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Comparative Study of Bearing Loads for Open Ended Pipe and H-Piles in Sandy Soil

Abstract- *This paper clarifies the response of steel piles installed in sand under vertical static compression load. To evaluate the ultimate load capacity of both piles, the results were introduced in a comparison form. Pile capacity of open ends pipe pile is affected by degree of soil plugging and sometimes the removal of soil plug may decrease the friction between soil and inner shaft of pile and causes a reduction in the load capacity. Therefore, to avoid plugging phenomenon occurred during piles installation; H-piles sections are manufactured based on the equivalent area steel of open pipe piles and tested under the same conditions. 36 steel piles with lengths equal to (30, 40, and 50) cm are tested. The piles are embedded using jacking technique in sandy samples with two different relative densities; medium sand (60%) and dense sand (80%).The results showed that H-pile has a load capacity greater than open ended pipe pile and increases with the increase in both length and diameter (width of flange) of pile. When relative density increased, plugging phenomenon does not occur in H-pile therefore, it can be used instead of open-ended pipe pile to get rid of plugging phenomenon problems.*

Keywords-*H-pile, Pipe pile, Soil plug, Bearing load*

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1. Introduction

Steel piles are either rolled steel H-section or pipe piles. Steel piles have the benefit of being strong, easy to handle, when driven on to a hard stratum, it can be able of carrying high compressive loads, and able of being driven inflexible to a deep penetration to be arrived to bearing stratum and developing a high resistance of friction. They can be designed as small displacement piles, which are useful in cases whereby ground upheave and lateral displacement have to be avoided [1]. H-piles are small-displacement piles, and their load react is likely to be in between those of non-displacement and large-displacement piles. The boundary shaft capacity of H-piles perhaps mobilized 1) sideways the entire surface area of the H pile (full soil-pile interface contact circumference); involving the web and the flanges or 2) sideways, the outer boundaries of the H-pile cross section [2].

Generally, pipe piles are widely implemented for foundation design of offshore structures, the bearing capacity of open-ended pipe piles can just appraise for the unplugged or fully plugged modes of penetration. Practically, the partial plugged mode occurred when the pipe piles are inserted in sandy soil. When plug capacity is computed, the soil plugging is considered as a concatenation of horizontal thin discs [3]. Many researchers conducted the investigations on steel piles (H- pile or open pile), some of these studies will be briefly stated below:Lehane and Randolph [4] made a presumption from examination the minimum base resistance for driven pipe piles in sand. They illustrated that for piles with ends open the base capacity installed in a plugged coring or fractionally plugged state is the same as that for piles with ends closed.

Yang et al. [5] tested a full-scale field of two steel H piles jacked into dense sandy soils. The experiments consequences indicated that the most the pile-capacity was conveyed by shaft-resistance instead of base-resistance. This observing denotes that the design conception that piles in dense sand have very large base-capacity and small shaft-resistance is possibly to be inapplicable for jacked piles.

Yu [6] studied results of full-scale loading tests on two steel H-piles driven into dense sandy deposits. Both piles were exhibited a base resistance about 60% of the prettified capacity. It was also found that the shaft-resistance was contributing essentially by the friction between the pile shaft and the fully or highly decomposable granite.

Al-Soudani [7] deduced that the pile load-carried capacity in dense sand is several times greater than those in loose and medium sands, particularly in the state of closed ended or open ended pipe piles, since the pipe pile can

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producing internal and external skin friction additionally to the end bearing resistance that makes the total pile-capacity approximated to that of closed ended pipe pile.
Actually, the soil mechanical processes and the varied factors of effect on the plugging influence are mostly unknowable. The present study concentrates on the performing bearing capacity of H-pile and pipe pile with ends open embedded in sandy soil. The modeling of piles are conducted to make a comparison between the pipe and H-piles depending on the friction area and load bearing to avoid the plug problems occur during driven process.

2. Experimental Work

I. Soil Properties

Sand used is taken from east of Baghdad in Iraq. A series of laboratory tests are conducted to distinguish it. According to (USCS), sand used is classified as poorly graded sand (SP), with D_{10}=0.29 mm and D_{50}=0.70 mm. The maximum and minimum dry unit weights of sand are 19.32 and 15.8 kN/m3, respectively. Table 1 summarizes the outcomes of experimental testing. According to the shearing test, the friction angles are 31.5^{o} and 38.7°, for medium sand (Dr =60%) dense sand (Dr = 80%) respectively. Reason for selecting these two relative densities, which most of Iraq's sandy soils range between these percentages and steel piles are not preferable to use in loose soils.

II. Sample Preparation

All testing are carried out on piles model installed in air dry sand compacted inside a steel container with dimensions (100×75×70) cm^3. Sand deposit is prepared using a hammer manufactured with square shape (15×15) cm^2 with 5mm thickness. The depth of container is 70 cm, so the sample soil is compacted in seven layers, each layer is 10 cm compacted to desire depth which previously identified by lines drawn on the sides of container, then the top layer is leveled using a ruler with sharp edge. Plate 1 represents the steps of the sand deposit setup.

Plate 1: the steps of the sand deposit setup.

3. Pile Models and Testing Program

36 steel piles are tested to attain the aim of this study (Plate 2). Eighteen piles models are open pipe piles with diameters (2.5, 3.5, and 4.1) cm and others are H-piles with flange widths (2.6, 3.6, and 4.4) cm, embedded in dry sand. The length for all piles models are (30, 40, and 50) cm. Pile diameters of pipe pile, flange widths and thickness of the H -piles are selected according to Jardine and Chow [8] who suggested that (d/t) ratios (outer pile diameter to wall thickness) are varying between 15 and 45, with roughly an average of 27. Table 2 and plate 3 gives details of piles models according to (d/t). To simplify and notate every piles used in this study; each pile was encoded in accordance with testing type (static (S)), pile type (open pipe (O), H pile (H)), pile diameter (d), wall thickness (t), flange width of H-pile (B), web depth (dh) and pile length (L). The axial loading is applied on model using a hydraulic jack having a maximum loading capacity of (1 ton).
Load cell with maximum capacity of (2 ton) is used and connected with a digital weighing indicator to measure the applied load. The system of pile driving consists (86 × 20) cm^2 base plate with thickness of 2 cm. The holder is added on this plate with different diameters (width of flange) depending on the type of pile. For open piles, the holder is made from a steel material with dimensions of (10×10×2) cm and it has a circular hole with different diameters, but for H-piles, the holder is wood material with dimensions (15×15×4) cm having a hole with

different widths (plate 4). After the completion of the bed of sand to the desired relative density, the container fixed under the axial load frame, and then fixed with base plate and then holders installed on it. The piles models are installed vertically in the hole of the base plate that is being in the holder. Thereafter, the hydraulic jack is lowered on the top of piles model until become in touch with load cell at the top of the pile.

After that, the applied vertical load from jack was applied on the pile and read it by the indicator for each 2.5cm penetration to measure plug length using a measuring tape for open pipe pile until reaching a desired embedded length rails and fixed in position in such a manner. The aluminum plate on the top of the pile was fixed, the container was moved along that the center of the aluminum base plate of the piston coincided with the center of the pile model. Then the vertical static load is gradually applied with 0.03mm/sec controlled displacement. The load was measured until the recorded settlement exceeded 15% of the pile diameter according to ASTM D1143M-07 [9], (plate 5).

Table 1: Physical properties of the test sand

Property	Value	Specification
Effective sizes, D10, D30, D50, D60. mm	0.29, 0.45, 0.7, 0.9	ASTM D2487 -11
Coefficient of uniformity, Cu	3.10	
Coefficient of curvature, Cc	0.78	
Classification (USCS)	SP	ASTM D2487-11
Specific gravity, Gs	2.66	ASTM D854-14
Maximum unit weight, γ_d (max.) kN/m^3	19.4	ASTM D4253-14
Minimum unit weight, γ_d (min.) kN/m^3	15.8	ASTM D4254-14
Maximum void ratio, e_{max}	0.68	
Minimum void ratio, e_{min}	0.371	
Relative density, %	Medium = 60	Dense = 80
Dry unit weight (γ_d) kN/m^3	17.75	18.5
Void ratio	0.55	0.44
Angle of internal friction (φ), deg.	31.5	38.7 ASTM D3080-11

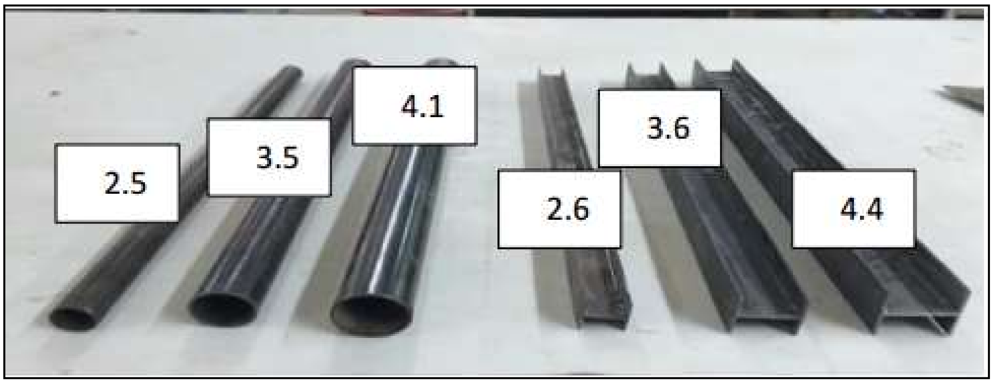

Plate 2: model piles used

Table 2: Dimensions of model and prototype of piles

Model Pile (Open pipe piles)					**Prototype Pile (Open pipe piles)**						
d (cm)	T (cm)	d/t	P (cm)	Area steel (cm^2)	D (cm)	T (cm)	d/t	Area steel (cm^2)			
2.5	0.15	16.67	7.85	1.11	27.3	1.63	16.67	131			
3.5	0.2	17.5	10.99	2.07	30.5	1.74	17.5	157.21			
4.1	0.2	20.5	12.88	2.45	35.6	1.74	20.5	185.1			
Model Pile (H- piles)					**Prototype Pile (H- piles)**						
B (cm)	T (cm)	d_h (cm)	B/t	P (cm)	Area Steel (cm^2)	B (cm)	T (cm)	d_h (cm)	B/t	Area steel (cm^2)	Sect-ion
2.6	0.15	2.3	17.3	15.3	1.11	33.5	1.94	29.5	17.3	190	Hp33×149

3.6	0.2	3.2	18	21.2	2.07	26	1.44	22.5	18	108	Hp25×85
4.4	0.2	4	22	26	2.45	26.5	1.2	22.5	22	955	Hp26×75

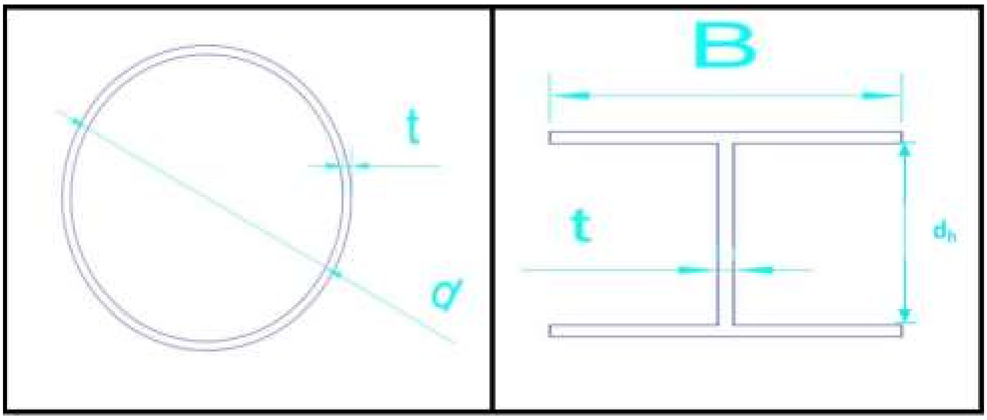

Plate 3: Open pipe and H pile sections.

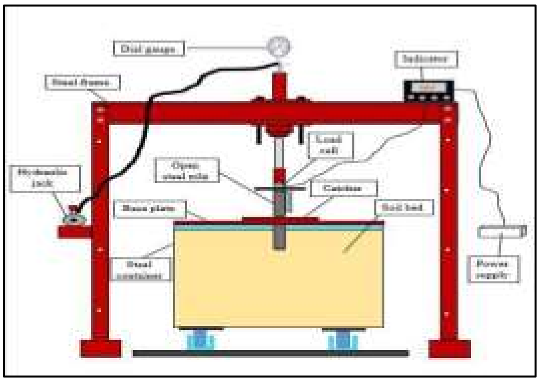

Plate 4: steel loading frame

Plate 5: testing model

4. Model Pile Test Results

I. Soil plugging

Soil plugging degree in the open-ended pipe pile significantly affects the behavior of these piles. Variation of soil plugging length with pile penetration depth is drawn in Figures 1 and 2. It can be observed that the length of soil plug increases with increasing the pile diameter for the same pile length which creates more friction between inner shaft of pile and surrounding soil (increase in skin friction area). This phenomenon does not occur in H-piles because the soil surrounds H-piles in all sides during inserted it to desired depth, and this will prevent the plug phenomenon occur during insertion. For this reason, H-pile is characterized from the open pipe piles.

II. Plug Length Ratio (PLR)

Plug length ratio defined as "ratio of soil plug length to the pile penetration". Pile penetration is mainly depends on length and diameter of pile. Figure 3 shows that the plug length ratio increases with increase pile diameter and relative density when the pile has the same length. In addition, Figure 4 illustrates that for the same pile diameter, plug length ratio decreases with increasing of pile length, soil density and pile diameter. The load capacity of open-ended pipe piles is affected by the soil plug degree, which it is specified by the plug length ratio (PLR). Figure 5 confirms that the ultimate load capacity increases with decreasing the plug length ratio when the pile diameter and relative density increased with the same pile length.

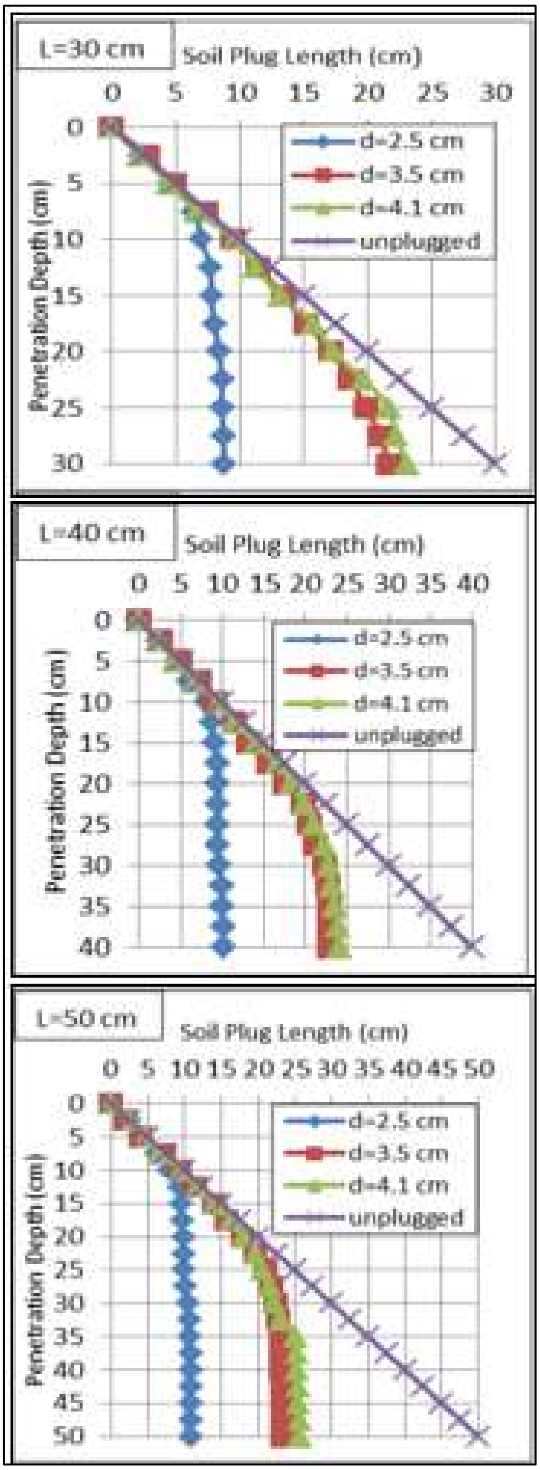

Figure1: Soil plug length versus penetration depth for DR=60%.

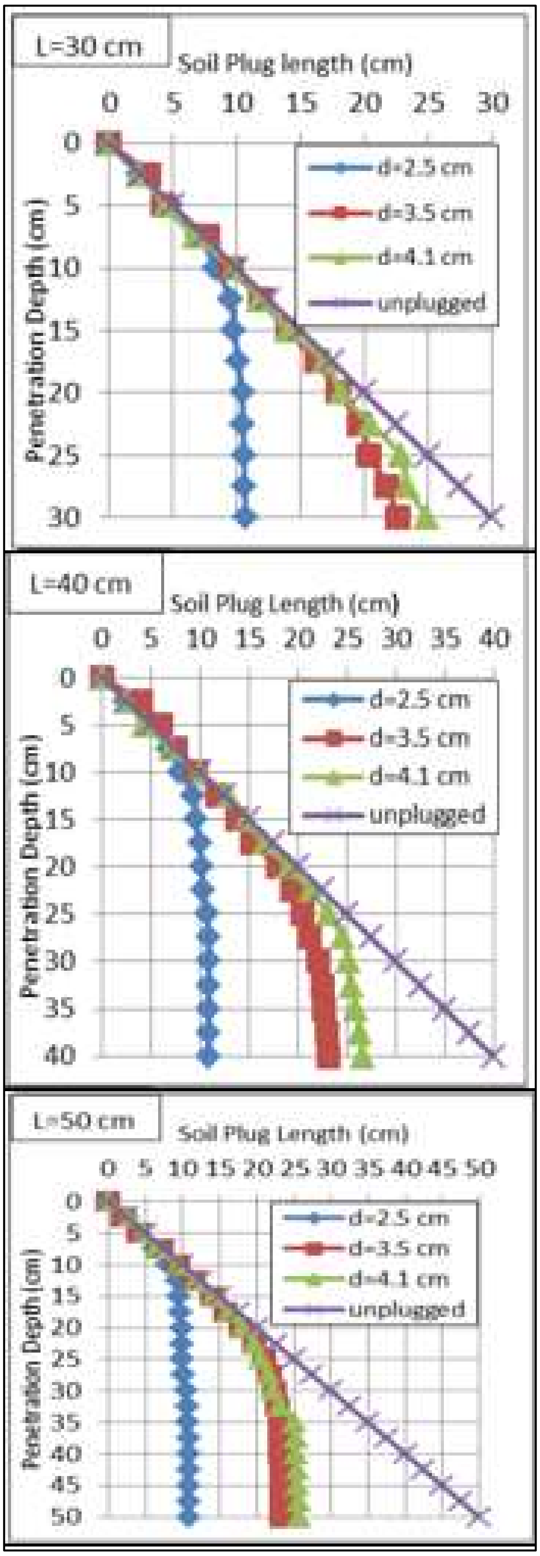

Figure 2: Soil plug length versus penetration depth for DR=80%.

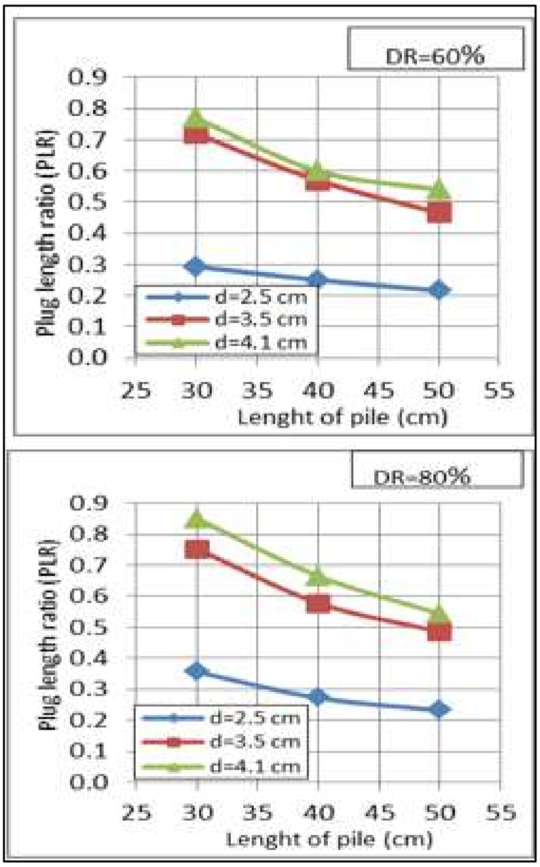

Figure 3: Plug length ratio with length of pile.

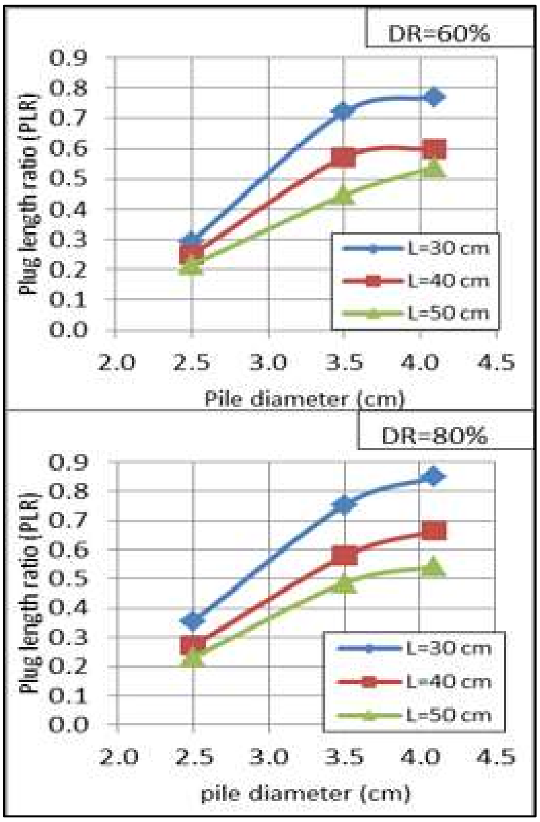

Figure 4: Plug length ratio with diameter of pile.

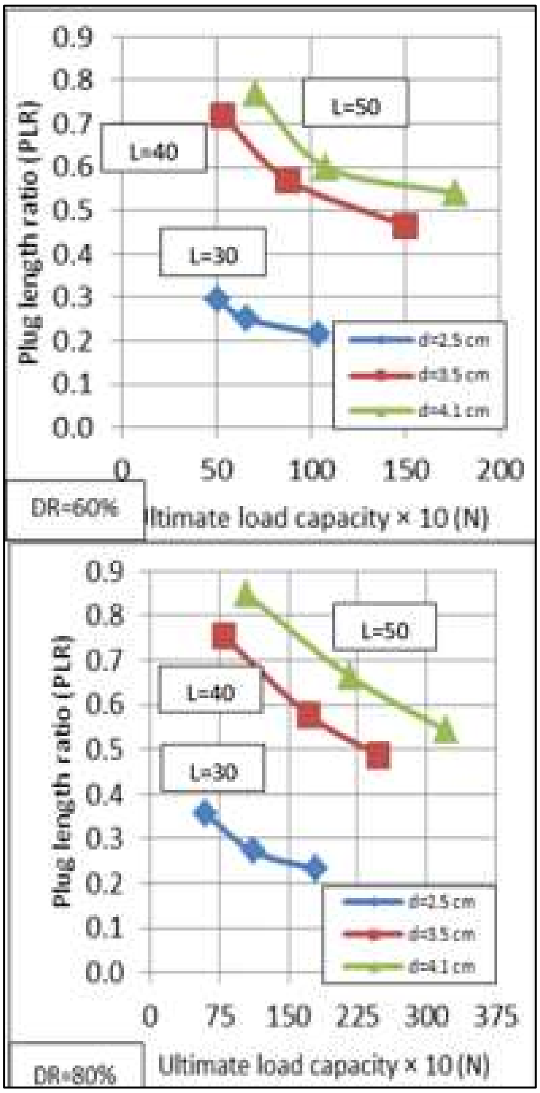

Figure 5: Ultimate load capacity and plug length ratio for piles length (30, 40 and 50) cm

III. Jacking Load of Open and H-piles during Installation

Figures 6 and 7 represent the effect of jacking installation method for open-ended pipe and H-piles. To simplify the data presentation, the results are drawn in the form of variation of jacking installation ratio as (Lj/Qult) where Lj is load of jack) with penetration to diameter ratio (D/d).Generally, it can be observed that the relation of increasing penetration to diameter ratio with increasing the Lj/Qult is positively for both open pipe and H piles until to the desired depth. The values of Lj/Qult are variable due to difference in the pile length and relative density. The reason for this behavior is that in case of open ended piles only the pile shaft resistances varied, therefore, when the approximately approach to the closed-end pile behavior due filling of skin friction inside pile (decreased by weight of soil plug) that bypassed the ultimate bearing load (static) of the soil beneath the tip of the pile (pile toe), and this behavior is same applied at H-piles.

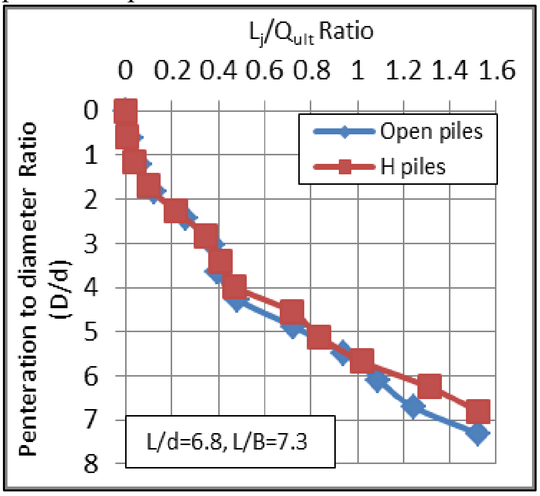

Figure 6: jacking installation ratio verses penetration to diameter ratio for DR=60% (d=4.1, B=4.4, L=30) cm.

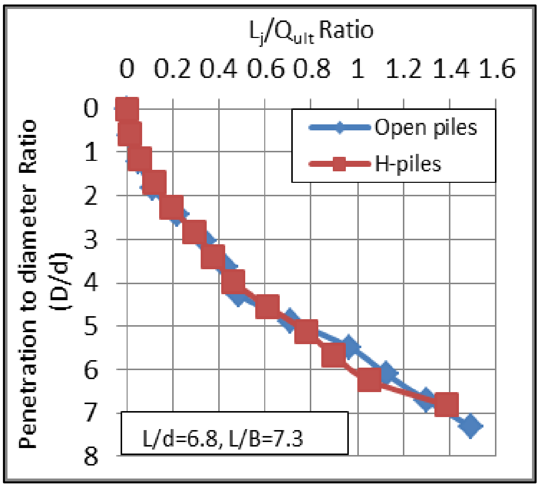

Figure 7: jacking installation ratio verses penetration to diameter ratio for DR=80% (d=4.1, B=4.4, L=30) cm.

Figures 8 and 9 represents the comparison between open and H-piles for the same pile diameter with different pile lengths. The pile capacity of H-piles is higher than open piles. Identically, the rate of increase in pile capacity for the same pile length is increased with increase of pile diameter (width of flange) and relative density. This increasing in capacity of H-piles obtains that H-pile affords a vertical load greater than open pile, and this resulting a skin friction in H-pile greater than that in open-ended pipe pile, despite that the open pipe pile has two friction areas (outer and inner area).

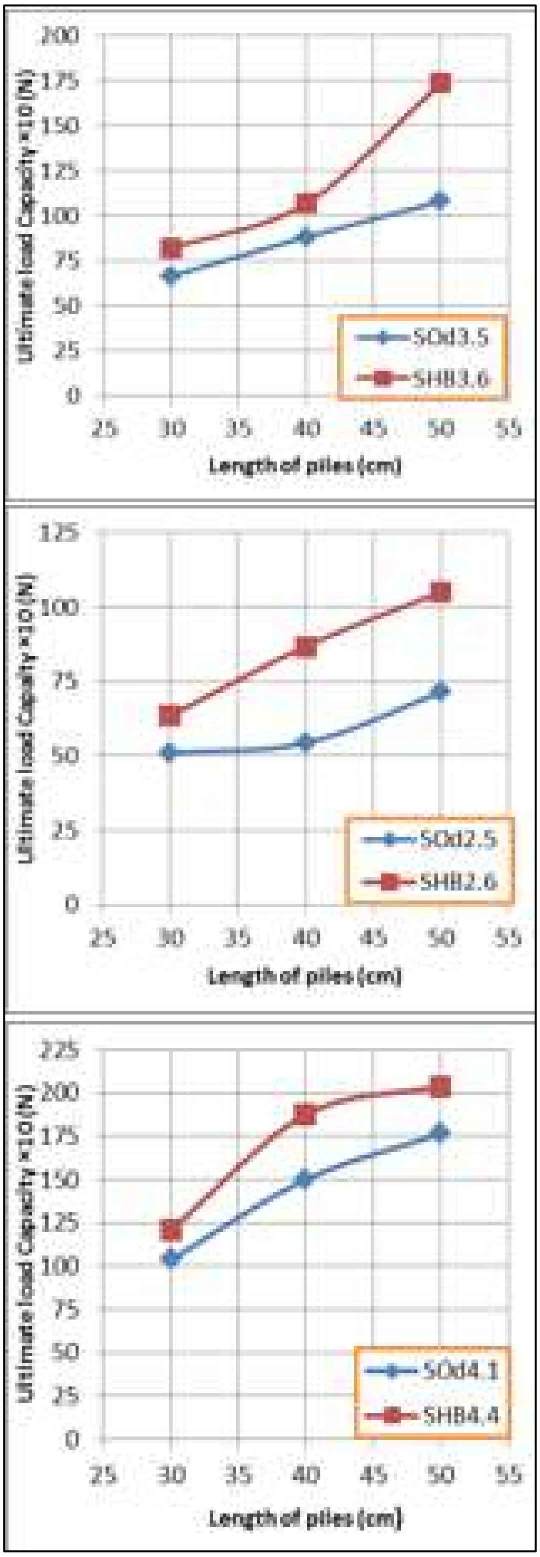

Figure 8: Effect of pile length on the ultimate load capacity for DR=60%.

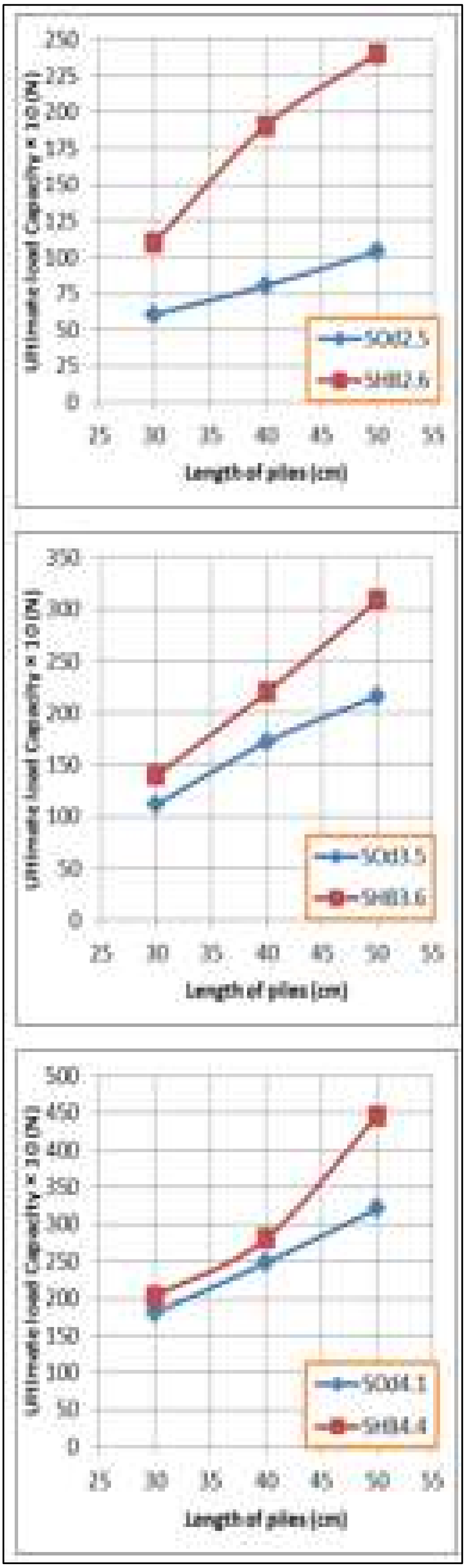

Figure 9: Effect of pile length on the ultimate load capacity for DR=80%.

5. Conclusions

The conclusions obtained from this research are-:

1) Soil plug of open pipe piles is depends on mainly pile diameter, pile length and soil density. Soil plug length to pile length ratio decreases with increasing pile length and relative density, but increases with increasing pile diameter.

2) Length of soil plug increases positively with pile diameter for the same pile length, which creates a more friction between inner shaft of pile and surrounding soil in addition to the external friction of pile.

3) The ultimate load capacity increases with decreasing plug length ratio and with increasing in pile diameter and relative density for the same pile length.

4) Behavior of open-end pipe pile approximately approach to the closed-end pile behavior due filling of skin friction inside when the pile penetration to pile diameter ratio increased.

5) H-pile has ultimate load capacity greater than open-ended pipe pile, and it increase with increases in both length and diameter of pile and when relative density increase. The plugging phenomenon does not occur in H-pile.

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Author's biography

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Since 2010, he has been Assistant Professor. Since 2003 to yet, he has been a teaching staff with the Building & Construction Engineering Department/ University of Technology. He is the supervisor of more than 16 postgraduate (M.Sc. and Ph.D.) students. He has published more than 35 scientific researches and he have one patent.

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