TECHNICAL NOTE

ULTIMATE PULLOUT CAPACITY OF SHALLOW VERTICAL ANCHORS IN CLAY

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ABSTRACT

Model test results for the ultimate pullout capacity of shallow rectangular vertical anchor plates embedded in saturated clay have been presented. The width-to-height ratio of the anchor plates used in the tests has been varied from one to five. The ultimate pullout load of an anchor can be expressed in the form of a nondimensional breakout factor. Based on the experimental results, an empirical equation for determination of the ultimate pullout load has been presented.

Key words : cohesion, cohesive soil, model test, pullout capacity, vertical anchor (IGC : E 3)

INTRODUCTION

Shallow vertical anchor plates are generally used in the design and construction of earth retaining structures, sheet pile bulkheads, and pipeline bends. In the past ten to fifteen years, a number of experimental and theoretical works as related to the ultimate pullout capacity of shallow vertical anchors in sand have been published. Some of those results can be found in the works of Ovesen and Stromann (1972) ; Neeley, Stewart, and Graham (1973) ; Das and Seeley (1975) ; Das, Seeley, and Das (1977) ; and Das (1975). A review of most of the works regarding the ultimate pullout resistance of anchors

in sand has been given by Das (1983). However, a closely related problem which concerns the ultimate pullout resistance of shallow vertical anchor plates in clay has received very little attention recently. The purpose of this paper is to present some recent small-scale laboratory model test results for the pullout capacity of vertical anchors in saturated clay.

REVIEW OF PAST WORK

The general parameters for the evaluation of the ultimate pullout capacity of vertical anchors embedded in saturated clay are shown

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Fig. 1. General parameters for a vertical anchor embedded in clay

Fig. 2. Plot of $\frac{P_u}{B h c_u}$ vs. embedment ratio for continuous anchor (after Mackenzie, 1955; and Tschebotarioff, 1973)

in Fig.1. The ultimate pullout capacity, P_u , of an anchor can be expressed as

$$P_u = f(H, h, B, c_u, \text{ and } \gamma) \quad (1)$$

where H =depth of embedment measured from the surface of the soil to the bottom of the anchor plate, h =height of anchor plate, B =width of the anchor plate (at right angles to the cross-section shown in Fig.1), c_u =undrained cohesion of the clay, and γ =unit weight of soil.

Mackenzie (1955) conducted a number of model tests in two saturated clayey soils to determine the ultimate pullout capacity of continuous anchor plates at various embedment ratios (H/h). The average plot as obtained from these model tests has been given by Tschebotarioff (1973) and is shown in Fig.2 in a nondimensional form [i.e., $P_u/(B h c_u)$ vs. H/h]. Tschebotarioff (1973) has also suggested that, in the results obtained from small scale model tests such as those shown in Fig.2, the effect of the unit

weight of soil, γ , is rather negligible. For that reason, the ultimate pullout capacity of anchors obtained by using Fig.2 may be slightly on the conservative side.

Another fact that also needs to be pointed out from Fig.2 is that the breakout factor $N_c^* = P_u/(B h c_u)$ of anchors increases with embedment ratio, H/h , to a limiting maximum value. However, beyond a critical embedment ratio $H/h = (H/h)_{cr}$, the value of N_c^* remains constant. In Fig.2, $(H/h)_{cr} \approx 12$; and, for $H/h \geq (H/h)_{cr}$, $N_c^* \approx 8.5$. Anchors with embedment ratios $H/h \leq (H/h)_{cr}$ may be defined as shallow anchors; and those with $H/h > (H/h)_{cr}$ are referred to as deep anchors. In practice, most of the anchors used are shallow anchors.

A review of existing literature shows that no attempt has yet been made to evaluate the ultimate pullout capacity of square and rectangular anchors embedded in saturated clay. The purpose of the present paper is to present some recent model test results on the ultimate pullout capacity of shallow anchor plates ($H/h=1$ to 5) with limited width-to-height ratios varying from one to 5.

EXPERIMENTAL PROCEDURE

Laboratory model tests were conducted in a box having inside dimensions of 0.915 m $\times$ 0.915 m $\times$ 0.915 m. Four model anchor plates having dimensions of 50.8 mm $\times$ 50.8 mm, 50.8 mm $\times$ 101.6 mm, 50.8 mm $\times$ 152.4 mm, and 50.8 mm $\times$ 254 mm were used in the test program. This gave width-to-height ratios (B/h) of 1, 2, 3, and 5. The model anchors were made out of aluminum plates having a thickness of 9.5 mm.

The general properties of the clay soil used for the tests are given in Table 1. In order to conduct the model tests, well pulverized soil was thoroughly mixed with water and was stored in several plastic bags for a week in a humid curing room. At the end of the curing period, the moist soil was removed from the bags as needed and compacted in the model test box in 25.4 mm to

Table 1. Properties of the clay soil used for tests

<i>GENERAL</i>	
Percent passing No.200 U.S. sieve	68%
Less than 2μ	26%
Liquid limit	39%
Plastic limit	14%
Plasticity index	25%
<i>DETAILS OF COMPACTED SOIL</i>	
Average moisture content	27%
Average moist unit weight of compaction.	19.17kN/m ³
Average degree of saturation	94%
Average undrained shear strength (c_u)	16kN/m ²

Fig. 3. Schematic diagram for experimental setup

50.8 mm thick layers. A flat-bottomed rammer was used for compaction in sections. The desired model anchor plate was placed in the box, and the height of compaction of the soil above the anchor was adjusted according to the embedment ratio needs for a given test. The details of the soil compaction are also given in Table 1.

For application of load, the desired anchor plate was rigidly attached to a steel rod having a diameter of 7.94 mm. The steel rod was in turn attached to a steel cable having a diameter of 4.76 mm. The cable passed over a pulley. The other end of the cable was attached to a load hanger. Step loads were applied on the hanger, and the corresponding deflection was recorded by a dial gauge. A time of about 5 to 8 minutes was allowed between each step load. This is primarily due to the fact that noticeable displacement of the anchors was observed on the dial gauge during that time period immediately following the application of a given step load. After about 5 to 8 minutes of each step load application, the horizontal

Table 2. Sequence of model tests

Model test No.	Anchor plate size, $h \times B$ (mm)	Embedment ratio, H/h
1 to 5	50.8 $\times$ 50.8	1, 2, 3, 4, 5
6 to 10	50.8 $\times$ 101.6	1, 2, 3, 4, 5
11 to 15	50.8 $\times$ 152.4	1, 2, 3, 4, 5
16 to 20	50.8 $\times$ 254	1, 2, 3, 4, 5

Fig. 4. Nature of load displacement variation as observed in the laboratory

movement of the anchors practically stopped. A schematic diagram of the test arrangement is shown in Fig.3.

MODEL TEST RESULTS

A total of 20 model tests were conducted. The sequence of the model tests is given in Table 2. The general nature of the load-displacement relationships obtained from the tests is shown in Fig.4. It needs to be pointed out that the nature of the load-displacement plots as described in Fig.4 are based on the displacements observed after an elapse of 5 to 8 minutes time following the application of each step load. The failure load (P_u) for this study is defined as the load at which the anchor was completely pulled out, or beyond which the load-displacement plot became practically linear. The ultimate loads (P_u) thus determined are given in Fig.5.

During the tests, it was observed that, for all anchors with embedment ratios (H/h) up to about 4, surface cracks first appeared immediately above the anchors. Around the

Fig. 5. Experimental ultimate pullout load

Fig. 6. Plot of experimental breakout factor with embedment ratio

ultimate load, the failure surface in front of the anchors was clearly visible. However for $H/h=5$, surface cracks above the anchors were only visible at around the ultimate load.

ANALYSIS OF MODEL TEST RESULTS

As proposed by Mackenzie (1955), the ultimate load of anchors can be expressed in a nondimensional form as

$$N_c^* = \frac{P_u}{Bhc_u} \quad (2)$$

where N_c^* = breakout factor.

Fig. 7. Plot of shape factor with embedment ratio

By using the ultimate loads as given in Fig. 5 and Eq. (2), the experimental breakout factors have been calculated and are presented in Fig. 6. It can be seen from this plot that the breakout for any given plate continues to increase with embedment ratio and does not reach a constant value within the limits of tests. For that reason, they all represent shallow anchor condition.

As in most practical foundation design works, tests for anchors with width-to-height ratios of 5 or more ($B/h \geq 5$) can be assumed to be plane-strain case (Neeley et al, 1973). With this assumption, the ultimate pullout load for an anchor in saturated clayey soil can be written as

$$P_u = SBhc_u N_{c^*}^{(B/h=5)} \quad (\text{For } H/h \leq 5) \quad (3)$$

where S = shape factor.

The value of the shape factor given in Eq. (3) will be equal to one for $B/h \geq 5$, and is greater than one for $B/h \leq 5$. The variation of S with embedment ratio can be calculated as

$$S = \frac{N_{c^*}^{(B/h)}}{N_{c^*}^{(B/h=5)}} \quad (\text{For same value of } H/h) \quad (4)$$

Using the experimental values of the breakout factor shown in Fig. 6, the variations of the shape factors for the four anchor plates used in this test program have been calculated and are given in Fig. 7.

In order to develop a more practical rela-

Fig. 8. Plot of $N_c^* (B/h=5)$ vs. embedment ratio

tionship of the ultimate pullout capacity of shallow anchors in clay, the experimental variation of $N_c^* (B/h=5)$ with embedment ratio has been plotted in a log-log graph in Fig. 8. It can be seen from this figure that

$$N_c^* (B/h=5) \approx 2(H/h)^{0.74} \quad (5)$$

Combining Eqs. (3) and (5)

$$P_u = 2SBhc_u (H/h)^{0.74} \quad (\text{For } H/h \leq 5) \quad (6)$$

For shallow continuous anchors, the ultimate pullout load per unit length can be estimated as ($S=1$)

$$P_u' = \frac{P_u}{B} = 2hc_u (H/h)^{0.74} \quad (\text{For } H/h \leq 5) \quad (7)$$

where P_u' = ultimate pullout load per unit length of continuous anchors.

CONCLUSIONS

Small scale laboratory model test results on shallow vertical anchors embedded in saturated clay have been presented. The width-to-height ratio of the model anchor plates has been varied from one to five. Based on the model test results, the following conclusions can be drawn.

1) The ultimate pullout resistance of a vertical anchor can be conveniently expressed in the form of a nondimensional breakout factor N_c^* .

2) For shallow anchors, the breakout factor increases with the embedment ratio.

3) For a given value of embedment ratio, the breakout factor increases with the de-

crease of width-to-height (B/h) ratio of the anchor.

4) Based on the experimental results, an empirical relation (Eq. (6)) for the ultimate pullout resistance of shallow vertical anchors has been presented.

5) The present test results are based on small-scale laboratory model tests. Some large-scale field tests need to be conducted to verify their applicability and possible scale effects.

NOTATION

B = width of anchor plate

c_u = undrained cohesion

H = depth of embedment

N_c^* = breakout factor

P_u = ultimate load

P_u' = ultimate load per unit length for strip anchor

S = shape factor

γ = unit weight

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