Use of MATLAB in identifying borehole log at a particular location of a site

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ABSTRACT: In this paper, numerical analysis is carried out to identify borehole log at a particular location of a site thus producing a number of parameters which are empirically related to SPT values. The Standard Penetration Test (SPT) remains the most common site investigation tool used throughout the world. Physical properties of soil are found by correlations with values of recommended standard N_{60}, determined in SPT tests. Janjira Approach road of ongoing Padma Multipurpose Bridge Project was considered for this study to collect 15 borehole log along 20 km stretch. Disturbed soil sample were collected up to 19.5m depth in every 1.5m interval to perform Sieve-analysis test. Spreadsheet was used to input of over 600 data including SPT-N values, Percent Sand & Percent Fines at depths, Reduce Level & Ground Water Table at different Chainage locations. By using all these data- a mathematical model was developed in MATLAB, a high-level language and interactive environment for numerical computation, visualization, and programming. Rectangular grids in multidimensional space were created for Interpolation and/or Extrapolation for 2-D and/or 3-D gridded data in 'meshgrid' format. The purposes of the study are to find vertical SPT profile & soil-profile in a particular alignment of the site and to extract borehole log form SPT profile & soil-profile at intermittent locations of that alignment. SPT profile is presented graphically using contour plot of matrix and soil-profile is presented by 3-D shaded surface plots. Predicted borehole log could be useful for preliminary selection of a project site, land use planning, zoning ordinances, pre-disaster planning, and capital investment planning. Seismic soil liquefaction was evaluated for this site in terms of the factors of safety against liquefaction (FS) along the depths of soil profiles for different peak ground acceleration ranging 0.3g to 0.45g and earthquake magnitude ranging 6 to 7.5 on Richter scale. Cyclic Strength Ratio (CSR) and Cyclic Resistance Ratio (CRR) was determined with 10 % probability of exceedance in 50 year using SPT-based simplified empirical procedure. Liquefaction potential index (LPI) is evaluated at borehole locations from the obtained factors of safety (FS) to assess the potential of liquefaction to cause damage at the surface level at the site of interest. To validate the model, recent occurred Nepal Earthquake was taken as an example to compare the level of liquefaction severity assessed by in-situ and predicted borehole log data.

1 INTRODUCTION

In civil engineering projects, it is widely appreciated that the largest element of financial and technical risk usually lies in the ground. Almost exclusively, the scope of geotechnical investigations is governed not by what is needed to characterize the subsurface conditions appropriately but, rather, by how much the client and project manager are willing to spend. There is often little correlation between the variability of the ground and the scope of the investigation (Jaksa, et al., 2003).

Before commencing of the final design or construction the subsoil conditions at any proposed civil engineering site should be properly investigated. It is important for safe and economic infrastructural development. The characteristics of the formations of rocks and soils is needed to know on which the foundation of any structures are intended to rest or buried. Engineering structures (e.g. roads bridges, dam embankments, buildings, retaining walls, etc.) must be anchored on or buried in earth materials of proven integrity. The overall investigation should be detailed so that it may provide sufficient information for the geotechnical engineer to reach conclusions regarding site suitability, design criteria, probable construction problems and environmental impact. Laboratory and in-situ or field (surface and subsurface) techniques are routinely used to obtain information about physical and mechanical properties of rocks and/or soils. Laboratory techniques include Atterberg limits, Hydraulic conductivity, sieve analysis, etc., while geological profiling, auger boring, drilling, soil sampling (disturbed or undisturbed), standard penetration tests, water level measurements, test pits are the commonly used field techniques. The overall consideration in the choice of a method or a combination of methods is depends upon the cost implication, although this consideration must not override the need for proper investigation. The study focuses on the standard penetration test. It is one of the relatively cost-effective but informative field techniques most commonly used for subsurface exploration in Bangladesh.

Bangladesh is a low-lying country crisscrossed by numerous rivers. Communication network has been a great challenge for road and rail-line construction, as most road or rail-line links require building of numerous river crossings. Three large rivers: the Padma, the Jamuna and the Meghna divide the country. most of these rivers have braided characteristics that make the banks unstable and variable soil condition exist across the crossings, Geotechnical conditions for foundation of soils across crossings is complex and are usually heterogeneous both in vertical and horizontal direction. Soils consists of wide varieties of material ranging from poorly graded sand to silt and clay. In general there is a predominance of silt-sized materials (Safiullah, 2005). Janjira approach road of ongoing Padma Multipurpose Bridge project is considered for this study to gather data of 15 borehole locations within 20 km of chainage.

Data availability and accessibility can reduce both time and the expense of the projects, especially during feasibility stage. In the last few years, the numbers of construction projects in Bangladesh have been increased rapidly and continuously. Consequently, the number of soil boring reports has been accumulated largely. Data interpretation, management and appropriate processing, then, cannot be regarded as simple tasks. The utilization of the various numerical and graphical techniques can be served the geotechnical engineer as the very effective tools. Not only for non-data area prediction but also used to interpret the complex data area with reliability and accuracy. In geotechnical engineering, soil formation, physical and engineering properties of soil are very important data. With the good soil information, engineers can make proper decision and effectively design (Suwanwiwattana, et al., 2001). However, nature of soil is vary and more complicate in some area depending upon its formation process or some disturbing condition. Thus well subsoil survey planning during feasibility and detail design stage of the project is necessary for balancing of cost and acquiring the significant data. Although significant data are obtained, data management and interpretation are also very important processes and not easy tasks to achieve the subsoil information.

The purpose this study is to elaborate the usage of numerical and graphical methods to manage and interpret the soil data and establish geotechnical database system to provide information support to others geotechnical work. Furthermore this system can be used as a decision support system for geotechnical engineers.

2 OBJECTIVES OF THE STUDY

Site investigation and estimation of physical soil characteristics are essential parts of a geotechnical design process. Geotechnical engineers must determine the average values of soil parameters and variability of soil properties. Evaluation of properties of soils beneath and adjacent to the structures at a specific region is of importance in terms of geotechnical considerations since behavior of structures is strongly influenced by the response of soils due to loading. In-situ testing has become increasingly important in geotechnical engineering, as simple laboratory tests may not be reliable while more sophisticated laboratory testing can be time consuming and costly (Al-Jabban, 2013). The study was aimed to prepare a model that could present a soil profile thus producing borehole log at a particular location using the adjacent soil data. The main objectives of the study were:

i. To develop a mathematical model that could plot SPT profile & soil profile at a particular alignment of a site.
ii. Predict borehole log at intermittent location using GPS coordinates or chainage location.
iii. To use predicted borehole log in case study of designing practical problem.
iv. To validate the model using known soil profile data.

3 MATLAB MODELING

This study was conducted to produce a model for soil profile using MATLAB and Excel Spread sheet. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. MATLAB is used to analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable to explore multiple approaches and reach a solution faster than with traditional programming languages, such as C/C++ or Java. (Anon., 1994-2015) MATLAB is the language of technical computing and functions are similar to C functions or FORTRAN subroutines. Key features include: 4^{th} generation language for numerical computation and application development, tons of mathematical functions, built-in graphics for visualizing data, tools for building applications with graphical interfaces.

3.1 *MATLAB & M-files*

The present study was aimed at developing a modeling to generate soil profile at a selected location using SPT and grain size data of neighboring boreholes. MATLAB computer was used that provides the user with a convenient environment for performing many types of calculations. In particular, it provides a very nice tool to implement numerical methods. MATLAB uses three primary windows including- Command window which is Used to enter commands and data; Graphics window which is Used to display plots and graphs; Edit window. The most common way to operate MATLAB is by entering commands one at a time in the command window. M-files provide an alternative way of performing operations that greatly expand MATLAB's problem solving capabilities. An M-fine contains a series of statements that can be run all at once. Such files are stored with a *.m* extension (Chapra, 2007).

3.1.1 *Script files*

A script file is merely a series of MATLAB commands that are saved on a file. They are useful for retaining a series of commands that can be executed on more than one occation. The script can be executed by typing in the command window. For this study 2 script files were created for SPT contour plot and Soil Profile surface plot.

3.1.2 *Function files*

Function files are M-files that start with the word *function*. In contrast to script files, they can accept input arguments and return outputs. Hence they are analogoys to user defined functions in programming languages such as Fortran, Visual Basic or C. interp2, meshgrid, contour, surf**,** etc. built-in functions were used for this study.

3.2 *Multidimensional Interpolation*

The interpolation methods for one-dimensional problems can be extended to multidimensional interpolation. In this section, the simplest case of two-dimensional interpolation in Cartesian coordinates is described in addition to MATLAB's capabilities for multidimensional interpolation. *Tow-dimensional* interpolation deals with determining intermediate values for functions of two variables, $z = f(x_i, y_i)$. Assuming values at four points: $f(x_1, y_1), f(x_2, y_2), f(x_3, y_3)$ and $f(x_4, y_4)$. To interpolate between these points to estimate the value at an intermediate point $f(x_i, y_i)$, using a linear function, the result is a plane connecting the points. Such functions are called *bilinear* (Chapra, 2007). Fig 1 shows a simple approach for developing the bilinear function:

MATLAB has two built-in functions for two- and three- dimensional piecewise interpolation**:** interp2 **and** interp3**.**

First, by holding the y value fixed and applying one-dimensional linear interpolation in the x direction. Using the Lagrange form, the result at (x_i, y_1) is-

$$f(x_i, y_1) = \frac{x_i - x_2}{x_1 - x_2} f(x_1, y_1) + \frac{x_i - x_1}{x_2 - x_1} f(x_2, y_1)$$

And at (x_i, y_2) is-

$$f(x_i, y_2) = \frac{x_i - x_2}{x_1 - x_2} f(x_1, y_2) + \frac{x_i - x_1}{x_2 - x_1} f(x_2, y_2)$$

These points can be used to linearly interpolate along the y dimension to yield the final result:

$$f(x_i, y_i) = \frac{y_i - y_2}{y_1 - y_2} f(x_i, y_1) + \frac{y_i - y_1}{y_2 - y_1} f(x_i, y_2)$$

A single equation can be developed by substituting these equations to give:

$$f(x_i, y_i) = \frac{x_i - x_2}{x_1 - x_2}\frac{y_i - y_2}{y_1 - y_2} f(x_1, y_1) + \frac{x_i - x_1}{x_2 - x_1}\frac{y_i - y_2}{y_1 - y_2} f(x_2, y_1) + \frac{x_i - x_2}{x_1 - x_2}\frac{y_i - y_1}{y_2 - y_1} f(x_1, y_2) + \frac{x_i - x_1}{x_2 - x_1}\frac{y_i - y_1}{y_2 - y_1} f(x_2, y_2)$$

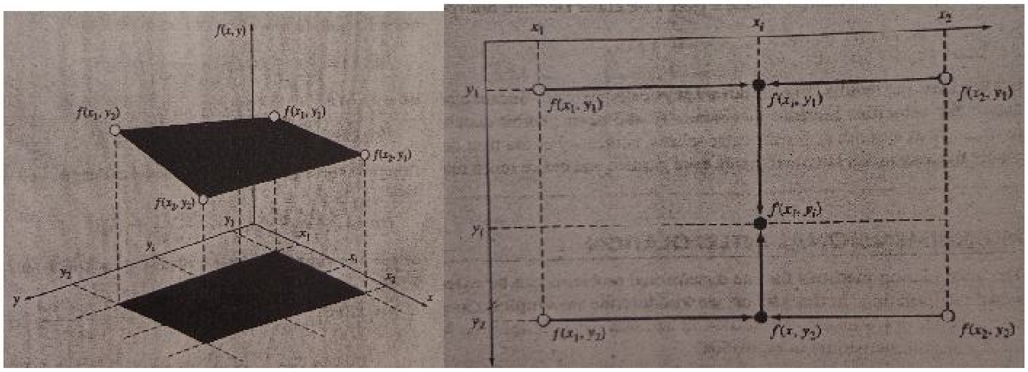


Figure 1. Graphical Depiction of two-dimensional bilinear interpolation

4 INPUT AND OUTPUT FOR BOREHOLE LOG

A MATLAB program was developed in this study that uses SPT-N values and grain size data from 15 borehole locations of Padma Bridge approach road at Janjira site. The boreholes were conducted along the chainage of approach road in a 20 km stretch with approximately 500 m spacing. The present study is aimed at generating borehole log at the intermittent locations. The modes of data input and output are described in the following section.

4.1 *Project Site*

The geology of the Padma River is of Holocene age and comprises mainly river borne alluvial silt, sand and gravels. Stratification within the geological profile are intermixed with depth with mainly silty fine sands to slightly silty fine to medium sands to about -70 m PWD where an unconformity occurs with the grain size becomes suddenly larger to include some fine to medium gravel within a silty fine to coarse sand matrix and rarely coarse gravel and cobbles are encountered. The granular strata is increasing more consolidated with depth to dense sand but increases to very dense sand or sand with gravels from about -60 m PWD. The very high sand density is indicative of high energy compaction from seismic activity whereas material above this level is less dense and has a liquefaction potential during seismic events. The gravel layer unconformity may be indicative of the previous immediately past glacial period with terrestrial sands, gravel and cobbles being present (Silva, et al., 2010). Fig 1 showing the project site located in Madaripur district of Bangladesh. The alignment of the Janjira approach road where boreholes were conducted is dipicted through Fig 3 to Fig 5. In Fig 3 red color marked indicates the location where the predicted borehole log is generated and compared with in-situ borehole log data.

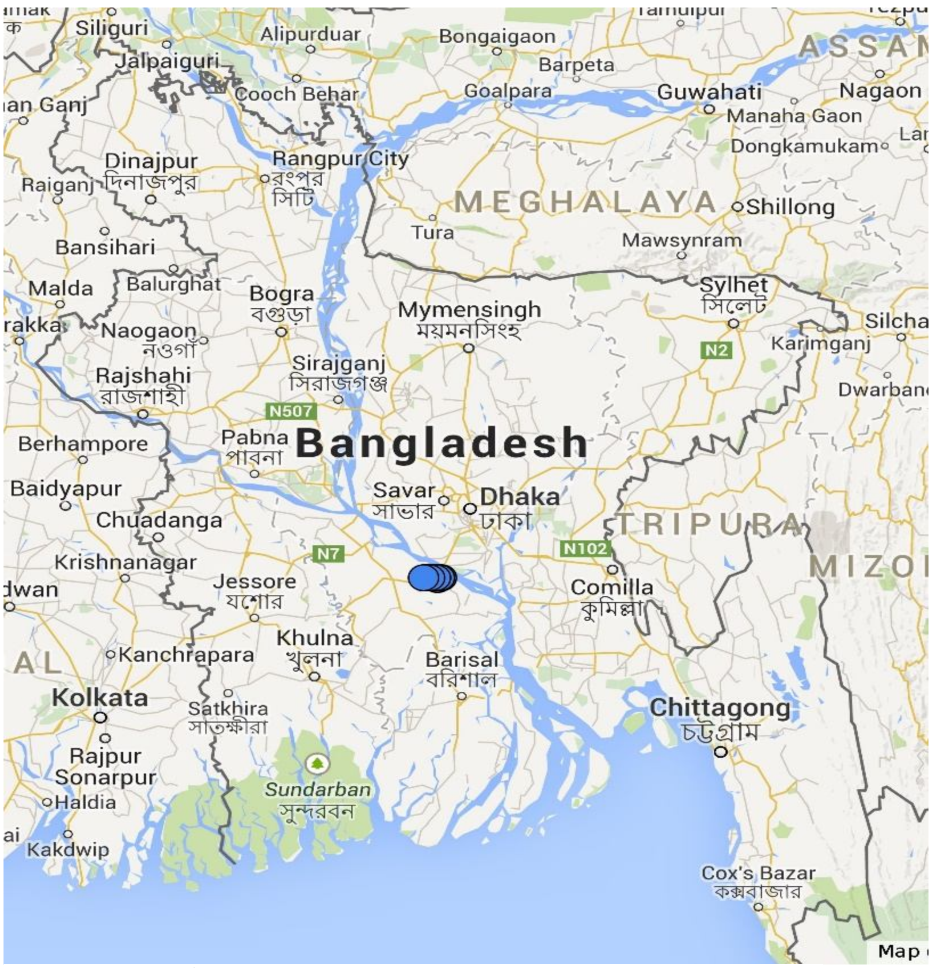
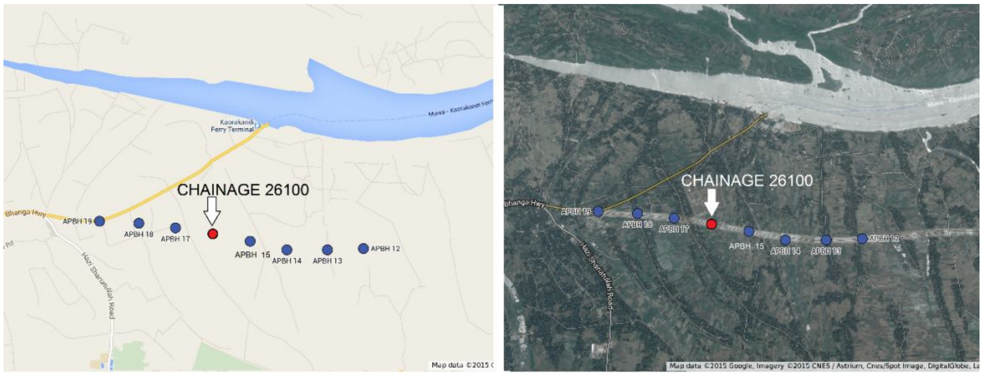


Figure 2. Location of site where boreholes were conducted



(a) Map View

(b) Sattelite view

Figure 3. 8 boreholes within chainage 24100 to 27600 at Janjira approach road

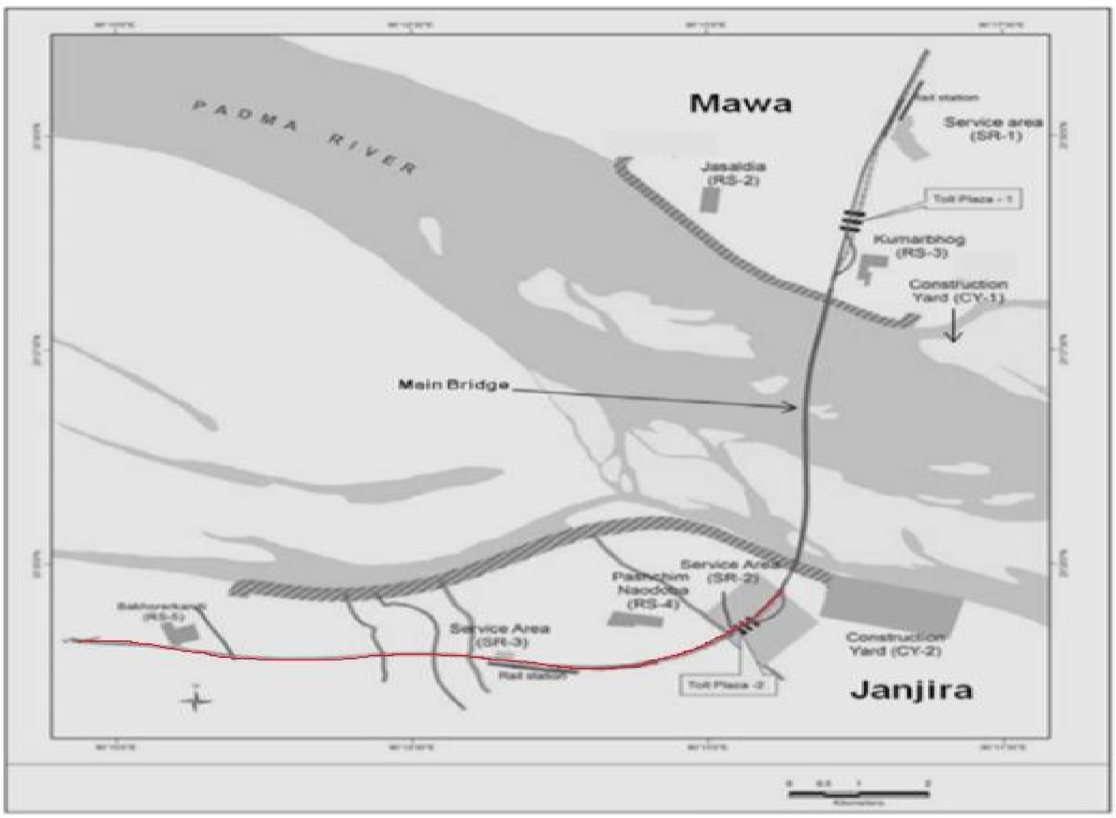


Figure 3. Janjira approach road alignment of Padma Multipurpose Bridge project

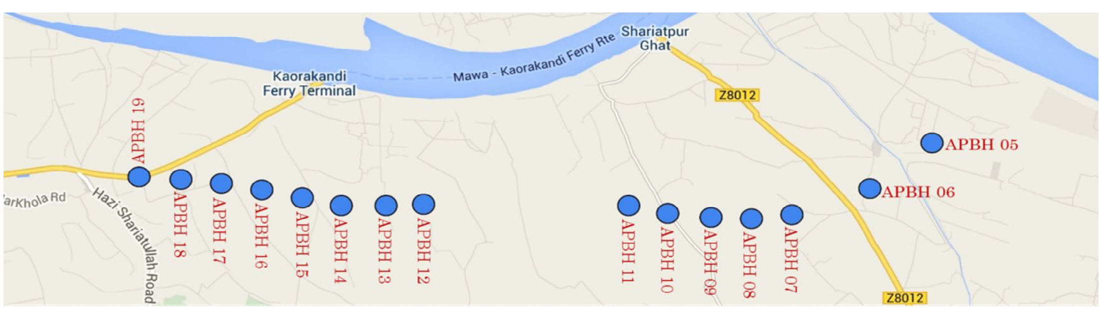


Figure 5. Janjira Approach Road with all 15 boreholes within Chainage 17600 to 27600

4.2 *INPUT Data*

SPT-N values, percent sand & percent fine with depth data was used as input and databases in spreadsheet. SPT-N values and grain size data of the boreholes are presented in Table 2 & 3 in Appendix. The in-situ borehole log is furnished in Fig 10 in Appendix.

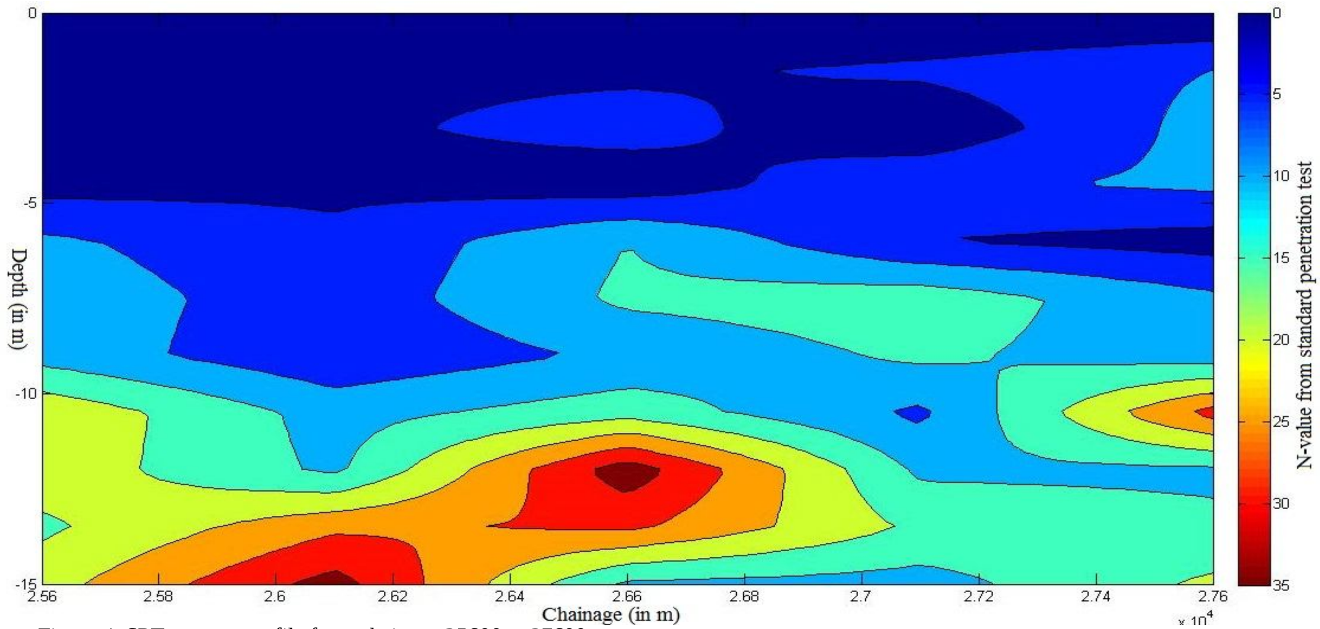


Figure 4. SPT contour profile from chainage 25600 to 27600

4.3 *OUTPUT Plots*

The MATLAB program developed in this study yields SPT contour matrix plot and grain size surface plot (Sarker & Abedin, 2015). Fig 6 represents SPT profile on the other hand Fig 7 represents Soil-profile along an alignment. From Fig 6 & 7, borehole log at chainage 26100 is extracted and depicted in Fig 8.

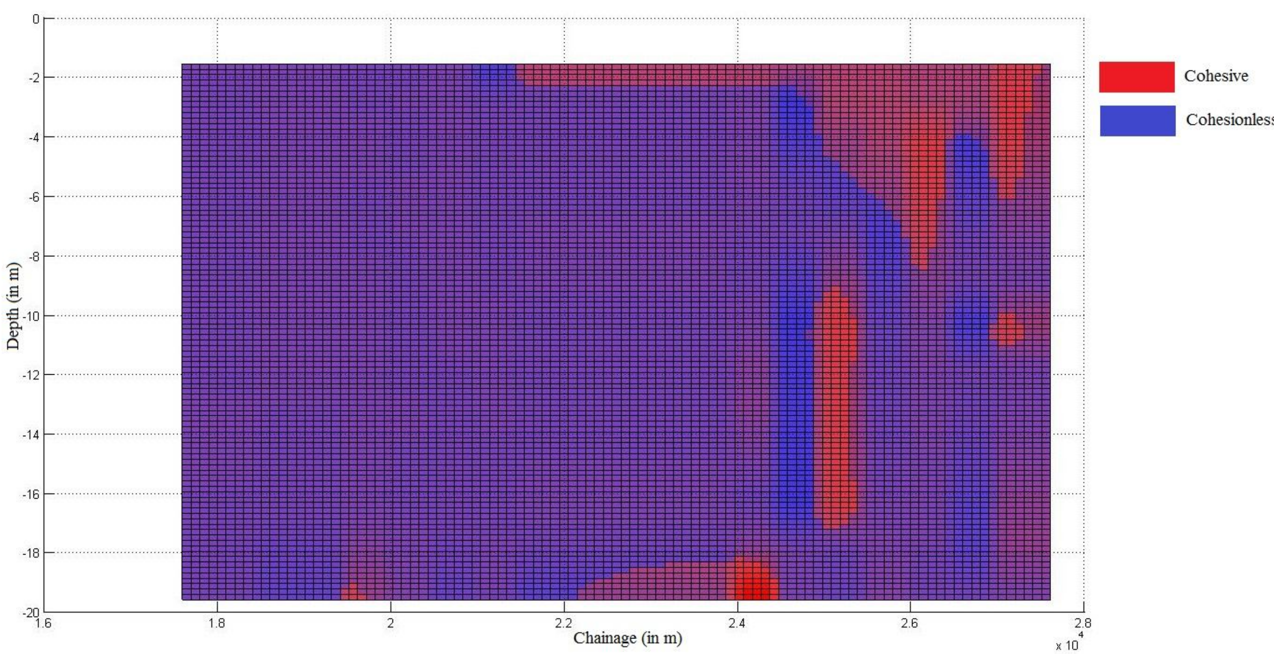


Figure 5. Vertical soil profile along with chainage up to 19.5 m depth

Project:		Project Number:		Client:		Boring No.	
Address:	Madaripur	Position:	Latitude (deg)	23.4009			
Chainage:	26100		Longitude (deg)	90.1735			
		Groundwater Depth (m):		Elevation(m) PWD:		Total Depth of Boring:	
		2.5		5.804		15	

γ (kN/m^2)	15
γ sat (kN/m^2)	18

Depth (meter)	Sample Type	Sample Number	Blow Counts (blows/foot)	Graphic Log	Soil Type	Consistency	Relative Density	Undrained Shear Strength (kPa)	effective stress
0			0		cohesive	very soft	N/A	0	0
1.5			5		cohesive	soft	N/A	46.2	23
3			6		cohesive	soft	N/A	48.8	42
4.5			3		cohesive	soft	N/A	39.9	54
6			13		cohesionless	medium	0.63	N/A	66
7.5			15		cohesionless	medium	0.64	N/A	79
9			12		cohesionless	medium	0.55	N/A	91
10.5			21		cohesionless	dense	0.7	N/A	103
12			31		cohesionless	dense	0.83	N/A	115
13.5			25		cohesionless	dense	0.72	N/A	128
15			19		cohesionless	medium	0.61	N/A	140
16.5									
18									
19.5									

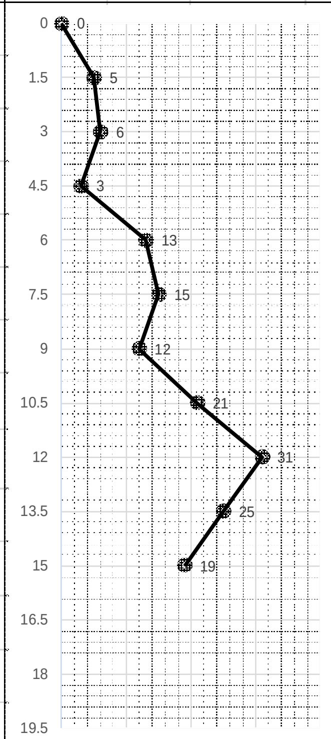


Figure 6. Typical predicted borehole log at Chainage 26100

5 CASE STUDY OF GEOTECHNICAL PROBLEM

Standard penetration Test is widely used in various parts of the world as an indirect method of subsurface insitu soil test. Extensive research has been done and there are established relationships bearing SPT. Foundation design parameters are obtained by correlation with SPT-N values. The site is at Janjira approach road of Padma Multipurpose Bridge Project which lies in Madaripur district shown in Fig 2. In the following section seismic soil liquefaction is evaluated as a case study of the project site.

5.1 *Seismic Soil Liquefaction*

Liquefaction and associated ground failures have been widely observed during high magnitude earthquakes. Liquefaction occurs generally due to rapid loading (e.g. seismic events) when there is not enough time for excess pore water pressure to dissipate by natural drainage. The increased pore water pressure transform granular materials from a solid to a liquified state. Shear strength of soil also decreased due to increase in pore water pressure. Generally Liquefaction is observed in loose, saturated, and clean to silty sand. The soil liquefaction depends on the magnitude of earthquake, peak ground accelaration, intensity and duration of ground motion, distance from the epicenter, site condition, grain size distribution e.g. fine content, hydraulic conductivity of soil layer, position of ground water table. As our site is located in flood prone area, (from Fig 2) considering the worst case scenario, to analyze the factor of safety against seismic soil liquefaction, ground water table is assumed to be at ground level.

The liquefaction potential index (LPI) states the severity of liquefaction and predicts surface prone to liquefaction and liquefaction damage. The level of liquefaction severity with respect to LPI as per Iwasaki et al. (1982), Luna and Frost (1998), and MERM (2003) is given in Table 4 in Appendix. The factors of safety against liquefaction (FS) and the corresponding liquefaction potential index (LPI) are determined by comparing the seismic demand expressed in terms of cyclic stress ratio (CSR) to the capacity of liquefaction resistance of the soil expressed in terms of cyclic resistance ratio (CRR) (Dixit, et al., 2012).

The liquefaction potential was estimated using actual borehole and predicted borehole data by simplified emperical procedure (Sarker & Ansary, 2015). Output plots are presented in Fig 9. Is was observed the liquefaction potential as estimated by predicted borehole data was slightly higher as compared to the value obtained for actual borehole data.

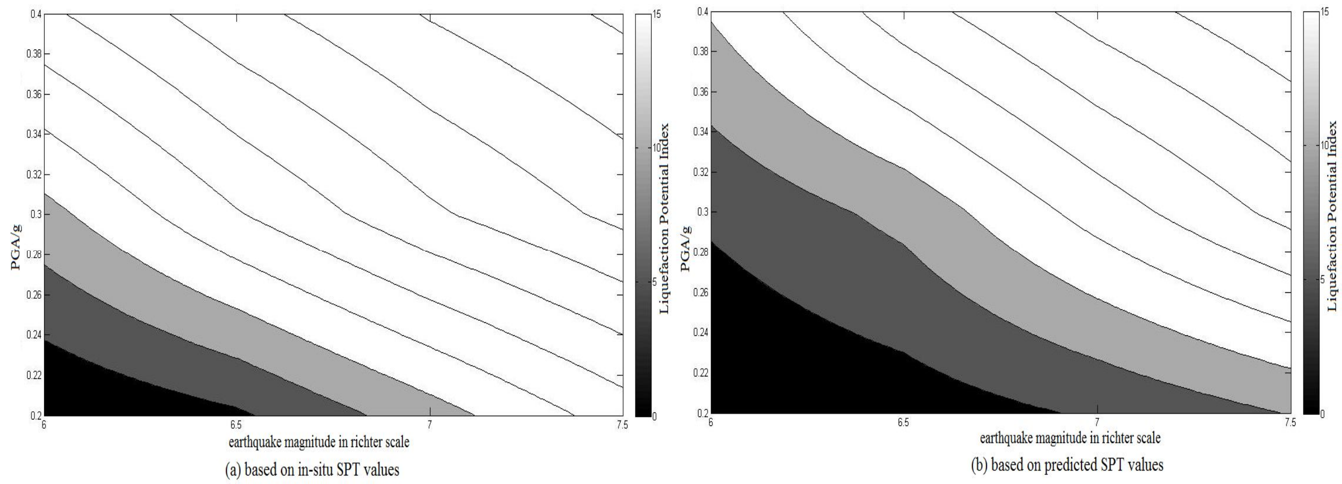


Figure 7. Liquefaction Potential Index for variable Peak Ground Acceleration & Earthquake Magnitude at chainage 26100

5.2 *Model Validation: Nepal Earthquake 2015*

The 2015 Nepal earthquake occurred on 25th April with a moment magnitude (M_w) of 7.8 and a maximum Mercalli Intensity of IX (Violent). A major aftershock of magnitude 6.7 M_w occurred on 26th April in the same region (Wikipedia, 2015). Its epicenter was approximately 830 km from our site and its hypocenter was at a depth of approximately 15 km. The earthquake was initially reported as 7.5 M_w by the United States Geological Survey (USGS) before it was quickly upgraded to 7.9 M_w and finally downgraded to 7.8 M_w.

An attenuation relationship of Peak Ground Acceleration for the earthquake is used for this study to calculate LPI (Ulusay, et al., 2004)-

$$\log PGA = 0.65M - 0.9 \log R - 0.44 \qquad (1)$$

where, M is the earthquake magnitude and R is the distance to epicenter in kilometers.
For earthquake magnitude of 6.7 and 7.8 estimated PGA are 0.02 and 0.12 respectively.

LPI was calculated and liquefaction severity was determined from Table 4 in Appendix for both in-situ and predicted values of SPT. Results are compared in Table 1.

Table 1. Liquefaction severity comparison

Magnitude	6.7	7.8
In-situ	None	Low
Predicted	None	Low

6 CONCLUSIONS

SPT can provide useful and reliable data and has become most popular tool in Bangladesh for geotechnical characterization of a site primarily due to its usability and cost effectiveness. In this study, a MATLAB computer software based mathematical model has been developed for in-situ and laboratory testing parameters in order to generate borehole log at intermittent locations of a site. Usually SPT-N value increases with depth. At chainage 26100 N-value remained constant till 4.5m depth, decreased after 6.5m and increased again from

10.5 m. Predicted borehole log also depicted similar results. So, the MATLAB model developed can predict an intermittent borehole log with reasonable accuracy. As the program yields grain size surface plots that may be used to identify soil profile. Validation of model is done by evaluating the factor of safety against liquefaction (FS) and corresponding liquefaction potential indices (LPI) for a seismic scenario (e.g. Nepal earthquake 2015) for the site using SPT-based semiempirical procedure. This study reveals that the susceptibility of liquefaction at a particular location depends on higher thickness of alluvium deposits and ground water table at shallow depth which can be evaluated using the predicted borehole log. The predicted borehole log, surface plot of soil-profile & LPI contour plots will help the geotechnical engineers to make decisions regarding soil improvement & foundation design as well as structural designers & city planners to develop seismic safety plans.

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APPENDIX

Table 2. SPT-N value input in spread sheet

	APBH 10	APBH 11	APBH 12	APBH 13	APBH 14	APBH 15	APBH 16	APBH 17	APBH 18	APBH 19
chainage-depth	21100	21600	24100	24582	25100	25600	26100	26600	27100	27600
1.5	5	2	5	5	5	5	4	4	6	10
3	5	6	17	17	3	4	4	7	1	12
4.5	33	5	10	9	13	3	4	2	9	11
6	31	24	6	10	14	11	6	15	5	3
7.5	30	19	8	11	12	13	7	16	18	11
9	9	23	11	26	16	13	6	11	16	12
10.5	12	32	12	22	14	24	13	18	9	32
12	13	35	22	24	9	23	14	38	14	14
13.5	14	20	24	18	4	19	29	31	19	16
15	11	18	23	21	5	23	37	14	13	21

Table 3. Grain size data input in spread sheet

				APBH-05		APBH-06		APBH-07		APBH-08		APBH-09		APBH-10		APBH-11		APBH-12	
Start	End	Avg	Chainage	17600		18600		19600		20100		20600		21100		21600		24100	
				Sand %	Fine %	Sand %	Fine %	Sand %	Fine %	Sand %	Fine %	Sand %	Fine %	Sand %	Fine %	Sand %	Fine %	Sand %	Fine %
1.35	1.8	1.35	D1	86	14	92	8	94	6	90	10	86	14	94	6	15	85	18	82
2.85	3.3	3.075	D2	93	7	83	17	94	6	92	8	93	7	94	6	87	13	86	14
4.35	4.8	4.575	D3	94	6	84	16	86	14	93	7	87	13					82	18
5.85	6.3	6.075	D4	91	9			92	8	89	11	92	8	92	8	91	9		
7.35	7.82	7.585	D5			84	16			88	12	88	12	94	6	90	10	94	6
8.85	9.3	9.075	D6	87	13			87	13			88	12			91	9	95	5
10.35	10.8	10.575	D7	88	12			89	11	91	9	87	13	90	10	92	8		
11.85	12.3	12.075	D8	90	10	85	15	92	8	94	6	91	9	90	10	91	9	63	37
13.35	13.8	13.575	D9	85	15	89	11	87	13	89	11	91	9	86	14			63	37
14.85	15.3	15.075	D10	89	11	90	10	87	13	90	10	89	11	88	12			84	16
16.35	16.8	16.575	D11			92	8	90	10	92	8	90	10	90	10	84	16		
17.85	18.3	18.075	D12	96	4	95	5	67	33	92	8			87	13	89	11		
19.35	19.8	19.575	D13			94	6							88	12	88	12		

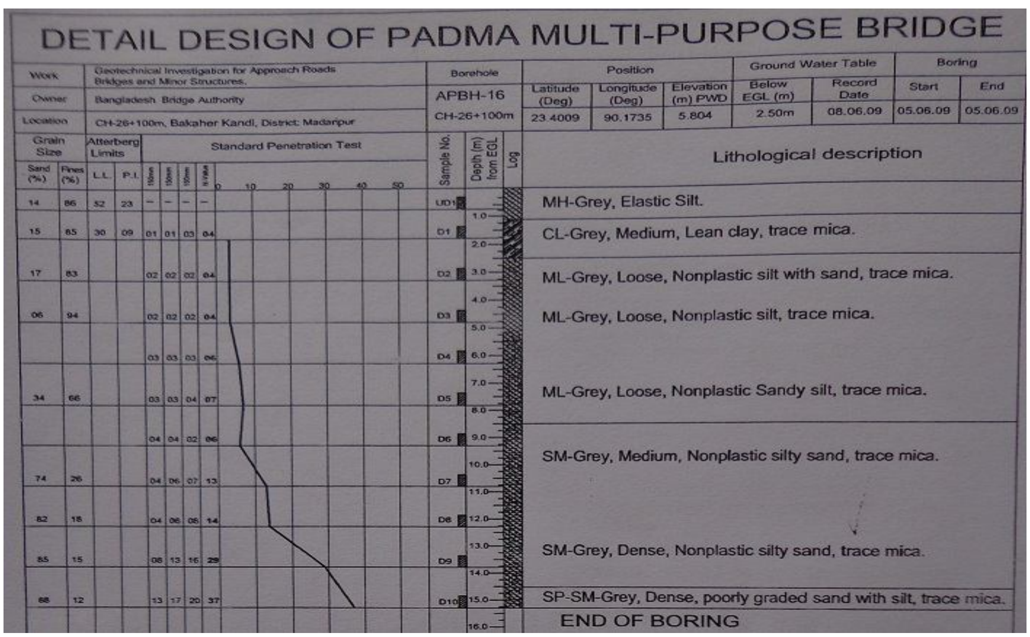

Figure 10. Borehole log at chainage 26100

Table 4. The level of Liquefaction severity

LPI	Iwasaki et al. (1982)	Luna and Frost (1998)	MERM(2003)
LPI=0	Very low	Very Little to None	None
0<LPI<5	Low	Minor	Low
5<LPI<15	High	Moderate	Medium
15<LPI	Very high	Major	High