Suction effect in plate anchors in soft clays

L'effet de succion des plaques d'ancrage dans les argiles molles

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SYNOPSIS: The vertical breakout capacity of plate anchors in clay is governed by the breakout resistance offered by soil and the soil suction force. Very little attention has been focussed on identifying the magnitude of the soil suction force and the factors which control it. This paper presents results of an experimental study conducted to understand this component of breakout capacity. The study reveals that suction force can cause breakout factors to increase by 0 to 6 depending upon the soil-water system and the rate of loading. The suction force may contribute to the breakout capacity of plate anchors under short term loads but should be neglected for long term stability.

INTRODUCTION

The need to understand the behaviour of anchors embedded in soft clay has come to the fore in India in view of the likelihood of finding commercially exploitable reserves of hydrocarbons off the eastern coast of India. The offshore environment in this region is characterized by a narrow continental shelf with deposits of soft underconsolidated clay. The large water depth and low strength soil will require offshore platforms of a variety different from the jacket-type being used extensively at Bombay High. To determine the appropriate variety requires a consideration also of floating platforms anchored to the sea bottom. At the Marine Geotechnology Laboratory at IIT Delhi an exhaustive study of anchors in soft submarine soils has been underway for some years now. This study has received additional impetus recently through sponsorship by ONGC.

As per literature, the static holding capacity of an embedded anchor is considerably enhanced by the suction that develops between the base of the anchor and the underlying soil. The life of this component, i.e. the time duration for which the component contributes to the holding capacity is however not known. This paper describes the results of an investigation directed at studying the magnitude of the "suction component".

BREAKOUT FORCE

Figure 1 depicts schematically the forces relevant in defining and assessing the breakout force of a plate anchor embedded in clay at the bottom of the sea, from which it is evident that

$$(P_{ult})_v = W_s + F_v + R_v + P_{sv} \qquad \text{Eq.1}$$

where, $(P_{ult})_v$ is the ultimate vertical breakout force; W_s is the submerged weight of anchor; R_v is the resistance offered by soil, and, P_{sv} is the force on account of suction. In a plate anchor, the thickness of the anchor "t" in comparison to the dimension B is usually so small that one can ignore F_v. Plate anchor is not a dead weight anchor and as such W_s is small and can be ignored. Eq.1 thus reduces to

$$(P_{ult})_v = R_v + P_{sv} \qquad \text{Eq.2}$$

Studies by Vesic (1971) have shown that for deep anchors in soft soil (D/B>2) the resistance offered by clay, R_v, is essentially similar regardless of whether the object in clay is subjected to downward force as in a foundation or to upward force as in an anchor and has a magnitude of

$$R_v = C\,N_c = 9C \qquad \text{Eq.3}$$

Where C is the undrained strength multiplied by plan area of anchor and N_c is the bearing capacity factor related to undrained shear strength. There is scant information about P_{sv}, the other force contributing to breakout force. Its magnitude has been expressed in term of C by a number of researchers as given in Table 1. From Table 1 it is evident that the magnitude of P_{sv} is not insignificant. The factors on which P_{sv} depends have, however, not been identified and the current views are based on too few tests.

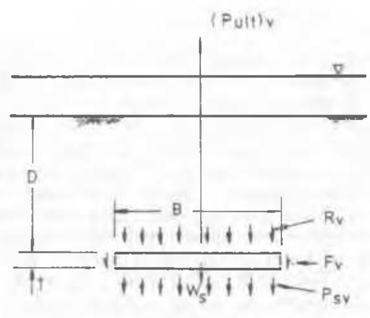

Figure 1. Forces during plate anchor pullout.

Table 1 Suggested Values of Breakout Factor due to Suction Force (P_{sv}/C)

Authors	Anchor Shape and size(cms)	Engg.Prop.of clays used: Soil Type	LL	PL	Su kg/cm^2	Method of eliminating suction	No of tests conducted	Pullout velocity mm/min	Recommended value of P_{sv}/C
Bemben & Kupferman (1975)	Fluke dia = 7.6	Bentonite	115	54	0.15	Atmospheric pr.below anchor	large number	0.025	6
Nhiem (1975)	Circle 5.73 Square 4.5 Rect. 3X6 Strip 2X12	Silty Clay	34-35	17	0.05 to 0.06	Details not given	20	40	5-7
Davie & Sutherland (1977)	Circular Dia = 2.5 - 20	Sodium Bent.& Glycerine	-	-	0.05 to 0.18	Details not given	2 with suction	1.5	3

EXPERIMENTAL PROGRAMME

In the study under report, tests have been conducted on one clay type, one anchor size, one anchor shape, one depth of embedment but the following parameters have been varied:

a) Water content of clay - 3 values in the range of 33.0% to 40.0% when L.L. for this soil is 51% and P.L. is 30%.

b) Pullout mechanism and pullout rate : strain controlled with pullout velocities of 0.2, 1.0, 5.0 and 25.0 mm/min and stress controlled with load increments of -

(i) 1/8th of breakout force as determined from strain controlled test. Each increment applied for a duration of 1/2 hour.

(ii) Same load increment as in (i) above but each increment applied for a maximum duration of 4 hours.

For each set of variables indidcated above, two pullout tests were conducted, one in which suction below anchor was definitely not allowed to develop and one in which it could develop.

EXPERIMENTAL SET UP

Figure 2 schematically shows the arrangement used for model testing. A load cell measured the break- out force and a LVDT measured the upward displacement of anchor. For stress controlled tests the load was applied by dead weights and transmitted to the anchor through 2 pulleys. For strain controlled tests the deformation was induced by a motorized gear box unit and transmitted through 1 pulley. Figure 3 gives the detailed dimensions of the anchor, anchor rod, tank used, embedment depth and depicts the arrangement for eliminating suction below the anchor

EXPERIMENTAL PROCEDURE

Soil, after mixing with the required quantity of water, was placed in the tanks by hand ensuring that no air pockets were formed. Soil placement was stopped when the level at which anchor had to be located was reached. Anchor with the anchor rod were placed on soil and the anchor rod clamped in position. Soil placement was then continued to give the anchor the desired embedment. The tank was then left for 7 days after covering it with a polythene sheet for the soil moisture to equilibriate and for thixotropic gain of strength to take place-most strength gain in this soil took place in the first 3 days

For control purposes, moisture content was determined at 4 depths and at 5 locations at each depth. Results indicated that the moisture content was essentially constant in the zone of the anchor and anchor displacement. Undrained

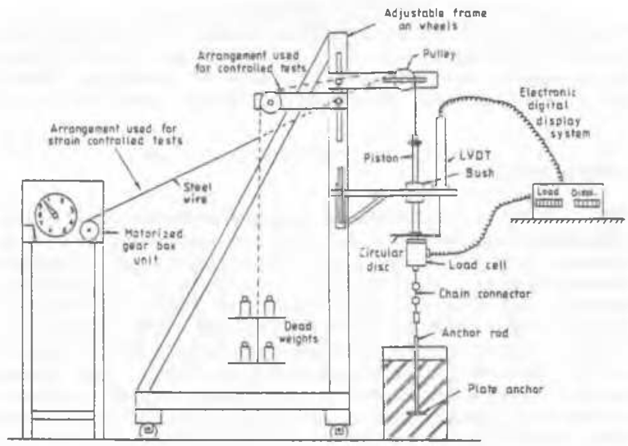

Figure 2. Arrangement for model testing.

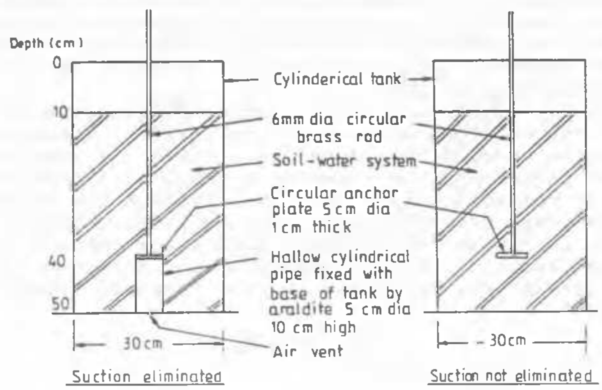

Figure 3. Details of anchor, tank and arrangement for eliminating suction.

strength,Su,was measured by bringing the vane shear apparatus on top of the tank after anchor had been pulled out. Su was measured at 3 depths and 2 locations at each depth. In calculating breakout factors Su measured in the zone of the anchor and anchor displacement was used.

OBSERVATIONS

Breakout force-anchor displacement curves obtained from model tests under different pullout mechanisms and pullout rates at average water content of 33.7% are shown in Figs. 4,5, and 6. Similiar results were obtained at average water contents of 35.4% and 38.3% Since peaks were not observed in all the curves, anchor faliure was assumed to have occurred at displacement equal to the diameter of the anchor.

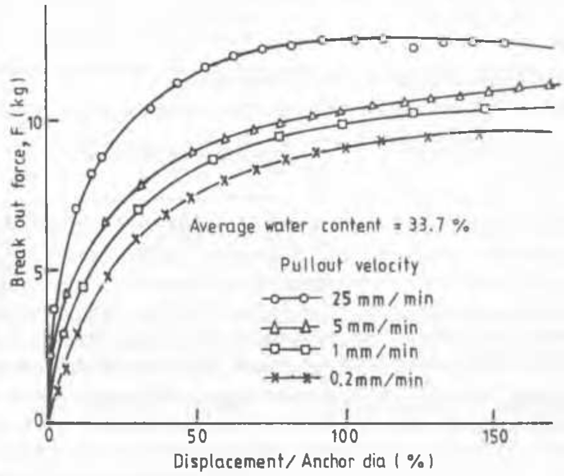

Figure 4. Breakout force - anchor displacement curves for strain controlled tests.

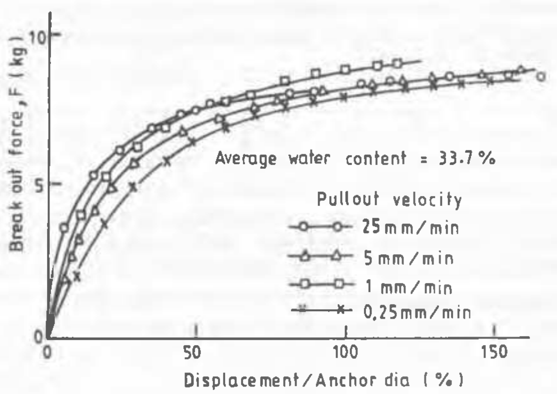

Figure 5. Breakout force - anchor displacement curves for strain controlled tests with suction eliminated.

Suction Force increases as Pullout Velocity Increases.
For similiar soil conditions, the breakout force in tests in which suction was not eliminated was observed to be more than in tests in which suction was eliminated when tests were conducted at high pullout velocity. For low pullout velocity there was little difference between the observed breakout forces.These observations are depicted in Fig.7.in which percentage of suction is plotted V/s pullout velocity. Percentage suction force is defined as:

$$\frac{P_{sv}}{(P_{ult})_v} = 100 \times \frac{(P_{ult})_v \text{ with suction not eliminated} - (P_{ult})_v \text{ suction eliminated}}{(P_{ult})_v \text{ with suction not eliminated}}$$

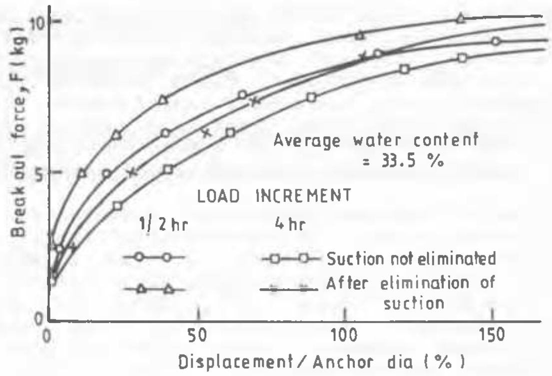

Figure 6. Breakout force - anchor displacement curves for stress controlled tests.

Suction Force Reduces with Increases in Water Content.
Percentage Suction Force is observed to diminish with increase in water content in the range of water content investigated as is evident from Fig.7.
Breakout Force not Influenced by Pullout Velocity when Suction Force Eliminated.
In tests conducted with suction force eliminated by placing hollow cylinder below the anchor, the breakout force is only on account of the resistance offered by the soil above the anchor i.e. R_v.There is no mechanism by which R_v should vary significantly with pullout velocity in the range of velocities used. This is corroborated by experimental observations as shown in Fig. 8. Also evident from Fig.8. is that breakout force increases with reduction in water content since the Su increases with reduction in water content.

Breakout Force is Constant when Suction Force is Eliminated or not Developed.
When pullout conditions are such that suction force is either eliminated or not developed, the breakout force will equal R_v and will thus be dependent only on the undrained strength of soil. This is evident from Table 2 where the range of measured breakout force for each water content is narrow for the following testing conditions :
(i) Strain controlled tests with suction eliminated i.e. P_{sv} ensured to equal zero.

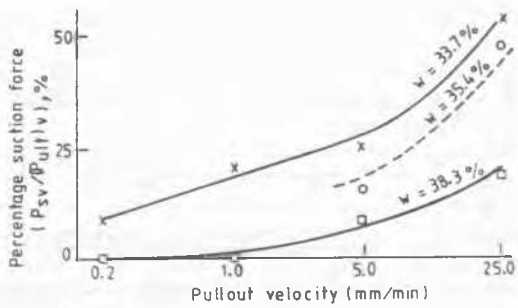

Figure 7. Suction force increased with increase in pullout velocity.

(ii) Strain controlled test with suction not eliminated but at slow pullout velocity of 0.2 mm/min i.e. P_{sv} does not develop and equals to 0.

(iii) Stress controlled tests with suction eliminated i.e. P_{sv} ensured to equal zero.

(iv) Stress controlled tests with suction not eliminated but load applied slowly under which condition P_{sv} does not develop and equals to 0.

Magnitude of Breakout Factor-Soil Resistance.
As indicated in Eq.3. the Breakout Factor, R_v /C has been found to be about 9. The Breakout Factors observed in the current series of tests are tabulated in Tables 3 & 4. Except for one value which had a magnitude of 15.57 the other values range between 7.5 and 11.29 in strain controlled tests and between 7.1 and 11.87 in stress controlled tests thereby generally corroborating previous evidence.

Magnitude of Breakout Factor - Soil Suction
Table 1 presented the summary of literature relating to the observed values of Breakout Factor due to suction force, P_{sv} /C, and they ranged between 5 and 7 except that a value of 3 had been observed in 2 tests in a soil-glycerine system.The observed values of P_{sv} /C are tabulated in Tables 5 & 6.The highest value observed was 5.41 for pullout in soil with the lowest water content and at the higest pullout velocity. The lowest value observed was zero. The observed data indicates that the contribution of suction force to breakout force is a function of the breakout time and also of the state in terms of its water content.

IMPLICATIONS

The experimental work reported herein is not exhaustive enough to arrive at and list conclusions. Neverthless it is more extensive than any so far published in literature and reveals that

(i) Suction force is likely to develop only when breakout time is short.

(ii) Suction force is a function of the state of the soil-water system.

(iii) The magnitude of the Breakout Factor due to suction force can vary from 0 to values of the order of 5 to 6.

The inference from these implications in relation to anchoring floating platforms in the offshore environment which apply sustained load on the anchor may well be that one cannot rely on the suction force for long term stability; the suction force may contribute to resistance that the anchor-soil system can mobilize when additional loads on a short term are to be withstood.

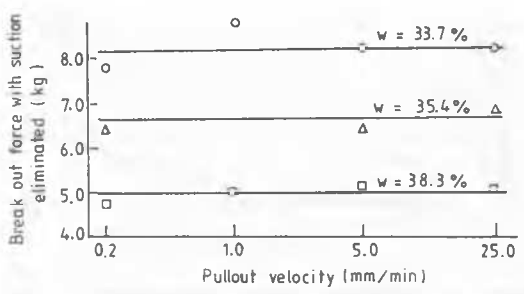

Figure 8. Breakout force with suction eliminated not influenced by pullout velocity.

Table 2 Breakout Force when P_{sv} is zero (Kg).

Water Cont. w%	Strain Contr. Suction Elim.	Strain * Controlled Suction not Eliminated	Stress Contr. Suction Elim.	Stress Contr. Suction not elim.	Avg. Val. Kgs.
33.7	7.8-8.8	9.0	8.6-9.4	7.7-8.5	8.45
35.4	6.4-6.9	-	4.5-6.0	5.2	6.00
38.3	4.7-5.1	4.7	4.0-5.2	4.5-5.5	4.87

* (Pullout Velocity = 0.2mm/min.)

Table 3 Rv/C from Strain Cont.Tests with P_{sv} =0

Pullout Velocity mm/min.	Water Content w% 33.7	35.4	38.3
25	8.81	10.60	11.25
5	8.60	10.32	11.25
1	7.50	-	15.57
0.2	8.00	-	9.70

Table 4 Values of Breakout Factor, Rv/C from Stress Controlled Tests with Suction Eliminated

Duration of application of each increment	Water Content,w% 33.5	37.7	39.7
1/2 hour	-	7.10	-
4 hour	7.44	7.41	11.87

Table 5 Values of Breakout Factor due to Suction Force, P_{sv} /C from strain controlled test

Breakout time Min.	Pullout Vel.mm/min.	w (%) 33.7	35.5	38.3
4	25	5.41	4.35	1.70
20	5	2.50	2.00	0.75
100	1	1.00	-	0.00
500	0.2	1.30	-	0.00

Table 6 Values of Breakout Factor due to Suction Force,P_{sv} /C from Stress Controlled Tests

Breakout time min	Duration of application of each increment	w(%) 37.7	39.7
250	1/2 hr	2.00	-
1800	4 hr	-	1.50

REFERENCES

Bemben,S.M. & Kupferman,M.(1975). The Vertical Holding Capacity of Marine Anchor Flukes Subjected to Static and Cyclic Loading. Proceedings Off-shore Technology Conference, Houston, OTC 2185, 363-374.

Davie,J.R. & Sutherland,H.B.(1977). Uplift Resistance of Cohesive Soils. Journal of the Geotechnical Division, Proceedings ASCE, Vol.103, GT9:935-952.

Nhiem,Tran Vo.(1975). Uplift Resistance of Anchor Slabs in Soft Clay . Proceedings Soil Mechanics and Foundation Engineering Conference,Istanbul, Vol.2,114-123.

Vesic,A.S.(1971). Breakout Resistance of Objects Embeded in Ocean Bottom .Journal of Soil Mechanics and Foundations Division, Proceedings ASCE, Vol 97:SM9 1183-1205.