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PS Logging for Site Response Analysis in Dhaka City

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Abstract: *The purpose of this research is to measure shear wave velocity of different areas of Dhaka city using PS Logging and estimate the site amplification of those areas based on shear wave velocity. For this purpose, seventeen locations were selected in Dhaka city. Among them, PS logging was carried out at ten locations by the author and data of rest seven locations were collected from CDMP. Using 189 pairs of values of corrected SPT N and Shear Wave Velocity from seventeen locations, a correlation among Shear Wave Velocity, SPT N Value and Depth was developed and proposed for Dhaka city. For estimating site amplification for those seventeen locations, acceleration computer program DEEPSOIL was used. With soil layer depth, unit weight (γ) and shear wave velocity (Vs) as inputs, soil amplification by equivalent linear analysis was estimated. Four input motions (The Imperial Valley Earthquake; the Kobe Earthquake; the Kocaeli Earthquake and the Northridge Earthquake) were used in these analyses, which were scaled to 0.19g value for bedrock in the Dhaka region.*

Key words: *PS Logging, SPT, Shear Wave Velocity, Site Amplification, DEEPSOIL, etc.*

Introduction

Bangladesh did not suffer any large majon earthquakes in the recent past, but in the past few hundred years, several large catastrophic earthquakes struck this area. The 1897 Great Indian Earthquakes with a magnitude of 8.7, which is one of the strongest earthquake in the world killed 1542 and affected almost the whole of Bangladesh (Oldham, 1899). Recently, Bilham et al. (2001) pointed out that, there is a very high possibility that a huge earthquake will occur around the Himalayan region based, on the difference between energy accumulation in this region and historical earthquake occurrence. The population increase around this region is 50 times than the population of 1897 and city like Dhaka has population exceeding several millions. It is a cause for great concern that the next great earthquake may occur in this region at any time. So it is very important to measure shear wave velocities of different locations and perform ground response analysis of the areas.

Ps Logging and Its History

The word "PS Logging" means P wave and S wave logging. That means compression wave and shear wave logging. It is a technique to measure seismic wave velocity using an apparatus including a receiver and a source. P-S suspension velocity logging was first developed in the mid-1970s to measure seismic shear wave velocities in deep, uncased boreholes; it was originally used by researchers at the OYO Corporation of Japan (Kaneko et al., 1990). It gained acceptance in Japan in the mid-1980s and was used for other velocity measurement methods to characterize earthquake site response. Public Works Research Institute (PWRI) of Japan has measured S-wave velocities in boreholes using the PS suspension logging tool since 1980. Since the early 1990s it has gained acceptance in the United States, especially among earthquake engineering researchers of US.

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Information of Study Area

Dhaka is situated in the centre of Bangladesh, between longitude 90°20′ E and 90°30′ E and latitude 23°40′ N and 23°55′ N. The present area of the city is 256 square kilometers, bounded by the Demra in the east, the Turag River in the west, the Tongi Khal in the north and the Burhiganga River in the south. In and around the city, an area of 280 square kilometers has been mapped.

Dhaka City is almost flat, with many depressions, bounded by rivers on all four sides topographically. The surface elevation of the city ranges between 1.7 and 14 meters above mean sea level, but is generally around 6.5 meters. The average depth of the groundwater table is 3 meters. The seasonal variation of the water table ranges from 1 to 2 meters. The urban area is situated in a seismic zone, which has experienced earthquake intensities of up to IX at the Modified Mercalli scale. Geologically, nine units can be distinguished. The depressions and abandoned channels are dominated by organic clay and peat. The main part of the city lies either on Madhupur Clay, old natural levees, high flood plains, or filled-in gullies. The Madhupur Clay, with its average thickness of 8 meters, consists of over-consolidated clayey silt and is underlain by the Plio-Pleistocene Dupi Tila Formation. Figure 1 shows the location map of the study area.

The area investigated is divided into seven engineering geological units based on their physical properties, homogeneity, and distribution of subsurface strata. Engineering geological units I, II and III consist generally of consolidated clayey silt layers at the top, underlain by dense Dupi Tila sand, found above the normal flood level, a favorable condition for urban settlement. However, the present expansion of the city is towards the low-lying areas, notably in depressions and flood plains. In general, the fill layer in depressions is about 5 meters thick. Fine-grained sand, clayey silt, organic clay, even peat and garbage are being used as fill materials.

Unfortunately, most of the natural drainage systems are currently obstructed due to these filling activities. Every rainy season, the city faces problems due to stagnant water. As part of the city's flood control measures, the construction of a flood-protection embankment under way, along the rivers, mainly in depressions, using locally excavated sediments without any core.

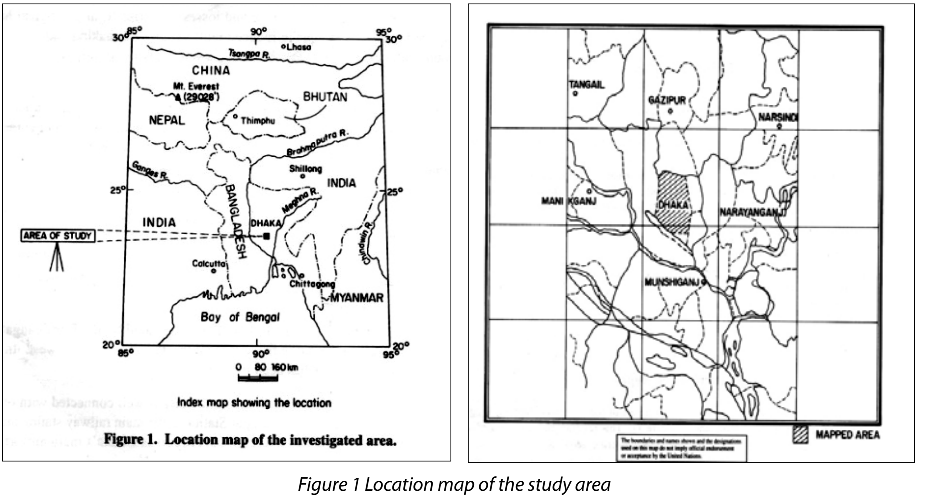


Figure 1 Location map of the study area

Methodology

PS Logging test can be performed using both up-hole and down-hole techniques. For the research work, PS Logging equipment of BUET-JIDPUS was used. It was bought from the OLSON INSTRUMENTS. The testing system consists of several basic components packaged into a padded carrying case plus the Freedom Data PC in its own case. The padded case stores the down-hole source, tri-axial geophones, down-hole links, dummy probes, compressor, pressure gage, cables and battery charger. Different components of the test system are shown in Figure 2.

The down-hole seismic test requires only 1 borehole (preferably a 2.5-3 in diameter hole with PVC pipe installed up to the depth in which competent soil or rock is reached) to be used for the geophone receiver. Usually PVC pipes are used to permanently stabilize the hole. The standard for the test technique is set forth in the ASTM D4428/D4428M.

For preparing the boreholes for Suspension PS Logging Test at all ten selected areas of the Dhaka City, Standard Penetration Test (SPT) was conducted according to ASTM D1586 (ASTM, 2000). In every location 3 in borehole was prepared by SPT method and N value was observer at every 5 ft and in some places every 10 ft interval. Figure 3 shows the SPT test at MIST, Mirpur. After preparing the borehole, a PVC pipe was for protecting the hole from caving. Figure 4 shows the installation of the PVC pipe at Aftabnagar.

Disturbed and undisturbed sample were collected during the test. After preparing the borehole using the SPT test, installation of the PVC pipe was found to be the most difficult of the test procedure, because of seven caving of sand. It was shown in many places that after performing a 100 ft SPT boring, PVC pipe was installed at only 50-80 ft depending on the time and method of pipe installation. In some placesa second boring was performed because of caving of soil. The SPT test is described below.

Figure 2 Different components of Suspension PS Logging Test Equipment used in this study.

(a) Data Pc (b) Cables from Freedom Data PC to Receivers (c) Tri-axial Geophone Receiver (d) Dummy Probes (e) Pressure Gage (f) Rope cleat

Figure 3 SPT Test at MIST

Figure 4 Burning of PVC pipe at bottom before installation

In the Research work, N value was taken at 5 ft intervals in some places and at 10 ft interval in others. Undisturbed and disturbed samples were collected where N value was taken. After performing the borehole, 3 in diameter PVC pipe (20 ft each pipe) were installed along the borehole for protecting the soil from caving. Firstly the bottom of the first pipe was burnt (Figure 4) and sealed before installing for protecting the soil from hydraulic or soil heaving from bottom. Each pipe had socket system at both end for connecting each other. So when one pipe was penetrated, another pipe was connected with the previous pipe using the socket and then penetrated. For a 100ft borehole, 5 pipes were needed.

For the test, a wooden plank source of 6 in x 30 in area and 3 m (10 ft) in length was used. Figure 5 shows the wooden plank used for the test at Kamrangichor. A vehicle was placed on the plank, to hold the plank tightly. There was a sensor attached to the wooden plank. The plank was hit separately on both ends to generate shear wave energy in two different directions. It was also hit vertically in the downward vertical direction to generate vertically polarized compression wave energy. The shear wave energy was polarized in the direction parallel to the plank as was the transverse component. The transverse component was used to measure the shear wave energy. The vertical component was used to measure the vertically polarized compression wave energy. Typically 3-5 records are taken for each type of wave –east going, west going shear wave and vertical compression wave. Using the test plans that come with the Freedom Data PC down-hole Seismic / Cross Hole Seismic – 2 system, 8 records were taken for each wave type. Figure 6 shows PS logging test at Gulshan-2.

Figure 5 A heavy wooden plank

Figure 6 PS Logging Test Setup at Gulshan-2

Sample of data obtained from test is shown in Figure 7 for calculating shear wave. Figure 7 shows the data of shear wave generated by giving blow with hammer in both directions horizontally. For computing the arrival time of the shear wave, the first point of the time domain data of the transverse component taken when both wave generated from both horizontal directions just overlap each other. From the calculated travel time of the compression and shear wave, the velocity can be determined by dividing the distance of the source to receiver by the travel time. Shear wave velocity was determined using this method.

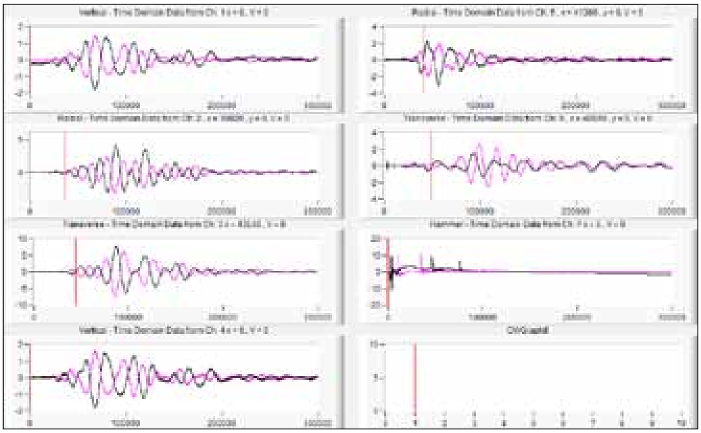
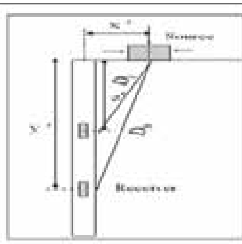


Figure 7 Time Domain data for shear wave



$$D_t = \sqrt{(z^2 + x^2)}$$

$$D_b = \sqrt{(y^2 + x^2)}$$

$$V_p = \frac{D_b - D_t}{t_b - t_t}$$

Here,

D_t = Distance between top receiver to source

D_b = Distance between bottom receiver to source

T_t = Travel time of wave to top geophone

T_b = Travel time of wave to bottom geophone

Figure 8 PS Logging test in Seismic Down-hole method

Field Investigation

Ten locations of Dhaka city were selected for conducting PS Logging Test. Also PS Logging Test data of seven more locations of Dhaka city were collected from CDMP. The locations are shown below in Figure 9. SPT values and SPT N values of different locations with respect to depth is shown below in figure 10 and figure 11.

Tested by Author

Site-1: BUET JIDPUS
Site-2: MIST, Mirpur
Site-3: Hazaribag
Site-4: Gulshan 2
Site-5: Kamrangichor
Site-6: Dakhin Kafrul
Site-7: Maniknagar
Site-8: Aftabnagar
Site-9: Lake City Concord, Khilkhet
Site-10: RHD, Tejgaon

Tested by CDMP

Site-11: Mehernagar, Uttara
Site-12: Jubok Project, Ashulia
Site-13: Mirpur-1, Avenue-2
Site-14: Akash Nagar, Mohammadpur, Beribadh
Site-15: United City Project, Beraidh
Site-16: East Nandipara
Site-17: Asian City, Dokhinkhan

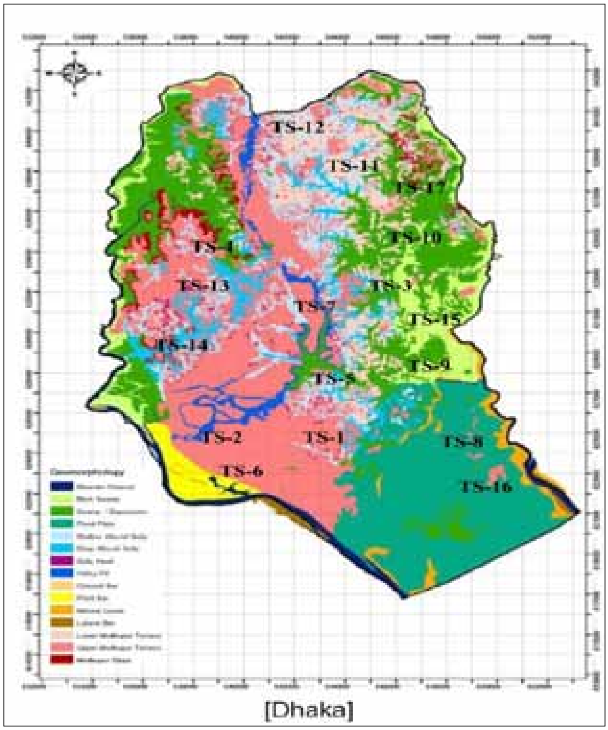


Figure 9 Test Site Map of Dhaka City

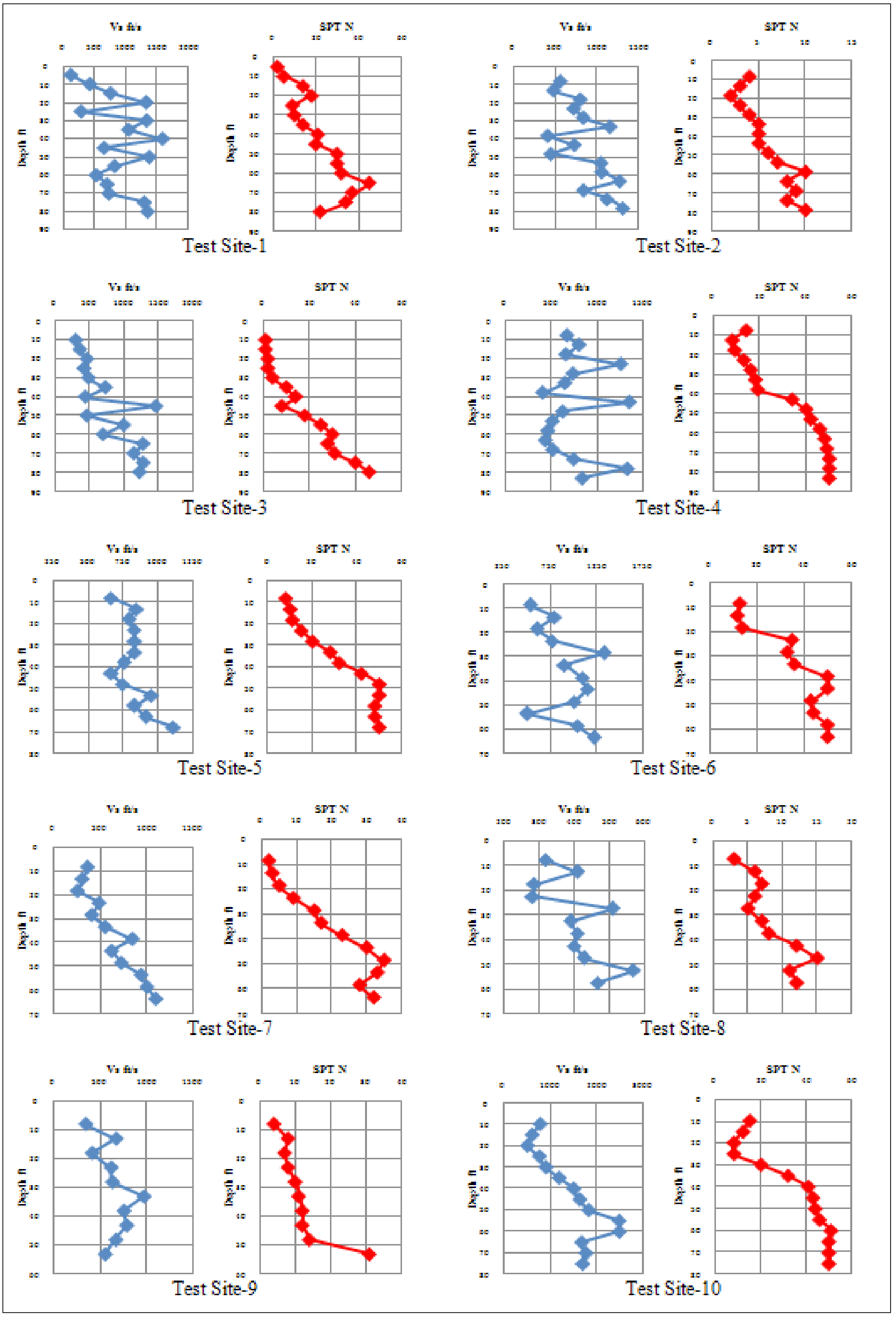


Figure 10 Field Investigation Result of different locations tested by the author

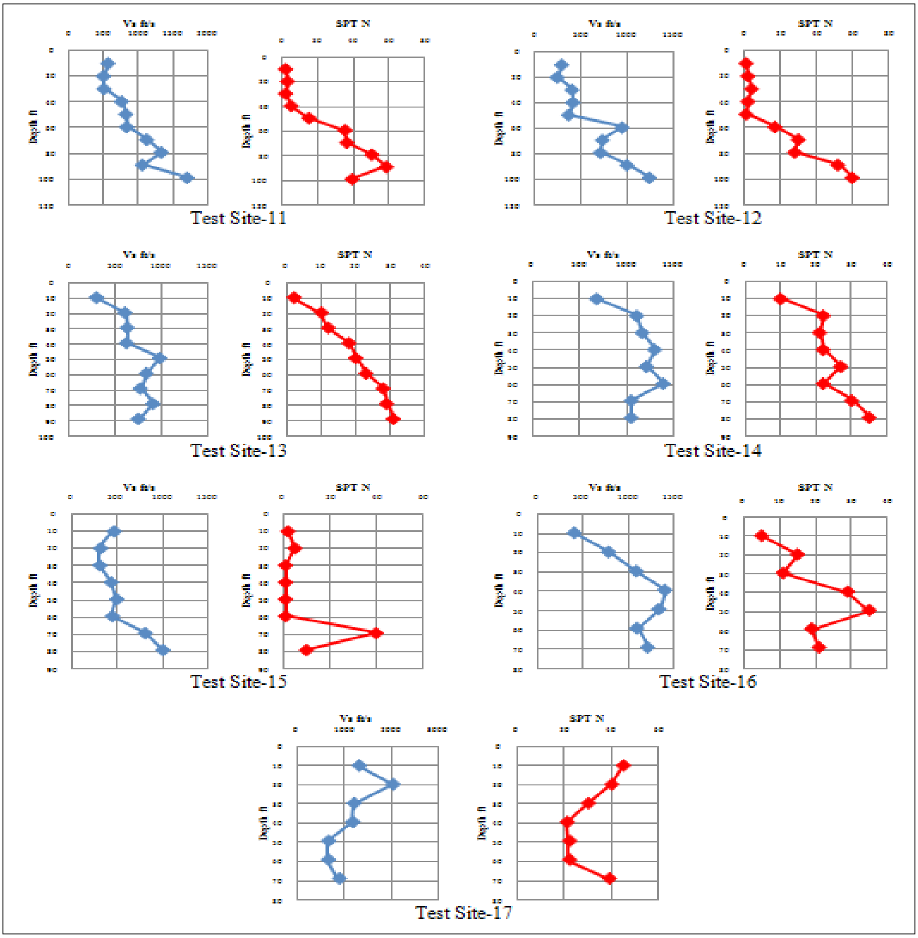


Figure 11 Field Investigation Result of different locations tested by CDMP

Correlations between SPT N – Shear Wave Velocity (Vs) and Depth

The SPT has historically been the most widely used in situ geotechnical test throughout the world. Researchers have studied the relationship between VS and SPT N values since the 1960s. A correlation was suggested using 189 set of data of depth, SPT N value and shear wave velocity. Figure 12 shows the relation between the Vs and depth and Vs and SPT N value.

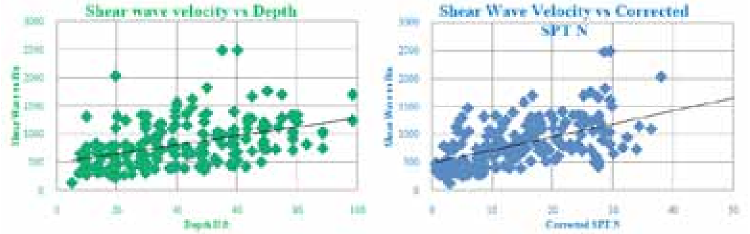


Figure 12 Graph of Shear Wave Velocity (Vs) and Depth and Shear Wave Velocity (Vs) and Corrected SPT N

Considering Vs as the dependent variable and depth and the SPT N value as the independent variables following correlation was obtained for top soil at Dhaka City.

$$V_S = 169\ N^{0.2638}\ D^{0.2396}\ [r^2 = 0.45]$$

Here,

V_S = Shear wave velocity in ft/sec

N = Corrected Standard penetration Number

D = Depth in ft.

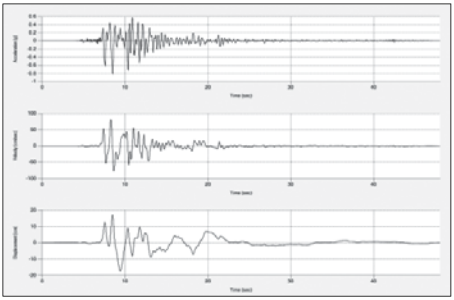
Analysis Result

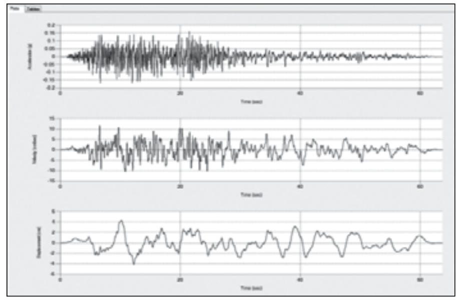
During earthquake, propagation of seismic waves through soil column alters the amplitude, frequency and duration of ground motion by the time it reaches the surface. The effects of ground motion are propagated in the form of waves from one medium to another. So, physically it is a problem of prediction of ground motion characteristics whereas mathematically it is a problem of the wave propagation through continuous medium. The evaluation of such response of the site to dynamic loading is termed as ground response analysis.

Most of the places of Dhaka city are underlain by loose sandy silts and silty clay which makes it vulnerable during an earthquake due to the ground motion amplification of the young, loose soil deposits in the area. Site response analysis consists of estimation of local site effects and surface ground motion. This section deals with the estimation of surface ground motion for Dhaka city. This section presents the ground responses analysis outputs of the selected locations in Dhaka city.

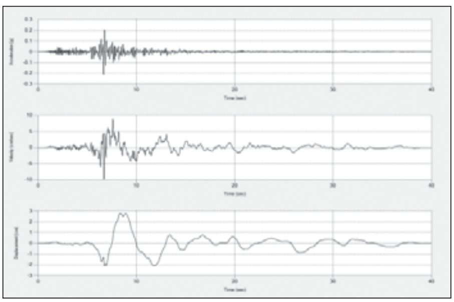
In Dhaka City information about the depth of bedrock was unavailable due to lack of deep boreholes. In DEEPSOIL (Hashash, et al., 2011), rock depth was assumed to be below the last layer, so to prevent erroneous results the last layer was assumed to be the same up to a depth of 100m.

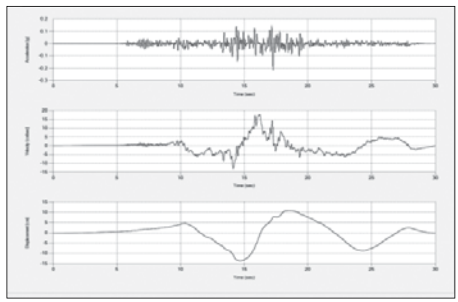
For site response analysis by equivalent linear method the results are considered to be accurate for estimating PGA up to 3sec for general projects (Finn, 1995; Martin, 1994; Durward, 1996; Dobry, 2000; Dickenson, 1995). Input ground motion have to be selected in such way that they represent the regional seismicity and must incorporate the anticipated earthquakes. The selection of ground motion can be done based on expected magnitude and distance, soil profile, strong motion duration, seismic-tectonic environment, acceleration to vertical ratio, spectral matching etc. In this study, The Kobe Earthquake in South-Central Japan on January 17, 1995 (Mb-7.2);The Imperial Valley earthquake in Mexico–United States border on October 15, 1979; The Northridge earthquake in the north-central San Fernando Valley region of Los Angeles, California on January 17 1994 (Mb-6.7) and The Kocaeli Earthquake at Kocaeli, Turkey on August 17, 1999(Mb-7.4) were selected as input motion for ground response analysis. The time history of the earthquake input motions are shown in Figure 13. All input motions were converted to Site class A, to be imposed on the bottom of the bed rock. Then it was scaled to 0.19g. The spectral acceleration of the converted input motions are shown in Figure 14.





Kobe Earthquake *Imperial Valley Earthquake*





Northridge Earthquake *Kocaeli Earthquake*

Figure 13 Time History of different input motions.

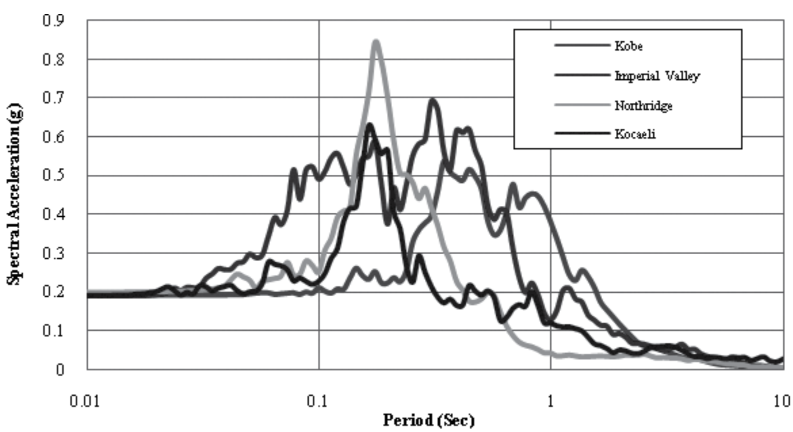


Figure 14 The spectral acceleration variation of the different input motions

The Response Spectrum of different sites for different input motions are shown as graphical form in Figure 15 and Figure 16. Peak Ground Acceleration of different sites for different input motions are shown as graphical form in Figure 17 and Figure 18.

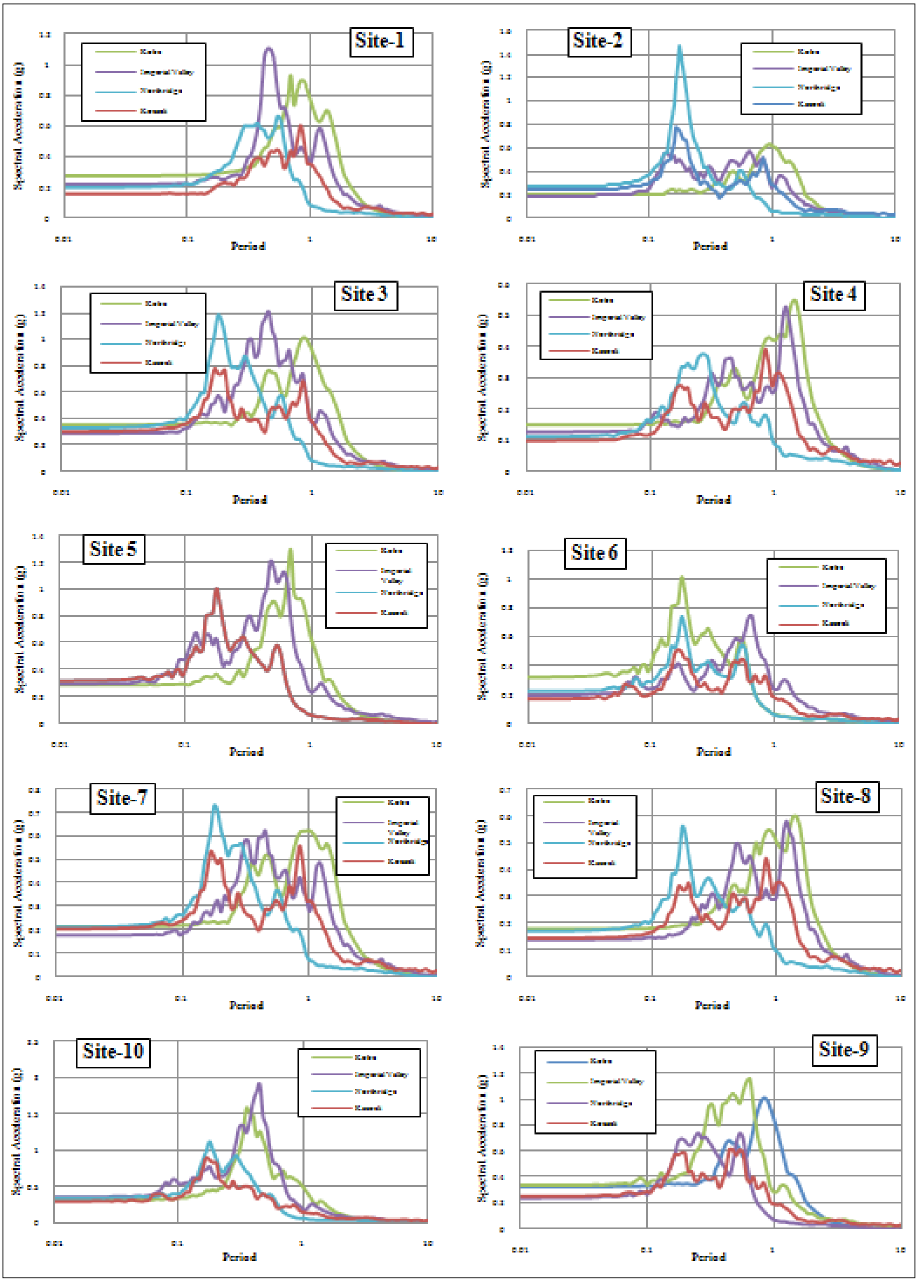


Figure 15 Response Spectrum of Site 1 to Site 10

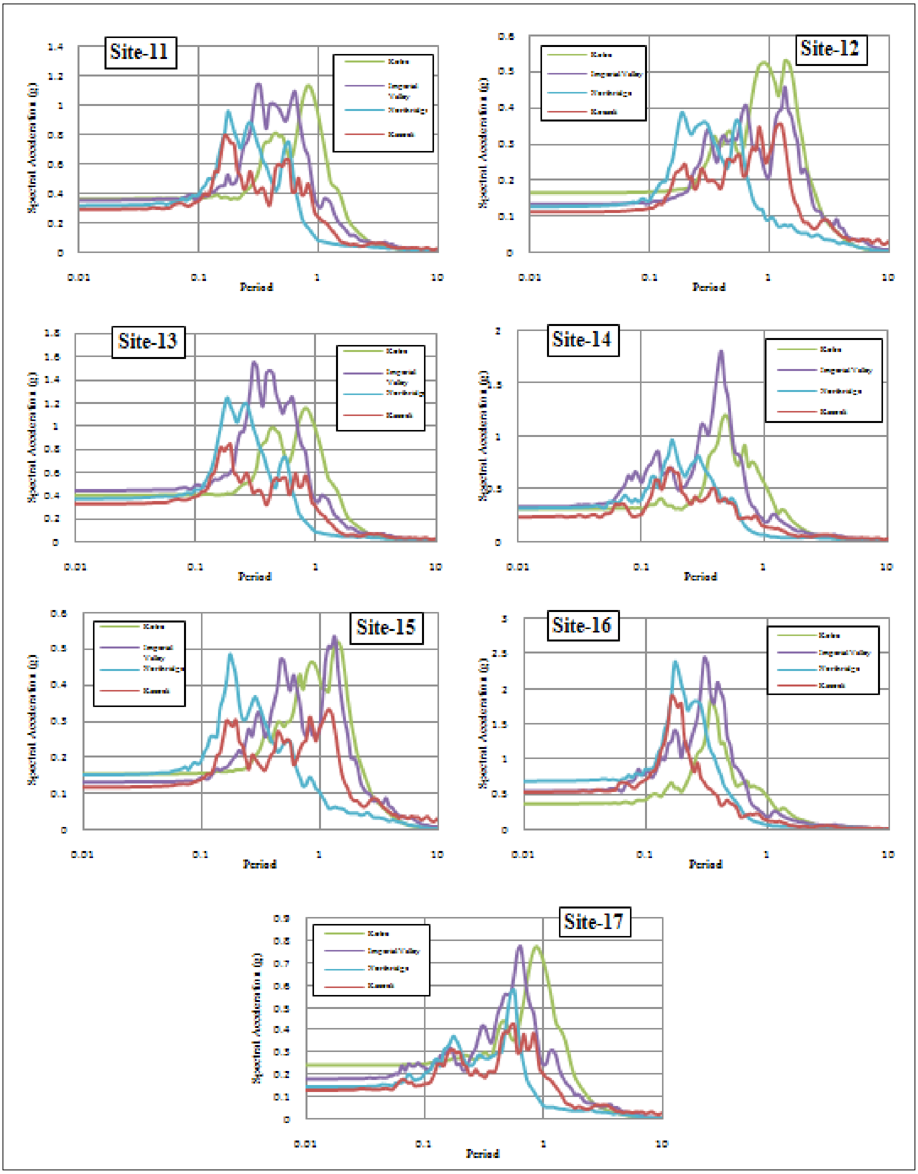


Figure 16 Response Spectrum of Site 11 to Site 17

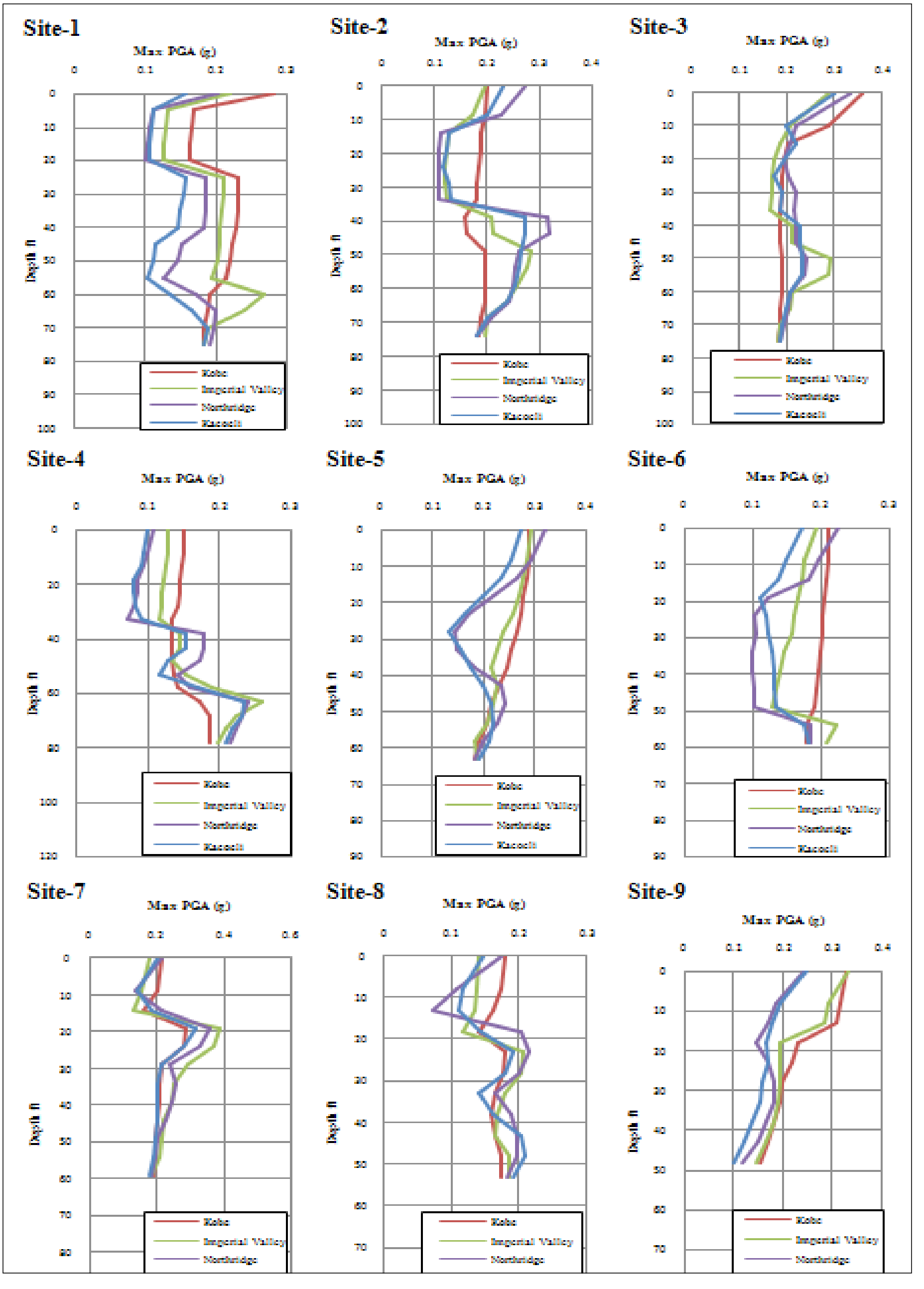


Figure 17 PGA of site 1 to site 9 for different input motion

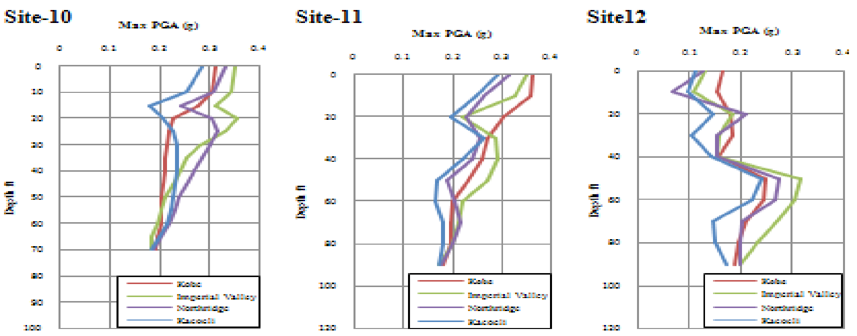


Figure 20 PGA of site 10, site 11, and site 12 for different input motion

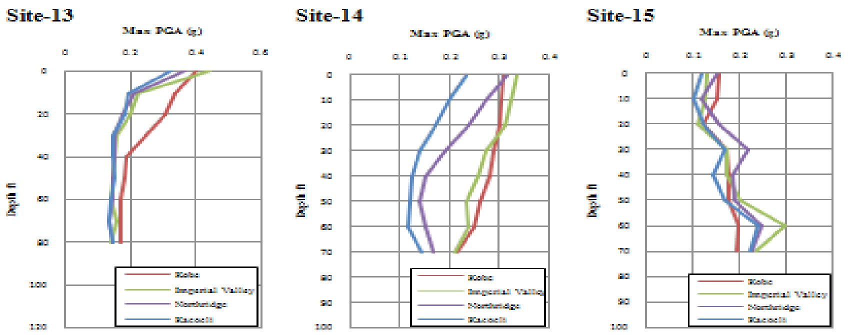


Figure 21 PGA of site 13, site 14, and site 15 for different input motion

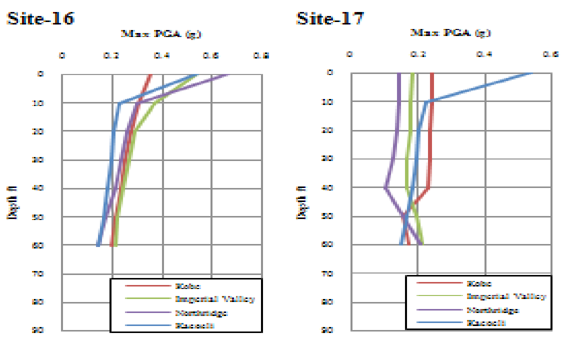


Figure 18 PGA of site 10 to site 17 for different input motion

Site amplification factors at sub surface layers are often used as one of the parameters for estimation of ground response. The amplification factor is the ratio of peak ground acceleration at surface to that of acceleration at hard rock. The amplification factors are determined as:Amplification Factor = PGA recorded at ground surface / PGA recorded at hard rock. The amplification factors of different locations are shown in figure 19.

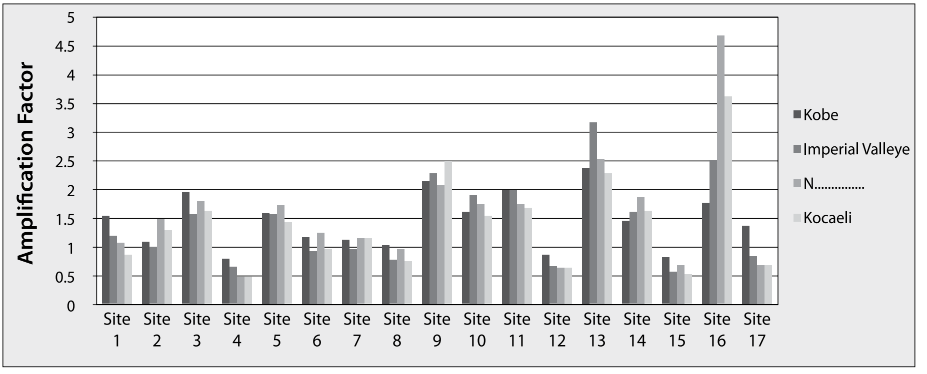


Figure 19 Amplification factors of different sites for different input motion

Verification of Shear wave velocity measurement of Dhaka City using PS Logging Test

In a research program, Dr. Md Zillur Rahman and Dr. Sumi Siddiqua (2015) estimated average shear wave velocities of the subsurface geological materials of Dhaka City up to a depth of 30 m using in-situ site investigation techniques. PS Logging test were conducted in seven sites. Three of them were represented. The test locations are shown in table 1 and the test results are shown in figure 20. Two sites mentioned in the research are in proximity to the research sites investigated in this paper.

Table 1 Locations of PS Logging Test

Boring Code	Locations
DBH 4	Khilkhet
DBH 6	Asulia
DBH 8	Adabar, Mohammadpur

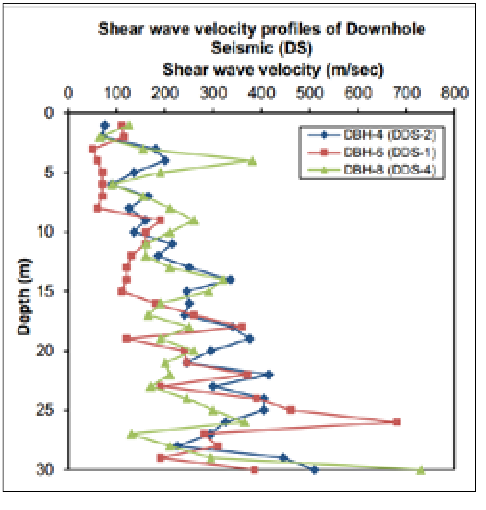


Figure 20 PS Logging Test results

We can see DBH 4 Khilkhet and DBH 8 Adabar Mohammadpur are near to Site 9 Lake City Concord, Khilkhet and Site 3 Hajaribag, Mohammadpur. In DBH 8 the Vs is about 60 m/s to 400 m/s and in Site 3 the values varies between 87 m/s to 448 m/s. Also in DBH 4 the values are within 70 m/s to 400m/s (upto 16m) and in Site 9 the values are within 100 m/s to 300 m/s. So there is a very close match between two datasets of nearby locations.

Conclusion and Recommendations

In the seismic hazard assessment of any area, ground response analysis is an important step. To evaluate and remediate geotechnical and structural hazards, response of a site to seismic shaking is required. The main purpose of the present study was to use the Suspension PS Logging to estimate the seismic wave velocity of ten selected areas of Dhaka City and to estimate the ground response. From the PS Logging tests and detailed site response analysis, we can see the response spectrum for different locations were remarkably high. The peak ground acceleration values measured were also higher for many sites. The values exceed the design PGA value 0.15 g of Dhaka City. Also we can see the amplification factor of surface soil is more than 1 of maximum locations. Therefore detailed and accurate measurement of shear wave velocity using different geophysical methods in strongly recommended. Detailed seismic hazard analysis should be conducted using the measured shear wave velocity and the seismic hazard map from the analysis should be proposed.

References

Ali, M.H and Choudhury, J.R (1992) "Tectonics and Earthquake Occurrence in Bangladesh", 36th Annual Convention, IEB, Dhaka.

Ansary, M. A; Noor, M. A. and Rashid, M. A. (2004) "Site amplification characteristics of Dhaka city", Journal of Civil Engineering (IEB), 32 (1) pp-5.

Molnar, S., Cassidy, J.F., Monahan, P. A. and Dosso1, S. E., "Comparison Of Geophysical Shear-Wave Velocity Methods" in Ninth Canadian Conference on Earthquake Engineering Ottawa, Ontario, Canada, 26-29 June, 2007, pp. 390-391.

Luna, R. and Jadi, H., "Determination Of Dynamic Soil Properties Using Geophysical Methods" presented at International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, St. Louis, MO, December 2000.

Urban Geology of Dhaka, Bangladesh, Atlas of Urban Geology, Volume 11.

Rashid, A. (2000), "Seismic Microzonation of Dhaka City based on site amplification and liquefaction", M. Engg. Thesis, Department of Civil Engineering, BUET, Dhaka, Bangladesh.

Rizvi M. S. (2014) "Site Amplification of the selected areas of Dhaka City Based on Shear Wave Velocity", M. Sc. Engg. Thesis, Department of Civil Engineering, BUET, Dhaka, Bangladesh.

U.S Geological Survey, National Seismic Hazard Maps (2012).

Luna, R. and H. Jadi, (2000) "Determination of Dynamic Soil Properties Using Geophysical Methods," Proceedings of the First International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, St. Louis, MO.

"Engineering Geological Mapping of Dhaka, Chittagong and Sylhet City Corporation Area of Bangladesh", (June, 2009), Comprehensive Disaster Management Program (CDMP), Ministry of Disaster Management and Relief.

Rahman, Md Zillur and Siddiqua, Sumi (2015) "Shear Wave Velocity Mapping of Dhaka City for Seismic Hazard Assessment" The 11th Canadian Conference on Earthquake Engineering, July 2015.

Hashash, Y.M.A, Groholski, D.R., Phillips, C. A., Park, D and Musgrove, M. (2011) DEEPSOIL 4.0, User Manual and Tutorial. 98 p.

System Reference Manual 2007, Crosshole And Downhole Seismic Test, Freedom Data PC with WINGEO Software Version 2.1, Olson Instruments.