Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Resistance Capacity of Inclined Anchored Pile Group to Lateral Load in Sandy Soil

Ali H. Ahmed*, Hassan O. Abbas

Department of Civil Engineering, University of Diyala, 32001 Diyala, Iraq

ARTICLE INFO

Article history:
Received December 19, 2021
Accepted February 11, 2022

Keywords:
Inclined anchored pile
Anchored piles
Inclined piles
Resistance capacity
Inclination angles
Number of helix

ABSTRACT

This study was conducted to investigate the lateral behavior of inclined anchored pile group by using (3 pile) model embedded in sandy soil by relative density 65% under lateral static load. The distances used between the piles are 60 mm which represents (3) Dh (helix diameter), noting that the diameter of the pile is 10 mm. The types of piles used are three types, and they are a pile with a single helix, a pile with a double helix and a pile without a helix (ordinary pile), noting that the depth embedded in the soil of piles (L/d) 330 mm. The angles of inclination used in this study are (5°, 10°, 15°). The results showed that increasing the angle of inclination of the pile leads to a higher amplitude of the lateral resistance of the pile group, the side resistance of pile with a single helix increase to about (9% and 18%) upon inclination angle increase from 5° to (10°,15°) respectively. While piles with double and single helix in the groups in same angle of inclination which is (10°) increases the lateral resistance from ordinary pile (pile without helix) about 24% and 19% respectively.

1. Introduction

Anchored piles are used for the purpose of obtaining better ability to resist tensile and axial pressure in addition to lateral loading as it is one of the types of deep foundations [1]. Anchored piles consist of one piece or more from circular pieces of steel attached to hollow or solid circular shafts [2]. One of the factors on which the presence of the number of helical screws depends on the anchored piles is the resistance capacity of those piles and the type of soil in which they will be used. By applying a downward rotational force of torque to the piles, the spiral piles are immersed in the soil, which leads to the piles penetrating the soil in a downward circular motion. [3]. One of the most important advantages of anchored piles (the possibility of using them in slopes, less vibration and noise when immersed in the soil, low cost, does not require a large displacement of water during work, easy installation, lack of equipment required to work and quick installation, the possibility of removing it from the soil and using it again and feature bound stitches) [4,5]. One of the first tests that were carried out using inclined and side-loaded piles by Tschebotariofl, 1953, where the ability of a single pile inclined at an angle (15°) for tensile, compression and axial pressure was measured [6]. In the case of an urgent need to strengthen the foundation structure or the lack of lateral resistance of the soil into which the piles are inserted in order to overcome the horizontal forces transmitted to the foundations, in this case it is necessary to use tilted piles in the foundations to provide high and solid resistance to meet the horizontal loads with the possibility of using them with the piles vertical [7]. In waterfront structures, inclined piles are the most

* Corresponding author.
E-mail address: temimi71@yahoo.com
DOI: 10.24237/djes.2022.15107

common in use because they provide high resistance against lateral loads caused by ship impacts, water waves and wind force [8]. (Winds, earthquake vibrations, collisions, slope collapse, ice effects,waves, etc.). All of the above are considered sources of lateral loads [9]. There is a previous study regarding vertical screw piles which included checking the lateral bearing capacity of these piles and studying the effects of (models, distances between piles, pile lengths) [10, 11]. Many studies have been conducted on the axial and uplift capacity of anchored piles, while few have dealt with the lateral resistance of these piles [12]. Some studies have been conducted in Iraq regarding the anchored piles of some soil types [13-15]. The use of inclined piles in the group pile increases the performance and resistance of the group to lateral loads in marine structures [14]. The few studies and lack of knowledge about inclined piles in the past made them poor in earthquake resistance [16] therefore, it is necessary to identify and study the behavior of inclined piles. Some studies showed that increasing the angle of inclination of the piles with a maximum angle of (15°) increases the vertical capacity of the piles, then it gradually decreased [17]. In recent years, the use of inclined piles has increased widely in offshore drilling platforms, bridge piers and transmission line towers construction projects [18-19]. A study was conducted using the finite element modeling program to know the dynamic behavior of a group of inclined concrete piles subjected to seismic vibrations, it was found that increasing the angle of inclination of the piles or the spacing between them reduces pile displacement ,shear strength and bending moment [20]. In a previous experimental study for the foundation of inclined piles using (3-pile) and (6-pile) models for each of the pile group and raft piles under the influence of lateral and vertical loads, where this study concluded that the introduction of inclined piles in the foundation of the pile raft leads to an improvement in the performance and resistance of the foundation by increasing its stiffness for both horizontal and vertical directions, as well as reducing the settlement resulting from these loads [21].The objective of this study is to verify the lateral behavior of the inclined pile group through a practical study on the effect of the angle of inclination of the piles and the effect of the number of helixes in the pile on the performance and resistance of the pile group to lateral loads.

2. Experimental work

2.1 Soil used

In this study, sandy soil was brought from Karbala city / Iraq. To determine the properties of sand, a number of experiments are performed as the results of which are presented in Table 1 & Table 2.

Table 1: The results of the sandy soil examination used in the study

Item	Properties	Value
	Dry unit weight	
1	Maximum, γd (max.) (kN /m^3)	17.65
2	Minimum, γd (min.) (kN /m^3)	14.85
3	Maximum void ratio, $emax$	0.81
4	In place void ratio, eo	0.59
5	Minimum void ratio, $emin$	0.5
6	Initial dry unit weight, γd (kN/m^3)	16.56
7	Relative density Dr.	65%

Table 2: The results of the sandy soil examination used in this study

Item	**Properties**	**Value**
	Grain size analysis	
1	Effective size, D_{10} (mm)	0.18
2	D_{30} (mm)	0.29
3	Mean size, D_{50} (mm)	0.41
4	D_{60} (mm)	0.47
5	Coefficient of uniformity, Cu	2.61
6	Coefficient of curvature, Cc	1.11
7	Classification (USCS)	SP
8	Specific gravity, Gs	2.67
9	Angle of Internal Friction (Ø)	35.83
10	Cohesion (c) (kN/m^2)	0

2.2 Test container

In this study, two cylindrical containers made locally of steel, thickness of 4 mm, diameter 50 cm, and height 65 cm were used, each containing two small pieces of iron at the head of the container, dimensions (20 × 4) cm and thickness of 4 mm for the purpose of moving easily. The test container is covered with three layers of anti-corrosion dye. Six wheels have been added under the examination container to purpose of facilitating the movement of the container in all directions. As shown in Figure 1.

Figure 1. Test container

2.3 Pile and Pile Cap

Anchored pile (3 piles) model with diameter 10 mm and length 370 mm is made of solid steel used in this study as shown in Fig.2. One pile consists of one or two pieces of iron helix with fixed inter-helix spacing of 60 mm, and used ordinary pile (without helix). One helix has a diameter of 20 mm and a thickness of 2 mm. The substrate end of the lower change tip is terminated by 45% to provide ease of pile stitches into the soil. Figure 3 shows the pile cap of the study, which is made of iron, with a thickness of 6 mm with inclined angles (5°,10°,15°) for region contact piles. Figure 4 shows the top and side view of the set of inclined vertical piles (3 pile model) in this study with inclination angles (5°,10°,15°).

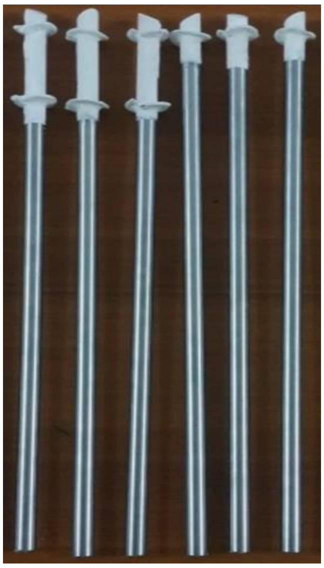


Figure 2. Pile models

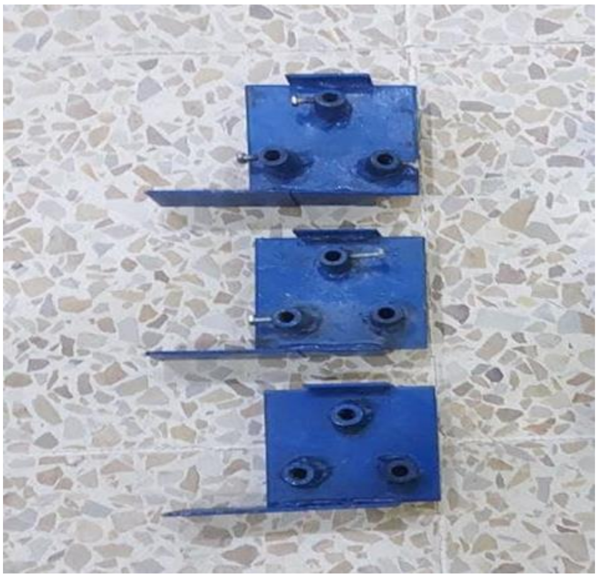
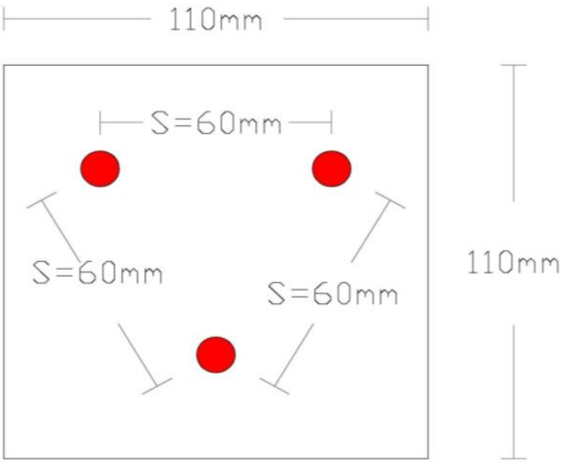
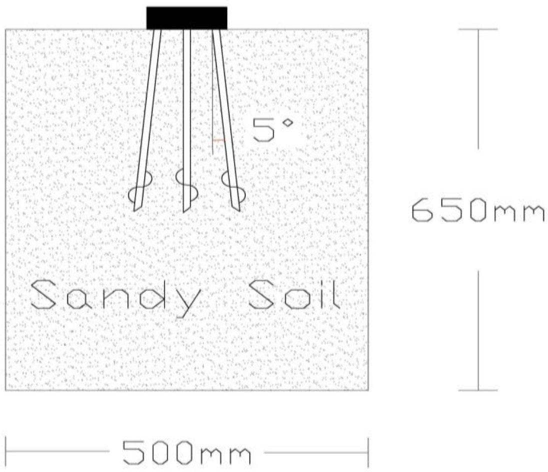


Figure 3. Pile cap model



(a)



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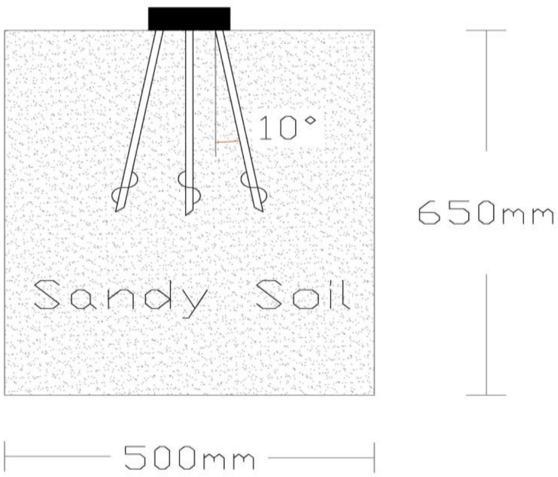
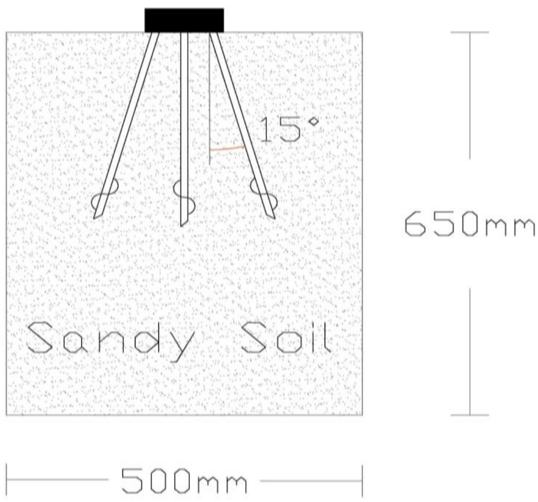
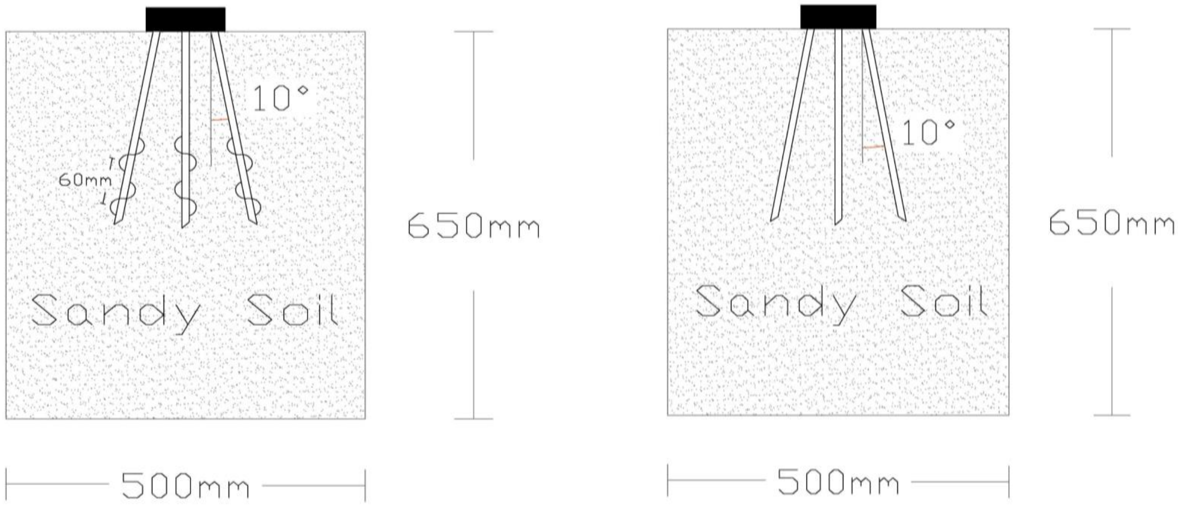


(c)



(d)



(e) **(f)**

Figure 4. (a) Cap dimensions and pile spacing for model used in the study **(b)** Single helix-pile with inclination angle (5°) **(c)** Single helix-pile with inclination angle (10°) **(d)** Single helix-pile with inclination angle (15°) **(e)** Double helix-pile with inclination angle (10°) **(f)** Ordinary pile (without helix) with inclination angle (10°)

2.4 Soil preparation

The sandy soil is prepared using raining technique for the purpose of obtaining a homogeneous relative density of all sand layers inside the examination vessel. The raining device used in this study consists of two iron columns with a height of 3600 mm and a distance between them of 1100 mm with iron pieces connecting them. Lifting and lowering linked to the structure and the rain cone by means of four chains with a length of 500 mm. As for the rain cone, it consists of a circular diameter with dimensions of 500 mm and a height of 280 mm and a conical part diameter it (400) mm and a height of 450 mm with a key at the end of the cone with a diameter of 50 mm and a length of 150 mm as shown in the figure 5. Through this device, different relative densities are obtained, knowing that the relative density used in this study is 65%.

Figure 5. Raining technique device

2.4 Pile installation process

After preparing the soil, the required angle of inclination is determined in the examination by lifting the suture device by a manual jack, and then the angle is measured by an electronic scale to obtain the exact required angle The examination container is placed inside the piling device, where the pile is fixed from the top of the container by a circular piece with an inner and outer diameter of about (11,25)mm respectively, to obtain accurate distances between the piles after the completion of the stitching process. The stitching process is carried out through a downward torque generated by this device; with a stitch depth of 330 mm where the number of revolutions per minute and the bottom speed is determined depends on the angle of inclination or slope of helix pile [23]. It is necessary to install the anchored pile so that the pile is inside the ground with a value proportional to the degree (p) of the helix for each turn completed in the direction to reduce ground disturbance [21]. So the stitch rate of (7 mm/min) and rotational speed of (2.5 rpm) is used for all check-ups. After completing the insertion of the first pile with a length embedded (L/d) of 330 mm, we turn off the device, separate the shaft from the pile and rotate the test container to insert the second pile into the group. In this process, the installation of the pile group in a container test is finish as shown in the Fig. 6.

Figure 6. Pile installation device

2.5 Test device

After the piling is completed, the inspection vessel is placed inside the loading device and it is fixed with quarter-circular rings that hold the vessel to prevent its movement during the test. After that, a tension-resistant wire is attached from the side centre of the cap, passing through parallel rollers and connected to the device. At the end of the wire, a loading disk is placed on it gradually and at uneven intervals, as shown Fig.7. After that, the loading increases gradually by adding weights to the loading disc at uneven intervals of time. The lateral deflection measured by dial gage fixed on the opposite side. The maximum lateral capacity is taken at the lateral deflection for the group equal to 20% from the diameter of the helix based on the Brom’s failure criteria [24]. Figure 8 represents a diagram of test device with details of the device parts.

Figure 7. Test device

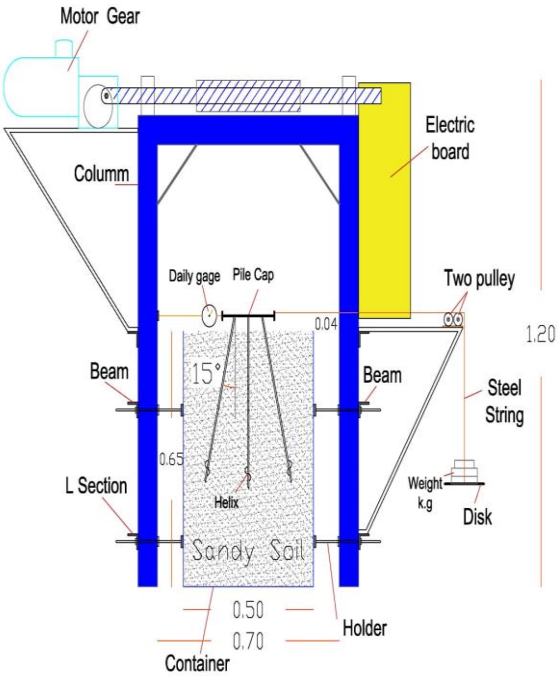


Figure 8. Diagram of test device with details of the device parts

3. Results and discussion

3.1 Effect of inclination angles

The effect of the angles of inclination of the piles in degrees (5°,10°,15°) was studied, as it was found that increasing the angle of inclination increases the lateral resistance to the static load applied to the group as shown in Fig. 9. An example of this is the increase in the lateral resistance of piles with a single helix and tilted at angles (10°, 15°) over it compared to angle (5°) as shown in Table 3.

Table 3: Effect of inclination angles on lateral resistance

Inclination angles used	Increasing in lateral resistance
	Single helix
10°	9%
15°	18%

3.2 Effect of number of helix

Through the results, it was found that piles with single and double helix and a tilt angle of 10° have an increase in their lateral resistance to static load compared to ordinary piles with the same tilt angle about 19% and 24% respectively, which indicates that increasing the resistance due to increase in the screws which increases the lateral resistance capacity of the group pile. This means that the screw increases the resistance surface area of the piles. The lateral resistance of the piles may increase as a result of the aforementioned increase over time due to the improvement of the shear strength [25].

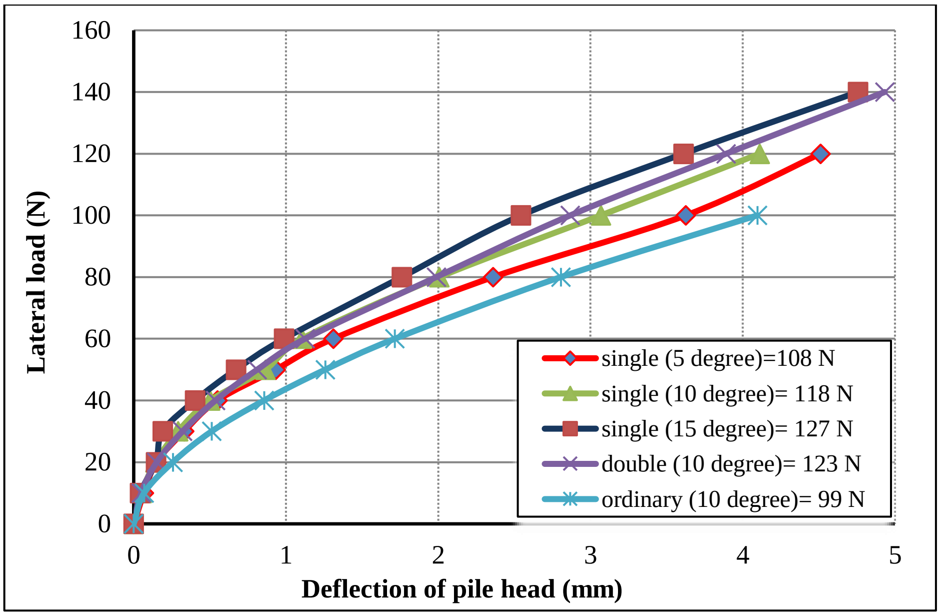


Figure 9. Load-lateral displacement curve for group (3- pile) model, for single helix-pile by inclination angle (5°,10°,15°) & for double helix-pile, ordinary pile by inclination angle (10°)

4. Conclusions

Several tests were carried out for the inclined anchored pile group under static lateral loading to verify the effect of the angle of inclination of the piles and the effect of the number of helixes on the performance and resistance of the group to lateral displacement using a model (3-pile) model. The following conclusions are derived from the above results:

1. The lateral resistance of the pile group increases when the angle of inclination of the pile group increases. A pile with a single helix at an angle of inclination (10°, 15°) has more lateral resistance than if it were tilted at 5° about 9% and 18%, respectively.
2. The number of helix affects the lateral resistance of the pile group, as the lateral resistance of the single-helix pile and double- helix pile is greater than that of the ordinary pile (pile without helix) about 19% and 24%, respectively.
3. The lateral resistance for pile group increases when the number of helix increases.

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