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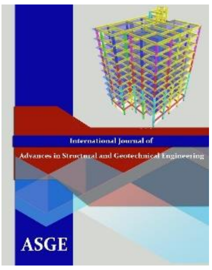

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Effect of Using Swelling Concrete in Piles on the Bored Piles Capacity

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ABSTRACT

Pile foundations are the most popular form of deep foundations used for both onshore and offshore structures. They are often used to transfer large loads from the superstructure into deeper, competent soil layers particularly when the structure is to be located on shallow, weak soil layers. Bored piles are commonly used to support heavily loaded structures such as high rise buildings and bridges in view of its low noise, low vibration and flexibility of sizes to suit different loading conditions and subsoil conditions. Many techniques have been proposed to improve the pile capacity. This paper discuses a new technique for increasing the pile capacity by using swelling concrete. Experimental testing program was carried out to investigate the influence of pile length (Le), pile diameter (D), water cement ratio (w/c), and relative density of soil (Dr) on the capacity of bored piles when using swelling concrete. This paper summarizes the effect of increasing skin-friction resistance on the capacity of bored pile by using swelling concrete that causes increasing in the volume of concrete mass. The main conclusions of this study is increasing the ultimate capacity of pile by swelling concrete (α)% from 10.4% to 30.4%.This study concluded to an empirical equation relating between different studied parameters which affect the ultimate capacity of bored piles with the use of swelling cement.

Keywords: *Swelling concrete, Shrinkage compensating cement type-k, Pile foundations, Experimental tests, Pile response, Ultimate capacity of pile.*

INTRODUCTION

Foundation design and construction involves assessment of factors related to engineering and economics. In the last few decades, situations commonly exist where shallow foundations are inappropriate for support of structural elements. These situations may be related to the presence of unsuitable soil layers in either the subsurface profile, adverse hydraulic conditions, or intolerable movements of the structure. So, deep foundations are the solution that transfer load down through weak soil strata and into deeper and stronger strata to minimize the settlement of a structure. Deep foundations also consist of a single pile or a group of piles with a pile cap which can be driven, drilled, cast-in-place, or alternatively grouted-in-place [3]. Moreover, Deep foundations are frequently needed because of the relative inability of shallow footings to resist inclined, lateral, or uplift loads and overturning moments. Furthermore, deep foundation has meant security to many designers. There are numerous types of deep foundations based on type of material, configuration, installation technique and equipment used for piles installation. Bored piles are considered one of the most important deep foundations and do not receive sufficient research attention although they are widely used in the United States, United Kingdom, Egypt and other countries in the world [7]. The expansive cement is a recent cement type, which is used, in concrete mix to produce swelling concrete, which in turn increases in volume after hardening. A new technique is proposed for executing the bored piles by using the swelling concrete that increases the pile volume laterally after concrete hardening. Subsequently, the lateral earth pressure on piles increases and this leads to a considerable increase in the frictional resistance of piles. This paper presents the details of experimental set-up, properties of the capacity of bored piles (Drilled shaft), the formation and main properties of proposed improving material of concrete by (expansive cement type k), and full description of the testing program.

Finally, the efficiency of using swelling concrete is discussed and evaluated. In addition, the effect of many studied parameters on the capacity of swelling concrete bored piles is presented.

EXPERIMENTAL WORK

Testing Program:

The testing program consisted of two series of experimental tests. The first one was to determine the necessary characteristics of soil and swelling concrete that used during the experimental testing program. It included sieve analysis test, modified Proctor test and shear box test for the dense sand, besides determining the compressive strength of concrete, which was used in casting the bored piles. The second series was carried out through twenty-eight pile-loading tests, which were conducted on a bored pile model using the testing set-up shown in figure (1). The testing procedures were applying the load on a steel pile cap fitted to the pile model and 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.

Experimental Device:

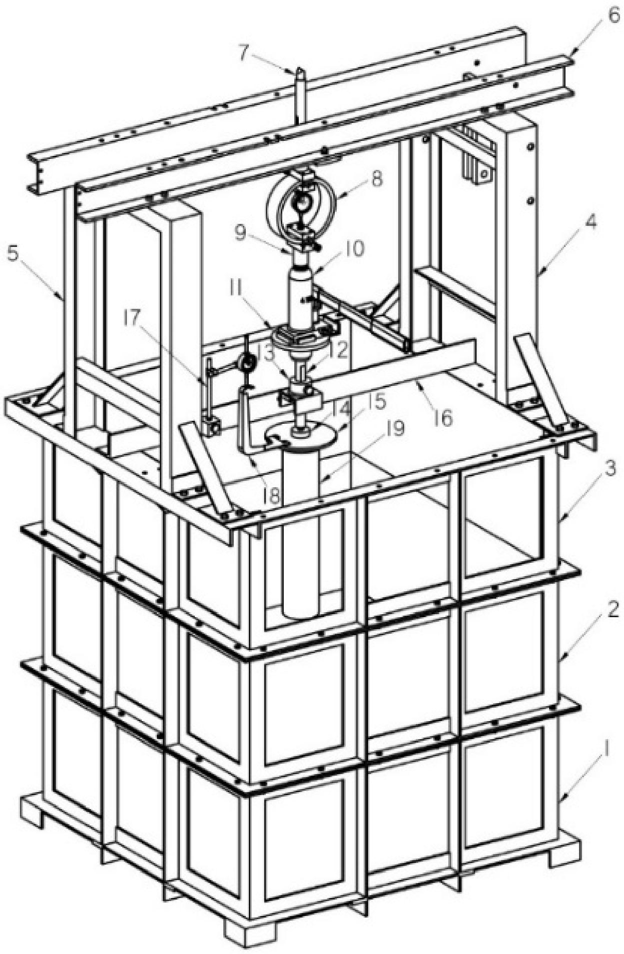
Figure (1) shows the testing set up used in the second series of the experimental tests. It consisted of steel container that was divided into three parts bottom box, middle box and top box .The internal dimensions of each box were 1000x1000 mm and a height of 400 mm. It is made of angular steel 50x50 mm and is encased inside with a panel of steel 1.5 mm thickness in three sides, while the fourth panel is encased in transparent plastic that can be moved up and down. The bottom of the box was covered with a steel plate of thickness 1.5 mm ,two legs made of channel steel (U) shape ,with dimensions 100x70x70 mm and height 800 mm , main beams that consisted of two channel of steel (U) shape, with dimensions 100x70x70 mm and length 1400 mm. To form the final form of the device, proving ring with the capacity of 28 KN, which was used for measuring the effective load on the column, and hydraulic jack to generate the required load on the pile model with capacity of 4 tons were fitted in the upper part of testing setting.

Testing Series 1:

The first series of experimental tests was performed to determine the main properties of the used soil sample and concrete for experimental testing program. Figures (2) to (4) and table (1) illustrate the achieved results.

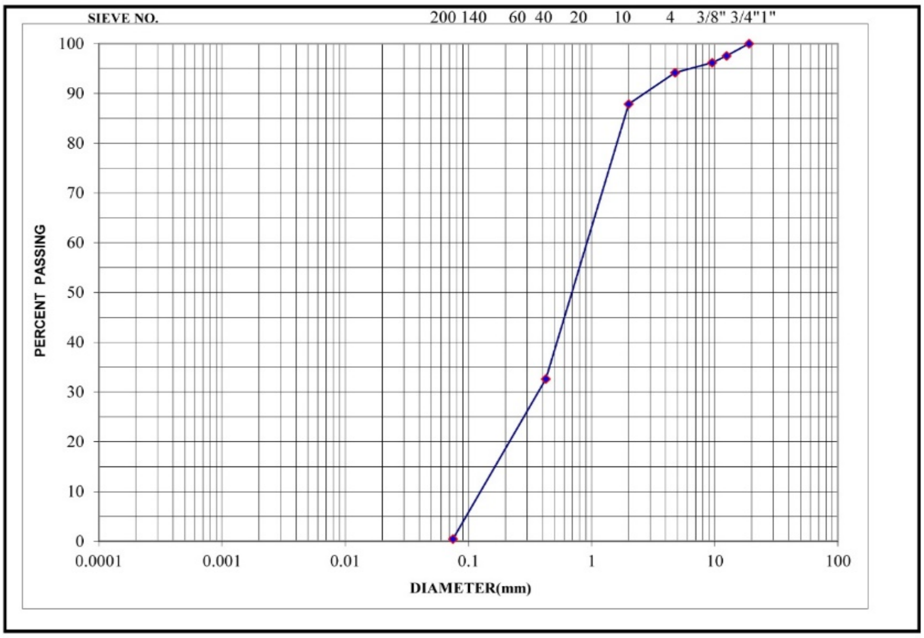
Testing Series 2:

The implementation of bored pile model consisted of five phases The container filled with dense sand by layers each layer was 100x100x5 cm and compacted carefully by compacting tool to achieve the required relative density (Dr) whose values were 70% , 60% , 55% and 50%. Plastic pipes were installed in the center of the container through the sand to as a casing to support the sides of drilling. These pipes had a diameter (D) with values of 1.5 , 2 , 3 , 4 inches and embedded length (Le) ranged from 50 cm to 35 cm. After adjusting the embedded length of the pile and compacting the sand according to the required relative density (Dr), concrete would be prepared for casting in the pipe. The concrete casted and compacted by a hammer, then casing pipe was withdrawn slowly to complete the operation of pouring the concrete of the bored pile. Steel pile cap was setting in the center of the pile and was adjusted horizontally by the water leveling device. Pile load system which consisted of hydraulic jack , dial gauge and proving ring was prepared to install in the device. The load was applied gradually through hydraulic jack and the force was accurately determined by means of proving ring until the pile settlement ,that measured by dial gauge, reached the ultimate value of one tenth of pile diameter or the pile failure. That series of tests was a group of twenty eight pile loading tests. Table (2) shows full details and results of these tests. Two types of cement were used and four parameters were studied. The studied parameters included the embedded pile length (Le), pile diameter (D), relative density of soil surrounding the pile (Dr), and water-cement ratio of the pile concrete (w/c).



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

Fig. 1: Testing Set-up



PERCENT PASSING

200	40	10	4	3/8"	1/2"	3/4"
0.46	32.62	87.85	94.15	96.15	97.54	100.00

Fig. 2: Grain Size Distribution Curve of Soil Surrounding the Pile Model

Table 1: Compressive Strength of Concrete.

Type of sample	Standard cubes of concrete 10x10x10 cm

			Using portland cement				
Size of cube(cm3)	Weight of cube(kg)	Specimen (Num)	Date of cast	Duration of curing	Date of break	Density of cube (kg/cm3)	Stress (kg/cm3)
1000	2.4	1	4/4/2017	7 Days	12/4/2017	0.0024	170
1000	2.5	2	5/4/2017	7 Days	13/4/2017	0.0025	173
1000	2.6	3	6/4/2017	7 Days	14/4/2017	0.0026	175

			Using expensive cement type k				
Size of cube(cm3)	Weight of cube(kg)	Specimen (Num)	Date of cast	Duration of curing	Date of break	Density of cube (kg/cm3)	Stress (kg/cm3)
1000	2.6	4	26/7/2017	7 Days	3/8/2017	0.0026	165
1000	2.6	5	27/7/2017	7 Days	4/8/2017	0.0026	165
1000	2.7	6	28/7/2017	7 Days	5/8/2017	0.0027	167

Table 2: Second Series of Experimental Testing Program.

Using portland cement				
Embedded length (Le) cm	Relative density (Dr) %	Diameter (D)	Water cement ratio (w/c)	Ultimate capacity (Qu) kg
50	60%	3"	0.53	1490
45				1477
40				1444
35				1407
40	70%	3"	0.53	1604
	60%			1444
	55%			1072
	50%			1016
40	60%	1.5"	0.53	987
		2"		1239
		3"		1444
		4"		1598

Using expensive cement					
Embedded length (Le) cm	Relative density (Dr) %	Diameter (D)	Water cement ratio (w/c)	Ultimate capacity (Qu) kg	Ratio of load increase (α) %
50	60%	3"	0.53	1944	30.40%
45				1720	16.40%
40				1608	11.30%
35				1554	10.40%
40	70%	3"	0.53	2028	26.40%
	60%			1608	11.30%
	55%			1412	31.70%
	50%			1212	19.20%
40	60%	1.5"	0.53	1322	33.90%
		2"		1504	21.30%
		3"		1608	11.30%
		4"		1804	12.80%
40	60%	3"	0.6	1554	
			0.53	1608	
			0.45	1748	
			0.4	1902	

Where:
Le = embedded length.

Dr = relative density

D = pile diameter.

w/c = water- cement ratio.

α = Ratio of pile capacity increase.

$$\alpha = \frac{\mathrm{Qu(expansive\ cement)} - \mathrm{Qu(portland\ cement)}}{\mathrm{Qu(portland\ cement)}} \times 100\ \%$$

Fig. 3: Samples of The Pile Model

RESULTS ANALYSIS of PILE LOAD TESTING

This section presents the results of the experimental tests which studied the effect of four main parameters on the ultimate pile capacity (Qu) and the ratio of pile capacity increase (α) in case of using expansive cement. The studied parameters were the embedded length of pile (Le), pile diameter (D), the relative density of sandy soil surrounding the pile (Dr) and the water-cement ratio of the pile concrete (w/c). Each case was tested twice, the first when using ordinary Portland cement in concrete mix of the pile, and the second when using the expansive cement.

Effect of the Pile Embedded Length (Le) on the Ratio of Pile Capacity Increase (α):

Figure (4) represents the relationship between the ultimate pile capacity (Qu) and the ratio between embedded length of pile and the pile diameter (Le/D) in case of using both of Portland cement and expansive cement in pile concrete mix. The results show that the ultimate capacity of the pile (Qu) increases with the increase of the embedded length of the pile (Le) for the two types of cement but on the other hand, using expansive cement type-k in concrete mix causes positive improvement on the ultimate pile capacity. The ratio of load increase (α) grows up with the increase of the embedded length of the pile and it ranges from 10.4% to 30.4% as a result of using expansive cement as shown in figure (5). So, using expansive cement may be recommended for piles of large values of (Le/D) to increase the ultimate capacity.

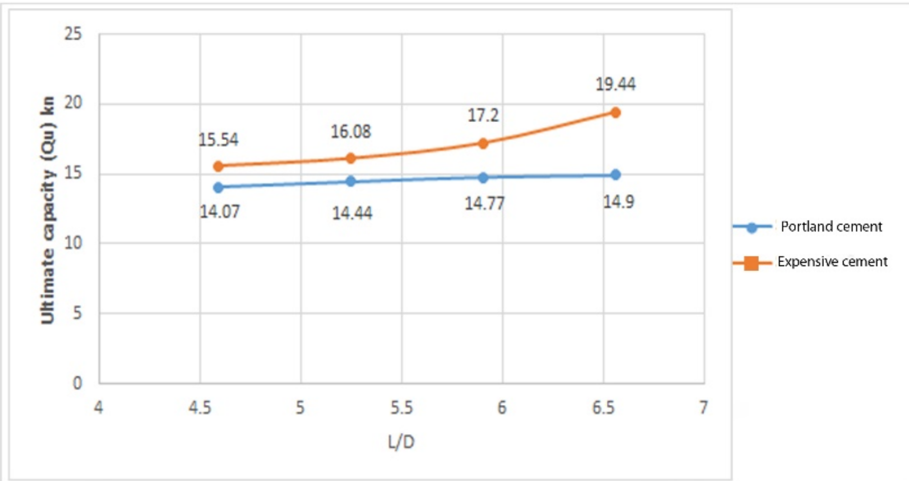


Fig. 4: Relationship between (Qu) and (Le/D)

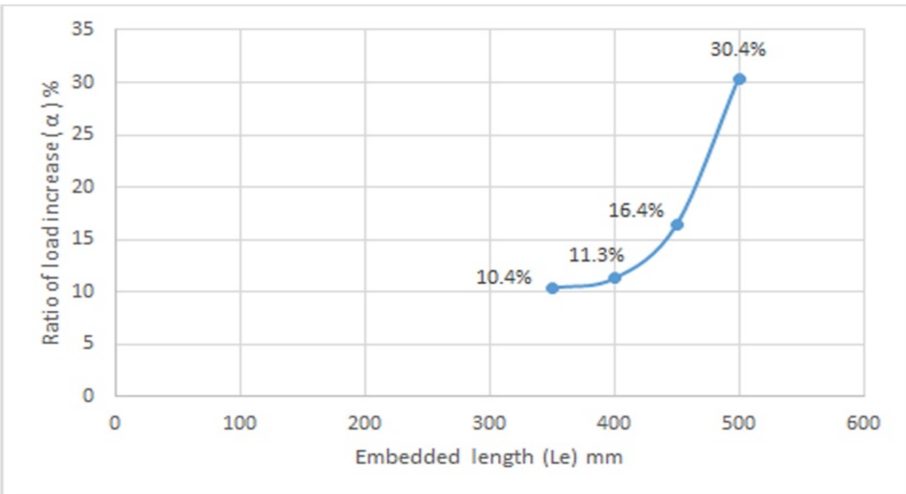


Fig. 5: The Effect of Embedded Length of Pile (Le) on the Ratio (α)

Effect of the Pile Diameter (D) on the Ratio of Pile Capacity Increase (α):

Figure (6) shows the relationship between the ultimate pile capacity (Qu) and pile diameter (D). It demonstrates that using each of Portland cement and expansive cement almost has the same trend of the (Qu versus D) relationship. The value of (Qu) is always directly proportional to the value of pile diameter (D). Figure (7) illustrates an interesting observation. It shows that the ratio of pile capacity increase (α) was inversely proportional to the pile diameter (D) and ranged from 33.9% (for D=1.5") to 12.8% (for D=4").I This seems to be logical because in case of constant increase in pile diameter, the ratio between swelled diameter to the original diameter became larger in case of small diameters and smaller in case of large diameters. Subsequently, the increase of pile surface area (i.e the frictional resistance) for small pile diameter is larger than large pile diameter. These results concluded that using expansive cement is useful in all cases but more effective for smaller pile diameter.

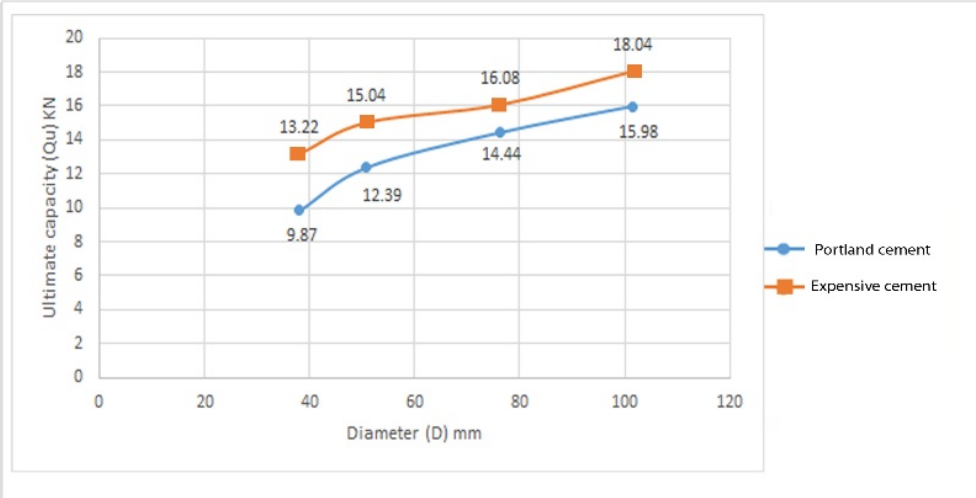


Fig. 4: Relationship between (Qu) and Pile Diameter (D)

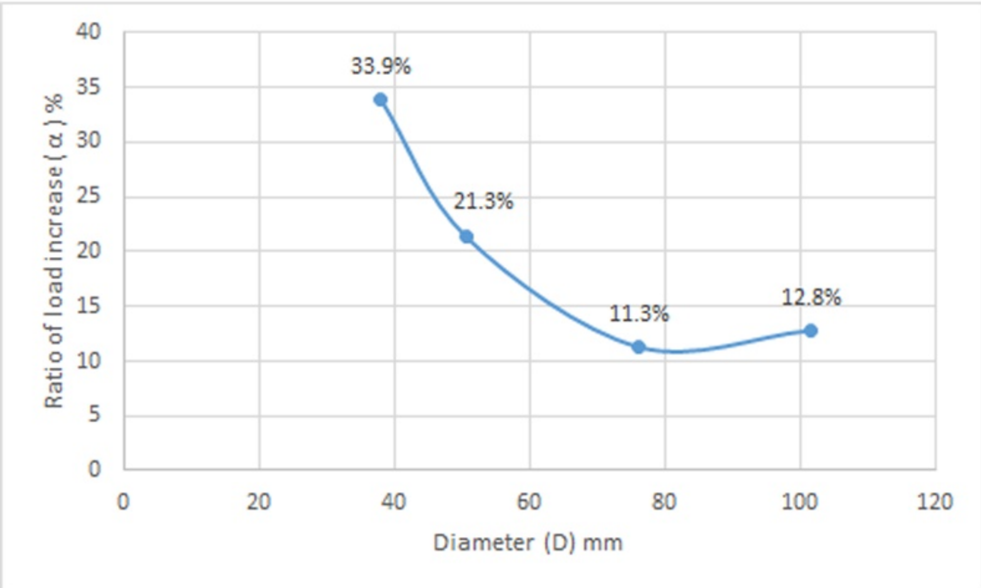


Fig. 7: The Effect of the Pile Diameter (D) on the Ratio (α)

Effect of the Relative Density of Soil (Dr) on the Ratio of Pile Capacity Increase (α):

Figure (8) illustrates that for both ordinary Portland cement concrete and expansive cement concrete, the ultimate pile capacity (Qu) is directly proportional to the relative density of soil surrounding the pile shaft (Dr). The ratio of pile capacity increase (α) when using expansive cement for this group of tests ranged from 11.3% to 31.7% as listed in table (2). The reason may be attributed by the increase of lateral earth pressure (tending to passive state) with the increase of soil relative density (Dr) which is reflected on the value of frictional resistance and subsequently the ultimate capacity of pile (Qu).

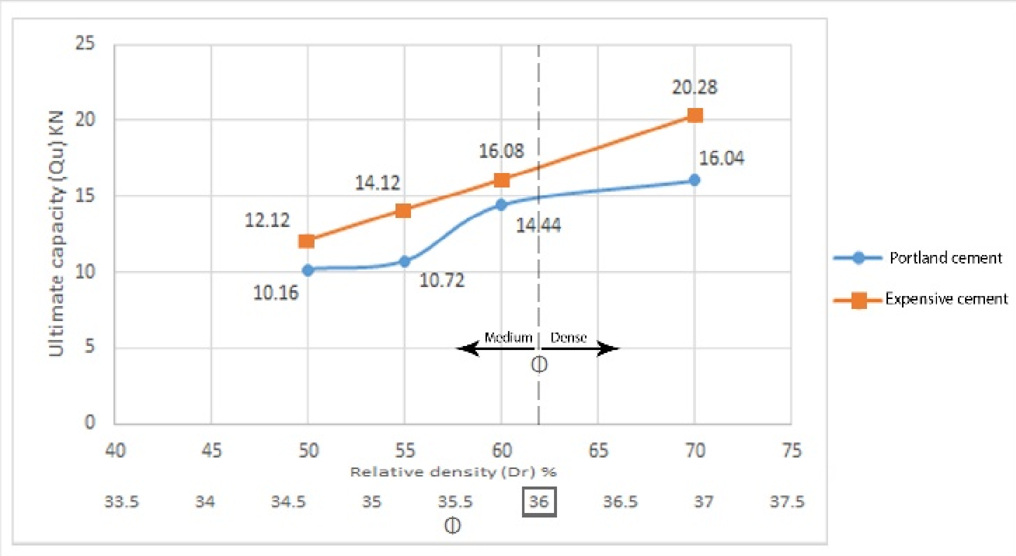


Fig. 8: Relationship between (Qu) and Pile Diameter (Dr)

Effect of the Water - Cement Ratio (w/c) on the Ultimate Pile Capacity (Qu):

For all experimental tests, except this group, the water – cement ratio (w/c) was constant and equal to (0.53) as recommended by the producer of the expansive cement. But ,to explore the effect of the ratio (w/c) on the ultimate pile capacity (Qu) in case of using expansive cement, other four experimental tests were carried out. It was that decreasing the ratio (w/c) resulted an increase in the ultimate pile capacity (Qu). These results mean that the concrete swelling, which in turn increases the pile capacity, is inversely proportional to the water – cement ratio (w/c) as illustrated in figure (9).

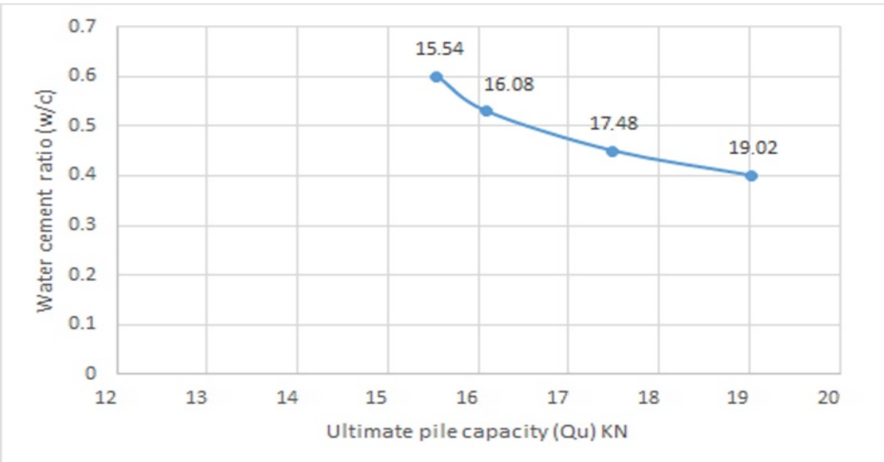


Fig. 9: Relationship between (Qu) and Water – Cement Ratio (w/c)

CONCLUSIONS

The main conclusions drawn from the reported study are given below:
- For all studied cases, using the swelling concrete increased the ultimate pile capacity more than the corresponding cases of Portland cement concrete.

- Using the swelling concrete in bored piles resulted in an increase of the ultimate piles capacity with a ratio (α) ranging from (10.4%) to (30.4%) , where

$$\alpha = \frac{\text{Qu(expansive cement)} - \text{Qu(portland cement)}}{\text{Qu(portland cement)}} \text{ x } 100\%$$

- The ratio of pile capacity increase (α) was directly proportional to the embedded length of pile (Le) and the relative density of soil (Dr) surrounding the pile shaft. Whereas, it was inversely proportional to the pile diameter (D) and the water - cement ratio (w/c).

- Using the swelling concrete for bored piles is more effective in case of long piles more than short piles.

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