SOME STUDIES ON ANCHOR PLATES IN SAND

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ABSTRACT

A number of laboratory tests on pullout resistances of square and rectangular model anchors made of aluminium plates in loose sand have been taken up for this investigation. The main purpose of this paper is to present some recent model test results for square and rectangular plates in sand at constant compactive effort and outlines the pullout resistance of anchor plates with a vertical axis of different sizes and a load displacement relationship of the model tests. Moreover, the ultimate anchor resistance has been expressed in terms of nondimensional force coefficient and breakout factor. For rectangular and square anchors, the breakout factor increases with relative depth of embedment ratio to a certain extent and then tends to approximately constant at greater depths. The critical embedment ratio for rectangular anchors is about five while there is no meaningful results in case of square anchors. An attempt has also been focussed to understand the basic behavior of embedded anchors. The depth of embedment, size of anchors and the relative density of the sand are also important factors in this investigation.

Key words : anchorage, model test, sand (IGC : C 8/D 6)

INTRODUCTION

The bulk of anchor plate research works to date have been performed mainly with the resistance of earth anchors to vertical and horizontal pullout forces by several authors (Andreadis et al, 1981 ; Andreadis et al, 1978 ; Barley, 1982 ; Das, 1975 ; Das and Seeley, 1976 ; Huechel, 1957 ; Hanna et al, 1972 ; Harvey and Burley, 1973 ; Harvey et al, 1974 ; Meyerhof, 1951 ; Rowe and Davis, 1982 ; Vesic, 1971), but it still remains a complex domain. Anchors are, generally, used to resist force in any direction. The anchor plates with a vertical axis are used for the construction of

sheet pile bulkheads and other lateral load bearing structures to tolerate the displacement due to load imposed on it. The theoretical ultimate resistance of anchors have been reported by Neely et al (1973) using both limit analysis and the method of stress characteristics. Kananyan (1966) and Meyerhof (1973 a) have documented the uplift resistance of inclined anchors. Meyerhof (1973 b) also developed a semiempirical relation for the breakout resistance of horizontal anchors. Consequently, the full-scale tests on ground anchors in fine sand have been presented by Davis and Plumelle (1982).

However, laboratory model test results for

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the pullout resistance of square and rectangular anchors are not many. Therefore, six model anchor plates of different sizes have been selected for the experimental work of this investigation. The main purpose, herein, is to present some recent laboratory model test results on the pullout resistance of shallow vertical rectangular and square model anchor plates in loose granular soil and to study the effect of force coefficient, breakout factor, embedment ratio and the width-to-height ratios of the anchor plates. Besides, this paper addresses the pullout resistances of vertical anchors of different sizes and a load displacement analysis of the model tests.

LABORATORY MODEL TESTS

A number of laboratory experiments have been performed on soil anchor plates in dry sand for the present work. The experiments were carried out in a rectangular box of transparent material measuring $40\text{ cm} \times 30\text{ cm} \times 40\text{ cm}$ deep that contained a well graded sand. The grain size distribution curve of sand is given in Fig.1. For each model test the sand was compacted in 2.54 cm thick layer to an average density of 1.44 g/cm^3 . The physical properties of sand are shown in Table.1.

An aluminium plate of 0.5 cm thickness was used for this experimental work. The required size of anchor plates were then cut out from the aluminium plate. The different dimensions of anchor plates used in this investigation are presented in Table 2.

Fig.1. Grain size distribution of sand

Table 1. Physical properties of sand

Specific Gravity of Sand	2.702
Relative Density	48.9%
Maximum Dry Density	1.60 g/cm ³
Minium Dry Density	1.31 g/cm ³
Angle of Friction	29°30'
Uniformity Coefficient	1.52

Table 2 Type and size of anchors

Type of Anchor	Height of Anchor (h) (cm)	Width of Anchor (B) (cm)	Width/Height Ratio (B/h)
Square	2.54	2.54	1
	5.08	5.08	1
	7.62	7.62	1
Rectangular	2.54	5.08	2
	2.54	10.16	4
	2.54	15.24	6

At the starting of each test a 7.62 cm thick layer of sand was compacted into the bottom of the box. The anchor plate was then placed in proper position on the top of this layer with the help of a tie rod. The sand was then rained in layers into the box from a required height in order that the compaction remained constant and the plate was buried at the required depth. The geometry of the anchor and schematic diagram of the box for pullout tests are placed in Figs. 2 and 3 respectively.

The anchor plates were pulled by a tie rod of 0.2 cm in diameter attached at the center of the aluminium plate. The tie rod was then passed over a smooth pulley attached to the outside of the box. The tie rod was connected to the load cell. A load cell and a pullout device were used for the measurement of the pullout forces of anchor plates. The detailed diagram of load cell is given in Fig. 4. The calibration constants of the load cell

Fig.2. Geometry of anchor

Fig.3. Schematic diagram of pullout box

Fig.4. Diagram of load cell

were tested and the relation between the strain of the test piece and force were calculated. The speed of pullout was 7.5 mm/min. The movement of the anchor plate due to pullout force was measured by automatic strain-time recorder. The test for ultimate resistance were conducted at various embedment ratios with the average density as mentioned above. Each test was repeated three times to check the experimental procedure and the density control of sand placing. The variation of the ultimate pullout loads was within 2.4 to 5.6 percent. The average values

Fig.5. Load displacement curves ($1\text{ kgf} = 9.8\text{ N}$)

Fig.9. Load displacement curves (1 kgf=9.8 N)

of the ultimate horizontal pullout loads of three tests are taken into consideration. The ultimate failure load was determined from the average strain-time diagrams where the anchor plate suddenly failed or showed excessive displacement due to applied force. Typical average load displacement curves at various embedment ratios are shown in Figs.5 to 9.

TEST RESULTS AND DISCUSSION

The results of the ultimate pullout tests on anchor plates from the model tests for rectangular anchor can be defined as a nondimensional form: $M_{rq} = P/\gamma Bh^2$. In case of square anchor, $M_{rq} = P/\gamma h^3$, in which M_{rq} is the force coefficient of anchor plate, P is the ultimate pullout resistance, γ is the dry unit weight of sand, B is the width of the anchor plate, and h is the height of the anchor plate. The force coefficient versus embedment ratio of square and rectangular anchor plates are given in Fig.10. Fig.11 represents the pullout force-embedment ratio of square and rectangular anchor plates. From the analysis of Neely et al (1973) and Meyerhof (1951) force coefficient can be written as $M_{rq} = C(H/h)^n$. In which, C is a constant for the sand with a given angle of friction, and H is the depth of embedment of anchor. The inspection of our results show the average n value is 2.1 for different width/height ratio. But Das and Seeley (1976) have hypothesized that the value

Fig.10. Force coefficient versus embedment ratio of square and rectangular anchors

of n varies from 1.8 to 1.68 depending on the different width/height ratio. The anchor capacity described by Rowe and Davis (1982) seems to be reasonable with the results of the Authors' model tests.

The ultimate pullout resistance of the rectangular anchor based on the force coefficient can be said as $P_u = C\gamma(H/h)^{2.1}Bh^2$. In case of square anchor, $P_u = C\gamma(H/h)^{2.1}h^3$.

The ultimate load of an anchor can also be expressed in the form of a nondimensional

Fig.11. Pullout force embedment ratio of square and rectangular anchors (1 kgf=9.8 N)

Fig.12. Breakout factor and embedment ratio of square and rectangular anchors

breakout factor as $N_q = P_u / \gamma A H$, where, N_q is the breakout factor; γ is the dry unit weight of soil and A is the area of anchor plate. The breakout factor and embedment ratio of square and rectangular plates are given in Fig.12. It has been observed from the experimental results that the breakout factors increase with the embedment ratio for all types of anchors. The interesting point is that there appears to be a similarity in critical embedment ratio in the case of rectangular anchor plates. On the other hand, the square anchor plates have not shown any considerable critical embedment ratio. More researches

are needed with various types of anchors and degree of compaction. The critical embedment ratio for a rectangular anchor plate is approximately five.

SUMMARY AND CONCLUSIONS

(1) In this paper, an attempt has been made to determine some factors which may affect the behavior of anchor plates. It can be concluded that the load displacement behavior of anchor plates are significantly dependent on the geometry of the anchor plates and the type of experiments.

(2) The reduction of force coefficient with increased anchor sizes depend on the grading and density of the sand. The pullout resistance of an anchor plate with a vertical axis can improve the analytical solution in order that the design can be undertaken for the field applications.

(3) Model studies are essential to determine the various important parameters which will not be possible in the construction site.

(4) The breakout factors increase with depth upto a certain depth and then tends to an approximately constant value. There is no specification for the critical embedment ratio in the case of square anchor plates while rectangular anchor plates indicate a considerable critical embedment ratio.

(5) Improvement in load displacement is not proportional with an increase in the size of the rectangular anchor as observed by the experimental investigation.

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NOTATION

A =area of anchor plate
 B =width of the anchor plate
 C =constant for a given angle of friction
 H =the vertical distance between the sand surface and the bottom edge of the plate
 h =height of anchor plate
 M_{rq} =force coefficient of anchor plate
 N_q =breakout factor
 P =ultimate pullout resistance
 S_a =size of anchor plate

γ =unit weight of sand

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