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Expansive Concrete for Bored Piles Embedded in Stratified Soil

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ملخص البحث:

تعتبر الأساسات العميقة الحل الأمثل لمهندسي التربة في حالات ضعف طبقات التربة السطحية التي تعلو طبقات سفلية قوية. الأساسات الخازوقية هي النوع الأكثر شيوعا في الأساسات العميقة، وبالأخص خوازيق الحفر (أو التفريغ) التي تمتاز بكونها مناسبة لتحمل أشكال مختلفة من المنشأت, و بالتالي من المهم إيجاد طرق لتطوير أداء هذه الأنواع من الخوازيق. من المقترحات الواعدة لتحسين قدرة تحمل الخوازيق هي استخدام الخرسانة المنتفشة في صب الخوازيق. يتناول هذا البحث دراسة تجريبية والتي تمت لاستكشاف جدوى استخدام هذه الطريقة في حالة خوازيق الحفر المدفونة في طبقات تربة طينية ومرتكزة على طبقات رملية عميقة قوية. يقدم هذا البحث نتائج الدراسة المعملية لخوازيق الحفر المرتكزة ع طبقات الرمل ومحاطة بطبقات من التربة الطينية. المادة المستخدمة في صب تلك الخوازيق هي الخرسانة المنتفشة، ومن خلال هذه التجارب المعملية تم التحقق من تأثير تغيير العوامل المدروسة ومنها قطر الخازوق وطول الخازوق المدفون بالتربة والتصاقيه التربة المحيطة بالخازوق. أظهرت النتائج عن زيادة في قدرة تحمل الخازوق بنسبة تتراوح من 37% الى 75%

Abstract:

Deep foundations are a very good solution for geotechnical engineers in cases of weak surface layers underlain by a firm soil layer. The most common type of deep foundations is piled foundations, specially bored piled foundation, Bored piles have many advantages so they can be a suitable choice to support a wide range of structures. Consequently, it is important to improve the performance of such type of piles. One of the promising proposals for improving the capacity of bored piles is using the expansive concrete in the construction of piles. This paper presents an experimental study which was conducted to explore the feasibility of using this technique in case of bored piles embedded in clayey soil underlain by firm sandy soil. This paper presents the results and conclusions of experimental study on bored piles resting on sand bed and surrounded by clayey soil. The material of the tested piles was expansive concrete, and the experimental tests program was performed to investigate the different effects of many studied parameters including pile diameter (Dp), embedded length(Le), and cohesion of the surrounding clay (C). The results showed an increase in the pile capacity ranging from 37 % to 75 %.

Keywords: expansive cement, bored piles, expansive concrete, cement type k, pile capacity.

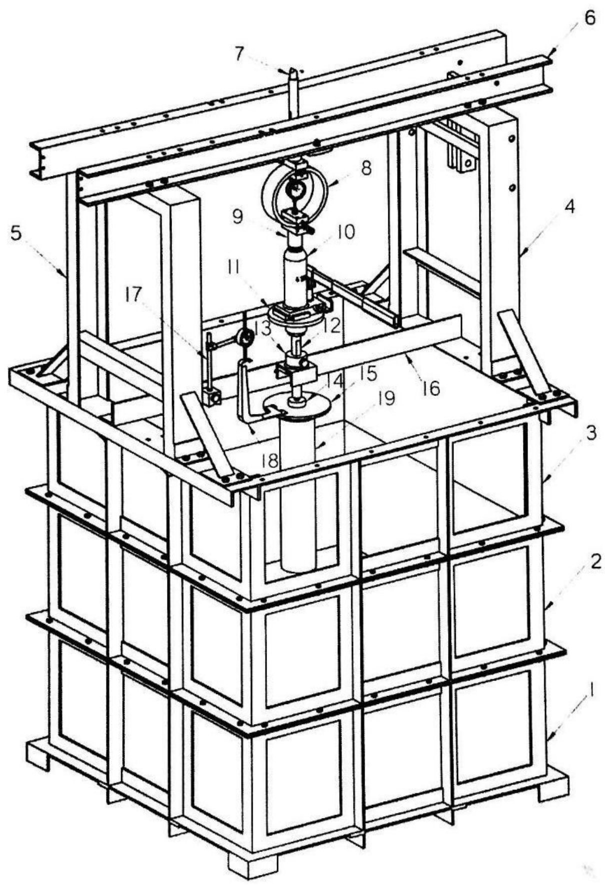
1- Introduction:

Deep foundations have always been the embodiment of geotechnical engineering applications, by neglecting weak soil strata and transferring the load to deeper stronger strata to minimize settlement of structures due to vertical, inclined, lateral, uplift loads and over turning moments according to H. G. Poulis. Piles are usually classified based on method of installation, the material of which they are formed and load carrying characteristics of piles as reported by Bernard A. Grand, Hardesty and Hanover (1946). Bored piles have been commonly used for its efficiency and ease of application. A new technique is proposed for increasing the capacity of bored piles by using the Type K expansive concrete. Type K cement (Expansive cement) is used in concrete mix, according to (ACI 223R), a shrinkage compensating concrete mix, that results in an increase in the volume after hardening. In a previous study, "Effects of using Swelling Concrete in Piles on Bored Piles Capacity" by Mohamed E. Elsaid, experimental tests were conducted to show the increase in ultimate load capacity when using expansive concrete in bored piles embedded in sandy soil. The results shown an increase of ultimate load of piles ranging from (10.4% to 30.4%), explained to be due to an increase in the frictional resistance of piles with sand. Bored piles in general are more commonly stranded in weak soil strata, applying the load to bearing soil layer. In this study, other experimental tests were performed to investigate the effect of using expansive concrete on the ultimate pile capacity of end-bearing bored piles resting on sand and overlaid by clayey soil. The material of piles was expansive concrete and many different parameters where studied.

2- Experimental Work:

2.1-Testing Program

The testing program consisted of two series of experimental tests. The first series was to determine the physical and mechanical properties of soil types and expansive concrete behavior. The second series was through static loading of thirty-two bored piles, which wereconducted on a bored pile model using the testing set up, shown in figure (1), The tests were performed by applying load on a steel pile cap fitted at the top of the pile model, the load was applied to the pile in stages, each maintained until the rate of settlement of pile is lower than
0.305 mm/hr or until 2 hours have elapsed as stated by A.S.T.M D1143-57T for the maintained load testing procedure, measuring the corresponding settlement, and consequently determining the ultimate pile capacity at which, the pile base settlement (S) was equal to one tenth of pile diameter as stated in Civil engineering code of practice No.4, (1954) and "Soil Mechanics in engineering practice" by Karl Terzaghi, Ralph B. Peck, Gholamreza Mesri .



1: Base box
2: Middle box
3: Top box
4: Right leg
5: Left leg
6: Main beam
7: Base load
8: Proving ring
9: Top base of jack
10: Jack
11: Bottom base of jack
12: Main bar load
13: Guide of load
14: Disc load
15: Base of pile
16: Beam as a guide for loading shaft
17: Dail gauge
18: Base of dail gauge
19: Tested pile

Figure (1): Experimental Device.

Experimental Device.

Soil Type	**Soil composition**	**Optimum Moisture content (%)**	**Maximum dry density (gm/cm2)**	**Angle of friction (Φ)**
Sand	Fine/medium sand, trace gravel, trace fine	12	1.86	36.01°
Soil Type	**Soil composition**	**Liquid Limit (%)**	**Plastic limit (%)**	
Clay	Clayey silt, some fine sand	24	16	

Table (1): Soil Properties

Specimen Water content	12%		13%	14%		16%	
ɣ Wet	1.5	1.7	1.7	1.5	1.7	1.5	1.7
Unconfined compressive strengthqu KN/m2	90.2	186.3	158.9	45.1	141.2	32.4	115.7
Effective cohesion c KN/m2	45.1	93.2	79.4	22.6	70.6	16.7	57.9

Table (2): Unconfined compressive strength test results

2.2- Experimental Device:

The testing set up used in the second series of experimental tests shown in figure (1) consists of a steel container that was divided into three box shaped parts of internal dimensions 1000x1000 mm, height of 400 mm, made of angular steel 50x50 mm. These boxes are hollow from the front side where 3 sheets of transparent plastic are fitted. Two legs made of (U) shape steel channel, with dimensions 100x70x70 mm and height 800 mm, main beams that consisted of two (U) shape steel channel, with dimensions 100x70x70 mm and length 1400 mm. Before applying the load on the pile, a Hydraulic jack of 5-ton capacity with a pressure gauge which was used for measuring the applied load on the pile, calibrated with a proving ring of 10-ton capacity, which was fitted in the upper part of the test device setting.

2.3-Testing series (1):

The first series was conducted to determine the characteristics of two types of soils, the sand soil atop of which the pile rests, and the clay soil placed surrounding the pile. Also, some tests were conducted for the expansive concrete used during the experimental testing program. Table (1) shows the results of sieve analysis test, modified proctor test and shear box test for the sand, and hydrometer test (Particle size analysis), plastic and liquid limit forclay. Unconfined compressive strength test, results shown Table (2), was also conducted onclay soil. A series of compressive strength tests, results shown Table (3) were conducted on different ratios of expansive komponant at ranges from 15%-17% of total cementitious content as recommended by manufacturer (CTS Komponent Datasheet) to ensure keeping the stress similar to Portland concrete.

2.4-Testing series (2):

The Implementation of the bored pile model consists of 5 phases, the test began by filling the container with the bearing soil layers (Sand) each layer is 50 mm in height compacted using compacting tool to reach the desired relative density of sand, capped at the pile base

layer. Secondly, a plastic pipe was installed in the center of the container resting on the sand soil, acting as the pile casing where concrete is poured later. These pipes vary in diameters whichwere 50, 63, 75, 89, 100 mm, and lengths of 300, 400, 500, 600, 700 mm, varying with parameter studied. Thirdly, clay was formed outside the container by using kaolin clay powder and water, a specific weight of clay was placed around the plastic pipe in the container. Each layer was compacted to 50 mm in height to reach different wet densities of clay surrounding the pile shown figure (2). By changing the wet densities of clay as well as the water content, different cohesion values of clay soil were achieved, previously determined by unconfined compressive strength test which were 22.5, 45.1, 57.9, 70.6, 79.4,
93.1 KN/m2 varying with the parameter studied Table (2). After that, Concrete was preparedfor casting in the pipe. The concrete then was casted and compacted by a hammer, and at thesame time casing pipe was removed slowly to complete the process of pouring the concrete of the bored pile. Steel pile cap was set in the center of the pile and is adjusted horizontally by the water leveling device. After leaving the concrete for 7 days, a pile load system was applied on top of the pile using a Hydraulic jack of 5-ton capacity with a pressure gauge, calibrated with a proving ring of 10-ton capacity. The load was applied gradually through thehydraulic jack and was accurately determined by the pressure gauge on the hydraulic jack, until the settlement measured by the dial gauge reached tenth of pile's diameter to determine the ultimate bearing capacity of piles. That series was conducted on thirty-two bored piles shown in Table (3) categorized under two groups of different types of concrete with three varying parameters including embedded length (Le), pile diameter (Dp) and effectivecohesion of surrounding soil, clay, (c').

Figure (2): Formation and placement of clay

No.	Komponat	Cube size (Cm3)	Cube weight (kg)	Curing time (Days)	Density (gm/cm3)	Weight (kg)	Stress KN/m2	Average
1	15%	3375	8.01	7	2.37	30870	14709.98	115.667
2	15%	3375	8.025	7	2.38	30820	13435.11	
3	15%	3375	8.055	7	2.39	13750	5883.99	
4	15%	3375	8.155	28	2.42	62790	27370.36	252.333
5	15%	3375	8.06	28	2.39	41920	18269.79	
6	15%	3375	8.02	28	2.38	65620	28596.19	
7	16%	3375	7.905	7	2.34	31782	13827.38	164
8	16%	3375	8.37	7	2.48	38610	16867.44	
9	16%	3375	7.86	7	2.33	40260	17553.9	
10	16%	3375	8.29	28	2.46	59730	26085.69	231.167
11	16%	3375	7.905	28	2.34	54790	23879.19	
12	16%	3375	7.955	28	2.36	41810	18044.24	
13	17%	3375	7.77	7	2.30	30210	13140.91	128.667
14	17%	3375	8.16	7	2.42	26920	11767.98	
15	17%	3375	8.255	7	2.45	29710	12944.78	
16	17%	3375	8.065	28	2.39	35830	15612.19	179.867
17	17%	3375	8.09	28	2.40	52300	22790.65	
18	17%	3375	8.045	28	2.38	33180	14513.84	
19	18%	3375	8.095	7	2.40	29980	13042.84	149.333
20	18%	3375	7.885	7	2.34	35020	15200.31	
21	18%	3375	7.825	7	2.32	36160	15690.64	
22	18%	3375	8.25	28	2.44	30980	13533.18	181
23	18%	3375	8.42	28	2.49	44890	19613.3	
24	18%	3375	8.445	28	2.50	46110	20103.63	
25	19%	3375	8.325	7	2.47	27090	11767.98	115.333
26	19%	3375	7.935	7	2.35	25200	10983.45	
27	19%	3375	8.235	7	2.44	25650	11179.58	
28	19%	3375	7.91	28	2.34	41030	17848.1	162.933
29	19%	3375	8.12	28	2.41	39330	17142.02	
30	19%	3375	7.845	28	2.32	29630	12944.78	

Table (3): Compressive strength test for Expansive concrete

Tests	Bearing Layer (Sand)	Soil Surrounding the pile (Clay)			Embedded length	Diameter of pile	Qu (Portland cement)	Qu (Expansive Cement)	α %
	? (gm/cm3)	? (gm/cm3)	W.C (%)	c’ (KN/m2)	Le (mm)	Dpile (mm)	at S=10% Dp (KN)	at S=10% Dp (KN)	
1	1.8	1.7	16%	57.9	300	75	4.17	8.14	95
2					400		5.00	8.24	80
3					500		5.49	9.41	70
4					600		6.08	12.44	61
5					700		7.75	10.79	61
6	1.8	1.7	16%	57.9	400	100	11.18	16.08	45
7						89	9.17	12.94	44
8						75	5.00	8.24	44
9						64	4.85	5.88	42
10						50	4.41	6.28	37
11	1.8	1.5	14%	22.5	400	100	9.81	22.36	90
12		1.5	12%	45.1			15.30	13.73	53
13		1.7	16%	57.9			11.18	16.08	75
14		1.7	14%	70.6			11.38	21.18	53
15		1.7	13%	79.4			13.34	22.36	43
16		1.7	12%	93.1			18.83	22.16	37

Table (4): Experiments Parameters and Results

Where;

Le = Embedded length of pile.
Dp = Diameter of pile.
c’ = Effective cohesion of pile’s surrounding soil.Qu = Ultimate bearing capacity of pile.
α = Ratio of pile capacity increase.

W.C = Water Content of clay soil surrounding the pile.S = Settlement of pile

Figure (3): Specimens of tested piles

3-Result Analysis of pile load testing:

The results of the Experimental tests are presented in table (3). Each case was studid twice , once by using portland cement for producing the used concrete and the other by using Expansive concrete. An increase in the volumn of piles can be noticed figure (3) between Portland concrete and Expansive concrete piles. The ultimate load capacity of pile, may be recognized as the load that causes a settelment equal to 10% of the pile diameter. It can also be defined as the load at which the rate of settelment continues undimineshed without further incrementation of load (Civil engineering code of practice No,4,1954). The studied cases covered the nessecery tests to investigate the effect of the three parameters (Dp),(Le),(c') on the value of (Qu) , subsequently when comparing the results of each case by using the two types of cement, it is easy to determince the increase of Qu resulting from using expansive concrete. The increase of Qu is expressed by the ratio α , where α :

$$\alpha = \frac{Qu(Expansive\ Concrete) - Qu(Portland\ Concrete)}{\mathrm{Qu(Portland\ Concrete)}} x\ 100\%$$

3.1- Effects of pile's embedded length (Le) on the ratio of pile capacity increase (α):

Figure (4) show that the relationship between the ultimate pile capacity (Qu) and the embedded length of pile (Le) is directly proportional either when using ordinary cement or

expansive cement for producing the pile concrete, which seems logical. To evaluate the effect of using expansive concrete in the studied cases, the relationship between ultimate pile capacity (Qu) and the ratio of pile capacity increase (α) is constructed as shown in figure (5).

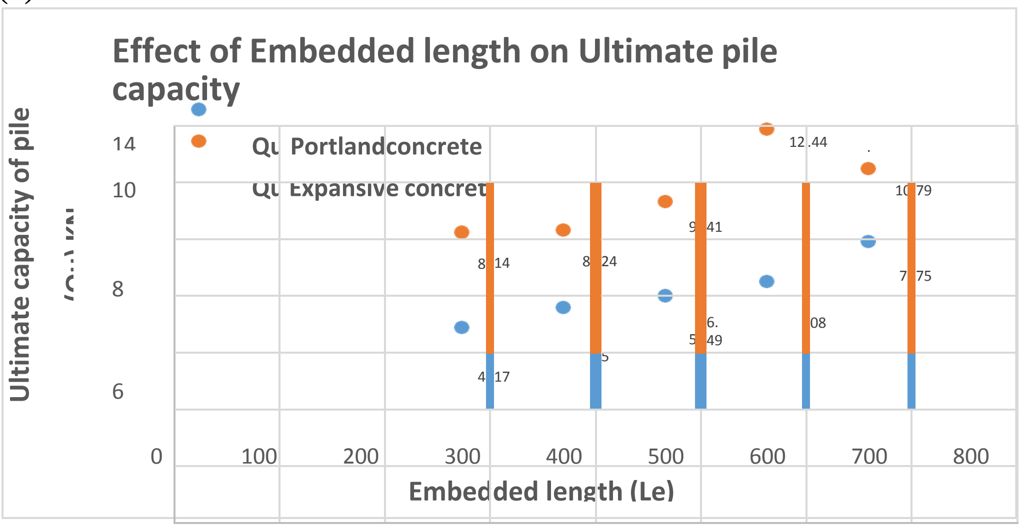


Figure (4): Relationship between embedded length (Le) and pile load capacity (Qu)

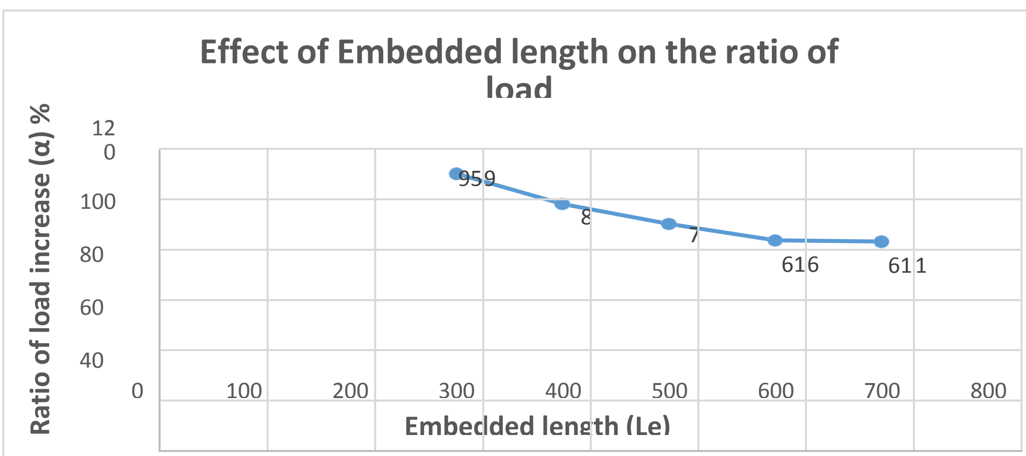


Figure (5): Relationship between ratio of load increase (α) and embedded length of pile (Le)

3.2- Effect of Pile Diameter (Dp) on the ratio of pile capacity increase (α):

Figure (6) show that the relationship between the ultimate pile capacity (Qu) and the diameter of pile (Dp) is directly proportional either when using ordinary cement or expansive cement for producing the pile concrete, which seems logical. To evaluate the effect of using expansive concrete in the studied cases, the relationship between ultimate pile capacity (Qu) and the ratio of pile capacity increase (α) is constructed as shown in figure (7).

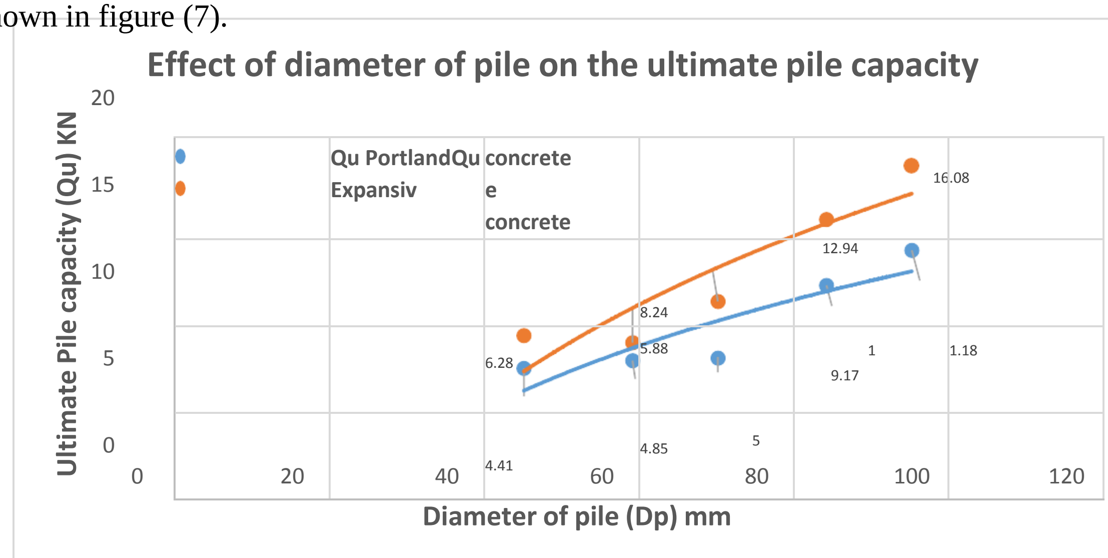


Figure (6): Relationship between pile diameter (Dp) and pile load capacity (Qu)

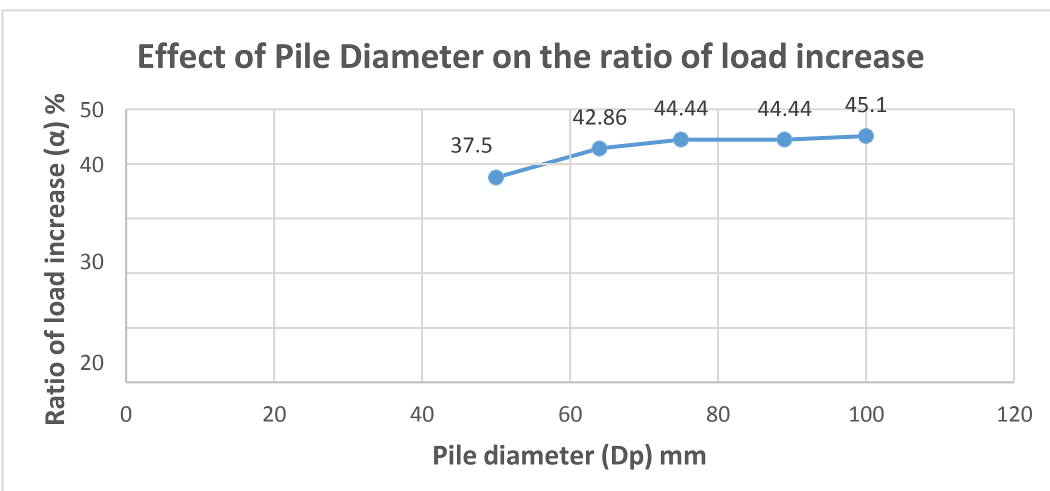


Figure (7): Relationship between the ratio of load increase (α) and pile diameter (Dp)

3.3- Effects of Cohesion of clay soil surrounding the pile (c’) on the ratioof pile capacity increase (α):

Two different wet densities of clay soil surrounding the pile, which were ɣ=1.7 gm/cm3 and ɣ= 1.5 gm/cm3, are used throughout the testing program. A relationship was constructed between ultimate load capacity of pile (Qu) and clay soils with wet densities ɣ=1.7 gm/cm3 only, shown figure (7). Also, figure (8) is a relationship between ultimate load capacity of pile (Qu) and all different soil densities used throughout the testing program. These relationsshow that the ultimate pile capacity (Qu) and the effective cohesion of pile’s surrounding soil (Clay) is directly proportional either when using ordinary cement or expansive cement for producing the pile concrete. To further evaluate the effect of using expansive concrete in thestudied cases, the relationship between ultimate pile capacity (Qu) and the ratio of pile capacity increase (α) is constructed as shown in figures (9), (10).

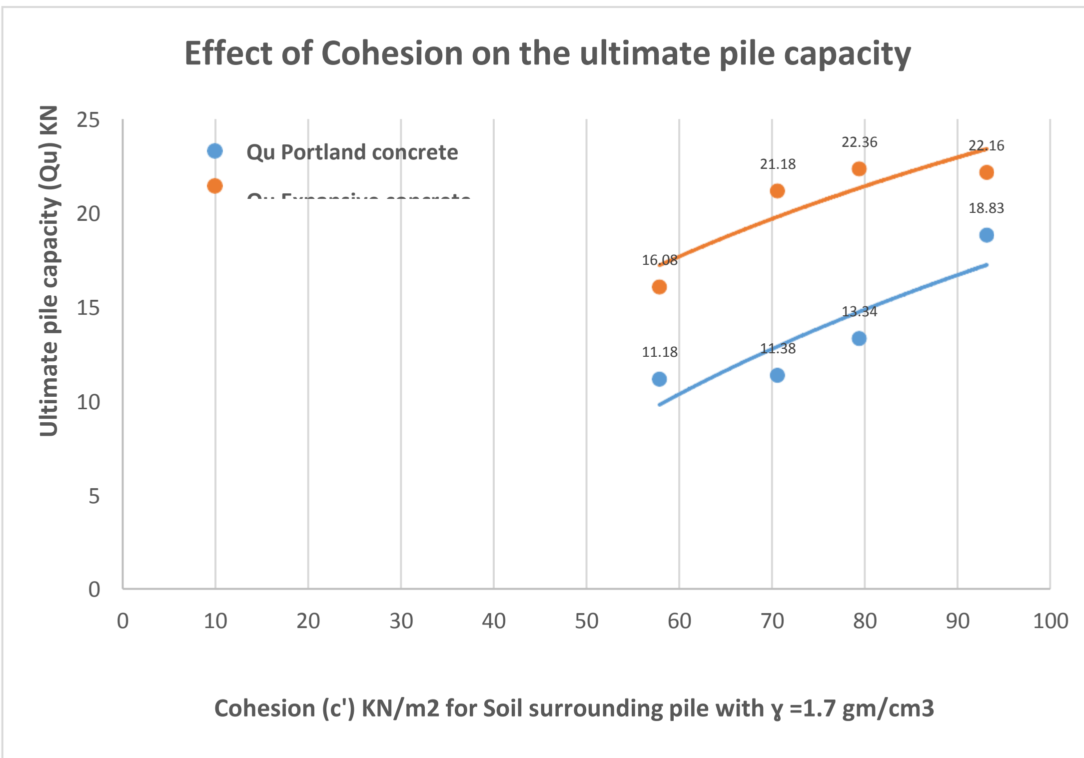


Figure (8): Relationship between the ultimate pile capacity (Qu) and cohesion of surrounding soil (c’)in case ɣ=1.7 gm/cm3

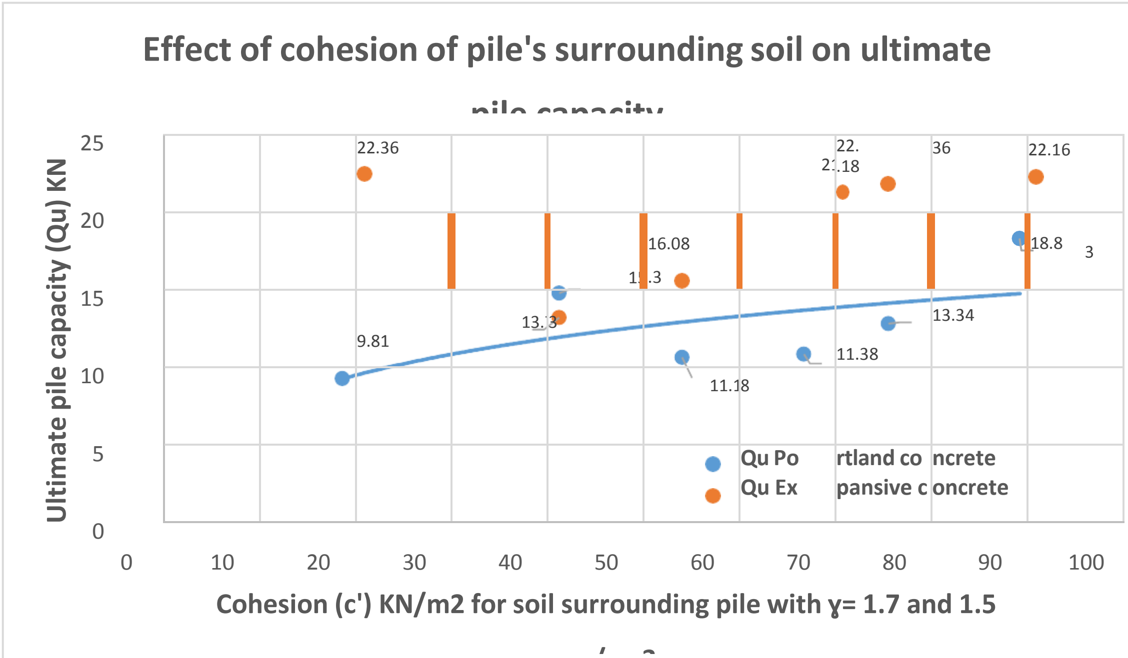


Figure (9): Relationship between the ultimate pile capacity (Qu) and cohesion of surrounding soil (c')in case ɣ=1.7 gm/cm3 and 1.5 gm/cm3

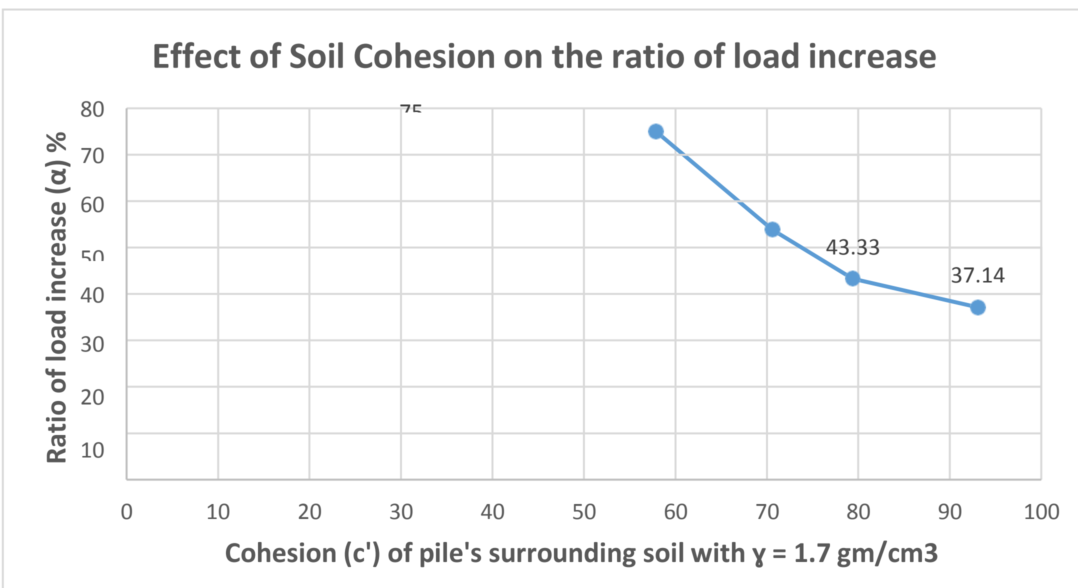


Figure (10): Relationship between the ratio of load increase and cohesion of surrounding soil (c') incase ɣ=1.7 gm/cm3

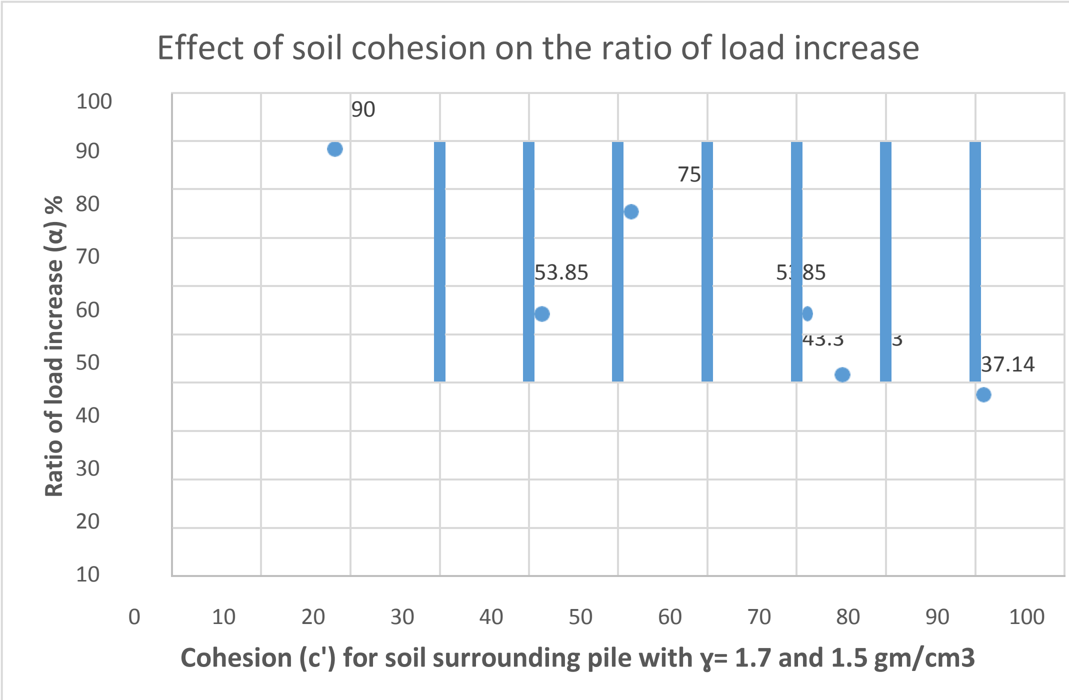


Figure (11): Relationship between the ratio of load increase and cohesion of surrounding soil (c') in case ɣ=1.7 gm/cm3 and ɣ=1.5 gm/cm3.

<u>4- Conclusions:</u>

The main conclusions obtained from the presented study are:

- Using the expansive concrete results in an increase in the value of ultimate pile capacity (Qu) for all studied cases.
- The ratio of pile capacity increase (α) is directly proportional to pile diameter (Dp), while inversely proportional to both the embedded length of piles (Le), and the effective cohesion of surrounding clayey soil (c').
- For the majority of cases studied, the ratio (α) as a result of using expansive concrete in bored piles embedded in clayey soil and resting on sandy soil, is ranging between37% to 75%, where α:

$$\alpha = \frac{Qu(Expansive\ Concrete) - Qu(Portland\ Concrete)}{\mathrm{Qu(Portland\ Concrete)}} x\ 100\%$$

<u>5- References:</u>

(1) H. G. Poulos, E. H. Davis, “Pile foundation analysis and design”.

(2) BERNARD A. GRAND, Hardesty and Hanover “Types of Piles: Their Characteristics and General Use” (1946).

(3) ACI 223, KSC Type k expansive cement.

(4) Mohamed E. El-Said, “Effect of using swelling concrete in piles on the bored pilescapacity”.

(5) A.S.T.M D1143-57T for the maintained load testing procedure.

(6) Civil engineering code of practice No.4, (1954).

(7) Karl Terzaghi, Ralph B. Peck, Gholamreza Mesri, “Soil Mechanics in engineeringpractice”.

(8) CTS Cement Komponant data sheet, “Komponat shrinkage compensating concrete”.