



# **ASSESSING THE INCREASE IN BEARING CAPACITY OF BORED PILES IN SANDY SOIL USING EXPANSIVE ADDITIVES**

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## **ABSTRACT**

The pile foundation is usually designed to exceed the weak soil to the strong stratum. There is very close relation between the pile capacity and surrounding soil conditions. In cohesionless soil, the bored pile is effecting surround soil by loosening deposits through a combination of pile volume replacement and exist of pile case used for installation of bored pile. In this study, the improvement of the weak soil that surrounds the pile and observing the effect of improvement on pile increase the skin friction of the bored pile capacity for bored pile carried out. This study conducts research into the use of expansive additives in concrete bored piles. The aim of this project was to investigate how  $\text{Na}_2\text{CO}_3$  as an additive in concrete can increase the shaft resistance of a bored pile. Several tests were conducted on concrete single piles with a variation of length to the diameter ratios and different percentages of soda ash additives. All tests were made in dry, sandy soil at loosening state. All tests showed that the shaft capacity could be increased using expansive additives due to increase the volume of the pile or enlargement of pile volume during concrete setting ;it was also concluded that the shorter expansive piles could be able to achieve the same pile capacity as a longer conventional pile. This would lead to reductions on the volume of concrete poured, the amount of steel reinforcement used and the amount of soil excavated. Therefore, construction costs can be decreased and construction times can be shortened.

**KEYWORDS:** Bearing capacity, additives, sandy soil, pile, foundation, soil improvement.

## 1. INTRODUCTION

In foundation practices, the main point of concern is bearing capacity of soil and settlement. Bearing capacity can be defined as the maximum load that can be carried by the soil strata. When the soil is strong enough that it can carry the whole load coming on it, then we use shallow foundation. Shallow foundations are usually used where hard soil strata is available at such a depth that construction of foundation is not too costly (Craig, 2004). Evaluation of pile bearing capacity is still a subject of many researches. Several researches mentioned that, the calculated pile bearing capacity by conventional methods often gives poor agreement with the load test results (Kraft, 1991; Randolph et al., 1994). If hard soil is available at deeper levels of earth, then there is a need of some source that can transfer the load of the structures on the deep hard soil strata. This source can be said to be at the deep foundation. Pile foundation is a type of foundation in which the pile is usually used as the source to transfer the load to deeper soil levels. Pile shaft resistance represents the major component in total pile capacity when the pile is subjected to cyclic loading. Failure can occur at a very low load level in some sandy soil (Chan and Hanna, 1980).

Piled foundations are an increasingly common method of conveying loads from a structure built on soft ground to a strong bearing stratum. Bored piles, especially friction piles, rely on shaft resistance to carry vertical loads. The design load to be resisted determines the length and diameter of the bored pile, which in turn determines its cost. However, the skin friction may not be being maximized, meaning that piled foundations may be being built deeper or wider than necessary. Hence, this project aims to investigate whether the shaft resistance of a bored pile can be enhanced by using ( $\text{Na}_2\text{CO}_3$ ) expansive additive.

### 1.1. Improving bearing capacity of bored piles

There is very close relation between the pile capacity and surrounding soil conditions. In cohesionless soil the bored pile effected on surround soil by loosening deposits through a combination of pile volume replacement and exist of pile case used for installation of bored pile. The pile foundation usually designed to exceed the weak soil to the firm deposit.

Improvement of the weak soil surrounds the pile leads to improvement on pile capacity for bored pile. The improvement on soil surrounding pile model will lead to affect the pile load capacity. The question here how to improve the surrounding soil of piles. This has been done using many expansive materials led to compact on surrounding soil and increase in skin friction of piles. Here it will be studied the expansive materials and expansive cement. (Harydharaan 2012).

## **1.2. Expansive cement**

Expansive cement is a relative of Portland cement that contains materials that increase in volume as they set. It usually uses with concrete mixtures in situations for situations where the shrinkage of conventional cement is undesirable or where the cement or concrete mixtures needs to create pressure on another part of a structure. Some products made with expanding cement can be used to seal small cracks and holes in concrete walls, such as foundation walls, and can help to prevent leaks in some applications ([Hoff 1972](#)).

## **1.3. History and development**

According to the Encyclopedia Britannica, expanding cement was invented in France during the mid-1940s. This cement included not just sulfo aluminate and Portland cement but also blast furnace slag, which was added as a stabilizing agent. The result was the first successful expanding cement that worked reliably and remained stable over a long period. Another type of expanding cement, developed in Russia around the same time, uses Portland cement, gypsum and alumina cement. Expansive cement ingredients have remained roughly the same since the product development, though manufacturers have since improved the cement's predictability, strength and working time ([Hoff 1972](#)).

## **1.4. Uses and benefits**

Most Portland cements shrink as they dry because the water used to activate them increases their volume. In some applications, this shrinkage can reduce the strength of the cement bond to nearby objects and structures or create leaks. Expansive cements allow contractors to create large, continuous floor slabs without joints, and they work well to fill holes in foundations and to create self-stressed concrete that is stronger than conventional Portland cement concrete. Prestressed concrete components for bridges and buildings are made using this material. ([Currell et al., \(1987\)](#)).

## **1.5. Bored Piles with Expansive Cement**

Non-displacement or bored piles become more common as buildings become ever taller. They are constructed by boring a hole in the soil, lowering in a reinforcement cage and pouring in concrete to fill the hole, which sets to form the pile. The piles carry the vertical load from the superstructure by two means: end bearing resistance and shaft resistance, together known as pile capacity. Friction piles are those where the majority of the load is carried by shaft resistance, typically when the pile is not bearing on bedrock. For such piles, and for piles where the base capacity is generally low, the shaft resistance is usually very important. Shaft resistance

depends on the length and diameter of the pile and the unit shaft friction: a combination of the friction angle between the soil and the pile, and the effective stress profile in the ground.

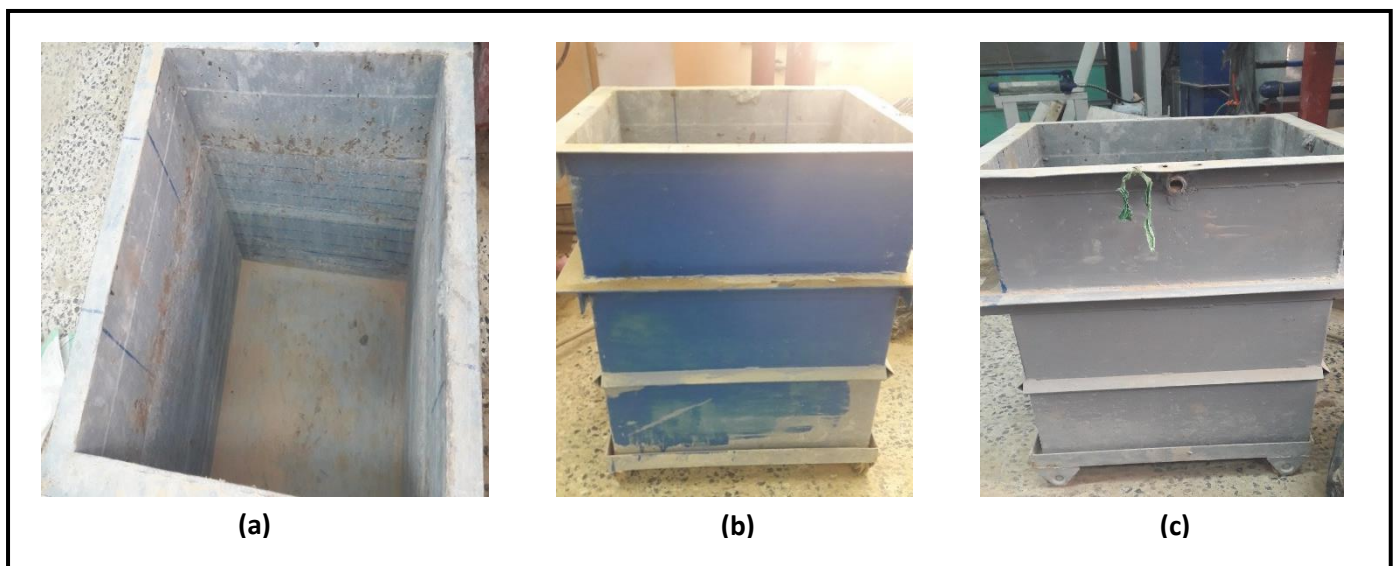
Pile length and diameter are usually the design variables that are manipulated to achieve the required shaft resistance to support the building. As construction costs increase with pile length or diameter, it would be advantageous if the unit shaft friction could be increased, allowing the length or diameter of the pile to be reduced. By casting the pile using concrete containing expansive additives, the friction angle at the interface between the soil and the concrete pile could be increased, therefore increasing the unit shaft friction and, consequently, the shaft resistance.

## 2. EXPERIMENTAL APPARATUS

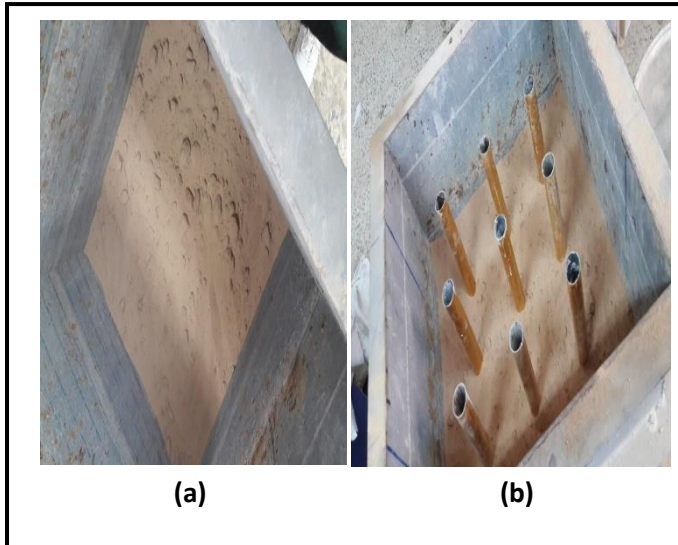
The description for the steel box container and the pile installation method are explained in this section.

### 2.1. Model Steel Container

The steel tank box apparatus used for the single pile models subjected to axial vertical compression load. The box container was made of steel plate of (6mm) in thickness and dimensions are (600x 600 x 750) mm as shown in [Plates 1, 2 and 3](#). The piles were distributed about 15cm each direction whereas spacing between piles are 15cm center to center (about five Pile diameter) as shown in [Fig. 1](#).



**Plate 1. Steel box container.**

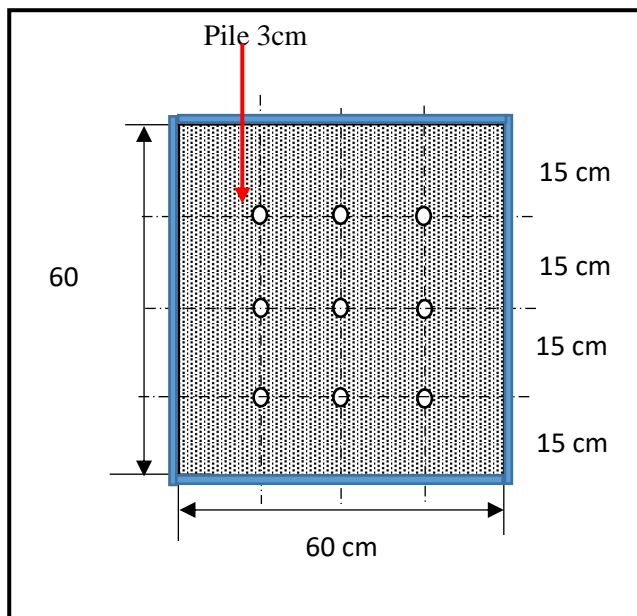


**Plate 2. Steel box and pile layout**

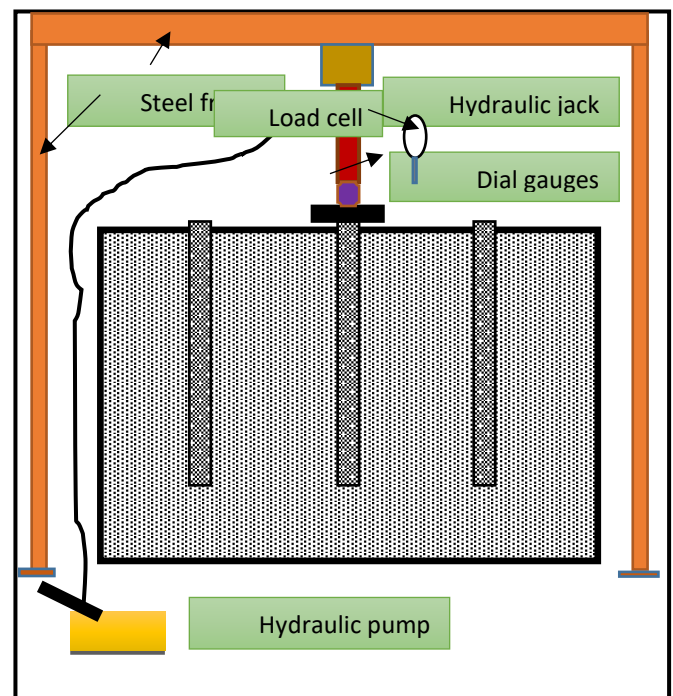


**Plate 3. Pile layout and sand bed.**

In this study, the pile tips to the box bottom is always greater than  $(5D)$  for  $(600 \text{ mm})$  piles length and  $(30 \text{ mm})$  pile diameter which is considered a sufficiently larger than the zone of the slip surface of the soil at pile tip during loading, as this ratio is estimated to be between  $(2D)$  to  $(4D)$  according to [Bowels \(1996\)](#).



**Fig. 1. Box container and pile distributed**



**Fig. 2. Steel container and loading system diagram.**



## 2.2. The vertical axial loading system

The axial loading system encompasses of vertical loading steel frame that exerts an axial force by hydraulic jack system applied on upper part of pile shown in Fig. 2 and plates 4 and 5.

To prepare the sand specimens, the container was fixed in its vertical position and filled with dry sand as layers, each layer about 100mm in height with certain relative density in loosening state (35%). To check density in each trial, small metal tins of known volumes previously were used to collect the samples, it positioned at several places in the test tank.



**Plate (4): pile loading system**

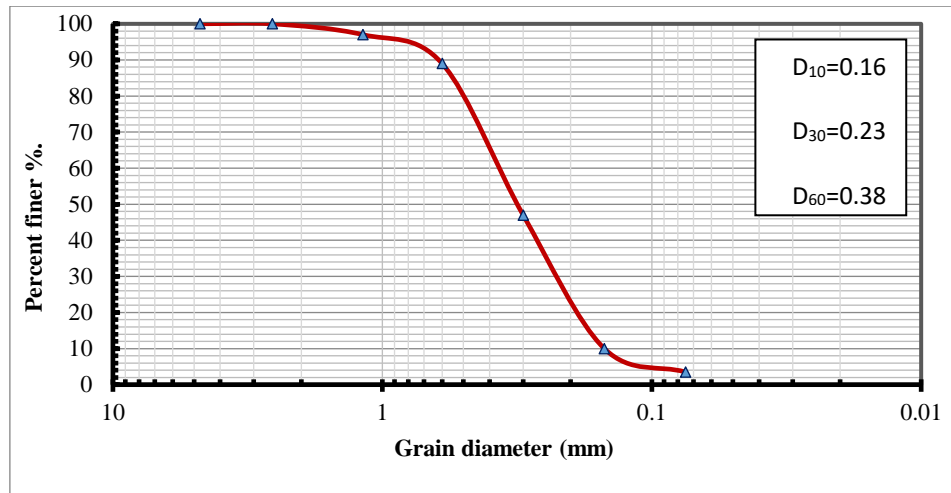


**Plate (5): pile loading system**

## 3. MATERIALS USED

### 3.1. Soil

Dry sand was used in this research to study the effect of using expansive materials with concrete mixture to improve bearing capacity of bored piles. A sieve analysis was performed on the sand used and the resulting grain size distribution is shown in Fig. 3. The characteristics that should be noted are the mean particle size  $D_{50}$  is 0.32 mm, the effective size  $D_{10}$  is 0.16 mm, as well as  $D_{30}$  is 0.23 mm and  $D_{60}$  is 0.38. The coefficient of uniformity,  $C_u$  is 2.38 and the coefficient of curvature,  $C_c$  is 0.87. According to these results it can be classifying the used sand into medium size and according to the Unified Soil Classification System (USCS), the sand is classified as (SP) and described as poorly graded sand.



**Fig. 3. The grain size distribution curve of the used sand.**

A summary of the test results with standard specification following each test is presented in Table 1.

**Table 1. Properties of the sand used.**

Index Properties		Value
Grain Size Analysis	Specific gravity, $G_s$	2.68
	Effective size (mm), $D_{10}$	0.16
	$D_{30}$ (mm)	0.23
	$D_{60}$ (mm)	0.38
	$D_{50}$ (mm)	0.32
	Coefficient of uniformity, $C_u$	2.38
	Coefficient of curvature, $C_c$	0.87
	Soil classification (USCS)	SP
Dry Unit Weights	Maximum dry unit weight ( $\text{kN/m}^3$ ), $\gamma_{d \max}$	18.8
	Minimum dry unit weight ( $\text{KN/m}^3$ ) $\gamma_{d \min}$	15.3
	Dry unit weight ( $\text{kN/m}^3$ ) at $Dr=50\%$ $\gamma_d$	16.87
	Dry unit weight ( $\text{kN/m}^3$ ) at $Dr=35\%$	15.78
	Angle of internal friction (at $Dr=50\%$ ) $\phi$	35.5
	Angle of internal friction (at $Dr=35\%$ ) $\phi$	30
Void Ratio	Maximum void ratio $e_{\max}$	0.71
	Minimum void ratio $e_{\min}$	0.39

### 3.2. Pile cap

A 100 mm length and 50mm width steel plate was used as a pile cap for all pile testes .The steel plate used to ensure rigidity of pile cap with respect to pile and was used as hinged support. In all testes, a 10 mm thickness of plate was used, (Plate 6).

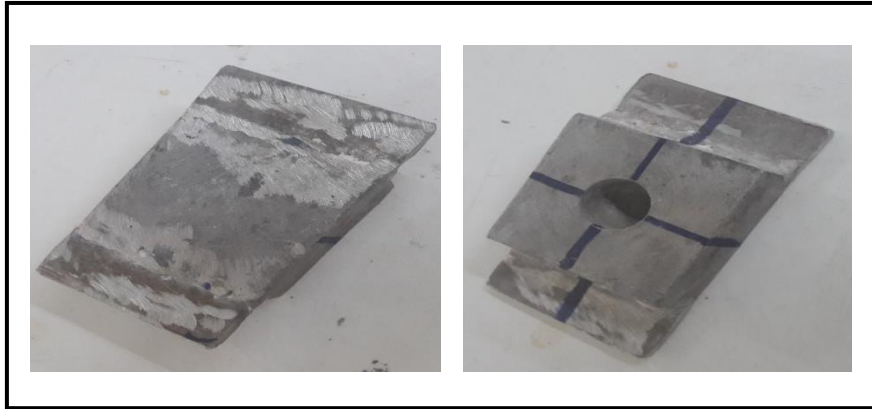


Plate 6. Steel plate used as pile cap.

### 3.3. Concrete Pile

The piles model used in this study is concrete piles. The outer diameter of piles is 30 mm, and the lengths of piles are 300, 450 and 600mm. The embedment ratios (depth to diameter) ( $L/D$ ) equal to 10, 15 and 20 where L is the embedded length of pile and D represents the outside diameter of the pile.

All piles carried out using temporary steel casings were put when reached certain depths, and then extruded during concrete pouring. Shown in plates from Figs. 7 - 9.



Plate 7. Pile installation

Plate 8. Pile installation and pouring

Plate 9. Pile installation and pouring



It is worth to mention that, in each test all concrete with and without additives were tested by taking many concrete cubes (100x100 x100) mm during pouring. The samples of the test are shown in [Plate 10](#).



**Plate 10. Concrete cubes and testing.**

### 3.4. Expansive materials

The Sodium carbonate also  $\text{Na}_2\text{CO}_3$  known as, soda ash and soda crystals, was used as expansive material, Chemical formulas  $\text{Na}_2\text{CO}_3$ . Because it contains the element sodium, known for its high expansive also for its cheap price, in addition the main reason for the selection of the inability to obtain an expansive cement in this narrow period. Several tests were made to measure the expansion ratios. These tests were explain in the [Table 2](#).

**Table 2. Properties of the expansive materials used.**

w/c	Wt. cement, gm	Wt. $\text{Na}_2\text{CO}_3$ , gm	Expansion %
0.33	100	0	1
0.33	95	5	2
0.33	90	10	3
0.33	80	20	5

### 3.5. Model Preparation and Experimental Procedures

The testing procedure consisted of three stages. The first stage is filling of homogeneous sand soil preparation by eight layers; each layer has 100 mm in height to the certain relative density. The second stage is the process of casting the piles in the aluminum tubes that were installed at certain depths in the box before the process of filling the model with soil. The work involves placing a quantity of concrete inside the tube, after which the pipe is pulled out of the tube and the concrete is placed until the tubes are filled with concrete .The third stage is preparation of upper part of soil and head of pile to carry out a load test using the hydraulic jack system explain

in the section before. It is worth mentioning after pile concreting, several days taken before load test to ensure the compressive strength of concrete achieve the acceptable value.

Same procedure was used with each model test of pile, and it takes more times. The procedure can be listed in below points.

1. Using multi lengths to diameter ratios or embedment ratios, ( $L/D$ ) and multi amount of expansive material (0, 10, 15 and 20% by weight of cement were used).
2. The sand bed was levelled by a steel plate of straight edge
3. A steel hollow section 25 mm square was located on the top of the test tank as a guide.
4. The steel casings were located in their positions and held vertically using a tropical device.
5. After that, filling has been continued sand as layers until the container has been filled with certain relative density.
6. After filling the tank with sand and leveling the surface, concrete was poured inside steel casing with rolled compaction and pull-out the casing gradually with filling the casing with concrete.
7. Then waiting several days until concrete take suitable compressive strength.

### 3.6. Testing Program

A series of laboratory model tests were conducted on single piles to indicate the effect of using expansive agents adding to concrete mixture of bored piles to increase skin friction capacity of piles. The testing program consists of 12 model tests for single pile imbedded in sand deposits and poured by different ratios of additives and different embedded ratios with and without treatment. The loosen soil with relative density about 35 % was adopted in order the effect of expansive material be more clear. As shown in flowchart in Fig. 4.

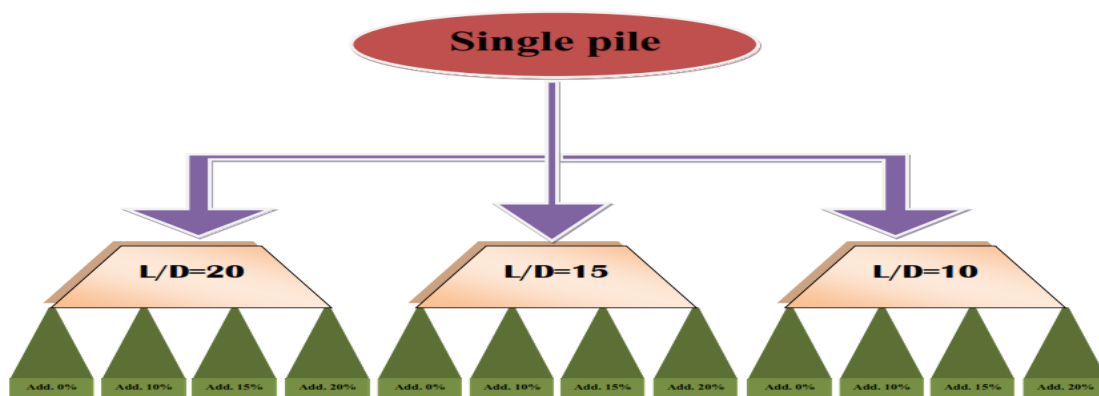


Fig. 4. Testing program flow chart.

#### 4. ANALYSIS OF THE RESULTS

This section presents the results of twelve model tests on single piles. The test results will present the effect of various imbedded length to diameter ratios and percentage of additives on bearing capacity of single piles, vertical settlement of pile cap in loose dry sand. These results are presented in [Figs. from 5 to 14](#).

The results are explained in sections according to effect on bearing capacity of piles. [Figs. from 5-14](#) show load settlement curves for single piles for different lengths to diameter ratio ( $L/D$ ), and different percentages of soda ash (additives). As a result, the [Figs. 15](#) and [Table 3](#) represent the concluded comparison between the percentage of additives and ultimate bearing capacity for different embedment ratios.

##### 4.1. Influence of embedded ratio on bearing capacity of pile

To determine the effect of embedded ratio rate on the ultimate bearing capacity of piles, load test according to the ASTM D1143 was complicated with some of modification. After completing the load test for all piles and down, ultimate bearing capacity of the pile was calculated. There are many methods for deriving the magnitude of ultimate bearing capacity of piles so as Branch Hanson method, Debeer, Davisson offset method, Decort, Kondner, two tangent lines and many other methods. In this study the two tangent lines was chosen for simplicity and because of the failure occurrence.

From all figures, it can be seen that the increasing in length of pile to the diameter ratio leads to increase in the bearing capacity of piles.

Pile dimension has a significant effect on pile capacity increasing the pile length means more stress generated at the pile interface along its length and will lead to increase pile capacity. Also, increasing the diameter of pile means increasing in the surface area of the shaft contact with the surrounding soil, which in turn will lead to increase in the shaft resistance. In addition, increasing the diameter of the pile means more end bearing resistance area of pile. ([Akoobi, 2012](#))

##### 4.2. Influence of percentage of additives on bearing capacity of pile

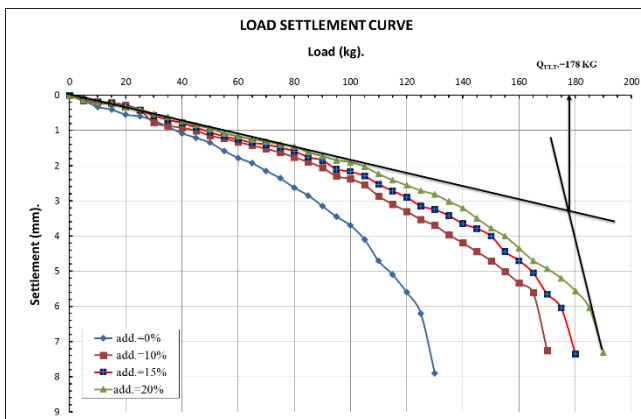
Pile length and diameter are usually the design variables that are manipulated to achieve the required shaft resistance to support the building. As construction costs increase with pile length or diameter, it would be advantageous if the unit shaft friction could be increased, allowing the length or diameter of the pile to be reduced. By casting the pile using concrete containing expansive additives, the friction angle at the interface between the soil and the concrete pile

could be increased, therefore increasing the unit shaft friction and, consequently, the shaft resistance.

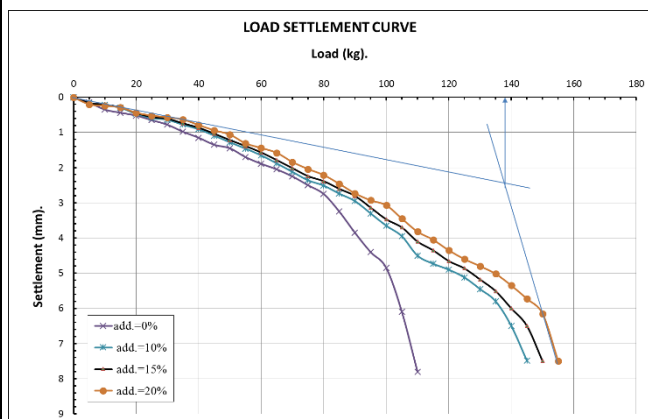
This study conducts research into the use of expansive additives (soda ash) in concrete bored piles. From all figures and Table 3, it can be concluded that the increase in the percentage of additives cause increasing in bearing capacity of piles. These phenomena means the addition the expansive material to the concrete mixture leads to make concrete expand inside the hole this leads to compact the soil surround pile and increase in skin friction of the piles. In addition, the shaft capacity can be increased with expansive additives; there can be implications for the construction of deep foundations in the future.

Shorter expansive piles could be able to achieve the same pile capacity as a longer conventional pile. This would lead to reductions on the volume of concrete poured, the amount of steel reinforcement used and the amount of soil excavated. Therefore, construction costs can be decreased and construction times can be shortened. The enlargement of pile volume after concreting and testing shown in Plate 11.

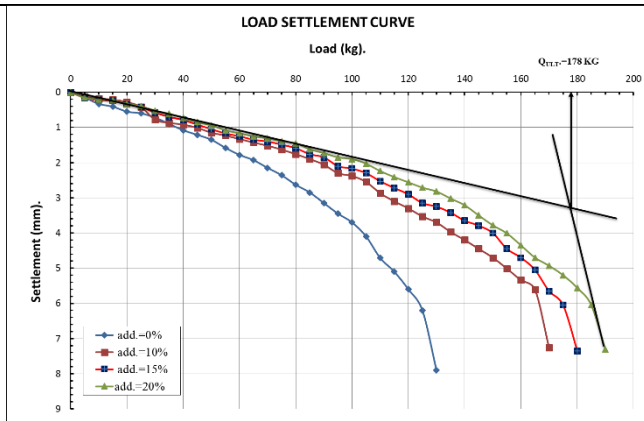
It is worth mentioning that the use of expansive concrete resulted in higher (15 -50%) side resistance and that the settlement is reduced by about 25% in most of the loading range compared with values for a normal concrete shaft.



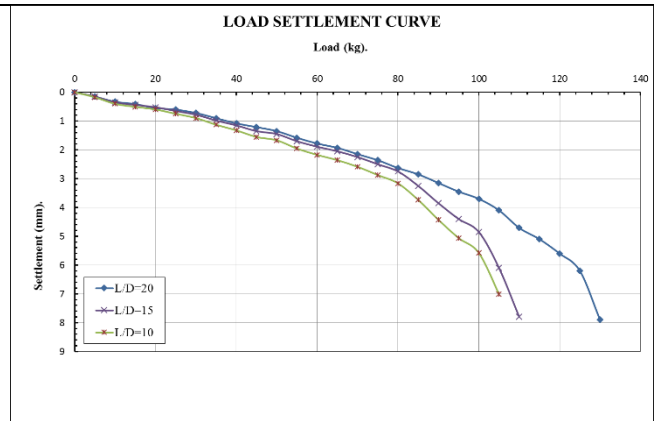
**Fig. 5. Load settlement curve for single pile length = 60cm diameter 3cm with different percentages of additives (0, 10, 15 and 20%).**



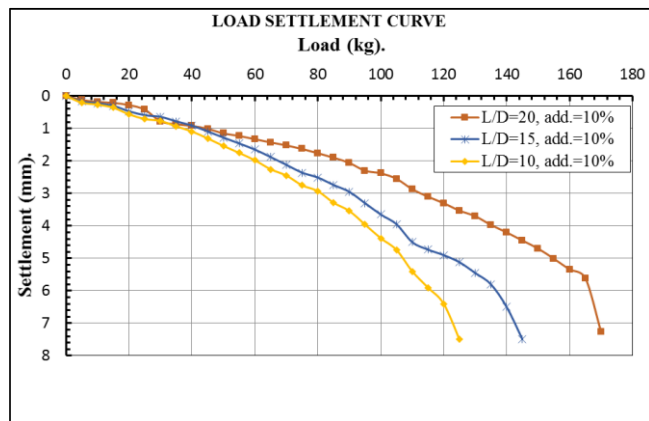
**Fig. 6. Load settlement curve for single pile length = 45cm diameter 3cm with different percentages of additives (0, 10, 15 and 20%).**



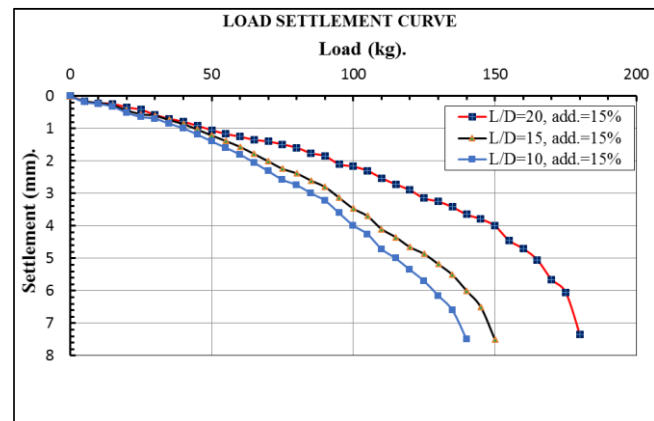
**Fig. 7. Load settlement curve for single pile length = 30cm diameter 3cm with different percentages of additives (0, 10, 15 and 20%).**



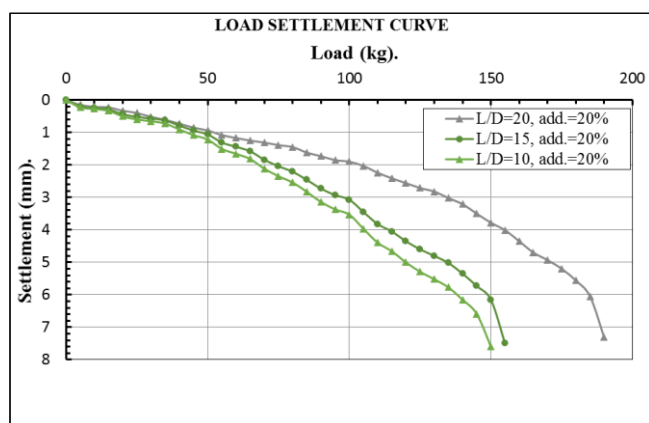
**Fig. 8. Load settlement curve for single pile for different L/D ratios (20, 15 and 10) with 0% percentage of additives.**



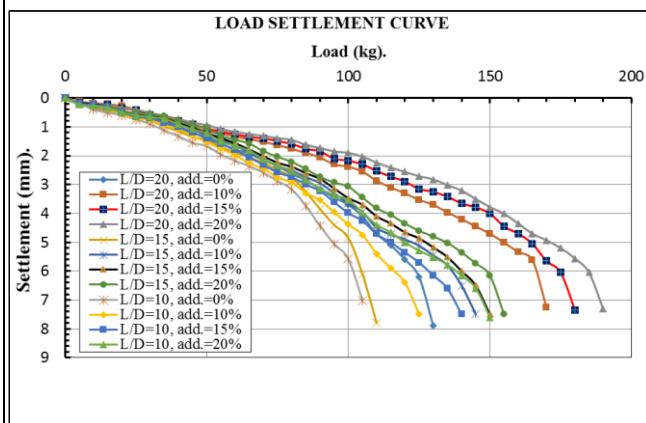
**Fig. 9. Load settlement curve for single pile for different L/D ratios (20, 15 and 10) with 10% percentage of additives.**



**Fig. 10. Load settlement curve for single pile for different L/D ratios (20, 15 and 10) with 15% percentage of additives.**



**Figure (11): Load settlement curve for single pile for different L/D ratios (20, 15 and 10) with 20% percentage of additives.**



**Figure (12): Load settlement curve for single pile for different L/D ratios (20, 15 and 10) with (0, 10, 15 and 20%). percentage of additives.**



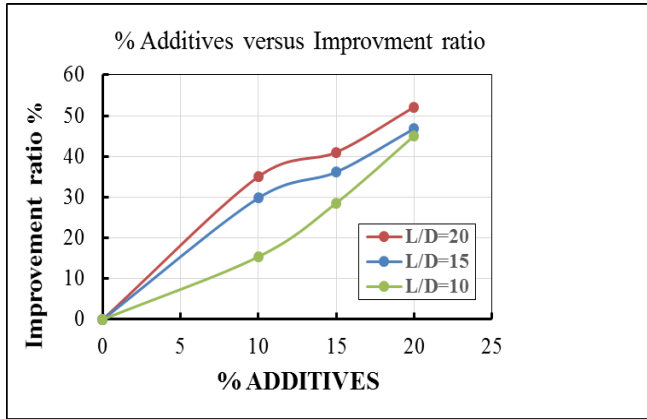


Fig. 13. Improvement ratio for different embedded ratio and different percentage of additives.

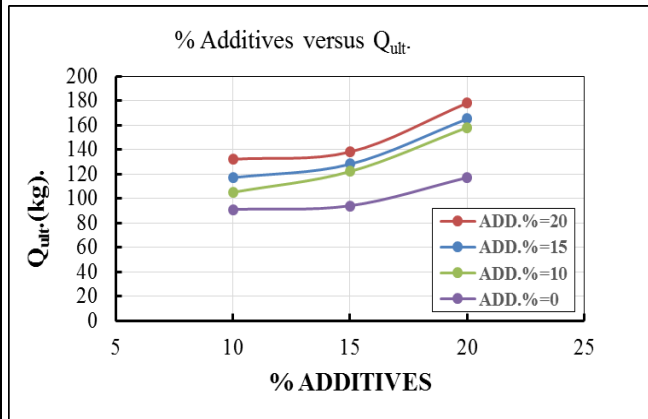


Fig. 14. ultimate bearing capacity with additives for different embedded ratios.

$$\text{improvement ratio} = \frac{Q_{\text{treated}} - Q_{\text{untreated}}}{Q_{\text{untreated}}} \times 100\%$$

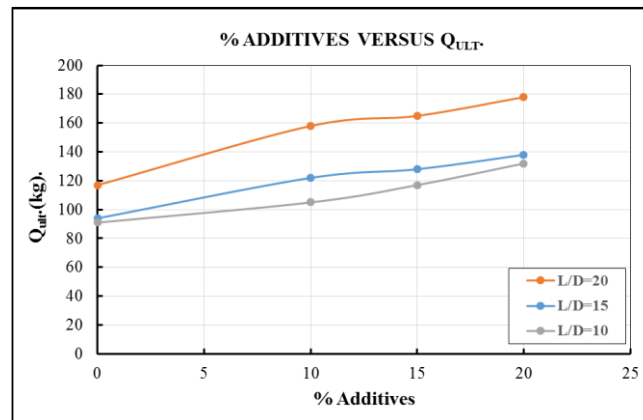
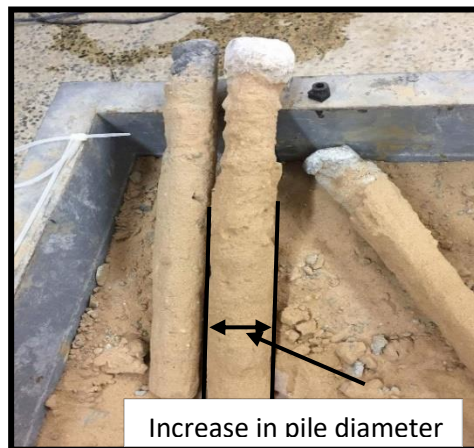


Fig. 15. Ultimate bearing capacity with embedded ratio for different percentage of additives.

**Table 3. Ultimate bearing capacity for different embedment ratio and additives.**

Pile length, mm	Pile dia., mm	L/D	Add%	$Q_{ult.}$	Notes
600	30	20	20	178	
600	30	20	15	165	
600	30	20	10	158	
600	30	20	0	117	No additives
450	30	15	20	138	
450	30	15	15	128	
450	30	15	10	122	
450	30	15	0	94	No additives
300	30	10	20	132	
300	30	10	15	117	
300	30	10	10	105	
300	30	10	0	91	No additives

**Plate 11. Enlargement of pile due to expansion.**

## 5. CONCLUSIONS

The following points are the conclusions which were drawn from the work that has been done:

1. The increasing in length of the pile to the diameter ratio leads to increase in the bearing capacity of piles specially the skin resistance so that increasing the embedment ratio ( $L/D$ ) of pile means increasing in the surface area of the shaft contact with the surrounding soil, which in turn will lead to increase in the shaft resistance.
2. The investigation concluded that  $\text{Na}_2\text{CO}_3$  causes piles to expand due to the increase in volume of the pile, which compresses the surrounding soil and increases shaft resistance, hence, pile capacity. This means that there can be a reduction in the design length or diameter of bored piles, which would reduce construction costs and timescales.
3. The use of expansive concrete resulted in higher (15 -50%) side resistance and that the settlement is reduced by about 25% in most of the loading range, compared with values for a normal concrete shaft.
4. Shorter expansive piles could be able to achieve the same pile capacity as a longer conventional pile. This will reduce the cost and time shortened
5. It is worth mentioning that it can carry out more tests for axial compression and pullout resistance of piles for more types of soils with different relative densities and consistencies and study the effect of additives on group of piles with different pile spacing ratios different embedded ratios of pile.

## 6. REFERENCES

- Akoobi. S. I, (2012), "Effect of stress level of surrounding soil on bored pile capacity in sand", University of Technology. Eng. &Tech. Journal, Vol.31, Part (A), No.15, 2013
- Bowles J. E, (1996), "Foundation Analysis and Design", Fifth Edition, Mc GRAW Hill, Singapore.
- Currell, B. R. et al., (1987), "The acceleration and retardation of set high alumina cement by additives", Cement and Concrete Research, 17(3), pp. 420–432.
- Chan, S., Hanna, T.H, (1980), "Repeated loading on single piles in sand". Journal of the Geotechnical Engineering Division, American Society of Civil Engineers 106 (2), pp.171–188
- Craig. R. F, (2004), "Soil Mechanics", Seventh Edition, Department of Civil Engineering University of Dundee UK".

Harydharaan Gopalan, (CHR) (2013), “Bored piles with expansive concrete”.

Hoff G. C, (1972), “Expansive Cements and Their Use”, U.S. Army Engineer Waterways Experiment Station, Concrete Laboratory. Vicksburg, Mississippi, USA.

Kraft I. M, (1991), “Performance of axially loaded pipe piles in sand”, Journal of geotechnical engineering. ASCE. 117 (2):pp. 272-296.

Manai R, (2010), “Enhancement of Pile Capacity by Shaft Grouting Technique in Rupsa Bridge Project”, Geotechnical Engineering Journal of the SEAGS & AGSSEA, Vol. 41 No.3

Mohammed M. S, (2014), “The effect of improvement surrounding soil on bored pile friction capacity”, International journal of civil engineering and technology (IJCET) volume 7, issue 1, Jan. 2016, pp. 260-273.

Randolph M.F., Dolwin J., Beck R, (1994), “Design of driven piles in sand”, geotech. Vol. 44, No.3, pp. 427-448

Shamim A. Sheikh and Michael W. O'Neill, (1985), “Long-term behavior of expansive concrete drilled shafts”, Department of Civil Engineering.

Wang Q., Zhang Z, (2009), “Study on the Application of Expansive Concrete in Bored Piles”, The Electronic Journal of Geotechnical Engineering (EJGE), Vol. 14.

Yoshito .M, Kiyoshi O, Hidetoshi O, (2007), “Improvement of Horizontal Bearing Capacity by Composite Ground Foundation Method in Soft Ground”.

Al-Shakarchy, Y. and Al-Muhamady, N., (1984) “Foundation Engineering”.