Pullout capacity of batter pile in sand

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Abstract Many offshore structures are subjected to overturning moments due to wind load, wave pressure, and ship impacts. Also most of retaining walls are subjected to horizontal forces and bending moments, these forces are due to earth pressure. For foundations in such structures, usually a combination of vertical and batter piles is used. Little information is available in the literature about estimating the capacity of piles under uplift. In cases where these supporting piles are not vertical, the behavior under axial pullout is not well established. In order to delineate the significant variables affecting the ultimate uplift shaft resistance of batter pile in dry sand, a testing program comprising 62 pullout tests was conducted. The tests are conducted on model steel pile installed in loose, medium, and dense sand to an embedded depth ratio, \( L/d \), vary from 7.5 to 30 and with various batter angles of 0°, 10°, 20°, and 30°. Results indicate that the pullout capacity of a batter pile constructed in dense and/or medium density sand increases with the increase of batter angle attains maximum value and then decreases, the maximum value of \( P_a \) occurs at batter angle approximately equal to 20°, and it is about 21–31% more than the vertical pile capacity, while the pullout capacity for batter pile that constructed in loose sand decreases with the increase of pile inclination. The results also indicated that the circular pile is more resistant to pullout forces than the square and rectangular pile shape. The rough model piles tested is experienced 18–75% increase in capacity compared with the smooth model piles. The suggested relations for the pullout capacity of batter pile regarding the vertical pile capacity are well predicted.

Introduction

Batter piles are commonly used to support offshore structures, towers, and bridges since this kind of structures are subjected to overturning moment due to wind, waves, and ship impact. In order to transfer the overturning moment to a compression and tension forces, a combination of vertical and batter piles are used. In the literature the pullout capacity of batter pile in sand has been the subject of few studies. Experimental studies showed a wide discrepancy exists among them. It was found from the full scale results reported by Meyerhof [1] that the pullout capacity for batter piles in sand increases due to an
increase of inclination angle, $z$, of the pile with respect to the vertical, in this study the tests are performed on dense sand. On the other hand Awad and Ayoub [2] showed that the pullout capacity of these piles decreases due to an increase of the angle, $z$. An empirical equation was developed for determining the ultimate pullout capacity of inclined piles.

$$P_s = P_o \left( \frac{\cos z}{\sin z} \right) \tag{1}$$

where $P_o$ = net ultimate pullout capacity of batter pile, $P_s$ = net ultimate pullout capacity of vertical pile, and $z$ = inclination angle of the pile in degrees. Hanna and Nguyen [3] confirmed the observation of Meyerhof [1] for the shaft resistance of single piles subjected to compression loading. The experimental results reported by Afram [4] showed that no significant change on the pullout capacity of batter piles due to an increase of the pile inclination. This investigation is performed on medium density sand having an angle of shearing resistance of 35°. Hanna and Afram [5] conducted experimental investigation to evaluate the pullout capacity of vertical and batter piles. From this investigation it was found that the shaft resistance was not highly affected by the inclination of pile. They suggested an empirical formula to evaluate ultimate pullout resistance for inclined pile in sand.

$$P_s = P_o \cos(z/2) \tag{2}$$

The theoretical analysis results reported by Chattopadhyay and Pise [6] concluded that for equal length piles, the ultimate uplift capacity of inclined pile increases with increase in inclination of pile and decreases after reaching maximum value at inclination angle, $z$. Sharma and Pise [7] carried out extensive work on uplift behavior of anchor piles in sand under axial pulling loads. They concluded that uplift capacity increases with increase in pile friction angle, depth of embedment and $L/d$ ratio. al-Shakarchi et al. [8] concluded that the vertical pile has ultimate uplift load greater than the batter pile. Different theories regarding behavior of piles under different loading conditions have been developed over the years. The reliability of the theories can be demonstrated only by comparison of experimental results on model or field piles with the theoretical predictions. Full-scale field tests, though highly desirable, are generally expensive and difficult to perform. Due to the conflicting conclusions reported in the literature for the pullout capacity of batter piles, an extensive model study is performed to support the published results. In the absence of resources and scope of testing prototype small scale laboratory model test conducted on piles in foundation prepared under controlled condition may serve the purpose to some extent. Properly conducted laboratory tests, with known parameters affecting the soil–pile response under pulling loads would provide information on quantitative and qualitative contributions of such parameters on ultimate resistance of piles in the absence of field test results. Compared to previous studies in this area, this investigation proposes to consider wider range of parameters and their effects on the uplift capacity of piles.

**Experimental**

**Model test tank**

Tests were conducted in a specially fabricated steel tank, having inside dimensions of 1.00 m x 0.60 m in plan and 0.75 m in depth. The tank is made from steel with the front wall made of 20 mm thick glass and is supported directly on two steel columns as shown in Fig. 1. These columns are firmly fixed in two horizontal steel beams, which are firmly clamped in the lab ground using four pins. Axial pullout loads were applied to the piles through double pulley arrangement the steel loading frame, movable along the length of chamber with an inverted pulley was used to align the axis of batter pile and wire rope. The non-extensible steel wire rope was attached to the pile top by bolting. The wire rope was taken first through an inverted pulley and then over the second pulley. Loading pan where dead weights were put for loading was fixed at the other end of wire as shown in Fig. 1. The position of first pulley was fixed according to the alignment of the wire rope and pile axis as per the inclination of the pile. A long steel flat plate was placed along the width of the chamber to mount magnetic base of two dial gauges. Two dial gauges were fixed equidistant from pile axis. The loads were applied by dead weights in the loading pan starting the smallest with gradual increase in stages. Dial gauge readings were observed for both dial gauges for each increment of loading when it becomes stable. Average value of displacement as recorded from both the dial gauges have been taken as axial displacement of the pile corresponding to the pullout load applied.

**Sand bed**

The sand used in this research is medium to coarse sand, washed, dried and sorted by particle size. It is composed of rounded to sub-rounded particles. The sand has a very low impurity level with a quartz ($SiO_2$) content of 97%. The specific gravity of the soil particles was determined by the gas jar method. Three tests were carried out producing an average value of 2.654. The maximum and the minimum dry unit weights of the sand were found to be 17.99 and 14.15 kN/m$^3$ and the corresponding values of the minimum and the maximum void ratios are 0.305 and 0.593, respectively. The particle size distribution was determined using the dry sieving method. The effective size ($D_{50}$), the mean particle size ($D_{so}$), uniformity coefficient ($C_u$), and coefficient of curvature ($C_c$) for the sand were 0.15 mm, 0.50 mm, 4.07 and 0.77, respectively.

Sand beds were placed in 50 mm thick layers by a raining technique in which sand is allowed to rain through air at a controlled discharge rate and different heights of fall to give uniform densities. The relative density achieved during the tests was monitored by collecting samples in small cans of known volume placed at different locations in the test tank. The raining techniques adopted in this study provided uniform relative densities of 25%, 50% and 81%, representing loose, medium density and dense sand conditions. The corresponding average unit weights are 14.95, 15.84 and 17.06 kN/m$^3$ respectively. No particle segregation was noticed during raining and uniformity tests showed that the obtained relative densities from the three samples did not depend on the location of the cans. The estimated internal friction angle of the sand determined from direct shear tests using specimens prepared by dry tamping at the same relative densities were 30.50°, 36° and 43.5° respectively.

**Model anchor piles**

Tests under axial pullout have been carried on Piles. The shaft was made of mild steel hollow pipes having out side diameter
25.0 and wall thickness is 1.5 mm. The corresponding embedment lengths to diameter ratio \((L/d)\) were 7.5, 15, 22.5 and 30 respectively. Tests were conducted at different inclination angle with vertical axis as \(0^\circ, 10^\circ, 20^\circ\) and \(30^\circ\). Two surface roughnesses were tested to model the anchor piles. Smooth pile where the pile is used without any treatment for the outer surface, to simulate the steel pile condition. Rough condition is performed by gluing a sand layer onto the outer perimeter of pile to simulate concrete piles. The pile surface roughness was measured for smooth and rough piles used in the experimental study. The profile of the pile surface had a maximum roughness, \(R_{max}\), as determined by a Perthometer, of 4.1 \(\mu m\) in its smooth state and 24.62 \(\mu m\) in its rough state.

**Experimental setup and test program**

The sand was placed in 50 mm thick layers using raining technique with the sand level observed through the front glass wall. In reaching the tip pile level, the pile was placed in position and clamped vertical or inclined using special guide that attached to the tank edge, and the sand was rained in layers until reaching the required embedment depth. Finally, the wire was fixed to the load hanger and the dial gauge was placed in position. The load was applied incrementally by adding weight increments until reaching failure. Each load increment was maintained constant till the pile head displacement had stabilized. A 0.01 mm dial gauge mounted outside the box was used to measure the pile head axial displacement as shown in Fig. 1. A total of 62 model tests were carried out on model test piles on sand to study the effect of pile inclination on its axial pullout capacity. Several arrangements of the piles were investigated in nineteen series of tests. Each series was carried out to clearly find out the gain or loss of axial pullout capacity due to one parameter while the other variables were kept constant. The varied conditions include the pile length, \(L\), the shape of the cross section of the pile, pile inclination, \(\alpha\), sand relative density, \(R_d\), and pile roughness. Table 1 summaries all tests program with both the constant and varied parameters. Several tests were repeated, at least twice, to verify the repeatability and consistency of test data.

**Results and discussion**

The ultimate axial pullout capacity of vertical and batter pile was obtained from load displacement curves. The pile displacement \((S)\) is expressed in non-dimensional form in terms of pile diameter \((d)\) as percentage ratio \((S/d)\,\%\). The ultimate pullout capacity of the pile is obtained from the load–displacement curve as the point where the slope of the load settlement curve first reached to zero or steady minimum value. Fig. 2 shows
typical load versus normalized displacement ratio (\(S/d\)) for rough pile under axial pull that constructed in dense sand (\(\phi = 43.5^\circ\)). It is clear that, the ultimate pullout capacity of batter rough pile constructed in dense sand increases with the increase of batter angle attains maximum value and then decreases. The maximum value of \(P_u\) occurs at batter angle approximately equal to 20\(^\circ\). It is also observed linear relationship in the early stages of the loading up to normalized displacement of about 4\% but afterwards they are non-linear. It is also observed that the significant effect of pile diameter or pile width, \(d\) as relative displacement ratio, \(\alpha\) close to or equal \(\varphi\) the Ks significantly increased. For smooth shaft when \(\alpha\) is much smaller than the angle of internal friction between pile and sand, \(\varphi\) causes slight increase to Ks. But in the case of rough piles the value of \(\alpha\) close to or equal \(\varphi\) the Ks significantly increased.

### Influence of pile shape

In order to study the effect of pile shape on pullout resistance of vertical pile, three different pile shapes are tested. These shapes are circular pile has diameter of 25 mm, square pile of section 19.5 \(\times\) 19.5 mm and rectangular pile of section 26 \(\times\) 13.5 mm, these three pile shapes have an embedment depth of 375 mm. These dimensions give an almost equal perimeter for the three shapes. The pullout load–displacement curve of the three pile shapes is shown in Fig. 4. The pile displacement \((S)\) is expressed in non-dimensional form in terms of pile diameter or pile width, \(d\) as relative displacement ratio, \((S/d, \%)\). The figure indicated that at earlier stage of loading no significant effect for pile shape on its pullout capacity up to \(S/d 2\%\). It is also observed that the significant effect of pile shape on the pullout resistance of vertical pile when the value of \(S/d\) exceeds 2\%. The ultimate pullout capacity of the pile is obtained from the load–displacement curve as the point where the slope of the load settlement curve first reached to zero or steady minimum value. From this figure it can be seen that the pullout capacity of rough round pile constructed in dense sand is 360 N and the relative displacement value about 7\%.

Where as the pullout capacity of square and rectangular piles

### Table 1 Model tests program.

| Series | Constant parameters | Variable parameters |
|--------|---------------------|---------------------|
| 1      | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 2      | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 3      | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 4      | \(R_d = 50\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 5      | \(R_d = 50\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 6      | \(R_d = 25\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 7      | \(R_d = 25\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 8      | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 9      | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 10     | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 11     | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 12     | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 13     | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 14     | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 15     | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 16     | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 17     | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 18     | \(R_d = 81\%, L/d = 15.00\), smooth piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |
| 19     | \(R_d = 81\%, L/d = 15.00\), rough piles | \(x = 0^\circ, 10^\circ, 20^\circ, \text{ and } 30^\circ\) |

\(R_d\) relative density of sand, \(L\) pile embedment depth, \(d\) pile diameter, and \(x\) is the inclination angle.
decrease to 260 N and 220 N and the relative displacement value about 11% and 12% respectively. The figure also clearly demonstrates that circular pile is more resistant than the square and rectangular pile shape. The difference in pile capacities is attributed to the change in radial stress around the pile perimeter for the different pile shapes which have significant effect in the earth pressure. The round shape pile has smaller head deformation than the square and rectangular shape of pile at the same load intensity. It is clear that at any load increment the relative displacement for round pile is small, while the value is increased for square and rectangular respectively. There is no appreciable effect of the pile shape on the value of relative displacement at failure load.

**Influence of pile roughness and sand density**

The ultimate axial pullout capacity of the vertical and batter pile was obtained for rough and smooth pile that constructed in sand with different density. The relation between inclination angle, $\alpha$ and pullout capacity of rough and smooth pile, $P_{u\text{ rough}}$ and $P_{u\text{ smooth}}$ is expressed in non-dimensional form in term as ratio $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})$. Fig. 5 illustrates the variations of the $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})$ with inclination angle $(\alpha)$ for different sand densities. It is clear that as the sand density has a significant effect on the ratio of $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})$. It is clear that for loose sand ($R_d = 25\%$ and $\phi = 30.5^\circ$) the ratio is about 1.75; this value is almost constant and independent of pile inclination angle $(\alpha)$. While the ratio is reduced to value ranged between 1.33 and 1.18 for medium and dense sand ($R_d = 50\%$ & $\phi = 36^\circ$ and 81% & $\phi = 43.5^\circ$), also these values are independent of the pile inclination angle. Therefore, it is concluded that increasing the sand density causes decrease of the ratio of $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})$.

**Influence of pile slenderness ratio**

In order to investigate the effect of pile slenderness ratio $(L/d)$ in the ultimate uplift capacity of inclined pile Fig. 6 is presented. The figure gives the relation between pullout capacity of inclined pile and pile slenderness ratios and different sand densities. It is clear that ultimate pull out capacity increases with the increases of the slenderness ratio for the pile installed in loose, medium and dense sand. It is clear that the sand density has significant effect on the pullout capacity of the pile installed either vertical or inclined. It is also observed that the rate of increase in the pullout capacity increases with the increase in the sand density however; the ratio of increasing the capacity for the pile installed in medium sand is ranged between 2.2 and 2.90 compared with the pullout capacity of the pile installed in loose sand. Regarding the pile installed in dense sand the ratio of increase is ranged between 11.50 and 12.90. The rate of increase of the pullout capacity with slenderness ratio is small for loose sand and medium for medium sand. While the rate is high for dense sand, the rate of increase is considered as an average slope of the pullout capacity and slenderness ratio. This rate is found to be 3.0 for loose, 9.00 for medium sand, and 34.00 for dense sand. It is concluded that the sand density and slenderness ratio are effective values for pullout capacity of vertical and batter piles.

**Influence of pile inclination angle**

In order to study the effect of inclination angle $(\alpha)$, twelve series of tests using rough piles installed both vertical and inclined in loose, medium and dense sand with variable embedment ratios $(L/d)$ of 7.5, 15, 22.5 and 30 were carried out. Fig. 7 illustrates the variation of $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})\%$ with pile inclination angle $(\alpha)$. It is clear that the value of $(\frac{P_{u\text{ rough}}}{P_{u\text{ smooth}}})\%$ of a batter pile constructed in dense or medium density sand increases with the increase of batter angle attains maximum value and then decreases, the maximum value of occurs at batter angle approximately equal to $20^\circ$, and it is about $110–123\%$. While increasing the batter angle more than $20^\circ$ causes significant reduction for this value. Due to inclination of the pile the radial stresses around the pile’s shaft is not uniform. The pile
cross section is divided into four zones; two of them are perpendicular to the line of inclination which is almost not affected by pile inclination as indicated in Fig. 8 (zones 2 and 4). While the remaining two zones in the line of inclination are the zones that governs whether the shaft resistance increases with pile inclination in zone 1 or decreases in zone 3, this depends on the net value of the earth pressure. The behavior is attributed to the dilation that occurs when dense sand is subjected to shear stress causing an increase in the earth pressure. This observed trend for all embedment ratios, the peak value is clearly shown for shallower embedment ratio, $L/d = 7.50$. However for loose sand condition, $R_d = 25\%$ increases the inclination angle causes reduction in $(P_a/P_v)\%$ for all embedment ratios. It is clear that significant reduction is obtained for shallow embedment ratio, $L/d = 7.50$. This amply that a kind of relaxation takes place into the soil when the pile under uplift force this can explained by: That during uplift, the soil moves upwards with the pile, accordingly the earth pressure reduces from a high value to low one at failure such that the earth pressure reaches to limit les than the in situ earth pressure.

The ultimate uplift pull out capacity of single vertical and batter pile ($P_u$) in sand can be expressed in term of uplift skin friction and the weight of pile Hanna and Afram [5]. Thus;

$$P_u = P_{av} \cdot \frac{\pi \cdot D \cdot L}{2 \cdot \pi D^2} \cdot K_u + W$$

(3)

where $\gamma =$ unit weight of sand, $D =$ pile diameter, $L =$ length of pile embedded in sand, $K_u =$ uplift coefficient, $P_{av} =$ Average skin friction, and $W =$ own weight of pile.

The uplift coefficient and average skin friction is back-calculated using test results. The calculated values for average skin friction and ratio of $L/d$ are plotted in Fig. 9. From this figure it is clear that the shaft resistance increases with the increase of embedment ratio. This increase is due to the increase of the overburden pressure with the embedment depth that generates the horizontal earth pressure that acts as normal force on the pile shaft. It is observed that at certain depth which is defined as the critical depth ($L/d$ critical), the rate of increase in shaft resistance start to decrease or to sustain a constant value. The critical depth is found to be about 14, 16 and 25 for loose, medium and dense condition respectively. These ratios are almost constant and independent of the batter angle. Mansur and Kaufman [9] were reported that the critical depth value of 16 for dense sand, however, Mohab [10] reported this value as 30, 26 and 18 for dense, medium density and loose sand respectively. It is concluded that the sand density has a significant effect on the critical depth for the pile installed either vertical or inclined subject to axial pullout.

From the test results of this investigation, it is found that the sand density has significant effect on the pile capacity. So the following empirical formulas are suggested to predict the pullout capacity of inclined pile ($\alpha \leq 30^\circ$) regarding the vertical pile capacity.

Fig. 7 Variation of pullout capacity with batter angle, $\alpha$.

Fig. 8 (a) Battered pile subjected to axial tension load. (b) Stress distribution on the pile cross section.

Fig. 9 Variation of shaft with embedment ratio, ($L/d$) resistance of vertical and Batter rough pile.
For dense and medium density sand Eq. (4) is suggested

\[ P_a = P \{ \cos \alpha \times (\cos \alpha + 2/3\alpha) \} \]  

while Eq. (5) for loose sand

\[ P_a = P_f(1/C_0^{0.2}\alpha) \]  

In order to examine the validity of the suggested relations Figs. 10 and 11 are constructed to compare the measured and predicted values for pullout capacity of batter piles, \(L/d = 15\) for both smooth and rough surface pile in sand for loose, medium and dense sand condition. From these figures reasonable agreement between predicted and measured pile capacities for both rough and smooth conditions is found. So these figures confirmed that the pile capacity is increased with increasing the batter angle regarding the vertical pile capacity for the pile that constructed in dense and medium density sand; while the capacity is reduced for the pile that constructed in loose sand. Table 2 gives comparisons between measured and predicted pullout capacity of batter pile. The suggested formulas are to predict the ultimate pullout capacity of battered pile related to ultimate tension capacity of vertical pile at the same conditions which is the subject of many researches.

The suggested model was validated with the prototype test results and laboratory models of Afram [4], Meyerhof [1], Meyerhof and Ranjan [11], Tran-Vo-Nhiem [12] and al-Shakarchi et al. [8]. The comparison is shown in Figs. 12 and 13 for loose sand and medium to dense state respectively. The figures compare between the predicted values using the suggested formulas and others measured values which showed a reasonable agreement between them.

### Table 2 Comparison between predicted and measured pullout capacity of rough and smooth batter pile, \(L/d = 15.00\).

| Inclination angle, \(\alpha\) (°) | Pullout capacity of rough pile |
|-------------------------------|--------------------------------|
|                               | Loose sand | Medium dense sand | Dense sand |
| \(P_a\) Predicted/(\(P_a\) measured, (%) | 100        | 100               | 100        |
| 0                             | 100        | 100               | 100        |
| 10                            | 101.2      | 102.9             | 102.9      |
| 20                            | 100.9      | 97.7              | 99.9       |
| 30                            | 100.4      | 98.2              | 101.6      |

| Predicted/measured, (%)     | 100        | 100               | 100        |
| 0                             | 100        | 100               | 100        |
| 10                            | 99.7       | 97.4              | 102.5      |
| 20                            | 99.4       | 94.7              | 102.5      |
| 30                            | 99.1       | 94.7              | 103.3      |
The stress level around the small scale pile in sand, the following conclusions can be summarized:

Conclusions

From the present investigation for pullout capacity of the batter pile, the following conclusions can be summarized:

1. Pile embedment ratio, $L/d$, has a significant effect on the pullout capacity of batter pile, the resistances offered by pile at any axial displacement increases significantly with increase in this ratio.
2. The rough model piles experienced 18–75% increase in capacity compared with the smooth model piles.
3. The ultimate pullout capacity of a batter pile that constructed in dense and/or medium density sand increases with the increase of batter angle attains maximum value and then decreases. The maximum value of $P_u$ occurs at batter angle approximately equal to 20°, and it is about 10–23% more than the vertical pile capacity.
4. The ultimate pullout capacity of a batter pile constructed in loose sand decreases with the increasing of the batter angle of pile.

5. The circular pile is more resistant to pullout forces than the square and rectangular pile shape.
6. The suggested relations for the pullout capacity of batter pile regarding the vertical pile capacity are well predicted.

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