Pullout Behaviour of Circular Plate Anchors in Sand: A Small Scale Experimental Investigation

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ABSTRACT

Soil anchors are the most suitable foundation elements that are used to support structures subjected to uplift which may occur due to wind loading in transmission towers or wave action on offshore structures or buoyancy force on buried pipelines. This study presents a small scale experimental investigation on the pullout behaviour of 100 mm diameter circular plate anchor in dry sand of loose, medium dense and dense relative densities. The study characterizes the load-displacement behaviour, expressing the pullout capacity in terms of the dimensionless breakout factor. Embedment ratio and relative density of sand has a significant influence on the pullout capacity. Pullout capacity increased with the increase in embedment ratio, for all relative densities investigated. Critical embedment ratio for loose and medium dense sand is 10 and for dense sand, it is 12. The critical embedment ratio signifies the transition in behaviour of anchors from shallow to deep. The displacement corresponding to the ultimate load is used to find the critical embedment ratio. The displacement corresponding to ultimate pullout load is higher for loose sand irrespective of increase in embedment ratio.

Key words: Flat circular plate anchors, uplift capacity, embedment ratio, critical embedment ratio, ultimate displacement

INTRODUCTION

Several on-shore and off-shore structures like tension cables of suspension bridges, towers, guyed lattice tower, mooring systems, submerged platforms, buried pipe-lines are subjected to uplift forces. Conventional foundations are unable to take this type of loading and soil anchoring systems are required to resist the pullout forces. Anchors and anchor piles are common foundation elements that are used to resist uplift tensile forces by providing passive resistance. They hold down the structure when the uplift load is greater than the self weight of the structure, allowing the transmission of the pullout load to soil below at a greater depth and away from the structure. Three broad categories of anchors are anchor piles, gravity and plate anchors. Choice of an anchor depends on magnitude and type of load and soil conditions. Plate anchors and mushroom anchors are the most common choice when direct embedment anchors are required for structures subjected to vertical pull. This can be attributed to their efficiency and utilization of the shearing resistance of the soil in which they are embedded (Ilamparuthi and Muthukrishnaiah, 1999). Plate anchors
present an economic and efficient option to resist uplift in structures like underground reservoirs below water table, transmission line towers, suspension bridges, retaining walls and off-shore structures etc.

Different theories regarding behavior of piles under different loading conditions have been developed over the years (Balla, 1961; Meyerhof and Adams, 1968; Rowe and Davis, 1982; Sutherland et al. 1982; Chattopadhyay and Pise, 1986; Das, 1983; Deshmukh et al., 2010). Empirical relations that correlate the geometric properties of single anchor and characteristics of foundation medium (soil) are suggested to estimate the pullout capacity (Udvari et al., 1973; Mitsch and Clemence, 1985; Hoyt and Clemence, 1989). Pullout capacity of single anchor in sand is predicted from analytical models based on assumed failure mechanism where failure planes are made of set of planes (Murray and Geddes, 1987; Ghaly et al., 1991; Ilamparuthi and Muthukrishnaiah, 1999), circular (Baker and Konder 1963; Vesic, 1971) or cylindrical failure surface (Meyerhof and Adams, 1968; El-Hansy, 1980; Mitsch and Clemence, 1985). An upper bound solution consisting of a straight line and log-spiral failure plane was developed by Wang and Wu (1980). Ghaly and Hanna (1994) used theoretical models based on limit equilibrium approach with Kotter’s differential equation to determine the shear stress on the log-spiral surface to estimate the pullout capacity of single anchor in various depths: Shallow, transition and deep. Deshmukh et al. (2010) used Kotters equation to find the uplift capacity based on distribution of soil reaction on axi-symmetric failure plane. An elaborate and detailed review of the various theories used for anchor design is presented by Dickin and Leung (1990) and Ilamparuthi et al. (2002).

The reliability of the theories can be confirmed only by comparison of experimental results on model or field tests with the theoretical predictions. Full-scale field tests, though highly preferred, are expensive and difficult to perform. In case of limited resources and scope, small scale laboratory models can be used to study the performance of anchor piles in prepared foundation bed under controlled conditions. Carefully performed laboratory investigations with known parameter that affect soil pile response on application of uplift forces provide qualitative and quantitative information on ultimate resistance of anchor piles when field results are not available. A number of model tests are reported by Das and Seely (1975), Stewart (1985), Tagaya and Scott (1988), Ilamparuthi and Muthukrishnaiah (1999), Patra et al. (2004), Ilamparuthi et al. (2002) and Niroumand et al. (2011). This study reveals the pullout performance of circular plate anchor in sand of different densities under vertical pull for various embedment ratios. The study also characterizes the load-displacement behaviour, expressing the pullout capacity in terms of the dimensionless break-out factor. The displacement corresponding to the ultimate load is used to find the critical embedment ratio.

MATERIALS AND METHODS

Test under axial pullout is carried out on mild steel model piles of diameter 12 mm and circular plate anchor of 100 mm diameter for embedment ratios 8, 10, 12, 14 and 16. Model chamber of size 1000×1000 mm is used to conduct the experimental investigation. Sand in loose, medium-dense and dense relative densities is used to study the pull-out behaviour.

Properties of soil: A well graded river sand having specific gravity of 2.66 is used for the tests. The coefficient of curvature (Cv) of the soil is 1.55. The soil used as foundation medium falls under well graded sand (SW) category according to Indian Standard Soil Classification System.
Model anchor piles: Surface characteristics of the pile used as model anchor pile is uniform and is made of mild steel, with a diameter of 12 mm. The corresponding embedment length to diameter (H/D) ratio is 8, 10, 12, 14 and 16. The base plate attached to the bottom of the pile shaft is circular in shape and is made of mild steel, 10 mm thickness and 100 mm diameter. A circular hook like arrangement is provided at the top of the pile shaft to fasten the inextensible string to the load (Fig. 1).

Experimental set-up: Axial pullout loads were applied to the piles through double pulley arrangement. The non-extensible steel wire rope is attached to the pile top. The wire rope is taken first through an inverted pulley and then over the second pulley. Loading pan where dead weights are put for loading is fixed at the other end of wire as shown in Fig. 1. The position of first pulley is 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 a dial gauges. The loads are applied by dead weights in the loading pan starting with smallest and are gradually increased in stages. Dial gauge readings are observed for each increment of loading when it becomes stable.

The technique of sand placement plays an important role in the process of getting reproducible densities in a reasonable amount of time. The reliability of the results depends much on the density of foundation material and therefore the required density of sand was predetermined. Rainfall

Fig. 1: Schematic sketch of the experimental set-up
technique is used to pour sand in the chamber. The sand is poured in the chamber continuously through the silt of hopper keeping the height of fall of sand about 35 cm, achieving a relative density of 85%, 20 cm, achieving a relative density of 62% and 5 cm for a relative density of 30%. This technique was used by several authors (Chattopadhyay and Pise, 1986; Patra et al., 2004). After placing the pile in position the sand was poured uniformly around the pile by moving hopper by hand. The dial gauge fixing arrangement is attached to the pile top by tightening bolt and screw arrangement.

RESULTS AND DISCUSSION

The results of the analysis on flat circular anchors are presented in Table 1. The results include embedment ratio, ultimate pullout load, corresponding ultimate displacement and break-out factor. These parameters are used to describe the pull-out behaviour of circular flat anchors in sand of loose, medium dense and dense sand.

Load-displacement behaviour: In general, similar load-displacement trend is observed for all relative densities investigated and it is observed that pullout capacity increases with the embedment ratio (Fig. 2-4). The shape of curve shows that load increases gradually with displacement and rate of increase of displacement increases with load, irrespective of depth of embedment. For higher depth of embedment, load increases rapidly with displacement compared to shallow embedment. In general, the shape of the curve is more or less the same irrespective of the depth of embedment.

Ultimate pullout load: Ultimate pullout load is an essential parameter in design to ensure stability of anchors. Pullout capacity varies with the change in embedment depth and this is vital information in the anchor design. The load at which the load displacement curve shows maximum

<table>
<thead>
<tr>
<th>H/D ratio</th>
<th>Pu (N)</th>
<th>du (mm)</th>
<th>Nq</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loose sand (Unit weight 15.4 kN m⁻³)</strong></td>
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<td></td>
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</tr>
<tr>
<td>8</td>
<td>38</td>
<td>0.14</td>
<td>3.27</td>
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<tr>
<td>10</td>
<td>66</td>
<td>0.23</td>
<td>4.55</td>
</tr>
<tr>
<td>12</td>
<td>84</td>
<td>0.73</td>
<td>4.83</td>
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<tr>
<td>14</td>
<td>101</td>
<td>1.25</td>
<td>4.97</td>
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<tr>
<td>16</td>
<td>117</td>
<td>1.56</td>
<td>5.04</td>
</tr>
<tr>
<td><strong>Medium dense sand (unit weight 16.23 kN m⁻³)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>42</td>
<td>0.12</td>
<td>3.43</td>
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<tr>
<td>10</td>
<td>72</td>
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<tr>
<td>12</td>
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<td>14</td>
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<tr>
<td>16</td>
<td>129</td>
<td>1.42</td>
<td>5.27</td>
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<tr>
<td><strong>Dense sand (unit weight 16.88 kN m⁻³)</strong></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>43</td>
<td>0.10</td>
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<tr>
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<tr>
<td>16</td>
<td>166</td>
<td>1.40</td>
<td>6.52</td>
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</table>
Fig. 2: Load-displacement characteristics of loose sand

Fig. 3: Load-displacement characteristics of medium dense sand

curvature is the ultimate pullout load and it increases with the increase in the embedment irrespective of the relative density of sand (Table 1). The rate of increase increases with the embedment ratio till a certain embedment ratio beyond which it shows a decrease in trend (Fig. 5). For a given embedment ratio, the ultimate load is higher for dense sand (i.e.) ultimate load increase with the increase in density and it is significant at higher embedment ratio.

**Breakout factor**: Ultimate pullout is expressed as a dimensionless parameter called breakout factor (Nq) and is defined as follows:

\[ Nq = \frac{Pu}{\gamma AH} \]  \hspace{1cm} (1)

Where:
Pu = Ultimate pullout load
\gamma = Unit weight of soil
Fig. 4: Load-displacement characteristics of dense sand

Fig. 5: Effect of embedment ratio on ultimate pullout capacity

A = Plan area of flat circular anchor
H = Height of embedment

The breakout factor obtained using Eq. 1 for various embedment ratio and densities are shown in Table 1. It is noted to increase exponentially with increase in embedment ratio (Fig. 6) and its rate of increase decreases with embedment ratio irrespective of the relative density of foundation bed. The breakout factor tends to become asymptotic after an embedment ratio of 12 for dense sand and 10 for medium dense sand and loose sand. The Nq is higher for an embedment ratio at higher density. The effect of density is small at shallow embedment than at higher embedment. To determine the depth at which the anchor changes its behaviour from shallow to deep, the breakout factors are plotted as given in Fig. 6. The change in slope observed at embedment ratio of 12 indicates that it corresponds to the critical embedment ratio in case of dense sand. Similarly, critical embedment ratio is 10 for loose sand and medium dense sand.
Fig. 6: Effect of embedment on breakout factor

Fig. 7: Effect of embedment ratio on ultimate displacement

**Displacement:** The typical load-displacement behaviour of flat circular anchors are described in Fig. 2-4. The displacement corresponding to ultimate pullout is shown in Table 1. In order to compare the displacement required for development of the ultimate pullout load, displacement at ultimate pullout is plotted against embedment ratio (Fig. 7). The general shape of curve is concave upward initially followed by a decrease in slope and becomes almost asymptotic with increase in embedment ratio. The $\delta u$ for medium dense and dense sand are more or less equal for a given embedment ratio.

For shallow embedment ratio (upto 10) the ultimate displacement ($\delta u$) for loose sand is almost equal to that of medium dense and dense sand and for embedment ratio greater than 10, ultimate displacement ($\delta u$) in loose sand is higher than that of the other two densities irrespective of embedment ratio.

**CONCLUSION**

Small scale investigations carried out on flat circular anchors at different embedment ratios in dry sand beds at different densities showed concurrence with published results. The study points to the following conclusions:
Ultimate Pullout load increases with increase in embedment ratio for the investigated relative densities of the foundation bed. Critical embedment ratio is observed to be 10 for loose and medium dense conditions and 12 in dense sand.

- It also increases with increase in unit weight of sand.
- Break-out factor (Nq), a dimensionless parameter that represents the relation between ultimate load, unit weight of sand and embedment, increases an increase in embedment ratio. It also increases with increase in sand density.
- Displacement is higher for lower densities of sand and higher for higher embedment ratio. Ultimate displacement is higher in loose sand and is almost equal for loose and medium dense sand.

**NOMENCLATURE**

- \( A \) = Plan area of flat circular anchor
- \( H \) = Height of embedment
- \( Nq \) = Break-out factor
- \( Pu \) = Ultimate pullout load
- \( \delta u \) = Ultimate displacement
- \( \gamma \) = Unit weight of soil

**REFERENCES**


