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PERFORMANCE OF LATERALLY LOADED MODEL FINNED PILES IN CLAY SOIL

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PERFORMANCE OF LATERALLY LOADED MODEL FINNED PILES IN CLAY SOIL

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ABSTRACT

Finned piles are a novel pilling technique which is used as a foundation for many structures such as: transmission towers, bridge abutments, ocean engineering structures, marine dolphins, dock-fendering systems and moorings that subjected predominantly to both laterally loads beside the vertical loads.

This paper presents a series of experimental tests that were conducted to lateral loaded piles with/without fins in clay. Piles with different types were fitted with different fins geometry and numbers. The results of this study indicated that the pile lateral capacity increased and the horizontal deformation of pile decreased at the same load level after mounting fins is compared to regular normal pile without fins. It has been found that the optimum geometry of adopted fins is found to be its length equals to (0.4) of the embedded pile length and width equals to the pile diameter. The existence of such fins considerably increased the ultimate lateral capacity by as much as (54% and 35%) of it is initial value for short and long piles respectively.

Keywords: Soft Clay, Finned Piles, Model Tests, Laterally Loaded.

1. INTRODUCTION

Pile foundation are widely used to support huge structures as power transmission line, high-raise building, offshore structure, bridge abutment, chimneys and wind farms that subjected to different types of lateral loads as violent winds, ocean waves, hurricanes and earthquakes [1, 2].

These loads were made the pile subjected to severe deflection/movement which can cause a significant foundation failure. Therefore, the design of piles must sustain the effect of horizontal or lateral loads to avoid any failure hazards.

As a matter of fact, the pile lateral capacity is a function in three main parameters, the soil type, the loading direction and the pile geometry. Therefore, to improve the pile capacity and resistance against lateral loading it is necessary to change of the pile geometry by using other types such as (tapered, tripod, helical piles) [3, 4]. Based on that, many researchers dealt with the problem to improve the lateral response of pile or pile under such loads using variety of mentioned techniques.

The finned pile concept based on an improvement can be reached by adding fins to expansion the cross section of the pile to increase the passive soil area that resist the lateral loads. Thereby the fins will improve the lateral resistance and decrease the horizontal movement. Finned piles formed by attaching steel plates in the top of the pile at (90°) to the pile [5]. Previous experimental, numerical and field studies were conducted on pile or piles group with/without fins to investigate the degree of the improvement and lateral pile response under different loading conditions in sandy soil [6-11].

Besides that, several experimental investigations have been performed to point out the effectiveness of applied wings to the upper part of pile to increase the pile lateral capacity and minimize the lateral deformation [12]. Others studied the effect of finned piles under monotonic lateral load and under cyclic load, results proved that the addition on wings can significantly reduce the displacement by approximately up to (50%), also the adjusting wings increased the pile bearing capacity by approximately up to (40%) compared with regular monopiles for the same load level [13].

Using in- situ, studies proved that addition of fins in the conjunction of embedded piles in sand can significantly improve the bearing capacity of regular piles. Results showed that that lateral load increased by as much as (16%) for fin length of (0.14 Lp) and this ratio increased to (36%) by increasing the fin length to (0.28 Lp), relative to the plain reference pile [14].

Regarding this paper in literature, it has been found that, most of previous studies deals with studying of the behavior of laterally loaded finned piles in sand, While, It is evident that there is a lake of knowledge about the finned piles technique in clay everywhere about the pile foundation commonly installed in cohesive soil.
In view of the above, the present study, tries to discover, analyze and assess the potential benefits of adding fins to the pile to improve the pile performance subjected to lateral loading. The lateral load responses and load capacities of finned piles embedded in soft clay were investigated in comparison to normal regular piles. The investigations were carried out by varying both geometric and number of fins, and for different piles stiffness.

2. EXPERIMENTAL SETUP AND PROCEDURE

To achieve the main purpose of this research and to study the fin pile-soil interaction under lateral loads, a set of laboratory model tests with steel pipe piles embedded in soft clay soil beds was performed. The investigations performed, and the relevant observations made are sequentially described in this section.

2.1 The Test Tank

The schematic diagram of the test setup is shown in (Figure 1). Tests were conducted on model piles embedded in soft clay in a cubic steel testing chamber with internal dimensions of (50cm) for both wide and length, and (70cm) as a depth and a thickness of (3mm) to prevent any lateral deformation on the tank's sides.

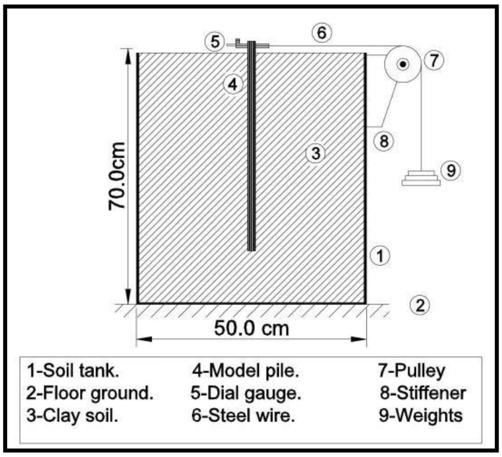

Figure 1. Schematic diagram of the experimental setup and test apparatus.

It is noteworthy that in the present study the tank dimension was chosen to neglect the effect of both the scale effect and boundary conditions and minimize their effect on the test results [15].

To facilitate piles lateral loading, each pile model cap had a hanger firmly attached to a (4.00mm) high tension steel wire by an eye bolt. The outer side of the wire strung over a smooth adjustable lubricated pulley to prevent any friction between the wire and the pully and connected to a load plate form to place the weights which were applied incrementally. Loads were applied in small increments and, each load increment was maintained at a constant value until the pile deformation has been stabilized. To record the correct lateral displacement of the piles for every load applied. Two sensitive digital settlement dial gauges having at least a count of (0.01 mm) were used, then the average of the readings was taken[16].

2.2 Soil Characterization

Experiments were conducted separately with single pile in soft clay. Locally available white kaolin powder from (El Basatin for Industry/ Cairo /Egypt) was intimately mixed with water to prepare the soft clay bed deposits. To reach full saturation and homogeneity, the clay slurry was mixed at crossbedding water content of (36%) to obtain the desired density and cohesion. The test was carried out at shear strength of (15 kPa), which can be determined and checked with the direct shear box test.

To obtain the grain size distribution of the kaolinite, first the soil was wet sieved and then hydrometer test was performed. Hydrometer test indicated that (93.5) percent of the material passes a (No.200) sieve and that the clay fraction is (50) percent, the silt is (43.5) percent as reported by the (MIT) organization. The liquid limit (L.L) and the plastic limit (P.L) were found to be (29.4%) and (15%), respectively and the plasticity index was (PI = 14.4%) the classification of the clay according to united soil classification system (USCS) as clay with low plasticity (CL).

2.3 Model Piles and Fins

To study the behavior of finned piles subjected to static lateral load, series were conducted to a smooth- surface steel circular piles. In all test program the pile models have an external constant outer diameter (D) of (25mm), internal diameter of (19 mm) and wall thickness of (3mm). Embedment lengths (Lp) of the piles were (250 and 550 mm) were used to represent (short/long) single and finned piles in this investigation. The length ratio to the pile diameter were (L/D = 10 and 22) to represent both of short rigid and long flexible piles respectively [17-19]. Piles were fitted with steel plates fins of (3.0 mm) in thickness with various geometric and numbers to gain a further understanding of the fins effect to improve the pile behavior. Fins were welded at the top of the pile to be just below the soil surface, as plotted in (Figure 2) which presents the schematic dimensions of finned piles. Fins with variable dimensions (width and length) were adopted to investigate the effect of geometric fins dimension on the lateral behavior for short and long piles respectively. The effect of fins number was also studied.

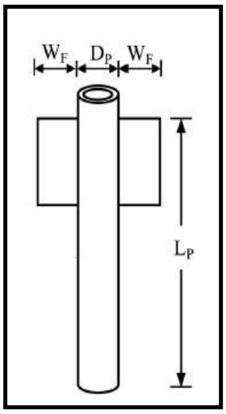

Figure 2. Schematic dimensions of examined finned piles.

2.4 Preparation of Experimental Setup

In the present study, the clay bed was prepared as the following procedure. The clay slurry was mixed in a mechanical mixer with the required amount of water for (20 minutes) to get the required under shear strength (Cu).

At the middle of the mixing process, the mixer was stopped, to check the quality of mixing and the slurry was checked by hand and freed from any created masses (lumps). Before, the fill up of clay in the tank, the inner sides and the bottom of the tank were covered with a plastic cover, to preserve the water content moisture of soil and to expulsion of air voids. Soft clay was placed in layers each one (50mm) until the below of the pile tip at predetermined depth, then the pile was installed after that the clay was placed and hand-packed in the test tank in several layers (50mm) thickness and was tamped by hand to remove the entrapped air during the replacement of soil to ensure homogenous condition. During the tests random soil samples were collected from various depths of the soil layers to check water content, density, and undrained shear strengths (Cu) by the direct shear box test and results showed that the shear modulus of clay is almost constant with depth [15, 16].

Then the soil tank surface was covered by plastic cover and kept for (24) hours before the test was applied. Finally, the dial gauges were mounted in it position and reset to the zero value, then the loads were applied instrumentality until the pile failure. The lateral load was applied horizontally through a smooth adjustable lubricated pulley via a wire attached to the pile cap, avoiding any eccentric load as mentioned previously. It is worth mentioning that each load was kept constant until the horizontal displacement had stabilized. For each increment of load the dial gauges reading were taken at constant intervals of (15) minutes[16].

3.TESTING PROGRAM AND STRATEGY

This research presents a parametric study that investigated different variables of fins geometry and numbers to evaluate their effects on the enhancement of lateral capacity and load deformation of single piles. The problem statement and both of constant and variable parameters are mentioned in (Table 1). Initially investigations of the behavior of model piles without fins under lateral load were conducted as a reference for comparison with finned piles. For all examined piles the fins were constructed perpendicular to the applied

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static loading direction at the upper part of the pile just beneath the soil surface of the embedded pile depth. This referred to an optimum location to gain the significant improvement on the ultimate load capacity.

Table 1: Constant and Variable Parameters

Group	Constant Parameter	Variable Parameter	No. of Tests
G1	L/D=10,22 without fins	Pile stiffness	2
G2	L/D=10,22 with rectangle fins	Lf = (0.2,0.3 and0.4) LP	6
G3	L/D=10,22 with rectangle fins	Wf = (0.5,0.75 and1) Dp	6
G4	L/D=10,22 with rectangle fins (Lf=0.4LP and Wf=Dp)	Fins No. 3(two cases of loading direction)	4
G5	L/D=10,22 with rectangle fins (Lf=0.4LP and Wf=Dp)	β= (0° and 45°)	4
TOTAL NUMBER OF SERIES			**22**
L / pile length, D / pile diameter, Cu / undrained shear strength, Lf / fins length, LP / pile length, Wf / fins width, Dp / pile diameter, β / fins inclination angle.			

4.RESULTS AND ANALYSIS

From the experimental results the pile head lateral load and the pile displacement are plotted and discussed through figures (3 to 10). For the (P-Y) curves the pile head horizontal displacement (S) is expressed as a dimensionless ratio to pile diameter (D) as a (S/D) and the ultimate lateral load is presented as (Pult). Failure of short or long piles takes place when the lateral load corresponds a horizontal displacement exceeds than (10%) of pile diameter [20].

4.1. Effect of Fin Length

Test were conducted for various fin length to pile length ratios (Lf/LP) of (0.2, 0.3 and 0.4) by keeping the fin width (Wf/DP= 1.0) constant. The tests were carried out for different piles stiffens to get the effective fins lengths. From (Figure 3) it is obvious that by increasing the fins length a great improvement in the lateral capacity is achieved. Besides that, the pile stiffness (L/D) has a great effect on increasing the lateral load capacity of finned piles, as confirmed by (Figure 5) which shows that the higher stiffness provides more improvement in lateral capacity. Results showed that for pile stiffness of (L/D =22), the lateral pile capacity at failure (S/D=0.1) was increased by (35.5 %) for fin length of (0.4LP). Whereas for short piles of (L/D =10), the improvement in lateral resistance of piles relative to normal piles were found to be (54%).

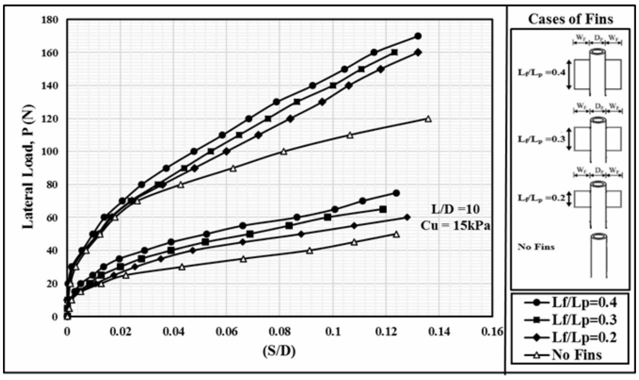

Figure 3: P-Y curve for various fin lengths (L/D=10 and 22, Wf/DP= 1.0)

Actually, there are two main important factors to resist lateral force, pile length and fins area. In the fact, the effective area to resist soil resistance is the area perpendicular to the load direction. In the example of a normal regular pile, the effective area is the pile diameter multiplied by the pile length. But, for a finned pile, the section above the fin tip has an effective area of the pile diameter plus the fins area (width of the fins multiplied by the length of the fins). Therefore, the area behind fins can significantly effect on the induced passive resistance.

4.2. Effect of Fin Width

To study the effect of fin width on the lateral response of piles, in (Figure 4) show the relation between (P-Y) curves for different piles stiffness and different cohesions. The results obviously showed that the existence of such fins with higher width leads to significant increase in lateral pile resistance with lesser lateral movement. The increase in fin width can distinctly modify the (P-Y) curve according to pile stiffness. In case of pile stiffness of (L/D =22), the lateral pile capacity at failure (S/D=0.1) was increased by 23.8% for fin width of (0.5Dp) while at fins width of (0.75 Dp and 1Dp) the value of lateral pile resistance was improved as much as (30.8% and 35.5%) respectively at the same conditions. Whereas for short piles of (L/D =10), the improvement in lateral resistance of piles relative to normal piles were found to be (23.8%, 38% and 54.7%) in case of (0.5 Dp, 0.75 Dp and 1 Dp) respectively.

This can be explained as in the regular pile the soil flowed surrounded the outer pile parameter only. On the contrary fins extension and increasing its width will include a higher soil resistance due to the increase in passive soil area in front of the finned pile which cause a new equivalent pile diameter triple times the regular ones presented in (Figure 5).

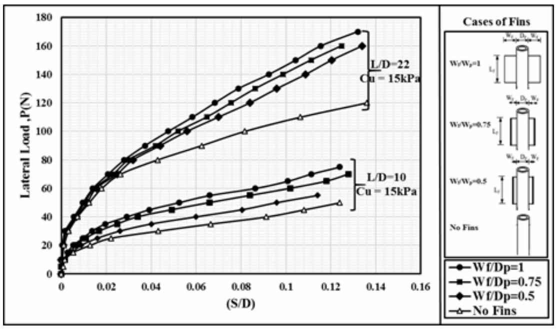

Figure 4: P-Y curve for various fin widths (L/D=10 and 22, Lf/LP= 0.4)

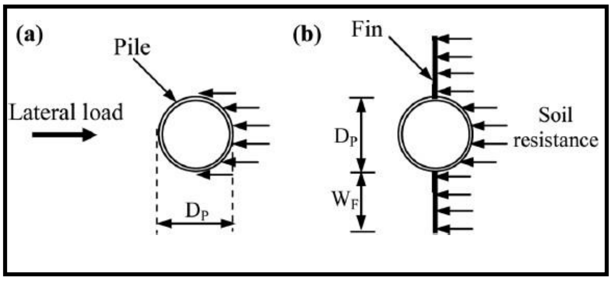

Figure 5: Soil Distribution (a) regular pile, (b) finned pile

4.3 Effect of the Fins Number

Tests focused on to explore the effect of number of fins to increase the resistance of laterally loaded piles, by keeping (Lf/LP= 0.4, Wf/DP= 1) constant and change the number of fins in the upper part of the pile by using three fins and change the static loading direction. The (P-Y) curves demonstrates that as the number of fins increases and the loading direction acting on the largest reaction surface that leads to an increase in pile capacity against lateral load. (Figure 6) ensures that the structural stiffness of finned in the direction of lateral load has major effect on the lateral resistance. From the obtained results for pile stiffness of (L/D =22), the lateral pile capacity at failure (S/D=0.1) was increased by (68%) as compared to regular pile. Whereas for short piles of (L/D =10), the improvement in lateral resistance of piles relative to normal piles were found to be (72%).

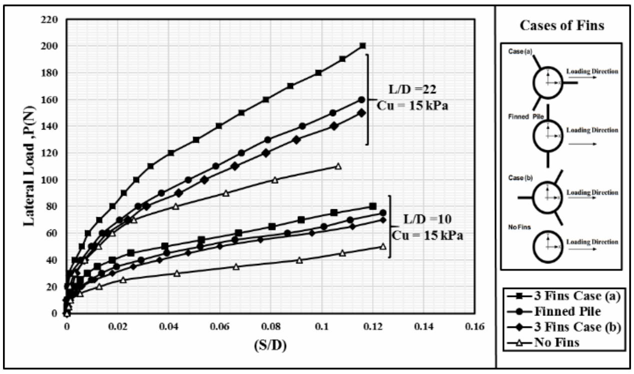

Figure 6: P-Y curve for various fin No. (L/D=10 and 22, Lf/LP= 0.4 and Wf/DP=1)

In practice, lateral load may act in any direction, hence it is always beneficial to consider more than two number of fins to resist lateral loads. One of the aims in the present study, is to investigate and discuss the effect of increasing the number of fins. Three fins were considered to study the behavior of pile under lateral loading. Soil resistance distribution in front of the fin section could be presented by the passive strain area as shown in (Figure 7).

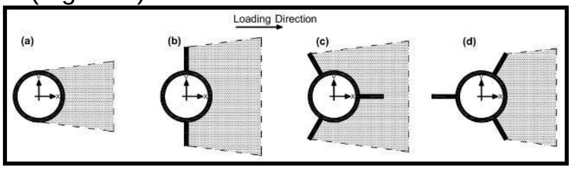

Figure (7): Schematic diagrams of soil resistance region under lateral loading (a) a regular pile, (b) a finned pile (c) a finned pile subjected to load at larger area surface and (d) a finned pile subjected to load at smallest area surface.

It is evidence seen that strain area of the finned pile are larger than that of the regular pile because of the fins. While, the finned pile resistance to carry more lateral load capacity is more than the case of three fins (in case of smallest soil area). Finally, the three-fin configuration subjected to lateral load at the larger surface are exhibits higher lateral load capacity compared to two finned pile because of the largest passive soil area in front of the fins and the increase in pile rigidity due to three fins instead of twice.

4.4 Effect of Fin's Inclination Angle

The fin's inclination angle was the last parameter to be assessed in this laboratory study. So, series of testing the fin's inclination angle were carried out on rectangle fins piles by keeping both (Lf/LP= 0.4) and (Wf/DP=1) constant and change of fin's inclination angle. From (Figure 8) it clearly seen that piles with diagonal fins provided a considerably higher resistance and a stiffer behavior than case of no inclination angle and finned pile. From the obtained results for pile stiffness of (L/D =22), the lateral pile capacity at failure (S/D=0.1) was increased by (78%) as compared to regular pile and increased about (27 %) than the case of no inclination angle. Meanwhile, the lateral capacity in case of pile stiffness of (L/D =10) increased by about (73%) than regular piles.

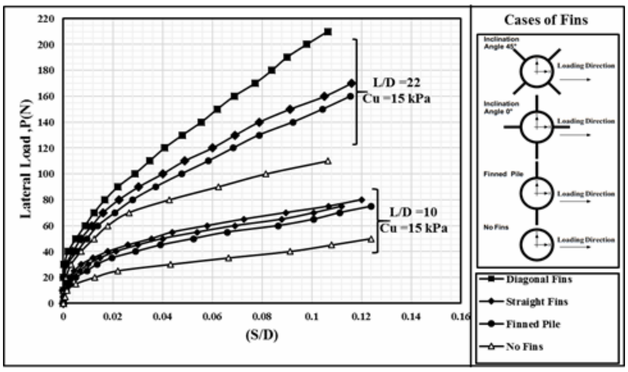

Figure 8: P-Y curve for various fin No. (L/D=10 and 22, Lf/LP= 0.4 and Wf/DP=1)

Soil resistance distribution in the fin section could be presented by the passive strain area as shown in (Figure 9). The soil strain area established from different pile conditions. Strain area of the finned pile are larger than that of the regular pile because of the fins. While, for a straight finned pile subjected to a load at (0°) facing the fins the soil strain area is equal to the case of finned pile, but the pile rigidity is more than the finned pile. Finally, the diagonal finned pile, has the biggest lateral resistance capacity because of the largest passive soil area which is determined by the internal friction angles between pile and soil.

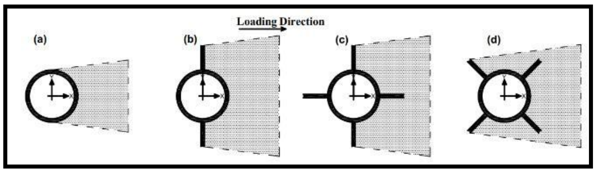

Figure 9: Schematic diagrams of soil resistance region under lateral loading (a) a regular pile, (b) a finned pile, (c) straight finned pile subjected to load at (0°) and (d) diagonal finned pile subjected to load at (45°)

The Schematic diagrams illustrated the effective area and the distribution of soil resistance for a finned pile subjected to a lateral load from different directions. The soil around the diagonal finned pile was assumed (shown as the area enclosed by dashed line) in (Figure 10) may work as a block enclosed between the diagonal fins and with the pile and will resist the lateral load with the fins. Consequently, the optimum direction that can be provided higher improvement is the diagonal finned pile.

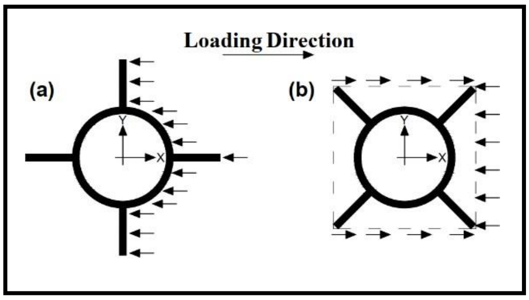

Figure (10): Effective area to sustain the soil horizontal stress, (a) a finned pile subjected to load at 0° and (b) a finned pile subjected to load at 45°

5.FAILURE MODES

From the above discussion, it could be understood that, fins increase the lateral load capacity of normal piles. Besides, placing fins in the top of the pile is beneficial which will help to improve the lateral load carrying capacity and reduce pile deformation.

During the experimental tests several failure mechanisms and tension cracks were clearly appeared in the soil surface near to the pile head as shown in (Figure11).

It has been observed that lateral loads on piles can initiate the formation of a gap at the rear side of pile and the tension cracks near the soil surface were appeared to the outer side of the fins. Utilization of fins caused an increase in the pile diameter to a new value which is triple and caused a block of soil in front of the pile to resist the lateral load as shown in (Figure12).

The failure mechanism of piles fitted with three fins can be clearly seen in (Figure13). In front of the pile a passive wedge was mobilized. On the other hand, soil separation from piles with a gap opening on the rear side of pile was appeared. Cracks were developed near to the fins and occurred on the ground surface of soil.

Finally, for the diagonal finned pile lateral load caused a soil separation and formatted a gap behind the pile, soil heave in front of the pile was visualized near to the soil surface. Tension cracks near fins were appeared, shear cracks were appeared surrounded the fins, because of the friction of the soil which works as a block enclosed the diagonal fins and the pile to resist the lateral load as plotted in (Figure 14).

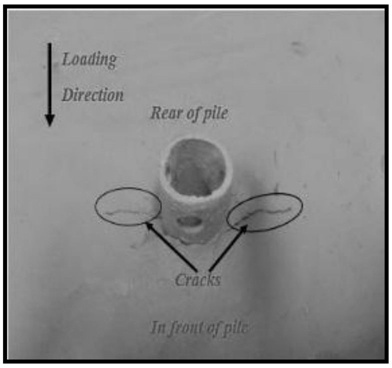

Figure 11: Normal Pile Failure

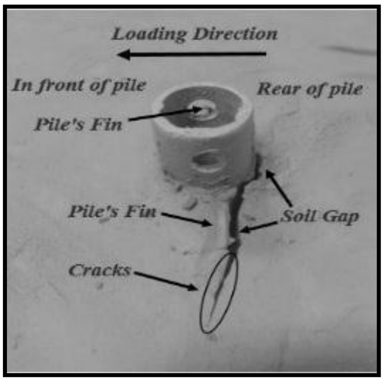

Figure 12: Finned pile Failure

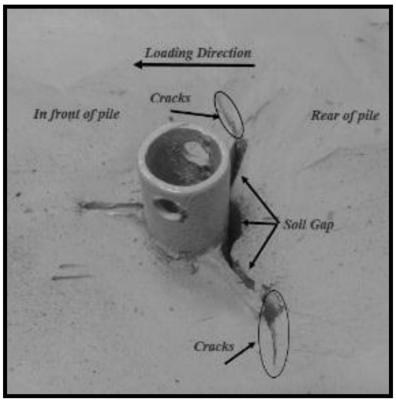

Figure 13: Three Finned Pile Failure.

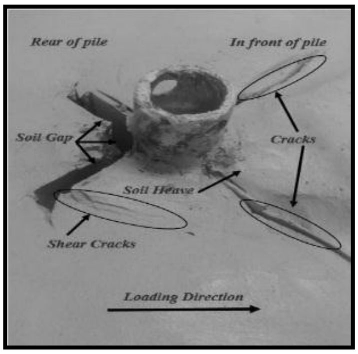

Figure 14: Diagonal Finned Pile Failure

6.CONCLUSION

Design of piles must sustain the effect of horizontal or lateral loads beside the vertical loads. Finned piles an innovative pilling technique to improve the response against lateral loads. This paper presents a comprehensive study on the performance of lateral loaded finned piles in clay soil. From the obtained results and after the comparisons between the response of finned and regular piles, and assessing the goals of identifying the optimal conditions for the best performance, the following points can be summarized:

1) The attachment of fins on the pile in the foundation design considerably increases the lateral load resistance and decrease the lateral deflection at the same load level. This will in turn help to reduce overall pile length and diameter.

2) Ultimate lateral resistance depends on fins location, so fins must be placed near the top of pile head to gain more resistance, and fins orientation must be perpendicular to lateral load in case of lateral loading.

3) The optimum fin efficiency is obtained at a fin width equals to the diameter of the regular pile (Wf/DP=1), and the fin length equals (0.4) of the pile length.

4) For both long and short piles adjusting fins increases the lateral pile capacity by as much as (35.5% and 54%) respectively.

5) When the pile is finned with (3) rectangle fins, it is obvious that for both short and long piles the fin efficiency increases by (72% and 68%) respectively in soft clay.

6) At the optimum fin's dimensions, diagonal fin piles carry more lateral load and then followed by straight fin piles. This due to that diagonal fins mobilize more friction stress and resistance between the fins and the soil.

7) For short, diagonal fin piles the capacity is increased by as much as (73%), and for long, diagonal fin piles the resistance is increased by as much as (52%) for piles embedded in soft clay.

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