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Prediction of Pile Capacity using Pile Loading Tests and CPT Tests

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Abstract. There are several methods of calculating pile load capacity. One of the most accurate, costly and difficult of these methods is to do a pile loading test. The least accurate and costly method to predict the pile load capacity is the use of the theoretical static formula based on soil properties determined from the laboratory tests. Using in-situ tests such as static cone test (CPT) to determine the pile load capacity is considered to be average cost and easy to implement, and its results are appropriate. In this research, pile load tests were performed on seven (7) piles in the site of the construction of "2760 Residential and Social Units" in Alsalam area in Port Saied City, Egypt. The pile load tests were conducted up to load of 2000kN which was 2.5 times the design load. Also, three (3) static penetrometer tests (CPT) were performed to depths of 25 m below the existing ground surface at the site. Six methods were used to analyze the pile loading tests data. These methods were: Davisson, Brinch Hansen, Chin-Kondner, Decourt, Mazurkiewicz's and DeBeer. Two methods were used to predict pile load capacities from CPT test results. The first one was Bustamante and Gianeselli (LCPC) as a direct method whereby the measured readings are scaled up for evaluation of full-size pilings. The second was the DIN-4014 as an indirect method via indirect CPT assessments of shear strength parameters. The pile load capacities predicted from pile load tests were discussed and compared with those predicted from CPT tests.

Keywords: (CPT test, Load Capacity, Loading test, Piles, analysis methods)

الملخص العربى

التنبؤ بقدرة تحمل الخوازيق باستخدام اختبارات تحميل الخوازيق واختبارات CPT

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هناك عدة طرق لحساب قدرة تحمل الخوازيق. ومن أدق هذه الطرق ولكنها الأكثر تكلفة وصعوبة هي إجراء اختبار تحميل مباشر على الخوازيق. ومن أقل هذه الطرق دقة وتكلفة هو باستخدام إحدى الصيغ الاستاتيكية التى تعتمد على خواص التربة التى تحدد من نتائج الاختبارات المعملية. ويعتبر استخدام الاختبارات الحقلية مثل اختبار المخروط الاستاتيكى (CPT) لتحديد أحمال الخوازيق متوسط التكلفة وسهل التنفيذ كما أن نتائجه مناسبة. وفى هذا البحث تم إجراء اختبارات تحميل مباشرة (Pile load tests) على سبعة (7) خوازيق في موقع إنشاء "2760 وحدة سكنية واجتماعية" في منطقة السلام بمدينة بورسعيد ، مصر. وقد تم التحميل حتى حمل 2000 كيلونيوتن وهو ما يعادل مرتين ونصف الحمل التصميمى. كما تم كذلك إجراء ثلاثة (3) اختبارات المخروط الاستاتيكى (CPT) ، وذلك حتى عمق يصل إلى 25 مترًا تحت سطح الأرض بالموقع. وقد استخدمت ستة (6) طرق مختلفة لتحليل نتائج اختبارات تحميل الخوازيق ، وهذه الطرق هى : ديفسون ، برنك هانسن ، تشين ، ديكورت ، مازركويز ، ديبيير. واستخدمت طريقتان لتحليل نتائج اختبارات المخروط الاستاتيكى. الطريقة الأولى هى طريقة بوستمان وجينسيللى وهى طريقة مباشرة باستخدام القراءات الناتجة من الاختبار ، والطريقة الثانية وهى المستخدمة فى المواصفات الألمانية DIN-4014 وهى طريقة غير مباشرة عن طريق تعيين معاملات القص للتربة ومن ثم استخدامها فى حساب قدرة تحمل الخوازيق. وتمت مناقشة النتائج المستنتجة من اختبارات تحميل الخوازيق ومقارنتها بنتائج اختبارات (CPT).

1. INTRODUCTION

Piles are usually used when the upper soil layers are weak. Piles transfer loads to the strong deep soil layers either by friction or by bearing. There are several methods of calculating the load capacity of piles. These methods can be divided into three main groups: methods depending on pile load tests, methods based on results of laboratory tests and methods based on results of in-situ tests such as the cone penetration test [1]. Using CPT tests to determine the pile load capacity is an easy, inexpensive and reasonably reliable method [1]. Pile load test is the most accurate method to predict the pile load capacity [2], but its cost is high and difficult to conduct. Conversely, the estimation of the load capacity of the piles based on the results of laboratory tests is considered to be less accurate. In this research, different methods used to predict the pile load capacity from pile loading tests and CPT tests were discussed and the results obtained from a certain site were compared. Pile load tests were performed on seven piles at the site of the construction of "2760 Residential and Social Units" in Alsalam area in Port Saied City, Egypt [3]. The tests were conducted up to load of 2000kN which was 2.5 times the design load. Also, three static cone penetrometer tests (CPT) were performed in the site. All CPT tests penetrated down to depths of 25 m below the existing ground surface to provide information on the foundation soil and its properties to estimate the pile load capacity. The load capacities of the piles predicted from pile load tests were discussed and compared with the results of the CPT tests.

2 PILE LODING TESTS

The main objective of the pile loading test is to confirm the pile load capacity. In the case of soft or medium soils it is possible to carry out the pile loading test up to the failure load, and then the design load can be easily obtained. While in other cases, it is difficult to reach the failure load and therefore there is a need to analyze the results of the test to get it [2]. Terzaghi (1942) stated that the pile load capacity is the load corresponding to movement equal to 10% of the pile diameter [4]. There are several methods to analyze the test data such as Brinch Hansen (1963), DeBeer (1968), Chin-Kondner (1970), Davisson (1972), Decourt (1999) [4], and Mazurkiewicz's method [5]. These methods will be reviewed and applied to the tests conducted in this study.

3. USED METHODS OF PILE LOADING TEST ANALYSIS

3.1 Davisson Method

Davisson method is used in many regions worldwide due to its ease to analyze without need of extrapolation. The ultimate load capacity P_{ult} is obtained at the intersection point of the load-settlement curve with the line of the following equation as shown in Fig.1 [2]:

$$s = 4\ mm + D/120 + PL/(AE) \quad (1)$$

Where:

s is the settlement

D is the pile diameter

P is the applied load

L is the pile length

A is the pile cross sectional area

E is the modulus of elasticity of the pile

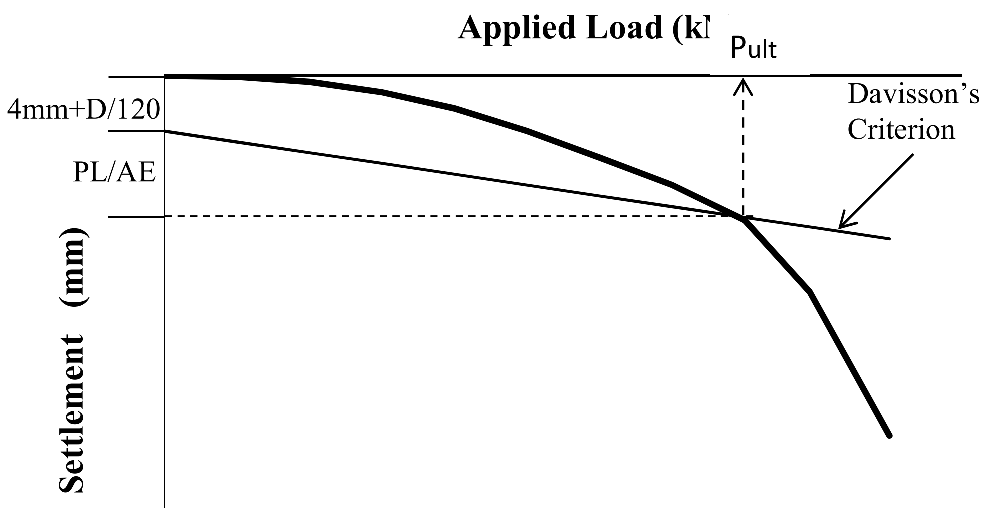

Fig.1. Davisson method of determining P_{ult} from static load test data

3.2 Brinch Hansen Method

Brinch Hansen obtained the ultimate load from a parabolic load-settlement curve using either Brinch Hansen 80% criterion or Brinch Hansen 90% criterion, Fig 2. He noted that the settlement at failure load is four times the settlement at 80% of failure load and twice the settlement at 90% of failure load for the two criteria respectively [2]. For more accurate solution, 80 %Hansen's criterion can be estimated from √s/Q versus S diagram, Fig.3 [4]. Parabolic load-settlement curve can be determined using the slope of the straight line (C_1) and the y-intercept (C_2) from the following relation:

$$Q = \sqrt{s}/(C_1.s+C_2) \qquad (2)$$

P_{ult} of 80%Hansen criterion can be calculated from the following equation [6]:

$$P_{ult} = 1/2\sqrt{(C_1.C_2)} \qquad (3)$$

Also, P_{ult} of 90%Hansen criterion can be calculated from the following equation [7]:

$$P_{ult} = 2\sqrt{3}/(7\sqrt{(C_1.C_2)}) \qquad (4)$$

Check must be done to ensure that Hansen's criteria are achieved along the hyperbolic curve.

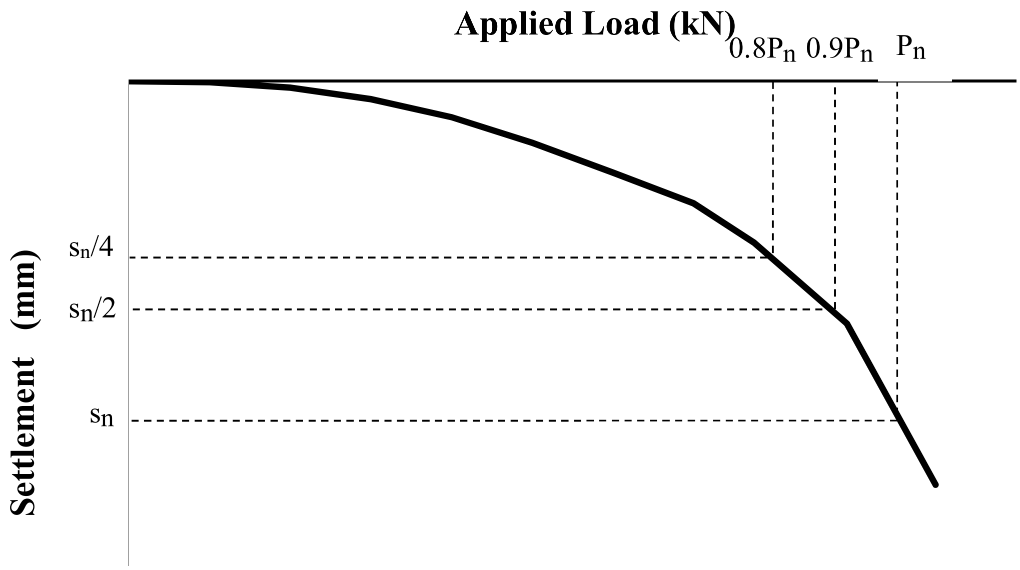

Fig.2. Brinch Hansen method of determining P_{ult} from static load test data

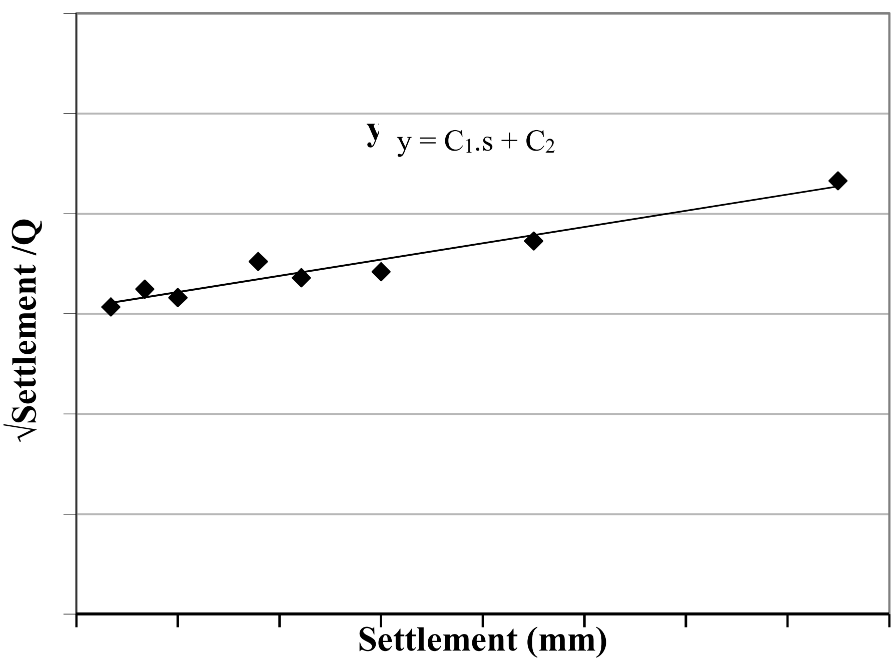

Fig.3. Hansen plot for 80% criterion

3.3 Chin-Kondner Method

Chin-Kondner method used the relationship between the settlement values (s) and settlement value divided by the corresponding load (s/Q). This relationship represents normally a straight line, except for the values corresponding to the beginnings of the loading test Fig. 4. The ultimate load is the inverse slope of this line as in the following equation [6]:

$$P_{ult} = 1/C_1 \qquad (5)$$

Hyperbolic load-settlement curve can be determined using C_1 and C_2 from the following relation

$$Q = s/(C_1.s+C_2) \qquad (6)$$

This hyperbolic plot is more close to the actual load-settlement curve than the parabolic curve obtained by Brinch Hansen method.

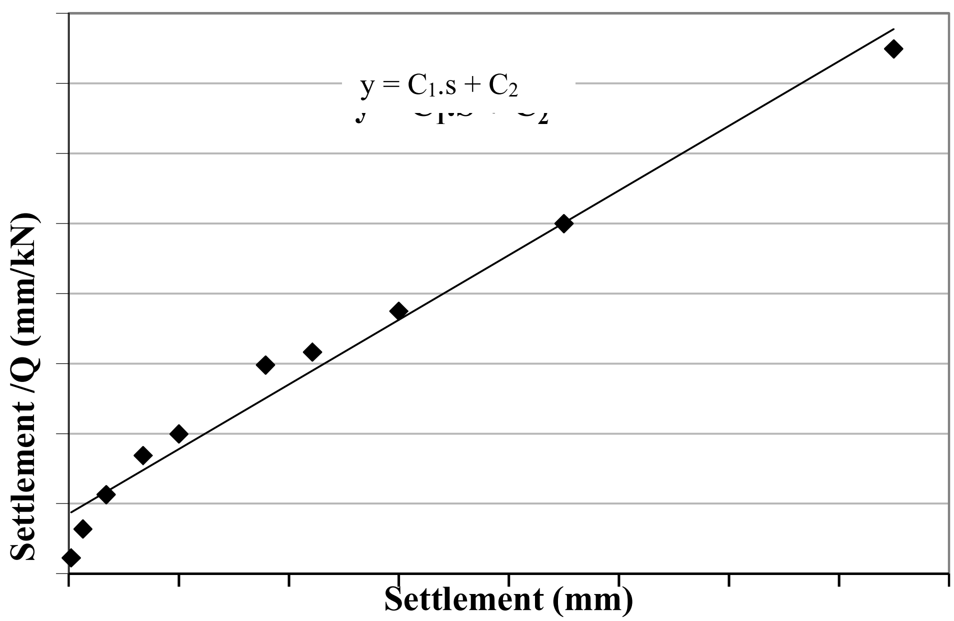

Fig.4. Chin method of determining P_{ult} from static load test data

3.4 Decourt Method

Decourt method used the relationship between the load values (Q) versus (Q/s) Fig. 5. The Decourt extrapolation load limit is equal to the ratio between the y-intercept and the slope of the line as in the following equation [4].

$$P_{ult} = C_2/C_1 \qquad (7)$$

Similar to Hansen method and Chin method, hyperbolic load-settlement curve can be determined using C_1 and C_2 from the following relation and compared to the actual load-settlement curve of the test.

$$Q = C_2.s/(1-C_1.s) \qquad (8)$$

3.5 Mazurkiewicz's Method

Mazurkiewicz's method obtained the ultimate load from a parabolic load-settlement curve. Then divide the settlement axis into several equal small sections and the corresponding loads are drawn to the load axis, as shown in Fig. 6. Then, lines are drawn at a 45-degree angle from the load points to intersect the next vertical line. A straight line is drawn through these intersections points; the intersection of this line with the load axis defines the ultimate failure load [8].

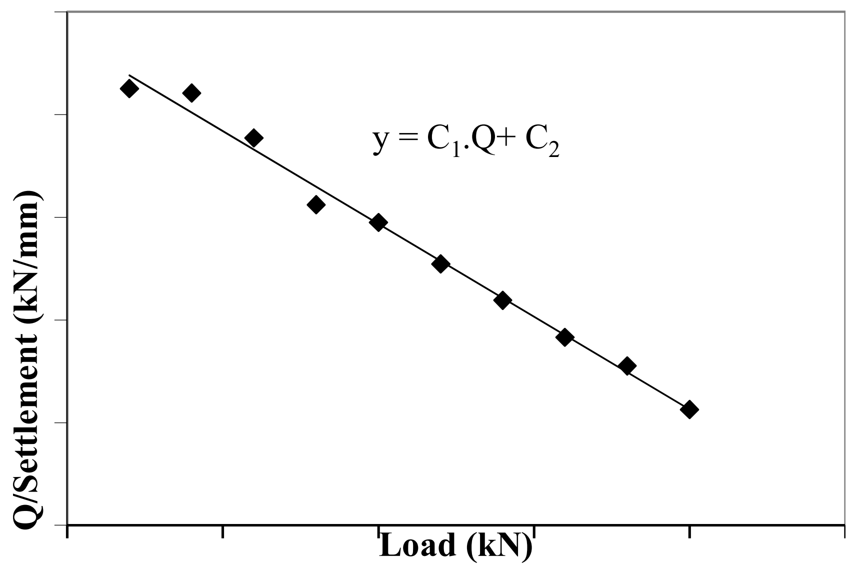

Fig. 5. Decourt method of determining Pult from static load test data

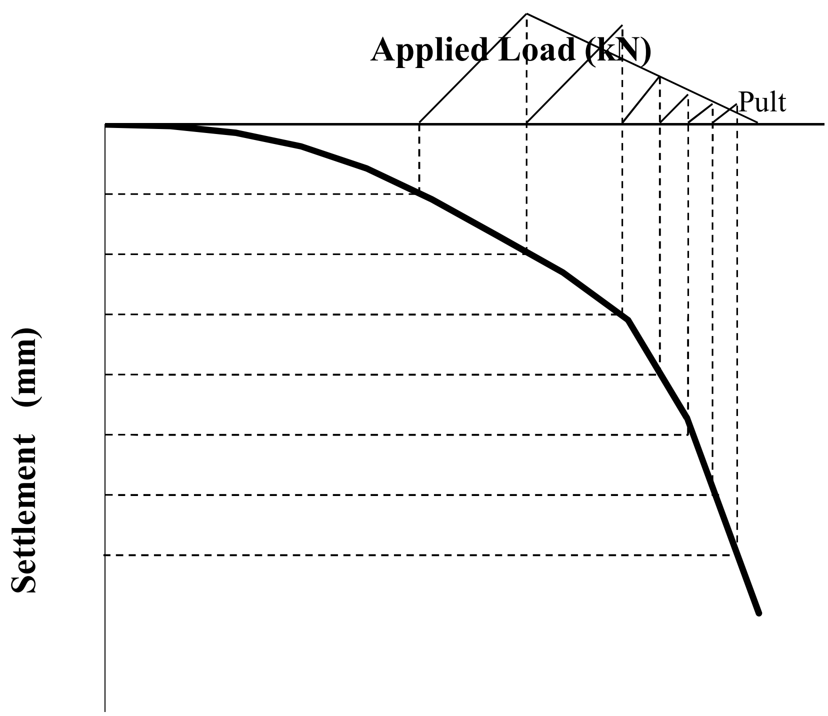

Fig. 6. Mazurkiewicz's method of determining Pult from static load test data

3.6 DeBeer Method

DeBeer method obtained the yield load at the intersection of the two lines appeared when the load-settlement data plotted using a double-logarithmic diagram as shown in Fig. 7. [4].

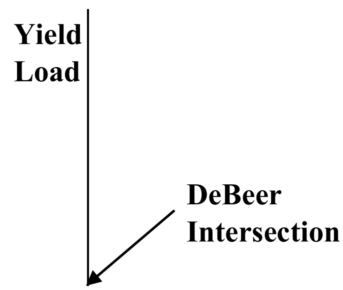

Fig. 7. DeBeer method of determining yield load from static load test data

4 CPT TESTS

The cone penetration test (CPT) is one of the in-situ tests used to interpret the pile load capacity, where, it is considered as a small-scale pile. CPT test is performed by pushing the standard cone (according to ASTM D 3441 with cross-section area of 10 cm^2) into the ground at a rate of 10 to 20 mm/s. Data of the tip resistance q_c, sleeve friction f_s, and pore water pressure U_2, are collected every 12-mm penetration using electric data acquisition equipment and a portable computer [3]. CPT tests can be performed easily in fine-grained soils, while it is more difficult in the case of granular soils. Two concepts are used to analyze CPT results to obtain the pile load capacity. The first one is the indirect method in which the in-situ test data are used first to calculate soil parameters and which used to predict the pile load capacity within theoretical formulas. The second one is the direct method whereby the measured readings are used directly for evaluation the pile load capacity [9]. There are several direct methods to predict the pile load capacity from the CPT test data such as Aoki & De Alencar (1975), Penpile (1978), Schmertmann (1978), de Ruiter and Beringen also known as the European method

(1979), Philipponnat (1980), Tumay & Fakhroo (1982), Bustamante and Giasenelli (1982) (LCPC method), Prince & Wardle (1982), Van Impe (1986), Eslami & Fellenius (1997) [10]. Alex Silvey (2018) calculated the pile load capacity for driven piles in Nebraska using eight known CPT based methods and he suggested that Penpile and LCPC methods are the most accurate prediction methods [10]. Andras (2003) used DIN 4014 method as an indirect method in case of cohesive soils to predict the pile load capacity for CFA piles in Hungary. He stated that this indirect method is affected by the prediction of undrained shear strength (Cu). Also, he used LCPC, EUROCODE 7-3 and ERTC 3 methods for pile capacity predictions. He suggested that LCPC method gives accurate pile capacity values. The LCPC and DIN 4014 methods will be reviewed and applied to the tests conducted in this study in the following:

4.1 Bustamante and Giasenelli (LCPC method)

LCPC method accommodates different pile systems and soils. The method depends on the cone resistance q_c to evaluate the unit skin friction along the pile and the unit end bearing beneath the pile toe [11]. Both end bearing load (Q_p) and the skin friction load (Q_F) are determined as follows:

$$Q_P=q_{ca}.k_c.\pi D^2/4 \qquad (9)$$

$$Q_F=\sum q_{si}.\pi Dl_i \qquad (10)$$

$$q_{si}=q_c/\alpha \qquad (11)$$

Where:

q_{ca} is the equivalent cone resistance at the pile point equal to the arithmetical mean of q_c measured along a height range between +1.5m and -1.5m from the pile point.

K_c is the bearing capacity factor, depending on q_c and soil type as shown in Table 1.

D is the pile diameter.

q_{si} is the unit skin friction at the level of the layer i

l_i is the thickness of the layer i

α is a coefficient depending on q_c, soil nature and pile type as shown in Table 2.

TABLE 1. Values of Bearing Capacity Factor kc in LCPC Method

Nature of soil	q_c (Mpa)	Factor k_c	
		Group I	Group II
1-Soft clay and mud	< 1	0.40	0.50
2-Moderately compact clay	1 - 5	0.35	0.45
3- Silt and loose sand	≤ 5	0.40	0.50
4- Compact to stiff clay and compact silt	> 5	0.45	0.55
5-Soft chalk	≤ 5	0.20	0.30
6-Moderately compact sand and gravel	5 - 12	0.40	0.50
7-Weathered to fragmented chalk	> 5	0.20	0.40
8-Compact to very compact sand and gravel	> 12	0.30	0.40

Group I:
- Plain, cased, mud and hollow auger bored piles
- type I micropiles (grouted under low pressure)
- Piers - barrettes (a rectangular pile used in europe)

Group II :
- Cast screwed piles - Jacked piles
- Driven piles, with or without post-grouting
- Type II micropiles (or small diameter piles grouted under high pressure, with diameters 250 mm)

TABLE 2. Values of coefficients α in LCPC Method

Soil	q_c Mpa	Coefficient α				Maximum value of q_s (Mpa)					
		IA	IB	IIA	IIB	IA	IB	IIA	IIB	IIIA	IIIB
1	<1	30	30	30	30	0.015	0.015	0.015	0.015	0.035	
2	1-5	40	80	40	80	0.035 0.08	0.035 0.08	0.035 0.08	0.035	0.08	≥0.12
3	≤5	60	150	60	120	0.035	0.035	0.035	0.035	0.08	
4	>5	60	120	60	120	0.035 0.08	0.035 0.08	0.035 0.08	0.035	0.08	≥0.2
5	≤5	100	120	100	120	0.035	0.035	0.035	0.035	0.08	
6	5-12	100	200	100	200	0.08 0.12	0.035 0.08	0.08 0.12	0.08	0.12	≥0.2
7	>5	60	80	60	80	0.12 0.15	0.08 0.12	0.12 0.15	0.12	0.15	≥0.2
8	>12	150	300	150	200	0.12 0.15	0.08 0.12	0.12 0.15	0.12	0.15	≥0.2

Note: the higher values of maximum qs are applied to careful execution and minimum disturbance of soil due to construction

Catogry IA :

- Plain, cased, mud and hollow auger bored piles

- Cast screwed piles - Piers - barrettes - Type I micropiles

Catogry IB :

- Cased bored piles - driven cast piles

Catogry IIA :

- Driven precast piles -Prestressed piles - Jaced concrete piles

Catogry IIB :

- Driven metal piles - Jaced metal piles

Catogry IIIA :

- Driven grouted piles

Catogry IIIB :

-High pressure grouted piles with diameter >250mm

-Type II micropiles

4.2 DIN 4014 (German Standard) method

The German Standard DIN 4014 provides empirical values for the unit base and shaft resistance of a bored pile for cohesive and non-cohesive soils [12]. The unit base resistances for non-cohesive and cohesive soils are shown in Table 3 and Table 4 respectively. The ultimate skin friction resistances are shown in Table 5 and Table 6.

TABLE 3 Point Resistance in Non-Cohesive Soil – DIN4014

q_c (Mpa)	Unit base resistance (Mpa)
10	2
15	3
20	3.5
25	4

TABLE 4 Point Resistance in Cohesive Soil – DIN4014

C_u (Mpa)	Unit base resistance (Mpa)
0.1	0.80
0.2	1.50

TABLE 5 Skin Friction Resistances in Non-Cohesive Soil – DIN4014

q_c (Mpa)	Unit shaft resistance (Mpa)
0	0
5	0.04

10	0.08
15	0.12

TABLE 6 Skin Friction Resistances in Cohesive Soil – DIN4014

C_u (Mpa)	Unit shaft resistance (Mpa)
0.025	0.025
0.1	0.04
0.2	0.06

5 TEST SITE

All the tests (CPT and static pile load tests) were performed at a site of construction of "2760 residential and social units" in Alsalam area in Port Saied City, Egypt. According to the carried out boring logs shown in Fig. 8, the soil formation at the site consists mainly of the following layers:

- A top layer of loose to medium dense sand with different ratios of silt of 13.5m thickness.
- Then, a layer of soft to medium silty clay with a thickness of about 28.5m.
- Followed by a layer of very dense sand with some silt with a thickness of about 4.0m.
- Finally, a layer of very stiff to hard silty clay layer extending up to a depth of 60.0m.

Table 7 shows the material parameters estimated from the results of standard penetration tests as well as laboratory testing including odometer, direct shear box and Atterberg limits.

Depending on the results of CPT tests, the top layers of sand are dense to very dense and intercalated with medium stiff to stiff silty clay of thickness varies between several centimeters to few meters. The minimum undrained shear strength of the soft to medium clay ranges between 25kPa and 30 kPa at the top of the layer and increases with depth to reach 60 kPa at 25m.

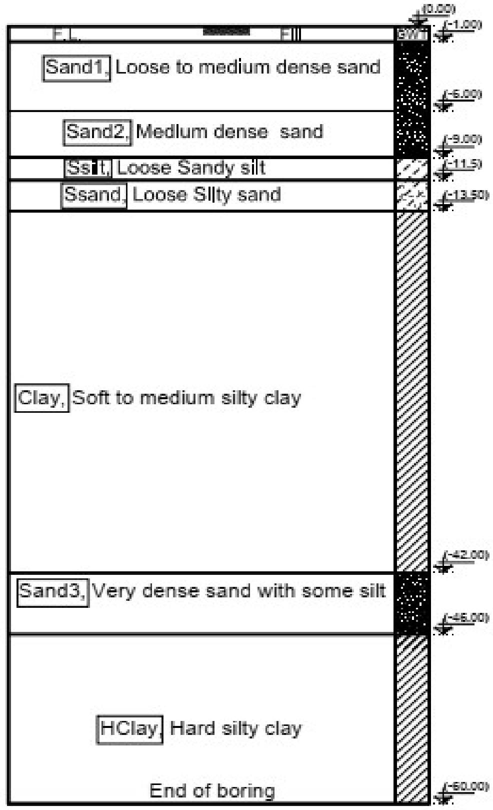

Fig. 8. Soil formation obtained from borehole logs

TABLE 7 Soil Parameters Obtained From Boring Logs

Parameter	Upper sand	Soft to med. clay	Lower sand
Total unit wt.(kN/m^3)	17	17	19
c' (kPa)	2	1	1
Ø' (degree)	32	22	42

6 STATIC PILE LOAD TEST RESULTS

Static pile load tests were performed on (7) bored piles of 60 cm diameter and 27m length. The piles design load was determined using static formula mentioned in the Egyptian code and it was 800kN. The tests were conducted up to load of 2000kN which was 2.5 times the design load. The resulting data are shown in Table 8 and the load-settlement relationships are shown in Fig. 9.

TABLE 8 Resulting Data of Pile Loading Tests

Load (kN)	Settlement (mm)						
	Pile (1)	Pile (2)	Pile (3)	Pile (4)	Pile (5)	Pile (6)*	Pile (7)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.33	0.26	0.44	0.47	0.43	0.30	0.36
400	0.57	0.46	1.40	0.95	0.69	0.74	0.84
600	0.90	0.71	2.39	1.58	1.22	1.22	1.30
800	1.32	1.02	4.13	2.56	1.96	1.90	2.10
1000	1.66	1.34	5.49	3.39	2.86	2.55	2.70
1200	2.21	1.73	7.54	4.74	3.35	3.35	3.94
1400	2.83	2.11	8.93	6.39	4.78	4.20	4.70
1600	3.66	2.59	9.79	8.74	6.13	5.10	6.00
1800	4.22	3.26	11.81	11.58	8.08	7.65	7.10
2000	5.95	4.91	17.81	17.54	13.12	--	9.13
1800	5.94	4.63	17.78	17.49	13.06	--	8.80
1600	5.71	4.31	17.75	17.3	12.93	7.15	8.50
1400	5.32	3.94	17.67	16.93	12.66	6.9	8.23
1200	5.04	3.53	17.33	16.56	12.38	6.5	8.00
1000	4.77	3.14	16.93	16.23	12.07	6.07	7.70
800	4.65	2.67	16.38	15.84	11.76	5.8	7.40
600	4.46	2.15	15.81	15.34	11.35	5.33	7.17
400	3.88	1.78	15.18	14.76	10.79	5.0	7.10
200	3.54	1.32	14.51	13.86	10.04	4.60	6.85
0.0	2.61	0.53	12.81	10.81	8.63	3.90	6.35

* Pile (6) was loaded up to load of 1800kN.

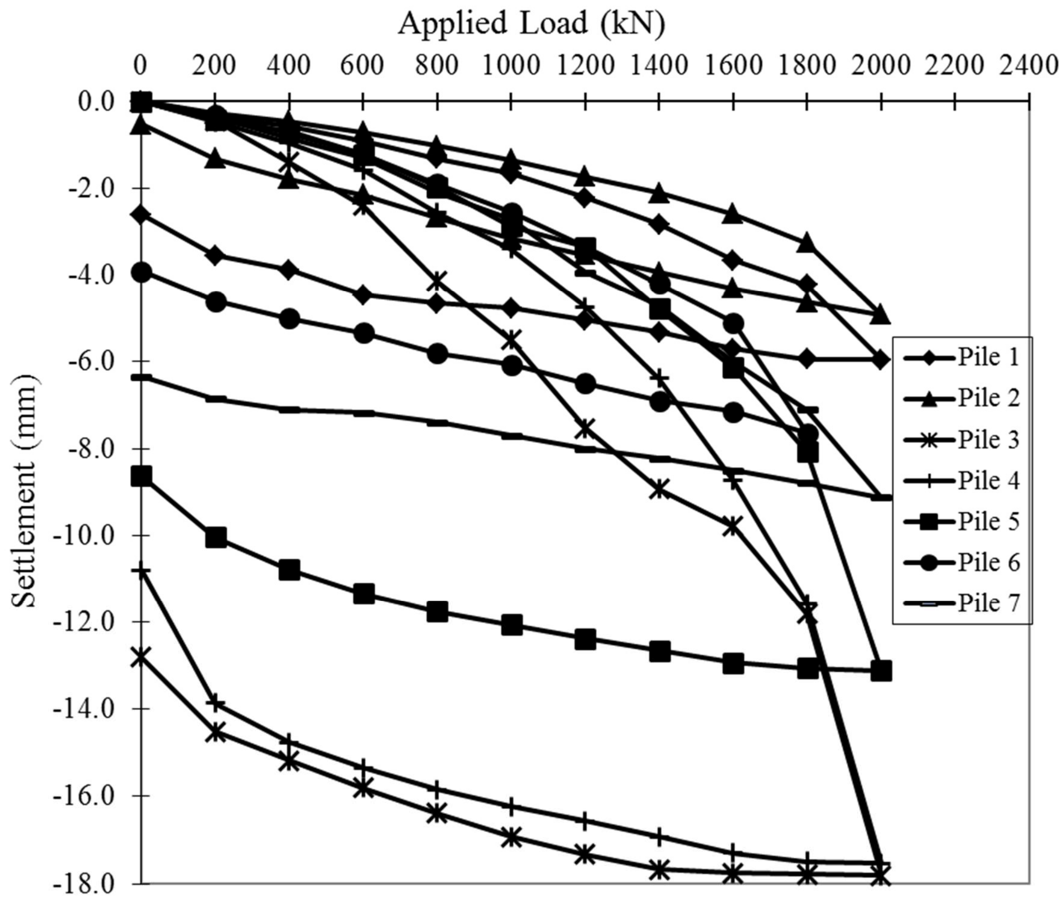

Fig. 9. Load-Settlement Relationships of the Pile Loading Tests

The tests results were analyzed using the above mentioned different methods. Results of the predicted values of the ultimate pile load capacities are summarized in Table 9. Davisson method was not applicable because Davisson's criterion line did not intersect the load-settlement curve for all tests. This is because Davisson method requires access to a test load close to the failure load. So, the hyperbolic load-settlement curve determined using C_1 and C_2 obtained from Chin-Kondner method was used in Davisson method because there was a good matching between this curve and the load-settlement plots obtained from tests. This hyperbolic plot is more close to the actual load-settlement curve than the parabolic curve obtained by Brinch Hansen method. In most cases, the results obtained from Davisson method were smaller than all used methods except for DeBeer method. Also, DeBeer method was not applicable for some tests because there was no noticeable change in the slope of the drawn line. DeBeer results were very low compared with other methods. It can be noticed that there was a convergence between the results of each of Chin-Kondner, Decourt and Mazurkiewicz methods, and their results were higher than other methods. Also, a very good matching was noticed for the results of

80%Hansen and 90%Hansen criteria which were smaller than each of Chin-Kondner, Decourt and Mazurkiewicz methods in most cases. The average values of the ultimate load capacities obtained from Davisson and Hansen methods were close together. The same notice was observed for the average values of Chin-Kondner, Decourt and Mazurkiewicz methods.

TABLE 9 Results of ultimate load capacities predicted from pile loading tests

Pile No.	Predicted Ultimate Load Capacity (kN)						
	Davisson	Hansen 80%	Hansen 90%	Chin	Decourt	Mazurk.	DeBeer
1	3150	2410	2390	3540	3640	3100	--
2	3200	2360	2330	3560	3960	3400	1800
3	2200	2570	2540	3350	2620	3000	1800
4	2120	2540	2510	2640	2630	2250	--
5	2280	2480	2460	2680	2840	2550	1200
6	2280	2330	2300	2660	2720	2550	1600
7	2600	3480	3450	3260	3110	3000	--
Average	2547	2596	2569	3099	3074	2836	1600

7 CPT TEST RESULTS

Three penetrometer tests (CPT) were performed at the site down to depths of 25 m below the existing ground. Fig.10 shows the measured parameters from CPT tests. Bustamante and Gianeselli (LCPC) method was used as a direct method to analyze the tests data. While, the method stated in DIN-4014 was used as an indirect method for analysis. Results obtained from the two methods are summarized in Table 10. Both the two used methods gave results close to each other. It can be noticed that the end bearing contribution is very small compared with the skin friction. The reason for this is because the pile ends in the soft to medium clay layer. The average ultimate pile capacities predicted from CPT tests were compatible with the values obtained from pile loading tests which analyzed using Davisson and Hansen methods.

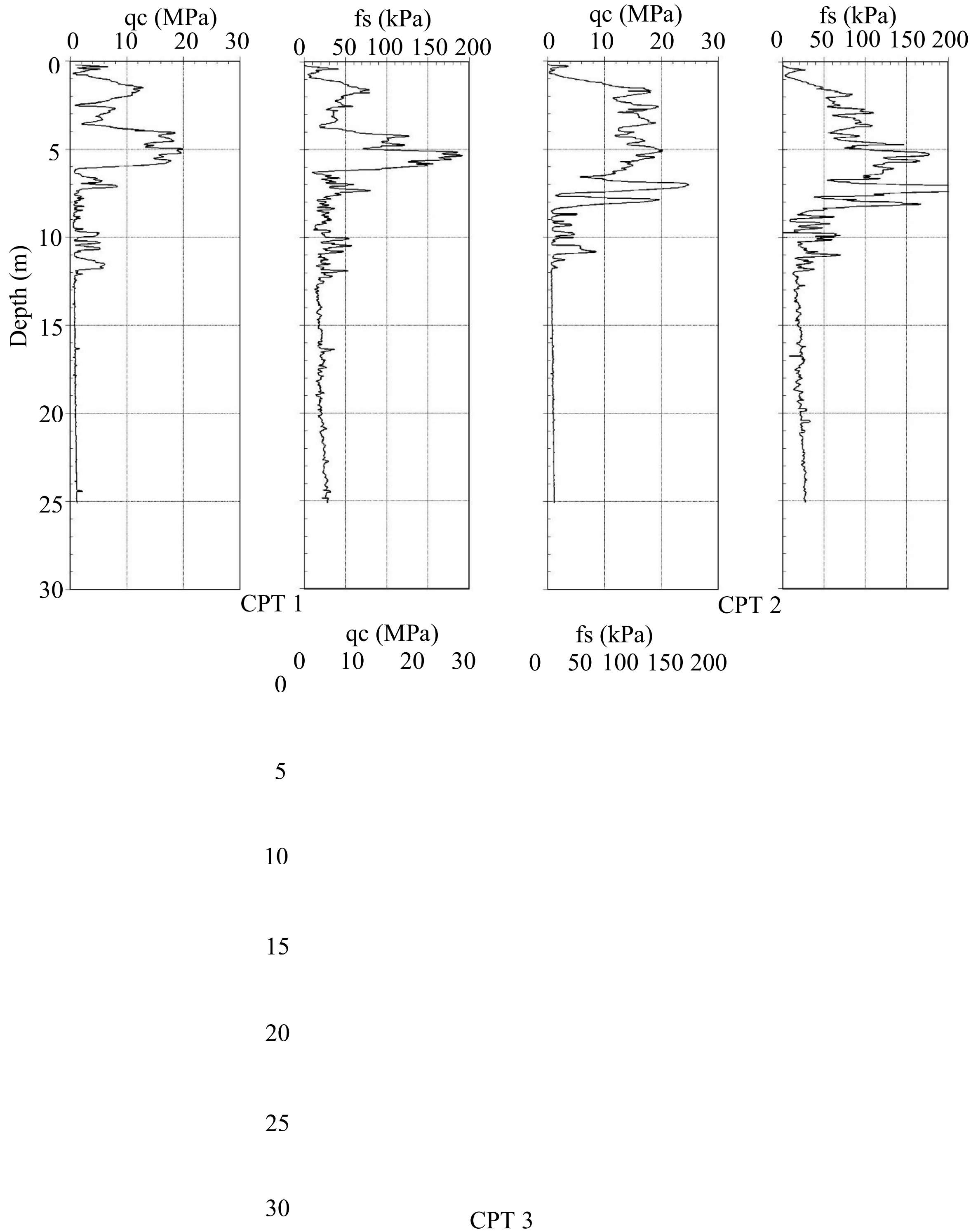

Fig. 10. Measured Parameters from CPT Tests

TABLE 10 Results of ultimate load capacities predicted from CPT tests

Test No.	Predicted Load (kN)					
	LCPC			DIN 4014		
	End Bearing	Side Friction	P_{ult}	End Bearing	Side Friction	P_{ult}
1	140	2220	2360	170	2130	2300
2	140	2330	2470	170	2400	2570
3	140	2490	2630	170	2700	2870
Average	140	2347	2487	170	2410	2580

8 CONCLUSIONS

Based on the results of this research the following conclusions may be drawn

1. The hyperbolic plot obtained from Chin method is more close to the actual load-settlement curve than the parabolic curve obtained by Brinch Hansen method.
2. Davisson's criterion line did not intersect the load-settlement curve in most cases because Davisson method requires access to a test load close to the failure load.
3. The results obtained from Davisson method were smaller than all used methods except for DeBeer method.
4. DeBeer method was not applicable for some tests because there was no noticeable change in the slope of the drawn line. DeBeer results were very low compared with other methods.
5. Chin-Kondner, Decourt and Mazurkiewicz methods gave convergence results, and their results were higher than other methods.
6. Very good matching was noticed for the results of 80%Hansen and 90%Hansen criteria which were smaller than each of Chin-Kondner, Decourt and Mazurkiewicz methods in most cases.
7. The average values of the ultimate load capacities obtained from Davisson and Hansen methods were close together. The same notice was observed for the average values of Chin-Kondner, Decourt and Mazurkiewicz methods.
8. Both LCPC and DIN 4014 methods to predict P_{ult} from CPT tests gave results close to each other.
9. The end bearing contribution is very small compared with the skin friction. The reason for this is because the pile ends in the soft to medium clay layer.
10. The average ultimate pile capacities predicted from CPT tests were compatible with the values obtained from pile loading tests predicted using Davisson and Hansen methods.

REFERENCES

[1] Andras, M., "Use of Cone Penetration Test in Pile Design", periodica polytechnica ser. civ. eng. vol. 47, no. 2, pp. 189–197, 2003.

[2] Coduto, D., Kitch, W., and Yeung, M., "Foundation Design Principles and Practices",

Third Edition, 2016. (Book style)

[3] Atta, A., "Dutch Cone Penetration Tests for Construction of 2760 Residential & Social Units Housing Authority – Governorate of Port Saied", unpublished report, 2013.

[4] Fellenius B. H., "Basics of Foundation Design", Electronic Edition, 2012.

[5] Kedar C., "Evaluation of Ultimate Pile Compression Capacity from Static Pile Load Test Results", 1st GeoMEast International Congress and Exhibition, Egypt, 2017.

[6] Fellenius, B. H., "The analysis of results from routine pile load tests", Ground Engineering, London, Vol. 13, No. 6, pp. 19 – 31, 1980.

[7] Don W. Dotson, "Technical note-Direct Solution of the Brinch-Hansen 90% Pile Ultimate Failure Load", DFI Journal, The Journal of the Deep Foundations Institute · June 2013.

[8] Abdelrahman G. E., Shaarawi E. M., and Abouzaid K. S., "Interpretation of Axial Pile Load Test Results for Continuous Flight Auger Piles", Proceedings of the 9th Arab Structural Engineering Conference, Abu Dhabi, UAE, pp. 791-801, 2003.

[9] Paul W. Mayne, "Cone Penetration Testing State-of-Practice", Synthesis Study Submitted to Transportation Research Board, 2007.

[10] Silvey, A., "Evaluation and Development of CPT Based Pile Design in Nebraska Soils", Civil Engineering Theses, Dissertations, and Student Research. 127. 2018.

[11] Bustamante, M., and L.Gianeeselli, "Pile Bearing Capacity Predictions by Means of Static Penetrometer CPT", Proceedings of the 2nd European Symposium on Penetration Testing, ESOPT-II, Amsterdam, Vol. 2, pp. 493-500, 1982.

[12] DIN 4014, Bored Cast-in-Place Piles, 1990