Experimental investigation on pullout capacity of model pile in Cohesionless Deposits

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Abstract. In this project, an experimental study is made on pile pullout capacity, varying the diameter of the pile (d), Length to diameter ratio (L/d), the effect of pile inclination or batter angle (α), nature of the pile surface by placing the pile in cohesionless soils. The experimental values are determined and are compared with case studies in literature. In this project, various literatures on pullout capacity of piles were studied and experiment procedure was derived. Poorly graded river sand was used for cohesionless deposit. The sand is tested for engineering and index properties. Two types of piles, rough and smooth with different lengths were tested at different batter angles. The results are plotted in the graph. These graphs are used for comparative studies of various outcomes of the experiment and results were established.

Keywords: Model pile, cohesionless deposits, Pile types

1. Introduction

The Construction of piles usually takes place through ground water table and even below it. In such cases, uplift forces acts on the pile which causes it to rise up known as “pull out”. Over the past few decades, only a few studies have been made on the pullout capacity of pile. The transfer of overturning moments takes place in the foundation of structures as compression on some elements and others as pullout. The capacity of the Pile to resist the Pull out forces is known as Pull out Capacity of piles. [1] The ultimate and net ultimate pullout capacity of pile increases when the diameter of the pile and L/d ratio of the pile increases. The increase in batter angle and roughness on piles increases the net ultimate pullout capacity. [2] By estimating the deformation of soil around the pile contributes to reliable design of structures under pullout force, the shear zones curve slightly outward near the ground surface. [3] Foundations in offshore structures are mostly the combinations of vertical and batter piles in order to counteract the overturning moments caused by wind load, wave pressure, and ship impacts.

Retaining walls subjected to horizontal forces due to earth pressure will require a similar kind of pile foundations which can resist uplift. Very few information are reported in the literature about estimating the pullout capacity of piles under uplift. [4]. On comparison to experimental methods, many simple closed form solutions are used in characterizing the pull out capacity of inclined and vertical piles. [5] Kotter’s equation is used for the computations of soil reactions and its distribution on the axis-symmetric failure surface.
The pile soil interface is assumed to be the shape of cone frustum with characteristic inclination angle. [6] When the magnitude of the compressive load on the pile increases, the net uplift capacity of the pile decreases, hence it is assumed to be the critical factor in resisting uplift capacity of the pile. [7] The self weight of the pile and the friction developed between the surrounding soil and the surface friction contributes more resistance to the uplift of the pile. Under reamed pile which is enlarged at the base in the form of bulb offers more resistance to the uplift of piles especially in the expansive clays. [8] The critical factors affecting the uplift capacity of the pile are insitu density of sand and the pile installation techniques. [9] The increase in horizontal or inclined pull in the vertical and batter piles increase the uplift capacity of the pile. The vertical pile has greater ultimate bearing capacity comparing to the inclined or batter pile except for the case of negative batter pile because the negative pile has greater ultimate uplift load comparing to positive batter pile.

2. Methods and Tests

2.1. Specific gravity

As specific gravity is essential in calculation of void ratio, density and unit weight, it is indeed to determine it. The ratio of the density of soil solids to density of water is termed as specific gravity. The specific gravity value depends upon temperature; hence its value is reported at standard temperature of 27°C. The specific gravity of soil particles lies within the range of 2.65 to 2.85. The index properties help in identification and classification of soil [10]. The specific gravity test is done by using pyconometer. The Specific gravity of the soil, \( G_s = 2.42 \)

2.2. Sieve analysis

Soils having grain size greater than 0.075 mm size are termed as coarse grained soils. Sieve analysis is mainly used for classifying coarse grained soils. The particle size distribution curve shown in figure 1 represents the gradation of the soil whether the soil is well graded or poorly graded. In order to get the desired grain size distribution, a few soils may be mixed in mechanical stabilisation. To proportionate the selected soil sample particle size distribution of each soil should be known. Size distribution is identified by using specified sieves.

Since, \( Cu < 6 \) and \( Cc < 1 \), the sand is poorly graded sand.

2.3. Relative density

Relative density or density index of sand is defined as the ratio of void ratio of sands in loosest state to densest state. Based on the denseness the sands are broadly classified into loose sand (LS), medium
dense sand (MDS) and dense sand (DS) [11]. The minimum density in the loosest state is obtained by pouring the soil sample into the mould from a standard height of 25 mm. The maximum density in densest state is obtained by applying vibrations to the mould with soil on a vibrating table. Sand replacement method is adopted mostly to find the in-situ density of sand.

Relative density = \[
\frac{\rho_{max}}{\rho_d} \times \frac{(\rho_d - \rho_{min})}{(\rho_{max} - \rho_{min})} \times 100
\]

= 27.8%

2.4. Shear strength parameter

Though the shear strength or angle of shearing resistance and the normal stress both can be measured directly, predetermined failure plane is obtained as horizontal failure plane [12]. The shear box assembly consists of a container in two pieces of 6 x 6 x 3 cm. The Two halves of the shear box are positioned relative to each other by two pins which can be pulled out when not required. There are two grid plates which transmit the shear to the specimen surface. The base plate is grooved and rests on pins in the sides of the lower half of the box. The top plate has an air vent and a central spherical knob, on which the vertical loading yoke rest. The outer container moves freely on ball roller strength strips paralleled to the axis of the load screw and proving ring. Shear parameter is identified using direct shear method graph shown in figure 2.

From Graph,

Cohesion, C = 0.02 kg/cm²
\[\tan \varphi = 0.716\]
Friction angle, \(\varphi\) = tan-1 (0.716) = 35°36’

2.5. Experimental setup

In this phase, the experimental model necessary for the project is setup. The experimental model consists of a glass tank, a steel loading frame, steel rope, Slotted weights, a digital spring balance; model steel piles and a dial gauge as shown in figure 3.a and figure 3.b. The size of the glass tank is 60cm x 60cm x 60 cm. The steel loading frame is fabricated in the lathe shop. The size of the loading frame is 1.2 x 1.5 x 1.2 m. It consists of two movable pulleys that can be fixed at desired positions, through which the steel rope is passed. The model steel piles with an internal diameter of 25mm with (L/d) ratio of 7.5 and 15 are fabricated with both smooth and rough surfaces. One end of the steel rope is attached to the model pile placed in the sand medium inside the Glass tank and the other end is attached to the load hanger. The dial guage records the displacement due to the applied load.
2.5.1. Smooth piles. In these piles, the outer surface is smooth. There are two piles used namely $P_{s1}$ and $P_{s2}$, with length 20cm and 40cm respectively. Each pile was tested for the batter angles $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$ and the results are listed below. The smooth piles used in the test are shown in figure 4.a.

2.5.2. Rough piles. In these piles, the outer surface of the piles is rough. In order to make the surface of the steel pile rough, the surface was chiselled and coated with a layer of sand using glue. There are two rough piles namely, $P_{r1}$ and $P_{r2}$, with $(L/d)$ ratio 7.5 and 15 respectively shown in figure 4.b. Each pile is tested for the batter angles $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$ and the results are listed below.

2.5.3. Experimental procedure. To determine the ultimate pull out capacity of model piles consists of the following steps: i) The Glass tank is emptied and then re-filled with the sand medium. The sand is filled by free fall at a height of 30 cm to maintain the required relative density. The sand is poured into the glass tank in layers, ramped and compacted at appropriate heights. ii) At the appropriate height, the model pile is placed at the required angle and the sand medium is filled around the model pile as before till the sand medium reaches the top of the pile. iii) Once the sand medium is filled, the model pile is attached to the steel rope through the digital spring balance. Load hanger is suspended on the other end of the steel rope. iv) A dial gauge is placed with its needle slightly touching the top surface of the model pile. Then the dial gauge is calibrated to Zero. This dial gauge measures the vertical displacement of the model pile due to the applied load. v) The Load is added in steps, by placing the weights one after another in the load hanger. The Digital spring balance reading and the dial gauge
reading is noted for each load added. vi) This is repeated for all the loads added until the model pile ‘pulls out’ of the sand medium. Then the pile is said to be failed.

3. Results and discussion

3.1. Effect of L/d ratio on pullout capacity in smooth piles
It is evident that the pullout capacity of the pile in sand medium increases with increase in L/d ratio, for a constant diameter. In other words, the pull out capacity of a pile increases with increases with increase in length of the pile at a fixed diameter. Comparative studies are made using graphs which is explained below. The graph representing the effect of (L/d) ratio on the pull out capacity on smooth piles is shown in figure 5.a. It is clear that the pile with the greater L/d ratio (P_s2) has a higher pull out capacity when compared with a pile of lower L/d ratio (P_s1) at a given diameter (25 mm) on a smooth surface. It is also noted that the displacement of P_s1 is greater than that of P_s2 at failure.

Figure 5.a Effect of (L/d) on smooth piles

3.2. Effect of L/d ratio on pullout capacity in rough piles
The graph representing the effect of (L/d) ratio on the pull out capacity on rough piles is shown in figure 5.b. It is clear that the pile with the greater L/d ratio (P_r2) has a higher pull out capacity when compared with a pile of lower L/d ratio (P_r1) at a given diameter (25 mm) on a rough surface. It is also noted that the displacement of P_r1 is greater than that of P_r2 at failure. On comparing the graphs from figure 5.a and 5.b, it is evident that the pull out capacity of a pile increases with increasing the L/d ratio. Also the displacement of the pile decreases with increase in (L/d) ratio for a constant diameter.

3.3. Effect of batter angle on pullout capacity of smooth surfaced short piles
The pullout capacity of the pile in sand medium increases with increase in batter angle up to a certain angle (α), and then decreases with increase in batter angle. This pattern observed is same in the piles with L/d = 7.5 and L/d = 15. Thus, this effect of batter angle on net ultimate pull out capacity of piles is irrespective of the L/d ratio. Comparative studies are made using graphs which is explained below. The graph representing the effect of batter angle on the pull out capacity on smooth pile P_s is shown in figure 5.c. The smooth pile P_s with L/d ratio 7.5 is tested at different batter angles 0°, 10°, 20° and 30°. This graph represents the variation of pull out capacity of pile P_s with respect to batter angle. The graph shows that the pull out capacity of the pile increases with increased batter angle until 20°. After 20°, the pull out capacity decreases.
3.4. Effect of batter angle of smooth surfaced long piles on pullout capacity
The smooth pile $P_{s2}$ with $L/d$ ratio 15 is tested at different batter angles $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$. This graph represents the variation of pull out capacity of pile $P_{s2}$ with respect to batter angle. The graph shows that the pull out capacity of the pile increases with increased batter angles until $20^\circ$. After $20^\circ$, the pull out capacity decreases with increase in batter angle. The graph representing the effect of batter angle on the pull out capacity on smooth pile $P_{s2}$ is shown in figure 5.d.

3.5. Effect of batter angle of rough surfaced short piles on pullout capacity
The rough pile $P_{r1}$ with $L/d$ ratio 7.5 is tested at different batter angles $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$. This graph represents the variation of pull out capacity of pile $P_{r1}$ with respect to batter angle. The graph shows that the pull out capacity of the pile increases with increase in batter angle until $20^\circ$ and then it shows decrement of pull out capacity with increase in batter angle. The graph representing the effect of batter angle on the pull out capacity on rough pile $P_{r1}$ is shown in figure 5.e.

3.6. Effect of batter angle of rough surfaced long piles on pullout capacity
The rough pile $P_{r2}$ with $L/d$ ratio 15 is tested at different batter angles $0^\circ$, $10^\circ$, $20^\circ$ and $30^\circ$. This graph represents the variation of pull out capacity of pile $P_{r2}$ with respect to batter angle. The graph shows that the pull out capacity of the pile increases with increase in batter angle until $20^\circ$ and then it decreases with increase in batter angle. From the comparison made above, it is evident that the pullout capacity of the pile shows significant improvement with increase in batter angle until a certain angle. After that the pull out capacity reduced with increase in batter angle. The maximum value of pull out capacity is observed when the pile is placed at $20^\circ$ inclination. The graph representing the effect of batter angle on the pull out capacity on rough pile $P_{r2}$ is shown in figure 5.f.
3.7. Effect of surface roughness on pullout capacity

Smooth and rough piles were used to study the effect of nature of the pile surface on the pullout capacity of piles in sand medium. Piles with same diameter (25 mm) but different lengths (L) i.e., (L/d) ratio 7.5 and 15 were used for this test. Thus, four piles P_{s1}, P_{s2}, P_{r1} and P_{r2} were used for this study. The graph representing the effect of nature of surface on the pullout capacity on piles P_{s1} and P_{r1} is shown in figure 5.g. The smooth pile P_{s1} and the rough pile P_{r1} with L/d ratio 7.5, is tested. This graph represents the behaviour of pullout capacity of piles with respect to nature of surface. The graph shows that the pullout capacity of the pile increases with increase in surface roughness of the pile. The graph representing the effect of nature of surface on the pullout capacity on piles P_{s2} and P_{r2} is shown in figure 5.f. The smooth pile P_{s2} and the rough pile P_{r2} with L/d ratio 15, is tested. This graph represents the behaviour of pullout capacity of piles with respect to nature of surface. The graph shows that the pullout capacity increases when the surface of the pile is rough.

![Figure 5.g Effect of surface nature on Pull out Capacity (L/d = 7.5).](image)

![Figure 5.f Effect of surface nature on Pull out Capacity (L/d = 15).](image)

4. Conclusion

A series of laboratory tests were conducted to study the pullout characteristics of pile capacity in cohesionless deposits i.e., Sand medium. Piles with different L/d ratio, Batter angles and surface roughness were tested and Load-displacement graphs were plotted. The results of the experiments established from the tests are as follows.

- The pullout capacity in cohesionless medium increases with increased L/d ratio, at a constant diameter (d).
- The pullout capacity increased with increase in batter angle (α) up to a certain limit. After this limit, there is decrease in net ultimate pullout capacity with increase in batter angle (α).
- This pattern of increase in pullout capacity followed by a decrease with increasing batter angle is observed in piles of all L/d ratios, i.e., It is irrespective of L/d ratio.
- The maximum value of Pullout capacity is observed when the batter angle is around 20°.
- The pullout capacity of battered piles shows an increased pullout capacity of 10 to 20% when compared with vertical piles.
- The pullout capacity of piles increases with increase in surface roughness of the pile.

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