Estimation of Standard Penetration Test (SPT) of Hilla City-Iraq by Using GPS Coordination

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ABSTRACT

In many parts of the world, The Standard Penetration Test (SPT) is still considered one of the most common *in-situ* tests to evaluate the strength of coarse grained soil and often the only *in-situ* test performed during a site investigation. In the present study, site characteristics of Hilla city are investigated by using *in-situ* (SPT) test by drilling five boreholes distributed over Hilla city with different depths (15-17) m below natural ground surface.

In this study, site characterization is treated as a task of function approximation of the large existing data from standard penetration tests of Hilla City, Iraq. The number of blows (N) from more than (950) field standard penetration tests has been collected with different depths from 110 boreholes spreaded over Hilla city, Iraq. Distribution and variation of N values of standard penetration tests at different depths are presented and discussed in this paper. Results from data analysis show that large variation of N values occurs at the upper layer of the soil and that variations decrease with increasing depth below ground surface. The results indicate that N values increase with increasing the depth to approximately 5 meters below natural ground surface, after that N values decrease with increasing the depth up to 8 m, then N values increase with increasing depth below 8m. Mathematical model is presented by using Statistica program to find N values (number of blows) of SPT test for Hilla city by using GPS coordination (Latitude (N) and longitude (E)) in any location of the study area. The results obtained show that the statistical model is accurate in predicting N values (number of blows) of SPT test in Hilla city and that the empirical equation can be depended on.

KEYWORDS: Hilla city, SPT, GPS , Coordination, Site characterization, Empirical equation.

INTRODUCTION

Site investigation and estimation of soil characteristics are essential parts of a geotechnical design process. Geotechnical engineers must determine the average values and variability of soil properties. As stated by Mair and Wood (1987), *in-situ* testing is becoming increasingly important in geotechnical engineering, as simple laboratory tests may not be reliable while more sophisticated laboratory testing can be time consuming and costly. One of *in-situ* testing methods is the Standard Penetration Test (SPT). SPT is used to identify soil type and stratigraphy along with being a relative measure of strength.

SPT, developed in the United States, is a well established method of investigating soil properties such as bearing capacity, liquefaction,… etc. As many forms of tests are in use worldwide, standardization is essential in order to facilitate the comparison of results from different investigations, even at the same site

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(Thorburn, 1986). The quality of the test depends on several factors, including the actual energy delivered to the head of the drill rod, the dynamic properties of the drill rod, the properties of the soil, the method of drilling and the stability of the borehole. Detailed description and interpretation of the SPT is given elsewhere (e.g., Seed et al., 1975; Marcuson and Bieganousky, 1977; Skempton, 1986; Liao and Whitman, 1986; Clayton, 1995), but it should be noted that the N value is related to the vertical resistance to penetration.

SPT is currently the most popular and economical means of obtaining subsurface information. As stated in Bowles (1997), 85–90% of conventional foundation design in North and South America is made using SPT. SPT, with its ease of performance and extensive correlation with parameters used in foundation design, is the prevalent method in evaluating the allowable bearing stress for foundation design. It is a routine part of almost every soil exploration program as one of the principal steps (Durgunoglu and Togrol, 1974).

According to the unavailability of equipment and also financial and time limitations in a project, in many cases various types of relationships may be needed to estimate the geotechnical parameters from the values extracted from the *in-situ* tests. One of these important parameters is bearing capacity of the soil which could be estimated from *in-situ* tests such as standard penetration test.

Standard Penetration Test (SPT) is used to determine the density of granular strata and correlate the undrained shear strength of cohesive soils. SPT is a frequently used and accepted method of empirically determining soil strength and calculating the bearing capacity and settlement of granular soils.

The present study area, Hilla city, Iraq, is investigated, for the first time, to estimate site characterization of the city that can be used as potential input for designing structures by city planners, civil and geotechnical engineers. In the present study, we have analyzed site responses of 105 boreholes at different locations in Hilla city in addition to five boreholes selected around Hilla city as shown in Figure 1. We evaluated the site characterization during SPT. It is so because SPT is an efficient geotechnical tool that can shed light on the soil characteristics of the study area.

BACKGROUND

SPT was introduced in the USA in 1902 by the Raymond Pile Company. The earliest reference to an SPT procedure appears in a paper by Terzaghi in 1947. The test was not standardized in the USA until 1958. It is currently covered by ASTM D1586-99 and by many other standards around the world (Robertson, 2006). SPT is one of the simplest, cheapest and most widely used tests used in many geotechnical projects worldwide. SPT is used for calculating static and dynamic properties of coarse-grained soils such as the internal friction angle (Ø), relative density (Dr), bearing capacity and settlement, as well as shear wave velocity (vs) of soils and liquefaction potential. Even though SPT was originally developed for coarse-grained soils and it has been applied to fine-grained soils to estimate engineering properties such as undrained compressive strength (qu), undrained shear strength (Su) and coefficient of volume compressibility (mv). However, its applicability for fine-grained soils is still argued (Sirvikaya and Toğrol, 2002).

The Standard Penetration Test consists of driving the standard split barrel sampler a distance of 460 mm into the soil at the bottom of the boring, counting the number of blows to drive the sampler the last two 150 mm distances (to obtain the N number) using a 63.5 kg driving hammer falling free from a height of 760 mm (Bowles, 1997). The boring log shows refusal if 50 blows are required for any 150 mm increment, 100 blows are obtained for a 300 mm increment or 10 successive drops produce no advance. SPT data have been used in correlations for unit weight, relative density, angle of internal friction and unconfined compressive strength (Kulhawy and Mayne, 1990).

However, it is recommended that the measured N value is standardized by multiplying it by the ratio between the measured energy transferred to the rod and 60% of the theoretical free-fall energy of the hammer (Bowles, 1997; Aggour and Radding, 2001).

Schmertmann (1979) provided valuable insight into the mechanics of the Standard Penetration Test. Schmertmann (1979) illustrated that the Standard Penetration Test is a combination of dynamic end bearing and side resistance test. That is, both end bearing and side resistance must be overcome in order for the sampling barrel or split spoon to advance into the ground. By comparison with parallel results from a mechanical friction cone, Schmertmann was able to demonstrate that the contribution of side resistance and end resistance to the advance of the spoon was a function of soil type.

Zekkos et al. (2004) studied the reliability of shallow foundation design using SPT test. The results of reliability analysis show that the factor of safety approach can provide an impression of degree of conservatism that is often unrealistic. The reliability-based approach provides rational design criteria, accounting for all key sources of uncertainty in the foundation engineering process and thus should be the basis of design.

Lutenegger (2008) showed that the SPT provides three numbers that can be used to evaluate soil properties through an analysis to illustrate how the incremental blow counts may be used to obtain more information from the test.

Hooshmand et al. (2011) used SPT to investigate the strength and deformation characteristics of Tabriz marls and their stress–strain behavior were investigated by various *in-situ* and laboratory tests. In order to study the deformation behavior of these marls, various experiments were used such as the pressure meter test, Plate Loading Test (PLT), seismic wave velocity test, uniaxial compression test and Standard Penetration Test (SPT).

Obiefuna and Adamu (2012) presented an assessment of the geological and geotechnical parameters in Wuro Bayare area of northeastern Nigeria. The results indicated that soils are poorly to well-sorted, soils have moderate to high plasticity, slight dry strength and are easily friable. From geotechnical analysis results, recommendations for erosion control were given, such as; construction of drainages, grouting concrete rip-raps and afforestation.

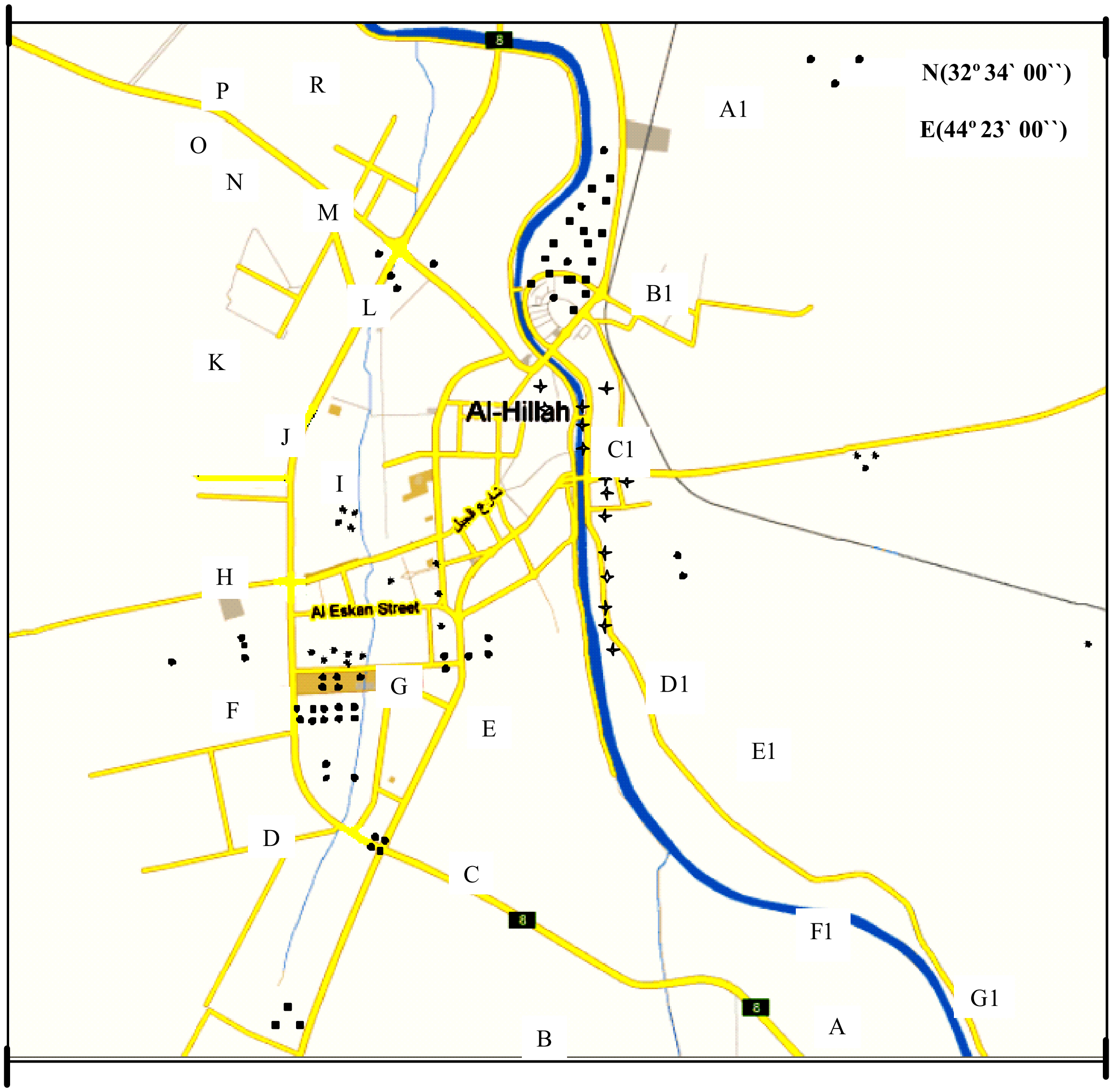
Site Description and Map of the Study Area

Iraq is located between two latitudes (N 29º 5´) and (N 37º 15´) and between two longitudes (E 38º 45´) and (E 48º 45´) (Buringh, 1960), while the site of study area is located in Babylon Governorate, Hilla city, between two latitudes (N 32º 34´ 00″) and (N 32º 25´ 00″) and between two longitudes (E 44º 23´ 00″) and (E 44º 31´ 00″). The site which is located southern of Baghdad (100km) is part of Quaternary sediments. The site in general is a flat area. The locations of the boreholes were distributed over the site. A general map of study area (from Google maps), locations of boreholes with different depths of boring and the coordination of study area (latitude (N) and longitude (E)) are shown in Figure (1).

Brief Geological History of the Steady Area

Hilla City in Babylon Governorate is part of a flood plain region, which represents the recent surface formation of Iraq geology, since it contains the recent alluvial sedimentation deposit from the two rivers, Tigers and Euphrates.

The majority of soil profile of Hilla city consists of silt-clay to clay -silt with a trace of sand, especially for shallow depths. After 6 m depth below natural ground surface, the amount of sand content increases and becomes more effective like clay and silt in most places of the study area. Also, we noted that the effect of sand decreases after 8 m depth below natural ground surface and the majority of soil profile consists of silt-clay to clay-silt in most places of the study area.



N(32° 25` 00``)
E(44° 23` 00``)

N(32° 25` 00``)
E(44° 31` 00``)

Depth of Boreholes
- BH 10 m Depth
- BH 15 m Depth
- BH 12 m Depth
- BH 20 m Depth

Figure 1: Satellite map of Hilla city with locations of boreholes and GPS coordination

METHODOLOGY

The scope of work of the study includes reviewing pervious geotechnical and environmental studies of the city, conducting additional test pit explorations in areas not previously explored and presenting our findings. Five boreholes were drilled in addition to 105 borings as a part of a soil investigation program in Hilla city, the depths of the borings ranged between 10, 15 and 20 m below natural ground surface. The groundwater level generally ranged between 0.2 and 0.5 m below natural ground surface, but in some boreholes it was as high as 1–2 m below natural ground surface and in others it was not encountered.

Statistical analyses were carried out by Statistica program, where graphs and regression lines were drawn and related equations were obtained. R-squared (R^2) values for each regression line were also provided as these are statistical measures of how well a regression line approximates real data points; e.g. an R-squared value of 1.0 indicates a very good fit. The present study was carried out in four phases as shown below.

Phase One: Reconnaissance Phase

The scope of work of this phase includes collecting available information from pervious geotechnical studies, finding locations of five boreholes in Hilla city and getting GPS coordination (latitude (N) and longitude (E)) by using GPS Garman CX76 type (accuracy**:** position: < 10 meters and velocity: 0.05 meter/sec steady state) . From pervious geotechnical studies, the total number of boreholes is (110) boreholes, (33) boreholes already have GPS coordination of each borehole included in each study and (72) boreholes are without any coordination , therefore, GPS coordination was taken for 74 boreholes by visiting thirteen different areas in Hilla city (each area has a group of boreholes) and getting GPS coordination by finding approximate location of each borehole using GPS instrument (Garman CX76). Finally, a general map of Hilla city with boreholes and GPS coordination is shown in Fig. (1).

In the present study, the total number of boreholes is (110) boreholes distributed over Hilla city; (105) boreholes from previous geotechnical studies and (5) boreholes from the present study. Distribution of boreholes in Hilla city is shown in Figure (1), and the total depth of boring of each borehole and the number of boreholes are presented in Tables (1) and (2).

Phase Two: Field Work

During this phase, the work is divided into two parts:

A- Allocation of Study Area and Boreholes

The scope of work includes finding suitable locations and drilling work for the boreholes. Five boreholes have been drilled to a depth of 15 m below natural ground surface by using mechanical machine type Flight Augers drill method with (10cm) diameter. Hydraulic drilling rig machines mounted on a four-wheel vehicle were used for drilling the boreholes adopting rotary bit drilling method. The method of drilling was in accordance with procedures specified in the code of practice for site investigation the American Society for Testing and Materials (ASTM D-1452-D5783) used for taking the samples.

The depth of boring extended to underneath the zone of influence of significant foundation pressure to materials that were relatively incompressible.

B- *In-situ* Testing, Standard Penetration Test (SPT)

During the drilling operations, standard penetration tests were performed in accordance with ASTM D-1586 at regular intervals between (1.5-2)m depth below natural ground surface using Standard Penetration Sampler to evaluate the relative density/consistency of the soils.

33 standard penetration tests were conducted in five boreholes in different locations and at different depths in Hilla city. All tests were conducted under water table in the present study and from results of previous studies. The penetration tests were performed by initially driving the sampler with a 50 mm external diameter thick-walled tube (split spoon sampler) into the bottom of the borehole using a 63.5 kg hammer falling freely from a height of 760 mm (automatic trip-hammer falling). The sampler was driven the first 150 mm to penetrate loose soil cuttings and “seat” the sampler. Thereafter, the sampler was progressively driven an additional distance of 300 mm with the results recorded as the corresponding number of blows required “N” value to advance the sampler 300 mm.

Phase Three: Analyzing the Results of Previous Geotechnical Studies

The scope of work includes analyzing large existing data from previous geotechnical studies of Hilla city. More than 950 field SPT (N) values have been collected with different depths from 110 boreholes spread over an area in Hilla city. The locations of boreholes are shown in Figure (1).

Previous geotechnical studies used in the present study are taken from different places; Babil Construction Laboratory, Consultant Bureau of Engineering College - Babylon University, Consultant Bureau of Science College - Babylon University and Consultant Bureau of Engineering College - Baghdad University.

Phase Four: Mathematical Model

Data analysis of N values of standard penetration tests depends on GPS coordination (latitude (N) and longitude (E)) of each borehole of those distributed over Hilla city with different depths under natural ground surface.

Mathematical model is derived to simplify the analysis from a hard, complicated analysis to more simple equations which take into account all parameter requirements. The mathematical model provides a tool to estimate N values at all locations of Hilla city.

The results obtained from *in-situ* field standard penetration tests of five boreholes in addition to the results of 105 boreholes distributed over Hilla city with a total of 950 N values of SPT with different depths are used together with the computer package (STATISTICA) to derive the mathematical model (equation) for predicting N values of SPT over Hilla city.

RESULTS AND DISCUSSION

In the present study, the area of study (Hilla city) is divided into two sides depending on the main flow in the middle of the city, separating Hilla city into two sides, Hilla site 1and Hilla site 2, as shown in Figure (1).

Hilla Site 1

Total number of boreholes in is Hilla site 1is (62) boreholes distributed over the site, (59) boreholes from previous studies and (3) boreholes from the present study. Distribution of boreholes in the site is shown in Figure (1). The total depth of each borehole and the number of boreholes in the site are presented in Table (1).

Table 1. Number of boreholes with depths for Hilla site1

Total depth of borehole below natural ground surface (m)	10	12	15	20	
Total number of boreholes in the site	22	12	20	8	Total boreholes = 62

From the analysis of the results of the present study and previous studies, the average values of standard penetration tests of soil at Hilla site 1with depths are presented in Fig (2). All tests are conducted under water table in the present study and from results of previous studies. The results indicate a wide variation between N values from standard penetration tests at same depth. This variation may be because of using different hammer types. In the present study, tests were conducted by using automatic trip-hammer falling. In previous studies, tests were conducted by using hand-lifted hammer in some boreholes and automatic trip-hammer in other boreholes. Therefore, N values varied widely at the same depth.

Generally, results indicate that N values increase with increasing the depth to approximately 5 meters below natural ground surface, after that N values decrease with increasing the depth up to 8 m, then N values increase with increasing depth below 8m under natural ground surface.

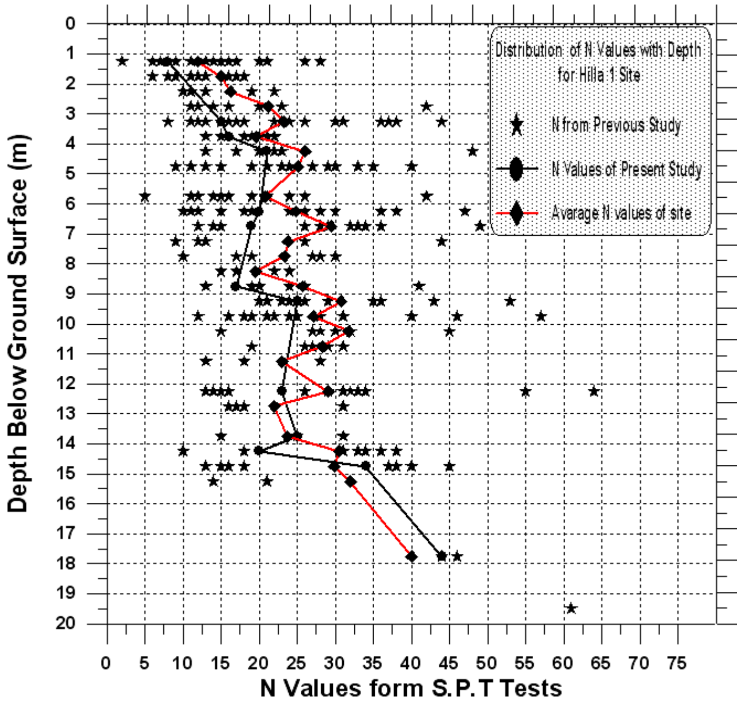


Figure 2: Average N values of tests with different depths in different locations for Hilla site 1

Table 2. Number of boreholes with depths for Hilla site2

Total depth of borehole below natural ground surface (m)	**10**	**12**	**15**	**20**	
Total number of boreholes in the site	**8**	**14**	**10**	**16**	**Total boreholes = 48**

In order to attempt to find the soil stratification layer of Hilla city, variations of N values with different depths and locations are studied. Also, comparisons between the results from the present study and previous studies are made as shown in Figure (3). The results indicate wide differences between N values near ground surface, especially for depths (0.5-2.5) m below ground surface, indicating that the soil layer does not have the same properties from strength side, because most of surface layer consists of filling materials added to the surface. From (2.5-5) m depth, results of N values of the tests converge in most of the area in Hilla city and that indicates that the soil layer has the same properties from strength side. From (5.5-7) m depth, the differences between N values are found because most of the soil layer is sand in some places and silty clay in other locations of Hilla city at these depths. Beyond 8 m depth, the variations between N values become less and convergence between them is found because most of soil layers consist of clay-silt to silt-clay and that indicates that the soil layers after 8 m depth approximately have the same properties from strength side and N values increase with increasing the depth below natural ground surface.

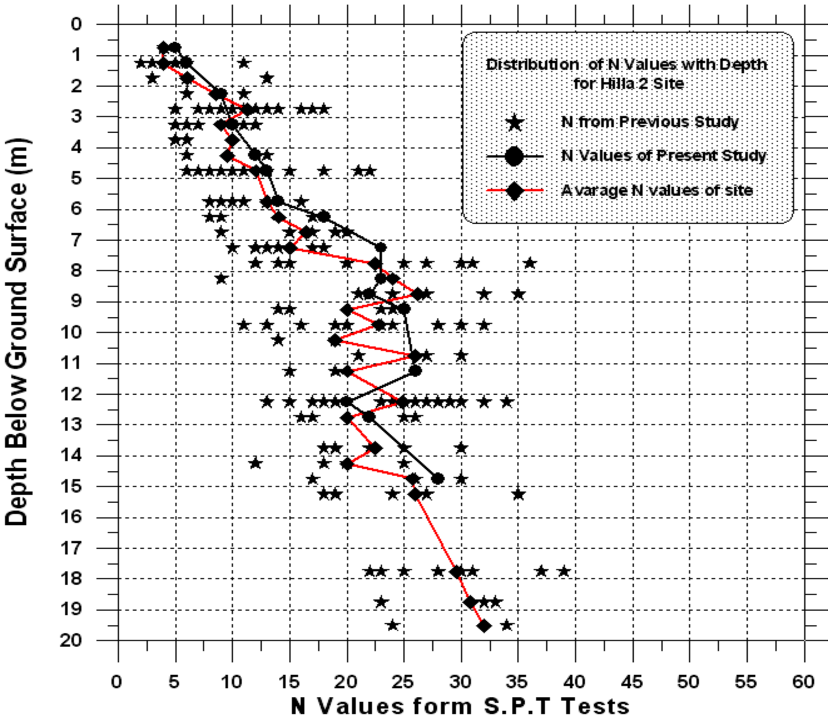


Figure 3: Average N values of tests with different depths at different locations in Hilla site 2

Hilla Site2

Total number of boreholes in Hilla site 2is (48) boreholes distributed over the site, (46) boreholes from previous studies and (2) boreholes from the present study. Distribution of boreholes in the site is shown in Figure (1). The total depth of each borehole and the number of boreholes in the site are presented in Table (2).

From analysis of the results of the present study and previous studies, the average values of standard penetration tests of soil of Hilla site 2 with depths are presented in Fig. (4). All tests are conducted under water table in the present study and from results of previous studies. The results indicate a variation between N values from standard penetration tests at same depth, but less than in Hilla site 1. This variation may be because of using different hammer types. In the present study, tests were done by using automatic trip-hammer falling. In previous studies, tests were conducted by using hand-lifted hammer in some boreholes and automatic trip-hammer in other boreholes. This may be a main reason in the variation of N values at same depth below natural ground surface. Generally, results indicate that N values increase with increasing the depth to 9 meters below natural ground surface. After that, N values decrease with increasing the depth up to 12.5 m, then N values increase with increasing depth below 12.5 m depth under natural ground surface.

In order to attempt to find the soil stratification layer of Hilla city, variations of N values with different depths and locations are studied. Also, comparisons between the results from the present study and previous studies are made as shown in Figure (5). The results

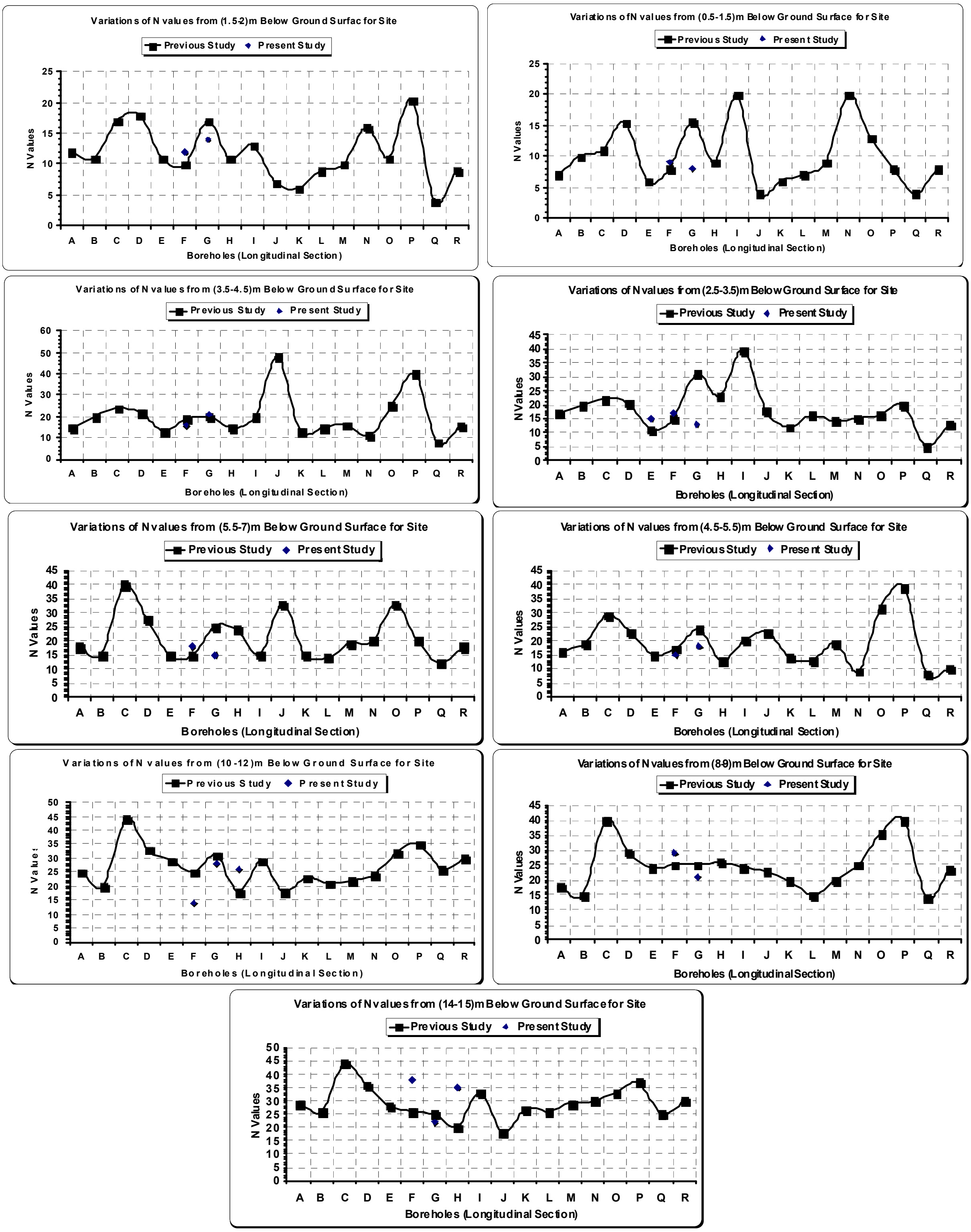


Figure 4: Average values of number of blows (N) from tests with different depths and locations for Hilla 1 site

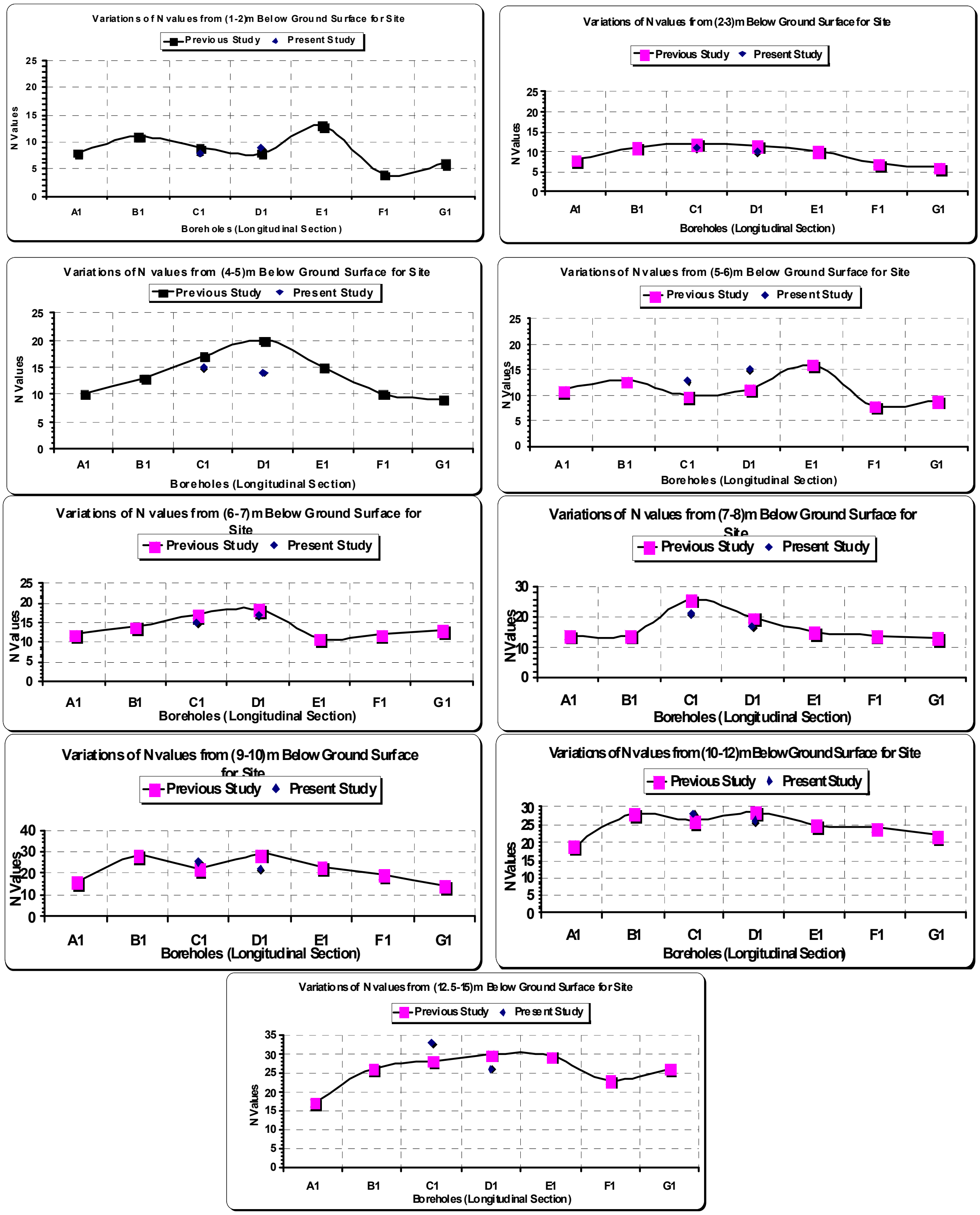


Figure 5: Average values of number of blows (N) from tests with different depths and locations for Hilla 2 site

indicate wide differences between N values near ground surface, especially for depths (0.5-2) m below ground surface indicating that the soil layer does not have the same properties from strength side, because most of the surface layer consists of filling materials added to the surface. At (2-4) m depth, results of N values converge in most of the locations of Hilla site 2and that indicates that the soil layer has the same properties from strength side. At (4-6) m depth, differences between N values are found because most of the soil layer is sand in some places and silty clay in other locations of Hilla city at these depths. After 9 m depth, the variation between N values become less and convergence between them is found because most of the soil layer consists of clay-silt to silt- clay and that indicates that the soil layers after 9 m depth approximately have the same properties from strength side and N values increase with increasing the depth below natural ground surface.

Formulation of the Mathematical Model

A general equation (a mathematical model) is formulated for the prediction of N Values of tests for Hilla city depending on GPS coordination (latitude (N) and longitude (E)). This equation is valid only for the area of study (Hilla city) which is located between two latitudes (N 32º 34` 00``) and (N 32º 25` 00``) and between two longitudes (E 44º 23` 00``**)** and (E 44º 31` 00``).

The computer package (STATISTICA) is used to make the analysis for the equation through a non-linear regression analysis.

The results of the present study are obtained by *in-situ* SPT field tests from five boreholes and from collecting and analyzing data from previous studies. More than 950 cases of test at different depths are adapted into a statistical analysis to derive the equation. This equation is functional with depths and GPS locations as shown below:

$$SPT(N)_{Values} = C_1 * D + \left[\frac{32 + (N_2)^{C2} + C_3 * (N_3)}{44 + (E_2)^{C4} + C_5 * (E_3)} \right]$$

where:

D: Depth below natural ground surface (in meters).

N_2: GPS coordinate (latitude (N)) in minutes.

N_3: GPS coordinate (latitude (N)) in seconds.

E_2: GPS coordinate (longitude (E)) in minutes.

E_3: GPS coordinate (longitude (E)) in seconds.

The values of the equation constants (C_1, C_2,…, C_5) that have been found are shown in Table (3). It is found that (R^2) of the proposed equation is about (81%) which means that the equation is dependable.

Table 3. Values of the equation constants

Factor	C_1	C_2	C_3	C_4	C_5	No. of cases = 950
Value	**1.382**	**2.3**	**0.95**	**1.389**	**0.576**	**R^2 = 81 %**

CONCLUSIONS

SPT can provide useful and reliable data and has become the most popular tool for geotechnical characterization of a site primarily due to its simplicity and relatively low cost.

In the present study, number of blows (N) have wide differences and variations between Hilla site 1and Hilla site 2, especially for shallow depths, and these differences decrease with increasing the depth below natural ground surface. Also, Hilla site 2 has lower values of the number of blows compared to Hilla site 1.

Generally, number of blows (N) generally increases with increasing depth below natural ground surface up to approximately 6 m, then it decreases with increasing depth up to 8 m below natural ground surface, and after 8 m depth, number of blows (N) increases with increasing depth below natural ground surface.

Finally, a general simple is derived equation to compute the number of blows (N) ant any location within Hilla city (study area) depending on GPS coordination (latitude (N) and longitude (E)).

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