

FIELD PULL-OUT EXPERIMENTS OF FLIP-TYPE GROUND ANCHORS DRIVEN IN GROUND OF CLAY AND SAND LAYERS

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ABSTRACT: The pull-out mechanism of square, circular, or rectangular embedded plate anchors in sandy and clayey grounds has been previously studied both in laboratory and field. However, similar experimental researches focusing on flip anchors have not been conducted in either laboratory or field. Therefore, this study aims to provide results of field pull-out experiments of actual flip anchors driven into the ground consisted of a top sand layer and a clay layer underneath. The behavior of pull-out resistance of flip anchors installed in clay is investigated, comparing with the behavior of flip anchors installed in sand. A total of 26 flip anchors were driven into the ground at positions of 2 m pitch grid using a percussion driving device and pulled out using a hydraulic jack. Five sizes of flip anchors were installed in the sand at a depth of 1.0 m or 1.2 m, or clay layer at a depth of 1.8 m. Vane shear tests were conducted in the clay layer to measure the undrained shear strength c_u . The anchors in the sand had a greater pull-out force than the corresponding anchors in the clay. The pressure acting on the anchor increased with decreasing the projected area of the anchor in the sand layer. In contrast, in the clay layer, the pressure was the same regardless of the projected area of the anchor plate. The maximum pull-out forces measured in the clay layer agreed well with the calculated values based on the interpretation of the T-bar penetration test.

Keywords: Flip-type ground anchor, Field experiment, Pull-out experiment, Clay, Sand

1. INTRODUCTION

1.1 Flip-Type Earth Anchors

Examples of Flip-type earth (ground) anchors (hereinafter, “flip anchor”) are shown in Figure 1. They are effective means for reinforcing slopes against slope failures. Moreover, flip anchors can be used for supporting tower structures against strong winds. Because they can be installed easily even in underwater condition, they are used as an anchor base for objects such as floating solar panels and floating piers.

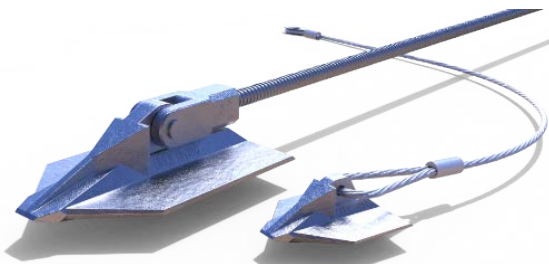


Fig. 1 Flip-type earth anchor [1]

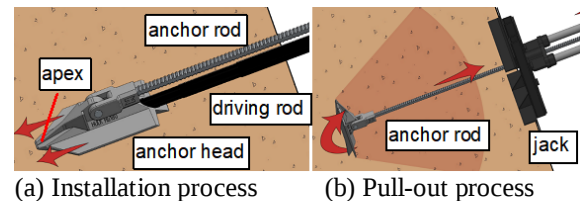


Fig. 2 Installation process of a flip anchor [1]

Figure 2 shows the installation process of a flip anchor. The flip anchor is driven into the ground as percussion anchor with the anchor head closed (Fig. 2a). After driving into a designated depth, the anchor head rotates to open when pull-out force acts on it (Fig. 2b) so that soil pressure sufficiently acts on it. Because the grouting and curing periods of grout are not required, flip anchors are suitable for small-scale reinforcement as well as restoration works in emergencies. Although the installation of flip anchors is simple and quick, the mechanism of their pull-out resistance has not been fully understood.

1.2 Review of Related Researches

The behaviors of square, rectangular, or circular anchors embedded in sandy or clayey grounds have been previously studied as follows.

1.2.1 Plate anchors embedded in sand

Through pull-out experiments, ground failure patterns caused by pulling the embedded plate anchors in sand were observed. Some theoretical approaches to estimate pull-out resistance of the anchors in sand have been proposed.

Majer [2] proposed the frictional cylinder model (Fig. 3a). The model assumes that the ground fails in a cylindrical shape with the anchor plate at the bottom. The pull-out resistance is calculated from the sum of the weight of the cylindrical soil above the anchor plate and the frictional resistance of the peripheral surface of the soil cylinder.

Mors [3] proposed the cone model (Fig. 3b). The model assumes that truncated cone-shaped soil mass consisting of failure lines extending to the ground surface with an angle of $90^\circ + \phi$ (ϕ : internal friction angle) from both edges of the anchor plate. In this model, only the weight of the soil in the truncated cone is considered to obtain the pull-out capacity.

Balla [4] observed a failure pattern consisting of curved failure lines from the edges of the anchor (Fig. 3c). The curved lines meet the ground surface at an angle of approximately $45^\circ - \phi/2$. The pull-out resistance is calculated from the weight of the soil mass and the friction along the curved failure lines based on the Kötter's equation.

The above mentioned models are applied to shallow anchors in sand ground.

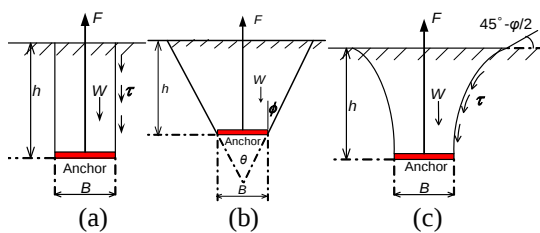


Fig. 3 Typical ground failure patterns of shallow anchors

In case of a deep anchor, the models of Figure 3 cannot be applied because slip lines do not reach the ground surface. As shown in Figure 4, in case of a deep anchor, a different ground failure pattern occurs. The highly compressed wedge I formed above the anchor pushes the radial shear zone II sideways into the plastic zone III [5].

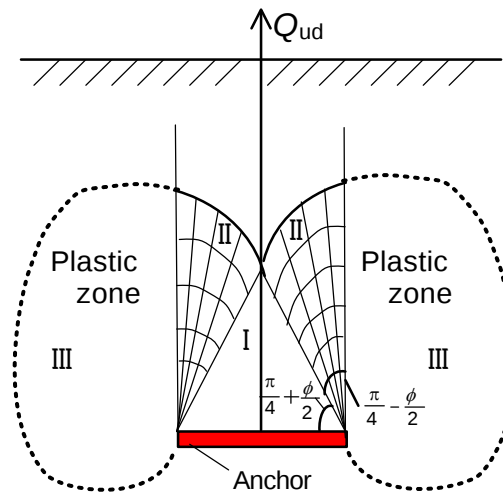


Fig. 4 Failure pattern of a deep anchor [5]

As the ground failure patterns are significantly different for a shallow or deep anchor, many researches observed ground failure when pulling the anchors to find the critical embedment ratio $(H/B)_{cr}$ that is used to distinguish between a shallow and deep anchor. For an example, embedment ratio H/B of 6 was pointed out as $(H/B)_{cr}$ for embedded plate anchors in sand ground [6].

Since $(H/B)_{cr}$ varies with a variety of experimental conditions, many researches including centrifuge tests have been conducted, considering other parameters, such as ground density or anchor shape [7-9]. Particle image velocimetry (PIV) or digital image correlation (DIC) methods were employed to observe ground failure patterns in push-up test on a trap door [10] or pull-out test of anchors [11].

1.2.2 Plate anchors embedded in clay

For anchors in clay ground, the maximum pull-out pressure p_{max} acting on a plate anchor has been generally estimated from the undrained shear strength c_u as $p_{max} = F_c c_u$ where F_c is breakout factor.

According to Das [12], F_c increases with H/B up to a critical embedment ratio $(H/B)_{cr}$ and F_c levels off beyond $(H/B)_{cr}$. Vesić [13] gave theoretical values of breakout factor F_c for shallow foundations (anchors), such as circular or rectangular anchors, in clay ground. Das [12] proposed a procedure for estimating pull-out resistance of embedded shallow and deep anchors in clay ground.

Merifield et al. [14] evaluated an effect of anchor shape on the pull-out capacity of horizontal anchors in clay ground using three-dimensional numerical limit analysis. Han et al. [15] observed soil deformation around an anchor plate in clay ground under sustained loading using PIV method, and carried out two-dimensional large deformation finite element (LDFE) analyses of the experiment.

However, few field pull-out experiments to investigate pull-out resistance of plate anchors have been conducted in clay ground. Moreover, similar experimental researches focusing on flip anchors have not been conducted in either laboratory or field.

1.3 Objectives of This Research

This study provides the results of field pull-out experiments of actual flip anchors driven into the ground consisted of sand and clay layers. The behavior of pull-out resistance of flip anchors installed in the clay layer is investigated, comparing with the behavior of flip anchors installed in the sand layer.

Based on the experimental results, an estimation method for pull-out resistance of flip anchors installed in clay ground is proposed.

2. OUTLINE OF FIELD EXPERIMENT

2.1 Property of the Ground

The test site was located at Shiga Prefecture, Japan. Figure 5 shows installation points of flip anchors, which were set at a position of 2 m pitch grids comprising three rows A, B, and C. Basically, nine anchors were installed in each row.

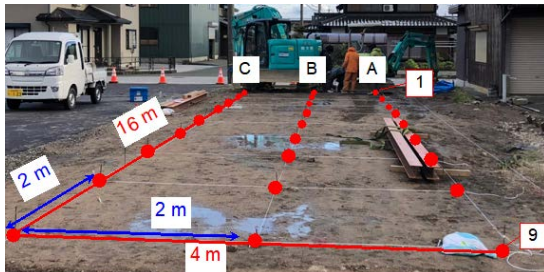


Fig. 5 Test site used for the pull-out experiments

The ground was consisted of a top sand layer overlying a soft clay layer. Portable dynamic cone penetration tests (DCPTs) were conducted at ten locations in the site (Fig. 6). It can be seen that the ground shallower than 1.8 m in which the anchors were installed was almost uniform in a plane. The DCPT device comprised a cone with a diameter of 25 mm, a drop hammer mass of 5 kg, and a hammer drop height of 500 mm. The converted SPT N -values (Fig. 7) were empirically estimated from the DCPT results. The converted SPT N -value to a depth of 2 m within the top sand layer and the underlying clay layer was around 5, and increased to around 15 in the bottom sand layer.

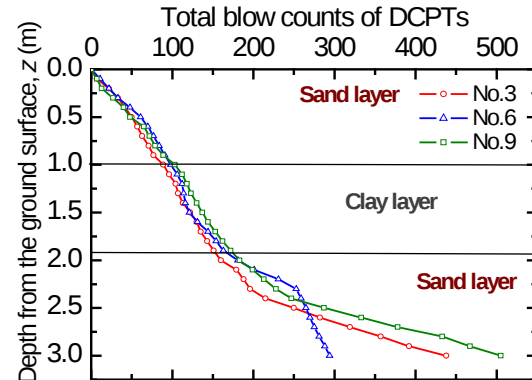


Fig. 6 Total blow counts of DCPTs

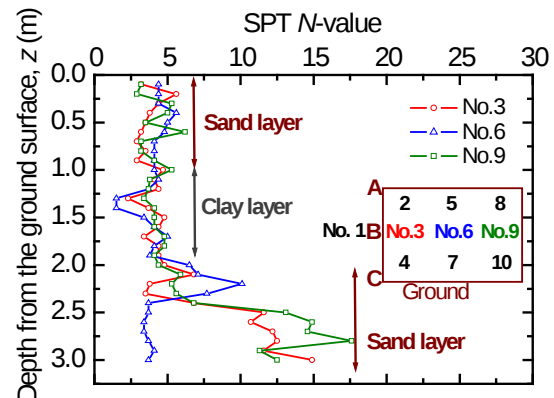


Fig. 7 Converted SPT N -values of the ground

Furthermore, the test ground was excavated at two locations in the test site for direct soil observation. The top sand layer was 1.0 m deep, followed by the clay layer to a depth of 1.8 m. Flip anchors were installed in the top sand layer or in the clay layer.

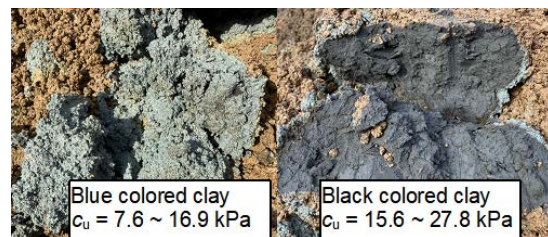


Fig. 8 Types of clay in the ground

As shown in Figure 8, the clay layer comprised two types of clay. The blue-colored clay contained a small amount of sand particles while the black-colored clay was pure sticky clay. The former was located in between the sand layer and the black-colored clay. Vane shear tests were conducted in the clay layer to measure the undrained shear strength c_u . The black-colored clay had a relatively larger c_u than the blue-colored clay.

Figure 9 shows the water content w_c of the ground. The w_c of the black-colored clay was nearly three times that of the blue-colored clay. No significant difference was observed in the water content at each location.

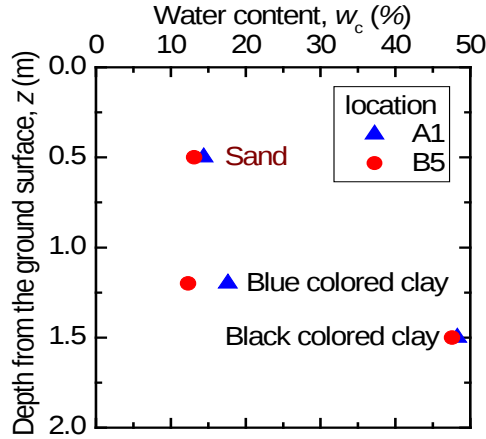


Fig. 9 Water content w_c of the ground

2.2 Flip Anchors Used in the Experiments

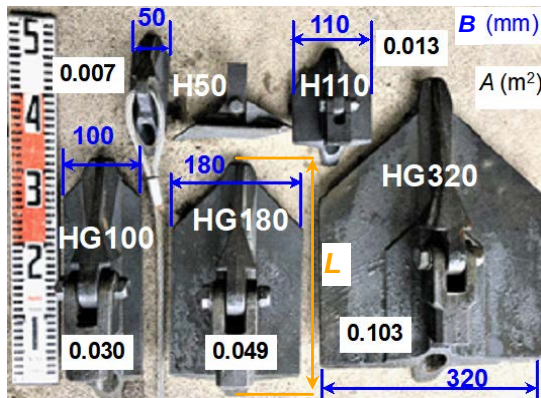


Fig. 10 Flip anchors used in the experiments

As shown in Figure 10, five types of flip anchors were used in the field experiments. The smaller anchors were called as H series, and the larger ones are called as HG series. The numbers after H and HG denote the width of the anchor B . Length of the anchor L is 160 mm for H50 and H110, 340 mm for HG100 and HG180, and 440 mm for HG320. The projected area of the anchors A are also indicated in the figure.

2.3 Experimental Cases and Procedure

As listed in Table 1, a total of 26 cases of pull-out experiments were conducted. Depth z denotes the installation depth from an apex of the closed anchor plate. Anchors were driven into the ground with a percussion device and pulled out with a hydraulic jack (Fig. 11). Pull-out force F and pull-

out displacement w were measured while pulling out the anchors.

Table 1 Experimental cases

Case	Anchor	Depth, z (m)	Soil	Max. force, $F_{\max}$ (kN)
A1	HG320	1.8	Clay	*37.3
A2	HG320	1.2	Sand	35.8
A3	HG180	1.2	Sand	51.1
A4	HG100	1.2	Sand	45.9
A5	HG320	1.8	Clay	*16.2
A6	H110	1.0	Sand	26.0
A7	H50	1.0	Sand	14.0
A9	HG320	1.8	Clay	*13.1
B1	HG100	1.8	Clay	-
B2	HG100	1.8	Clay	*7.9
B3	H50x2	1.0	Sand	16.2
B4	H110	1.0	Sand	20.5
B5	HG100	1.8	Clay	*12.5
B6	H110	1.8	Clay	*6.1
B7	H110	1.8	Clay	*8.5
B8	H50	1.8	Clay	*4.5
B9	HG100	1.8	Clay	*8.8
C1	HG180	1.8	Clay	*17.1
C2	HG320	1.2	Sand	66.1
C3	HG180	1.2	Sand	64.3
C4	HG100	1.2	Sand	62.7
C5	HG180	1.8	Clay	*17.7
C6	H110	1.0	Sand	37.6
C8	H50	1.0	Sand	22.3
C9	HG180	1.8	Clay	*12.5
BC2.5	H50	1.0	Sand	10.7

Note: * $F_{\max}$ between the depths of 1.8 and 1.3 m.

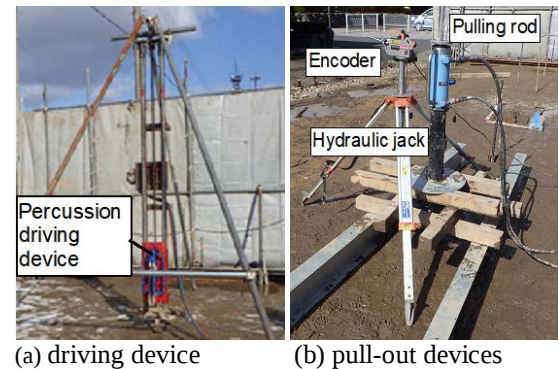


Fig. 11 Experimental devices

3. RESULTS OF THE EXPERIMENTS

3.1 Pull-Out Force vs. Pull-Out Displacement

Figures 12-16 compare the relationships between pull-out force F and pull-out displacement w of the anchors installed in the sand or the clay layer. The sand and the clay layers were separated

at about a depth of 1 m (Figs. 6 and 7).

In the initial stages of pull-out loading, the behaviors of all anchors showed similar trends. For all the anchors in the sand layer, except HG320, the pull-out resistance was mobilized very quickly with a small pull-out displacement w and then leveled off until w reached about 100 mm.

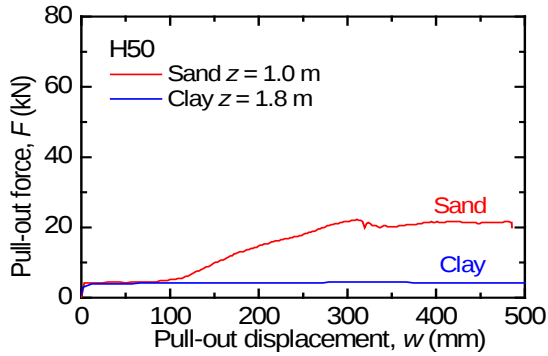


Fig. 12 F vs. w of H50 anchors installed in the sand or the clay layer

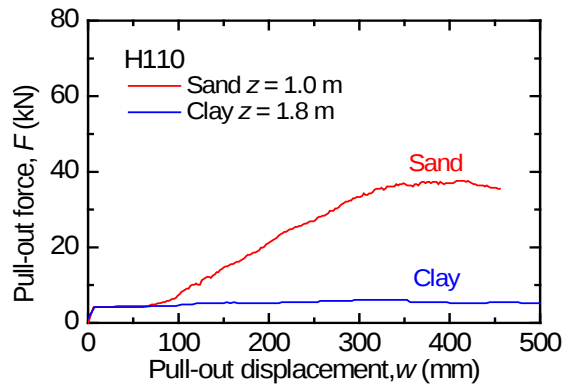


Fig. 13 F vs. w of H110 anchors installed in the sand or the clay layer

For anchors in the sand layer, F began to increase again after this plateau and attained a peak value at a relatively large w of 400-500 mm. By comparing Figures 15 and 16, F of the 440 mm-long HG320 anchor began to increase at about 50 % of w of the 340 mm-long HG180.

It is noticed that the anchor apex levels of HG180 and HG320 were equal and 200 mm-section of the anchors were embedded in the clay layer. That is, the section length of HG180 in the sand layer was 140 mm, while that of HG320 was 240 mm at the start of the pull-out tests. Hence, it is reasonable that pull-out resistance of HG320 was promptly mobilized by smaller w , compared with that of HG180.

In the clay layer, the anchors maintained a plateau from the initial stage to w larger than 500 mm, as shown in Figures 12 and 13 in which small-

sized anchors were tested. As shown in Figures 14 and 15, HG100 and HG180 anchors ($L = 340$ mm) required w equal to their anchor length until F began to increase again, and reached their peak values in the clay layer at an additional Δw of around 100 mm. The anchors seemed to be fully opened at this stage.

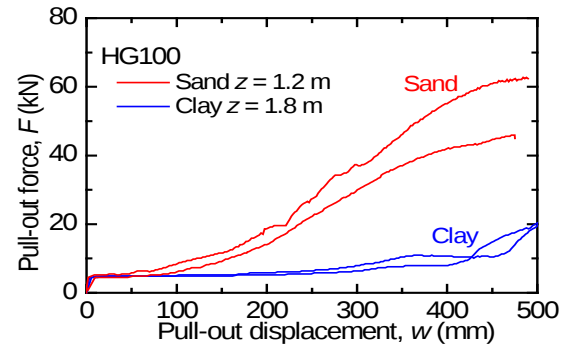


Fig. 14 F vs. w of HG100 anchors installed in the sand or the clay layer

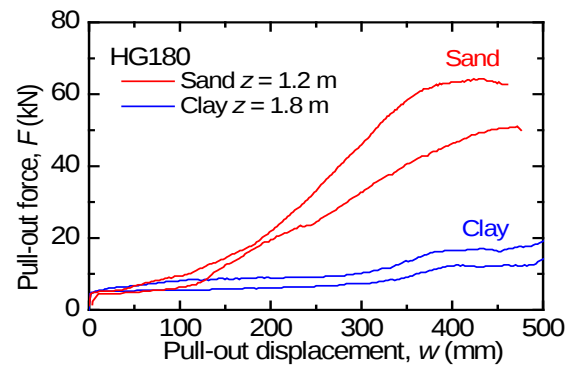


Fig. 15 F vs. w of HG180 anchors installed in the sand or the clay layer

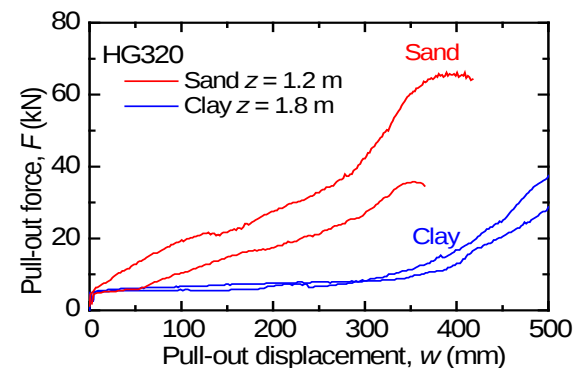


Fig. 16 F vs. w of HG320 anchors installed in the sand or the clay layer

As shown in Figures 12-16, the anchors in the sand layer had significantly greater F values than the anchors in the clay layer. However, overburden pressures in the sand layer were smaller than those

in the clay layer. Therefore, if the anchors are installed in the clay layer below the sand layer, the effects of the top sand layer could be ignored in design of pull-out resistance when the anchors do not reach the sand layer.

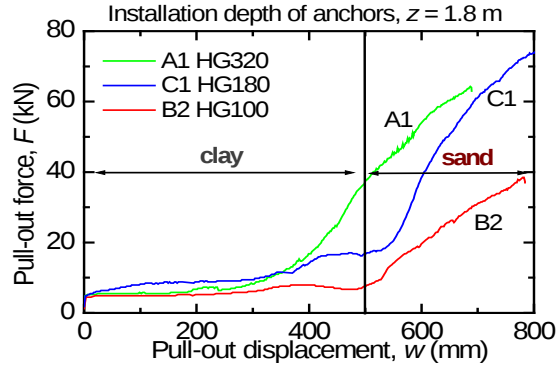


Fig. 17 F vs. w of HG anchors installed in the clay layer through the overlying sand layer

Figure 17 shows F vs. w of the anchors installed at a depth of 1.8 m. F of HG100 and HG180 began to increase rapidly when the anchors reached the sand layer. In the sand layer, the larger the anchor size was, the greater the pull-out force was. It can be seen that when the anchors were pulled in the clay layer, F was not affected by the overlying sand layer, when the distance to the bottom of the top sand layer was relatively large.

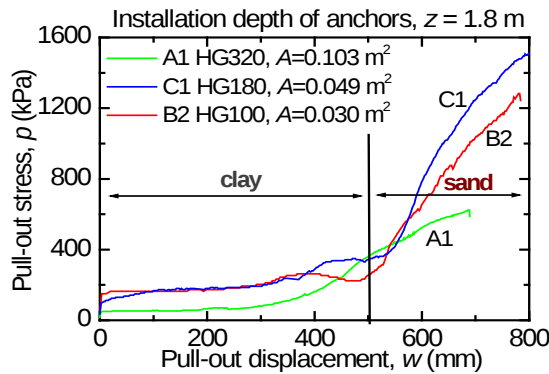


Fig. 18 p vs. w of HG anchors installed in the clay layer through the overlying sand layer

Figure 18 shows the relation between the pull-out pressure, $p = F/A$, and w of the HG anchors. In the sand layer, p becomes smaller as A increases. In sandy ground conditions, plate anchors such as rectangular and circular anchors lift inverted trapezoidal soil wedges above the anchor plates [10, 17, 18]. This ground failure mechanism usually increases p as A decreases. The measured trend of p in the sand layer conformed to the above

mechanism. The p values of HG100 and HG180 remained almost constant, and their amplitudes were almost similar during being pulled out in the clay layer. However, p of HG320 were smaller than the p of the former two anchors, when $w < 400$ mm. As HG320 had approximately three times A of HG100, a larger w was required to be opened sufficiently. Therefore, at w of 500 mm, p of HG320 were nearly equal to p of HG100 and HG180. It could be said that p in the clay layer is equal regardless of A when the anchor plate opened sufficiently at $w > 400$ mm. Therefore, in the clay layer, the p values of sufficiently opened anchors were nearly constant regardless of the size of the anchors.

3.2 Calculation Method of Pull-Out Resistance of Flip Anchors in Clay

3.2.1 Estimation methods for plate anchors in clay

Das [12] presented a procedure for estimation of the ultimate uplift capacity of shallow and deep anchors in clay as Eq. (1).

$$Q_0 = BL(\beta F_c^* c_u + \gamma H) \quad (1)$$

where Q_0 is the net ultimate capacity, B is the width of an anchor, L is the length of an anchor, $\beta = F_c/F_c^*$, F_c is breakout factor for a shallow anchor [$H/B < (H/B)_{cr}$], F_c^* is breakout factor for a deep anchor [$H/B \geq (H/B)_{cr}$], c_u is undrained shear strength of soil, γ is effective unit weight of soil, H is the embedment depth of the anchor.

In this procedure, once c_u is given, critical embedment ratio $(H/B)_{cr}$ can be calculated using Eq. (2) or Eq. (3) for a square and circular anchor $(H/B)_{cr(S)}$, or a rectangular anchor $(H/B)_{cr(R)}$, respectively.

$$(H/B)_{cr(S)} = 0.17 c_u + 2.5 \leq 7 \quad (2)$$

$$(H/B)_{cr(R)} = (H/B)_{cr(S)} [0.73 + 0.27 (L/B)] \quad (3)$$

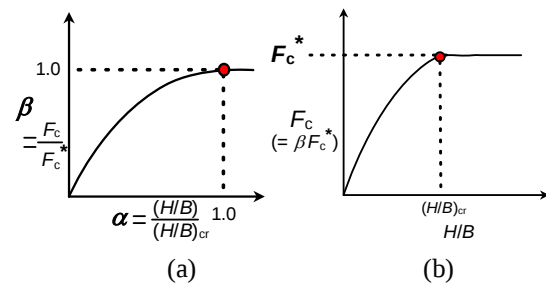


Fig. 19 Plots of (a) α vs. β and (b) F_c vs. H/B

Using the value of $(H/B)_{cr}$, $\alpha [= (H/B)/(H/B)_{cr}]$ can be estimated. Then, β can be estimated from the value of α (Fig. 19a). F_c increases with embedment

ratio H/B , then levels off at $(H/B)_{cr}$ keeping the maximum value ($= F_c^*$) (Fig. 19b). That is, β functions as a reduction coefficient for F_c^* for a shallow anchor.

Value of F_c^* is usually considered as F_c^* for a square or circular anchor ($= F_{c(s)}^* \approx 9$). $F_{c(s)}^* \approx 9$ is for a square or circular anchor.

For a rectangular anchor, $F_{c(R)}^*$ is estimated by means of Eq. (4) reflecting shape factor-[16].

$$F_{c(R)}^* = F_{c(s)}^* S \quad (4)$$

where $F_{c(R)}^*$ is breakout factor of a rectangular deep anchor, $F_{c(s)}^*$ is breakout factor of a square deep anchor and S is shape factor of an anchor [$S = 0.84 + 0.16 (B/L)$].

When all the parameters are determined in this process, pull-out resistance can be calculated using Eq. (1). However, in a field, c_u of the ground usually is not uniform, and $(H/B)_{cr}$ and F_c^* vary with c_u . And as the shape of flip anchors are neither square nor rectangular, the shape factor S and the $F_{c(R or S)}^*$ cannot be directly applied to flip anchors. Moreover, as a certain amount of pull-out displacement is necessary for flip anchors to attain maximum pull-out resistance, $(H/B) / (H/B)_{cr}$ for flip anchor cannot be estimated accurately.

Therefore, a more practical procedure is proposed for estimating pull-out resistance of flip anchors installed in clay ground.

3.2.2 A calculation method for flip anchors in clay

The interpretation method for T-bar penetration test is applied for estimating pull-out resistance of flip anchors in clay.

In the T-bar test, the c_u value is estimated using Eq. (5) [19] with the measured value of pressure p on the T-bar:

$$c_u = p / N_b \quad (5)$$

where N_b is the bearing factor of T-bar. N_b ranges from 8.5 to 12.5 for various types of clay with an average value of 10.5 [20]. In this field experiment, the range of c_u of the clay was estimated by means of the VSTs, as mentioned earlier. Even when estimating the c_u from soil tests other than the T-bar test, it is assumed that the pressure of the anchor p can be estimated using Eq. (6):

$$p = N_b c_u \quad (6)$$

Figure 20 shows the comparison of the measured p of the anchors and the estimated p using Eq. (6). It is seen from Figure 20 that the range of the calculated values of p reasonably agreed with

the measured values of p .

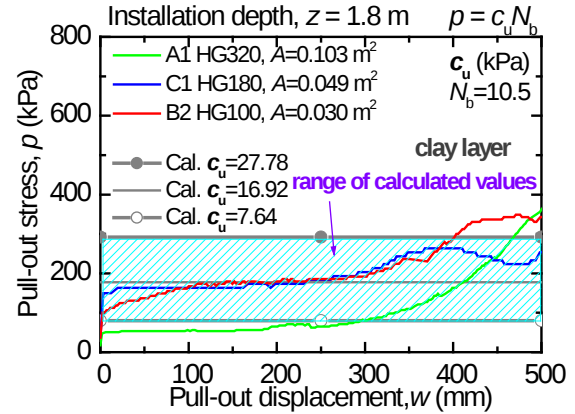


Fig. 20 Calculated p in clay vs. measured p .

When performing the T-bar penetration test on site, the p values from the T-bar test can be directly used in Eq. (7) to estimate pull-out resistance of a flip anchor.

$$F = pA \quad (7)$$

Currently, the T-bar penetration test is rarely used for site investigations in Japan. In practice, the c_u values are empirically estimated from the SPT- N values, VST, pressuremeter test, or unconfined compression test. Therefore, if the c_u value is obtained, the pressure on the anchor can be estimated using Eq. (6).

4. CONCLUSIONS

The field pull-out experiments of flip anchors were conducted in the ground where a top sand layer covered a clay layer, to investigate the pull-out mechanisms of flip anchors in clay.

Main findings from the experiments are summarized as:

- (1) Pull-out behavior of flip anchors in clay was quite different from that in sand.
- (2) As for the anchors pulled out in clay, unlike the case in sand, pull-out force F was not much affected by the overburden pressure. Moreover, F of the anchors in clay was not affected by the overlying sand layer.
- (3) In clay, F was proportional to the projected area of anchor A . This indicates that the stress p acting on the anchor head was constant regardless of the size of the anchor in clay.
- (4) The predicted p range estimated from the c_u of the VSTs and bearing factor of T-bar N_b of 10.5 agreed well with the measured p range.
- (5) The estimation method based on the interpretation of T-bar penetration test could be

a promising way to estimate pull-out resistance of flip anchors in clay ground.

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