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Behavior of the C.F.A Piles in Gharbia Governorate of Egypt by Using Numerical Simulation

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ملخص البحث:

سلوك منحنى الحمل والهبوط للخوازيق المنفذه بالحفر ، والتي تختلف من منطقه إلى أخرى في منطقه الدلتا من مصر وتحديدا (محافظه الغربية) ، يمكن توضيحها باستخدام نتائج اختبار التحميل للخوازيق وحيث ان طرق التحليل العددية هي من بين الادوات الواعدة التي يمكن اعتمادها لتقييم قدره التحمل القصوى للخوازيق . الهدف من هذا االبحث هو دراسة السلوك النظري لمنحنى الحمل والهبوط للخوازيق المنفذه بالحفر في مواقع مختلفه في محافظه الغربية ، استنادا إلى نتائج اختبار التحميل بالاضافه الى اجراء دراسة استقصائية شامله للقدرة الاستيعابية لللخوازيق في منطقه الدلتا في مصر والتي تحتوي علي مدن مثل طنطا ، زفتى، سمنود ، المحلة الكبرى ، السنطه ، قطور ، كفر الزيات وبسيون.

تهدف الدراسة الحاليه الى عمل تقييم لحساب قدرة تحمل القصوى للخوازيق ذات الاقطار اقل من 60 سم وذلك باستخدام التحليل العددى بواسطه البرنامج التجارى PLAXIS بالاضافه الى عمل محاكاه لاختبار تحميل الخازوق فى الموقع للتحقق من معاملات نموذج الحدود اللامتناهيه التى تتحكم فى سلوك منحنى الحمل والهبوط للخازوق وقد اظهر البحث وجود تقارب بين قدرة تحمل الخازوق المحسوبة بطريقه الحدود اللامتناهيه والمحسوبه من نتائج اختبارات التحمبل للخوازيق فى منطقه الدلتا بنسبة تصل الى 82 % للخوازيق المنفذه بالحفر وقد اشار البحث الى ان قدرة تحمل الخازوق القصوى فى طريقة الحدود اللامتناهيه تحدث عند هبوط يصل الى 2% من قطر الخوازيق ومن هذا الاستنتاج نستطيع ربط نتايج اختبارات التحميل للخوازيق بطريقه الحدود اللامتناهيه.

Abstract:

Behaviour of load-displacement curve of The Continuous Flight Auger (C.F.A.) piles, which varies from region to another in delta zone of Egypt (Gharbia governorate), can be illustrated by using the results of static pile load test. Numerical approaches are amongst the promising tools that can be adopted to assess the bearing capacity of piles. The objective of this paper is to study theoretically load-displacement behaviour of C.F.A piles at different locations in Gharbia governorate, based on static pile load test results. The study aims to perform a total survey of the bearing capacity of C.F.A piles in delta zone of Egypt which contains cities such as Tanta, Zifta, Samannoud, Al-Mahalla Al-Kubra, Alsanta, Qu-tour, Kafr El-zayat and Bassyun. The study was carried out with the aid of numerous software such as (2D PLAXIS, version 8.2), which is depend upon elastic perfectly-plastic finite element models, as well as (All Pile, version 7; SHAFT, version 8) which are relied on (p-y) analysis curve. In addition, the research showed that there is a convergence between the bearings capacities of the piles calculated in terms of the infinite limits calculated from the results of the tests of the rigging of the piles in the delta region up to 82% of the bored piles, so that the ultimate pile capacity is mobilized at settlement equal to 2% of pile diameter, which is in agreement with the ECP values for small diameters.

Keywords: Load-Displacement Curve, C.F.A Piles, Finite Element Method, 2D-PLAXIS program, Axial Capacity, Delta Zone of Egypt.

1. Introduction:

Piles are the most popular type of deep foundations. They have the capability of carrying the entire load of a large column from a bridge or tall building in terms of a single shaft.

Piles resist applied loads through side friction (shaft or skin friction) and end bearing as shown in Fig. (1). Friction piles resist a significant portion of their loads by the interface friction, which developed between their surface and the surrounding soils. On the other hand, end-bearing piles rely on the bearing capacity of the soil underlying their bases. Usually, end-bearing piles are used to transfer most of their loads to a stronger stratum that exists at a reasonable depth. Design bearing capacity (resistance) can be defined according to (**Wrana, 2015**) [1] as the following:

$$R_{c;d} = Q_b + Q_s = A_b * q_b + \sum A_{s,i} * q_{s;i;d} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

$R_{c;d}$: Design resistance as the capacity parameters which determined from designing standards

: Characteristics of unit base resistance.q_b

: Characteristics of unit shaft resistance in the i-th layer.$q_{s;i;d}$

A_b : Cross section area of end bearing pile.

$A_{s,i}$: Shaft area of side resistance of pile.

If the skin friction is greater than about 80% of the end bearing load capacity ,the pile is deemed a friction pile and if the reverse, an end bearing pile .The manner in which skin friction is transferred to the adjacent soil depends on the soil properties. To predict the pile capacity of piles, a number of methods have been developed that allow engineers to estimate the pile capacity at specific locations as well as the approximate length of pile to achieve a design capacity. The pile load test is one of the most practical and efficient techniques that determine resultant axial pile load capacity, however, it is very expensive and there is a need for new techniques that lower cost and efficient at same time. The load test may be carried out either on a driven pile or a cast-in-situ pile .load tests may be implemented either on a single pile or a group of piles.

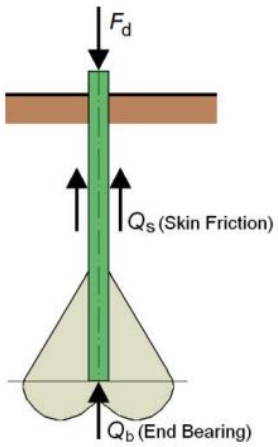
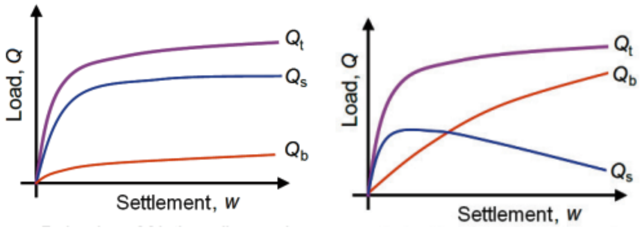


Figure 1: Pile's side friction and end bearing.

Fig. (2) shows typical load/settlement curves for compressive load of the shaft Q_S and the base Q_s load capacity and the total load capacity Q_t characteristic depending on soil layers: (a) for friction pile and (b) for end-bearing pile.



(a) **(b)**

Figure 2: Typical load/settlement curves for compressive load tests:
(a) Behavior of friction pile; (b) Behavior of end-bearing pile
under compression loading.

Load tests on a pile group are very costly and may be undertaken only in very important projects. Pile load tests on a single pile or a group of pile are conducted for the determination of axial load bearing capacity, Uplift load capacity and Lateral load capacity. In delta zones due to its lower level, the subsurface soil consists of successive layers of sand, clay and silt sediments. These deposits are usually built up from mix of these soils. In many cases, thick sand or stiff clay layers exist underlain with other soft soils at relatively shallower depths. These layers can be used as bearing soils for pile foundation with a careful study of the expected settlement. This study focuses on the load-displacement behaviour of bored piles at different locations in Gharbia governorate based on pile load test results.

2. Test Sites:

Eight sites, located in Gharbia governorate, were selected to perform a total survey of load- displacement behavior of bored piles, each city was represented by one borehole solely, because of the resemblance between the other boreholes in diameter, length, and cohesion. These sites contain cities such as Tanta, Zifta, Samannoud, Al-Mahalla Al-Kubra, Alsanta, Qu-tour, Kafr-Elzayat and Bassyun as shown in Fig. (3). what is more, all sites include piles which have a small diameter (diameter less than 0.60 m), and its length is varying from 13 to 23 m.

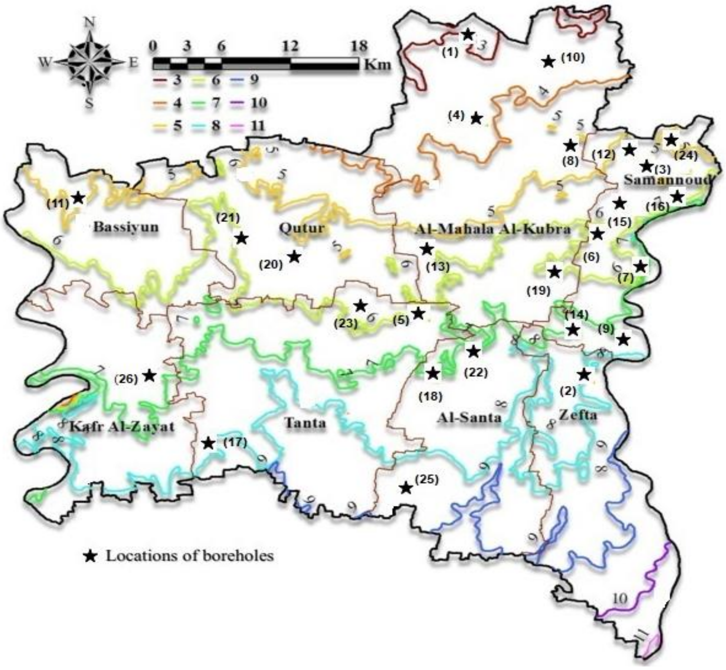


Figure 3: Elevation contours (m) of the Gharbia governorate with the locations of reprehensive boreholes.

3. Soil Profile at Study Sites:

In each side there is a borehole was executed. Fig. (3), shows both borehole and static load test locations for all the studied sites. Samples were collected from boreholes every meter and necessary tests were carried out. The final water level was found at depths 0.5 and 3 meter from the existing ground for the majority of sites. Majority of Soil profiles consists of the following layers as shown in Fig. (4).

1. Fill of grey loamy clay or fill of dirty loamy sand.
2. Brown soft to medium silt clay followed by dark grey very soft to soft silty clay.
3. Dark grey fine silty sand, traces clay, and trace mica.
4. Organic dark black clay.
5. Grey medium/fine sand with silt lenses and traces.
6. Yellowish grey medium/fine sand, and trace gravel.

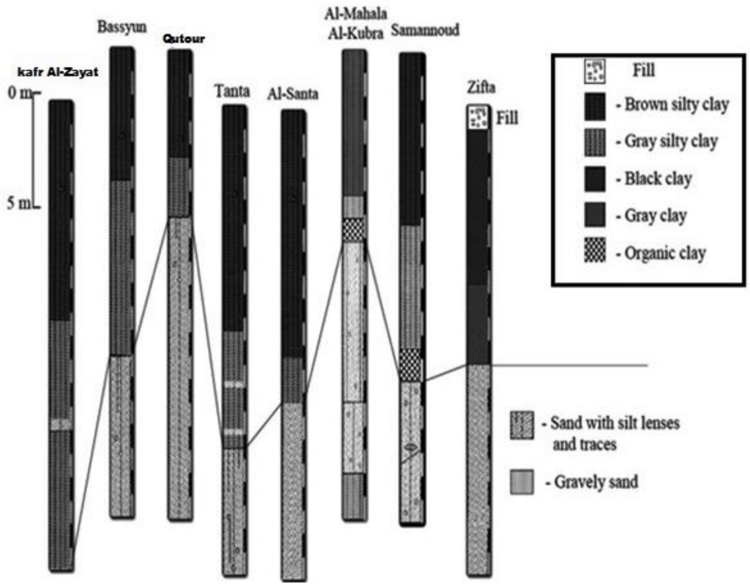


Figure 4: Topical soil profile of the Gharbia governorate region.

4. Estimation of Pile Bearing Capacity:

Pile foundations typically support heavier and more important structures, so it is appropriate to devote more time and effort to determine their axial load capacities. The methods of predicting these capacities may be divided into three broad categories:

1. Full-scale static load test.
2. Analyses based on soil properties obtained from laboratory or in-situ tests or from direct correlations with in-situ results. These are known as static methods.
3. Analysis based dynamic methods.

Full-Scale Load Tests

Most precise way to determine the axial load capacity is to drive a full-size prototype pile in the site and load it to failure .A load test also must include a means of measuring the displacement of the pile. This most frequently consists of dial gages mounted on reference beams as shown in Fig. (5). It is likewise to include aback up system, such as a surveyor's level.

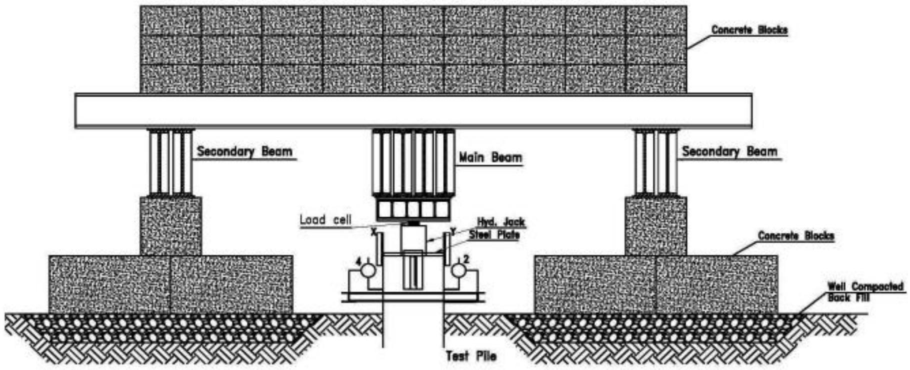


Figure5: Arrangement details of the axial compression pre-construction pile load test.

In this research the ultimate bearing capacity and the corresponding settlement contributions for each pile diameter were determined by using the Full-scale static Load tests in all the studied sites There are two categories of load tests: controlled stress tests and controlled strain tests, most load tests use controlled stress methods. These are also known as a maintained load (ML) tests. These tests typically use load increments of 25, 50, 75, 100, 125, and 150% of the proposed design load and hold each increment until the pile stops moving or until the rate of movement is accepted according to the Egyptian code of practice for soil mechanics and foundations, part (4)[2].

5. Numerical Modeling:

Numerical models are capable of predicting not only the onset of failure, but also the complete stress-strain response leading up to failure using different programs. The study was carried out with the aid of numerous software such as (PLAXIS 2-D, v 8.2) [3], which is depend upon elastic perfectly-plastic finite element models, (All Pile, v 7) [4] and (SHAFT, v 8) [5] which are relied on (p-y) analysis curve.

PLAXIS Program Model

Finite element modelling (FEM) were implemented adopting PLAXIS 2-D program. The geometry dimension was determined after several trials to insure taking the effect of surrounding soil.
For (PLAXIS 2-D, v 8.2) [3] program, the elastic-plastic Mohr-Coulomb model takes the increase of stiffness with depth into account, the Mohr-Coulomb model (MC) does neither include stress dependency nor stress-path dependency of stiffness or anisotropic stiffness. The Axisymmetric models as shown in Fig. (6), were used with the 15 nodes element. The mesh was generated by the program with (Fine) mesh as shown in Fig. (7), which subsoil is consisted of layers of 30 m thickness. The Mohr-Coulomb model was considered to model elastic- plastic behavior of soils samples. It involves five input parameters: which are (Es) and (ν) for soil elasticity; (Φ) and (c) for soil plasticity and (Ψ) angle of dilatancy. Since we considered sand soils in this study in the drained case, soil cohesion was set to 1*10-3 KPa to avoid errors. Standards fixities are applied at the edges (horizontally fixed edges) and fixed in both ways for the bottom edge.

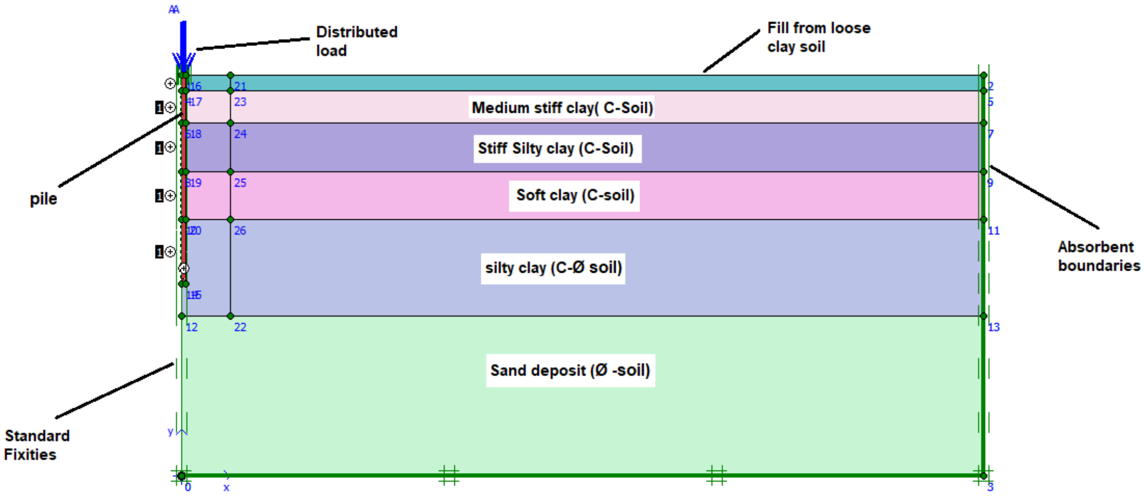


Figure 6: The geometry for 2D PLAXIS model.

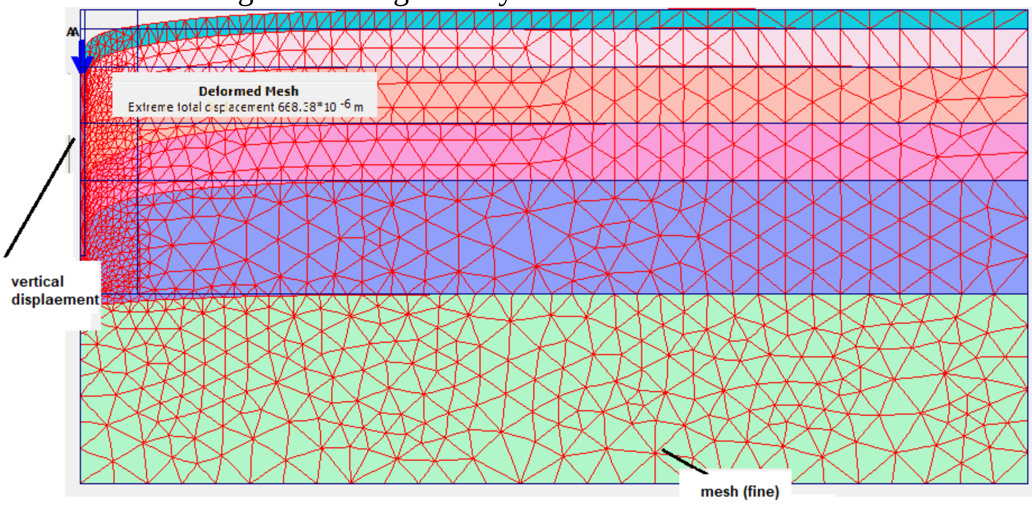


Figure 7: The deformed mesh for 2D PLAXIS model No (26) after applying load.

The pile modulus of 50% strength (E50) using the introduced an empirical formulae of (**Poulus, 1995**) [6] to calculate stiffness parameters of clay soil. The soil stiffness parameters presented were function of the undrained shear strength of clay soils as shown in Table (1).

E_S = (200- 400)*Cu ……………….. (2)

Table1: Soil properties for clay soils in PLAXIS program.

Soil classification	Modulus of elasticity (KN/m^2)	Unit weight γ (KN/m^3)	Poisson's ratio (ν)	Depth of ground water level m	Cohesion C (KN/m^2)	R inter
Soft	2250-4500	15.5-18.3	.35-.45	0.5-3.0	15-25	0.65-0.7
Medium	8000-16800	19.5-20.5			40-60	0.7-0.85
Stiff	21000-44000	20-21			70-110	0.85-1.0

A nonlinear analysis was assumed, so that (E50) represent a secant modulus for low load level. (**Kishida and Nakai, 1977**)[7] Introduced empirical formulae to calculate stiffness parameters of sand soil. The soil stiffness parameters presented were function of N of SPT number and were related to the relative density (Dr) of sand soils as shown in Table (2).

$$E_s = 1.6 * N_{SPT} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Table 2: Soil properties for sand soils in PLAXIS program.

Soil classification	Modulus of elasticity (KN/m^2)	Unit weight γ (KN/m^3)	Poisson's ratio (ν)	Angle of ϕ (deg)	Dilation angle ψ (deg)	R inter	Cohesion C (KN/m^2)
Medium -Dense	16-41.6	17.9-19.2	0.3-0.35	33-38	3-8	0.8-1.0	0.001

The interface around the piles is also carried out to fulfill the soil structure interaction. The interface strength was mentioned by (R_{int}) coefficient (**Gomes, 2013**) [8] .Values of R_{int} was set to be 0.8. Piles were made from R.C material. For R.C materials, the modulus of elasticity was set to be $2.2*10^7$ KN/m^2 and the Poisson's ratio (ν_c) was taken to be 0.20. Table (3) shows the properties of pile in (2D PLAXIS) model.

Table 3: pile parameters adopted in 2D PLAXIS program.

Material	fc (KN/m^2)	Diameter of pile (m)	Modulus of elasticity E (KN/m^2)	Unit weight (KN/m^3)	Poisson's Ratio (ν)
Pile	2500	0.5-0.6	2.2x10^7	25	0.2

All Pile Program Model

All Pile program analyzes pile load capacity efficiently and accurately. All Pile can handle all types of piles: drilled shaft, driven pile, auger-cast pile, steel pipe pile, H-pile, timber pile, tapered pile, bell pile, shallow foundation, etc. Additionally, define new pile types and input customized parameters based on local practices and experience. (The input parameters for clay, sandy soils deposits and piles are summarized in Table (4), Table (5) and Table (6) for (All Pile, v 7) [4] program respectively. Reese Method which based on (Reese and O'Neil, 1988) [9] was used for settlement analysis.

Table 4: Soil properties for clay soils in All Pile program.

Soil classification	Unit weight G (KN/m^3)	Cohesion C (KN/m^2)
Soft	15.5-18.3	15-25
Medium	19.5-20.5	40-60
Stiff	20-21	70-110

Table 5: Soil properties for sandy soils in All Pile program.

Soil classification	Unit weight G (KN/m^3)	N1 spt Value	Phi(deg)
Medium -Dense	17.9-19.2	10-26	33-38

Table 6: Element specifications of pile in All Pile program.

Material	width (m)	Modulus of elasticity E (MN/m^2)	I (m4)	A_t (m2)
Pile	0.5	22000	2.1475x10^-3	0.19635
	0.6		4.4532 x10^-3	0.2827

SHAFT Program Model

SHAFT is a special -purpose program based on rational procedures for analyzing a drilled shaft under axial loading, along with the distribution of axial load along the length of the shaft. The input parameters for clay, sandy soils deposits and piles are summarized in Table (7), Table (8) and Table (9) for (SHAFT, v 8) [5] program respectively. Program based on the studies by (**Rollins et al, 2005**) [9], a number of major improvements were implemented in (SHAFT, v 8) such as generate curves of load-settlement with pile penetration and computations of side resistances for sand based on SPT blow counts (when provided).

Table 7: Soil properties for clay soils in SHAFT program.

Soil classification	Total unit weight γ (KN/m3)	Cohesion C (KN/m2)	Side friction resistance factor
Soft	15.5-18.3	15-25	0.5
Medium	19.5-20.5	40-60	
Stiff	20-21	70-110	

Table 8: Soil properties for sandy soils in SHAFT program.

Soil classification	Total unit weight γ (KN/m3)	Blow count from spt Value	Angle of ϕ (deg)	End bearing Resistance factor
Medium -Dense	17.9-19.2	10-26	33-38	0.45

Table 9: Element specifications of pile in SHAFT program.

Material	width (m)	Modulus of elasticity E (KN/m2)
Pile	0.5	2.2x10^7
	0.6	

6. Results and Discussions:

The study aims to perform a total survey of the bearing capacity of C.F.A piles in delta zone of The results of each pile static load test were presented in terms of load versus displacement of bored piles at the different locations by using the measured values in the field test, the predicted values using (**Chin-Kondner, 1970**) [10] (**Brinch Hansen, 1965**) [11], All Pile for Reese Method, (2D PLAXIS FEM) and SHAFT program. Results of load-displacement, which obtained from static pile load test. The table below demonstrate the required results of different situations as well as the required details of each single pile .these details may be represented in terms of lengths, diameters, depth of cohesive soil and depth of ground water table,. Additionally, this table shows the deign load of each single pile according to its locations.

Table 10: Summarized field load test result in each region in Gharbia governorate

Test No.	Model NO.	Site Location	Pile length L (m)	Pile Diameter D (m)	Depth of Ground water level G (m)	Depth of Cohesive soil L^* (m)	Pile load Test Q (KN)	Field load test result		
								Quit Chin (KN)	Quit Brinch (KN)	Q_{ult} Average (KN)
1	2	Zifta	15.8	0.5	2.0	10.3	1000	1179.14	1257.75	1218.44
2	11	Bassyun	20	0.5	0.5	14	1600	1922.12	2050.26	1986.19
3	13	Al Mahalla-Al Kubra	16	0.5	2.6	8	1000	1491.13	1590.54	1540.84
4	21	Qu-tour	14	0.6	1.8	8	1200	1822.81	1944.33	1883.57
5	22	Alsanta	23	0.6	2.5	16	1200	1874.22	1999.92	1936.69
6	23	Tanta	15	0.6	3.0	7	1400	2088.92	2228.18	2158.55
7	24	Samannoud	22	0.5	1.9	17	1200	1213.29	1294.1	1253.73
8	26	Kafr-Elzayat	13	0.6	2.6	9	1000	1002.60	1069.44	1036.0

The following charts depict the results of pile load test, which implemented in site, and also the outcomes of the different programs (PLAXIS, All Pile, and SHAFT) for 8 samples. These samples were taken from 8 different sites, which located in Gharbia governorate, in which the site can be represented by a one sample.

Model No (2) –Zifta – Gharbia Governorate

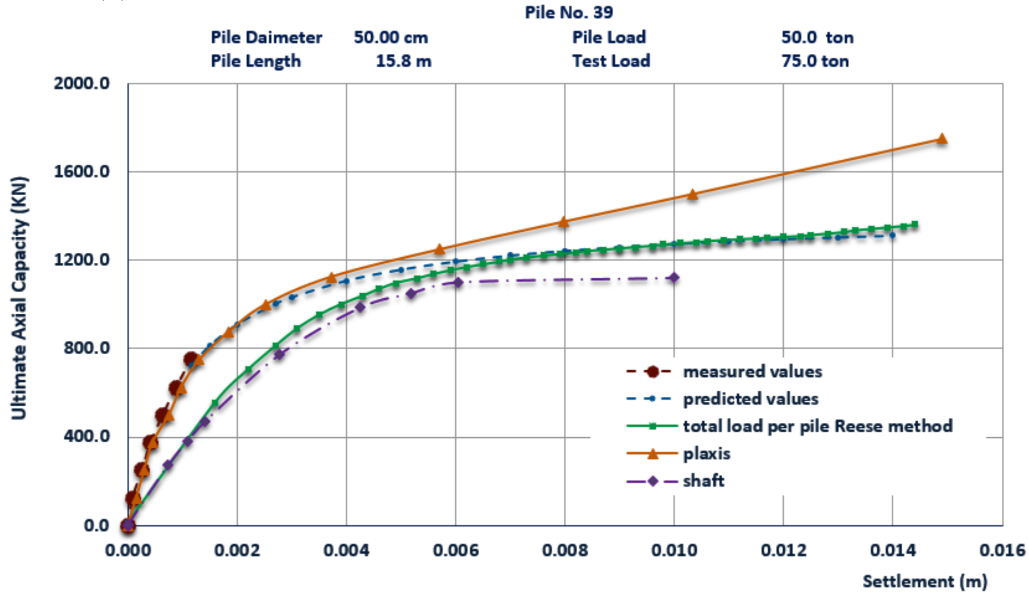


Figure 8: Load- settlement behavior of the pile model No (2) using different methods in a site at Zifta city.

Model No (11) –Bassyun– Gharbia Governorate

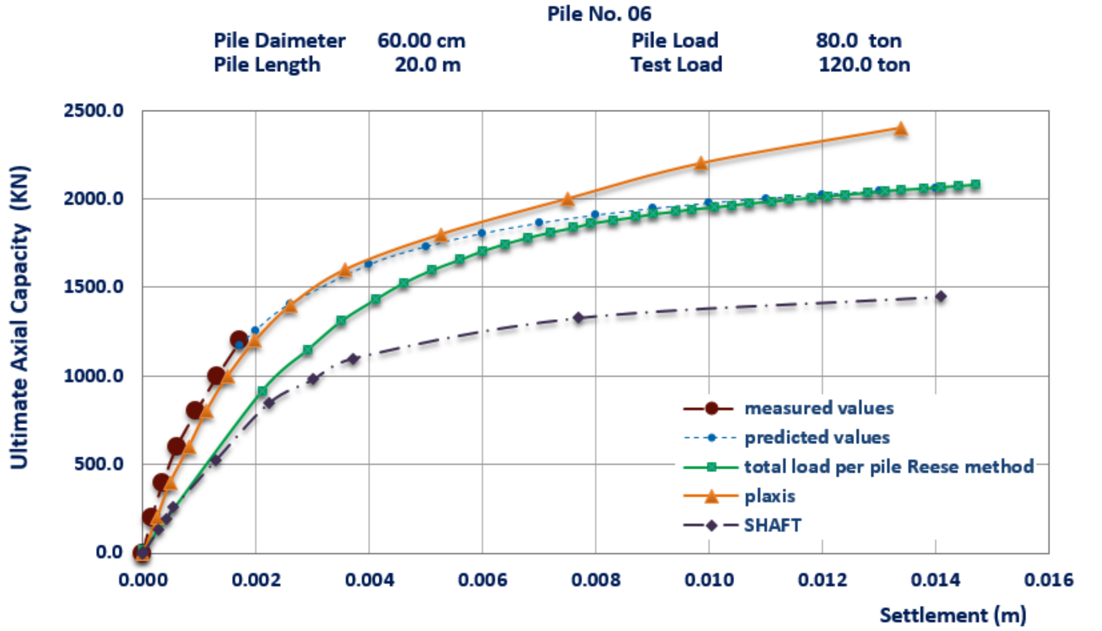


Figure 9: Load- settlement behavior of the pile model No (11) using different methods in a site at Bassyun city.

Model No (13) – Al-Mahalla Al- Kubra – Gharbia Governorate

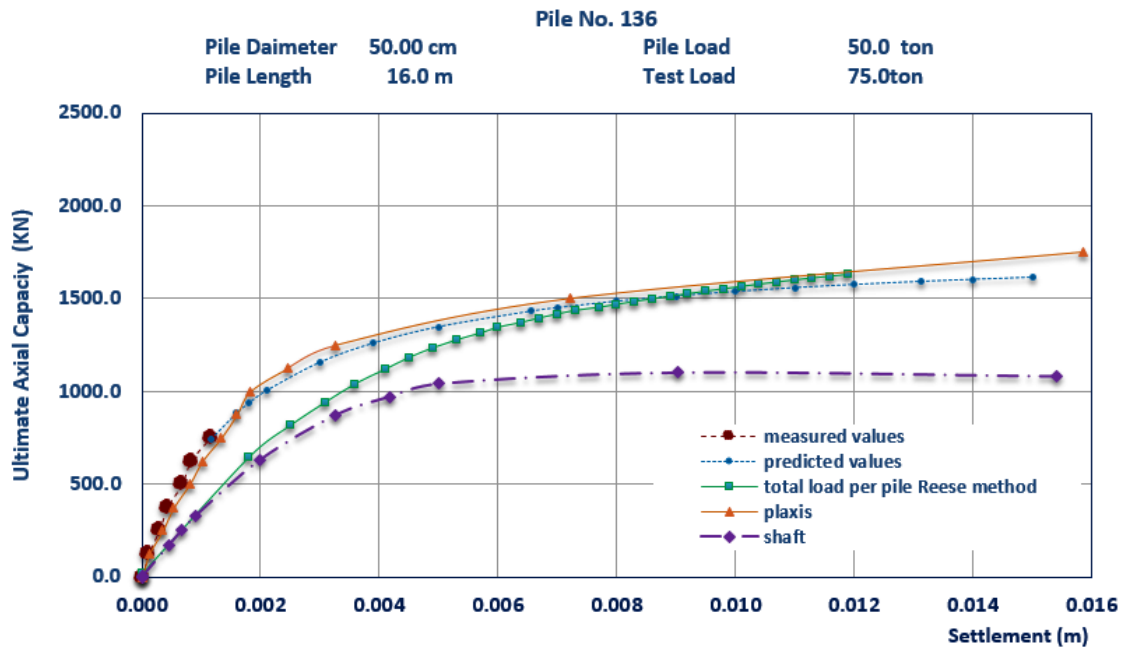


Figure 10: Load settlement behavior of the pile model No (13) using different methods in a site at Al-Mahalla Al- Kubra city.

Model No (21) – Qu-tour –Gharbia Governorate

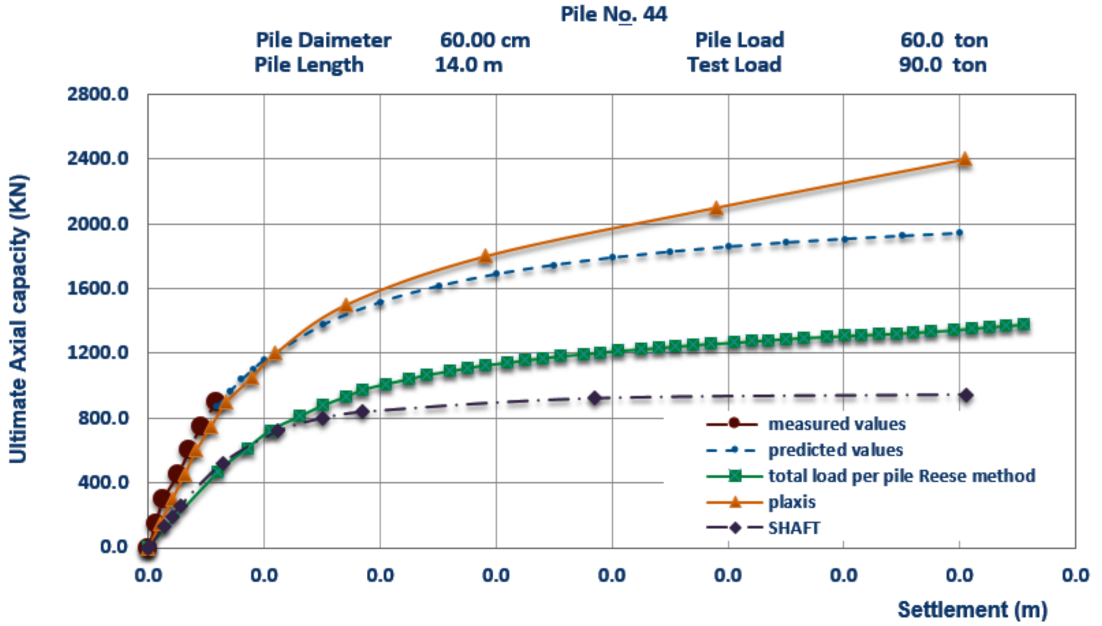


Figure11: Load- settlement behavior of the pile model No (21) using different methods in a site at Qu-tour city.

Model No (22) – Alsanta – Gharbia Governorate

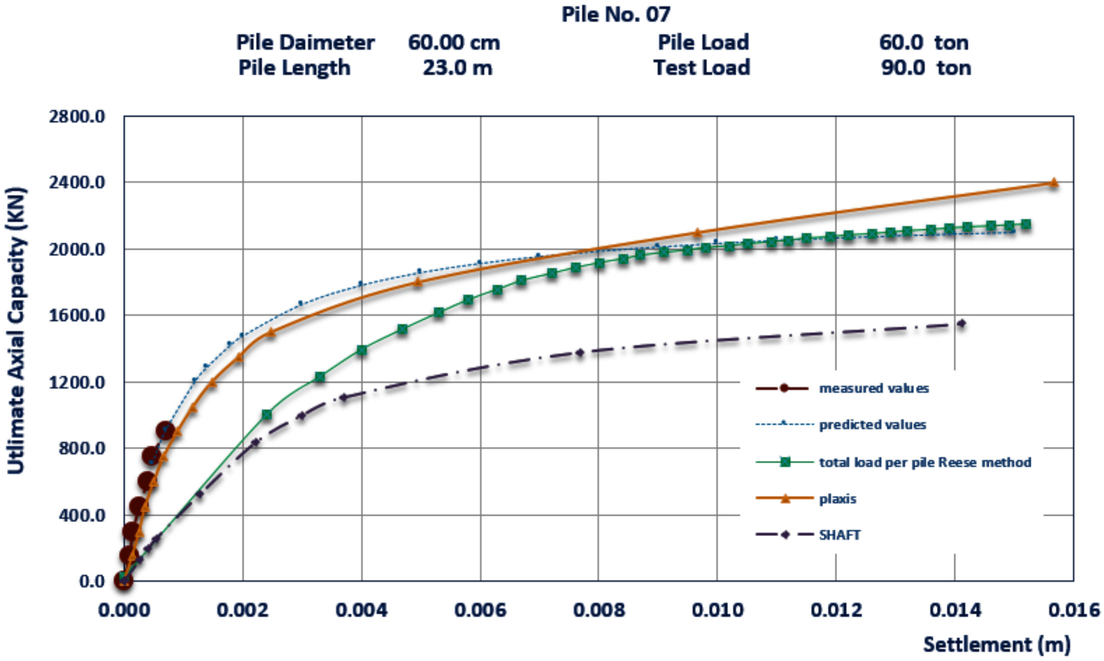


Figure 12: Load- settlement of the pile model No (22) using different methods in a site at Alsanta city.

Model No (23) – Tanta – Gharbia Governorate

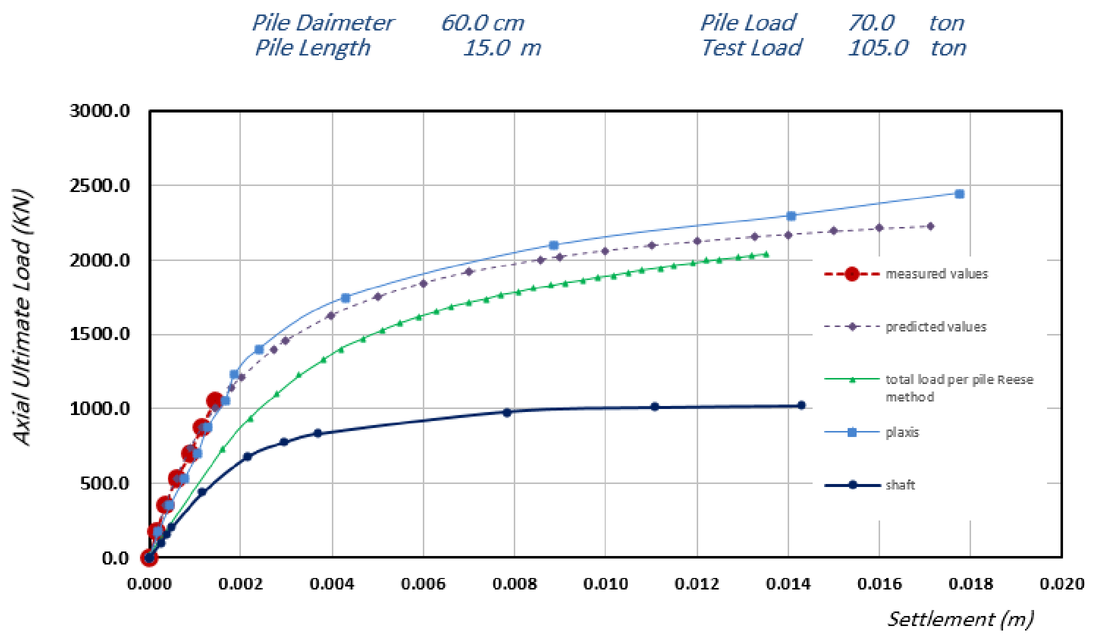


Figure 13: Load- settlement of the pile model No (23) using different methods in a site at Tanta city

Model No (24) – Samannoud – Gharbia Governorate

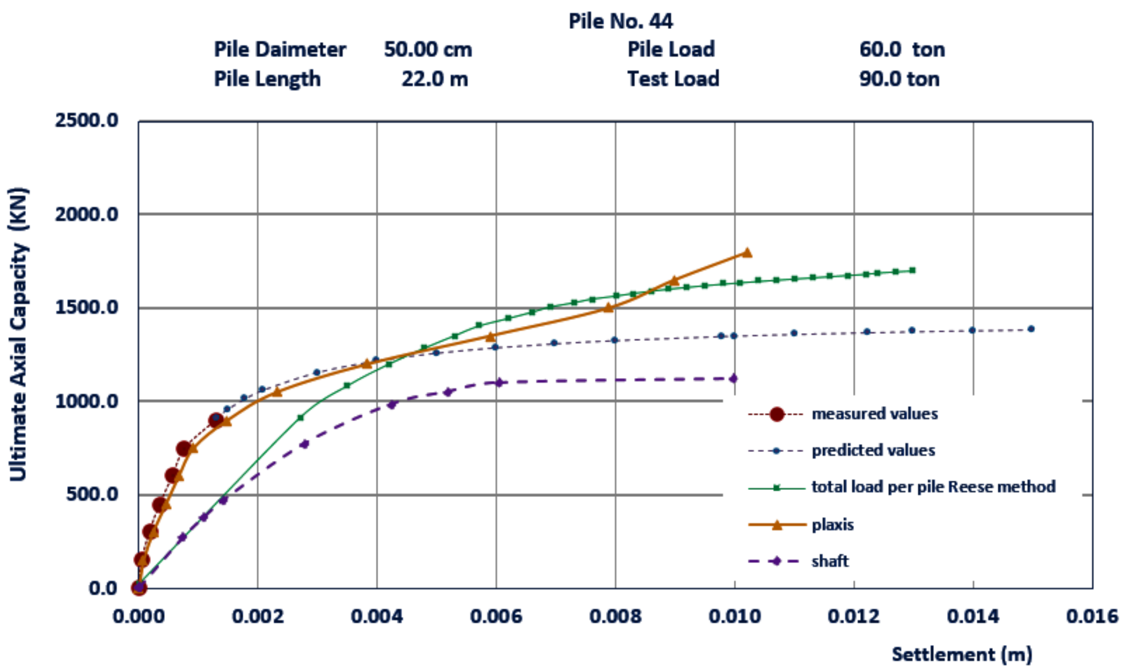


Figure 14: Load- settlement of the pile model No (24) using different methods in a site at Samannoud city.

Model (26) – Kafr-Elzayat – Gharbia Governorate

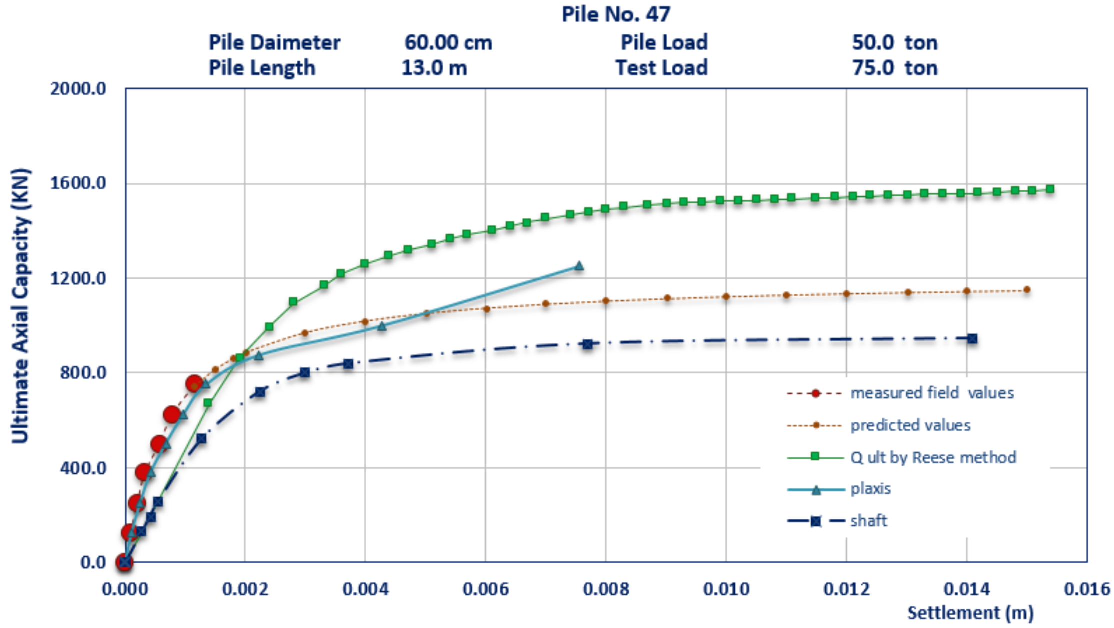


Figure 15: Load- settlement of the pile model No (26) using different methods in a site at Kafr-Elzayat city.

As shown in the above-mentioned Charts as well as the calculated results that shown in table (11), and with taking into consideration the comparison between the outcomes of programs and pile load test which carried out at load equal to one and half of its designed load according to the Egyptian code of practice. It is observed that PLAXIS' program results nearly coincide with the results of pile load test by 85% in comparison with the results of other programs (All Pile, SHAFT) as shown in table (12).

Table 11: Summarized settlement in different method in each region in Gharbia governorate.

Test No.	Model No.	At Pile load Design (Q)				At Pile load Test(150%Q)			
		Settlement in Field mm	Settlement in PLAXIS mm	Settlement in All Pile mm	Settlement in SHAFT mm	Settlement in Field mm	Settlement in PLAXIS mm	Settlement in All Pile mm	Settlement in SHAFT mm
1	2	0.6425	0.7551	1.409	1.547	1.1575	1.310	2.367	2.478
2	11	0.9375	1.11	1.847	3.247	1.715	1.98	3.09	5.982
3	13	0.6775	.80445	1.422	2.564	1.1675	1.34	2.253	4.364
4	21	0.6975	0.8189	1.51	2.723	1.17	1.341	2.721	5.367
5	22	0.3975	0.469	1.45	2.62	0.71	0.798	2.18	4.29
6	23	0.8975	1.06	1.527	2.68	1.4375	1.61	2.61	6.346
7	24	0.6686	0.785	1.77	1.94	1.30	1.49	2.66	4.146
8	26	0.5625	0.6684	1.172	1.124	1.155	1.34	1.47	3.10

Table 12: Summary of compared settlement rates between software program and test load results in each region at Gharbia governorate.

$\frac{\Delta\, Field}{\Delta\, program}\%$	At Pile load Design(Q)	At Pile load Test(150%Q)
PLAXIS	(84.2-85.2)%	(86.2-89.3)%
All Pile	(37.7-57.2)%	(38.6-60.2)%
SHAFT	(15.2-47.9)%	(17.8-54.7)%

Based on the above, and according to the Egyptian code of practice, ultimate failure load can be extracted at settlement equal to 2% of the pile diameter as shown in table (13). Additionally, the percentage of failure load in Egyptian code with respect to PLAXIS' program was calculated as shown in table (14).

Table 13: Summarized the ultimate load of the piles at 2% of the pile diameter in each region at Gharbia governorate.

Test No.	Model NO.	Site Location	Q_{ult} brinch (KN)	Q_{ult} PLAXIS (KN)
1	2	Zifta	1273.9	1480
2	11	Bassyun	1977.2	2260
3	13	Al Mahalla-Al Kubra	1537.14	1610.8
4	21	Qu-tour	1860.3	2260
5	22	Alsanta	2036.32	2140.90
6	23	Tanta	2127.2	2730.4
7	24	Samannoud	1348.9	1760.78
8	26	Kafr El-zayat	1134.7	1960.2

Table 14: Summary of compared load rates between ultimate loads of the piles in each region at Gharbia governorate.

$\frac{Qult}{Qult\, program}\%$	At field load result Average
PLAXIS	82%

7. Conclusions:

Based on the previous investigations of pile capacities of bored piles in delta zone of Egypt, it can be concluded the following:

1. The settlement, which observed in full scale field test is nearly coincide with the results at the same load in 2D PLAXIS program by 85%.
2. Using (2D FEM) has a good agreement in estimating the pile load capacity.
3. The load- settlement curves of bored pile in different regions using All Pile and SHAFT programs is so far in comparison with other methods.
4. Ultimate failure load of pile, located in Gharbia governorate, may be predicted by using proposed correlation, which states that ultimate load equals nearly 82% of load that generated by 2D PLAXIS program .

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