Experimental Study of Enlarged Base Pile under Tension Load in Sand

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***Abstract*- Important aspects of foundation design include developing an understanding of the behavior of enlarged base piles and aiming to predict their capacities when subjected to uplift loads. On single enlarged base piles implanted in cohesionless soil and subjected to pure tension loading, model experiments have been done. In a steel tank, the tests were carried out on straight-shafted vertical steel piles with an outside diameter (Do) of 25mm and inner diameter (Di) of 19mm, base diameter (Db) of 50mm and base angle (θ) of (45°). The embedment length-to-base diameter ratios (L/Db) of the studied piles are 5, 6, 8, and 12. The relative densities of 30%, 50%, and 80% are used to prepare the sand bed. The effect of pile embedment depth and relative soil density on the uplift loads is examined. The investigation showed that the behavior of single enlarged base piles under uplift loading is mostly determined by the ratio of pile embedment length to base diameter and soil parameters. It is concluded that the uplift capacity of enlarged base piles installed in different densities of sand increases as the embedment length to base diameter (L/Db) ratio increases.**

***Index terms:* Enlarged base pile; Relative density; Uplift capacity; Embedment length**

1- INTRODUCTION

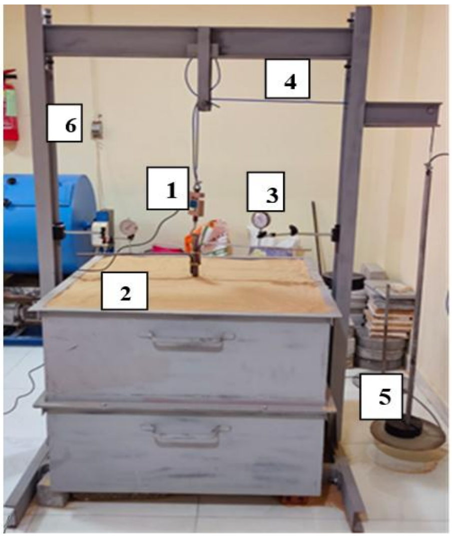
On tension-loaded pile foundations, structures resembling marine dolphins, dock-fendering systems, tower foundations, submerged platforms, and bridge abutments are built. In sand soils, shaft resistant is a significant source of pile capacity under axial loading, particularly when the pile is subject to uplift force. Steel pipe piles, steel H-piles, modified enlarged end, screw, and bladed piles are examples of typical piles that may support tension loads. Increasing the axial response of piles by constructing them pyramidal or tapered was studied (1, 2, 3, 4 and 5). An alternate technique for enhancing the uplift capacity of a single pile was to apply surcharge loading to the surface above the pile's head [6]. Underreamed piles were utilized to increase the uplift capability of a tensioned pile. (Nazir et al 2015) investigated the uplift capacity of enlarged base piles embedded in dense and loose sand. Then, it was concluded that, for the same base diameter, the pullout capacity decreased as the stem diameter increased, regardless of embedment length and base angle. (Moayedi and Mosallanezhad 2017) conducted a series of small-scale studies on single and multiple under-reamed piles in loose, dry sand. Additionally, the influence of various bulb placements on the pile stem was examined. Increasing the number of bulbs does not always increase the pullout capacity of under-reamed piles, as demonstrated by the results. In addition, the pullout capacity increased by up to 60 % when the bulb was positioned at the pile tip and dropped by approximately 4 %when it was installed at a depth equivalent to 67 % of the pile length from the pile tip. Using screw-pile technology, a different strategy, developed by a different team of researchers, has been shown to be effective in increasing the uplift capacity of piles. Typically, screw pile foundations resist tensile loads. Several studies have been conducted to test the effectiveness of screw piles when subjected to tension stresses. (Ghaly and Clemence1998, El Naggar and Abdelghany 2007, Sakr 2009, El Sharnouby and El Naggar 2012 and Abdelghany and El Naggar 2014). According to the findings of these investigations, the effectiveness of a single screw anchor during installation depends on the diameter of the anchor, the installation depth, and the characteristics of the sand. They also demonstrated a significant increase in the uplift capability of a single pile compared to a conventional pile. In this research, utilization of the base at the end of the pile to improve the pile uplift capacity under pure tension loads.

2- EXPERIMENTAL WORK

2-1 Experimental Setup

In a cube test tank with a 1000 mm length, a 1000 mm width and a 1000 mm height, pullout tests were performed. The thickness of the tank's walls was 3 mm. the tank is sufficiently thick and rigid enough to prevent any lateral deformation of the side walls. the minimum tank size necessary to prevent boundary effects is three times the diameter of the pile anchor [10]. the impact zone for tension piles is three to eight times the pile's diameter [24]. The walls were strengthened with vertical steel angle frames to improve their rigidity and avoid any lateral wall deformation. Wire and a smooth pulley are utilized to apply the uplift weight to the piles. A dial gauge with an accuracy of 0.01 millimeters is utilized in order to measure the vertical displacement. The experimental setup is depicted in Fig.1.

In this investigation, model piles consist of two main parts: the first part was a smooth steel pipe with an outer diameter (D_o) of 25 mm and an inner diameter (D_i) of 21 mm with a wall thickness of 2 mm, which was used as a control pile; the second part was the enlarged base of the pile, which was made from Teflon because the Teflon material was chosen due to its light weight; the weight of the pile and the base was neglected in this investigation. As can be seen in fig. 2, the base diameter of the pile was 50 mm, the shaft diameter was 25mm, the base angle was 45°, and the total embedment length of the piles was 600 mm.



1- *load cell*
2- *Test tank*
3- *Dial gauges*
4- *Wire rope*
5- *Loading hanger*
6- *Loading frame*

Fig. 1. Test arrangements for uplift loading tests.

2-2 Test materials (sand soil)

According to the Unified Soil Classification System (USCS), the sand that was used in this investigation has a classification of "poorly graded" (SP). Utilizing the dry sieving method, the particle size distribution was established. The effective diameter (D10) = 2.66mm, Uniformity coefficient (Cu)= 0.187, Coefficient of curvature (Cc)= 4.35, Maximum void ratio (e_{max} = 0.69%), Minimum void ratio ($e_{min=}$ 0.39%). For dense sand (unit weight γ= 18.3 kN/m^3 and Angle of internal friction of dense sand (φ = 39.1), for medium sand (unit weight γ= 17.2 kN/m^3 and Angle of internal friction of medium sand (φ = 35.2) and for loose sand (unit weight γ= 16.8 kN/m^3 Angle of internal friction of loose sand (φ = 33.6).

3- EXPERIMENTAL TEST PROGRAM

In this study, the behavior of enlarged base piles compared with the normal piles was investigated in sand with varied relative densities (loose, medium and dense) through an experimental testing programmed. The tests were carried out on enlarged base piles with varying embedment length to base diameter ratios (L/Db), where Db is the diameter of the base and L is the length of the pile at various relative densities (Dr= 30%, 50%, and 80%). The investigated values of (L/Db) are 5.0, 6.0, 8.0, and12.0 as shown in Fig. 2. Experiments were carried out on enlarged base piles to estimate the uplifting capability under different parameters including embedment length to base diameter (L/Db) and relative sand density. All the experimental testing program were performed at a constant ratio of (L/Ds= 24) as shown in the following table 1.

Table 1. Program of experimental testing

Series	Constant parameters	Variable's parameters	Number of tests
S_1	Dr = 30 %, Db/Ds = 2 and θ= 45°	L/Db = 5, 6, 8, 12	4
S_2	Dr = 50 %, Db/Ds = 2 and θ= 45°	L/Db = 5, 6, 8, 12	4
S_3	Dr = 80 %, Db/Ds = 2 and θ= 45°	L/Db = 5, 6, 8, 12	4
Total tests = 12			

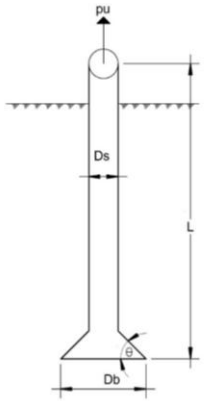


Fig. 2. The model pile tested.

4- RESULTS AND DISCUSSION OF THE TESTS

3-1 Load- displacement diagrams

A total of 12 experiments were carried out to investigate the uplift capability of enlarged base piles. The effect of embedment length to base diameter (L/Db) and sand relative density (30%, 50%, 80%) were investigated to study the uplift force. The axial uplift forces and displacements were obtained and discussed. The ultimate uplift capacity of the enlarged base piles was determined from load-displacement diagrams. The non-dimensional displacement (S) of the enlarged base pile is represented in terms of (S/Ds). The enlarged base pile ultimate uplift capacity is determined by the load-displacement curve prominent peaks, after which the pile fails. In curves where no definite failure is exhibited, the ultimate capacity is defined as the point at which the slope of the load displacement curve first achieves zero or a stable lowest value. The results are presented in Table 2. Figure 3 illustrates the load displacement diagrams for enlarged base piles with a sand relative density of 80%, a base angle of 45◦, and a base diameter to shaft diameter ratio (Db/Ds) of 2, all of which remained constant during this series of tests. For enlarged base piles with embedment length to base diameter ratios (L/Db) of (5, 6, 8, and 12) the corresponding capacities were estimated to be 377, 475, 597, and 925 N correspondingly.

From figure 3, it is indicated that, the uplift capacity of the enlarged base piles improves with the increase of the embedment length to the base diameter ratio (L/Db) and after the ratio reached to 8 an increase in the ratio has large effect in the pull-out capacity. The vertical displacement decreases as the ratio of length to base diameter (L/Db) increases under the same uplift load. At an uplift force of 350N, the normalized vertical displacement decreases from 30 % for an enlarged base pile with length to base diameter ratio (L/Db) = 5 to (25), (11), and (6) % with displacement reductions of (16.1), (63.33), and (80) % for (L/Db) ratios of (6, 8, and 12) respectively.

Figure 4 illustrates the load displacement diagrams for enlarged base piles with a sand relative density of 50%, a base angle of 45◦, and a base diameter to shaft diameter ratio (Db/Ds) of 2. For enlarged base piles with embedment length to base diameter ratios (L/Db) of (5, 6, 8, and 12) the corresponding capacities were estimated to be 329, 389, 492, and 585 N correspondingly.

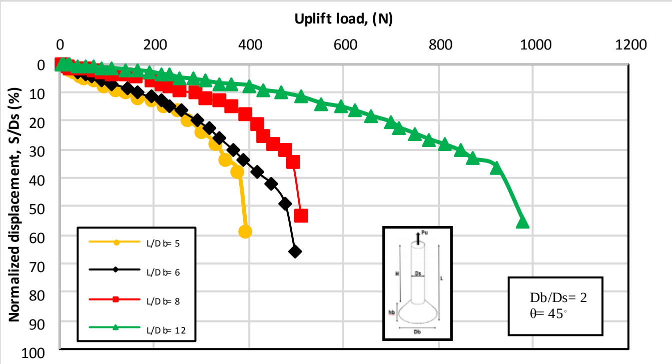


Fig. 3. Uplift loads variation with normalized vertical displacement for Dr =80 %, with base angle (θ= 45˚) with different embedment length to base diameter of pile (L/Db) ratios.

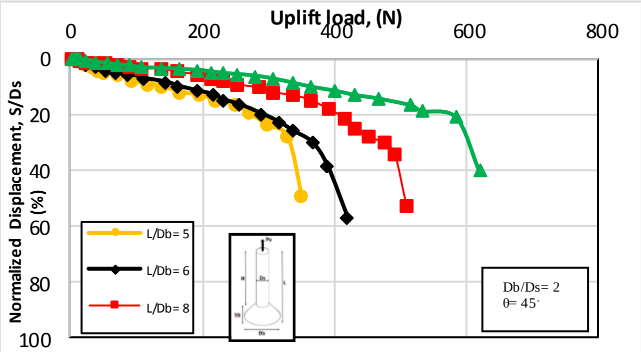


Fig. 4. Uplift loads variation with normalized vertical displacement for Dr =50 %, with base angle (θ= 45˚) with different embedment length to base diameter of pile (L/Db) ratios.

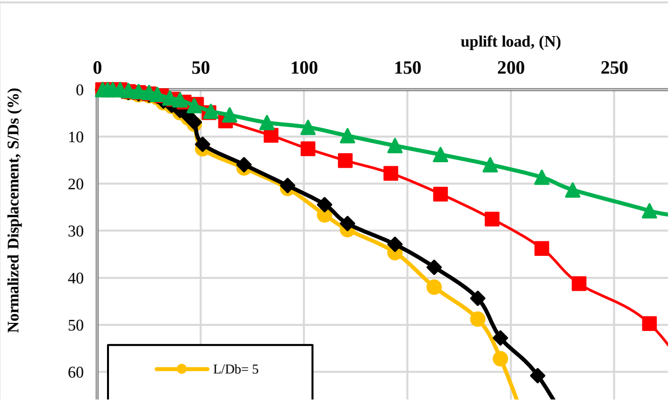


Fig. 5. Uplift loads variation with normalized vertical displacement for Dr =30 %, with base angle (θ= 45˚) with different embedment length to base diameter of pile (L/Db) ratios.

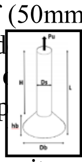
Based on fig. 4, it can be deduced that the uplift capability of the enlarged base piles increases as the embedment length to the base diameter ratio (L/Db) is increased. It is noticed that, when the ratio between the embedment length to base diameter (L/Db) = 8 and 12, the curves compatible with each other until approximately 3.36 % of the normalized vertical displacement. The value is 15 % for (L/Db) = 5 and 6. The vertical displacement decreases as the ratio of length to base diameter (L/Db) increases under the same uplift load. At an uplift load of 300N, the normalized vertical displacement decreases from 22 % for an enlarged base pile with length to base diameter ratio (L/Db) = 5 to (20), (10), and (8) % with displacement reductions of (9.1), (54.54), and (63.63) % for (L/Db) ratios of (6, 8, and 12) respectively.

Figure 5 illustrates the load displacement diagrams for enlarged base piles with a sand relative density of 50%, a base angle (θ) of 45◦, and a base diameter to shaft diameter ratio (Db/Ds) of 2. For enlarged base piles with embedment length to base diameter ratios (L/Db) of (5, 6, 8, and 12) the corresponding capacities were estimated to be 195, 213, 267, and 300 N respectively. Due to figure 5, it is indicated that, the uplift capability of the enlarged base piles improves with the increasing of the embedment length to the base diameter ratio (L/Db). It is concluded that, using the base at the end of the pile with diameter base to shaft diameter ratio (Db/Ds= 2), base angle (θ= 45˚) and when compared to the other ratios of embedment length to base diameter (L/Db), the ratio of embedment length to base diameter equal to 12 has a significantly greater effective improvement in uplift capability than the other ratios.

Table 2. Summary of the ultimate uplift load of enlarged base piles for different values of Dr (%) and (L/Db).

Relative Density (Dr) %	Uplift load (N)			
	L/Db = 5	L/Db = 6	L/Db = 8	L/Db = 12
30 %	195	213	267	300
50 %	329	389	492	585
80 %	377	475	597	925

3-2 Influence of embedment length to base diameter ratio (L/Db).

The influence of the embedment length to base diameter (L/Db) on the axial uplift capacity in various sand densities was investigated. As can be seen in Figures (3,4 and 5), the embedment length to base diameter ratios that were investigated were (5, 6, 8, and 12). The experiments were carried out with a constant shaft diameter (Ds) of (25mm), base diameter (Db) of (50mm) and base angle (θ) of (45˚) in various sand relative ds (Dr) of (30%, 50% and 80%). The significant effect edment length to base diameter ratio on axial uplift cap depicted in Fig. 6. From figure. 6. Utilization of the t the end of the normal pile improves the uplift capacity.

It is indicated that, the uplift capacity of enlarged base pile improves with the increase of embedment length to base diameter ratio (L/Db). As the relative density of the sand increases, the uplift capacity of enlarged base pile built in sand increases for the same embedment length to base diameter ratio (L/Db). As the relative density of sand increases, the percentage increase in uplift capacity with an increase in the embedment length to base diameter ratio (L/Db) increases. The increase in uplift capacity due to the weight of the soil column above the base, which gives a higher resistance for uplift loads with the increase in embedment depth for example, at embedment length to base diameter ratio (L/Db) of (12), the percentage increase in uplift capacity for medium and dense sand versus loose sand is determined to be 95 and 200 %, respectively.

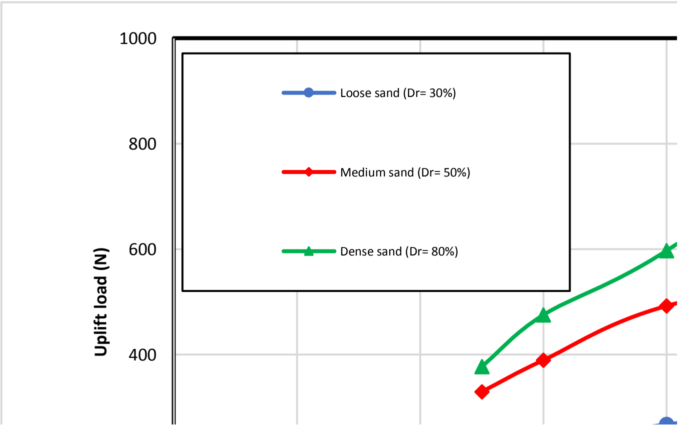


Fig. 6. Variation of uplift load with embedment length to base diameter ratio (L/Db) for varied relative sand densities (Db/Ds = 2 and θ = 45°).

4- SCALE EFFECT

Due to the high cost in both money and time required to conduct field experiments on full-size piles, it is common practice to conduct experimental tests using miniature models. Due to the characteristics of soils, particularly granular soils and scale effects, it is widely recognized that soils may not play the same effect in laboratory models as they do in the prototype. Due to the changes in stress level between the field testing and the model tests [21], these deviations appear initially [19]. Franke and Muth evaluated the effect of sand size on the model response and demonstrated that grain-size effects can be ignored with a ratio of anchored width to mean grain size greater than 30. Additionally, the diameter of base pile exceeds 48 times the mean grain size for pullout load of circular or rectangular anchor plates [22, 23]. According to Beijer et al, the ratio of pile diameter to average grain size (D50) should be more than 35.

5- CONCLUSION

In this study the enlarged base at the end of the regular pile to improve the capacity of the pile under tension loads may adopted. Based on experimental analysis, the uplift capacity of enlarged base piles has been determined to shed the light on their uplift response. On the basis of the study's findings, the following conclusions drown as following:
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1- The uplift capability of enlarged base piles installed in various densities of sand increases as the embedment length to base diameter (L/Db) ratio increases.
2- Utilization the base at the end of the pile can be increased the pile uplift capacity.
3- As the sand relative density increases, the pile capacity under tension loads increases.
4- When the ratio of embedment length to base diameter ratio (L/Db) of 12, the uplift capacity was 925 N in dense sand. While, this value was 585 N in medium sand and 300 N for loose sand.
5- When the ratio of embedment length to base diameter (L/Db) of 12, the percentage increase in uplift capacity for medium and dense sand versus loose sand is determined to be 95 and 200 %, respectively.

REFERENCES

1. Appolonia, E. D., and Haribar, J. A. Load transfer in steptapered piles. J. Soil Mech. Found.1963, Div., 89(SM3), 57–77.
2. Bakholdin, B. V. Bearing capacity of pyramidal piles. Proc., 4th Conf. on Soil Mechanics and Foundation Engineering, Akademiai Kiadó, Budapest, Hungary. 1971, 507–510.
3. Kodikara, K. K., and Moore, I. Axial response of tapered piles in cohesive frictional ground. 1993, J. Geotech. Eng., 10.1061/(ASCE). 1993, 675–693.
4. El Naggar, M. H., and Wei, J. Q. Axial capacity of tapered piles established from model tests. Can. Geotech. J.1999, 36(6), 1185–1194.
5. Duhrkop, J., and Grabe, J. Improving of lateral bearing capacity of monopiles by welded wings. Proc., 2nd Int. Conf. on Foundations,HISBRE Press, Garston, U.K. 2008, 849–860.
6. Azzam WR, Al Mesmary M. The behavior of single tension pile subjected to surcharge loading. NED Univ. J. Res. 2010, 7(1):1-12.
7. Ramli N, Hossein M, Pratikso A, Mosallanezhad M . The uplift load capacity of an enlarged base pier embedded in dry sand. Arabian Journal of Geosciences. 2015, 8(9):7285-7296.
8. Moayedi, H., & Mosallanezhad, M. Uplift resistance of belled and multi-belled piles in loose sand. Measurement. 2017, 109, 346-353.
9. Ghaly, A. M., and Clemence, S. P. Pullout performance of inclined helical screw anchors in sand. J. Geotech. Eng. 1998, 617–627.
10. El Naggar, M. H., and Abdelghany, Y. Helical screw piles(HSP) capacity for axial cyclic loadings in cohesive soils."Proc., 4thInt. Conf. on Geotechnical Earthquake Engineering, InternationalSociety for Soil Mechanics and Geotechnical Engineering, London, (2007a). Paper 1567.
11. El Naggar, M. H., and Abdelghany, Y.Seismic helical screw foundation systems. Proc., 60th Canadian Geotechnical Conf., Canadian Geotechnical Society, Richmond, BC, Canada, (2007b). Paper 160.
12. Sakr, M. Performance of helical piles in oil sand. Can. Geotech. J. 2009, 46(9), 1046–1061.
13. El Sharnouby, M. M., and El Naggar, M. H. Field investigation of axial monotonic and cyclic performance of reinforced helical pull-down micropiles. Can. Geotech. J. 2012, 49(5), 560–573
14. Abdelghany, Y., and El Naggar, M. H. Full-scalefield investigations and numerical analyses of innovative seismic composite fiberreinforced polymer and reinforced grouted helical screw instrumented piles under axial and lateral monotonic and cyclic loadings. Adv. Soil Dyn. Found. Eng. 2014, 414–424
15. Robinsky EI, Sagar WL, Morrison, CF. Effect of shape and volume on the capacity of model piles in sand. Canadian Geotechnical Journal. 1964, 1(4):189-204
16. Ghaly AM, Hana AM. Experimental and theoretical studies on installation torque of screw anchors. Journal of Geotechnical Engineering. 1991, 28(3):353-364
17. Sakr MA, Nazir AK, Azzam WR, Sallam AF. Model study of single pile with wings under uplift loads. Applied Ocean Research. 2020, 100:102187
18. Azzam WR, El-wakil AZ. Model study on the performance of single-finned pile in sand under tension loads. International Journal of Geomechanics. 2017, 17(3):1-10
19. azir A, Nasr A. Pullout capacity of batter pile in sand. Journal of advanced research.2013, 4(2):147-154.
20. Franke E, Muth G. Scale effect in 1 g-model tests on horizontally loaded piles. In International conference on soil mechanics and foundation engineering. 1985, 11:1011-1014.
21. Vesić AS. Analysis of ultimate loads of shallow foundations. Journal of the Soil Mechanics Foundations Division. 1973, 99(1):45-73.
22. Ovesen, NK. The scaling law relationship-panel discussion. In Proc. 7th European Conference on Soil Mechanics and Foundation Engineering. 1979, (4):319-323.
23. Dickin, E. A., & Leung, C. F. Centrifugal model tests on vertical anchor plates. Journal of Geotechnical Engineering. 1983, 109(12), 1503-1525.
24. Beijer Lundberg, A., Dijkstra, J., & Van Tol, A. F. On the modelling of piles in sand in the small geotechnical centrifuge. In Eurofuge 2012, Delft, The Netherlands, April 23-24. 2012, Delft University of Technology and Deltares.

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