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Research Article

A Comparative Analysis of Bearing Capacity of Pile Foundations Using SPT Measurements for Nasiriyah Soil

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ABSTRACT

Pile foundation is essential in structures including buildings, storage tanks, and bridges especially in geotechnical applications. The bearing capacity of pile foundations must be evaluated, and evaluating this usually involves the use of the static load pile testing method which is however expensive. Another approach is based on data derived from field tests including the Standard Penetration Test (SPT), which is normally conducted during investigation of the site. Nevertheless, there is no common technique to analytically determine the bearing capability of pile foundations because of the complexities in pile-soil-pile interaction. Different empirical methods that are developed from SPT results are widely used for estimation of the bearing capacity but the result using this approach could be different from that of the other methods of design approach. This paper analyses seven empirical equations derived from SPT for the estimation of pile foundation-bearing capacity. The data considered in this work is a part of the site investigation for water intake in Nasiriyah for the water intake project, which is provided by SPT test results of six boreholes. The nature of the subsoil was estimated from SPT data and was categorized according to disturbed and samples. The number of blows from the SPT was adjusted before performing the computational analysis with them. The results confirmed that it expressed the greatest of all bearing capacities consistently when applying it to six of the SPT results. However, other methods resulted in the lowest bearing capacity values for the piles. Some methods produced mid-range values, while others yielded higher values compared to the conservative estimates provided by certain methods. Based on this, it can be concluded that the method with the lowest values serves as a more conservative approach for estimating pile-bearing capacity.

1. INTRODUCTION

Some of the methods by which the bearing capacity of pile foundations can be determined are static analysis, dynamic analysis, dynamic testing, pile load testing and in-situ techniques including the Standard Penetration Test (SPT). Dynamic testing is preferable to static, performed by an experienced technician, and offers the bearing capacities after pile-driving. This method adapts and applies the wave mechanics handle-pile system as described in the research by Myerscough et al [1]. Pile load testing is best regarded as offering the most accurate prediction of bearing capacity due to its many demerits which include; high costs, long time consumption and the fact that piles have to be constructed in advance. Static analysis, implemented using the critical depth criterion, seems to be theoretically and experimentally rather weak.

Traditionally among these methods, the estimation of the bearing capacity of soil by using SPT is frequently implemented in case of pile foundation layout. Several empirical approaches have been put forward for this use, including those by [3]. These empirical equations predict the bearing capacity of the soil with the help of blows count in SPT [4]. These methods can produce varying results which underlines the need for searching for conservative, maximum and minimum estimation methods which are most appropriate for design Uses. A lot of studies have been done to assess these methods as some of them give low values and a few others give high values of bearing capacity with incorporation of ' 'factor of safety'.

However, no previous studies have applied these methods to the soils of Nasiriyah have been conducted before. Hence, the purpose of this study is to assess the applicability of these methods as well as assess their estimates of bearing capacity

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employing SPT data obtained from a site investigation carried out for a water intake project in Nasiriyah. The bearing capacity estimates derived from seven direct methods considering the number of blows registered during sound SPTs conducted at the project site are presented.

An initial idea of the soil profile is provided using data gathered through the SPT borehole samples taken. This study also compares the bearing capacity results from the various methods with those found in previous studies. The objective is to define conservative procedures and to find out which of the equations will give the minimum and maximum bearing capacity and the examination of the statistical fluctuation on these values. The results will prove useful in ascertaining the reliability of the direct methods in determining the bearing capacity of piles using the profile of the soil and the SPT values in Nasiriyah.

The site investigation for the water intake project by the use of SPT involved the following boreholes as indicated in Figure (a) below. The location of the site is about 55 kilometres northwest of Nasiriyah City. The test points for the site have been illustrated in the following Figure 1(b). This conforms with the requirement of the project as regards the distances between the boreholes. Only auger method was used in the drilling and all samples used in this study were subjected to ASTM D4220-95 method. The disturbed samples used in the determination of soil penetration resistance were tested in line with the American Society for Testing and Materials D421-85.

(a) (b)

Fig. 1. Locations of SPT test at a project site with 6 test points. (a) Location of boreholes (b) Site of the test points

2. GEOLOGIC DESCRIPTION OF THE SITE

Nasiriyah is in Babil Governorate in central-southern Iraq and the Mesopotamian Plain. The project site is not far from the Euphrates River, one of the two rivers that flow through Iraq. The depositional site is formed by the confluence of the Tigris and Euphrates Rivers located in a low-relief physiographic region. This region continues from the foreland basin of the Zagros fold-and-thrust belt [5]. It is identified that these two rivers stem from Turkey and then cross the basin from northwest to southeast.

Millions of tons of sediments have been delivered by the rivers into the floodplain area over the last 12000 years (12000 BP). This sediment is composed of silt, clay, and sand where; silt occupies 60 percent of the total sediments. The rest is made up of clay and sand." The silt and sand are for the most part dropped off in marshes, with the clay being transported to the Shatt al-Arab. For this reason, the soil elements in Nasiriyah are silt and clay and sand with the Silt is also apparent in the area.

3. STANDARD PENETRATION TEST (SPT)

Standard Penetration Test is one of the first blow count tests which is still in practice widely and has gained a global reputation. This type of construction is cheap and is widely applied in Iraq; most engineers love it because of its simplicity. The test is accorded international acceptance and is conducted by pushing a split spoon sampler, which has a diameter of 3 cm, into the soil with a standard hammer. The hammer weighs 63500 grams and is dropped from a height of 760 mm. The total strokes as measured and noted corresponds to the number of strokes needed to advance the sampler for penetration of every 15 cm.

SPT is used for the determination of the soil engineering characteristics from the disturbed samples obtained with a split spoon. Several correlations for use in calculating different engineering properties are available and a considerable amount of data is available worldwide. These correlations are based on the number of blow counts corrected values these give information on the stratification of the soil type and its engineering properties.

4. CORRECTION OF SPT

Such reasons as regard the depth, and number of blows for the same soil type profile are several and include the following: These factors include; Hammer efficiency Borehole size Rod length Sampling type Overburden pressure and Water table level of sampling, the overburden pressure, and the water table level by [6-10]. However, corrections need to be made to the raw SPT data to get better and good results.

$$N'_{60} = \frac{N\, C_H\, C_B\, C_s\, C_R\, C_N}{60} \qquad (1)$$

Where N_{60} is the number of blows computed to energy 60%
C_B = correction for borehole diameter
C_H = hammer efficiency (%)
C_s = sampler correction
C_R = correction for rod length
C_N = correction for overburden pressure
The value of these correction factors however can be obtained from [10, 11].
It is noteworthy that the dependence of the number of blows in sandy soils is highly sensitive to the effective overburden pressure. Thus it becomes necessary to modify this measured number of blows to a standard of the overburden pressure. As indicated in Table 1, there are several formulas suggested for this correction.

TABLE I. CORRECTION FORMULAS FOR SPT DUE TO OVERBURDEN PRESSURE EFFECT

Equation	Type of soil, and notes
$C_N = \left[\frac{1}{(C_p)}\right]^{0.5}$	
$C_N = \frac{2}{1+(C_p)}$	Normally consolidated fine sand
$C_N = \frac{3}{2+(C_p)}$	Normally consolidated coarse sand
$C_N = \frac{1.7}{0.7+(C_p)}$	For overconsolidated sand
$C_N = 0.77\log\left[\frac{20}{(C_p)}\right]$	$for\ \frac{\sigma'_o}{p_a} \geq 0.25$
$C_N = 1 - 0.25\log(C_p)$	
$C_N = \frac{4}{1+4(C_p)}$	For $\frac{\sigma'_o}{p_a} \leq 0.75$

Where p_a = the atmospheric pressure (=100 kN/m^2), and σ`$_o$ is the effective overburden pressure, $C_p$=σ`$_o$/p_a.

5. SOIL PROFILE FROM SPT CORRELATIONS

The data obtained from the Standard Penetration test (SPT) enables the determination of the soil profile. In the case of the field test, a disturbed sample is collected by hammering a split spoon sampler into the soil and extracting it afterwards to be extruded. However, the sample interrupts the natural formation of the soil and can be analyzed in the laboratory through sieve analysis of grain size distribution, hydrometer analysis, specific gravity, determination of organic content and Atterberg limits test.
In the context of the classification of clay soils, the nature of the soil can be depended on utilizing an index known as the consistency index. This index can be estimated using the following formula [12]:

$$CI = \frac{LL - w}{LL - PL} \qquad (2)$$

Where:
CI= Consistency index
w= Natural moisture content (%)
LL= Liquid limit
PL= Plastic limit

The consistency index is a useful parameter for assessing the behaviour of clay soils, helping to further refine the soil classification and understanding of its properties for engineering applications.

6. CONSISTENCY OF SOIL ACCORDING TO SPT

The standard penetration test blows cannot be relied on to determine the type of soil because different blow counts can represent similar types of soil. For instance, by using the BS 5930, a soil which received 8 blows could be categorized as loose sand, while using the Terzaghi et al. [13], the same soil could be categorized as firm clay. Hence, the best way of classification is first to determine the dominant soil type either clay or sand by the grain size distribution from the borehole test. Once we identify which of the mentioned types of soils is the primary type, ensuring that the other parameters such as consistency of the soil are identified from the proper table for sand or clay.

a) If the soil is identified as sand, the left side of Table 2 should be used.
b) If the soil is identified as clay, the right side of Table 2 is applied.

TABLE II. CONSISTENCY OF SOIL BASED ON NUMBER OF BLOWS FROM SPT TEST

Relative Density According to SPT	**Consistency of Clay (BS 5930)**	**Consistency of Clay (Terzaghi et al.)**
Blows/300 mm	**Relative Density**	**Consistency**
0-4	Very loose	< 2
4-10	Loose	2-4
10-30	Medium dense	4-8
30-50	Dense	8-15
>50	Very dense	15-30

7. APPROACHES TO ESTIMATING THE BEARING CAPACITY OF PILES

The bearing capacity of piles can be computed using two primary approaches. The first method relies on the mechanical characteristics of the soil that could be determined in laboratory tests or estimated from the data of field investigations. The second method is to utilize field test results of the like SPT blows to estimate the bearing capacity.

The use of soil parameters in the static analysis methods is associated with some degree of uncertainty, especially concerning the shaft resistance of both the cohesive and cohesionless soils. The uncertainty is contributed by the fact that the coefficient of the horizontal stress cannot be measured accurately. There is also uncertainty arising from the poor definition of the failure surface at the tip of the pile. Based on these considerations, for preliminary design, the methods most appropriate are either direct/indirect, which are based on field tests such as SPT. Research is currently underway to enhance the equations for empirical practice, particularly for bearing capacity estimated from SPT.

8. SPT-BASED BEARING CAPACITY OF PILES

The standard Penetration Test (SPT) is widely used among all in-situ tests designed to estimate the bearing capability of piles. Two main approaches are utilized to calculate pile-bearing capacity based on SPT: There are two broad approaches in organization development, the direct and the indirect.

1. Indirect Method: the angle of internal friction and the cohesion of the soil are estimated from correlations with the SPT. These parameters are then used in conventional bearing capacity equations for piles, derived from the classic bearing capacity equation which is:
2. Direct Method: Using the number of blows (N) obtained in the SPT test directly, the bearing capacity of the pile is determined through various empirical equations fixed to the direct method. This method is favoured since it does not require some additional correlations because this leads to errors resulting from the presence of many equations

Several techniques can be used to estimate the bearing capacity of piles and these are given in the following chapter in Table 3. From the table, the following are the seven methods applicable to both bored and driven piles in sand and clay. However, certain methods including those that have been developed by[14-18] are unique to sand soils.

TABLE III. SPT-BASED EMPIRICAL BEARING CAPACITY EQUATIONS FOR PILES

Method	Tip bearing (Qp)	Shaft resistance (Qs)	**Influence Zone**
[19]	$Q_p = mN_pA_p$ $q_p = 0.4p_a\ N_{60}\frac{L}{D} \leq 4\ p_a\ N_{60}$ Bored: 133N	$Q_s = n\overline{N}_sA_sD$ $f_{av} = 0.02\ p_a\ (\overline{N}_{60})$ Bored: 0.67N	m=400,000m = 400,000m=400,000 for driven piles, m=120,000m = 120,000m=120,000 for bored piles (N/m²)
	$Q_p = A_pq_p = A_pn_pN_p$ $n_p = \frac{K}{1.75}$ (MPa)	$Q_s = A_sLf_s = A_sL(n_sN_s)$ (kPa), $n_s = \frac{ak}{3.5}$,	n=2,000n = 2,000n=2,000 for driven piles, n=1,000n = 1,000n=1,000 for bored piles (N/m²)
[20]	$Q_p = A_pq_p = A_p\left(1+0.04\frac{D_b}{B}\right)N_p$ $\leq A_p(0.3N)$ in MPa	$Q_s = A_sLf_s = A_sL(n_sN_s)$	
[21]	$Q_p = 310\ N_1A_p$	$Q_s \approx 1.82(\overline{N}_{60})pL$	
[22]	$Q_p = A_pq_p = A_pn_pN_p$ $n_p = \frac{K}{1.75}$ (MPa),n_p= 0.06-2	$Q_s = A_sLf_s = A_sL(n_sN_s)$ (kPa), $n_s = \frac{ak}{3.5}$, N_s 2-4	
[22]	$Q_p = KN_pA_p$	$Q_s = \alpha(2.8N_s + 10)pL$	
[23]	$Q_p = A_pq_p = A_pn_pN_p$ (MPa) N_{gp} : the geometrical average of N values between 8D above and 4D below pile base, n_p =0.358	$Q_s = A_sLf_s = A_sL(n_sN_s)$	kb=0.325k_b = 0.325kb=0.325 for driven & bored piles in granular soil, kb=0.1k_b = 0.1kb =0.1 for driven piles in clay, kb=0.08k_b = 0.08kb=0.08 for bored piles in clay
[24]			ns=3.65ns = 3.65ns=3.65, kkk for sand (kPa)

9. RESULTS AND DISCUSSION

9.1. Soil Profile

From the results of the analysis of the soil obtained from the six boreholes, figure 2 below shows the composition of the soil at the site. For instance, Borehole S1 (BH1) illustrates that the bearing stratum is mainly clay soil .

1. First Layer: The upper soil layer includes clay which has penetrated up to a depth of 2.5 meters .
2. Second Layer: The second layer is the silt layer which goes down to 5 meters from the ground level under the clay layer.
3. Third Layer: After 5 meters, it is a clay formation layer .
4. Fourth Layer: About 8 meters, a sand layer appears.

These layers are not exceptional for many boreholes across the site. For example, Borehole S1 –S6 begins at around the 8th meter where the sand layer is found and Borehole S2 also indicates the sand layer around 13.5 meters. The whole log document showing the detailed stratigraphic differences and depths is graphically illustrated in Figure 2 below.

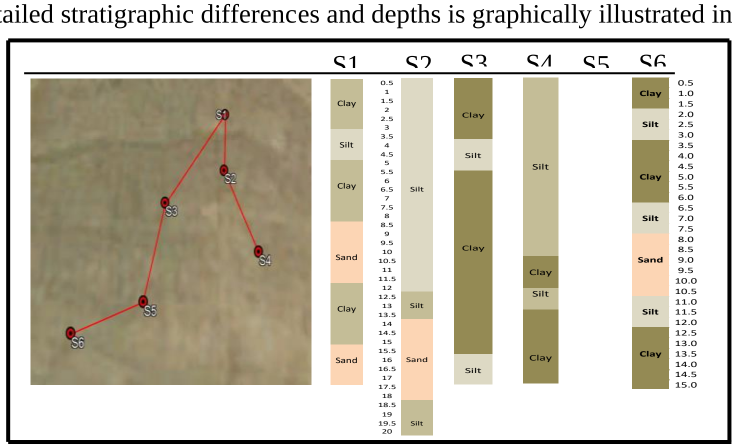

Fig. 2. The boreholes drilled in the site in addition to the location of these boreholes

9.2. Cross sections description

The soil distribution in the three boreholes is shown below in Figure 3 (a,b). The first identified layer is clay proceeding to 2.5m in Borehole BH1 and 1.5m in Borehole BH2. The second layer is the second highest silt layer, and it extends to 9 meters in Borehole BH2. The third layer of identification is below the silt; this forms the clay-holding soil and includes depths of 0 to 11 in borehole BH1. The fourth layer is an interval of sand detected in Borehole BH6, with a thickness of 1 meter. The soil appears to have a medium consistency similar to that of a grey silt in some parts while it becomes stiffer clay at some deeper levels. It is because of this long distance between the boreholes that the soil layer depth differs from borehole to borehole. The main solid phases of Borehole BH5 include silt and clay with a thin sand horizon at the base and the termination of Borehole BH4. The clay and silt layers are present in all three boreholes and are continuous but due to variation in thickness, this may pose some problems to geotechnical engineers in the evaluation of the bearing capacity of soil and its suitability for pile foundation.
Therefore, the detailed soil stratigraphy along a section passing through Boreholes 4, 5 and 6 is presented in Figure 3 (a,b). The main soil types identified are SILT and CLAY with only a thin layer of SAND at the toe of Borehole 6 and at the last twenty feet of Borehole 4. Borehole 5 reached down to 20 meters and there was steady interfinging of silt and clay layers. These represented the varying thickness of the soil layers to a depth which is important to geotechnical analysis as well as influencing the position of the sand layer and should not be neglected in the design of structures including the calculation of the bearing capacity of piles.

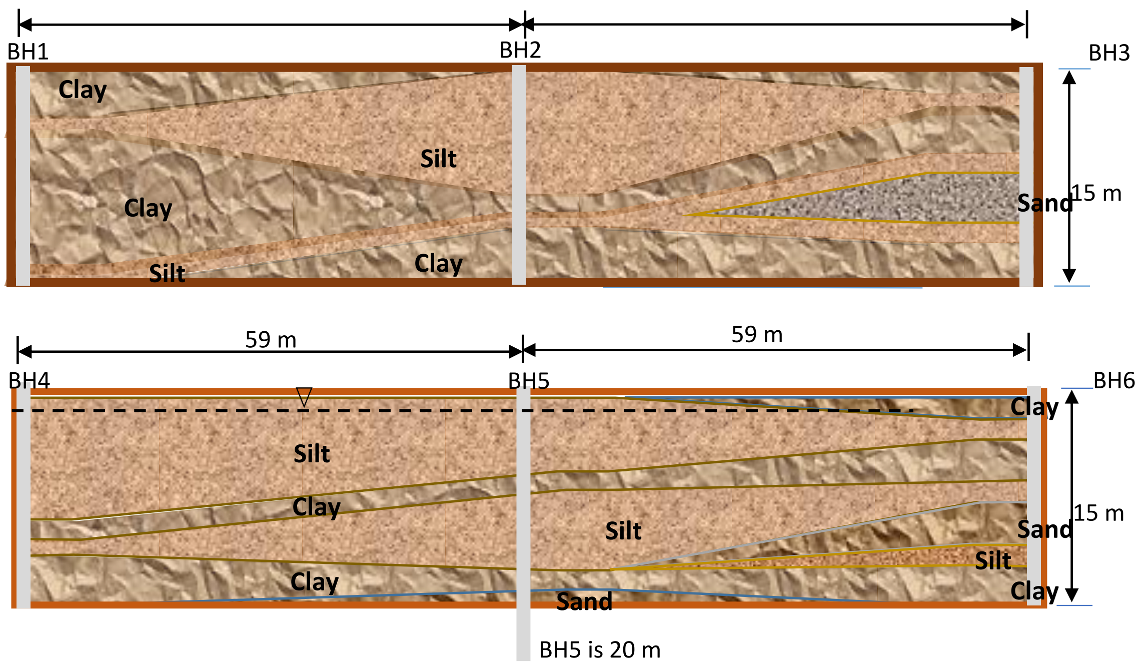

Fig. 3. (a,b): Soil Profile of Section through Boreholes 4, 5, and 6.

9.3. SPT Results

The Soil Penetration Test (SPT-N) values obtained during the field investigation are the number of blows recorded at six boreholes against depth as depicted in Figure 4. Examples of the SPT-N values that accompany this method are obtained between the surface and 15 meters and may vary from 3 to 22. The values of SPT-N also do not vary significantly with depth, which is appropriate with the ended geology of the area since the soil here is precipitated. From grain size distribution and hydrometer tests, fine-grained soil mainly comprises silt and clay. Sandy layers were encountered in some areas that deepen with depth however, there was no significant improvement in the SPT-N values with depth. Where sand is involved in the composition it is loose to medium one.
Figure 4 shows the SPT-N blows recorded in the six boreholes that were done on the site at various depths. SPT-N values obtained were between 3 and 22 primarily in the upper 15 meters and do not significantly vary with depth. This is in accord with the topographic features of the area, besides it has displayed geological features due to the sedimentation process. Grain size analysis and hydrometer test proves that the soil primarily comprises of silt and clay particles with layers of sand irregularly encountered at different intervals. Nevertheless, a great rise of SPT-N value with the depth is not noticeable even if sand soil is invaded, which is defined as loose to medium sand.

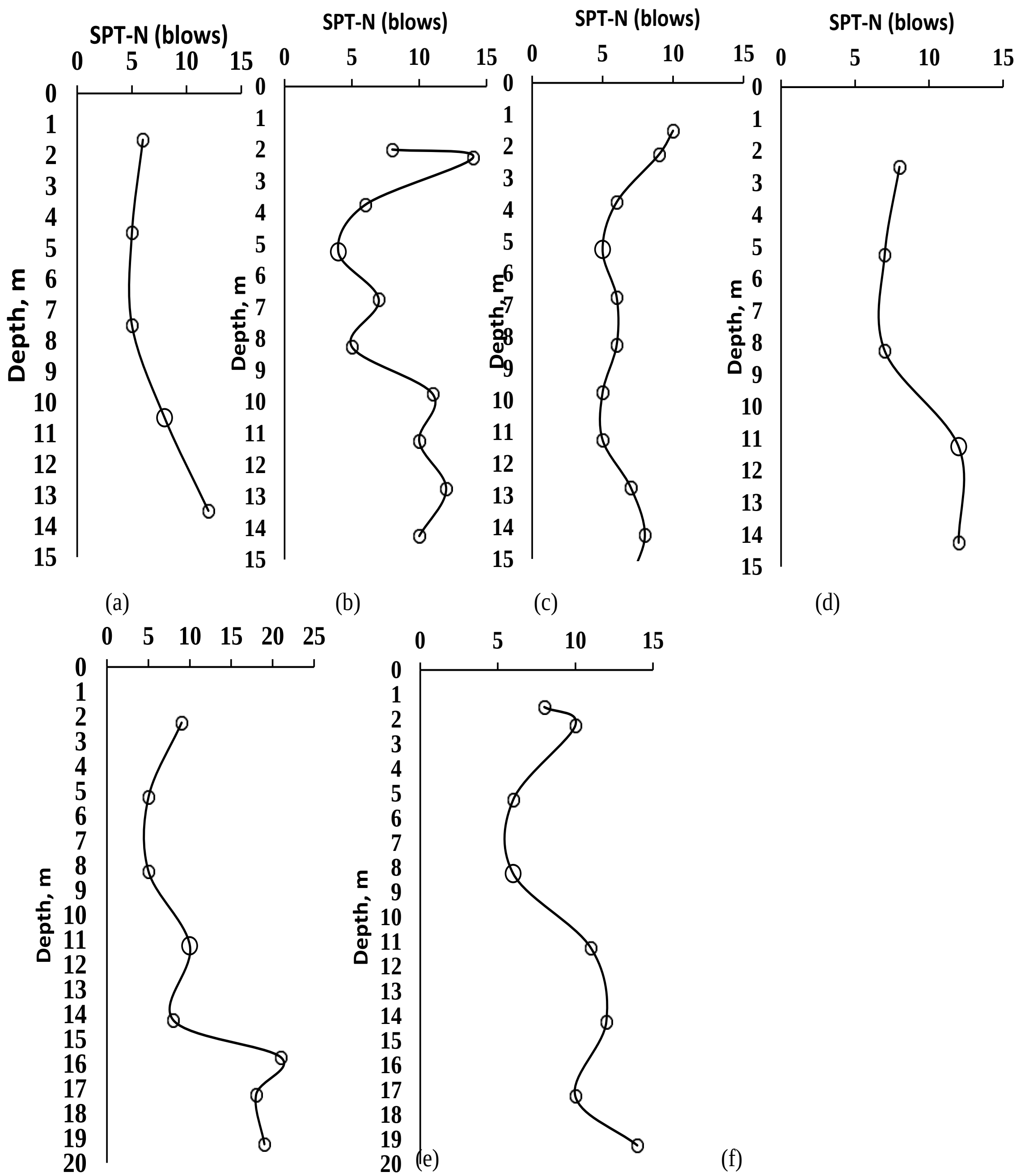

Fig. 4. SPT Results – Number of Blows with Depth for Boreholes S1, S2, S3, S4, S5, and S6.

9.4. Bearing Capacity of Piles

The allowable bearing capacity of piles with a length of 12 meters and width of 0.4 meters was determined using seven different methods based on SPT values. The method in ref. [2] provided the highest values, with a 1.783 times higher bearing capacity than the method in ref. [1] for the analyzed soils. The results showed a 14% higher bearing capacity, procedure also provided a greater bearing capacity. However, the method proposed by Bazaraa and Kurkur is considered conservative for estimating bearing capacity.

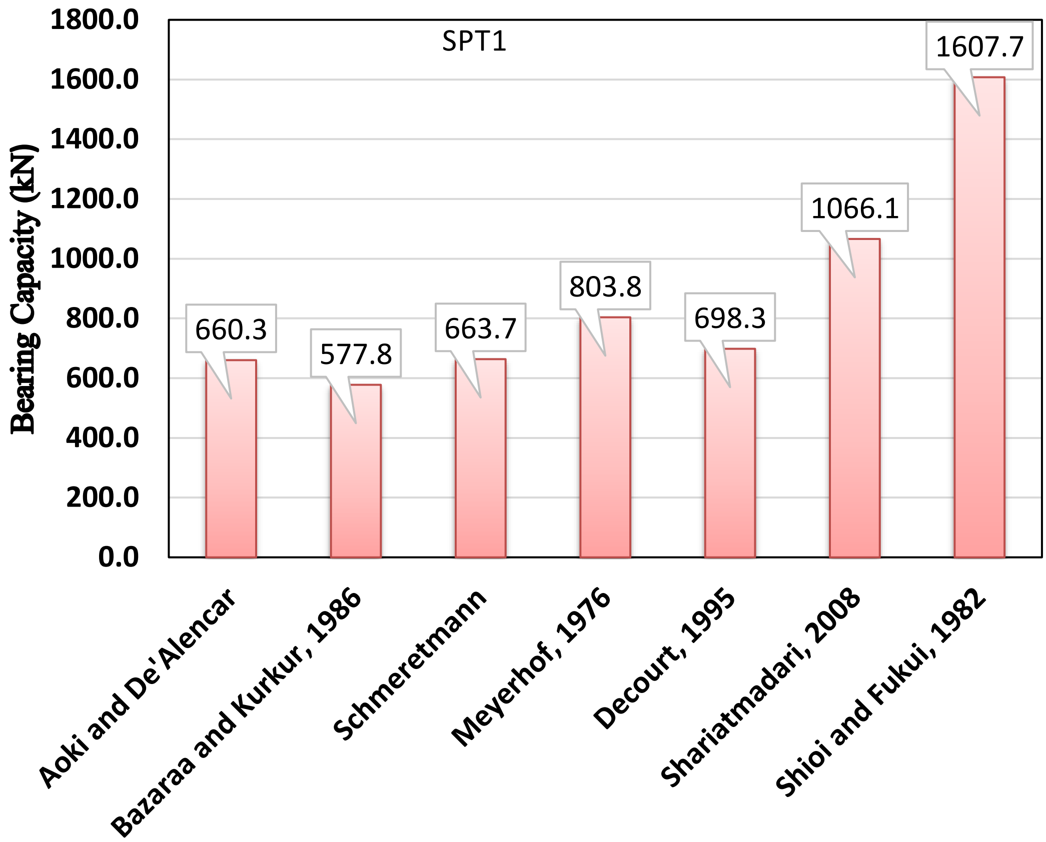

Fig. 5. Bearing capacity based on the results of SPT 1 using seven methods

Figure 6 illustrates the bearing capacity of piles calculated using the number of blows measured by SPT2, based on the seven methods. The lowest bearing capacity for SPT2 is determined using method [1], with a value of 519.9 kN/m². The highest bearing capacity is obtained using the method [2]. Methods [3,4] yielded similar bearing capacities of 597.3 kN/m² and 594.3 kN/m², respectively, which are approximately 14% and 14.3% higher than the value obtained by method [1]. Method [5] also provided a high bearing capacity, which, although lower than method [2], was still greater than all the other methods.

For SPT3 at BH3, the ultimate bearing capacity calculated using method [2] again showed the highest value, followed by methods [5,6], as reported in the study by [7], and method [3]. The lowest bearing capacity was found using method [1], with method [4] yielding the second lowest value.

For SPT4 at BH4, method [3] gave the lowest bearing capacity value, while method [1] provided a slightly higher value than method [3]. Methods [4] and [7] recorded the highest bearing capacity values, while methods [6,5], and [2] produced progressively higher values.

For SPT5, based on the results from SPT1, SPT2, and SPT3, method [1] showed the lowest bearing capacity value, while method [2] provided the highest value. Finally, for the bearing capacity calculated using SPT6, the ultimate bearing capacity progressively increased with methods [1-7].

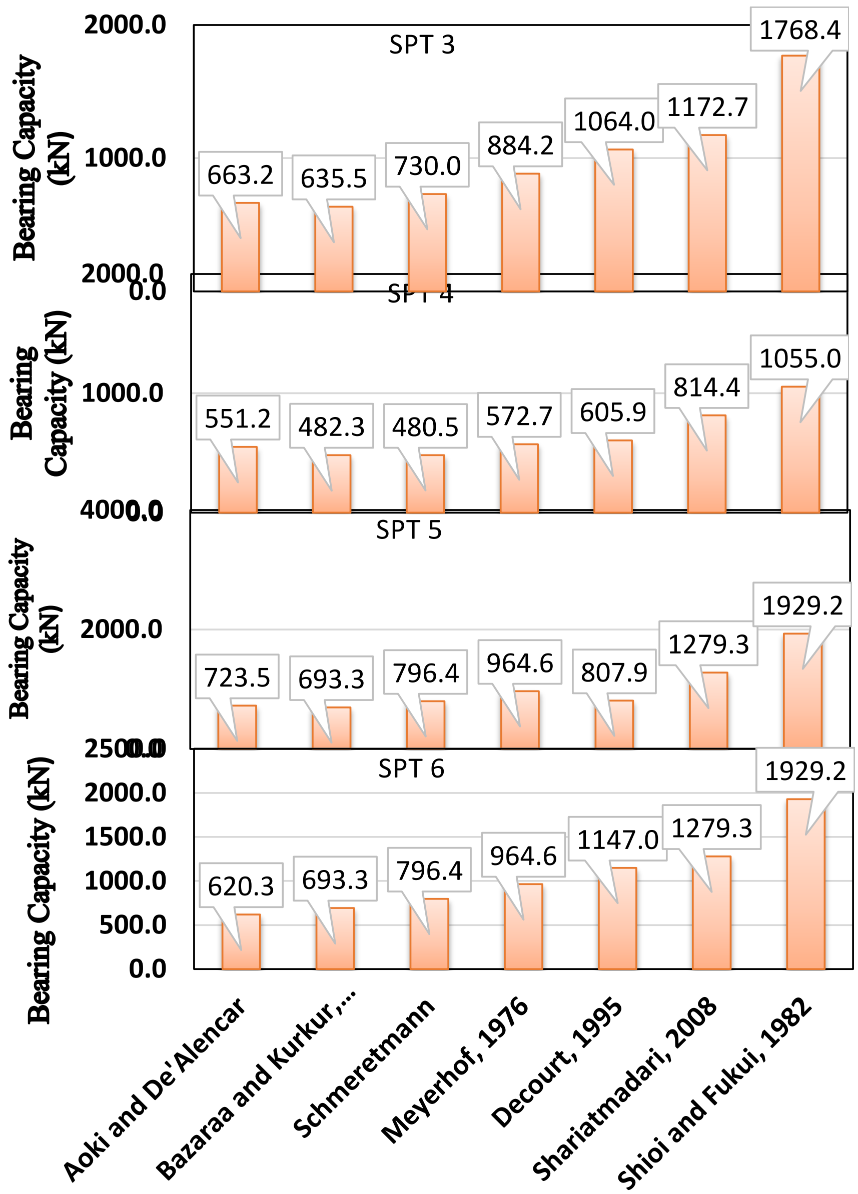

Fig. 6. Variation in pile bearing capacity values computed from SPT2 blows using seven empirical methods.

All the values of ultimate bearing capacity are summarized in Table 4. The table shows a comparison between the *bearing* capacity calculations using SPT at the six borehole locations using seven methods. These above-mentioned methods give differential estimates and there is no confusion as to which methods predict higher or lower bearing capacity.

TABLE IV. BEARING CAPACITY BASED ON SPT RESULTS USING DIFFERENT METHODS.

SPT1	SPT2	SPT3	SPT4	SPT5	SPT6
660.3	594.3	663.168	551.2046	723.456	620.277
577.8	520.0	635.536	482.304	693.312	693.312
663.7	597.3	730.037	480.495	796.404	796.404
803.8	723.5	884.224	572.736	964.608	964.608
698.3	643.6	1063.957	605.894	807.859	1146.979
1066.1	959.5	1172.70	814.415	1279.311	1279.311
1607.7	1446.9	1768.448	1055.04	1929.216	1929.216

The RESULTS consistently provided the lowest bearing capacity based on blows obtained through SPT at locations (1, 2, 3, and 5. For SPT) at location #4, the capacity was similar to other methods. For SPT at location 6, it provided the second-lowest value.

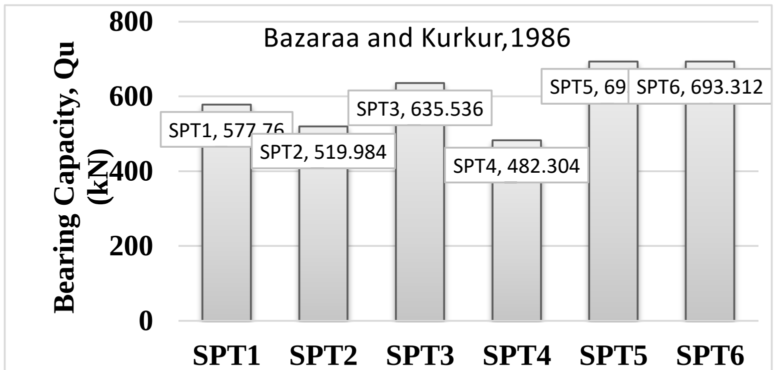

Fig. 7. Bearing capacity for proposed piles in all six profiles.

The SPT methods yielded the highest bearing capacity values for all borehole locations, primarily due to their design for sand piles. However, it may not be suitable for clay piles, and other methods should be used. The Shariatmadari method, which estimates bearing capacity for the pile's toe, is also not suitable for clay soil piles. The study found that the pile toe is mostly in clay or silt soil, except in two cases.

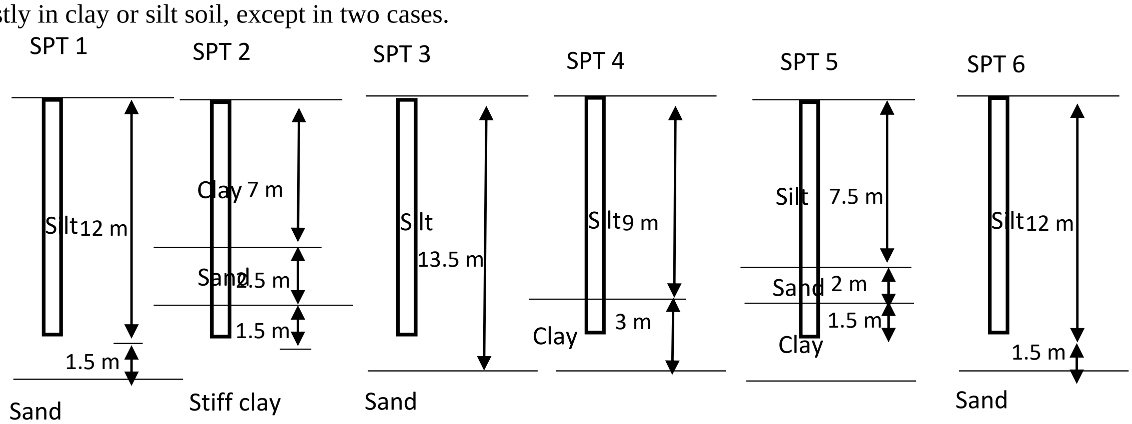

Fig. 8. The penetration of piles in the soil profile.

SPT 1 and SPT 3 and SPT 5 refer to similar types of soil namely sand but the number of blows recorded is almost varied. Thus, it is postulated that the calculated bearing capacity values for these SPT positions should be neither significantly different from one another. The above SPTs are expected to give a bearing capacity that is close to SPT 4 since it exposes the clay soil and not silt like the other profiles do with the pile penetration.

The comparison of soil profiles for SPT 2 and SPT 6 is also somewhat similar to other SPT locations, but the predominant sand layer affects only the friction part of the bearing capacity of the soil. These variations are believed to affect the results because the sand layer plays a different role against the pile resistance from the silt/ clay layers.

10. CONCLUSION

In conclusion, the research emphasizes the variability and uncertainty inherent in using empirical equations to estimate the ultimate bearing capacity of pile foundations based on Standard Penetration Test (SPT) results. The findings reveal that soil type significantly influences the accuracy of these predictions, with different soil characteristics affecting load-bearing capacity. The study advocates for the validation and refinement of empirical equations through real-world data and suggests incorporating additional factors, such as pile depth and moisture content, to enhance predictive models. Furthermore, it recommends exploring alternative methodologies, like numerical modelling, to improve understanding and accuracy in pile foundation assessments. Overall, these insights aim to foster more reliable engineering practices in foundation design

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Conflicts Of Interest

The author's paper emphasizes that there are no conflicts of interest, either perceived or actual, that could impact the research integrity.

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