Horizontal Pullout Capacity of a Group of Two Vertical Square Anchors Embedded in Dense Sand

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Abstract:
In the present study an attempt is made to evaluate the horizontal pullout capacity of a group of square anchors embedded in dense sand experimentally. The size of the model box used in the present study is 1.2 m length x 0.75 m width and 1.5 m height. A series of experiments were conducted on single and group of anchors subjected to horizontal pullout load on MS square plates of size 10 cm and 15 cm were used. In the present study the ratio of H/B is equal to 5 and 6; where H = depth of embedment from top of tank to bottom of lower anchor, B=width of anchor. The parameter S/B is equal to 0, 1, 2; where S = clear spacing between the anchor. It is also found that as H/B ratio increases the pull out capacity increases and also for each H/B ratio as the S/B ratio increases pull out capacity decreases due to decrease in passive resistance. In the present study the group efficiency factor is greater than 1 and further as S/B increases the group efficiency factor decreases for same H/B ratio. Also as H/B increases the efficiency factor also increases. All the tests were carried out on dry clean sand with a relative density of 80% and raining technique was adopted to prepare the sample in the model box to achieve the desired density. It is also found that anchor break out factor (N_s), increases with H/B ratio and increases with decrease in clear spacing between the anchors.

Keywords: Breakout factor, Embedment ratio, Group anchors, Horizontal pullout capacity, Relative density.

I. INTRODUCTION

Many modern engineering structures require a foundation system that provides adequate support by resisting loads that are imposed on the foundation of the structure or vertical and horizontal pullout forces. Stability and support of structures is provided by transferring foundational loads from the structures foundation through some form of anchors and then onto the surrounding soil and terrain. In many cases these loads and forces that are transmitted through anchors to surrounding terrain can cause the anchor to experience subsequence uplift forces. As a result, ground anchors have been developed so as to be fixed to structures and are embedded to sufficient ground depths to provide adequate amounts of support within required safety limits. It is therefore the primary focus of this project and subsequent dissertation to investigate the Pullout capacity of various ground anchors in sand. Ground anchors are generally designed and constructed to resist the forces that are applied to foundations of structures. The primary function of these anchors is to transmit the forces acting on the foundations of a structure to the surrounding soil or terrain. Generally anchors can be classified into five different forms of ground anchor that are currently in use in industry and they are as follows: plate anchors, direct embedment anchors, helical anchors, grouted anchors, and anchor piles. This project primarily focuses on the plate anchor. Plate anchors can be constructed using a many number of materials and can be constructed in numerous shapes. For example plate anchors may be made of steel plates, precast concrete slabs, poured reinforced concrete slabs or timber sheets just to name a few of the most common construction materials. Plate anchors may also be put into location in a number of ways, the two most common methods utilized are backfilled plate anchors or excavated trench plate anchors. Backfilled plate anchors are put into position by excavating the ground to the required depth, placing the anchor in position then backfilling and compacting with good quality soil. The other popular method of deposition is to install the plate anchor in excavated trench, then attach the anchor to tie rods that are either driven or placed through auger holes. (Das1990). The methodology used throughout experimentation in regards to this project will replicate the deposition method of backfilled plate anchors.

![Image of Types of Plate Anchors](Figure.1.Types of Plate Anchors)

II. LITERATURE REVIEW

Das et.al., (1976) Performed a model test on vertical square anchor plate in loose, medium and dense send and they expressed ultimate anchor resistance in terms of non dimensional breakout factor. They have found that for shallow anchors, breakout factor increases with embedment ratio, beyond a critical embedment ratio, when the anchors behaves as a deep anchors the breakout factor remains approximately constant. Hanna et.al., (2007) Performed on analytical models to predict the pullout capacity and load displacement...
relationship for shallow single vertical helical and plate anchors in sand. The models were developed based on the failure mechanism deduced from laboratory testing and utilize the limit equilibrium technique in order to find out the critical depth an Expression was given for a given anchor/soil conditions, which separates deep from shallow anchors and comparison also made for the proposed theory and also for the experimental data. From the results it was found that as the pullout capacity increases with an increase of the angle $\phi$ and the ratio (H/B) in a hyperbolic form. Sloan et.al., (2008) presented the numerical results obtained for the ultimate pull-out capacity of horizontal and vertical strip anchors in sand using the upper and lower bound methods of limit analysis. Results are presented in the familiar form of break-out factors based on various soil strength profiles and geometries. Kumar et.al., (2011). Conducted test on the horizontal pullout capacity of a group of two vertical strip anchor plates placed along the same vertical plane in sand has been determined by using the lower bound finite element limit analysis. The effect of vertical spacing (S) between the anchor plates on the magnitude of the total group horizontal failure load (PuT) has been determined for different combinations of H/B, $\phi/\phi$ and $\phi$. The magnitude of PuT has been obtained in terms of a group efficiency factor, $\eta_g$, with respect to the failure load for a single vertical plate with the same H/B.

**Group Efficiency Factor:**

$$\eta_g = \frac{PuT}{Pu}$$

Where Pu and PuT refer to the failure loads for a single and a group of two anchors, respectively, by keeping the value of H/B to be exactly the same in both the cases. It is found from the literature that most of the work pertaining to horizontal pullout capacity of group of anchors is carried out numerically and not much work was done on experimental evaluation of pullout capacity of group of anchors. Hence in the present study an attempt is made to conduct series of experiments to find out the horizontal pullout capacity of group of square anchors embedded in dense cohesion-less soils.

### III. MATERIALS AND METHODS

In the present study the dry clean sand was used. From the sieve analysis, following grain size parameters were measured:

- (i) $D_{10}$ = 0.24 mm,
- (ii) $D_{30}$ = 0.42 mm,
- (iii) $D_{60}$ = 0.7 mm,
- (iv) uniformity coefficient, $C_u$ = 3.04,
- (v) coefficient of curvature, $C_c$ = 1.096 where $D_{10}$, $D_{30}$ and $D_{60}$ are the sizes corresponding to which 10, 30 and 60% material by mass are respectively smaller than that size. In addition, this sand was measured to have:
  - (i) maximum unit weight ($\gamma_{max}$) = 17.75 kN/m$^3$,
  - (ii) minimum unit weight ($\gamma_{min}$) = 14.67 kN/m$^3$,
  - (iii) specific gravity of soil solids (G) = 2.61. From the GSD it was found that chosen sand was classified as poorly graded.

The experiments were performed on unit weight ($\gamma$) = 16.8 kN/m$^3$, these correspond to relative densities of 80% was achieved by means of rainfall technique. Using direct shear test, corresponding to an vertical stress of 150 kPa, the angle of internal friction ($\phi$=38)$^\circ$ was achieved.

#### A. CALIBRATION OF HEIGHT OF FALL.

Before carrying out experiment the height of fall for a particular density has to be determined by trial and error procedure, for that bowl of known volume has taken and placed at the bottom of the tank, and the sand was dropped from the raining box by fixing the particular height to achieve a reproducible density. From the graph it is found that for fixing a height of fall 400mm it is getting a density of 75-80% for dense case.

**Figure.2. Calibration of height of fall**

**Figure.3. Rainfall technique for dense case by raining box**
IV. EXPERIMENTAL SETUP AND PROCEDURE

Solid Mild steel anchor plate of size (100*100) mm and (150*150) mm size are used in the present experimental study. The anchors are kept in vertical position with varying spacing(S) of 0, 1 and 2 times the width (B) of Anchor. Sand is poured into the tank by using rainfall technique, Pullout load is applied to the anchor through Lever hatchet with flexible wire attached to connecting rod, and displacements are monitored for applied load increment with the help of L.V.D.T.

The term Density Index $I_d$ or Relative Density or Degree of Density is used to express the Relative compactness (or Degree of Compaction) of a natural cohesionless soil deposit. The Relative Density is defined as the Ratio of the Difference B/W the Voids Ratio of the soil in its loosest state $e_{\text{max}}$ and its Natural Voids Ratio (e) to the Difference B/W the Voids Ratios in the Loosest and Densest state

$$I_d = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}}$$

Where $e_{\text{max}}$ = Voids Ratio in its Loosest state
$e_{\text{min}}$ = Voids Ratio in its Densest state
$I_d$ = Relative Density
$e$ = Natural Voids Ratio

The experimental procedure is as follows:

- The proposed experiment aim is to determine the ultimate horizontal pullout capacity of both single and group of vertically placed square anchor plates. It consists of mild steel model tank of size (1.2*1.5*0.75) m, in which a group of square anchor plate of sizes (100*100*10) mm and (150*150*10) mm are embedded. The experiment is carried out for different spacing (i.e. 0B, 1B, 2B, here B is the width of anchor plates) and also with different H/B ratios (H is the distance from the bottom surface of the anchor to top of the tank).
- The tank is filled with Sand (which is Sun Dried or Oven Dried,) using Rainfall Technique which is achieved by pouring the sand through a Raining box, also through a pipe with funnel, this height is maintained uniformly for subsequent increment in the height of fall to achieve required density and this density is predetermined.
- After filling the sand to required height from the bottom of the tank anchor plates are placed vertically, and sand is poured up to the top of the tank uniformly.
- This anchor placing is varied for varying (H/B) and also clear spacing (S/B) between the anchor plates.
- Horizontal pullout force is applied to the anchor through Flexible wire in which one end of the wire with a hook, it is connected to the centre of the tie rod (where two anchor plates are connected) and the other end is connected to the strain controlled proving ring and this proving ring is connected to a manually operated loading jack called lever hoist. The lever hoist is supported by extension at the top of mild steel tank itself.
- The device called LVDT (Linear variable displacement transducer) is rigidly adjusted to the MS plate which is fixed to the wire rope so as to measure the displacement, and is positioned between the pulley and the face of the MS plate.
- LVDT is connected to a digital meter, from this displacement of the anchor plate is recorded in “mm”.
- The loading is stopped when large deformations are observed for small incremental loading (i.e. once it reaches a maximum load then it starts reducing).
- At the initiation of peak load failure surface is observed at the top sand surface of the tank.
- The above procedure is carried out for the entire test i.e. for varying H/B ratios, varying spacing’s, and also a different plate sizes.
- Finally horizontal pullout load v/s displacement graphs are plotted, peak load obtained from the graph represents the ultimate pullout capacity/break factor of that
particular anchor plate corresponding to their embedment depth, density of the Sand, and spacing between the anchor.

V. RESULTS AND DISCUSSIONS

A. HORIZONTAL PULLOUT LOAD VERSUS DISPLACEMENT

The variation of the horizontal ultimate pullout load \( P_u \) with change in the corresponding horizontal displacement was shown in Fig.7.1 to Fig.7.8 for group of square anchors and single anchors by varying the values of \( S/B \), between 0, 1, 2 (here B is the width of the anchor plate) and for two different values of \( H/B=5 \), and \( H/B=6 \). It is observed that as the ratio \( (S/B) \) decreases the ultimate pullout value increases due to increase in the passive resistance. Also it is observed that as the value of \( H/B \) increases the ultimate pull out capacity increases.

Figure.7.1. Variation of horizontal pullout load v/s displacement curve for \( h/b=6 \), \( b=10\text{cm} \).

Figure.7.2. Variation of horizontal pullout load v/s displacement curve for \( h/b=5 \), \( b=10\text{cm} \).

Figure.7.3. Variation of horizontal pullout load v/s displacement curve for \( h/b=6 \), \( b=15\text{cm} \).

Figure.7.4. Variation of horizontal pullout load v/s displacement curve for \( h/b=5 \), \( b=15\text{cm} \).

Figure.7.5. The variation of horizontal pullout load v/s displacement curve for \( h/b=5 \), \( b=15\text{cm} \).

Figure.7.6. The variation of horizontal pullout load v/s displacement curve for \( h/b=6 \), \( b=10\text{cm} \).
It is found from the present study that anchor break out factor decreases with increase in size of anchor.

Table 2. The values are tabulated in table for different S/B ratios and H/B ratios

<table>
<thead>
<tr>
<th>PLATE SIZE</th>
<th>SPACING (S/B)</th>
<th>H/B=5</th>
<th>H/B=6</th>
</tr>
</thead>
<tbody>
<tr>
<td>B=10 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.74</td>
<td>21.28</td>
<td>1.18</td>
</tr>
<tr>
<td>1</td>
<td>0.45</td>
<td>15.52</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>0.45</td>
<td>12.96</td>
<td>0.55</td>
</tr>
<tr>
<td>B=15 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.48</td>
<td>14.74</td>
<td>0.43</td>
</tr>
<tr>
<td>1</td>
<td>0.55</td>
<td>12.02</td>
<td>0.414</td>
</tr>
<tr>
<td>2</td>
<td>0.35</td>
<td>8.73</td>
<td>0.43</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

- It was observed from the experimental data that as the ratio of S/B increases for a given H/B, the pull out capacity decreases for a group of anchors due to decrease in passive resistance.
- It was observed from the experimental data that as the ratio of H/B increases for a given S/B, the ultimate pull out capacity increases for a single and group of square anchor this is due to increase in depth of embedment, the passive resistance increases.
- The collapse of the anchors occurs on account of the development of a thin curved plastic shear zone emerging from the bottom of the anchor and then terminating at the ground surface.
- The passive earth pressure acting on anchor plates decreases due to the increase of clear spacing between the anchors; hence there is decrease in the horizontal pull out capacity of group of anchors.
- The group anchor efficiency factor increases with an increase in the clear spacing between the anchors. The values of Group efficiency Factors are also shown in Table 1 for different S/B and H/B ratio.
- As the size of anchor increases, the Anchor Group Efficiency Factor increases.
- It is found from the present study the anchor break out factor decreases with increase in depth of embedment and also increases with decrease in clear spacing between the anchors.

VII. REFERENCES


