

Axial Load Capacity of Cast in Place Piles from SPT and CPTU Data

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Abstract

This paper aims to deal with the assessment of axial load capacity for cast in place pile foundations, which are made by the earth drill method, by using the data taken from Standard Penetration Tests (SPTs) and Piezocone Penetration Tests (CPTUs). These tests were carried out as part of the investigation program for P.N.G. Terminal-Power Plant, near Semani beach, in Hoxhara marsh, in the western part of Albania. The design of axial load capacity of piles is based on empirical formula using SPT and CPTU values. This study presents the results of axial load capacity analysis of cast in place piles by different analytical calculation methods, which are based on *in situ* tests results, and also referring to the Building Standard Law of Japan. In the end of our work, differences between calculations methods by using different *in situ* tests results are shown in tables and graphs.

Keywords

Cast in Place Pile, Axial Load Capacity, Standard Penetration Test (SPT), Piezocone Penetration Test (CPTU)

1. Introduction

The construction site, where the SPT and CPTU tests are carried out, is located in the area of Semani beach, near Fier city, Albania. The tests considered in this study, are executed according to the site investigation program at Terminal Power Plant (here in after referred as P. N. G.) in Seman. A plan of the construction site and the location of *in situ* tests are shown in **Figure 1**.

The results of 416 SPT and 12 CPTU are considered during the axial load capacity analysis.

SPT tests were carried out, as the primarily recommended tests for granular soils and other ground conditions

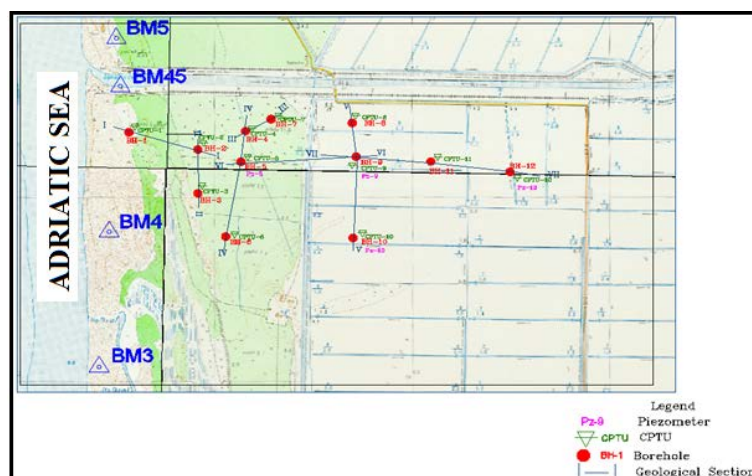


Figure 1. Plan of geological works.

where it is difficult to sample and test in laboratory. This test provides assessments of soils properties and foundation design parameters. It measures the soil resistance to penetration through computation of the number of blows required to drive the sampler 300 mm into the ground, after it has been advanced 150 mm. In recent years the N-value measured by SPT has been subjected to various corrections and is standardized to a reference value of 60% of the potential energy of SPT hammer [1].

Except SPTs, also CPTUs were performed, because the piezocone test allows the continuous monitoring of the pore pressure, u_2 , generated during driving, in addition to the electrical measurements of cone tip resistance, q_c , and sleeve friction, f_s . The determination of pile capacity is one of the earliest applications of the CPT data. CPT methods of axial pile capacity calculations generally give superior predictions, because CPT provides a continuous profile of soil and it is still the test that gives the closest simulation to a pile [2].

In this study, deep foundations of type cast in place piles are considered. The depth of pile is kept at a constant value of 20.0 m, meanwhile the diameter varies from 0.5 m until 2.0 m.

The data taken by Standard Penetration Test (SPT) will be involved in calculations according to O'Neill & Reese and the Japanese Design Law.

The data taken by Piezocone Tests (CPTU) will be involved in calculations according to Esllami & Fellenius Method.

All the results will be presented in tables and graphs, so it will be possible to compare the results obtained by different *in situ* testing techniques.

2. Axial Load Capacity of Piles by Using SPT

In this part are described analytical methods used to obtain Ultimate Axial Load Capacity, by using the results of 2 *in situ* tests, SPT and CPT. Also in this section of the paper, the Japanese Practice of axial load capacity analysis will be presented.

2.1. Axial Load Capacity from Japanese Method

The total load capacity of piles is calculated by using Equation (1), where toe bearing resistance and side friction resistance are both considered [3].

$$P_a = \frac{P_{ult}}{F} = \frac{P_t + P_s}{F} = \frac{q'_t A_t + \sum f_s A_s}{F} \quad (1)$$

where:

q'_t = net unit toe bearing resistance of pile, which is calculated by the equations given in **Table 1**

f_s = side friction bearing resistance of pile

A_t = toe area (normally, the cross sectional area of the pile)

A_s = circumferential area of the pile at depth z

F = factor of safety

According to Building Standard Law of Japan the allowable axial load capacity is defined in relation to ultimate axial load capacity, by using a factor of safety $F = 3$, in case of normal conditions. The ultimate bearing capacity of soils is estimated based on geotechnical investigations. The allowable axial load capacity of piles shall be calculated by the equations in paragraph **Table 2**, in cases when the soil in contact with the pile is a soft clay, or a loose sand, and also in those cases when it is estimated a big liquefaction potential of soils where are driven the piles or are installed the cast-in-place piles [4].

P_s = side-friction resistance calculated by the following equation:

$$P_s = \left(\frac{10}{3} \bar{N}_s L_s + \frac{1}{2} \bar{q}_u L_c \right) \varphi \tag{2}$$

\bar{N}_s = average percussion frequency (p.s. in our calculation \bar{N}_s are equal to $((N_1)_{60})$ by standard penetration test of sandy ground that is part of the ground around the foundation pile (if it exceeds 30, the value shall be 30).

L_s = total length of the foundation pile that is in contact with sandy ground that is part of the ground around the foundation pile.

\bar{q}_u = average singly compressive strength of clayey ground that is part of the ground around the foundation pile (if it exceeds 200, the value shall be 200).

L_c = total length of the foundation pile that is in contact with clayey ground that is part of the ground around the foundation pile.

φ = length of the circumference of the foundation pile [5].

2.2. O' Neill and Reese Method for Toe Bearing Resistance

Analytical design of cast in place piles is based on empirical formulas developed from instrumented full scale static load tests. O' Neill and Reese defined the toe bearing resistance as that which occurs at a settlement of 5% of the pile diameter. Based on this criterion they recommend computing the net toe bearing resistance in sand with $N_{60} \leq 50$ as follows [6]:

$$q'_t = 57.5 N_{60} \leq 2900 \text{ kPa} \tag{3}$$

where:

N_{60} = SPT N-value corrected for field procedures from pile's toe until the depth $2B_b$ under the toe.

B_b = diameter in base.

Net unit toe bearing resistance for cast in place piles, with diameter in base bigger than 120 cm, in sandy soils with $N_{60} \leq 50$ according O' Neill & Reese should be reduced by multiplying with the ratio of 1200 mm with the diameter in base of the pile. Otherwise a settlements analysis is required.

Table 1. Net unit toe-bearing resistance according to SPT-value [4].

Category of pile foundation	Allowable unit stress of soil at the tip of the pile foundation
Driven pile	$q'_t = 300\bar{N}$
Bored precast pile made with cement milk method	$q'_t = 200\bar{N}$
Cast-in-place pile made by the earth drill method, etc.	$q'_t = 150\bar{N}$

In this table \bar{N} (p.s. in our calculation \bar{N} are equal to $(N_1)_{60}$ shall represent average percussion frequency based on standard penetration test of the ground near the tip of the foundation pile (when it exceed 60, it shall be 60).

Table 2. Formulas for estimation of allowable load capacity of bearing piles [4].

	Allowable bearing capacity of ground under internal forces produced by sustained	Allowable bearing capacity of ground under internal forces produced by temporary
(1)	$P_a = \frac{1}{3}(q'_t A_t + P_s)$	$P_a = \frac{2}{3}(q'_t A_t + P_s)$

Because of their low hydraulic conductivity, it is assumed that undrained conditions exist in clays beneath the toe of the pile. The net unit toe bearing resistance for piles embeded in clay can be calculated by using the undrained shear strength, as given in the Equation (4). O'Neill and Reese recommend to use in this case the bearing capacity factor, which varies as a function of the undrained shear strength of the soil [6].

$$q'_t = N_c^* s_u \quad (4)$$

where:

$$q'_{tr} = q'_t \frac{1200 \text{ mm}}{B}$$

N_c^* = factor of bearing capacity (O'Neill & Reese).

s_u = undrained shear strength between the pile's toe and $2B_b$ under the pile's toe.

Net unit toe bearing resistance for cast in place piles, with diameter in base bigger than 190 cm, in clayey soils with $s_u \leq 250$ kPa, according O'Neill & Reese should reduced by using the reduction factor, F_r , as given by the formula below [5]:

$$q'_{tr} = F_r q'_t \quad (5)$$

The reduction factor is calculated by Equations (6):

$$F_r = \frac{2.5}{\psi_1 B_b + 2.5 \psi_2} \leq 1.0 \quad (6)$$

$$\psi_1 = 0.28 B_b + 0.083 (D/B_b) \quad \psi_2 = 0.065 \sqrt{s_u}$$

where:

D = the depth of pile's embedment.

2.3. β Method for Side Friction Resistance

When using the β method the soil is divided into layers, where each layer boundary is located at the soil strata boundaries or at the ground water table. Than is computed f_s by the formula given below [6]:

$$f_s = \beta \sigma'_z \quad (7)$$

- For cast in place piles embeded in sand, when the value of $N_{60} \geq 15$, O'Neill and Reese recommend the following values for β :

$$\beta = 1.5 - 0.245 \sqrt{z} \quad 0.25 \leq \beta \leq 1.20 \quad (8)$$

where:

z = the depth in the middle of the strata.

Side friction resistance, f_s , calculated by using the value of β is limited until 190 kPa.

If $N_{60} < 15$, the value of β should be multiplied by the ratio of $N_{60}/15$.

- For cast in place piles embeded in gravel (gravel grains >50%) Rollins, Clayton and Mikesell recommend the following values for β :

$$\beta = 3.4 e^{-0.085z} \quad 0.25 \leq \beta \leq 3.0 \quad (9)$$

- For cast in place piles embeded in gravelly SAND (gravel grains 25% - 50%) the following values of β are recommended:

$$\beta = 2.0 - 0.15z^{0.75} \quad 0.25 \leq \beta \leq 1.8 \quad (10)$$

- For cast in place piles embeded in silt or clay the following values of β are recommended by Fellenius:

$$\beta = 0.27 - 0.50 \text{ (Silt)} \quad \beta = 0.25 - 0.35 \text{ (Clay)} \quad (11)$$

3. Axial Load Capacity of Piles by Using CPT Tests Data

3.1. Eslami and Fellenius Method

Eslami and Fellenius recommend the application of an additional pore water pressure u_2 to correct the value of

effective resistance of cone as follows [6]:

$$q_E = q_T - u_2 \quad (12)$$

where:

- q_E = effective resistance of cone.
- q_T = corrected resistance of cone.
- u_2 = pore water pressure measure at cone tip.

3.2. Toe Bearing Resistance

Eslami & Fellenius method is widely used to correct the net toe bearing resistance, q'_t , with the effective resistance of cone, q_E . These analysis consider the values of q_E only withing the following zones:

- Piles installed through weak soils at the beginning and than passing through compact soils 8B above the end of the cone and 4B below it.
- Piles installed through compact soils at the beggining than passing through weak soils 2B above the end of the cone and 4B below it.

Average value, q_{Eg} , of n values q_E measured with the defined depth can be calculated as a geometrical average. Net toe bearing resistance, q'_t , should be correlated in empirically manner as shown in Equation (13) [6]:

$$q'_t = C_t q_{Eg} \quad (13)$$

where:

- C_t = bearing resistance coefficient = 1.
- q_{Eg} = geometric average effective resistance of cone.

3.3. Side Friction Resistance

The side friction resistance by using the data of CPT should be calculated by means of Equation (15) [6]:

$$f_s = C_s q_E \quad (14)$$

where:

The values of C_s depend on soil type and are taken in **Table 3**. Menawhile soil's classification is done in graphphical way by using the CPT data.

- C_s = coefficient of side friction.
- q_E = effective resistance of cone.

4. Results and Discussions

Since the analyses of Axial Load Capacity of piles in this construction site are related to the data of SPT and CPTU tests, at first we dialed with the results of these tests, which were reported in the geological study. Average field SPT N-values, corrected SPT(N₁)₆₀-values, average q_c-values and f_{sc}-values are considered. The geological profiles are constructed for every borehole (12 boreholes in total). In **Figure 2**, **Figure 3** and **Figure 4** are given the variances of field SPT N-value, SPTN₆₀-value and field CPTUq_c-value, f_{sc}-value with depth for 12 boreholes considered in this paper.

Table 3. Side friction coefficient, C_s , according to Eslami & Fellenius.

Soil Type	C_s	
	Range	Typical Design Value
Soft sensitive soils	0.0737 - 0.0864	0.08
Clay	0.0462 - 0.0556	0.05
Stiff clay or mixture or clay and silt	0.0206 - 0.0280	0.025
Mixture of silt and sand	0.0087 - 0.0134	0.01
Sand	0.0034 - 0.0060	0.004

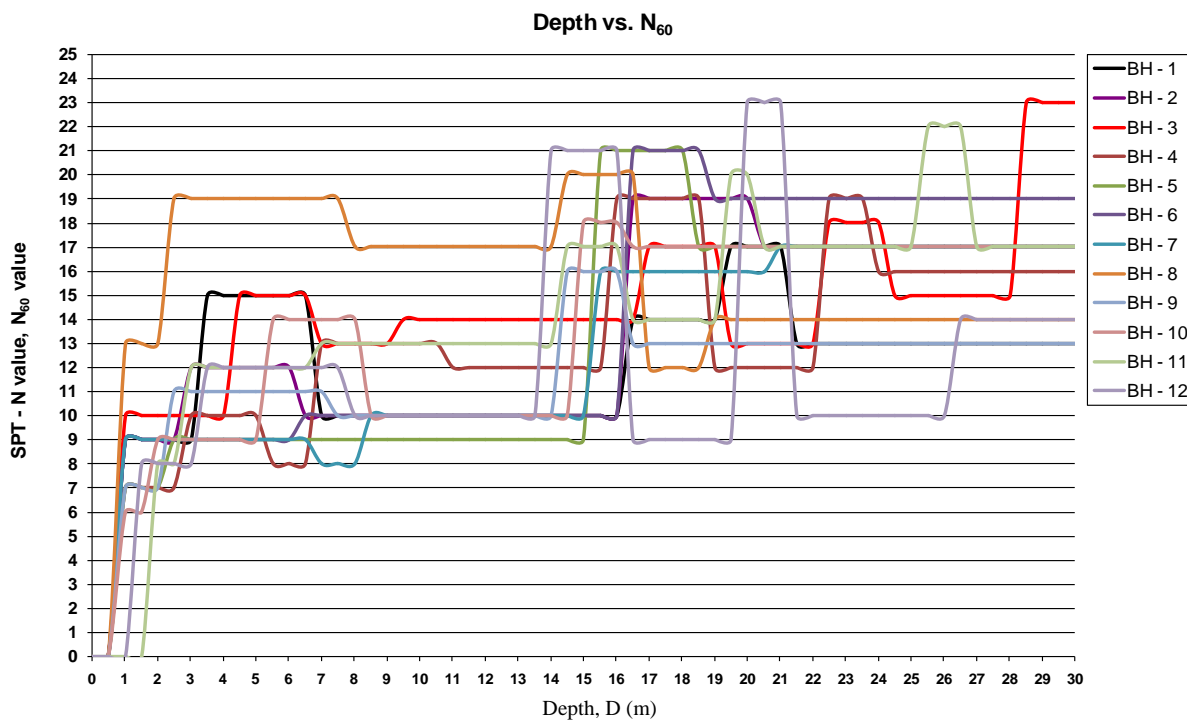


Figure 2. Field SPT N-value, $SPTN_{60}$ values.

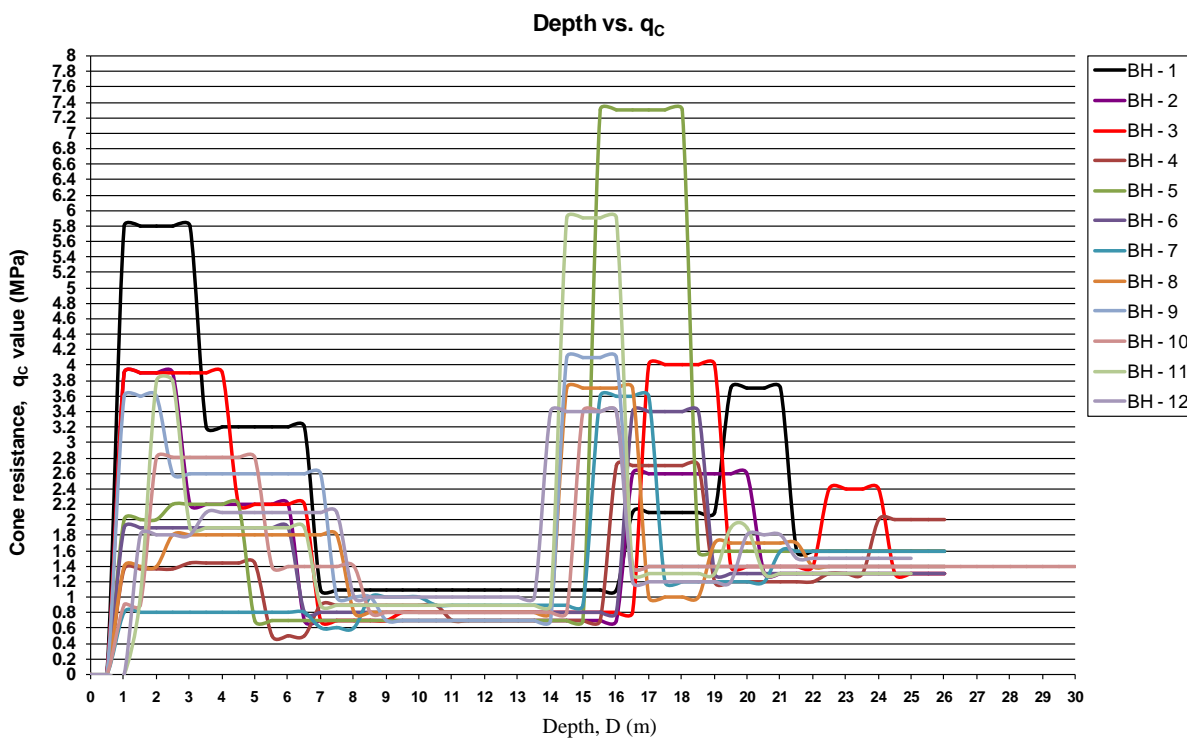


Figure 3. Field CPTU q_c -values.

The axial load capacity analyses are performed for each borehole based on the analytical methods already described above.

Considering soil profiles and soil conditions of every borehole, a suitable depth of 20 m is selected for cast-in-

place reinforced concrete pile foundations. Pile length is not varied; we have fixed it in a value of 20 m. The considered pile width (pile diameter) is varied in the interval 0.5 - 2.0 m.

All the results of our geotechnical calculations related to axial load capacity of piles are presented in charts considering various pile diameters (see Figure 5). In these charts, each graph presents axial load capacity related to pile diameter in certain soil conditions which belong to a certain borehole [7].

From the results presented in Table 4, Figure 5 and Figure 6, it is shown that calculated values of axial load capacity based on the SPT, CPTU data and on Japanese practice of design don't differ very much. We see that

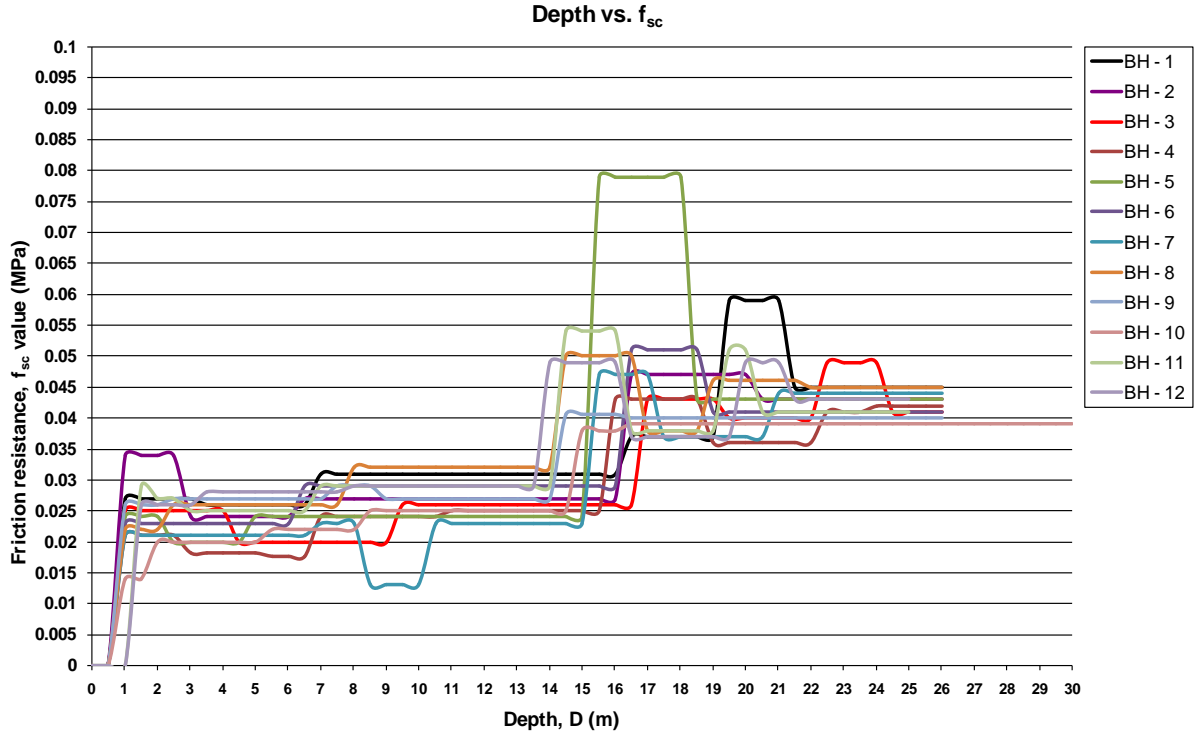


Figure 4. Field CPTU_{f_{sc}}-values.

Table 4. Axial load capacity for cast in place pile foundation (D = 20.0 m).

Table of axial capacity of cast in place pile foundation with 20 m length, based on 3 methods													
Methods	B (m)	Axial load capacity P _a (kN)											
		BH - 1	BH - 2	BH - 3	BH - 4	BH - 5	BH - 6	BH - 7	BH - 8	BH - 9	BH - 10	BH - 11	BH - 12
CPT Method	0.5	508	256.3	191.1	168.3	254.6	166.3	144.2	237.1	222.5	177	224.1	213.1
	1.0	1207	639.6	536.3	432.6	603.2	428.1	400.4	566.7	561.7	456.2	549.7	542.6
	1.5	1924	1179	1100	850.4	1140	810.6	739.8	975.4	986.9	823.5	978.3	969.9
	2.0	2681	1792	1706	1446	2064	1460	1267	1528	1484	1203	1435	1480
SPT Method (O'Neil & Reese)	0.5	396	405.8	385.8	413.2	418.9	404	393.3	487.8	431	421.2	464.5	515.8
	1.0	870.8	889.9	827.6	882.3	921.6	896.6	867.1	1048	929	928.4	1021	1150
	1.5	1353	1452	1325	1407	1508	1478	1349	1615	1494	1444	1587	1796
	2.0	1805	1844	1714	1823	1908	1858	1799	2153	1920	1926	2116	2394
Japanese method (by SPT)	0.5	525.8	578	504.9	462.5	520.4	558.2	441.5	630.4	509.4	470.6	579	539.4
	1.0	1257	1379	1174	1091	1277	1364	1093	1449	1214	1165	1405	1388
	1.5	2195	2404	2007	1887	2270	2418	1955	2456	2114	2084	2476	2544
	2.0	3337	3652	3005	2848	3499	3719	3027	3651	3209	3228	3793	4010

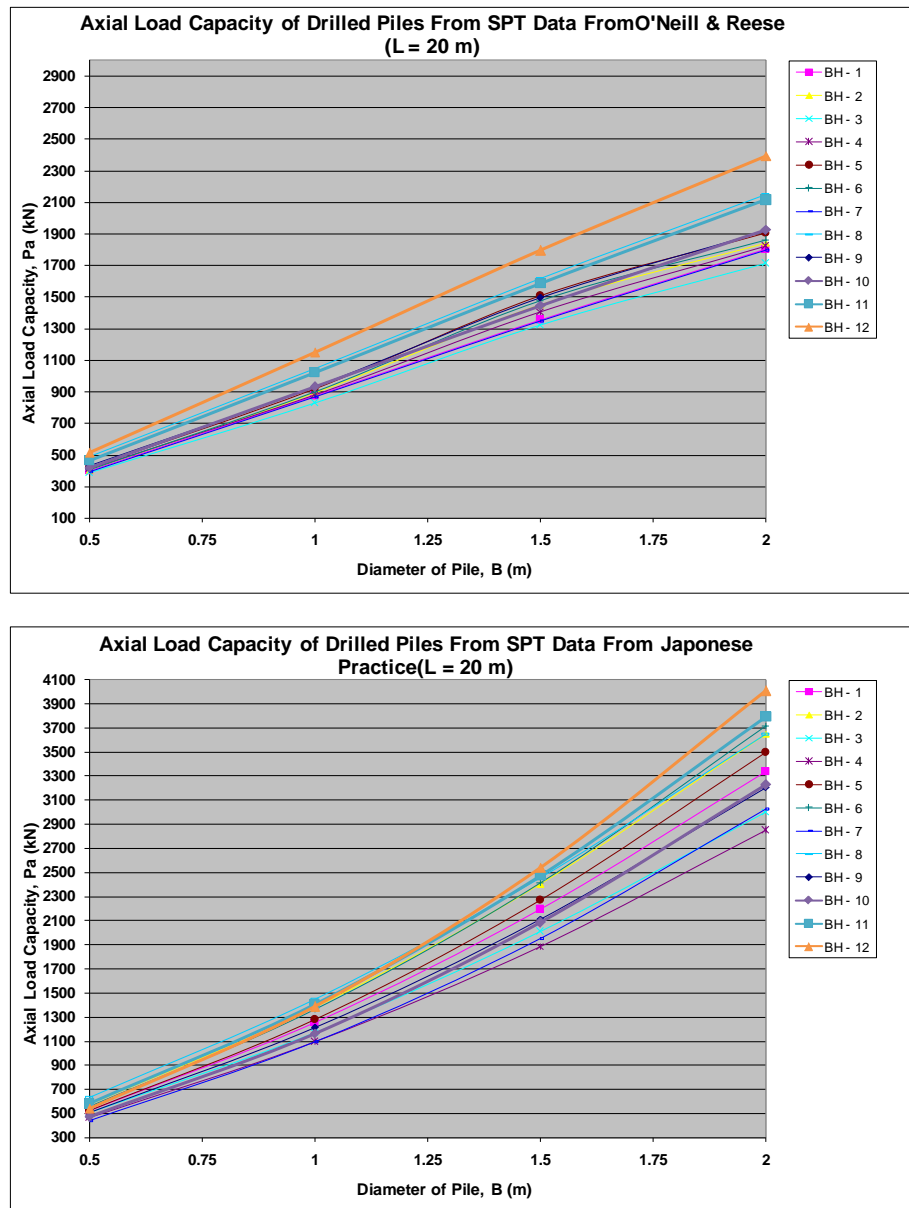


Figure 5. Axial load capacity of cast in place piles by SPT and based calculation methods.

constructed curves in all cases are similar and the gap between them is not significant, especially when the diameter is in the range of 1 - 1.5 m. We can say that all methods give comparable and consistent results for piles which have the same dimensions and are installed in the same soil surroundings.

5. Conclusions

Axial load capacities of piles at P.N.G. Terminal-Power Plant are assessed in this paper. From the results of calculations and discussion of them the below conclusions have resulted from the construction site mentioned above. The axial load in piles varies from one method of calculation to another. According to the SPT based calculations, known as O'Neill and Reese method, the axial load capacities varied from 400 up to 2400 kN. According to the Japanese Design Law the results vary from 500 to 4010 kN. The results taken by CPT based calculations method and the values of axial mode can be from 500 up to 1480 kN.

Maximal axial load capacity is reached according to Japanese Design Law, which is 4010 kN.

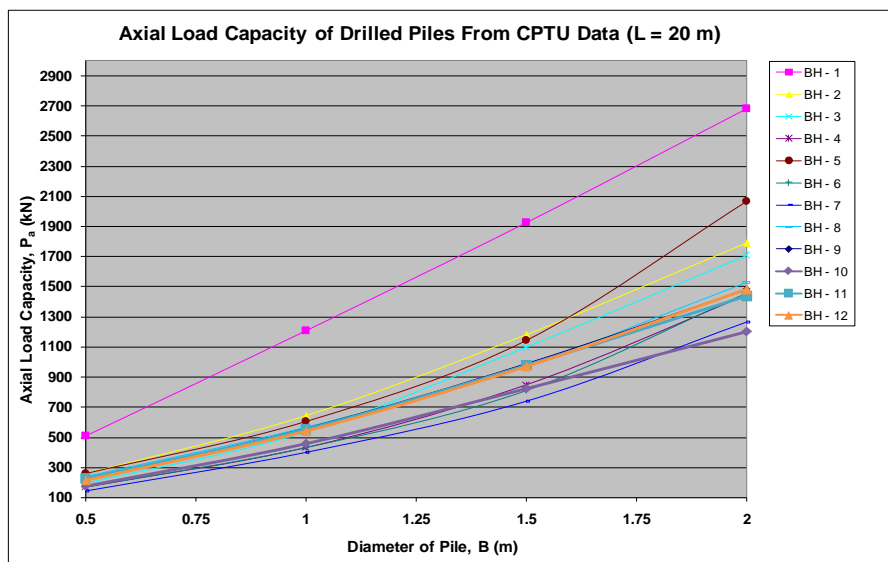


Figure 6. Axial load capacity of cast in place piles by CPT and based calculation methods.

According to the calculation based on CPT results the main important component of total axial load capacity is the toe bearing capacity, determined by the value of q_c and correlated by q_t .

At BH - 1 the pile's toe is supported by a layer of dense sand. This is the reason that between the other graphs a gap exists in this one. Other piles have almost the same axial load capacity, so the graphs do not create considerable gaps between each others.

Concerning to SPT, it is often noticed that for the same SPT N-value according to two different methods we obtain two different axial loads for pile diameter. This means that the real difference is attributed to toe bearing resistance, because side friction resistance is almost the same in these cases. This is due to different correlations methods of SPT data.

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