CHAPTER 134

ULTIMATE RESISTANCE OF VERTICAL PLATE ANCHORS IN CLAY

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Abstract

Laboratory model test results for the ultimate pullout resistance of vertical square anchors embedded in saturated or near saturated clay have been presented. The undrained shear strength of the clay and the embedment ratio of the anchors have been varied. Based on the model test results, an empirical parametric relationship for estimation of the ultimate pullout resistance of shallow and deep square anchors has been presented.

Introduction

Vertical anchor plates (Fig. 1) are generally used for construction and design of waterfront structures such as sheet pile bulkheads. More recently, a number of studies relating to the ultimate pullout resistance of vertical anchor plates embedded in sand have been published (1,4,5,6,8, 9,10). Most of the important findings have been summarized in a paper by Das (1). In contrast, very few attempts have so far been made for evaluation of the ultimate resistance of vertical plate anchors embedded in saturated clay (ϕ=0 concept). The purpose of this paper is to present the results of some laboratory experimental studies for the ultimate pullout resistance of square anchor plates in saturated or near saturated clay soils.

Previous Studies For Ultimate Resistance of Vertical Anchors in Clay (ϕ=0 Concept)

When an anchor plate embedded in a clay soil is being subjected to an ultimate pullout load Q_u (Fig. 1), the failure surface in clay in front of the plate may extend to the ground surface. This will be the case when the embedment ratio H/B (H=depth of embedment of the anchor plate; B= height of the anchor plate) of the anchor plate is small. This type of anchor is referred to as a shallow anchor.

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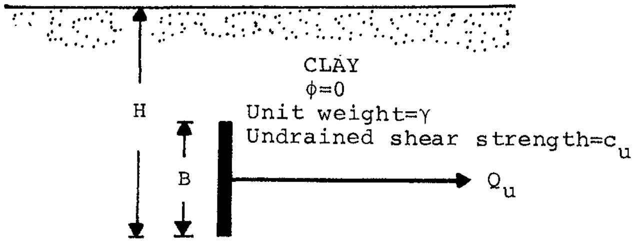

Figure 1. Vertical anchor plate.

However, if H/B is relatively large, local shear failure in the clay around the anchor will take place, and the failure surface in the soil will not extend to the ground surface. This type of anchor is referred to as a deep anchor. For shallow strip anchors with H/B<about 2, Teng (11) has suggested that

$$Q_u = L(P_p - P_a) \tag{1}$$

where L = length of the anchor plate at right angles to the cross section as shown in Fig. 1

P_p, P_a = Rankine passive and active force per unit length of the anchor in the front and the back, respectively

For $\phi=0$ condition

$$P_p = \tfrac{1}{2}\gamma H^2 + 2c_u H \tag{2}$$

and

$$P_a = \tfrac{1}{2}\gamma H^2 - 2c_u H \tag{3}$$

where γ = unit weight of the clay

c_u = undrained shear strength

Combining Eqs. (1), (2), and (3)

$$Q_u = 4c_u HL \tag{4}$$

For anchor plates with limited length-to-height ratios (i.e., L/B≤about 5 to 6), the resistance derived from the sides of the plate during pullout needs to be accounted for. For such cases, Teng (11) suggested that

$$Q_u = 4c_u HL + 2c_u H^2 \quad \text{(for H/B<about 2)} \tag{5}$$

Mackenzie (7) conducted a number of laboratory model tests on strip anchors in two different clay soils. According to this study and Tschebotarioff (12), the ultimate resistance of vertical anchors with dimensions B×L can be conveniently expressed in a nondimensional form as

$$F_c = \frac{Q_u}{BLc_u} \tag{6}$$

where F_c = breakout factor

Figure 2 shows the average variation of F_c with H/B as obtained by Mackenzie (7). It needs to be pointed out that

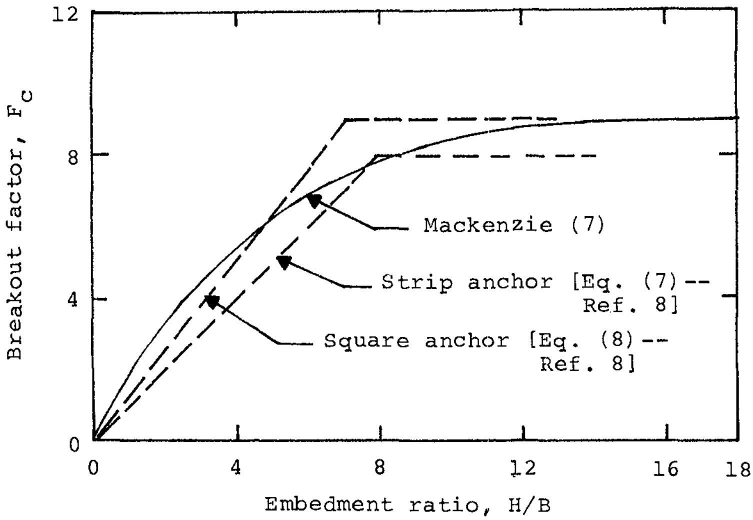

Figure 2. Breakout factor variation with embedment ratio from previous studies.

the magnitude of F_c increases with H/B up to a maximum value ($F_c=F_c^*$) at $H/B=(H/B)_{cr}$. For $H/B>(H/B)_{cr}$, the magnitude of the breakout factor remains practically constant (i.e., F_c^*). So, anchors with H/B less than or equal to $(H/B)_{cr}$ may be referred to as shallow anchors; and when the embedment ratio is greater than $(H/B)_{cr}$, they may be referred to as deep anchors. For Mackenzie's tests, the magnitudes of $(H/B)_{cr}$ and F_c^* are about 12 and 8.5, respectively.

Meyerhof (8) has suggested that conservative estimates of the breakout factor F_c with embedment ratio may be given as

$$F_c = 1.0(H/B) \leq 8 = F_c^* \quad \text{(for strip anchors)} \tag{7}$$

and

$$F_c = 1.2(H/B) \leq 9 = F_c^* \quad \text{(for square anchors)} \qquad (8)$$

For comparison purposes, these relations have also been plotted in Fig. 2. The present study relates primarily to the determination of the breakout factor variation of square anchors only.

Laboratory Investigation

Laboratory model tests for determination of the ultimate pullout resistance of vertical square anchors were conducted with two steel model anchor plates measuring 38.1 mm × 38.1 mm and 50.8 mm × 50.8 mm (B×L). Each of the plates had a thickness of 9.5 mm.

The model tests were conducted in a box measuring 0.915 m × 0.508 m × 0.915 m (height). The sides of the box were braced to avoid lateral yielding.

Two clayey soils (referred to as Soil A and Soil B) collected from the field were used for the present tests. Soil A had 78% passing No. 200 U.S. sieve, with liquid and plastic limits of 32 and 19, respectively. Similarly, Soil B had 68% passing No. 200 U.S. sieve. The liquid and plastic limits of Soil B were 39 and 14, respectively. Based on the Unified soil classification system, both soils belonged to the group CL. The soils were initially pulverized in the laboratory, and desired amounts of water were added to them. After thorough mixing, the moist soils were transferred to several plastic bags. The bags were then sealed and kept in a moist curing room for about a week before use.

A schematic diagram of the laboratory test arrangement is shown in Fig. 3. In order to conduct a test, the desired anchor plate was rigidly attached to a steel rod. The rod, in turn, was attached to a steel cable. The cable passed over a pulley attached rigidly to the side of the box. The other side of the cable was attached to a load hanger.

For conducting a test, the moist soil from the plastic bags was poured into the box and compacted in 50.8mm thick layers to the desired height. The compaction was done in sections by using a flat-bottomed rammer. After compaction, step loads were placed on the load hanger, and the corresponding horizontal movements of the anchor were observed by a dial gauge. A time lapse of 5-8 minutes was allowed between the placement of each step load. This time lapse between the step loads was allowed to take primary creep into account. Loading continued until failure occurred.

A total of five series of tests were conducted in the laboratory. Other details of the tests are presented in

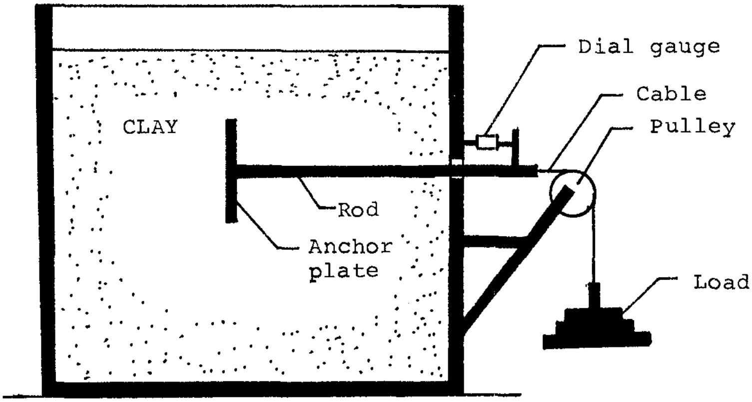

Figure 3. Schematic diagram of the model test arrangement in the laboratory.

Table 1. It may be noticed from this table that the larger model anchor plate measuring 50.8 mm × 50.8 mm was used for tests in softer clays.

Table 1. Model Test Details

Test series	Soil	Plate width, B (mm)	Properties of compacted soil (Average values)			
			Moist unit weight, γ (kN/m^3)	Moisture content (%)	Degree of saturation (%)	Undrained shear strength, c_u (kN/m^2)
1	A	50.8	19.65	24.5	97	20.3
2	A	38.1	20.76	17.6	94	42.4
3	B	50.8	19.03	28.5	98	12.5
4	B	38.1	20.29	18.5	92	28.1
5	B	38.1	20.65	16.2	93	52.0

Typical net load (Q) vs. horizontal displacement of the anchors as obtained from the laboratory tests are shown in Fig. 4. For all tests reported herein (a total of 41), a

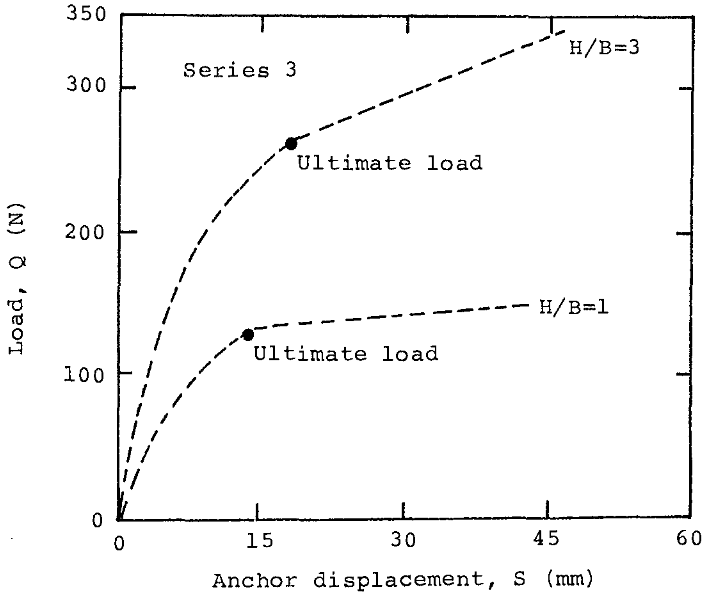

Figure 4. Typical net load vs. anchor displacement diagrams as obtained from the laboratory.

peak failure load was not observed. This is somewhat similar to the load-displacement plots obtained for local shear type of failure in soil in the bearing capacity tests of shallow foundations. The ultimate load for a given anchor pullout test is defined as the net load at which the load-displacement plot became practically linear (i.e., $\Delta Q/\Delta S$ became minimum). The net ultimate pullout loads for all tests conducted under this program are plotted in Fig. 5.

Model Test Results

Critical Embedment Ratio, $(H/B)_{cr}$

The relationship of the breakout factor for a rectangular anchor is given in Eq. (6). For square anchors, B=L; hence, the breakout factor

$$F_c = \frac{Q_u}{B^2 c_u} \tag{9}$$

By substituting the experimental values of the net ultimate load (Q_u), B, and c_u in the right-hand side of Eq. (9), the

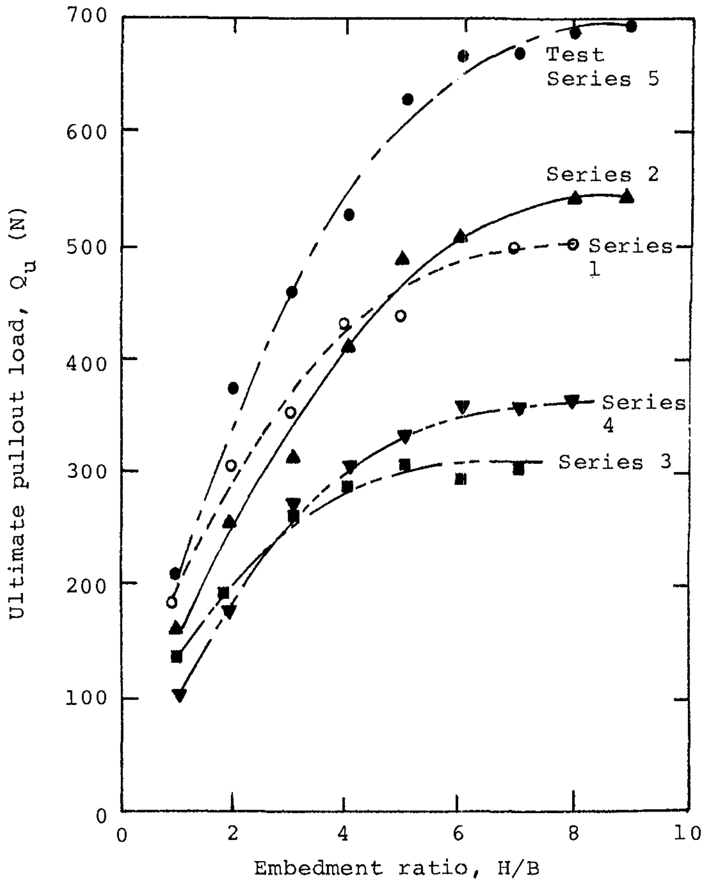

Figure 5. Ultimate pullout load for the model tests.

experimental values of the breakout factor F_c for all tests have been determined and have been plotted in Fig. 6. As expected, for a given test series the magnitude of the breakout factor increases with the embedment ratio H/B up to a maximum value and remains constant thereafter. Based on the average curves, the critical embedment ratios $(H/B)_{cr}$ at which the magnitude of F_c $(=F_c^*)$ becomes constant are also shown in Fig. 6. It can be seen from this figure that, for a given anchor plate, i.e., B/L=constant, $(H/B)_{cr}$ is not a constant. It is a function of the undrained shear strength of the clay in which tests are being conducted. The variation of the critical embedment ratios as determined from Fig. 6 have been plotted in Fig. 7 as a function of the undrained shear strength of the clay. The average plot in

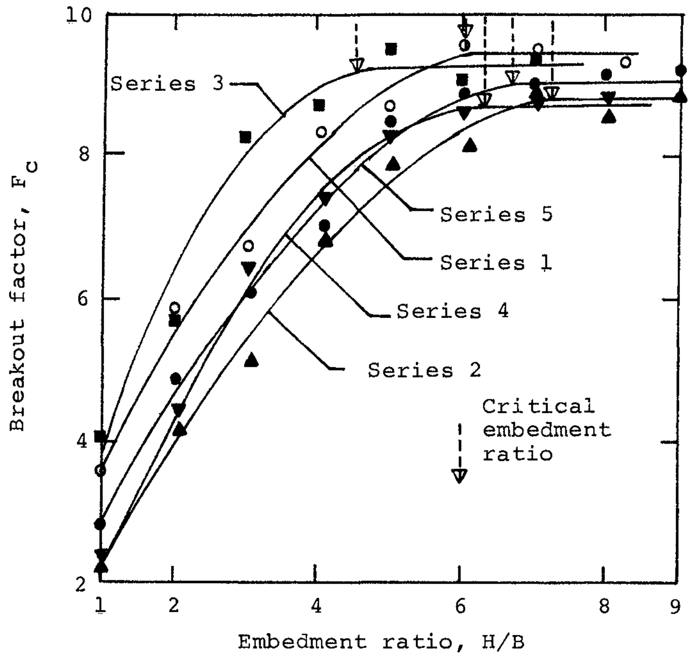

Figure 6. Variation of the experimental breakout factor.

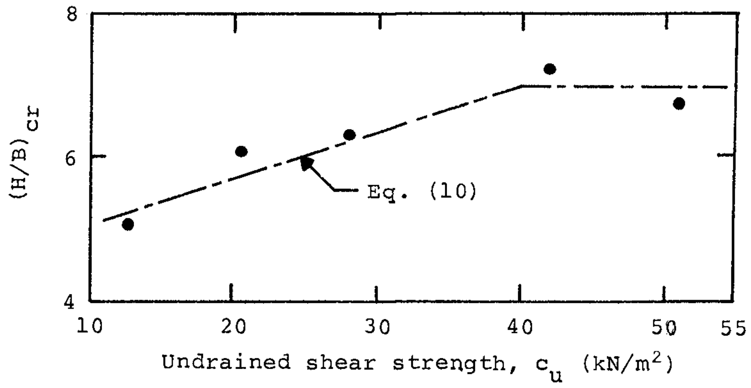

Figure 7. Variation of experimental $(H/B)_{cr}$ with c_u.

this figure can be approximated as

$$(H/B)_{cr} = 4.33 + 0.067 c_u \leq 7 \tag{10}$$

where c_u is in kN/m^2

Variation of Maximum Breakout Factor, F_c^*

As previously mentioned, the breakout factor for deep anchors is a constant, i.e., $F_c = F_c^* =$ constant. Figure 8 shows the plot of the experimental variation of F_c^* as obtained

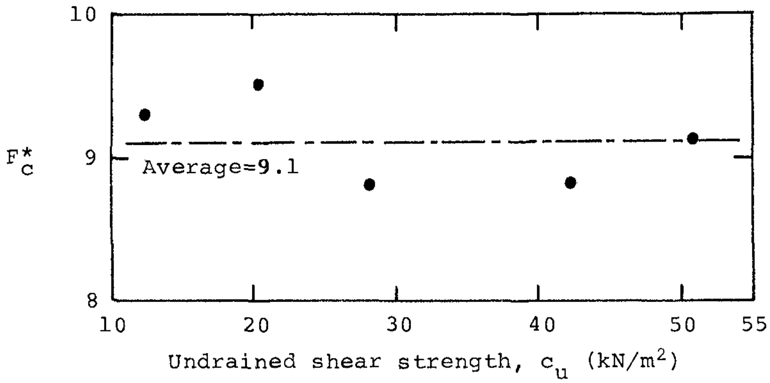

Figure 8. Experimental variation of F_c^* with c_u.

from the present tests with c_u. Based on this figure, it appears that F_c^* varies between 8.8 to 9.5, with an average of about 9.1. This indicates that F_c^* is not a function of the undrained shear strength of the soil and is similar to the magnitude of the bearing capacity factor N_c for square and circular foundations on saturated clay ($\phi=0$ condition). Hence, considering the errors involved in the laboratory tests of this type, the value of F_c^* may be assumed to be equal to 9.

Parametric Relationship for Breakout Factor of Shallow Foundations

In the process of developing a procedure for the estimation of the ultimate uplift capacity of shallow horizontal anchors embedded in saturated clay, Das (2,3) proposed a nondimensional parametric relationship which appears to be useful for the present problem under consideration.

The two parameters under discussion are as follows:

$$\alpha = F_c/F_c^* \tag{11}$$

and

$$\beta = \frac{(H/B)}{(H/B)_{cr}} \tag{12}$$

Using the above definitions, the experimental variation of β/α and β for each average plot of F_c vs. H/B as shown in Fig. 6 have been determined and are shown in Fig. 9. Although there is some scattering, all points in Fig. 9 appear

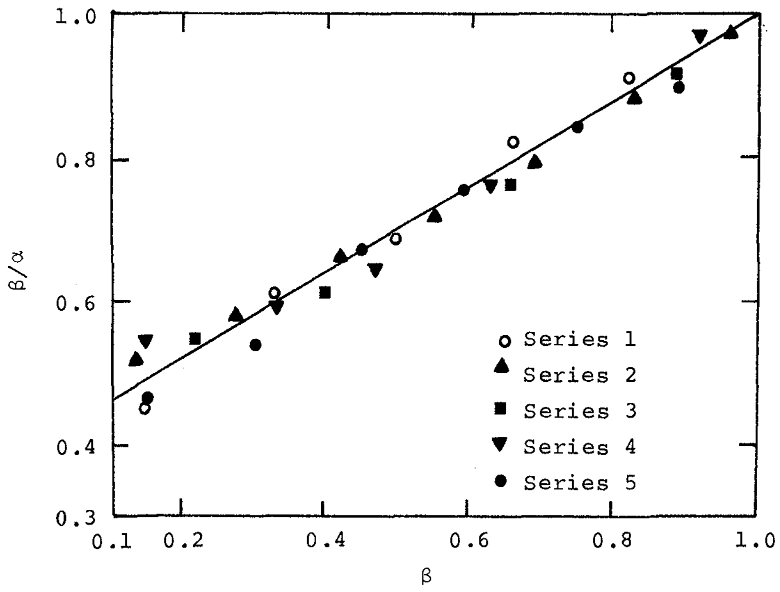

Figure 9. Variation of β/α with β--experimental results.

to fall in a narrow range. The average plot can be expressed in the form

$$\beta/\alpha = 0.4 + 0.6\beta \tag{13}$$

or

$$F_c = F_c^*\left\{\frac{(H/B)/(H/B)_{cr}}{0.4+0.6[(H/B)/(H/B)_{cr}]}\right\} \le F_c^* \tag{14}$$

Hence, once $(H/B)_{cr}$ is determined from Eq. (10), the value can be used in the preceding equation to obtain the breakout factor. However, based on previous discussions, if F_c^* is taken as 9, then

$$Q_u \simeq 9c_uB^2\left\{\frac{(H/B)/(H/B)_{cr}}{0.4+0.6[(H/B)/(H/B)_{cr}]}\right\}\leq 9c_uB^2 \qquad (15)$$

Conclusions

A number of laboratory model test results on square vertical anchors in clay (ϕ=0 concept) have been presented. Based on the model test results, the following conclusions can be drawn:

1. The ultimate pullout resistance of a vertical anchor can be expressed in the form of a nondimensional breakout factor, F_c.

2. The magnitude of the maximum breakout factor F_c^* is approximately equal to 9 for square anchors.

3. The critical embedment ratio increases with the undrained shear strength of clay; however, for stiff clays the magnitude of $(H/B)_{cr}$ is about 7.

4. The variation of the breakout factor with embedment ratio in clays of various consistencies can be expressed by a single nondimensional parametric equation [Eq. (15)].

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