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Uplift Capacity of Shallow Inclined Anchors

La Capacité Soulevée des Ancres Inclinaées, Enterrées peu Profond

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SYNOPSIS Laboratory model test results for the ultimate uplift capacity of shallow horizontal and inclined anchor plates in loose sand have been presented. The ultimate uplifting load increases with the increase of anchor inclination with respect to the horizontal. The rate of increase decreases with the increase of average embedment ratio. For deep anchors with moderate inclination with the horizontal, the ultimate capacity remains approximately the same.

INTRODUCTION

Horizontal and inclined anchors are sometimes used for stability consideration of foundations of structures, such as transmission towers and aircraft moorings, which are subjected to uplifting forces. When these anchors, which are subjected to axial pull, are located at relatively shallow depths, general shear failure of soil occurs at ultimate load, and the failure surface extends to the ground surface. These anchors are referred to as shallow anchors. Beyond a certain critical embedment ratio, D/B , (D = average depth of embedment and B = width of the anchor plate, Fig. 1) local shear failure of soil occurs at ultimate uplifting load, and they are called as deep anchors.

More recently, a number of laboratory model and field test results for the ultimate uplift capacity of horizontal anchors ($\beta = 0^\circ$, Fig. 1) have been reported by Balla (1961), Mariupol'skii (1965), Baker and Kondner (1966), Meyerhof and Adams (1968) and Vesic (1971). However, a review of literature shows that very little attention has been paid to the study of the ultimate capacity of inclined anchors ($\beta > 0^\circ$). Kananyan (1966) reported a limited number of field test results on the axial pullout resistance of shallow inclined circular anchor plate in fine sand with the angle of inclination of the anchor with respect to the horizontal varying from zero to 45° at a constant average embedment ratio of 1.25. The ultimate load increased with anchor inclination and was about 45% more at $\beta = 45^\circ$ as compared to that for horizontal anchors. Meyerhof (1973) observed a similar trend for ultimate uplift capacity in dense sand and clay. On the other hand, laboratory model tests in dense sand reported by Harvey and Burley (1973) showed that, for similar embedment ratios, ultimate capacities of horizontal and inclined anchors ($\beta = 0^\circ$ to 45°) are approximately the same.

With present knowledge regarding the uplift capacity of inclined anchors, it appears that more experimental and theoretical works are needed for a better understanding of the nature of variation of ultimate axial load of anchor with its inclination. This paper relates to a recent laboratory model test program to study the ultimate pullout load of shallow inclined anchors in loose sand.

LABORATORY EXPERIMENTAL PROGRAM

Laboratory tests were conducted on two model anchors made of aluminum plates 3.18 mm thick. The dimensions of the plates were 38.1 mm x 38.1 mm and 38.1 mm x 228.6 mm thus giving a length (L) to width (B) ratio

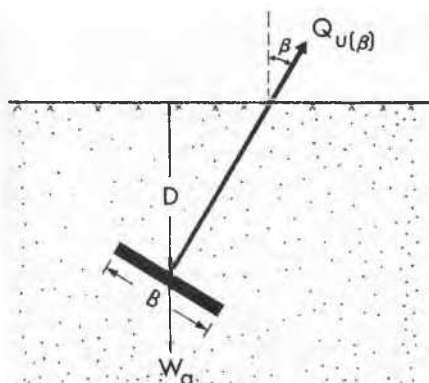


Fig. 1 Geometric parameters for an inclined anchor plate

of one and six, respectively.

Tests were made in a sand box measuring 0.76 m x 0.61 m x 0.61 m. A dry silica sand was used for the tests. The grain size distribution of the sand is given in Fig. 2.

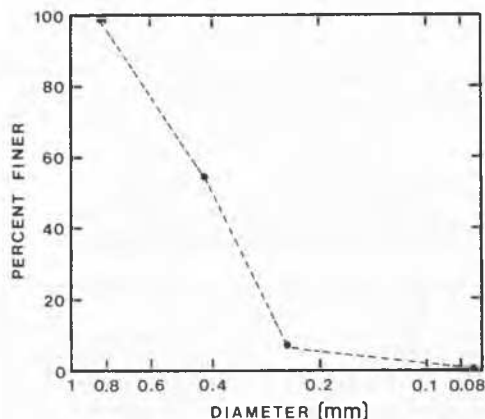


Fig. 2 Grain size distribution of the soil used for model tests

After careful placement of the anchor in the box, a predetermined amount of sand was poured into the box in 25.4 mm to 50.8 mm layers and loosely compacted to an average dry density of 1,510 kg/m³. For each test, sand was recompactd for the entire depth of embedment. The angle of friction (ϕ) at the average density of compaction was 31° (relative density = 21%).

Pullout tests for horizontal anchors ($\beta = 0$) were conducted by attaching a rigid rod 6.4 mm in diameter at the geometric center of the plates. The rod was connected to a lever arm which rested on a steel frame. The frame was placed on the test box and fixed to its sides. Pullout load was applied to the other end of the lever arm.

In the case of inclined anchors, tests were made for inclinations of $\beta = 30^\circ$, 40° and 50° . Fig. 3 shows a schematic diagram of the test arrangement. The anchor plates were centrally connected to a 6.4 mm diameter rigid rod which was then attached to a 3.2 mm diameter cable. The cable passed over two pulleys and was attached to the lever arm. The frame containing the two pulleys could be moved vertically and fixed at a desired position.

Pullout tests for each average depth of embedment and inclination were repeated two or three times. The average values of the tests are reported here.

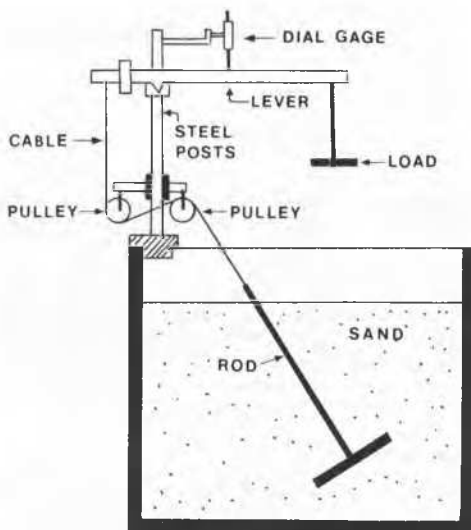


Fig. 3 Schematic diagram of laboratory setup for inclined anchor pullout

EXPERIMENTAL RESULTS

The gross ultimate axial pullout capacity of the anchor plates can be given by

$$Q_u(\beta) = Q_o(\beta) + W_a \cos \beta \quad (1)$$

in which $Q_o(\beta)$ = net ultimate axial pullout load and W_a = self weight of the anchor.

The net ultimate pullout loads can be represented as a nondimensional breakout factor (Vesic, 1971) in the form

$$N_q(\beta) = \frac{Q_o(\beta)}{\gamma A D} \quad (2)$$

in which $N_q(\beta)$ = breakout factor for anchor inclination of β , γ = effective unit weight of sand, and A = area of the plate.

The breakout factors for the square and strip ($L/B = 6$) model plates calculated from the experimental net ultimate loads are presented in Figs. 4 and 5, respectively.

For horizontal anchors ($\beta = 0$), the breakout factor increased with embedment ratio up to a certain limit. Beyond a critical embedment ratio, the value of the breakout factor remained approximately constant, indicating deep anchor behavior. The critical embedment ratios for square and strip anchors were about 4 to 4.5 and 6 to 6.5, respectively, thus showing an increase with length-to-width ratio of the plate.

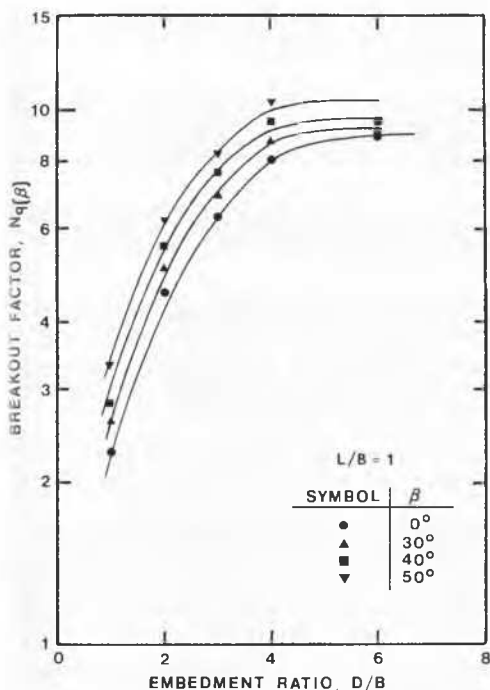


Fig. 4 Plot of breakout factor versus embedment ratio for square anchor

For inclined anchors, tests were limited to average embedment ratios varying from one to six. From Figs. 4 and 5, it can be seen that breakout factors for similar average embedment ratios increased with the anchor inclination for both the plates under consideration. The critical embedment ratio for the square plate falls clearly within the range of the test and is approximately the same as in the case of $\beta = 0$. In the case of the strip anchor, though the test has not been extended beyond $D/B = 6$, the critical embedment ratio appears to be approximately six.

For a quantitative evaluation of the increase of breakout factor with the anchor inclination with respect to the horizontal, the ratio of $N_q(\beta)/N_q(\beta = 0)$ for average embedment ratios of 1, 3 and 6 are shown in Fig. 6. This ratio may be defined as the inclination factor, α . From Fig. 6, it appears that the inclination factor for a given plate size and average embedment ratio increases with anchor inclination. At very shallow depths, the square plate gives somewhat higher inclination factors for similar

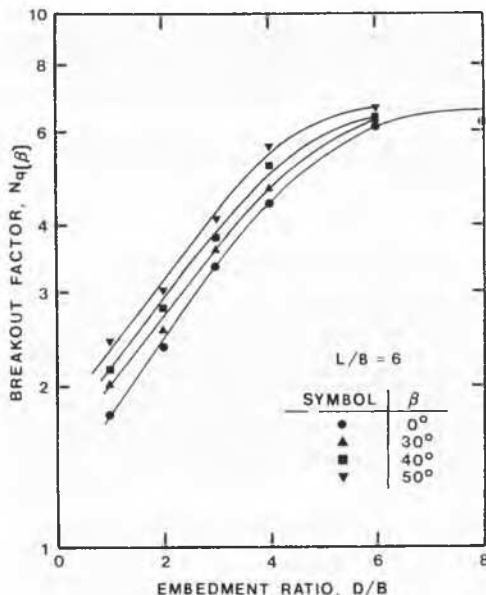


Fig. 5 Plot of breakout factor versus embedment ratio for strip anchor

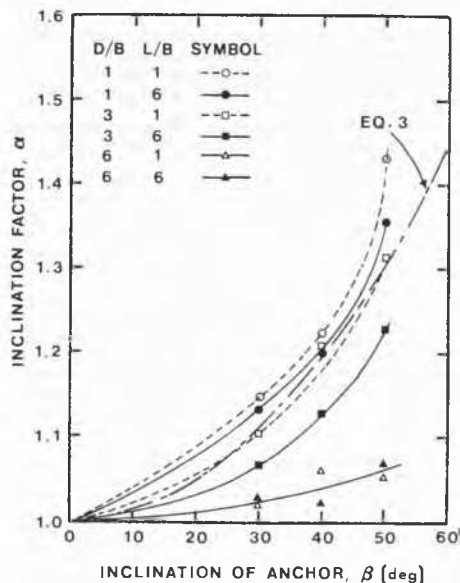


Fig. 6 Variation of inclination factor with anchor inclination

average embedment ratios and anchor inclinations. However, for square and strip anchor plates, the inclination factor decreases with embedment ratio (for a given value of β) and, at $D/B = 6$, it is practically the same for both plates.

Meyerhof (1973) gave an approximate empirical relation for the inclination factor in the form

$$\alpha = 1 + \left(\frac{\beta}{90}\right)^2 \quad (3)$$

in which β is expressed in degrees.

In order to compare with the present experimental results, the inclination factors calculated by using Eq. 3 have also been plotted in Fig. 6. Keeping in mind that the critical D/B for the square plate is about 4 to 4.5, it may be concluded that Eq. 3 gives a good average approximation for these tests for shallow anchor conditions ($D/B = 1$ to 4). However, for strip anchors, Eq. 3 somewhat gives an approximate upper limit.

CONCLUSIONS

Based on the present test results in loose granular soil, the following general conclusions may be drawn:

- For similar average embedment ratios, the axial pullout resistance of shallow anchors generally increases with increase of anchor inclination with respect to the horizontal.
- For a given average embedment ratio and anchor inclination, the inclination factor appears to decrease for strip anchors as compared to square anchors.
- The inclination factor for a given anchor plate decreased with increase of the embedment ratio.
- In the case of deep anchors, for anchor inclinations varying from zero to about 50° , the ultimate uplift capacity appears to be approximately the same.

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