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***Abstract*— on deep foundations, which are exposed to uplift stresses, a variety of structures are erected, including ones that resemble marine dolphins, dock-fendering systems, tower foundations, inundated platforms, and abutments. This research presents a contemporary modification approach for piles called a finned pile. The modification consists of two fins or four fins that can be easily attached at the top, middle, and bottom of a pile that circumnavigates the region. Normal piles without fins and piles with fins were both subjected to comparative small-scale model uplift testing. Altering the fin shape, fin position, number of fins, fin-length ratio (L_f/L_p), and fin-width ratio (W_f/W_p) were all manipulated throughout the course of the research. According to the findings, the piles' potential for being lifted to a higher level is significantly enhanced by the addition of fins to the very top of the pile. It was discovered that the ultimate lifting capability of rectangular shaped fins is greater than that of triangularly formed fins when the fins were put into two different shapes, such as triangular and rectangular shapes. The L_f/L_p ratio of 0.4 achieved the ultimate capacity of uplift piles, and it also showed that an increase in the width of the fins has a direct dependence on the ultimate capacity of uplift piles. The ultimate capacity of uplift piles was achieved by a four-finned pile rather than a two-finned pile.**

Keywords—uplift load, finned pile, load carrying capacity, deformation, tension

I. INTRODUCTION

Modern engineering constructions need the installation of a foundation system capable of withstanding vertical and horizontal pullout pressures or providing enough support by transferring loads to the earth. A foundation's depth may be divided into two categories: shallow and deep. As the depth of an excavation increases, shallow foundations are normally built up from the bottom of the hole. When the earth underneath the building is inadequate to hold the load with acceptable settlement or appropriate safety against shear collapse, deep foundations are used. To sustain uplift stresses, pile foundations are used in the construction of a wide range of structures including transmission towers, anchoring systems for ocean surface or submerged platforms and towering chimneys as well as other structures like jetty structures. Extensive theoretical and experimental study has been conducted in recent decades on the behaviour of piles or pile groups exposed to axial compressive, inclined, or lateral stresses. Both in the lab and out in the field, this study was conducted.

(Te Pei et.al 2022) observed that lateral loads typically impact pile foundations in their research. Steel fin pile foundations (SFPF) may have their lateral load capability increased by using steel plates (fins). FEM studies were used to determine how fin geometry affects SFPF lateral load capacity. (Maher T. EL-Nemr et.al 2021) modified traditional piles with a finned pile to improve their performance. This modification increases pile capacity by welding four fins around the bottom. Experiments were conducted on pile groups with different numbers and spacings of piles. The performance of all tests under the same conditions such as constant fin width, length, and number, embedding depth, and pile diameter—in order to assess the effectiveness of our pile modification strategy. (Buse Emirler et.al 2020) investigates about pile surface roughness affects uplift capability at varied pile spacing ratios. The research discusses the effects of uplift loading on a single pile and a group of piles. It is important to consider the pile surface and the embedment ratio. Finite element calculations were used to show how pile groups and pile interaction fail at various spacing ratios based on experiments with the aforementioned parameters.

(Mohamed Sakr et.al 2020) explains a novel method of increasing pile uplift is being tested. An investigation of the uplift capabilities of single normal piles (without wings) and anchor winged vertical piles in various densities of dry sand. Single-regular and anchor-wing piles were examined using sixty models. During the model testing, the embedment depth and the diameter of the piles were kept constant. The pile's apex had a variety of wing sizes, both long and wide. The uplift capability of anchor-wing piles is increased by the density of sand. (Boonchai Ukritchon et.al 2019) explains that many tensile-forced pile foundations use the uplift capacity of circular piles in sand as a design criterion. It is possible to forecast pile uplift capacity in sands using limit equilibrium or semi-empirical approaches, although they are not accurate. Computing limit analysis is utilised to study circular mounds of sand as part of this research. At the soil-to-pile interface, the impacts of characteristics such as pile diameter, length, and roughness are studied and compared using dimensionless parameters. Circular piles in sand may be approximated statistically using design equations derived from numerically deduced solutions and experimental data. To better anticipate the circular pile uplift capability in sand, new design equations have been presented.

In light of this a condensed version of the goals of the current research is to investigate the behaviour of tension-loaded regular piles, to determine whether the uplift resistance of finned piles is affected by the number of fins, to study the effect of Lf/Lp ratios on uplift load carrying capacity, in order to compare the influence of fin width on finned piles' ability to lift, finned piles' uplift resistance influenced by their form was the subject of this research.

II. EXPERIMENTAL WORK

A. Experimental Setup

In this experimental investigation, a pile with an embedment length of 600 mm and shapes of triangular and rectangular fins of varying sizes made of aluminium sheets with a thickness of 2 mm was used. In order to fix fins at an angle of 180 degrees, removable screws were employed in each pile part. They were placed at the top, middle and bottom of the pile. The pile is pushed vertically into the sand bed at a 45-degree angle.

In the end, dial gauges were placed on top of the pile head and adjusted such that there was no tensile displacement. Finally, the substance cracked under the weight of its own weight. As a result, the pile head was put under strain by using a hand jack mounted directly on the proving ring itself. The jack had one end attached to the loading frame and the other unattached. The uplift deformation of the dial gauge was recorded for each load increase, and this data was utilised to produce load-deformation graphs.

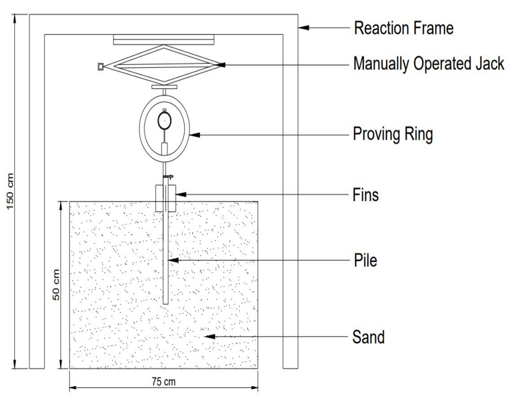

Fig. 1: A schematic diagram of Setup of Experiment

Fig. 2: Laboratory test setup

B. Test Materials

1. Model Tank

The experiments were carried out inside a custom-made iron tank that measured 750 mm in width, 750 mm in length and 500 mm in depth. The tank is outfitted with a reaction frame, which is responsible for supplying the load.

2. Sand

Sand that has been dried out from a river was used for the experiment. The Pycnometer method was utilised in order to ascertain the specific gravity of the soil particles. Properties of sand used for current study are as shown in the Table 1.

Table 1: Properties of Sand

PROPERTIES	SAND
Type of Sand	Dry clean sand
Specific Gravity (G)	2.48
Water Content, WC (%)	6.4
Grain size: D_{10}, D_{30}, D_{60} (mm)	0.17, 0.31, 0.6
Uniformity Coefficient, C_u	3.54
Coefficient of Curvature, C_c	0.94
Classification (IS 1498-1970)	SP
Maximum dry unit weight, Y_{max} (kN/m^3)	18.82
Minimum dry unit weight, Y_{min} (kN/m^3)	14.31
Maximum void ratio, e_{max}	0.7
Minimum void ratio, e_{min}	0.292
Relative Density (%)	35
Cohesion (c)	0
Angle of internal friction (ϕ)	36^0

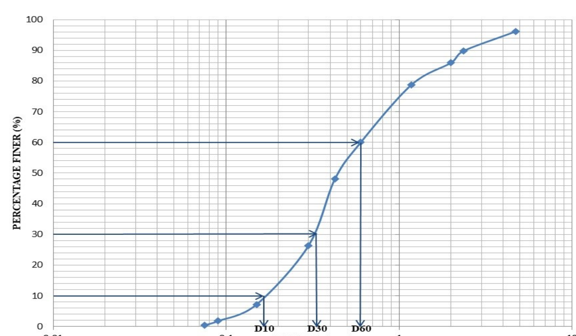

Fig. 3: Grain size analysis curve

3. Model Pile

An uplift pull out test was carried out on the pile. The shaft is constructed out of a solid rod of aluminium measuring 20 millimetres in diameter. Since the embedment length to diameter ratio (L/d) of vertical piles is 30, the length of the pile is 600 mm.

The surface of the pile is smooth when it is used in its natural state, without any treatment to the outside, to look like an aluminium pile. The pile is designed with three holes in the head, the middle, and the tip in order to accommodate a variety of fin configurations along its length.

Fig. 4: A smooth aluminium pile

Table 2: Dimensions of Pile

Type of Material	Aluminium (Solid)
Diameter of Pile (mm)	20
Length of Pile (mm)	600

4. *Fins*

The embedment ratio was constant and the number of fins were changed throughout the course of the tests, and the results were compared to those of a standard vertical pile.

Fig. 5: Attachable rectangular 2 fins

Fig. 6: Attachable triangular 4 fins

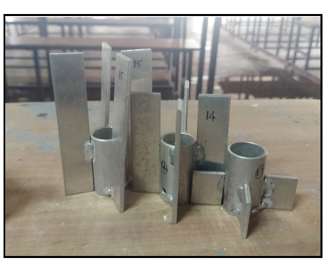

Fig. 7: Attachable rectangular 4 fins

C. Sand Bed Preparation

To establish a uniform density across the bed, sand was falling down from the sky at a regulated discharge rate and constant height of fall, so that the sand was evenly distributed. The relative density attained during the experiments might be tracked by collecting samples in tiny cans of a given capacity and distributing them around the test tank. Loose density circumstances were represented by the 35 percent range of the relative density created by the rainfall techniques used in this study. The average unit weight is 14.9 kilonewtons per cubic metre. The maximum and minimum densities were met in line with IS: 2720 (PART 14)- 1983.

There was no indication of particle segregation during the sand raining experiment, and the uniformity tests showed that the relative densities obtained from each of the three samples were independent of the cans' placements. The sand's internal friction angle was calculated to be 36°. Dry tamping and maintaining the sample's relative density at 35% yielded this result in a direct shear test.

Fig. 8: Sand bed prepared and leveled

1. *Calibration of Height of Fall*

A bowl with a known volume was used for the trial and error method that was used to determine the height of fall for a specific density before the experiment was carried out. The bowl was positioned so that it would rest at the bottom of the tank, and the sand was poured from the pouring box at a specific height that was held constant in order to achieve a density that was repeatable.

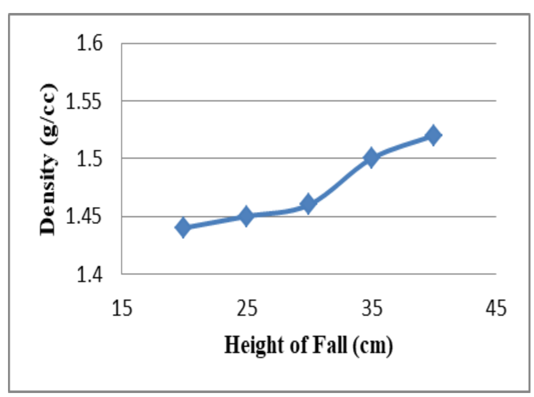

Fig. 9: Calibration curve

2. Rainfall Technique

In order to get a density that can be reproduced, the method used to deposit the sand is critical. At initially, sand was continually poured into the tank via the mesh, and the height of fall was maintained at roughly 40 centimetres for loose instances. Sand was poured into the tank to fill it to a height of 500 millimetres above the base.

From one side of the tank and moving toward the direction in which the tension load was being applied, pile was driven into the sand until it has reached the length of embedment measuring 600 millimetres. The technique of pouring sand is referred to as the rainfall technique, and it was reported that this technique was successful in achieving good reproducible densities. The surface of the sand was meticulously level. The pouring of sand using this technique resulted in a dry density of 1.52 grams per cubic centimetre. At the conclusion of each test, the density of the sand in the container was measured.

Fig. 10: Pouring of sand to the model tank by using a mesh

III. EXPERIMENTAL PROCEDURE

- With a 600-millimeter embedment length, the planned experimental programme seeks to find out how much uplift load the finned pile can handle. It consists of an iron model test tank measuring 750 mm in length, 750 mm in width, and 500 mm in height. The tank has been filled with a 20-millimeter-diameter pile with a 30-millimeter-to-length ratio.
- To fill the tank, either sun- or oven-dried sand is pumped in using the rainfall approach. The sand was poured through a 4.75-millimeter-diameter mesh in this method. The mesh was preserved at a constant height for the following sand filling. This was done to meet the predetermined density goals. At least 600 millimetres of sand must be put to the tank's bottom before it can be considered complete.
- It is then rammed into the bottom of sand layer once the tank has been filled with sand to the desired height from the bottom. In order to preserve the verticality of the plain pile without any fins, it has an embedment length of 600 millimetres.
- Six hundred millimetres in length, the finned pile has been pushed into the sandy layer by clockwise rotation. The pile is pulled higher and outwards using a screw. Both the pile and a strain-controlled proof ring are linked to the screw's threaded end. A hand-operated loading jack is attached to this proving ring. The jack is supported by the response frame.
- An aluminium plate attached to the pile head is permanently adjusted to accommodate a device known as a travel dial gauge, which has an accuracy of 0.01 mm, in order to measure displacement. During the course of the procedure, the burden was steadily raised. Each load increment was maintained at the same value throughout the process of stabilising the pile's deformation.
- For maximal deformation, the loading is only halted when it reaches its maximum value; after that, either it starts to decline or it remains constant.
- There's always the spinning of the mound on the top of the tank when anything goes wrong.
- While retaining the same embedment length, variable L_f/L_p ratios are used for the configuration of finned piles.
- After plotting uplift load vs. deformation plots, the maximum load may be determined. The ultimate uplift load capacity of the pile is dependent on the number, shape, location, and size of fins as well as the L_f/L_p ratios, with a maximum load of that amount.
- Different parameters of a finned pile are discussed in relation to a basic vertical pile to see what the outcomes are.

IV. RESULTS AND DISCUSSIONS

The uplift load-displacement response of various combinations of finned piles is the topic of discussion in this chapter. Experiments were carried out on vertical plain pile in addition to vertical finned pile, with the embedment length remaining the same but the fin parameters being changed. This chapter presents a plot that compares the net ultimate load to the amount of deformation that occurs. The condition of loose sand has been represented graphically in every possible way at this point.

A. Behaviour of plain pile with respect to Uplift Load

In the beginning, research was conducted on the performance of a regular pile with an L/D ratio of 30, which was then subjected to tension loads. Then, this gives the important reference information that is needed to make comparisons. The results of model tests conducted on a regular pile that was embedded in sand are presented in Fig. 11. Based on these results, it could be assumed that the piles can handle a ultimate tension load in terms of deformation.

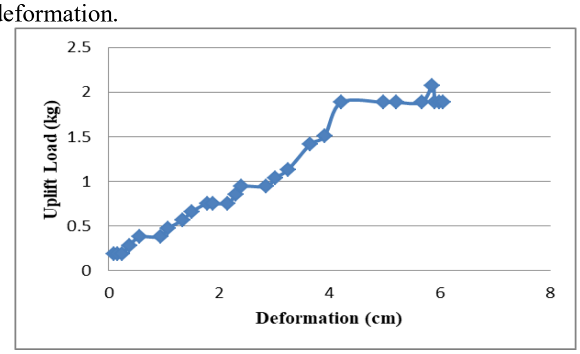

Fig. 11: Load-Deformation curve for a regular pile

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B. Effect of the Number of Fins on the Uplift Resistance of Finned Pile

Piles that have two distinct fin orientations, such as two-finned and four-finned oriented piles, behave the same way. However, as shown in Fig. 12, the ultimate uplift capacity of four finned piles is greater than that of two finned piles. A four-finned pile is more rigid than a two-finned pile, which means that the final uplift resistance of the pile will be higher than a two-finned pile. A four-finned feature's improved ultimate uplift resistance may be attributable to the fins' orientation. It is the diagonally-finned feature when compared to straight-finned and star-finned features, that will activate a bigger volume of sand around the pile, which will result in an increase in the uplift resistance of a pile.

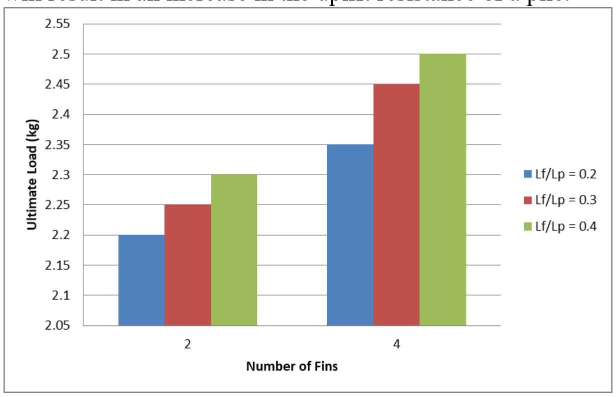

Fig. 12: Behaviour of pile for varying fin numbers under uplift loads

C. Effect of L_f/L_p Ratios on Uplift Load Carrying Capacity

Using a rectangular four fin at the top position of the pile, the tests are carried out in a 90-degree orientation. A fin width of 1.0 is used in the testing for different length-to-pile ratios (Lf/Lp) of 0.1, 0.2, 0.3, 0.4, and 0.5. As fin lengths increase, so does the ultimate uplift resistance of the piles seen in Fig. 13. As the Lf/Lp ratio increases, the ultimate uplift resistance of the pile increases. Even so, as can be seen in Fig. 13, the pile's increase in ultimate uplift resistance increased significantly until the ratio was equal to 0.4. However, if Lf/Lp is more than 0.4, the final uplift resistance decreases significantly. This means that the Lf/Lp = 0.4 ratio of the four fins' lengths is considered to be the best fin length for balancing strength and serviceability, resulting in the maximum uplift resistance attainable.

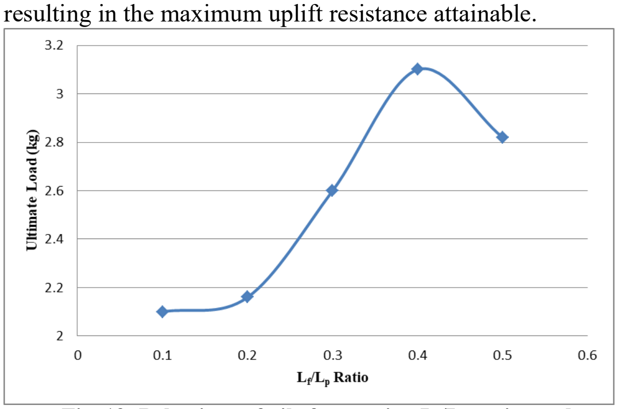

Fig. 13: Behaviour of pile for varying L_f/L_p ratios under uplift loads

D. Effect of the Width of Fins with the Uplift Capacity of Finned Pile

The optimal L_f/L_p ratio and a W_f/D_p ratio range of 0.5, 1.0, and 1.5 were used in a series of model tests to determine the effect of W_f/D_p on the uplift resistance of the pile when it is subjected to tension loads. The results of these tests were compared to those of a pile with an optimal L_f/L_p ratio and a W_f/D_p ratio of 1.5. If the breadth of the fins is increased, the impact of the fins may be seen immediately on the ground surface. A bigger increase in fin width than D_p will enhance fin efficiency despite a lower flow rate. There are several different W_f/D_p combinations that represent the ultimate uplift resistance of the pile in Fig. 14.

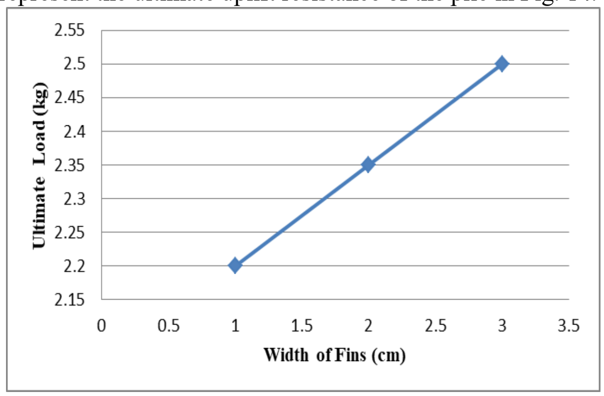

Fig. 14: Behaviour of piles for varying width of fins under uplift loads

E. Effect of the Shape of Fins on the Uplift Resistance of Finned Pile

Two kinds of fins, triangular and rectangular, are tested for their effect on the uplift resistance of the pile with fins in order to determine how their shape affects their performance., a L_f/L_p value of 0.2, 0.3, or 0.4, a W_f/D_p value of 1.0, and a four-finned diagonal feature (orientation of 90 degrees). Figure 15 shows what happens to a pile with two different kinds of fins: triangular fins and rectangular fins. The stiffness contribution is greater for rectangular fins than for triangular fins. If we put extra fins at this place, we'll notice a noticeable increase in stiffness. This is because rectangular fins have a larger surface area than triangular fins, which increases the resistance of the pile to being raised.

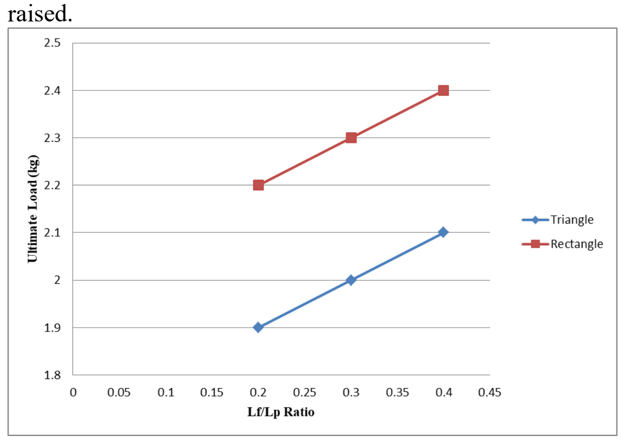

Fig. 15: Behaviour of pile for varying shape of fins under uplift loads

CONCLUSIONS

The results of this work led to the following observations and inferences:

- The load-deformation curves have a connection that is virtually non-linear.
- The uplift resistance of the pile was affected by both the length of the embedment and the density of the soil.
- An embedment length increases the ultimate tension load bearing capability of a finned pile driven in loose thick sand, reaching its maximum value and then decreases..
- When the plain vertical pile is put in loose sand, it doesn't offer as much resistance.
- The load-carrying capacity of a finned pile depends not only on the number of fins but also on the L/D ratios.
- According to the results of the model experiment, the ultimate load capacity of the finned pile in loose sand with $L_f/L_p(0.4)$ and $W_f/D_p(1.0)$ has greater resistance to deformation.
- The ultimate load capacity of the finned pile in sand is greater for piles with four fins when compared to piles with only two fins.
- The results of the model experiment show that a ratio of 0.4 L_f/L_p can be used to increase the load capacity of the finned pile in loose sand.
- It was found that the uplift resistance of all the finned piles was greater than that of the plain vertical piles in the loose sand.
- The ultimate load capacity of the finned pile in sand is greater for piles with rectangular fins when compared to piles without rectangular fins.

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