Enhancement of Pile Foundation Performance Using Grouting Techniques

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ABSTRACT

In this era of our development and reconstruction regular piles became not enough for the demands of bigger constructions, to achieve the required bearing capacity needs large diameter piles or bigger lengths relatively so that it's difficult to execute it and having a large cost. So that several ways have been suggested to improve bearing capacity of piles and one of them is Grouting. Grouting through imbedded pipe piles considerably increase the bearing capacity, reduce settlement, and improve the property of pile-soil working together. there was a need for experimental tests for These techniques, this paper provides results of tests (12 model) on using grouting to improve bearing capacity of piles by three different techniques (three spots to grout through piles), Iraqi (karbala) sand have been used in this experiment, slurry cement used as a material grouting. Manufactured equipment used to grout, and examines the models. Results of the tests showing high improvement for both bearing capacity and settlement.

INTRODUCTION

Pile foundations are presently the most important type of deep foundation in civil engineering construction in Iraq and abroad. Especially within the recent one or two decades, pile foundation technology has been developing very fast with the development of collective, large or heavy-type structures in civil construction and tall and super-tall buildings in city modification projects. Pile foundations have been more and more popular thanks to high single-pile capacity, good adaptability to various ground conditions and simplicity of construction machinery, without serious squeezed soil effect and vibration or noise pollution.

Almer E.C. van der Stoel in (2001) prepared a study aiming in increasing the bearing capacity of a pile foundation by three types of grouting (permeation, compaction, and jet), he used field piles made of steel and timber, and he found that grouting is an effective way for foundation renovation and increasing existing piles.

Xudong Fu, and Zhengbing Zhou (2003) compered between grouting piles and normal ones, by taking four piles (two of them are normal bored cast-in-situ piles with length of (29.4 ,24.4 m) respectively, one of the other two was pressure grouted only beneath its tip with length of (14.4m), the last one with 14m length grouted from its sides and tip, their diameter was (0.92, 0.88, 0.88, and 0.87) m respectively. placed in layered soil,

After grouting the two piles with slurry (water: cement: clay) with percentage of (0.6: 1: 0.025) with pressure about (1 MPa) for volume of grouting was (1.6 m^3), they found high increase by pile grouted from its sides and tip compared to the others , their bearing capacity was (6650, 6100, 9500(grouted), 10450(grouted))KN respectively.

Zhang et al. (2004) used grouting at the bottom of the pile to increase the bearing capacity, using water- cement mix with ratio (1:1, 0.8:1, 0.5:1) with grouting pressure of (2-3) mpa at the start and (1-2) for the rest. they reached of high improvement for single pile (from 7500 KN to 11735 KN)

Nguyen Khanh Tung and Wu Li (2015) studied Pile Bottom Post Grouting Technology to Increase the Bearing Capacity of Bored Piles in Vietnam, according to their testing results after grouted, pile's bearing capacity was increased 1.67- 1.75 times.

MATERIALS USED

Sand

in this present study Iraqi sand (Karbala) have been used, the properties of sandy soil used are detailed and listed in table (1), and it grain size distribution shown in figure (1). The soil is classified as SP according to (USCS) the unified soil classification system.

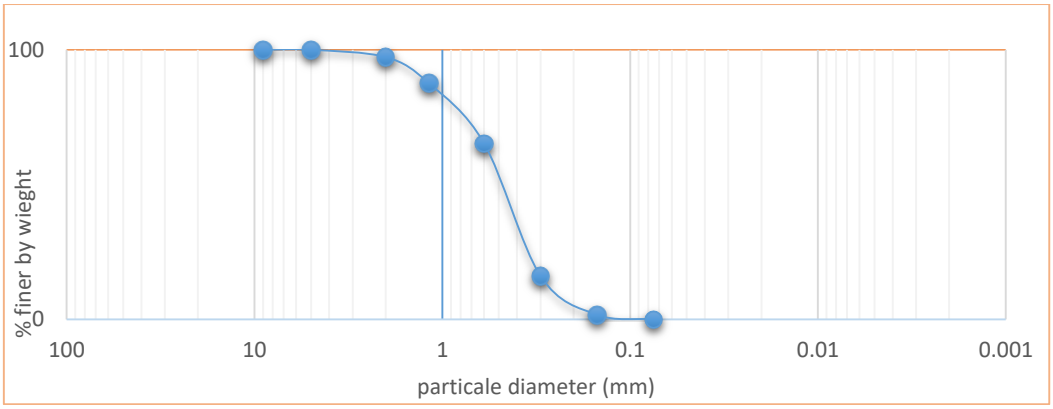

Figure (1) grain size distribution of sand used

Table (1) show the physical and mechanical properties of the tested sand

property	value		specifications
Classification (USCS)	SP		ASTM D2487 -11
Specific gravity, Gs	2.64		ASTM D854 -14
Dry unit weights (kN/m3)			
Maximum unit weight	17.94		ASTM D4253 -14
Minimum unit weight	14.64		ASTM D4254 -14
Void ratio			
Relative density	Loose RD=35%	Medium RD=60%	
Dry unit weight (γd) kN/m3	15.65	16.456	
Angle of internal friction (φ)	35	38	ASTM D3080 -11
Void ratio (e)	0.655	0.573	
Permeability cm/sec	$25.8 * 10^{-4}$	$8.7 * 10^{-4}$	ASTM D-2434
Gypsum content %	1.28		BS-1377-1975
SO3 %	0.59		

GROUTING MATERIAL

Cement

The type of cement that used in this slurry to achieve the purpose of this study was Resisting Portland Cement this type is very cheap and also available everywhere, table (2) illustrate cement properties.

Table (2) Typical Properties-Sulfate Resistant Cement

Parameters		% by weight
Lime Saturation Coefficient		0.83
SO3 Content %		2.47
Loss on Ignition %		1.6
(C3A) %		2.8
Fineness (cm^2/gm)		2670
Initial Setting Time (min)		135
Final Setting Time (Hr)		4
Soundness (autoclave)		0.08%
Compressive Strength as per Iraqi Standard (MPa)	3d	17.3
	7d	24.6

Super plasticizer admixture

The super plasticizer used in this slurry was Glenium 51, (polycarboxylic ether based, it has high range water reducing, and given a high early strengths and more durability, see table (3) for properties.

Table (3) super plasticizer properties

Manufacturer Properties for glenium 51	
Structure of the Material	Polycarboxylic ether based
Color	Amber
Density	1.082 - 1.142 kg/liter
Viscosity	128μ 30 @ 20º C
pH	6.6
Chlorine Content% (EN 480-10)	< 0.1
Alkaline Content% (EN 480-12)	< 3

Grouting mix have a specific properties illustrated in table (4).

Table (4) slurry cement properties

property	**Grouting mix without super plasticizer**	**Grouting mix with super plasticizer**
Plastic viscosity	4 cp	4.7
Apparent viscosity	2.8 cp	3.2
Bleeding	68%	76%
Fluidity	57.5 min	44.5 min

Piles used

The piles used in this study were steel pipe piles and it's in three types:(see figure (3-2)) .

1- Normal close ended pipe pile
2- 2/3 of length of the pipe pile are perforated.
3- 1/3 of length of the pipe pile are perforated.

The piles used to have length (30 cm) and diameter (2.5 cm) and thickness about (1.8 mm). The pattern of piles has hole diameter was (3 mm), and Distance between hole to hole horizontally was 4D (12 mm) c/c, and Distance between hole to hole vertically was 2D (6 mm) c/c, and The upper end of the pile was a scrolled end to connect it with grouting pump. And it illustrated in figure (3) to achieve grouting through piles, a manufactured compressor has been made, as shown in figure (3).

figure (3) perforated piles

figure (3) manual compressor

MODEL PREPARATION AND SETUP USED

To establish the reality of the soil and avoiding the effect of edges of steel container with dimensions of (120x120x80) cm and to avoid sitting of grouting slurry in the base of the container, it has been used (600 mm) depth of soil in shape of six layers (each layer has 100 mm depth), preparing the loose sand there was no need for the compactor on the other hand, when preparing the medium soil can only set by the compactor, see figure (4).

Figure (4) model with layered sandy soil

After setting all six layers of the sandy soil then starting to insert piles in the soil by using guide plate wood to make sure piles insert vertically and to prevent the movement of the pile during insertion, the piles were driven with constant speed using the hydraulic jack, See figure (5).

Figure (5) setting piles

Grouting operation

To prepare the slurry cement, must follows these steps:

1. Weighting needed amount of resistance cement and the volume of water that have been used,
2. Add the Glenium 51 to the water and mix them,
3. Add the cement to the mixed water and plasticizer and mixing them with the drill for about (3 min),
4. Put the slurry to the cylinder that connected to the compressor, and measure the height of the liquid,
5. Connect the outer joint with the pile that imbedded in sand, and open the valve that ejected air onside the grouting system, and start lifting the arm of the compressor slowly till all the air runs out, now close the upper valve and open the main valve that connected with the pile.
6. After the inside pile filled with liquid, the pressure gauge start moving, controlling the pressure manually by the arm that connects with the piston and remaining the pressure at 1.2 bar for grouting loose sand, and 1.8 bar for medium soil.
7. After the measured amount* of liquid grouted correctly, then close the valve and remove connector from the head of pile carefully, avoiding the movement of the pile.

- The amount of the grouted slurry related to the void ratio of the sandy soil and the covered volume needed to improve,

Therefor trails were made to collect the best amount of the injection liquid, and chosen the volume by:

a) The surface area for the expansion of the slurry taken with diameter equals to (7D) from the center of the pile and the height was (1/3*length of the pile) which equals to (10 cm),
b) For loose sand (RD=35%) the volume of the grouts equals to (950 ml),
1) For medium sand (RD=60%) the volume of the grouts equals to (640 ml),
2) After the grouting made, must wash and clean the compressor directly to avoid sitting the cement in the piston.

After preparing grouting mixer then start to grouting from two ways:

1- Through the pile, as shown in perforated piles.
2- From outside the pile, (grouting the base of the pile) like in figure (6).

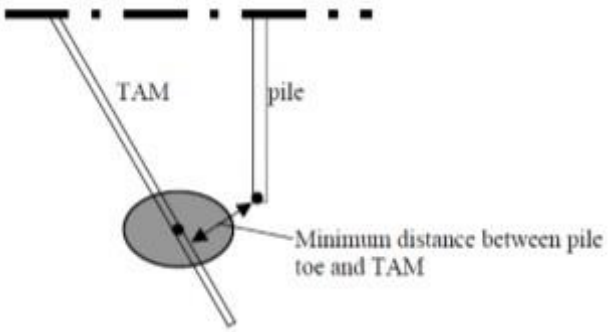

Figure (6) grouting base of piles

Bearing capacity test

The manual hydraulic jack of (10 ton) capacity was used in bearing test. To measure the applied load, a digital weighing indicator connected to the load cell has been used. A two of (0.01mm/division) accuracy dial gauges were placed at the aluminum cap of pipe piles and fixed with the sides of the box by two magnetic holders to measure the settlements during each increment of load. The readings of the digital weighing indicator were recorded with the two dial gauges. According to ASTM-D1143," Standard Test Method for Piles under Static Axial Compressive Load", each load increment is left for (10min). The test was continued until the settlement arrived to 15% from the diameter of pipe pile for the models without grouting and continuing the process for grouted piles, see figure (7).

Figure (7) testing pile

Results of experiment

At the beginning it piles in loose and medium sand without grouting have been tested to compare it with piles cured by grouting, and behavior of bearing capacity of piles without grouting illustrated in figure (8)

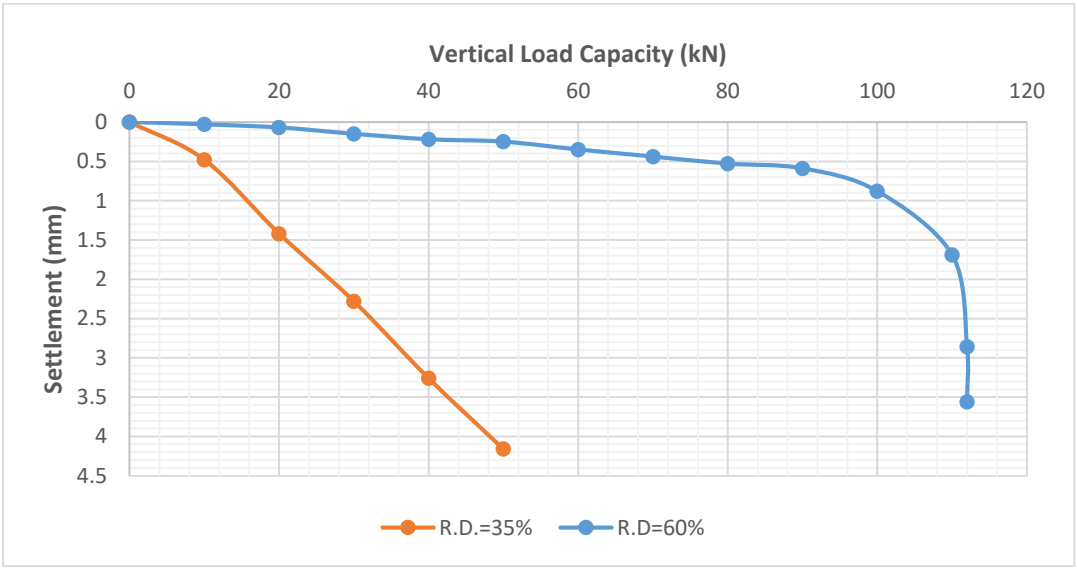

Figure (8) Relationship between static load and settlement with different relative density for single pile without grouting in dry sand

after grouting from three different ways, the results shown in figure (9)

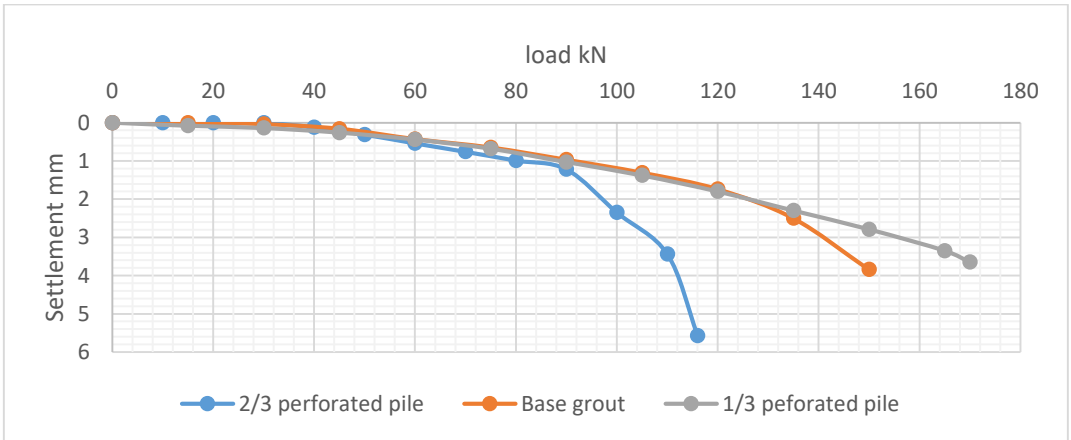

Figure (9) Relationship between static load and settlement with different techniques of grouting for single pile imbedded in dry loose sand

Fig (9) represent the relationship between the vertical load and settlement for pile imbedded in dry loose sand (R. D=35%) grouted by slurry of cement at depths (1/3 and 2/3) of the length of piles from the pile base, and base grouted pile from outside. it is noticed that the shape of load-setl. Curve changed from bunching to general shear failure.
It is cleared that the use of grouting effect on the load capacity. the load capacity is (170kN), (111kN), (142kN) and (43kN) for pile without grouting, pile grouted 1/3 L , 2/3 L and base grouted respectively. The load capacity ratio which is defined as the ratio of the ultimate load capacity with grouting to the ultimate load capacity without grouting are (395%), (258%) and (330%) respectively.

This improvement is attributed to the modification and compaction in soil around the pile tip occurred by pressuring slurry cement and the effect of cementation between grout mix and sand.

Figure (10) shows the amount of improvement on pile by using cement grouting (1/3 perforated) imbedded in loose sandy soil,

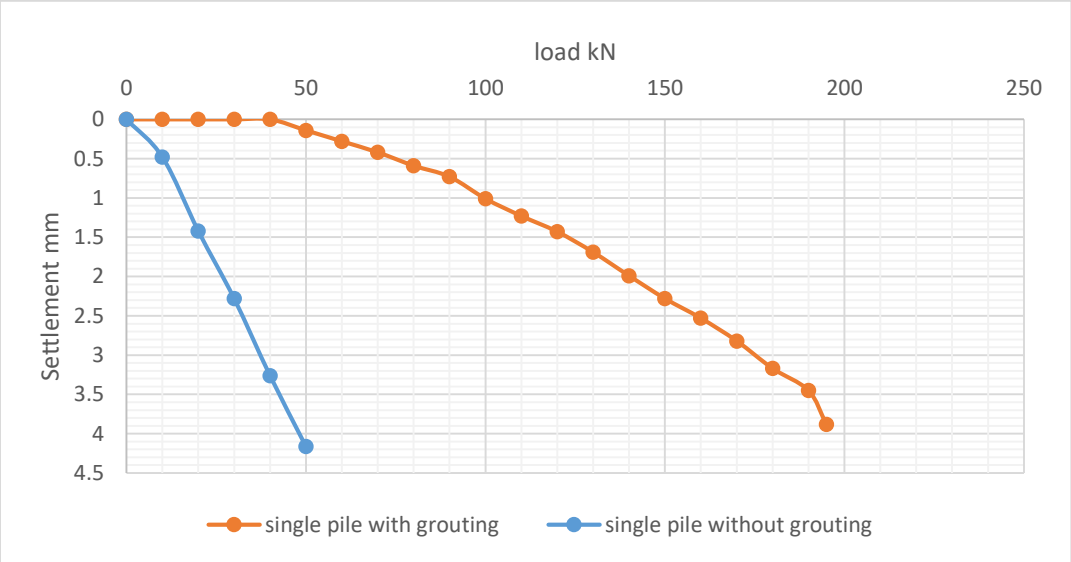

Figure (12) Relationship between static load and settlement of single pile (1/3 perforated) with and without grouting imbedded in dry loose sand

Figure (13) shows the amount of improvement on pile by using cement grouting (1/3 perforated) imbedded in medium sandy soil,

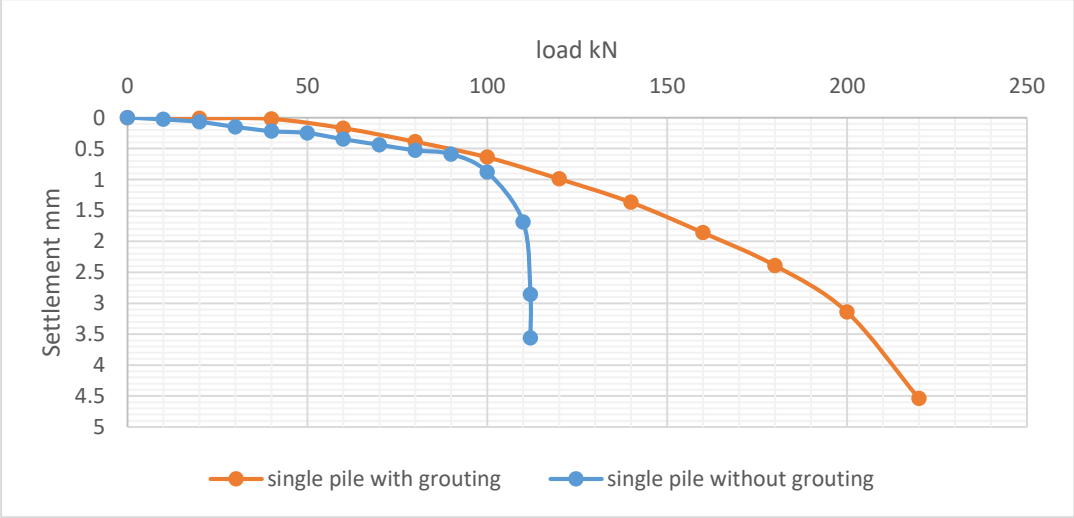

Figure (13) Relationship between static load and settlement of single pile(1/3 perforated) with and without grouting imbedded in dry medium sand

Figure (14) shows the amount of improvement on pile by using cement grouting (1/3 perforated) imbedded in saturated medium sandy soil,

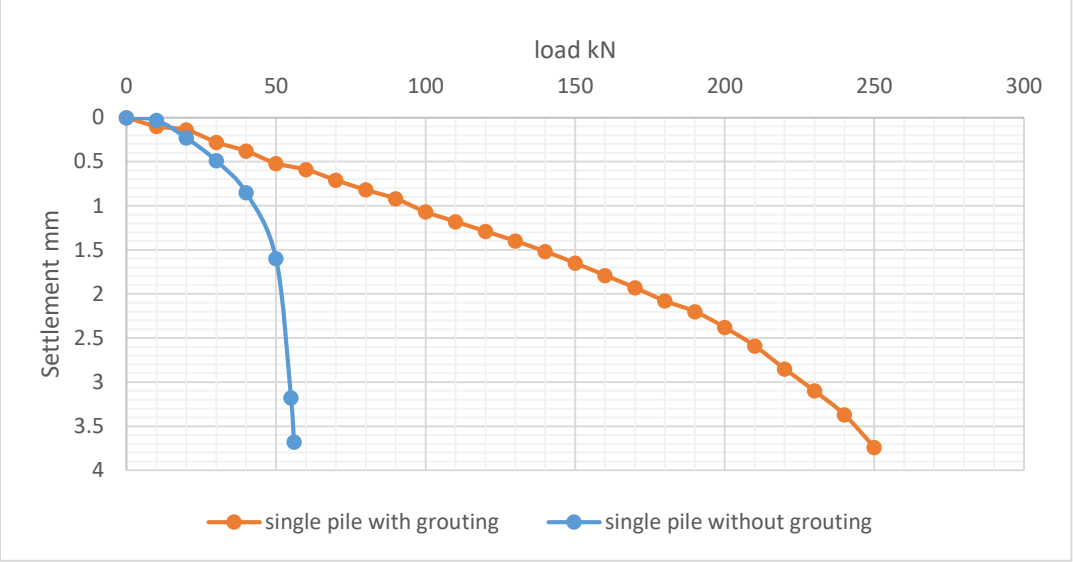

Figure (14) Relationship between static load and settlement of single pile (1/3 perforated) with and without grouting imbedded in saturated medium sand

Effect of curing time

by seeing the results of techniques it has been examine the effect of curing to the grouting piles, by using 1/3 perforated pile with curing time of grout (3,14 and 28 day) And it can be seen in figure (15).

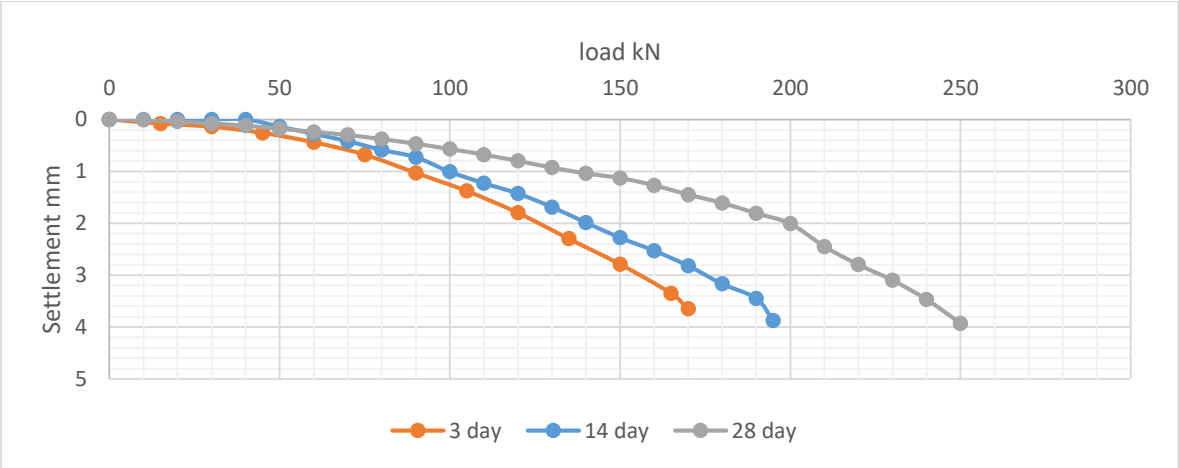

Figure (15) Relationship between static load and settlement with different Curing times for single pile (1/3 perforated) imbedded in dry loose sand

From figure above it's noticed that curing time have effect on bearing capacity of piles specially 28 days.

CONCLUSIONS

After using three different methods to improving piles by grouting, it can be noticed:

1- through proceeding the grouting, base grout needs a high pressure to grout compare to others (about 2.8 bar).
2- probability of uplifting pile through proceeding the grouting in base grouts.
3- The grouted volume in Base grout is small amount compare with the others, and that's related to the compactness under the pile tip.
4- Using (2/3) perforated pile gives some problems like heave and west of slurry out of effected area also allowing pressure are very small, because the holes are near to the ground surface.

5- From all the above the researcher chosen was (1/3) perforated piles to proceed grouting in other models (cases).

After comparing between piles with and without grouting its noticed that the shape of load-setl. Curve changed from bunching to general shear failure.

Using grouting techniques in pile foundation increases bearing capacity (2 to 4) times approximately.

Curing time of grouting effect on bearing capacity of piles (less effect at 14 days and match effect on 28 days).

Relative density effect on grouting (loose sand more improvement compare to medium sand).

Soil condition have a large effect on grouting (bearing capacity of piles in saturated medium sand have bigger improving compare to piles in dry medium sand).

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