Effect of installation method on the uplift capacity of piles in sand

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The piles in the foundations of transmission lines, transformer stations and onshore structures, are subjected not only to compressive force but also to tensile force or uplift force due to wind loads, wave and storm. This research aims to study the effect of pile installation method on the uplift capacity of pile in sand. Thirty tests on smooth steel piles embedded in very dense sand (Dr = 96%), loose sand (Dr = 36%) and medium sand (Dr = 48%) were carried out. The ratios of embedment length to diameter (L/D) were 10, 15, 20 and 25. The piles were subjected to pull out loads through a double pulley arrangement with flexible wire. The experiment results indicated that the uplift capacity increased with increasing the embedment / diameter ratios. The results indicate that shaft resistance increases linearly with depth for dense sand and parabolic increase at increasing rate for loose sand. The result of the experimental program indicated that the uplift capacity of driven piles is high with respect to the non displacement and jacked piles for loose sand. While the capacity for non displacement pile is bigger than that of driven and jacked piles in dense sand.

تتعرض أساسات بعض المنشآت مثل أبراج نقل الكهرباء أو خطوط محولات الكهرباء و بعض المنشآت البحريه المحموله علي خوازيق لقوة شد بالأضافه إلي قوي الضغط المنقوله للخوازيق. تتولد قوة الشد نتيجة تعرض هذه المنشآت لقوي الرياح أو صدمات الأمواج و العواصف . لذلك يهدف هذا البحث لدراسة تأثير طريقة تنفيذ الخوازيق علي قدرة تحملها للشد. تم عمل دراسه معمليه علي خوازيق نفذت أما بالدق أو الدفع أو خوازيق مدفونه مسبقا بالرمل و هذه الخوازيق عباره عن مواسير من الحديد الملساء ذات قطر خارجي ٢٢ مم و سمك جدارها١,٢٥ مم. تم تنفيذ الخوازيق بأطوال مختلفه بنسبة طول مدفون إلي القطر الخارجي ١٠ و ١٥ و٢٠ و ٢٥ لدراسة سلوك الخوازيق بزيادة عمق الاختراق. كذلك تم عمل الأختبارات لكثافة نسبية من الرمل (Dr) ٣٦ و ٤٨ و ٩٥ لدراسة تأثير كثافة الرمل علي قدرة تحمل الخوازيق لقوي الشد. من التجارب المعمليه أمكن الوصول لأن كثافة الرمل من أهم العوامل المؤثره في قدرة تحمل الخوازيق لقوي الشد كذلك أتضح أن قدرة تحمل خوازيق الدق أعلي من خوازيق الدفع أو الخوازيق التي تنفذ بدون أزاحة للتربة و ذلك في التربة السائبة أو متوسطة الكثافه. بينما تكون قدرة تحمل الخوازيق المنفذة بعدم أزاحه أعلي من خوازيق الدق أو الدفع في التربة الرمليه الكثيفه. كذلك أتضح أن خوازيق الدفع تتولد بها سدادة من الرمل أثاء تنفيذها و تكون ثابتة عند عمق أختراق يعادل ١٢ مره قطر الخازوق الداخلي و يكون طولها يعادل خمسة امثال قطر الخازوق الداخلي بينما في الخوازيق المنفذة بالدق تتولد بها سداده ثابته عند عمق أختراق يعادل ١٦ مره قطر الخازوق الداخلي و يكون ارتفاعها يعادل سبعة أمثال القطر الداخلي.

Keywords: Uplift capacity, Driven pile, Jacked pile, Method of installation, Skin friction

1. Introduction

Shaft resistance is a major design factor for piles supporting structures such as transmission towers, harbor structures, and offshore platforms. Method of pile instillation may have an important influence on its behavior Sherif [1]. Since installation of pile changes the initial conditions of soil mass near the pile, the properties of soil which govern its bearing capacity and settlement may differ considerably. It is acknowledged that the pile driving increases the density of loose and medium sand around the pile shaft and below its tip. Meyerhof [2] and Kishida [3] devised methods for estimating the extent of zones increased density around a pile driven in sand. Meyerhof [4] demonstrated that the values of end bearing and skin friction resistance for bored piles are much smaller than that driven piles. Frank [5] stated that settlements for bored pile are much bigger than those for driven piles. Accordingly this investigation was carried out to study the effect of method of pile installation on its uplift capacity. An experimental program for model piles in sand was conducted to study the shaft resistance of piles subject to uplift loads.

Model single steel pipe piles have outside-diameter of (22 millimeters) and open end type were subjected to static uplift loading to failure. The piles had variable embedded length ranged between 220 to 550 millimeters were installed by three different methods (driving, jacking, and a reference undisturbed method with negligible lateral displacement) to assess the influence of method of installation on shaft resistance. The tests were performed in three initial sand densities (loose, medium and very dense). The experimental results were analyzed statistically. The results show that the initial sand density and the method of pile installation are the most significant factors that affect uplift capacity for piles.

2. Laboratory tests

The equipment used in this program consisted of a sand box measuring 2.0 m in length by 0.60 m in width by 0.60 m deep. The box is divided into three cells of lengths of, 0.6,0.8 and 0.60 respectively. The model piles are smooth steel pipes of outside-diameter of 22 mm and the wall thickness of 1.25 mm. Uplift loading was provided by using dead weight placed in a bucket connected to the pile head by a cable over a pulley system. The soil used in the study was medium silica sand. Table 1 gives a summary of the sand properties.

3. Tests and test procedure

Three test series were carried out on loose, medium and very dense sand. The unit weight of sand and thus the required relative density was controlled by pouring a pre-determined weight of sand into the testing tank, to fill each layer, and then the sand surface was leveled and compacted. A loose sand deposit was achieved by a placement soil layers 50 mm thickness in zero fall height. In order to obtain a compacted sand structure the sand is placed in layers, each layer has 50 mm thickness and compacted using manual compactor 3.50 kg. The numbers of compaction passes are pre-evaluated for each layer at the beginning of the program to achieve the required sand density. For each relative density, three types of pile were installed: first type is non-displacement (undisturbed) reference pile. The sand box was filled with sand to the predetermined depth and the pile was fixed in position where its end was in touch with the surface of sand. The sand was then deposited carefully around the pile until the tank was filled. The second type of pile is driven pile, the sand tank was filled with sand and after its surface was leveled the pile was adjusted perpendicular to the surface. Then the pile is driven into the soil bed using constant driving energy of 5.0 Joule (dropping hammer has a weight of 4.50 kg and fall height is 11.5 cm). The third type is jacked pile, the pile is jacked into the soil bed after the soil tank is filled with sand using hydraulic Jack. During driving or jacking the pile, the height of the soil inside the pile and penetration depth were measured at 40-mm intervals in order to estimate the degree of soil plugging of the pile and also the height of plug inside the lower part of the pile. The hammer blow count was recorded during pile driving. The piles were tested after 24 hours from the end of piles installation. Load, in increments was applied to the pile at the ground surface by means of a mechanism consists of cable, pulleys and weights. For each pile, one dial gage was used to determine the uplift vertical displacement of the pile head after each load increment. Loading was continued until the pile was pulled out of the soil. Fig. 1 shows the model set up of the experimental program.

Table 1
Summary of sand properties

Maximum unit weight, kN/m3	18.44
Minimum unit weight, kN/m3	15.21
Specific gravity, Gs	2.66
Effective diameter, D10 mm	0.12
Uniformity coefficient, Cu	4.25
Coefficient of curvature, Cc	0.653

4. Analysis of test results

4.1. Pile drivability

Fig. 2 shows pile penetration depth versus hammer blow count for all the tested piles. As shown in the figure, the hammer blow count per unit length of penetration increases as pile penetration depth increases, since the

Fig. 1. Test set up for the experimental program.

penetration resistances acting on the base and the shaft of piles during driving generally increase with penetration depth. It is observed that the blow count per unit length of penetration increases as the sand density increases.

4.2. Soil plug behavior

The behavior of open-ended piles is governed by the degree of plugging. During jacking or driving the pile and the average movements of the top of the plugs were measured. Fig. 3 shows how the soil plug lengths change with pile penetration depth. It is seen in fig. 3 that the jacked pile is completely plugged at penetration depth about 240 mm. The depth is at twelve times the inside pile diameter. This result is almost the same finding proposed by Ryuho Rodrigo [6] which is eleven times the pile diameter. The length of soil plug is 100 mm which is five times the pile diameters. While the driven piles are fully plugged at sixteen times the inside pile diameter. The length of soil plug is 140 mm which is seven time pile diameter. It is clearly seen that the soil plug is moved inside the pile during driven process until full plugging is reached.

4.3. Analysis of test results

The results of the performed pull out tests are plotted in figs. 4 and 5 in the form of load displacement curves. The failure displacement was taken as that corresponding to failure load. A summary of failure loads obtained from the pull out tests are given in table 2, where the failure load is considered as the maximum load reached during test before the piles were pulled out of soil. From these figures it is seen that in loose and medium sand the uplift capacity of driven piles have bigger values than that jacked and non-displacement piles. This finding is due to that the vibration caused by driving the piles which make sand densification around the piles which increases the skin friction. Also during jacking process, small amount of densification around the piles is created; this led to some

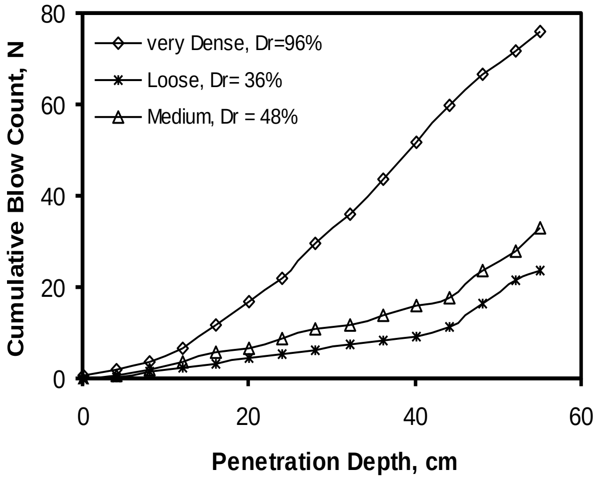

Fig. 2. Driving record for driven piles.

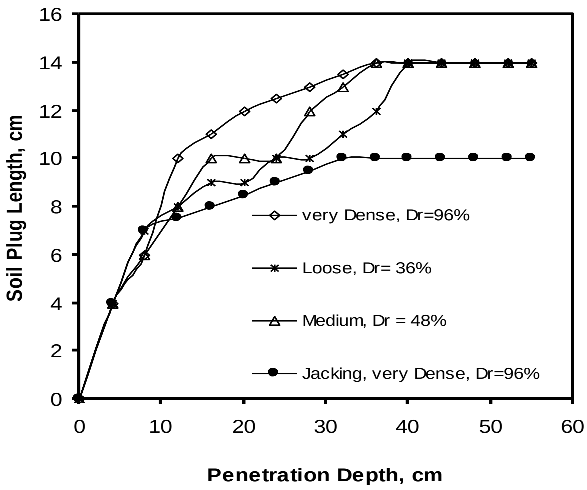

Fig. 3. Development of soil plug.

increase from the non-displacement pile capacity. While the non-displacement piles have the greater values for pull out capacity than that both of driven and jacked pile in the dense sand,. These phenomena may attribute to that the piles driving and jacking causes a soil disturbance of dense deposits around the piles which reduce the skin friction around the piles. Also the observed higher value for uplift capacity of non-displacement pipe pile may be due to the increase in the lateral earth pressure around the pile caused by the compaction of sand layer during preparation the soil bed. This increase in the lateral pressure gives a high value for uplift capacity. From the figures also it is observed that the piles in loose sand start to fail at uplift displacement about 0.75 mm about 3.4 % from the diameter of piles and independent of installation method, While the piles in very dense sand start to fail at displacement about 1.0 mm about 4.5 % from the pile diameter. So the displacement of piles when starting to fail due to tension loading of piles is independent on pile installation method, but the sand density has significant effect on the displacement. While the displacement of piles at ultimate uplift loads for non-displacement pile is bigger than that for driven and jacked piles. The failure loads will be analyzed in the following sections.

Assuming a linear increase of the lateral pressure over the pile length, the uplift capacity of the piles can be calculated from the following formula:

$$Q_u = 0.5\ \gamma' L^2\ \mathrm{D}\ \pi Ku\ \tan\varphi' + W. \qquad (1)$$

Where Q_u = the uplift capacity; γ' = effective unit weight of soil; L = depth of the pile; D = diameter of pile; Ku = the coefficient of earth pressure in movement; φ' = the interface friction angle of pile material with respect to surrounding soil, which is considered as 24° as proposed by Potyondy [7], he found that the frictional angle is equal to approximately 23° to 25° for a smooth steel surface and for medium to fine sand and this angle in independent of the relative density of the surrounding cohesionless material; and W=the effective weight of pile.

Substituting the failure loads obtained from figs. 4 and 5, γ' for loose, medium and very dense sand, L the different pile lengths, D=22.0 mm and φ' = 24° the coefficient of Ku is calculated and given in table 3.

These results are plotted in fig. 6. From this figure, the coefficient of Ku is shown to be very low for loose sand which is in quite agreement with Adams [8], he suggested a value of 1.0 for very loose sand. While the values of Ku in dense sand is in quite agreement with Broms [9], he reported a value of 5.0 for Ku for piles that have been buried in compacted dense sand and also the value reported by Ismael [10], which is 4.94 for bored pile in compacted dense sand. The obtained results are about 250% greater than that suggested by Adams [8].

The average skin friction along the pile shaft was calculated from

$$Q_u = f_s\, L\, D\, \pi + W. \qquad (2)$$

Where f_s= the average shaft resistance. Substituting the preceding values for Q_u, f_s, L, D, and W, f_s is calculated and the obtained results are given in table 4. These results is given in figs. 7 and 8 form the table the average skin friction is very low in loose sand for the different types of piles while the value of skin friction in increased rapidly with increasing the sand density. The average skin friction increased linearly with depth for dense sand and parabolic in loose sand with increasing rate for the range of length to diameter ratios of 10 to 25. The average skin friction is significantly affected by sand density and method of pile installation.

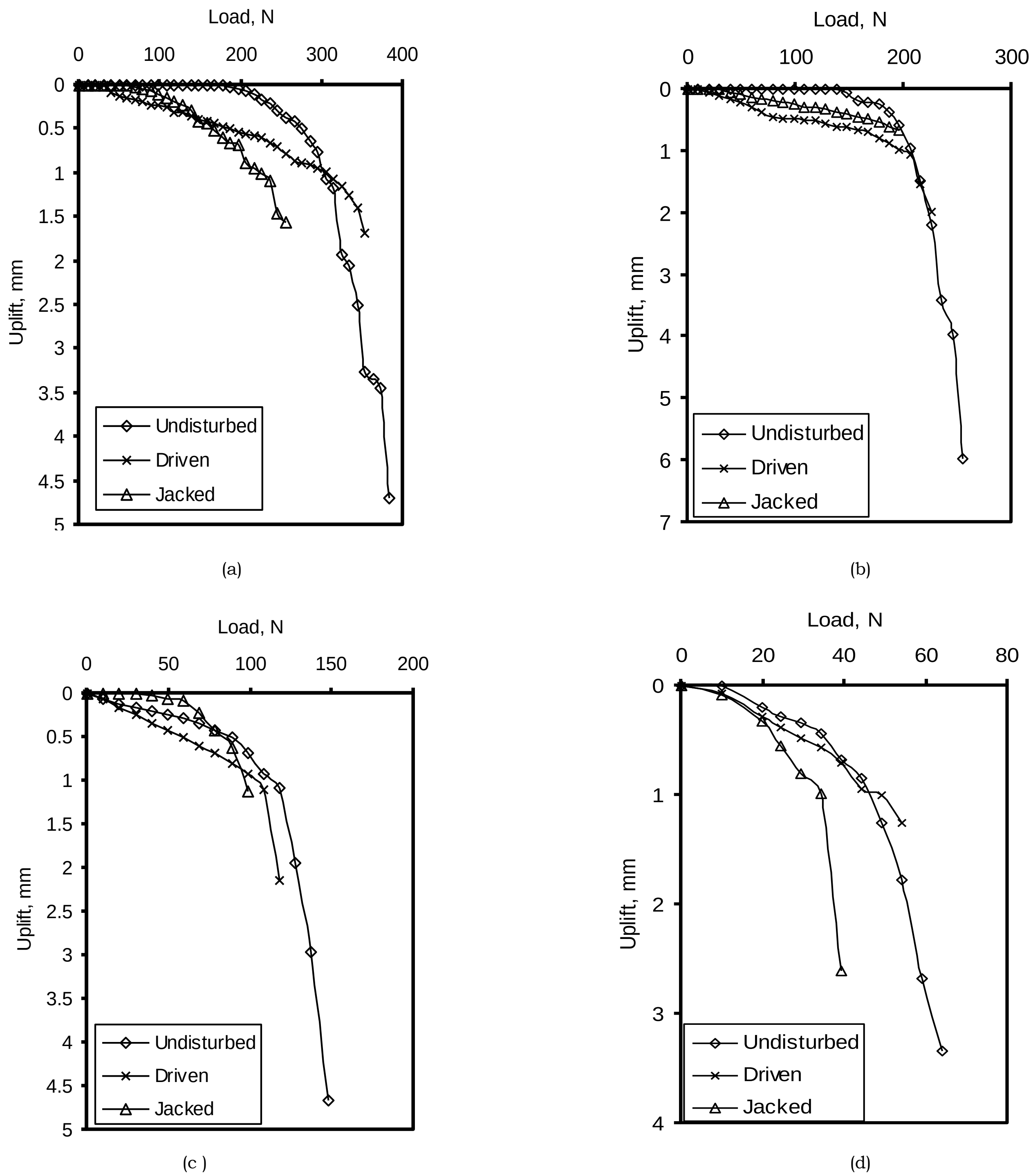

Fig. 3. Load displacement curves for performed tests in very dense sand, Dr =96%
(a) for L/D = 25, (b) L/D = 20, (c) L/D =15 and (d) L/D = 10.

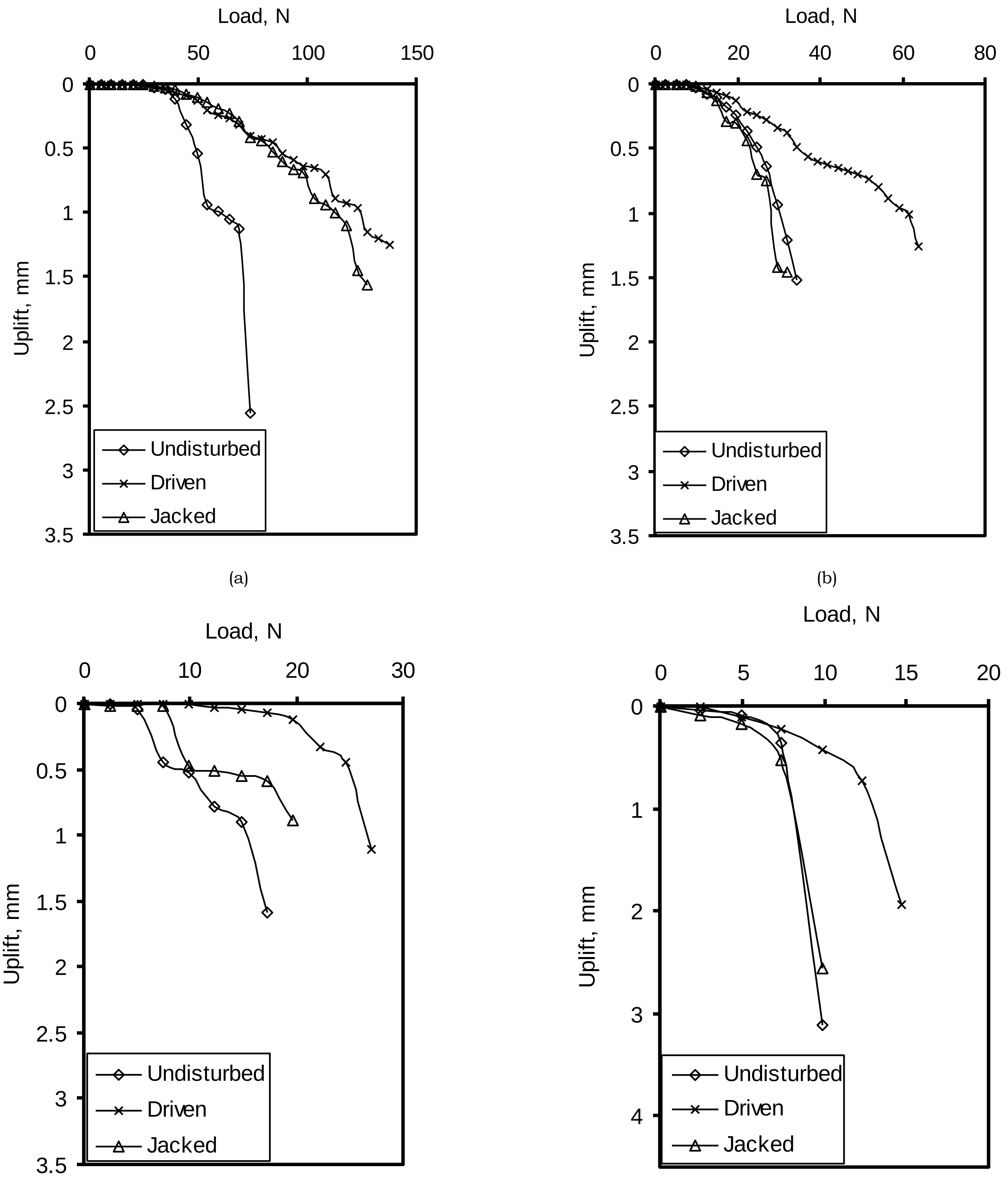

Fig. 4. Load displacement curves for performed tests in loose sand, Dr =36%
(a) for L/D = 25, (b) L/D = 20, (c) L/D =15 and (d) L/D = 10.

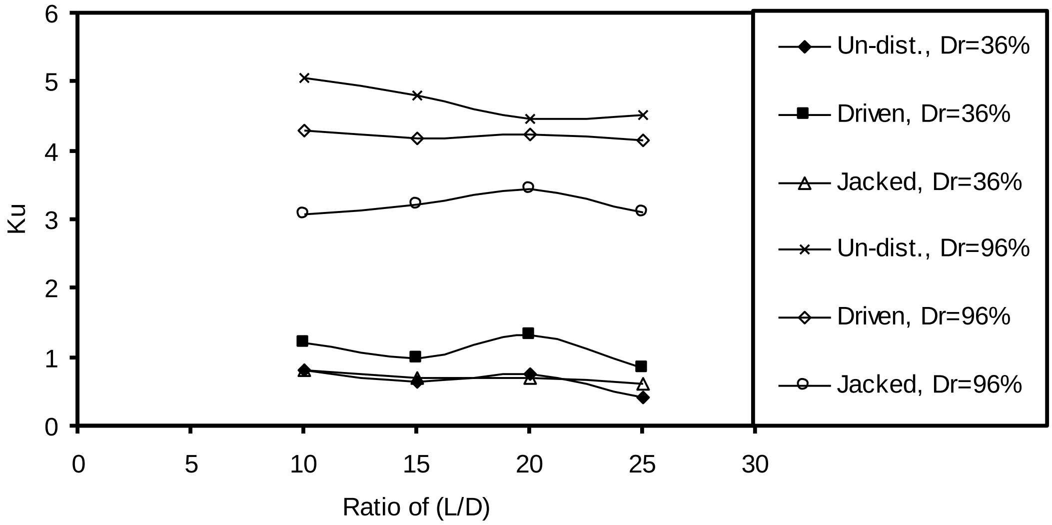

Fig. 5. Ku versus L/D for different sand relative densities.

Table 2
Summary of failure load

L/D	Failure load in N								
	Loose sand , Dr = 36 %			Very dense sand , Dr = 96 %			Medium sand , Dr = 48 %		
	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked
10	9.81	14.72	9.81	63.77	53.86	39.24	26.98	46.60	29.43
15	17.17	26.98	19.62	147.15	117.72	98.1	54.15	71.31	59.05
20	34.33	63.77	31.88	255.06	225.63	186.39	---	---	---
25	73.58	142.25	103	382.59	353.16	255.06	---	---	---

Table 3
Summary of coefficient of earth pressure in uplift, *Ku*

L/D	*Ku*, coefficient of earth pressure in uplift								
	Loose sand , Dr = 36 %			Very dense sand , Dr = 96 %			Medium sand , Dr = 48 %		
	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked
10	0.81	1.21	0.81	5.06	4.30	3.08	2.17	3.74	2.36
15	0.64	0.99	0.72	4.82	4.18	3.22	1.93	2.55	2.11
20	0.76	1.32	0.71	4.47	4.24	3.44	---	---	---
25	0.43	0.84	0.61	4.52	4.17	3.12	---	---	---

Table 4
Summary of the obtained f_s

L/D	f_s in kN/m^2								
	Loose sand , Dr = 36 %			Very dense sand , Dr = 96 %			Medium sand , Dr = 48 %		
	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked	Non displacement	Driven	Jacked
10	0.64	0.96	0.64	4.52	3.78	2.90	1.77	3.06	1.93
15	0.75	1.18	0.86	6.45	5.59	4.37	2.37	3.44	2.60
20	1.21	2.1	1.12	8.38	7.42	6.45	---	---	---
25	1.93	3.74	2.71	10.05	9.29	6.98	---	---	---

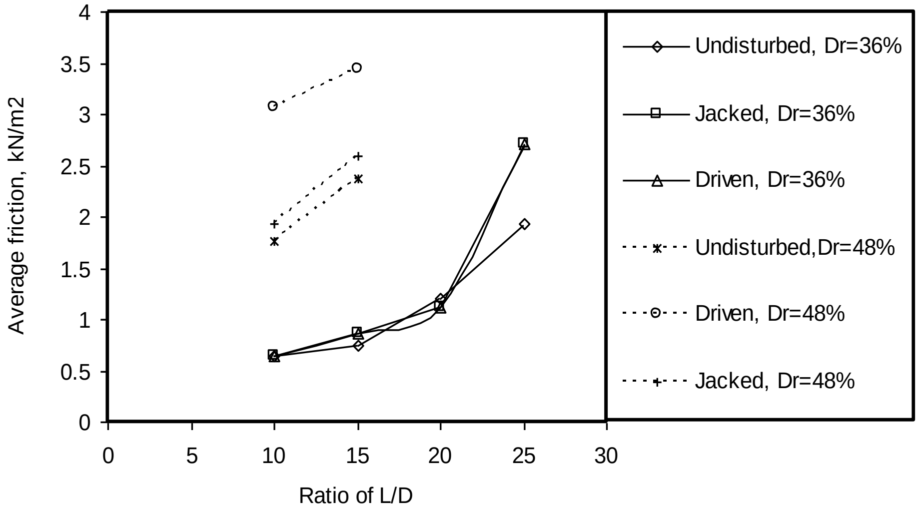

Fig. 6. Average skin friction versus L/D for loose and medium sand.

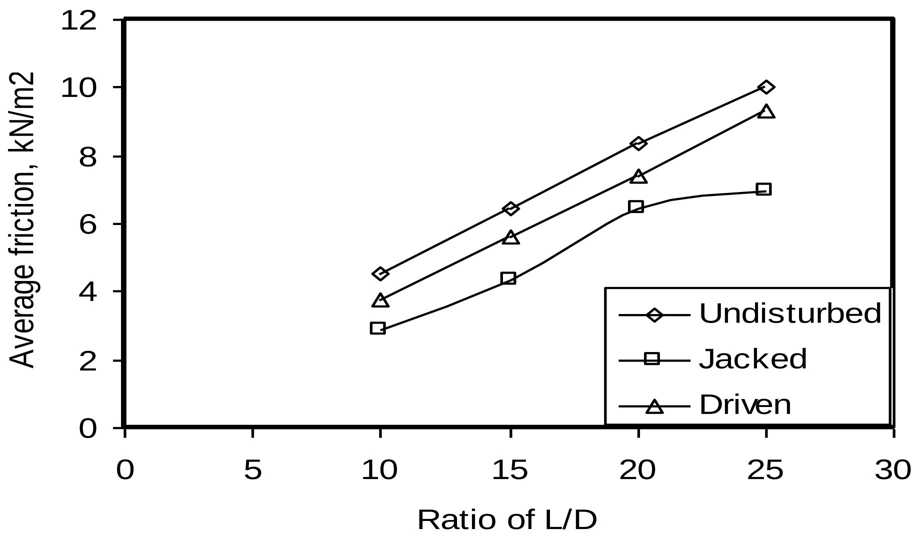

Fig. 7. Average skin friction versus L/D for very dense sand.

5. Conclusions

Based on the presented model study on the uplift capacity of pipe piles in sand, the following conclusions are drawn:

1. The uplift capacity of piles is increased with the increasing both of embedment depth and sand density
2. The average skin friction increased linearly with depth for dense sand and parabolic in loose sand with increasing rate for the range of length to diameter ratios of 10 to 25.
3. The ultimate uplift capacity of driven pipe piles in loose and medium density sand is bigger than that in jacked and non displacement pile.
4. The ultimate uplift capacity of non-displacement pile in very dense sand is greater than both driven and jacked pile.
5. The sand density has a significant effect on the uplift capacity of pipe type piles.
6. The failure displacement at stating of failure due to tension loading of piles is independent on pile installation method, but the sand density has significant effect on the displacement.
7. The displacement of piles at ultimate uplift loads for non-displacement pile is bigger than that for driven and jacked piles
8. The coefficient of lateral earth pressure in uplift, K_u is highly affected by sand density and method of pile instillation.
9. The jacked pile becomes fully plugged earlier in the penetration than that the driven pile.

References

[1] M.M. Sherif, G.B. Sherif and A.H. Hammam, "Effect of Method of Pile Installation on Its Behaviour", Proc. 11th ARCSMFE, pp. 253-267 (1995).

[2] G.G. Meyerhof, "Compaction of Sand and Bearing Capacity of Piles", JSMFE, ASCE, Vol. 85 (SM6), pp. 1-30 (1959).

[3] H. Kishida, "Ultimate Bearing Capacity of Piles Driven into Loose Sand", Soil and Found., Vol. 7 (3), pp. 20-29 (1967).

[4] G.G. Meyerhof, "Bearing Capacity and Settlement of Pile Foundations", JGED, ASCE, Vol. 102 (GT3), pp. 196-227 (1976).

[5] E. Frank, "Point Pressure versus Length and Diameter of Piles", Proc. 10 th Conf. SMFE, Vol. 2, pp. 717-722 (1981).

[6] Ryuho Paik and Rodrigo Salgado, "Effect of Pile Istallation Method on Pipe Pile Behavior in Sands", Geotechnical Testing Journal, Vol. 27 (1), paper ID GTJ1139-271 (2003).

[7] G.J. Potyondy, "Skin Friction Between Various Soil and Construction Materials", Geotechique, Institution of Civ. Engrs. London, England, Vol. XI, (4), pp. 339-353 (1961).

[8] J.I. Adams, "Investigation and Analysis of Transmission Tower Foundations", Ontario Hydro Research Division Report No. 75-51-H, Toronto, Canada, Jan. (1975).

[9] Broms and B. Bengt, "Skin Friction Resistance for Piles in Cohesionless Soils", Sols-Soils, September, pp. 33-43 (10) (1964).

[10] F. Nabil Ismael, "Field Tests on Bored Piles Subjected to Axial and Oblique Pull", Journal of Geotechnical Engineering, ASCE, Vol. 115 (11), pp. 1588-1598 (1989).

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