Ultimate resistance of vertical anchors in clay

La résistance ultime d'encastrement vertical dans l'argile

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SYNOPSIS Laboratory model test results for the ultimate pullout resistance of rectangular vertical anchor plates in clay have been presented. The width-to-height ratio of the model plates has been varied from one to five. The ultimate resistance of an anchor can be expressed in the form of a nondimensional breakout factor. The experimental results show that for shallow rectangular anchors, the variation of the breakout factor with embedment ratio can be represented by a single nondimensional relationship.

INTRODUCTION

During the past ten to fifteen years, the results of a number of theoretical and experimental works related to the ultimate holding capacity of horizontal anchors in sand and clay have been published. A summary of most of the work on horizontal anchors embedded in sand can be found from the works of Meyerhof and Adams (1968), Vesic (1971), and Das and Jones (1983). Similar reviews on the ultimate holding capacity of horizontal anchors embedded in saturated clays have been presented by Meyerhof and Adams (1968), Vesic (1971), and Das (1978, 1980). A closely related problem which concerns the ultimate resistance of vertical anchor plates has received somewhat less attention. Some laboratory model test results regarding the ultimate pullout resistance of vertical anchor plates in sand have been provided by investigators such as Das (1975), Ovesen and Stromann (1972), Neeley, Stuart, and Graham (1973), and Dickin and Leung (1983). Mackenzie (1955) conducted a number of laboratory model tests on vertical strip anchors ($B/h=\infty$) in two different clays. The ultimate resistance obtained from these model tests have been given in a non-dimensional form by Tschebotarioff (1973). A review of literature shows that no attempt has yet been made to determine the ultimate pullout resistance of vertical rectangular anchor plates in saturated clay. The purpose of this paper is to present some recent laboratory model test results on rectangular anchors in saturated clay soil.

DEFINITION OF PARAMETERS

Figure 1(a) shows a vertical anchor plate of height h and width B (at right angle to the cross-section shown) embedded in a saturated clay. The ultimate pullout resistance of the anchor, Q_u, can be expressed in a nondimensional form as

$$F_c = \frac{Q_u}{B\ h\ c_u} \tag{1}$$

where c_u = undrained shear strength of clay
F_c = breakout factor

The breakout factor for a given anchor plate in a given clay will continue to increase with the embedment ratio H/h up to a maximum value [Fig. 1(b)]. The embedment ratio at which the maximum value of $F_c=F_{c(max)}$ is obtained may be defined as the critical embedment ratio $(H/h)_{cr}$. For $H/h>(H/h)_{cr}$, the value of the breakout factor remains practically constant. Anchors with embedment ratios of $H/h<(H/h)_{cr}$ may be

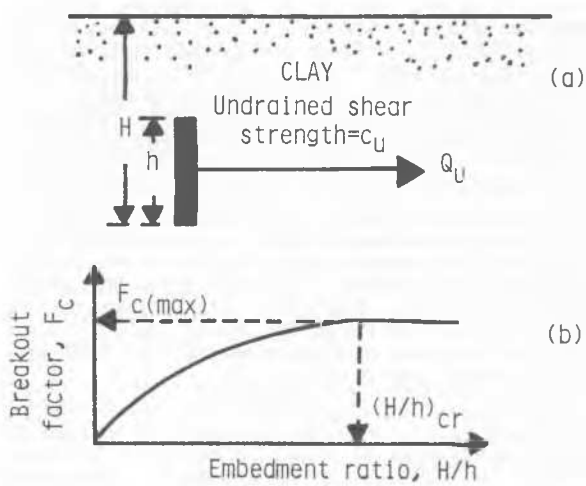

Fig. 1. (a) Parameters for a vertical anchor plate; (b) Variation of F_c with embedment ratio

referred to as shallow anchors. When anchors are placed at an embedment ratio of $H/h>(H/h)_{cr}$, local shear failure in soil takes place, and such anchors are referred to as deep anchors. Tschebotarioff (1973) has pointed out that the effect of soil unit weight, γ, on the breakout factor is negligible in small scale model tests. However, the results of such model tests will provide conservative estimates for practical design works.

LABORATORY MODEL TESTS

Four model anchor plates with dimensions of 50.8 mm × 50.8 mm, 50.8 mm × 101.6 mm, 50.8 mm × 152.4 mm, and 50.8 mm × 254 mm were used for the present model tests, providing width-to-height ratios of 1, 2, 3, and 5. The anchor plates were made of steel and were 9.5 mm thick.

The clayey soil used for the model tests had 100% passing No. 40 U.S. sieve, 68% passing No. 200 U.S. sieve, and 26% less than 2μ in size. The liquid and plastic limits of this natural clay were 39% and 14%, respectively. In order to conduct the model tests, a large quantity of the soil was pulverized and thoroughly mixed with the desired amount of moisture. The moist soil was then placed in plastic bags and sealed. These bags were kept in a moist curing room for a week before use.

The model tests were conducted in a box measuring 0.915 m × 0.915 m × 0.915 m. For a given test, an anchor plate was placed inside the box. The plate was rigidly attached at its center to a steel rod having a diameter of 7.94 mm. The rod, in turn, was attached to a steel cable with a diameter of 4.76 mm. The cable passed over a pulley attached to the side of the box. A load hanger was attached to the other side of the cable.

The moist soil was compacted in the box in about 50.8 mm thick layers up to the desired height. The compaction was done in sections using a flat-bottomed rammer. The average moisture content and moist unit weight of the compacted soil in the model test box were 27% and 19.17 kN/m³, respectively; and this gave a degree of saturation of about 94%. At this state of compaction, the unconsolidated-undrained triaxial test results (at a chamber confining pressuring of 70 kN/m² and strain rate of 1% per minute) yielded an average undrained shear strength (c_u) of 16 kN/m². At the end of soil compaction, step loads were applied to the load hanger attached to the cable until failure occurred. After each step load, a time of 5-8 minutes was allowed to elapse before the next load was applied. For each load increment, the deflection was measured by a dial gauge. A schematic diagram of the experimental arrangement is shown in Fig. 2.

MODEL TEST RESULTS

The general nature of load vs. displacement plots obtained for various anchor plates from the model tests is shown in Fig. 3. Also shown

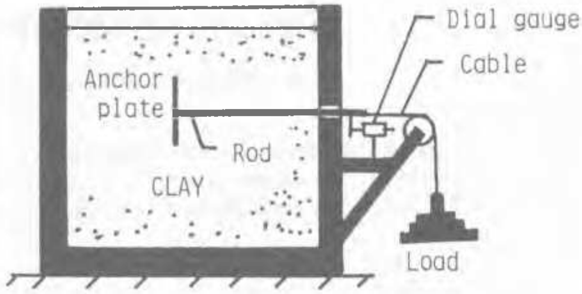

Fig. 2. Schematic diagram of the laboratory experimental arrangement

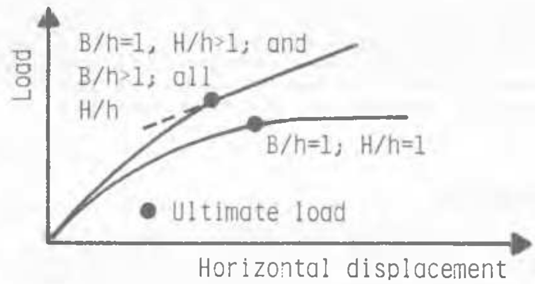

Fig. 3. Nature of load-displacement diagrams obtained in the laboratory

in this figure are the criteria used for obtaining the ultimate pullout loads. The ultimate load for this study has been defined as the load where sudden failure occurred, or the load at which the load-displacement plot became practically linear and gave a minimum slope. The above criteria are similar to that used to obtain the ultimate bearing capacity of shallow foundations. Similar criteria have also been used for determination of the ultimate capacity of vertical anchors in sand.

During the model tests, for anchors with H/h up to about 4, the surface crack first appeared immediately above the anchors. The failure surfaces in the soil in front of the anchor slabs progressed to the surface at about the ultimate loads. However, for deep anchors, only small surface cracks immediately above the anchors were noticed. This was similar to the observations of Tschebotarioff (1973).

The ultimate pullout resistances determined from all the model tests conducted under this program have been plotted against their corresponding embedment ratios in Fig. 4.

By using the experimental failure loads as given in Fig. 4 and Eq. (1), the experimental breakout factors for all the model tests have been calculated and are shown in Fig. 5. As expected, the plot of F_c against H/h followed the same pattern as given in Fig. 1(b). Based on Fig. 5, the following important observations can be made:

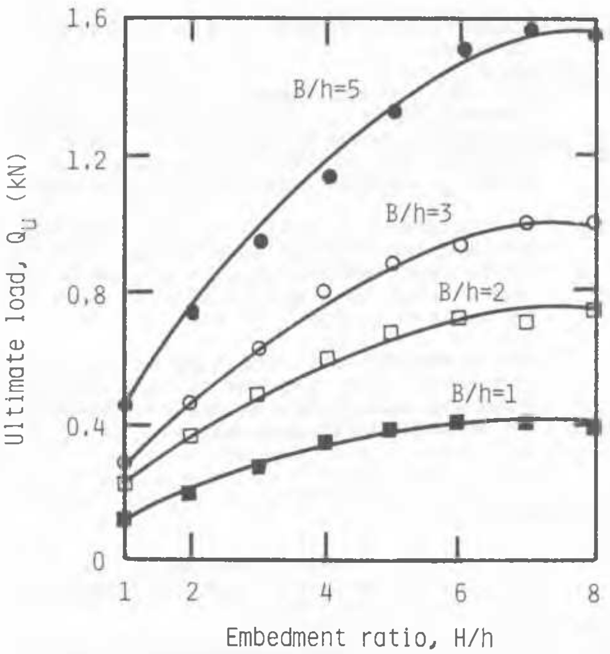

Fig. 4. Variation of ultimate load with embedment ratio

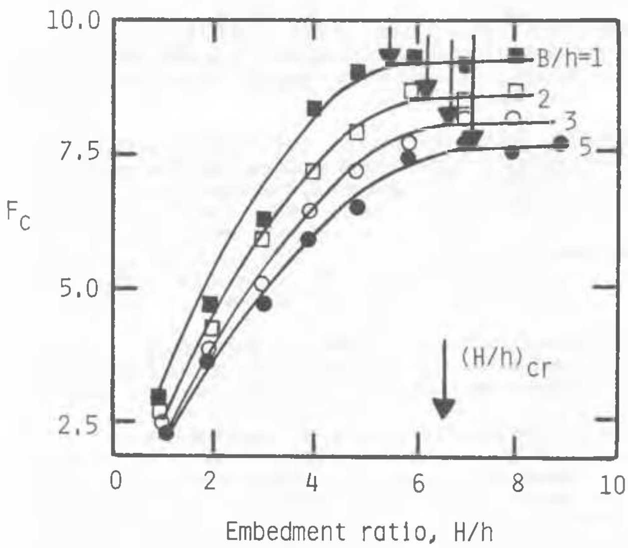

Fig. 5. Variation of breakout factor F_c with embedment ratio

(a) The critical embedment ratio, $(H/h)_{cr}$, tends to increase with increasing width-to-height ratio of anchors. The variation of $(H/h)_{cr}$ as interpolated from Fig. 5 is shown in Fig. 6.

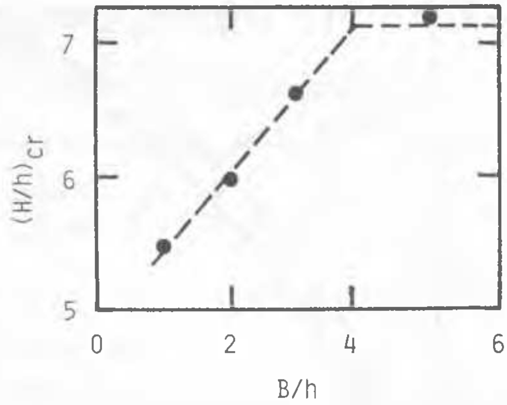

Fig. 6. Variation of critical embedment ratio with B/h

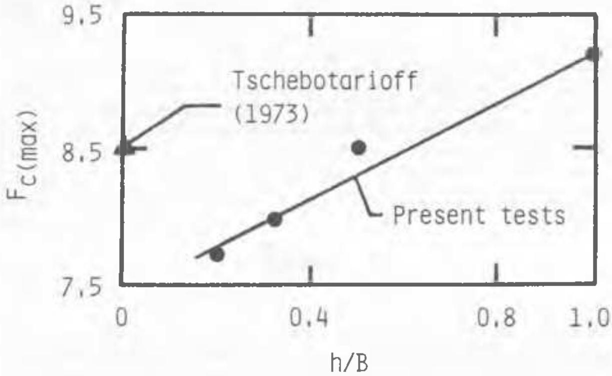

Fig. 7. Variation of $F_{c(max)}$ with h/B

(b) The maximum values of breakout factors $[F_{c(max)}]$ obtained for various anchor plates are shown in Fig. 7. Although there are some experimental variations, it appears that $F_{c(max)}$ bears a linear relation with h/B. This is similar to the bearing capacity factor (N_c) relationship given for deep foundations in saturated clay. For comparison purposes, the values of $F_{c(max)}$ for strip anchors as reported by Tschebotarioff (1973) are also shown in Fig. 7.

With the present experimental results, it appears that the ultimate pullout resistance of rectangular anchors in saturated clay can be expressed in terms of two nondimensional parameters, which may be defined as

$$\alpha = \frac{F_c}{F_{c(max)}} \tag{2}$$

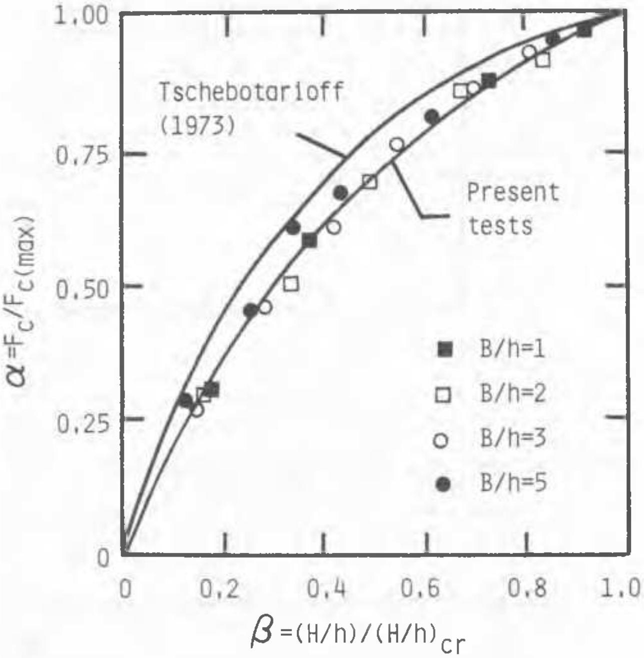

Fig. 8. Plot of α vs. β for the average curves shown in Fig. 5

$$\beta = \frac{H/h}{(H/h)_{cr}} \tag{3}$$

Figure 8 shows the plot of α vs. β parameters for the average curves of F_c vs. H/h given in Fig. 5. It appears that all α vs. β values in Fig. 8 fall within a very narrow band and they can be represented by a single relationship. For comparison purposes, the α vs. β plot as obtained from the model tests on strip anchors as reported by Tschebotarioff (1973) is also plotted in Fig. 8. For this plot, $F_{c(max)}$ has been taken to be equal to 8.5 at $(H/h)_{cr} \approx 12$. This plot appears to be the upper limit of the present tests on rectangular anchor plates.

CONCLUSIONS

Laboratory model test results for the ultimate pullout resistance of rectangular anchors in saturated clay have been presented. The width-to-height ratio of anchor plates has been varied from one to five. Based on the model test results, the following conclusions can be drawn:

(a) The ultimate pullout load of an anchor can be expressed in the form of a non-dimensional breakout factor, F_c.

(b) The breakout factor for a given plate increases with the embedment ratio up to a maximum value, $F_{c(max)}$, at an embedment ratio $H/h=(H/h)_{cr}$. For $H/h \geq (H/h)_{cr}$, the breakout factor remained practically constant.

(c) For the present tests, the critical embedment ratio increased with the width-to-height ratio of the anchor plate. However, for $B/h \geq 4$, the magnitude of $(H/h)_{cr}$ remained practically constant.

(d) The ultimate pullout loads for shallow rectangular anchors as obtained from the tests reported here can be approximately represented by a single plot of α vs. β as defined by Eqs. (2) and (3).

(e) The present tests have been conducted on one soil. More results of this type, when available, can be used to develop a rational design procedure.

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