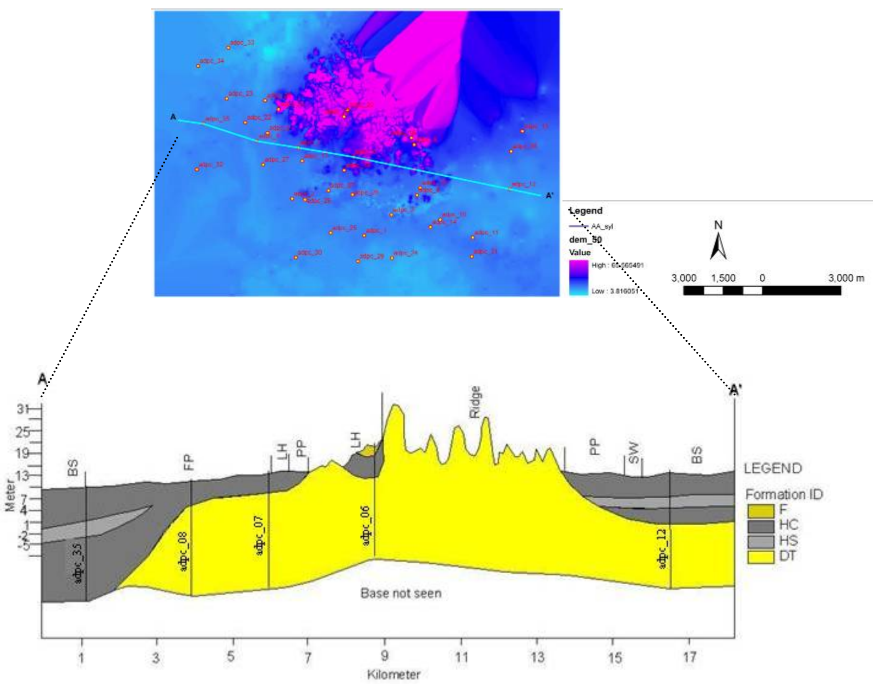


Figure 4-12 Schematic Geological Cross Section in Sylhet

4.2.3. Relationship between Vs and N

The S-wave velocity (hereinafter referred to as "Vs") is required to calculate amplification of subsurface soil. However, there is a little information of Vs in Bangladesh so far, and PS logging results conducted by this project is also limited (7, 6 and 6 points in Dhaka, Chittagong and Sylhet, respectively). Hence, the relationship between Vs and N-value (hereinafter referred to as "N") of SPT that has shown good relation most of the world is useful for estimation of the amplification. The procedure of estimated the relationship is shown in Figure 4-13, and their results are shown in Figure 4-14

The relationship between Vs and N for each geological classification in Figure 4-15 provides good correlation and their correlating equations in each geological classification are derived from the relation as shown in Table 4-2.

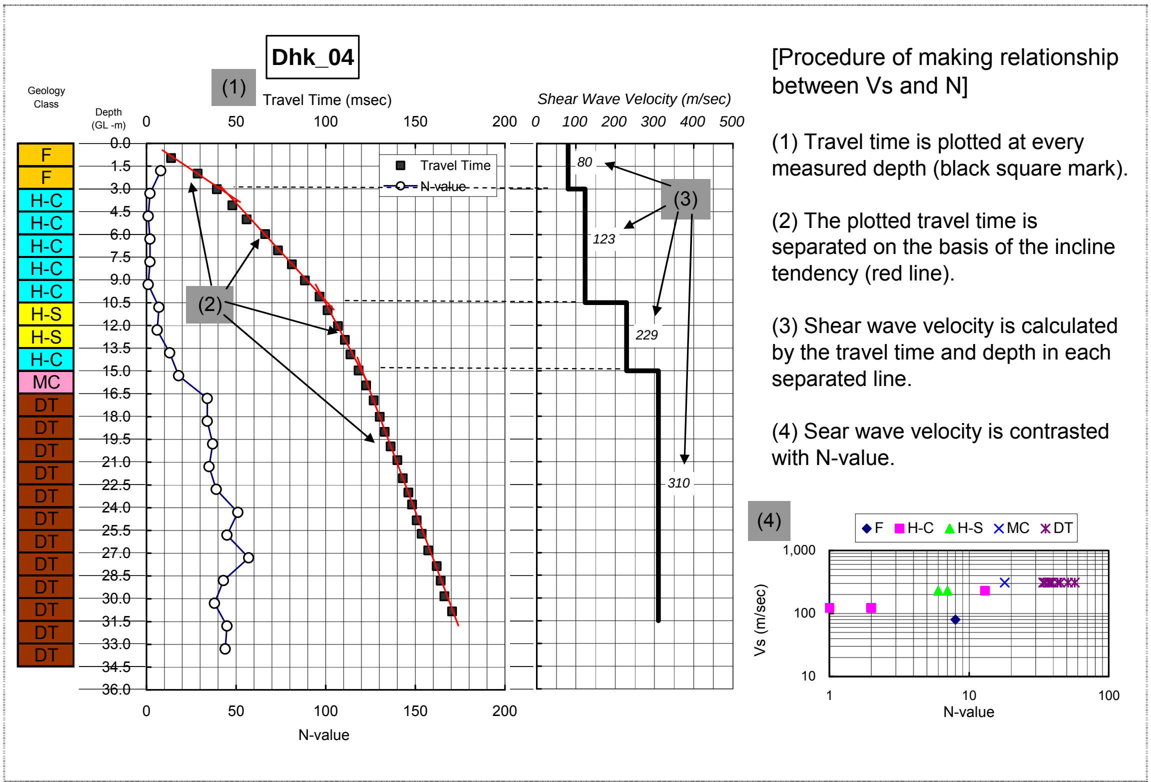
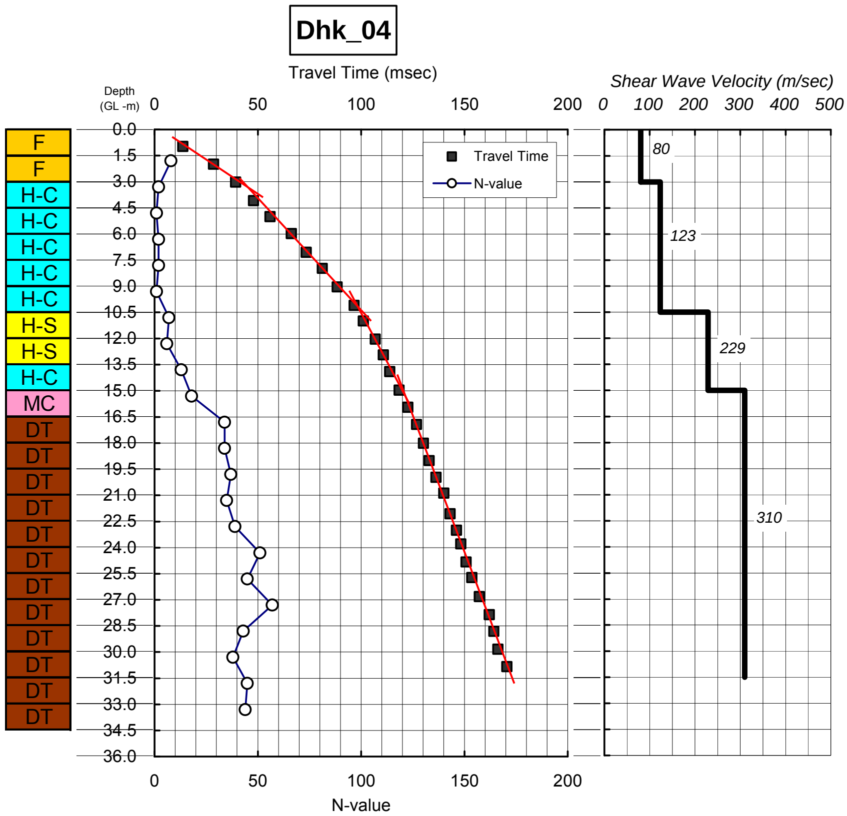
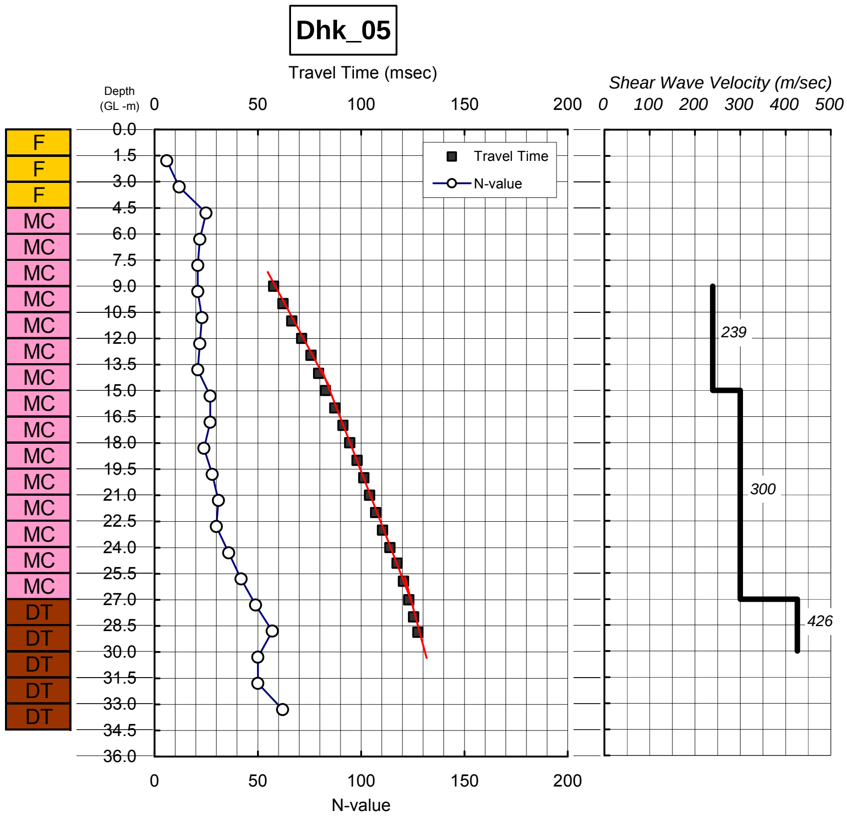


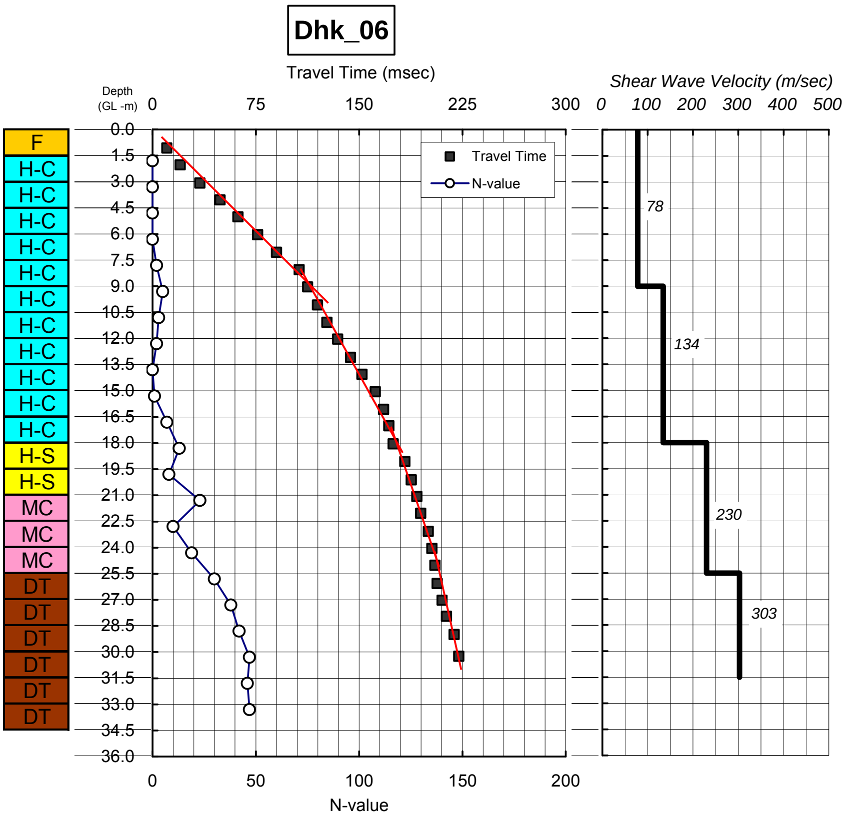
Figure 4-13 Procedure of Estimated Relationship between Vs and N

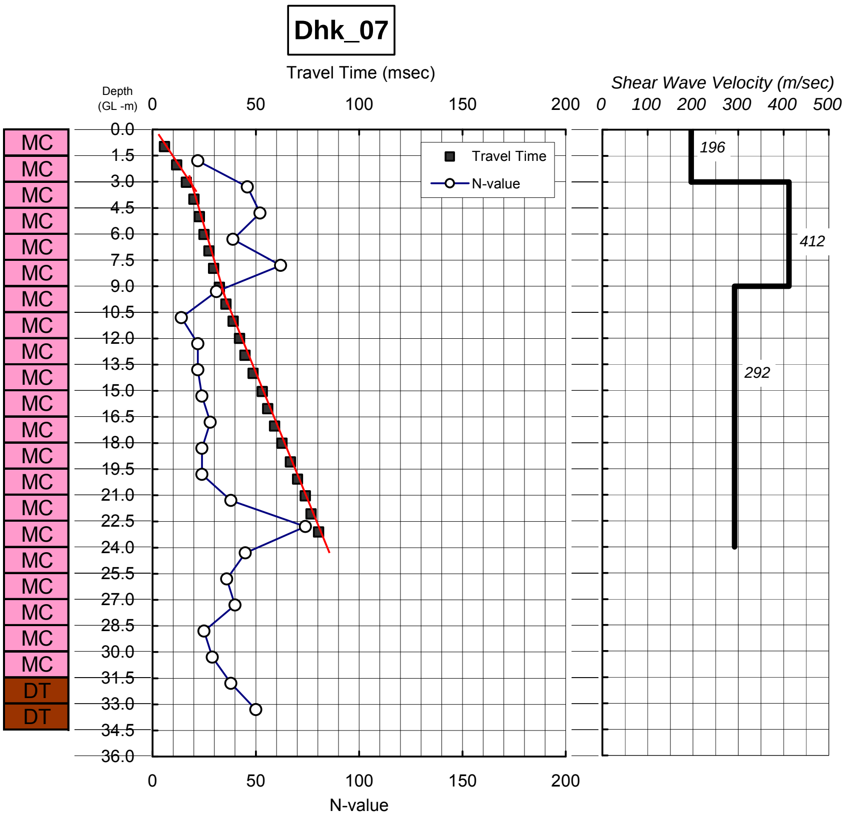




(Dhaka 1/4)

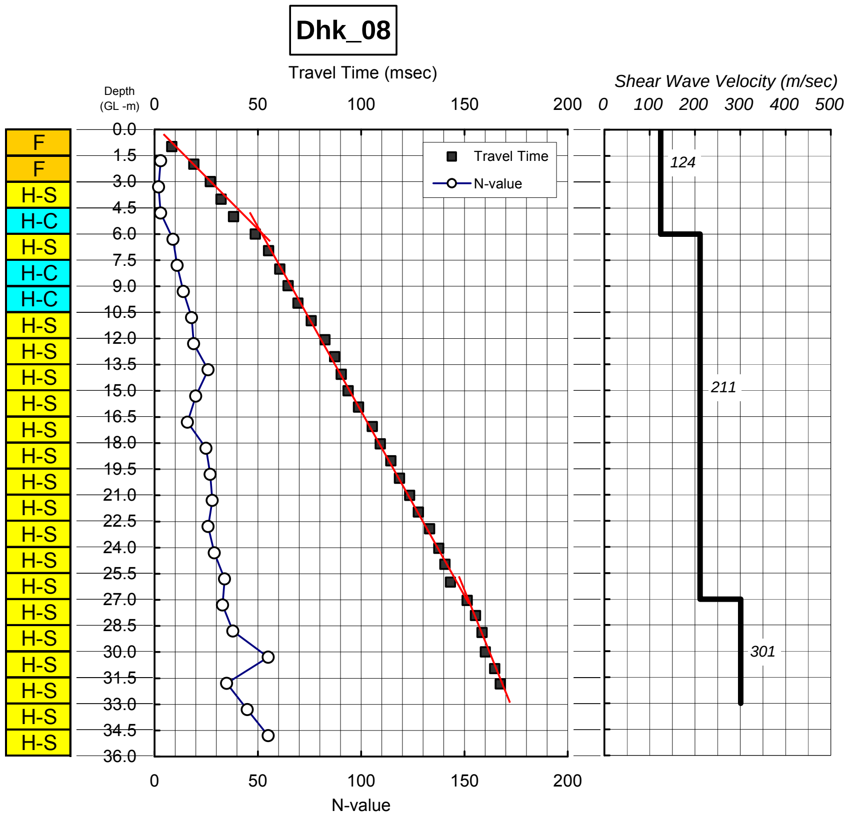
Figure 4-14 S-Wave Velocity Structure

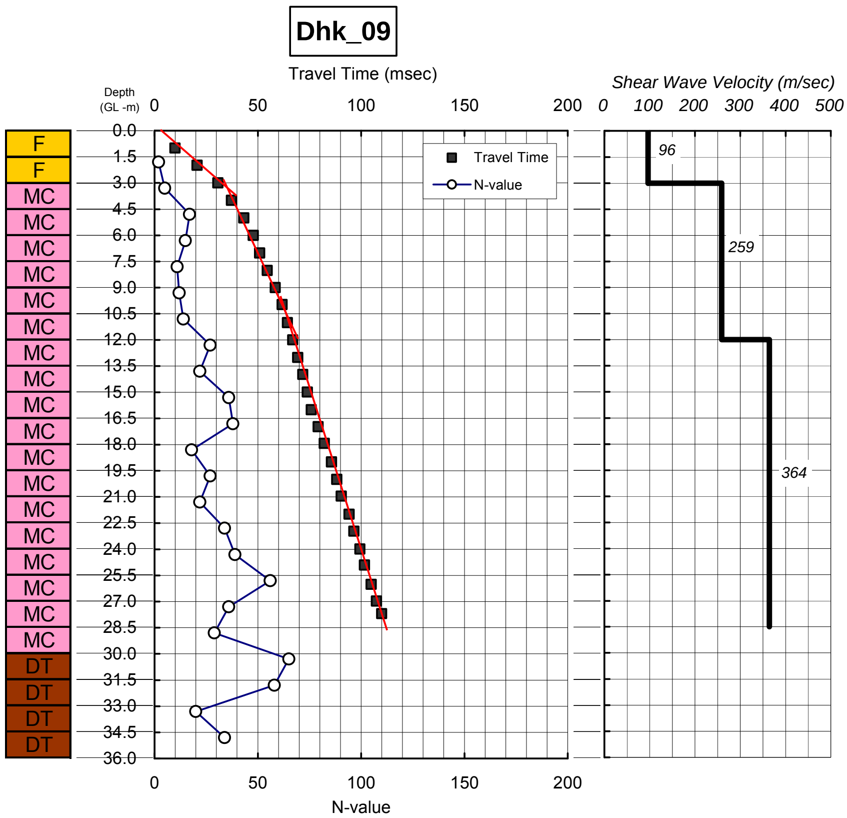




(Dhaka 2/4)

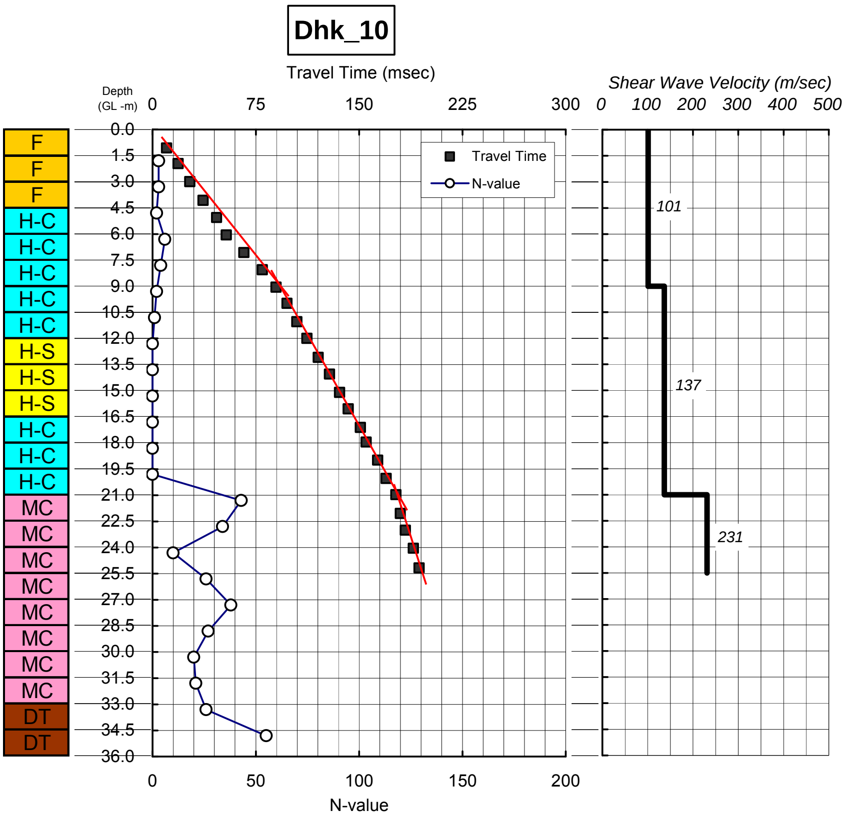
Figure 4-14 (cont.) S-Wave Velocity Structure





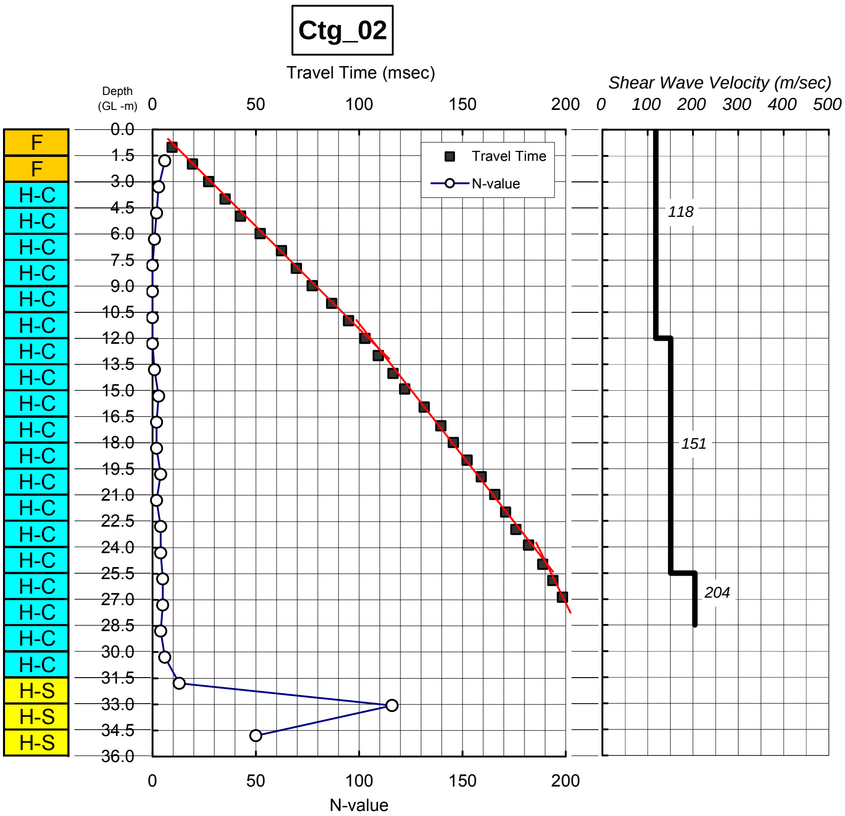
(Dhaka 3/4)

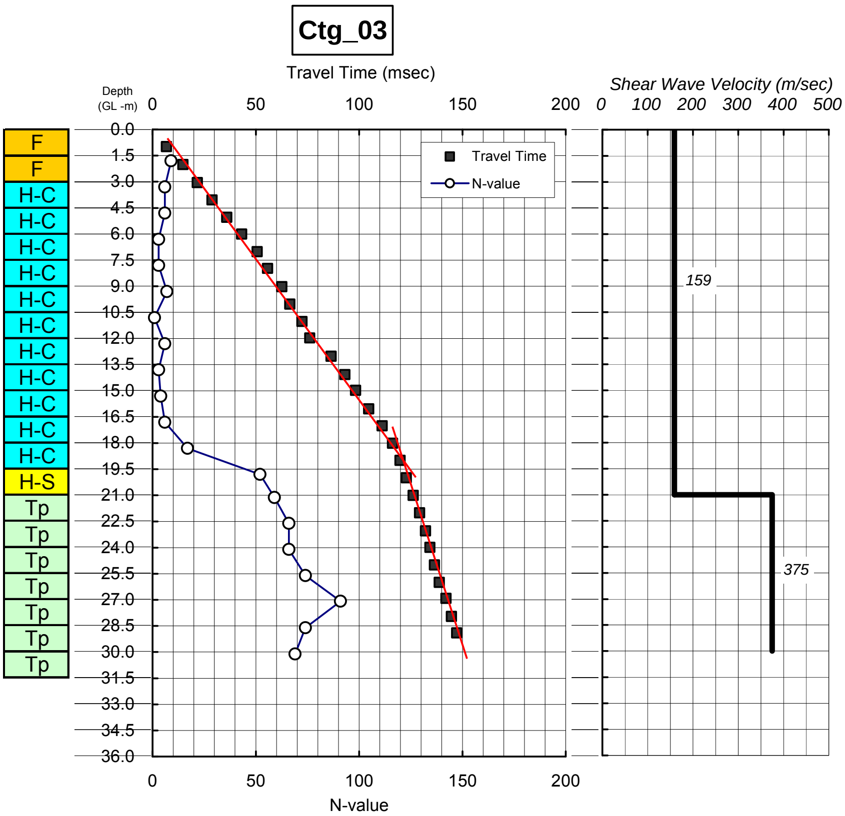
Figure 4-14 (cont.) S-Wave Velocity Structure



(Dhaka 4/4)

Figure 4-14 (cont.) S-Wave Velocity Structure

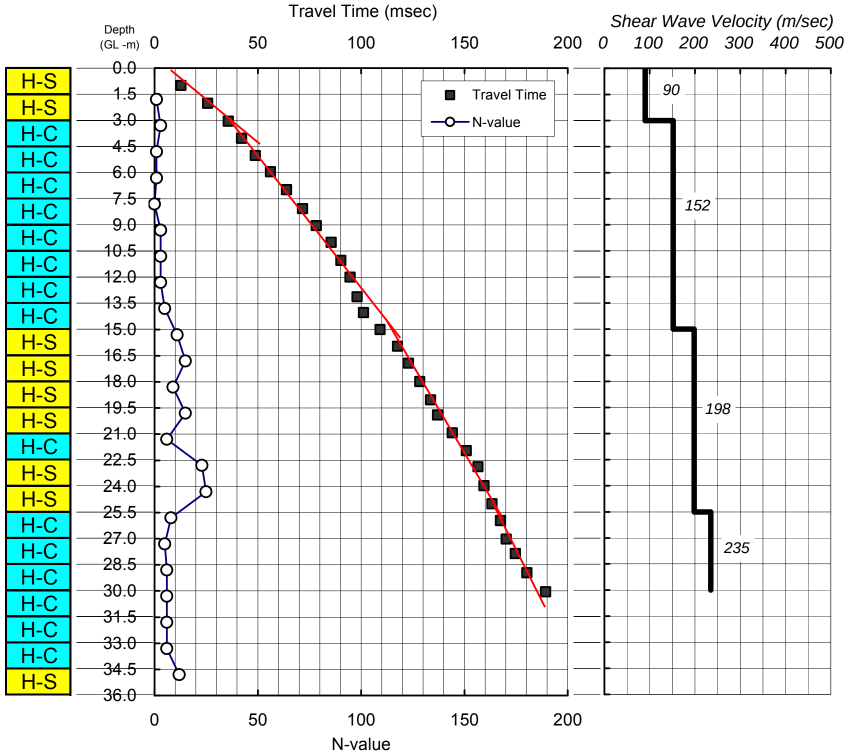




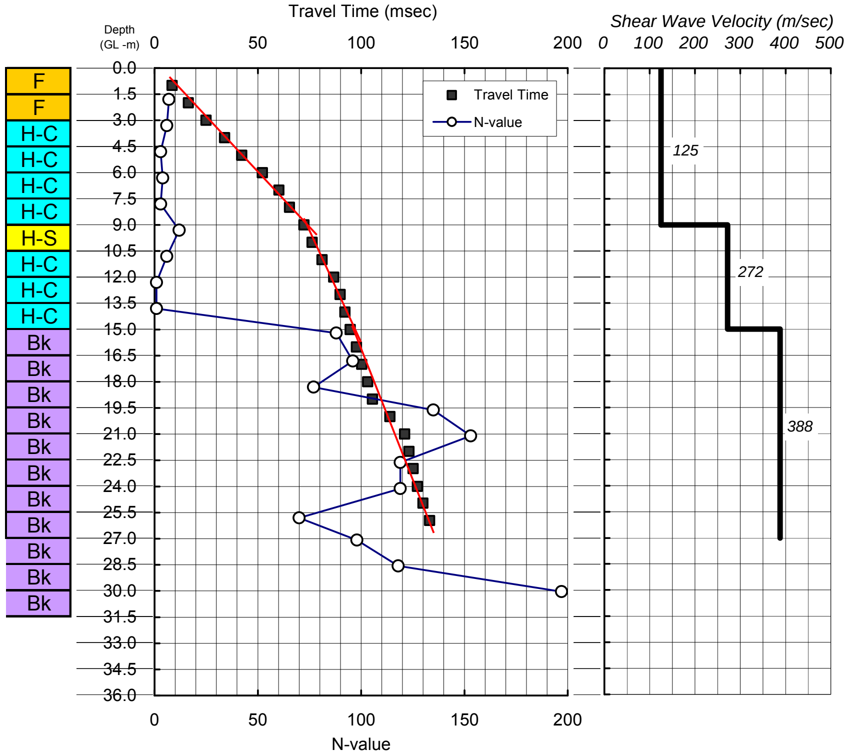
(Chittagong 1/3)

Figure 4-14 (cont.) S-Wave Velocity Structure

Ctg_04

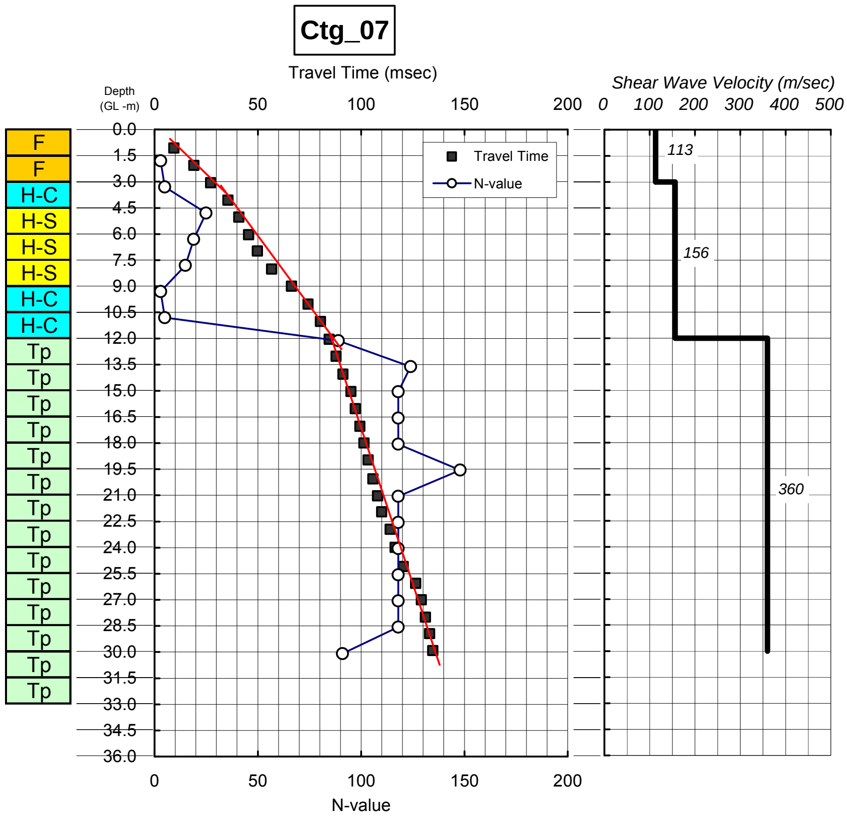


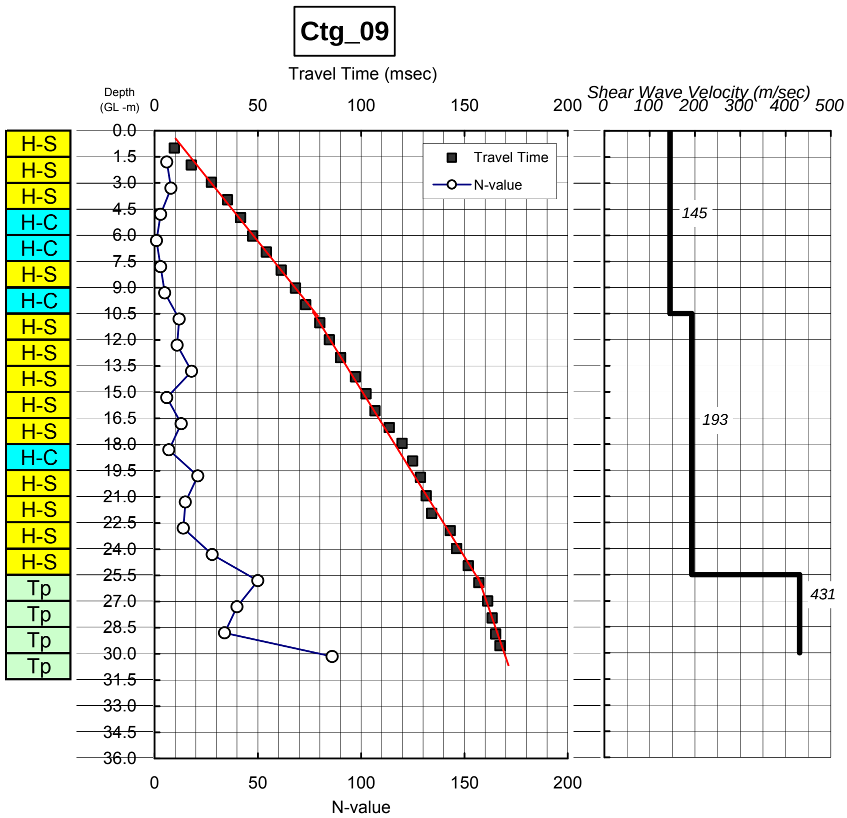
Ctg_05



(Chittagong 2/3)

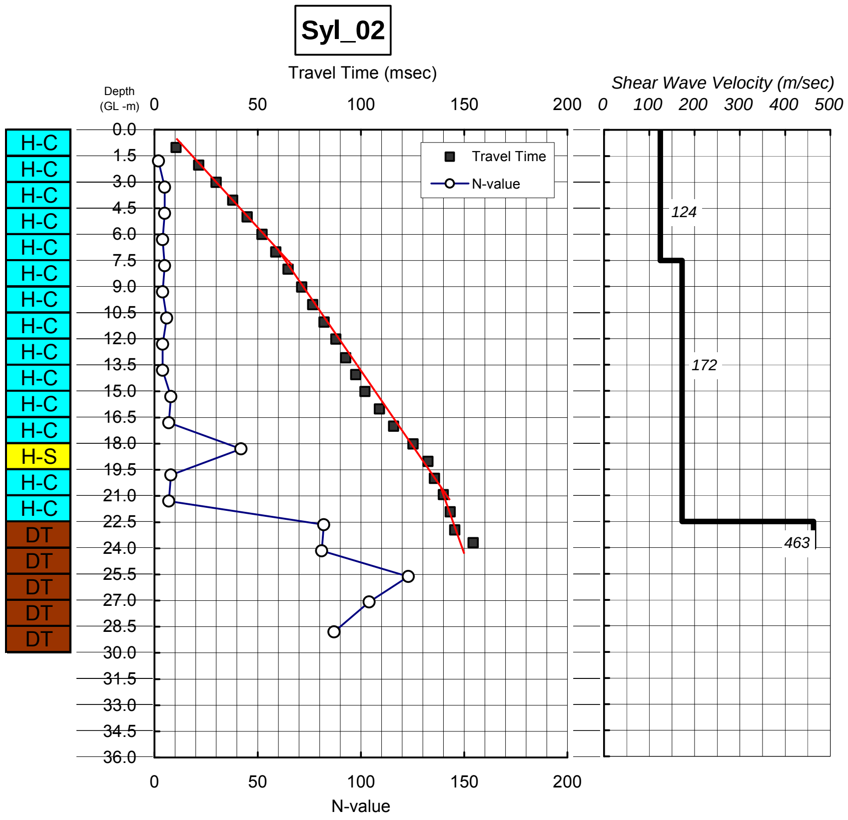
Figure 4-14 (cont.) S-Wave Velocity Structure

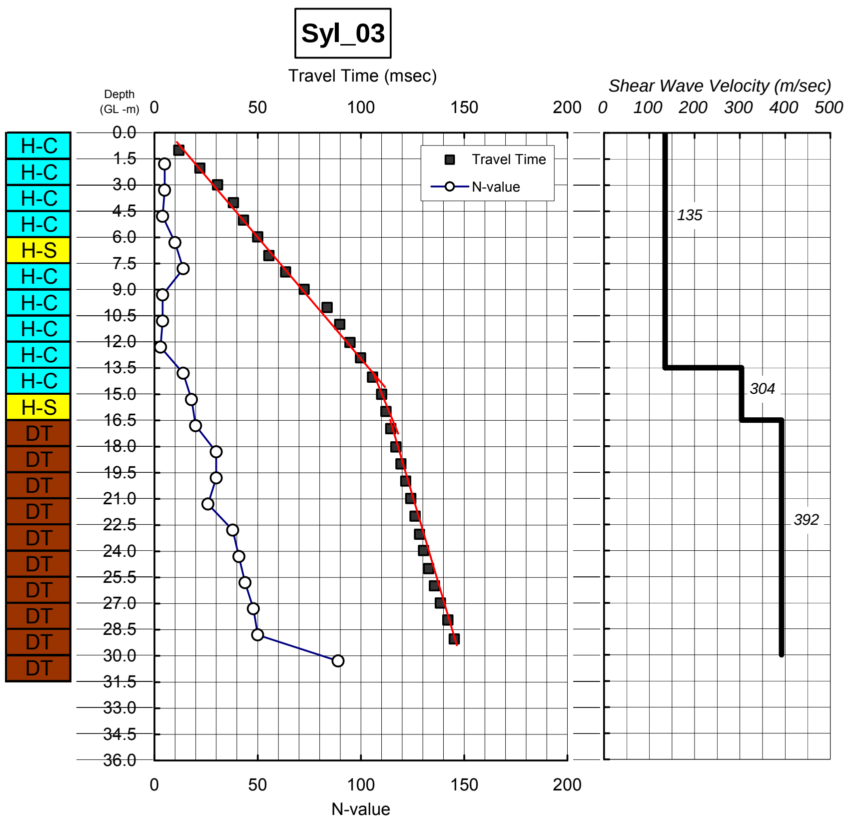




(Chittagong 3/3)

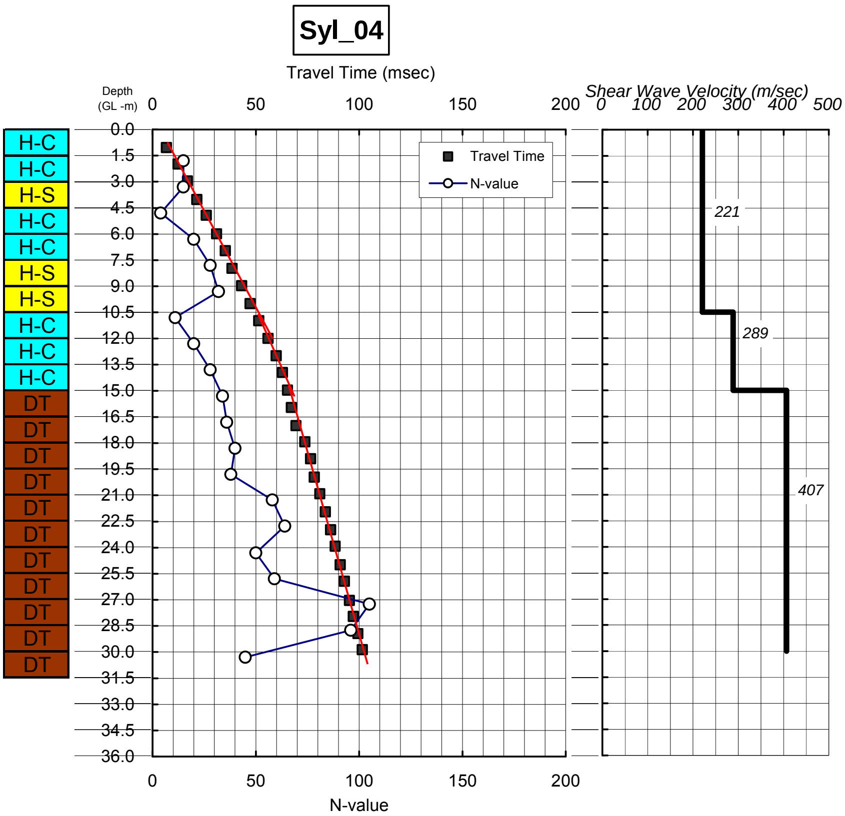
Figure 4-14 (cont.) S-Wave Velocity Structure

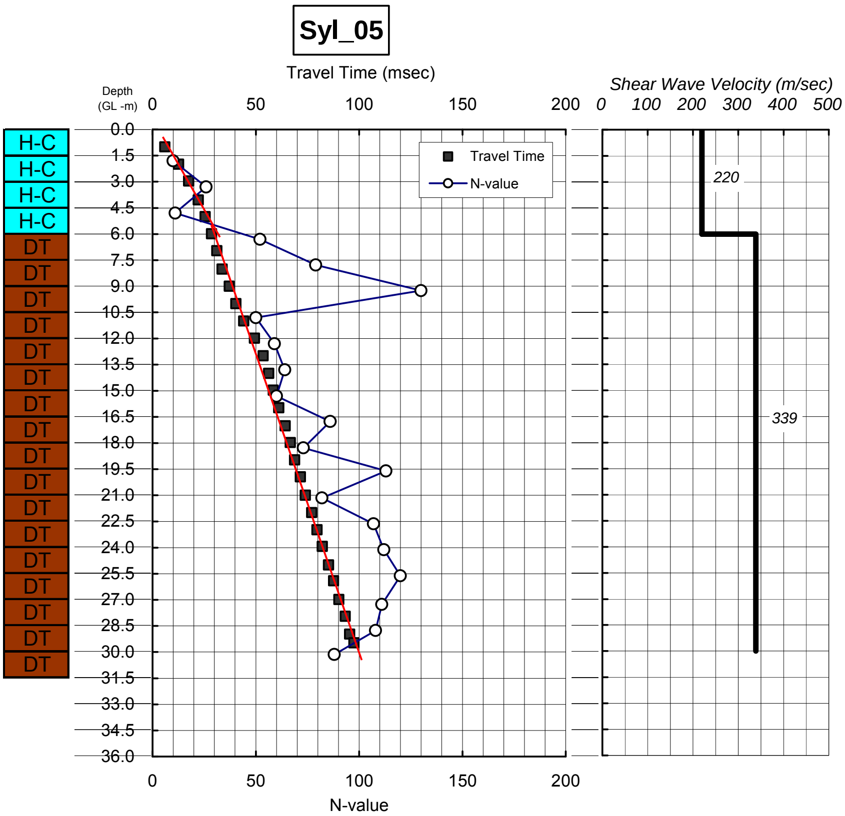




(Sylhet 1/3)

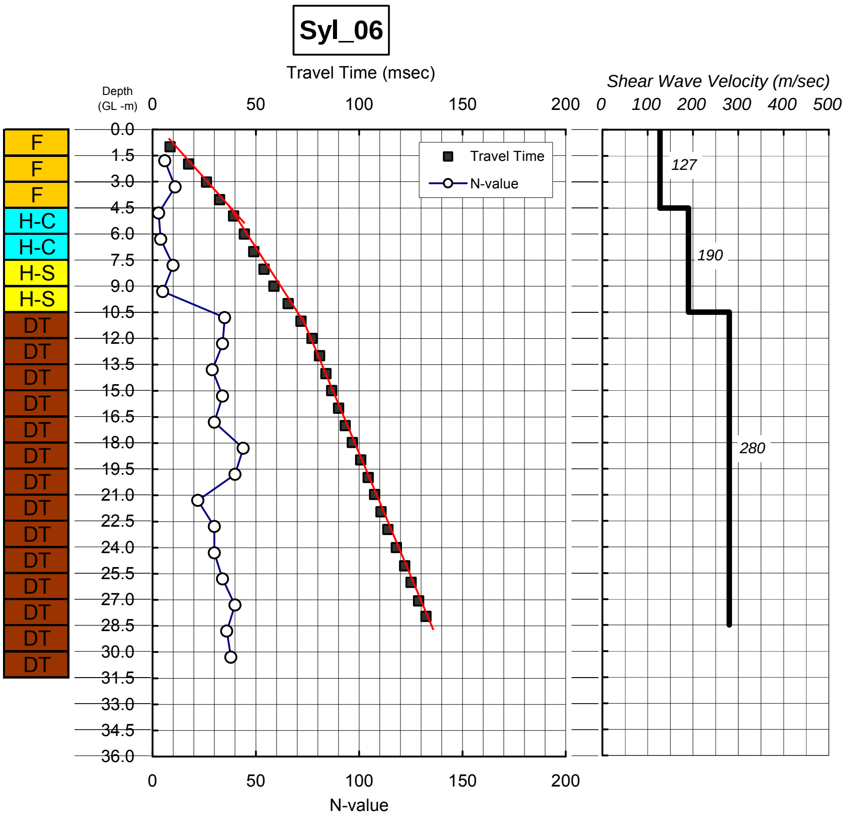
Figure 4-14 (cont.) S-Wave Velocity Structure

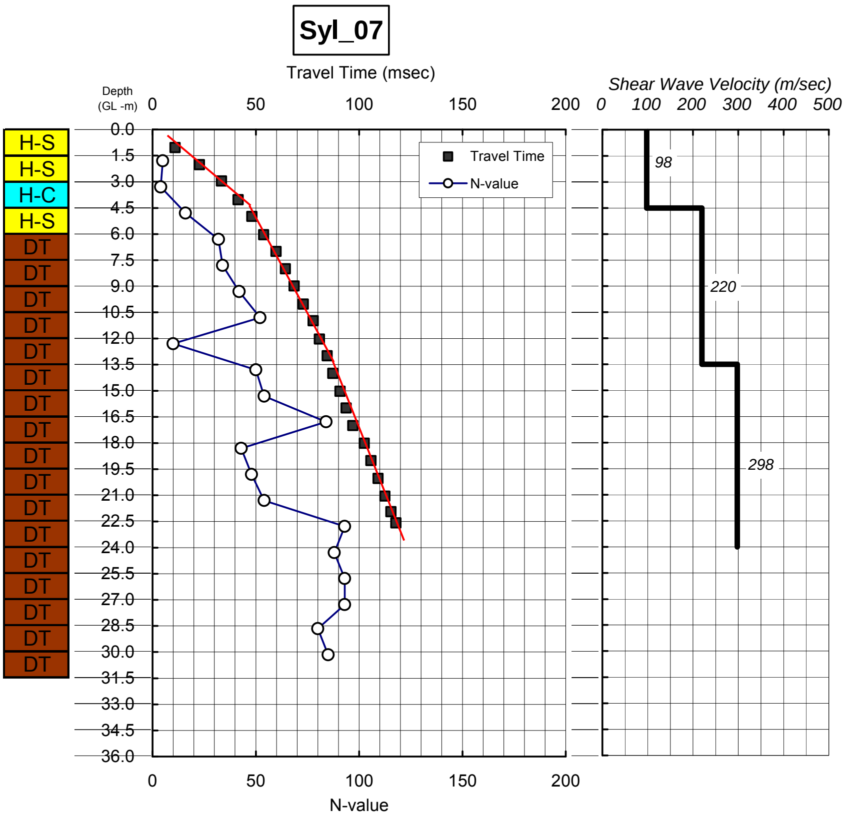




(Sylhet 2/3)

Figure 4-14 (cont.) S-Wave Velocity Structure





(Sylhet 3/3)

Figure 4-14 (cont.) S-Wave Velocity Structure

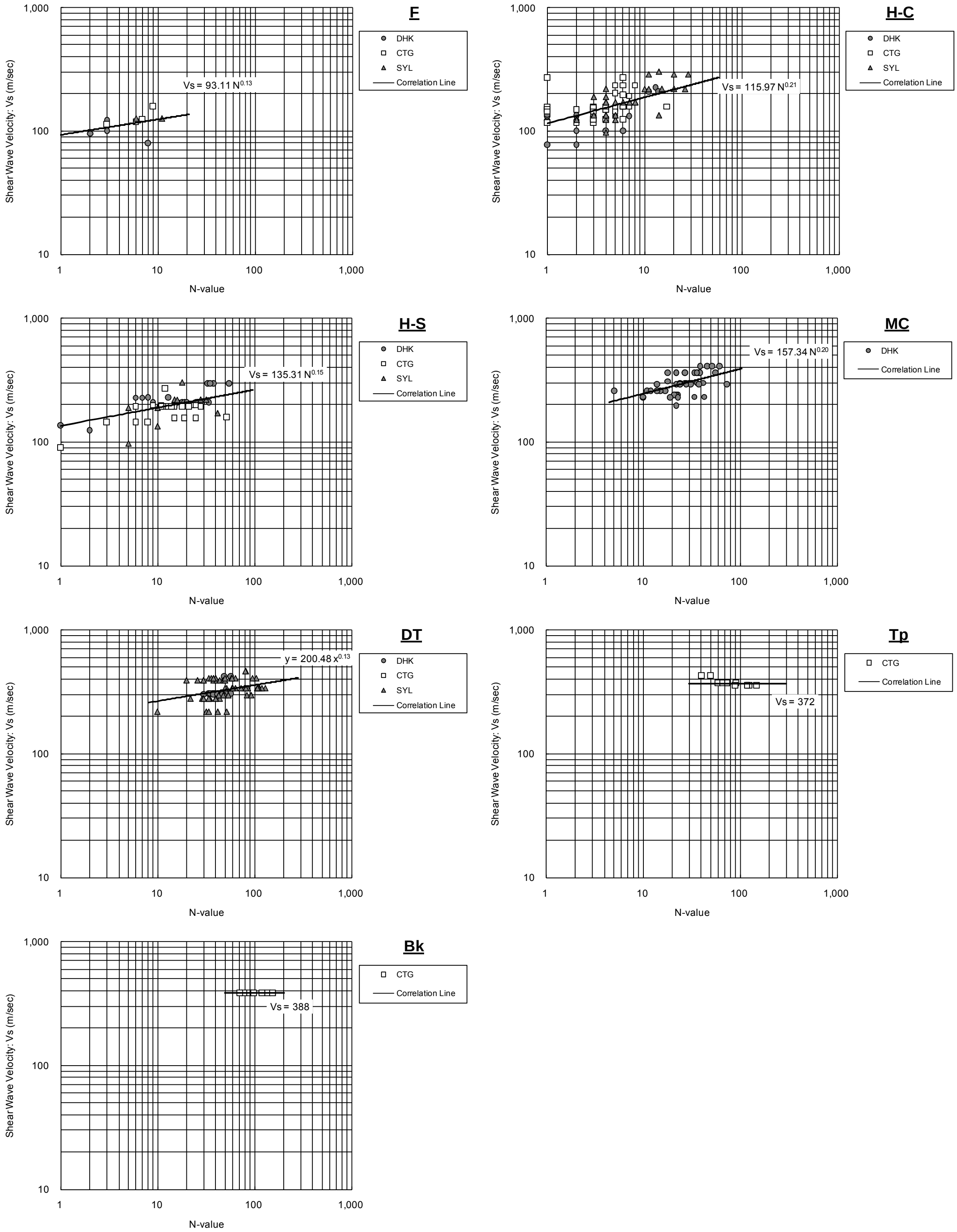


Figure 4-15 Relationship between Vs and N in each Geological Classification

Table 4-2 Correlating Equation of Vs and N

Geological Classification	Correlating Equation
Fill: F	$Vs = 93.11\ N^{0.13}$ (m/sec)
Holocene-Clayey Soil: H-C	$Vs = 115.97\ N^{0.21}$ (m/sec)
Holocene-Sandy Soil: H-S	$Vs = 135.31\ N^{0.15}$ (m/sec)
Modhpur Clay: MC	$Vs = 157.34\ N^{0.20}$ (m/sec)
Dupi Tila: DT	$Vs = 200.48\ N^{0.13}$ (m/sec)
Tipam: Tp	Vs = 372 (m/sec)
Bokabil: Bk	Vs = 388 (m/sec)

4.2.4. AVS 30 of the Borings

(1) Calculation

Using the distribution of geological classification (refer to Figure 4-5, Figure 4-8 and Figure 4-11) and the correlating equation (refer to Table 4-2), AVS 30 is calculated by following equation. And a sample of calculation procedure is shown in Figure 4-16, and the calculation sheets are attached in the Appendix. Table 4-3 shows the tabulated results at all borings carried out by this project.

$$AVS30 = \frac{30}{\sum_i \left(\frac{H_i}{Vs_i} \right)}$$

H_i: Thickness of layer i (m)

Vs_i : S-wave velocity of layer i (m/sec)

BH No	From (m)	To (m)	N-value	GC	Vs_i (m/sec)	H_i (m)	H_i / Vs_i (sec)	AVS 30 (m/sec)
Dhk_01	0.0	3.0	*10*	F	$93.11 \times 10^{0.13} = 126$	3.0	0.0239	249
	3.0	4.5	*14*		$93.11 \times 14^{0.13} = 131$	1.5	0.0114	
	4.5	6.0	*14*	MC	$157.34 \times 14^{0.20} = 267$	1.5	0.0056	
	6.0	7.5	*13*		$157.34 \times 13^{0.20} = 263$	1.5	0.0057	
	7.5	9.0	*24*		$157.34 \times 24^{0.20} = 297$	1.5	0.0050	
	9.0	10.5	*22*		$157.34 \times 22^{0.20} = 292$	1.5	0.0051	
	10.5	12.0	*32*		$157.34 \times 32^{0.20} = 315$	1.5	0.0048	
	12.0	13.5	*18*		$157.34 \times 18^{0.20} = 281$	1.5	0.0053	
	13.5	15.0	*13*		$157.34 \times 13^{0.20} = 263$	1.5	0.0057	
	15.0	16.5	*28*		$157.34 \times 28^{0.20} = 306$	1.5	0.0049	
	16.5	18.0	*32*		$157.34 \times 32^{0.20} = 315$	1.5	0.0048	
	18.0	19.5	*44*		$157.34 \times 44^{0.20} = 335$	1.5	0.0045	
	19.5	21.0	*38*		$157.34 \times 38^{0.20} = 326$	1.5	0.0046	
	21.0	22.5	*36*		$157.34 \times 36^{0.20} = 322$	1.5	0.0047	
	22.5	24.0	*28*		$157.34 \times 28^{0.20} = 306$	1.5	0.0049	
	24.0	25.5	*31*		$157.34 \times 31^{0.20} = 313$	1.5	0.0048	
	25.5	27.0	*28*		$157.34 \times 28^{0.20} = 306$	1.5	0.0049	
	27.0	28.5	*32*		$157.34 \times 32^{0.20} = 315$	1.5	0.0048	
	28.5	30.0	*22*		$157.34 \times 22^{0.20} = 292$	1.5	0.0051	

Figure 4-16 A Sample of Calculation Procedure of AVS 30

Table 4-3 Calculated AVS 30 in each Boring

Dhaka		Chittagong		Sylhet	
Bore Hole No	AVS 30 (m/sec)	Bore Hole No	AVS 30 (m/sec)	Bore Hole No	AVS 30 (m/sec)
Dhk_01	249	Ctg_01	177	Syl_01	247
Dhk_02	284	Ctg_02*	141	Syl_02*	183
Dhk_03	205	Ctg_03*	192	Syl_03*	208
Dhk_04*	180	Ctg_04*	163	Syl_04*	300
Dhk_05	249	Ctg_05*	226	Syl_05*	306
Dhk_06*	130	Ctg_06	162	Syl_06*	220
Dhk_07*	295	Ctg_07*	223	Syl_07*	211
Dhk_08*	190	Ctg_08	187	Syl_08	285
Dhk_09*	260	Ctg_09*	187	Syl_09	194
Dhk_10*	139	Ctg_10	206	Syl_10	201
Dhk_11	206	Ctg_11	157	Syl_11	205
Dhk_12	239	Ctg_12	159	Syl_12	205
Dhk_13	260	Ctg_13	138	Syl_13	237
Dhk_14	206	Ctg_14	155	Syl_14	194
Dhk_15	217	Ctg_15	155	Syl_15	224
Dhk_16	232	Ctg_16	183	Syl_16	273
Dhk_17	209	Ctg_17	206	Syl_17	209
Dhk_18	153	Ctg_18	208	Syl_18	346
Dhk_19	178	Ctg_19	163	Syl_19	300
Dhk_20	269	Ctg_20	184	Syl_20	315
Dhk_21	248	Ctg_21	220	Syl_21	232
Dhk_22	290	Ctg_22	179	Syl_22	212
Dhk_23	246	Ctg_23	177	Syl_23	240
Dhk_24	211	Ctg_24	191	Syl_24	162
Dhk_25	277	Ctg_25	181	Syl_25	264
Dhk_26	248	Ctg_26	192	Syl_26	183
Dhk_27	209	Ctg_27	177	Syl_27	196
Dhk_28	255	Ctg_28	306	Syl_28	258
Dhk_29	183	Ctg_29	249	Syl_29	280
Dhk_30	191	Ctg_30	240	Syl_30	224
Dhk_31	227	Ctg_31	199	Syl_31	167
Dhk_32	200	Ctg_32	180	Syl_32	223
Dhk_33	173	Ctg_33	203	Syl_33	204
Dhk_34	220	Ctg_34	222	Syl_34	201
Dhk_35	210	Ctg_35	170	Syl_35	177
Dhk_36	197	Ctg_36	228	Syl_36	217
Dhk_37	212	Ctg_37	281	Syl_37	264
Dhk_38	279	Ctg_38	173	Syl_38	228
Dhk_39	251	Ctg_39	169		
Dhk_40	236	Ctg_40	214		
Dhk_41	173	Ctg_41	177		
Dhk_42	275	Ctg_42	175		
Dhk_43	209	Ctg_43	278		
Dhk_44	260	Ctg_44	249		
Dhk_45	203	Ctg_45	194		
Dhk_46	172	Ctg_46	235		
Dhk_47	278	Ctg_47	219		
Dhk_48	256	Ctg_48	275		
Dhk_49	249				
Dhk_50	247				
Dhk_51	228				
Dhk_52	239				
Dhk_53	218				

* AVS 30 were calculated by results of PS logging

(2) Verification

AVS 30 calculated by the correlating equation between Vs and N is verified by AVS30 derived from PS logging results at PS logging sites as shown in Figure 4-17. Most of the data are plotted near the equivalent line. Hence, the AVS 30 by the correlating equation is able to be adopted to appropriately estimate AVS 30 value at other boring sites where have SPT data.

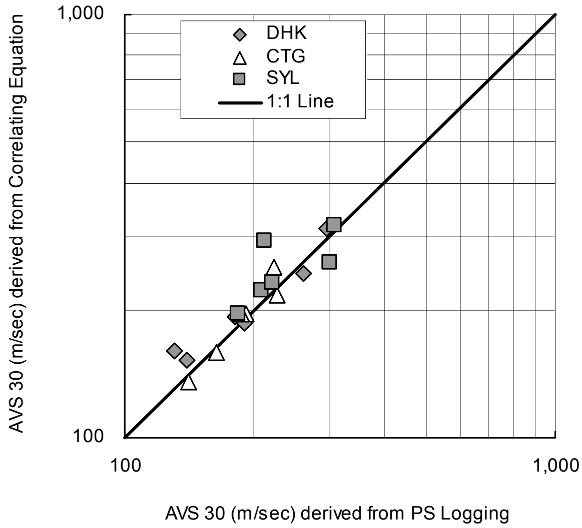


Figure 4-17 Verification of AVS 30 calculated by the Correlating Equation

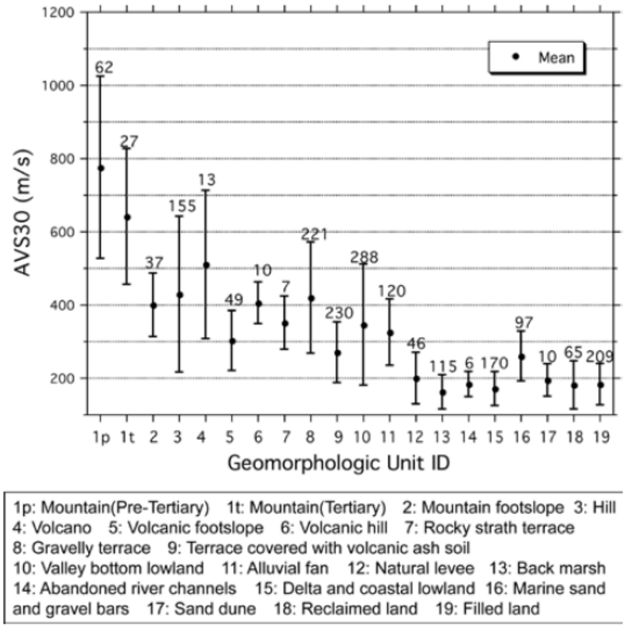
4.2.5. Relationship between Thickness of Holocene Soil and AVS 30

Many researchers have reported that AVS 30 has good relationship with geomorphic features. For instance in Japan, according to Matsuoka et.al (2005), relationship between AVS 30 and geomorphic unit were reported as shown in Figure 4-18, and and estimating equation of AVS 30 was examined as below.

$$\log AVS\ 30 = a + b \log Ev + c \log Sp + d \log Dm \pm \sigma$$

where,

AVS 30: Average S-wave velocity
Ev: Elevation
Sp: Slope angle
Dm: Distance from a mountain or hill or Pre-Tertiary period or Tertiary
a, b, c, d: Represent regression coefficients
σ: Standard deviation

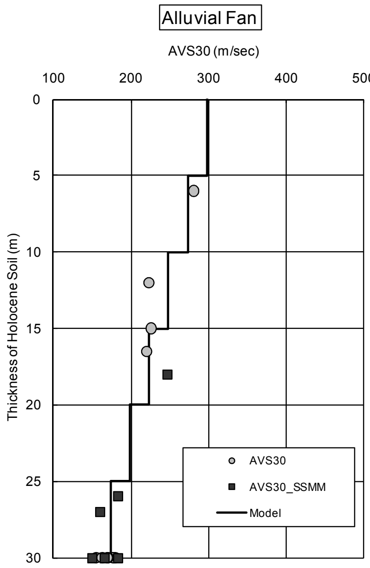


[after Matsuoka et.al (2005)]

Figure 4-18 Mean Value and Standard Deviation of Average S-Wave Velocity by Geomorphic Unit

In Bangladesh, S-wave velocity data is quite limited and digital national land information has not been developed / is developing so far. Hence, other concept for establishment of the relationship to estimate AVS 30 is required in this project, and we take note of relationship between AVS 30 and Holocene thickness.

Holocene soil that widely distributes in each city consists of loose sand and soft clay and covers the engineering baserock (Dupi Tila, Tipam, Bokabil). It is easy to assume that the more thickness Holocene soil sediments, the slower AVS 30 is observed. Therefore, thickness of Holocene soil and AVS 30 indicates some relationship as shown in Figure 4-19. The relationship is required to supplement / support creation of AVS 30 Map, because the borings with PS logging are not able to cover all 250 m grid.



[Procedure of setup of the relationship]

1. Plot the calculated AVS 30 derived from results of PS logging (circular mark) / small scale microtremor measurement (square mark) for every thickness of Holocene soil at the point.

2. Based on the plot distributions and geomorphic features, make a model by each applicable thickness taking into consideration with data precision on the basis of an engineering judgment (it is assumed that 250 m grid may have around 1 degree in gradient in its area, thus about 5 m difference is included in the model.)

Figure 4-19 Concept of created Relationship between the Thickness and AVS 30

Figure 4-20 to Figure 4-22 show the relationship in each city and Table 4-4 shows their tabulation.

It is noted that geological layer in Dhaka is simplified into 3 layers, which are Holocene soil, Modhupur Clay and Dupi Tila. Hence, converted thickness by average S-wave velocity in each layer is adopted and is calculated by below equation.

$$h = h_H + h_{MC} * (Vs_{H\_ave} / Vs_{MC\_ave}) + h_{DT} * (Vs_{H\_ave} / Vs_{DT\_ave})$$

where,

h: Converted thickness of Holocene soil (m)

h_H: Thickness of Holocene soil (m)

h_{MC}: Thickness of Modhupur Clay (m)

h_{DT}: Thickness of Dupi Tila (m)

Vs_{H_ave}: Average S-wave velocity of Holocene soil (m/sec)

Vs_{MC_ave}: Average S-wave velocity of Modhupur Clay (m/sec)

Vs_{DT_ave}: Average S-wave velocity of Dupi Tila (m/sec)

In Chittagong and Sylhet, the geological layer is simplified into 2 layers, which are Holocene soil and baserock layer such as Dupi Tila / Tipam / Bokabil. Consequently, thickness of Holocene layer and AVS 30 has a good relation directly as shown in below figures.

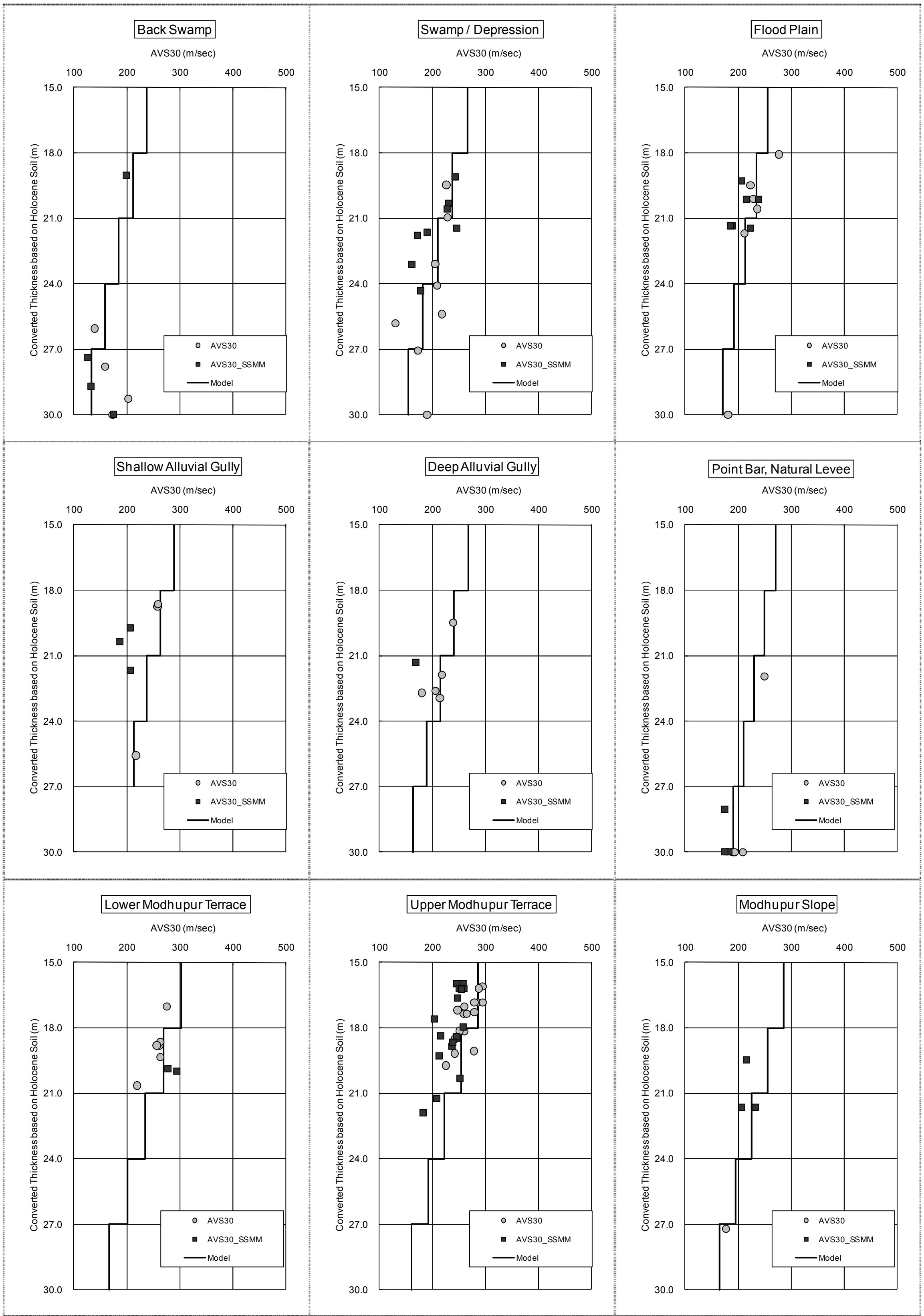


Figure 4-20 Relationship between Thickness of Holocene soil and AVS 30 in Dhaka

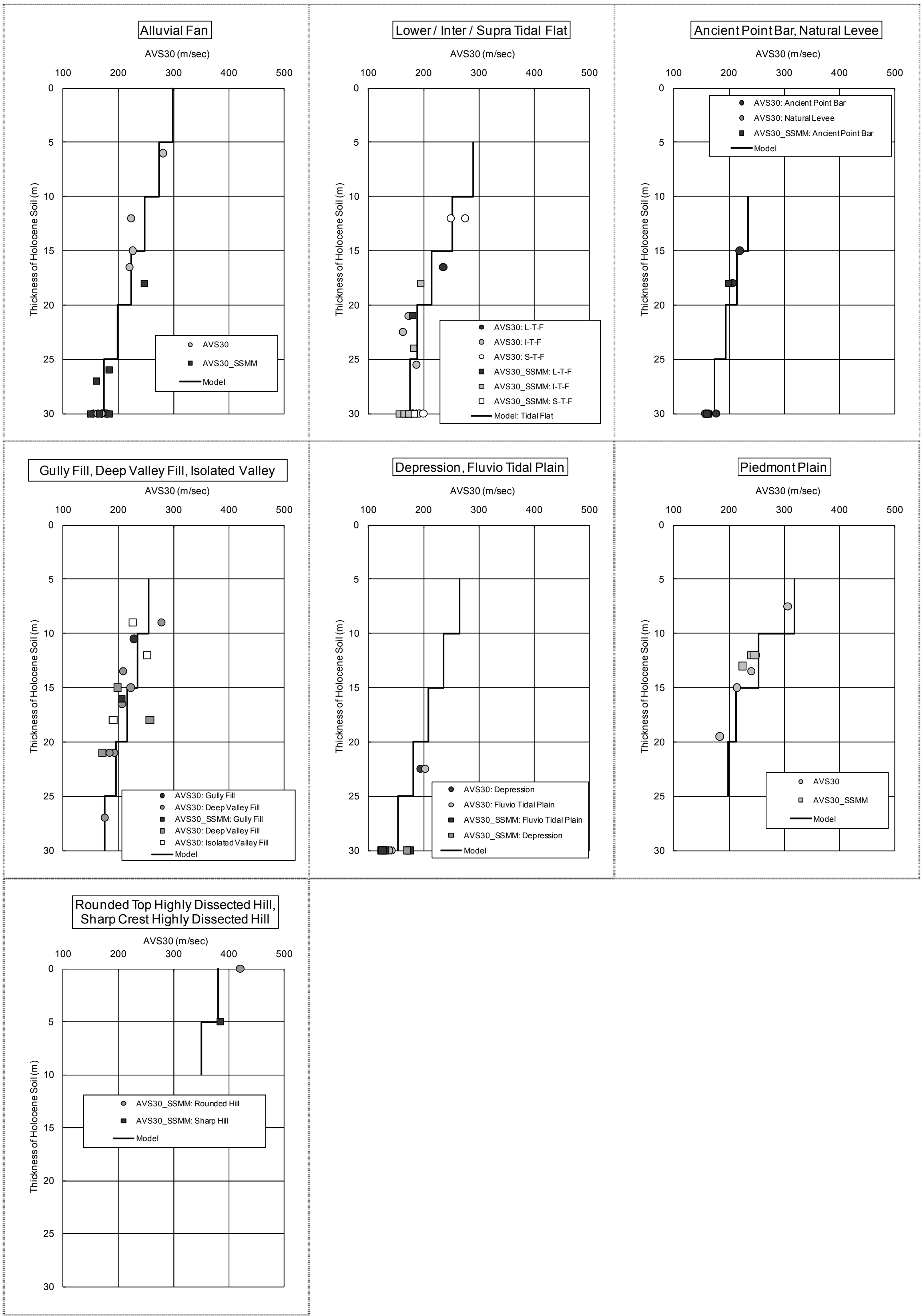


Figure 4-21 Relationship between Thickness of Holocene soil and AVS 30 in Chittagong

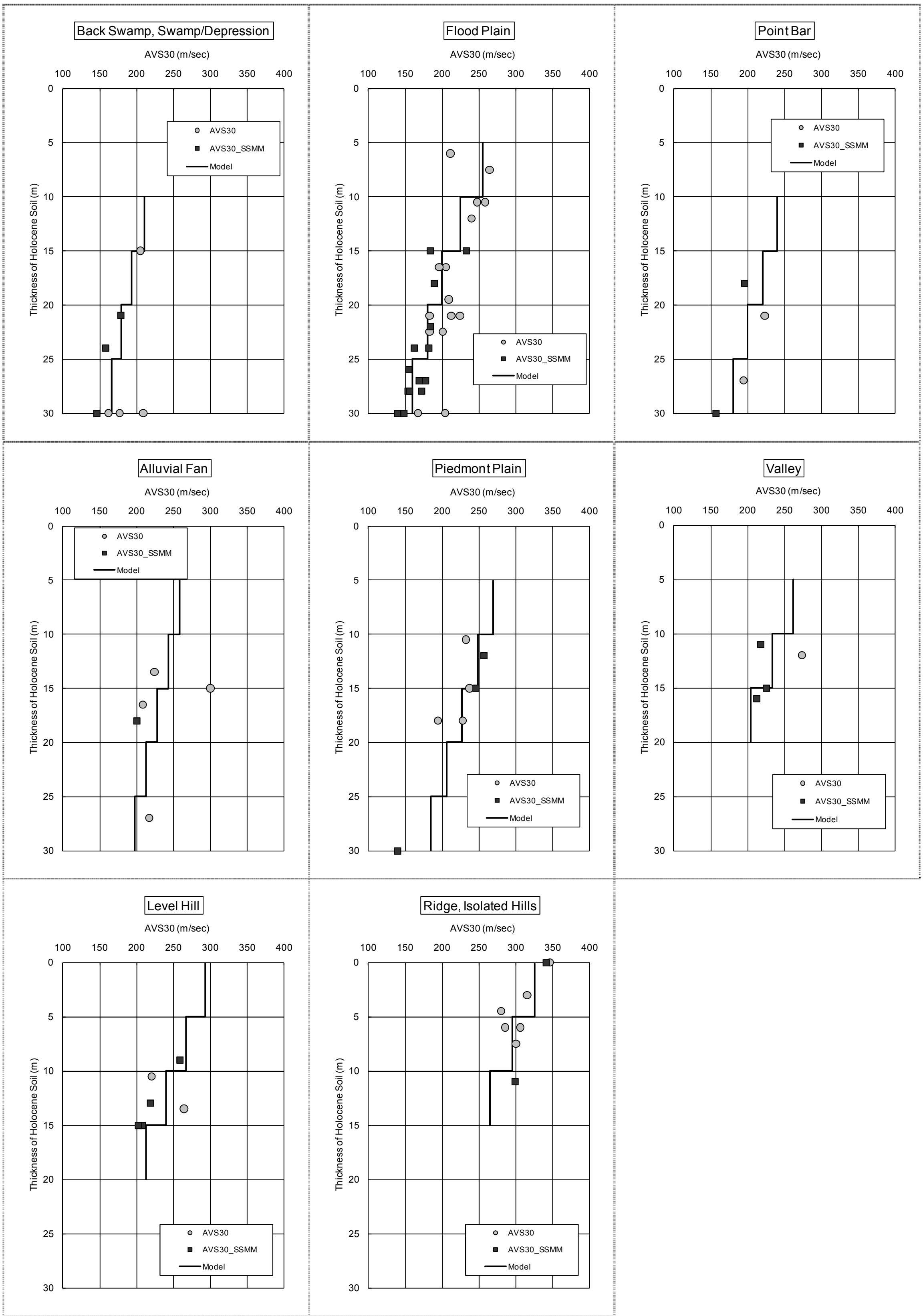


Figure 4-22　Relationship between Thickness of Holocene soil and AVS 30 in Sylhet

Table 4-4 Matrix for setting of AVS 30 in each City

[Dhaka]

[Unit: m/sec]

Geomorphic Unit \ Converted Thickness	< 18m	< 21m	< 24m	< 27m	<=30m
Meander Channel	-	-	-	-	-
Back Swamp	237	211	185	159	133
Swamp / Depression	266	238	210	182	154
Flood Plain	255	234	213	192	171
Shallow Alluvial Gully	288	263	238	213	-
Deep Alluvial Gully	267	241	215	189	163
Gully Head	288	263	238	213	-
Valley Fill	267	241	215	189	163
Channel Bar	270	250	230	210	190
Point Bar	270	250	230	210	190
Natural Levee	270	250	230	210	190
Lateral Bar	270	250	230	210	190
Lower Modhupur Terrace	303	269	235	201	167
Upper Modhupur Terrace	285	254	223	192	161
Modhupur Slope	285	255	225	195	165

[Chittagong]

[Unit: m/sec]

Geomorphic Unit \ Thickness	< 5m	< 10m	< 15m	< 20m	< 25m
Active Channel	-	-	-	-	-
Depression	-	264	236	209	181
Sandy Beach	-	289	251	214	188
Clayey Beach	-	289	251	214	188
Lower Tidal Flat	-	289	251	214	188
Estuarine Tidal Flat	-	289	251	214	188
Inter Tidal Flat	-	289	251	214	188
Supra Tidal Flat	-	289	251	214	188
Younger Point Bar	-	-	234	214	194
Ancient Point Bar	-	-	234	214	194
natural Levee	-	-	234	214	194
Sand Dune	-	-	234	214	194
Gully Fill	-	255	235	215	195
Deep Valley Fill	-	255	235	215	195
Isolated Valley	-	255	235	215	195
River Tidal Flat	-	264	236	209	181
Fluvio Tidal Plain	-	264	236	209	181
Alluvial Fan	298	273	248	223	198
Piedmont Plain	-	318	253	213	198
Hill Slope	-	318	253	213	198
Level Hill	380	350	-	-	-
Rounded Top Highly Dissected Hill	380	350	-	-	-
Sharp Crest Highly Dissected Hill	380	350	-	-	-
Sharp Crest Slightly Dissected Hill	380	350	-	-	-
Active Channel	-	-	-	-	-
Depression	-	264	236	209	181

Table 4-4 (cont.) Matrix for setting of AVS 30 in each City

[Sylhet]

[Unit: m/sec]

Thickness / Geomorphic Unit	< 5m	< 10m	< 15m	< 20m	< 25m
Water	-	-	-	-	-
Abandoned Channel	-	-	210	193	179
Meander Scar	-	-	210	193	179
Back Swamp	-	-	210	193	179
Swamp / Depression	-	-	210	193	179
Floodplain	-	255	225	200	180
Point Bar	-	-	240	220	200
Natural Levee	-	-	240	220	200
Lateral Bar	-	-	240	220	200
Alluvial Fan	-	258	243	228	213
Gully Fill	-	261	233	204	-
Valley	-	261	233	204	-
Piedmont Plain	-	269	248	227	206
Level Hill	293	267	240	213	-
Ridge	325	295	265	-	-
Isolated Hills	325	295	265	-	-

4.2.6. Thickness of Holocene Soil as the Geological Subsurface Model

Thickness of geological layer, especially Holocene soil, is the geological subsurface model in this study, because the above relationship between the thickness of Holocene soil and AVS 30 is adopted to examine the amplification analysis by area-wide. Thus, the model is set by each 250 m grid, and AVS 30 of the grid is able to be estimated. The model is estimated on the basis of boring data, geologic / geomorphologic conditions, altitude features and knowledge / experience of national experts of Bangladesh as shown in Figure 4-23. Figure 4-24 to Figure 4-26 show the grid map classified by the thickness of Holocene soil.

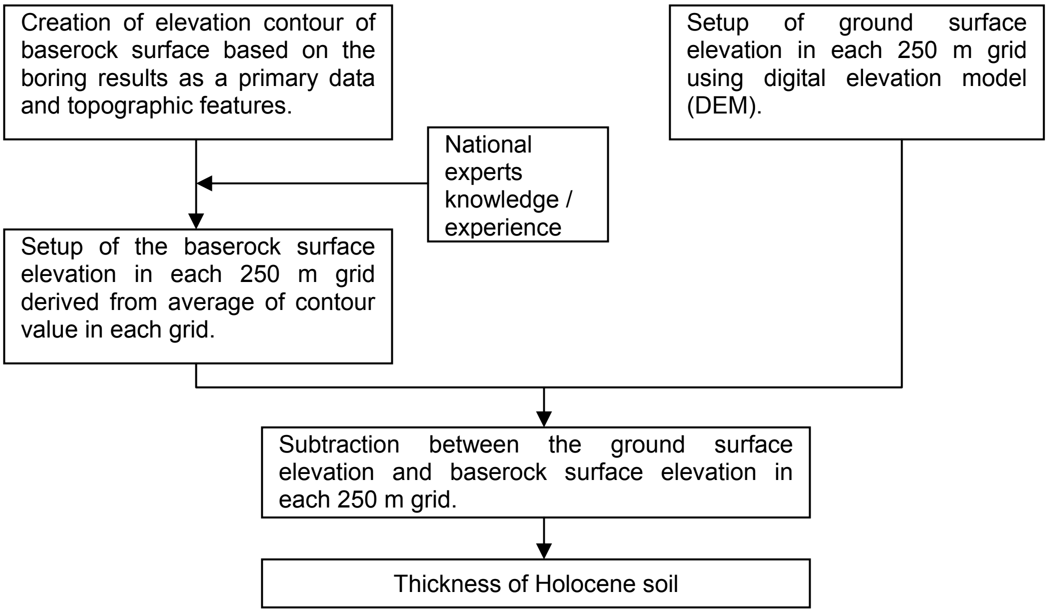


Figure 4-23 Procedure of Setup of the Thickness Model

It should be noted that this estimated model includes many assumptions / uncertainties due to several numbers of PS logging data as well as limited reliable boring numbers. Increasing adequate boring data and PS logging results contributes to be higher accuracy of the thickness model.

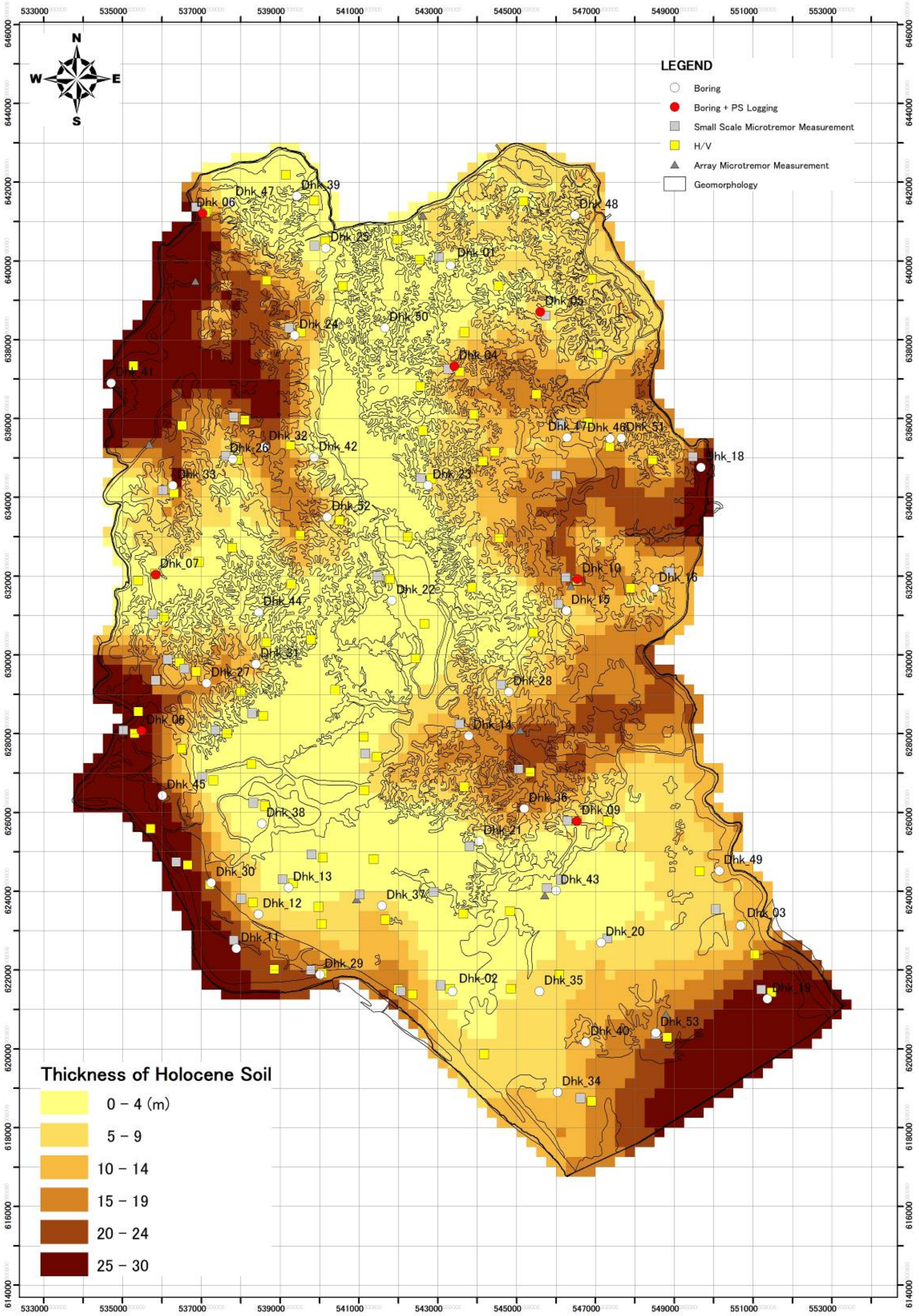


Figure 4-24 Thickness of Holocene Soil in Dhaka

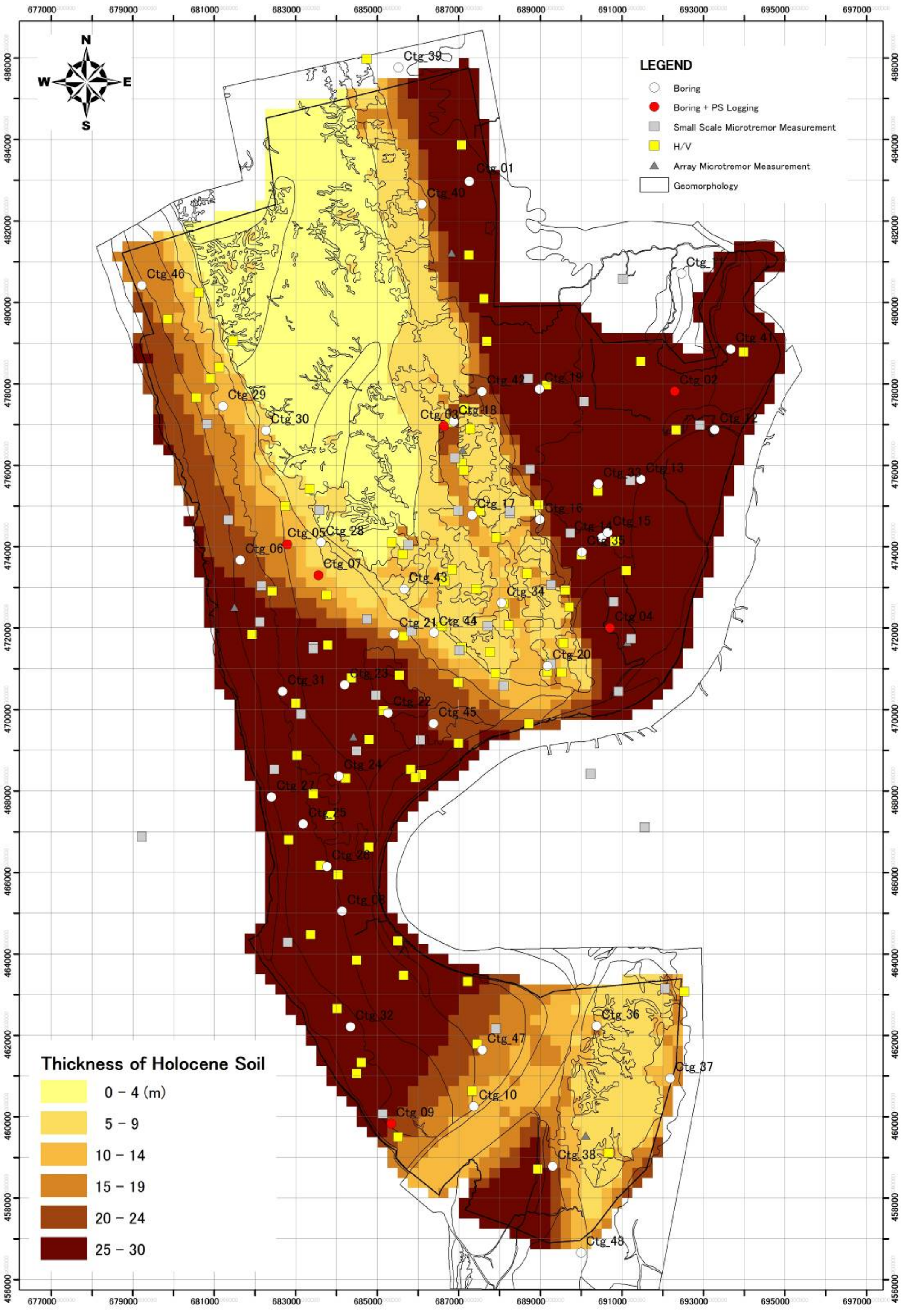


Figure 4-25 Thickness of Holocene Soil in Chittagong

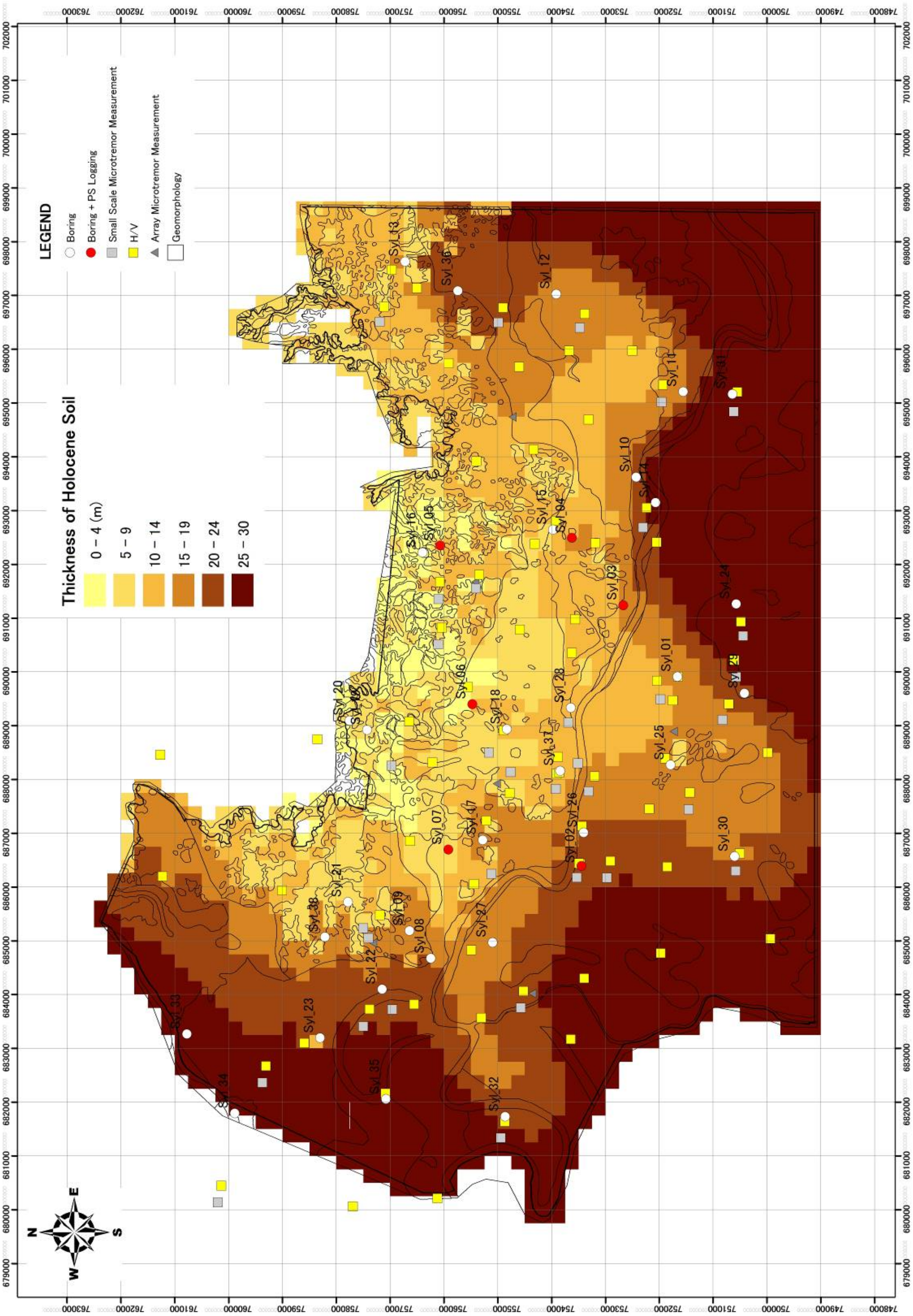


Figure 4-26　Thickness of Holocene Soil in Sylhet

4.2.7. AVS 30 at each 250 m Grid

Applying the relationship (thickness of Holocene soil and AVS 30) and thickness of Holocene soil, AVS 30 at each grid in each city can be calculated as shown in Figure 4-27.

Table-A: Attribute of 250 m Grid

Grid Code	Geomorphology	Holocene Thickness	AVS 30
27161916	Clayey Beach	24	188
27161915	Clayey Beach	25	175
27161914	Clayey Beach	26	188
27381937	Gully Fill	16	215
27381936	Gully Fill	13	235
27391932	Gully Fill	6	255
27321894	Alluvial Fan	11	248
27321893	Alluvial Fan	14	248
27321892	Alluvial Fan	16	223
27321891	Alluvial Fan	18	223
27321890	Alluvial Fan	21	298
27671885	Younger Point Bar	30	174
27361867	Depression	30	154
27381867	Depression	30	154
27381866	Depression	30	154
27391885	Depression	24	181

Table-B: Matrix for setting of AVS 30

Geomo. / Thickness	< 5m	< 10m	< 15m	< 20m	< 25m	<=30m
Depression	-	264	236	209	181	154
Sandy Beach	-	289	251	214	188	175
Clayey Beach	-	289	251	214	188	175
Younger Point Bar	-	0	234	214	194	174
Gully Fill	-	255	235	215	195	175
Alluvial Fan	298	273	248	223	198	173
Piedmont Plain	-	318	253	213	198	-

1. Table-A and Table-B (refer to Table 4-4) are prepared by thickness of Holocene soil in each 250 m grid and the correlating equation, respectively.

2. To obtain AVS 30 at a 250 m grid, at first geomorphology and thickness of Holocene soil of a target grid are searched from Table-A. In case of "27381937" of grid code, the geomorphology and the thickness are "Gully Fill" and "16 m", respectively.

3. In the second, Table-B is used to obtain AVS 30 tracing the geomorphology and the thickness. In this case, AVS 30 is 215 (m/sec).

Figure 4-27 Procedure of Setup of AVS 30 in each 250 m Grid

4.3. AVS 30 Map as an Engineering Geological Map

(1) Utilization Way and Creation of AVS 30 Map

AVS 30 Map is utilized for the amplification analysis such as a method provided by NEHRP (stands for National Earthquake Hazard Riduction Program, USA). NEHRP Provisions describes; at first to define the site class based on AVS 30, and secondly to set the amplification factors by the selected site class, as shown in Figure 4-28.

1. Definition of Site Class based on AVS 30

Site Class	Site Class Description	Shear Wave Velocity (m/sec)	
		Minimum	Maximum
A	**HARD ROCK** Eastern United States sites only	1500	
B	**ROCK**	760	1500
C	**VERY DENSE SOIL AND SOFT ROCK** Untrained shear strength $u_s \geq 2000$ psf ($u_s \geq 100$ kPa) or $N \geq 50$ blows/ft	360	760
D	**STIFF SOILS** Stiff soil with undrained shear strength 1000 psf $\leq u_s \leq 2000$ psf (50 kPa $\leq u_s \leq 100$ kPa) or $15 \leq N \leq 50$ blows/ft	180	360
E	**SOFT SOILS** Profile with more than 10 ft (3 m) of soft clay defined as soil with plasticity index PI > 20, moisture content w > 40% and undrained shear strength u_s < 1000 psf (50 kPa) (N < 15 blows/ft)		180
F	**SOILS REQUIRING SITE SPECIFIC EVALUATIONS** **1. Soils vulnerable to potential failure or collapse under seismic loading:** e.g. liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. **2. Peats and/or highly organic clays** (10 ft (3 m) or thicker layer) **3. Very high plasticity clays:** (25 ft (8 m) or thicker layer with plasticity index >75) **4. Very thick soft/medium stiff clays:** (120 ft (36 m) or thicker layer)		

2. Setup of Amplification Factors

Site Class B Spectral Acceleration	Site Class				
	A	B	C	D	E
Short-Period, S_{AS} (g)	**Short-Period Amplification Factor, F_A**				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8*
1-Second Period, S_{A1} (g)	**1.0-Second Period Amplification Factor, F_V**				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0*

* Site Class E amplification factors are not provided in the *NEHRP Provisions when* $S_{AS} > 1.0$ *or* $S_{A1} > 0.4$. Values shown with an asterisk are based on judgment.

[extract from HAZUS-MH MR2 Technical Manual]

Figure 4-28 Sample of Utilization of AVS 30 for the Amplification Analysis

Results of the site class and the amplification factor are described in "Report of Seismic Hazard Map" (Chapter 2)

Figure 4-29 to Figure 4-31 shows AVS 30 Map in each city based on the relation (thickness and AVS 30) and the geological subsurface model (thickness of Holocene soil).

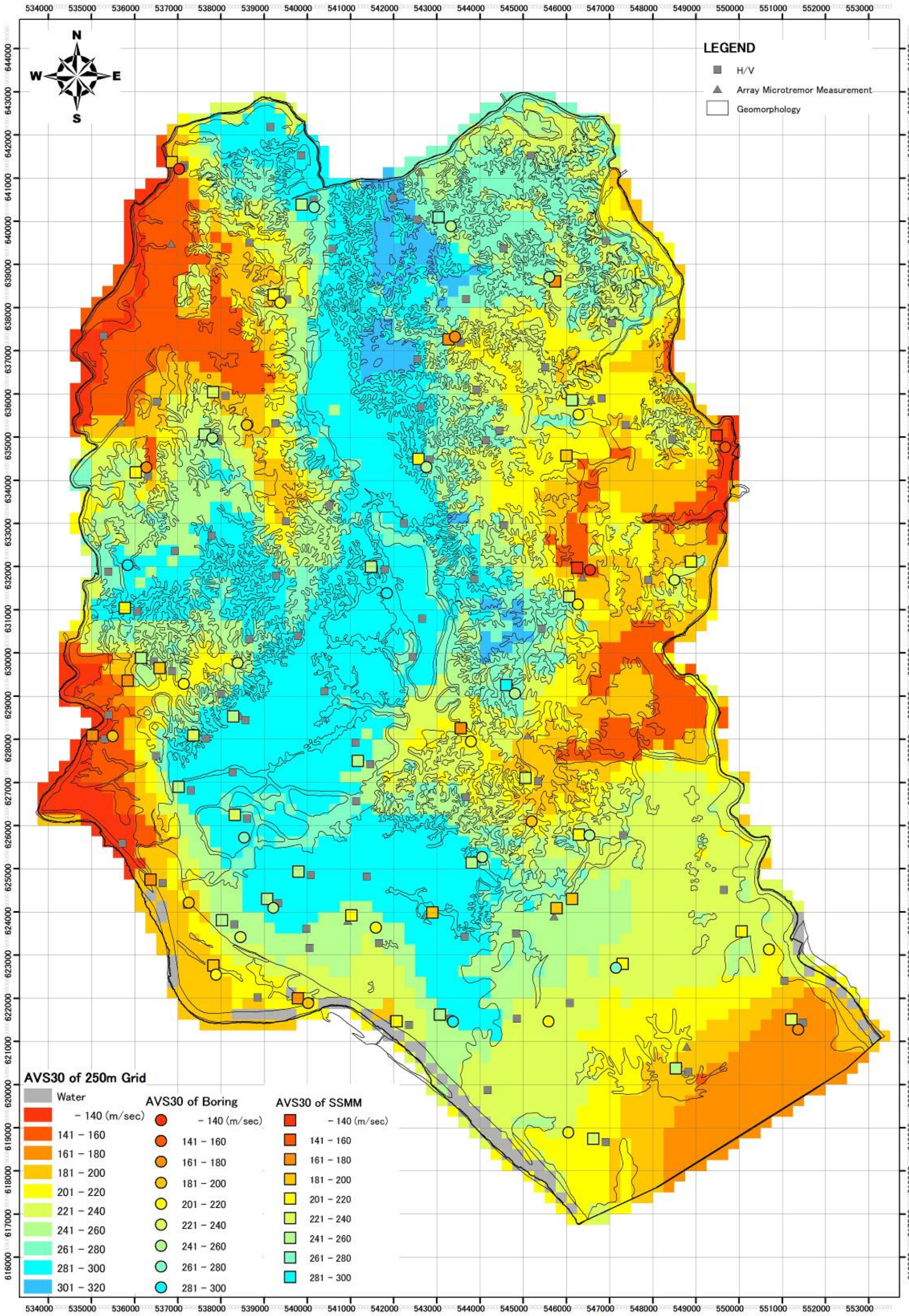


Figure 4-29 AVS 30 Map in Dhaka

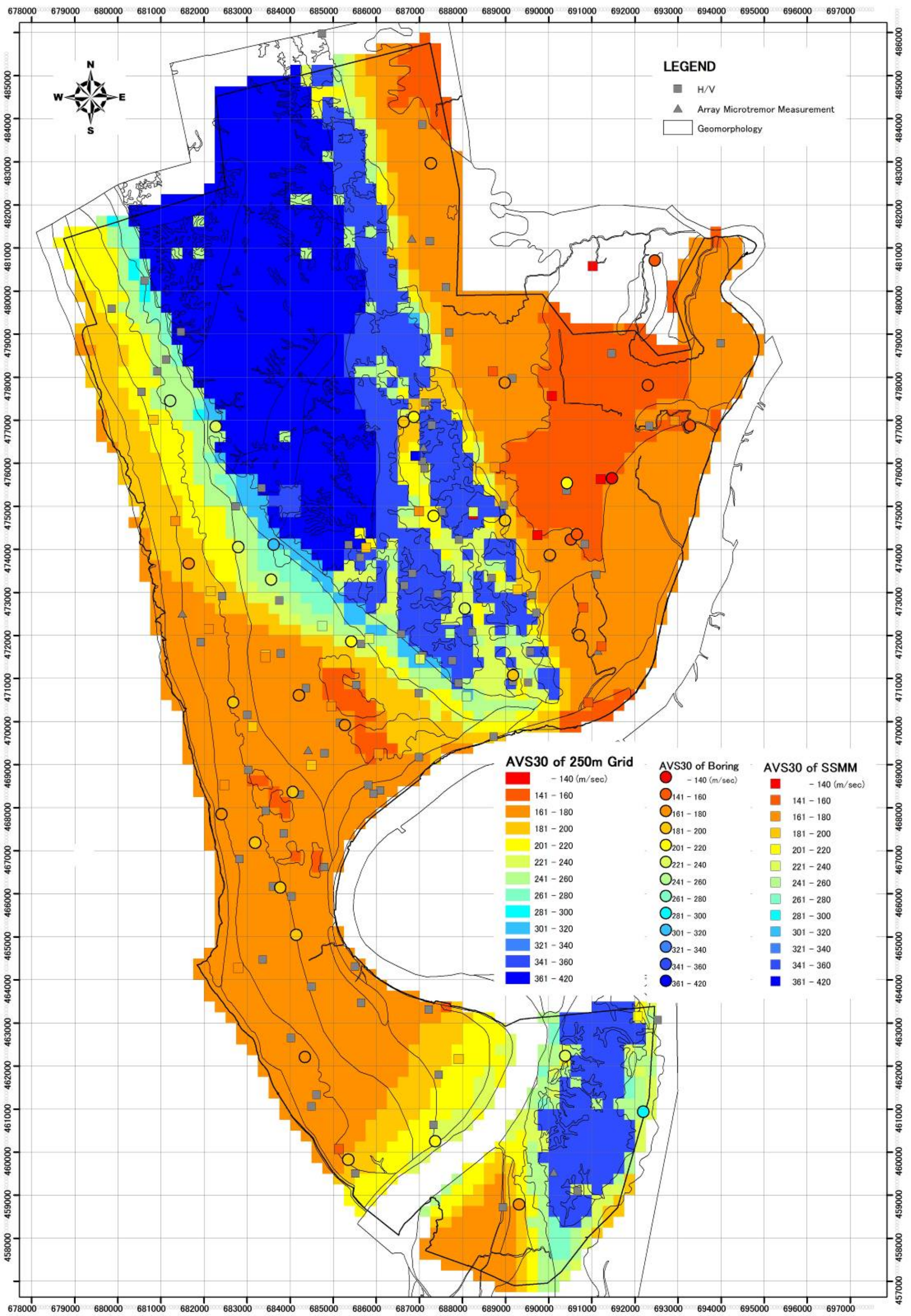


Figure 4-30 AVS 30 Map in Chittagong

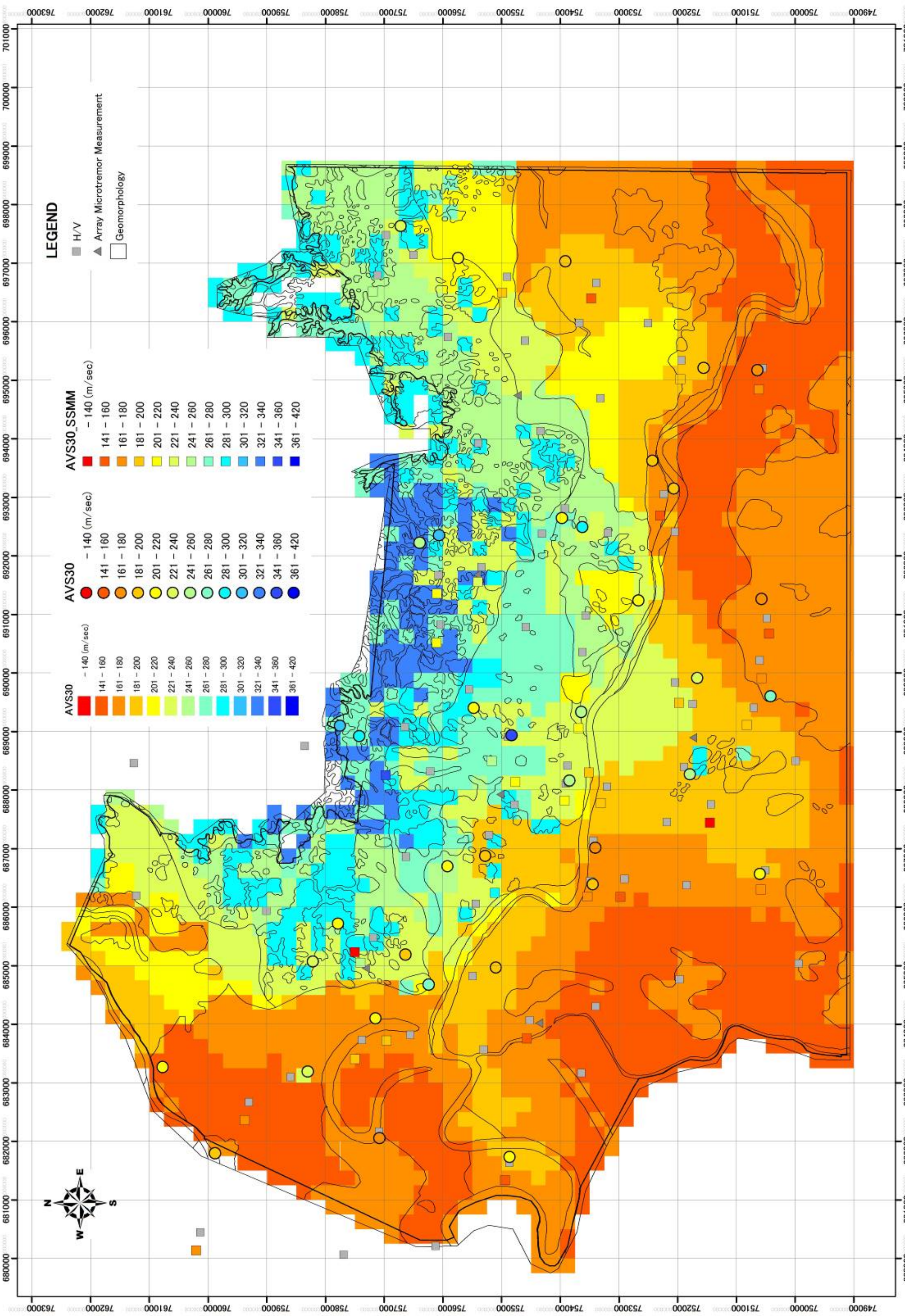


Figure 4-31 AVS 30 Map in Sylhet

(2) Verification of AVS 30 Map

Accuracy of AVS 30 Map is verified in comparison with estimated AVS 30 of the grid and AVS 30 derived from PS logging results (19 points in total) / the relationship between Vs and N at boring points (95 points in total) / results of small scale microtremor measurement (121 points in total) as shown in Figure 4-32.

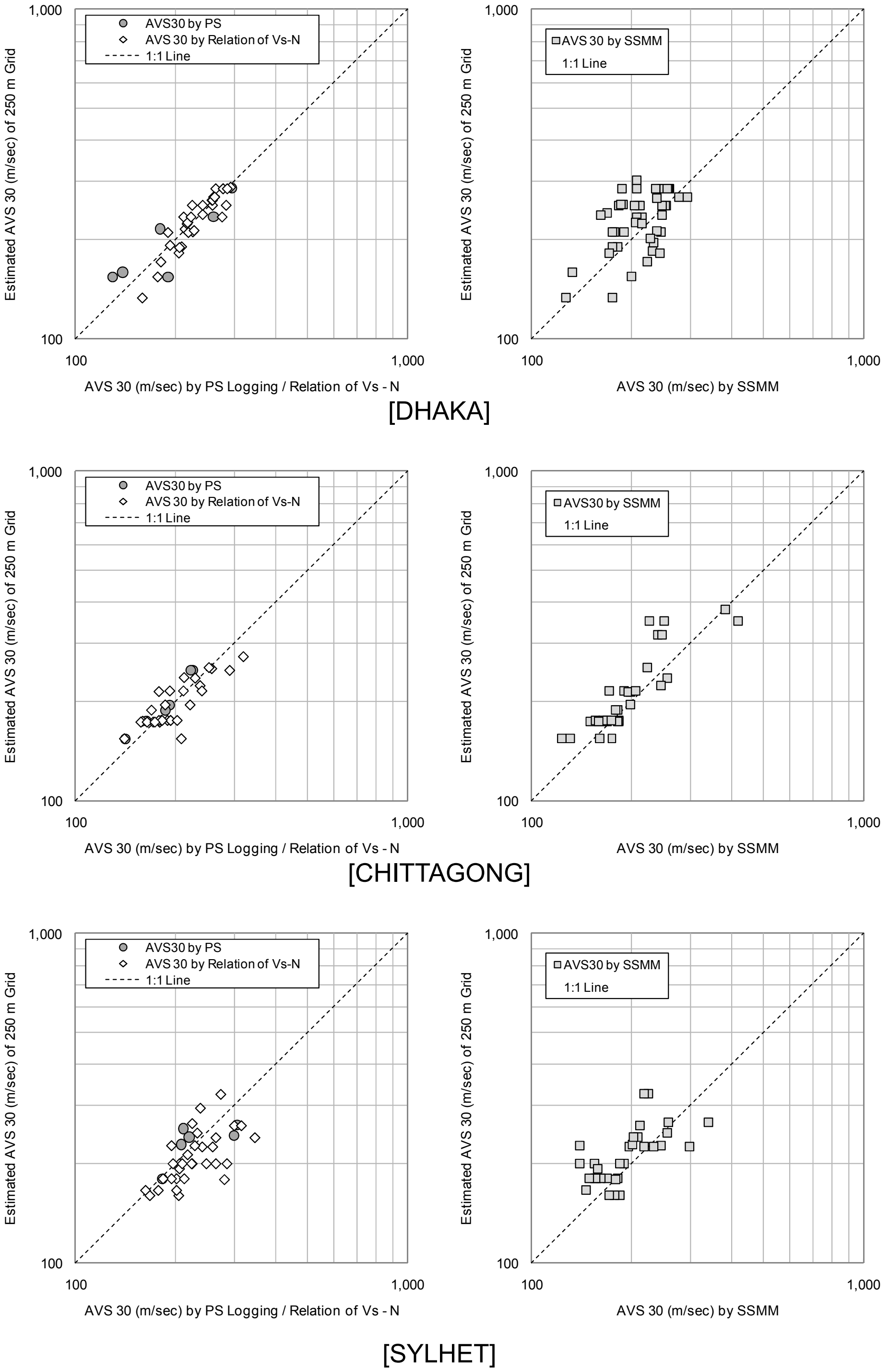


Figure 4-32 Verification of AVS 30 Map in each City

AVS 30 Map is a good matching with AVS 30 derived from PS logging results, from the relationship between Vs and N, and from SSMM in sequence. It means that primary data, which is PS logging results, is well reflected to AVS 30 Map, and indirect data, such as SSMM, is moderately suited it. Therefore, it is necessary to carry out boring investigation beside SSMM point in order to clarify characteristics of SSMM results and to accumulate them to reflect to improving AVS 30 Map in future.

References

[Chapter 1]

Mominullah, M., 1978: Geologyof the Northern Part of Chittagong District, Bangladesh. Records of the Geological Survey of Bangladesh. V.II, part 3.

[Chapter 3]

Kitsunezaki. C. ,N. Goto, Y. Kobayashi., T. Ikawa, M. Horike, T. Saito, T. Kurota, K. Yamane, and K. Okuzumi, 1990, Estimation of P- and S- wave velocities in Deep Soil Deposits for Evaluating Ground Vibrations in Earthquake, SIZEN-SAIGAI-KAGAKU,9-3,1-17 (in Japanese).

Okada, H., 2003, The microtremor survey method, Society of Exploration Geophysicist, Tulsa.

The Society of Exploration Geophysicists of Japan, "Application of Geophysical Methods to Engineering and Environmental Problems, 17 Microtremour", 285-301.

[Chapter 4]

Matsuoka M., K. Wakamatsu, K. Fujimoto and S. Midorikawa, 2005 July, Journal of Structural Mechanics and Earthquake Engineering, JSCE, No.794/I-72, pp.239-251,

DFID Department for International Development

European Union

UNDP Bangladesh

Technical Assistance: adpc Asian Disaster Preparedness Center
OYO International Corporation