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SUPERPILE ANCHORS IN SOFT CLAY

ANCRAGES DE SUPERPIEUX EN ARGILE MOLLE

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SYNOPSIS: A superpile anchor consists of an open ended pile in which the pile top is sealed after installation so that the soil inside the pile becomes an integral part of the pile itself. This paper presents the results of an experimental study conducted to identify the conditions under which the soil plug in a model superpile falls out. The pullout load-displacement behaviour of embedded model superpiles was also studied to identify the difference in behaviour from that of conventional model piles. The study reveals that in the absence of an air path connecting the top of the soil plug to the outside environment, the soil plug does not fall down in the case of clays under static conditions as well as under the influence of externally applied impact and vibrations. For sands, the soil plug does not fall out in the absence of an air path under static conditions but it falls when impact or vibrations are imparted. Under static pullout, superpiles do not show failure at low displacements but the pullout load continues to increase with displacement upto 30% of the diameter. In contrast, conventional piles show distinct failure at a much lower displacement of about 5% - 10% of pile diameter. The ultimate pullout load for superpiles is significantly greater than that of conventional piles. The pullout load of superpiles increases with pullout velocity.

INTRODUCTION

Beyond about 250 m of water depth, the cost of a jacket type structure increases rapidly. This has encouraged the development of compliant structures such as guyed towers and tension leg platforms. These structures are held in position by being anchored to the seabed.

One alternative of providing anchorage to the tendons of a tension leg platform is the gravity anchor. If the tension forces are too high or the soils are too soft, then long piles in tension may be more appropriate. Only little is known about the long-term performance of long piles when subjected to cyclic tension. Thus, the design of long pile anchors is often uncertain. Further, in very deep water, there are technical and logistic problems associated with the installation of very long piles. Hence, the search for an alternative foundation system is relevant.

The superpile is one such system proposed by Albert et. al.(1989). A superpile anchor consists of an open ended pile in which the pile top is sealed after installation so that the soil inside the pile becomes an integral part of the pile itself. A superpile differs from the conventional long tubular pile in three ways:

(a) The superpile is a large diameter short pile with a closed top whereas the conventional pile is normally a much smaller diameter long pile with an open top [Figures 1(a) and 1(b)].
(b) On account of the closed top of the superpile, soil within the pile is visualised to remain there and function as a soil plug to resist pullout loads. The breakout force is substantially enhanced on account of the dead-weight of the large quantity of soil within the pile. Figure 1 highlights the different components which contribute to breakout forces in the superpile anchor and the conventional pile anchor.
(c) Conventional pile anchors are installed by driving whereas superpile anchors would be installed with the help of a suction system at the top of the superpile.

Though the concept of a superpile anchor was proposed as early as 1989, no data has as yet, been reported in literature which validates the concept. This paper presents results of a laboratory-based model study conducted to understand the mechanisms which govern the formation of a soil plug inside a superpile. The objectives of the present study were:

(a) to identify the conditions under which the soil plug in a model superpile falls out; and
(b) to study the difference between the pullout load-displacement behaviour of embedded model superpiles and that of embedded model conventional piles.

Two separate experimental investigations were conducted to study the above two aspects.

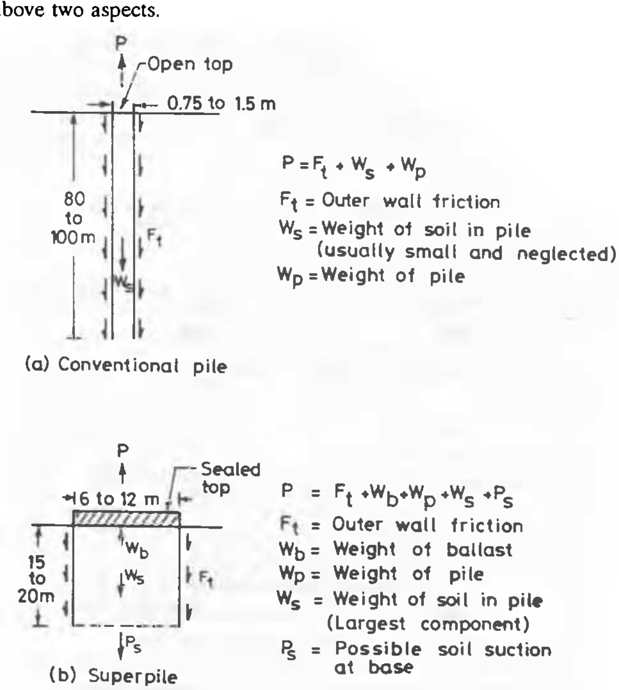

Fig. 1. Components of breakout capacity

SOIL PLUG MOVEMENT IN SUPERPILES

The ratio of length to diameter, L/D, of superpiles proposed by Albert et.al.(1989) ranges from 1.3 to 3.3 and the ratio of the weight of the soil in the superpile and the friction on the internal superpile wall, W_s/F_v, ranges from 1 to 2.

To study the factors influencing the formation and movement of soil plug, model superpiles made of perspex having a length of 10 cm, diameter of 20 cm and wall thickness of 5 mm were used. The W_s/F_v ratio of the model superpiles was equal to 2.2 for clay indicating that the internal friction in the superpile would not be sufficient to support the soil weight. The L/D ratio was however only 0.5. A shorter length was chosen because the propagation of air paths could be studied in more detail with shorter lengths.

Experimental Investigation

Soil was filled in model superpiles with the piles inverted. These were then upturned and the times taken for the soil plug to fall down under static conditions as well as under vibrations were recorded. Vibrations were induced by placing the model superpile on a vibrating table having a vibrating frequency of 280 cycles/min. Tests were also conducted by applying impact load on superpiles by physically lifting and dropping the superpile by 5 cm. In these tests, the number of drops which caused the soil plug to fall out were counted. Two types of soils were used:

(a) Dhanauri clay having a plastic limit of 28 and liquid limit of 45; and
(b) Yamuna sand, a medium fine silica sand.

Clay at a water content of 37% was kneaded into the model superpiles with hand ensuring that no air was entrapped. Sand placement was achieved by filling the inverted superpile with water and pouring sand in it.

An experimental programme was designed to study the influence of the following parameters on the movement of soil plug inside the superpile:

(a) Presence of holes at the top and at the sides of the superpile.
(b) Presence of an air gap between the soil and the top of the superpile.
(c) Influence of externally applied impact and vibrations.

Fig. 2 shows model superpiles in their actual testing positions. The open end of the model piles rested on spacers which in turn rested on a table or a vibrating table. Four series of tests were performed as described below.

In the first series, the top of the model superpile comprised of a solid perspex disc perfectly sealed at the contact with the pile wall [Fig. 2(a)].

In the second series, two holes of 5 mm diameter were provided diametrically opposite to each other on the pile top at a distance of 9 cm from the pile centre [Fig. 2(b)]. During soil filling, these holes were temporarily sealed.

The third series of tests was similar to the second series except that the holes were provided at two diametrically opposite locations at the sides of the pile at a distance of 1 cm from the top of the pile [Fig. 2(c)].

In the fourth series, an attempt was made to study the plug behaviour in the absence of a contact between the inner surface of the pile top and the upper surface of the soil. This was done by introducing an air gap at the top [Fig. 2(d)].

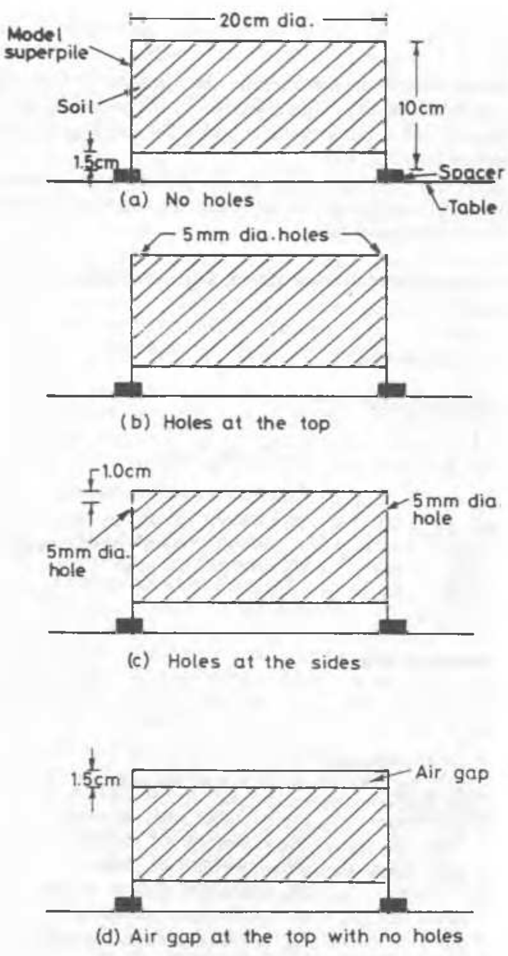

Fig.2. Arrangement for soil plug movement tests

Results

The results of the tests are tabulated in Table 1 for clay and Table 2 for sand. The following can be observed:

(a) When the superpile top is completely sealed (Series 1), both sand and clay do not fall down under static condition. Sand falls down after impact and vibrations are given, but clay does not.

(b) When there are two 5 mm diameter holes at the top (Series 2), clay does not fall down but sand falls down within 30 minutes under static conditions. For both clay and sand, as impact and vibrations are given, the soil starts separating from the inner surface of the pile top near the holes. After full separation takes place, the soil falls down rapidly. The number of drops and the duration of vibrations required for full separation to take place are higher for clays; for sand, separation takes place almost immediately.

(c) When there are two holes at the sides (Series 3), clay does not fall down but sand falls down within 24 hours under static conditions. With impact and vibrations, separation starts near the holes and gradually reaches the top plate resulting in the plug falling down both for clay and sand. The process is much faster for sand.

(d) When the superpile top is sealed with an air gap at the top (Series 4), clay does not fall down under static conditions. With impact and vibrations, the shape of the air gap changes and correspondingly, the clay profile changes at the bottom end, but the clay plug does not fall down. Under static conditions, sand also does not fall down even after 48 hours but water accumulates at the top. The sand at the bottom becomes dry and the dried portion falls off upon disturbance. The sand falls completely when impact and vibrations are given.

Table 1. Movement of Soil Plug (Clay)

Test Type	Movement of Soil Plug		
	Static	With Impact	With Vibration
Closed top, no air gap	Does not fall down	Does not fall even after 200 drops	Does not fall down even after 3 hours of vibrations
Two 5mm dia. holes at top, no air gap	Does not fall down	Falls down after 35 drops	Falls down slowly after 1 hour of vibrations
Two 5mm dia. holes at sides, no air gap	Does not fall down	Falls down after 30 drops	Falls down slowly after 1 hour of vibrations
Closed top with air gap	Does not fall down	Does not fall down; as the no. of drops increase, the shape of the air gap changes.	Does not fall down; as the duration of vibrations increases, the shape of the air gap changes.

Table 2. Movement of Soil Plug (Sand)

Test Type	Movement of Soil Plug		
	Static	With Impact	With Vibrations
Closed top, no air gap	Does not fall down	Falls down after 33 drops	Falls down after 2 hours of vibrations
Two 5mm dia. holes at top, no air gap.	Falls down within 30 minutes	Falls down after 1 drop	Falls down immediately
Two 5mm dia. holes at sides, no air gap	Falls down within 24 hours	Falls down after 3 drops	Falls down immediately
Closed top with air gap	Does not fall down even after 48 hours; water accumulates at the top and the sand at the bottom gets dry and starts falling off upon disturbance.	Falls down after 19 drops	Starts falling down after 30 minutes of vibrations.

PULLOUT BEHAVIOUR OF EMBEDDED SUPERPILES

Pullout tests were done on model superpiles buried in soft clay in model test tanks to understand the pullout load-displacement behaviour of superpiles. Different diameters of piles and different pullout velocities were used. Some tests were done by keeping the pile top open to simulate the situation of conventional piles and study their pullout load-displacement behaviour. The piles used were of length 12.5 cm, of wall thickness 3mm and the L/D ratios were 1.8, 2.1 and 2.8.

Experimental Investigation

A series of static pullout tests were conducted to identify the effect of the following variables on pile pullout load- displacement behaviour.
(a) Pile diameter - 4.4 cm, 6.0 cm and 7.0 cm
(b) Pullout velocity -0.2 mm/min., 1.0 mm/min. and 25 mm/min.
All tests were conducted using Dhanauri clay at a water content of 40%.

Fig. 3 shows the arrangement for model testing of embedded piles. A load cell measured the pullout load and a LVDT measured the upward displacement of the pile. The displacement was induced by a motorized gear box and transmitted through a pulley.

About 40 Kgs. of pulverized and dry clay was thoroughly mixed with the desired quantity of water and then placed in the test tanks by hand. To see that no air was trapped, the clay was placed in small quantities and pressed by hand lightly and uniformly. Soil was filled upto a height of 30 cm inside the test tank. A tubular superpile open at the top was then pushed into the soil slowly. Soil entered into the pile as the pile was pushed down. When the pile was fully buried, the pile was sealed at the top by fixing a pile cap made of perspex. The test tanks were kept covered and undisturbed for 4 days to allow thixotropic gain of strength. Pullout tests were then conducted.

At the end of each test, the undrained shear strength of soil surrounding each pile was determined by vane shear tests at two diametrically opposite locations and three depths inside the soil mass. Six tests were thus conducted in each tank. Uniformity of the water content was also checked in each test tank after the completion of each test. One soil sample each was collected from two diametrically opposite locations at six depths in the soil mass. A total of 12 samples for water content determination were thus taken from each test tank.

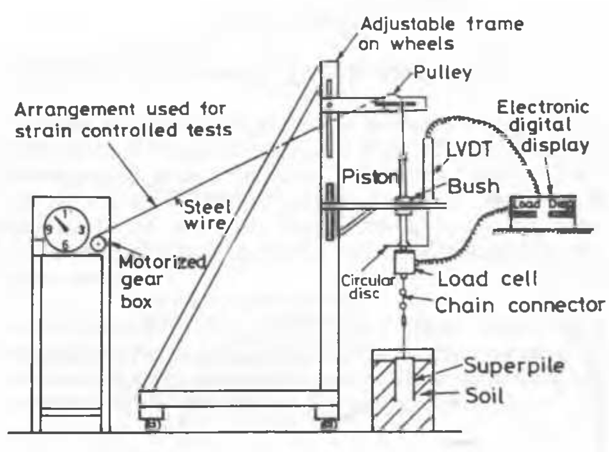

Fig. 3. Arrangement for model testing of embedded superpiles

Results

Fig. 4 shows the pullout load-displacement behaviour observed in tests conducted on superpiles and conventional piles of 3 different diameters. One observes from these figures that the conventional piles show failure at very low displacements of about 5% - 10% of pile diameter. On the other hand, superpiles do not show any distinct failure and the pullout load continues to increase with displacement upto as much as 30% of the superpile diameter. The ultimate pullout load of superpiles is higher than that of conventional piles. During the tests, it was observed that in conventional piles, the soil plug did not move up with the pile whereas in superpiles, the soil plug moved up with the superpile.

To investigate if suction at the tip of the pile was a contributing factor for pullout load, superpiles were pulled out at different velocities. Fig. 5 shows typical pullout load- displacement behaviour of a superpile at different pullout velocities. It is evident from this figure that pullout load increases with increase in pullout velocity. This increase is due to the increase in suction force with pullout velocity.

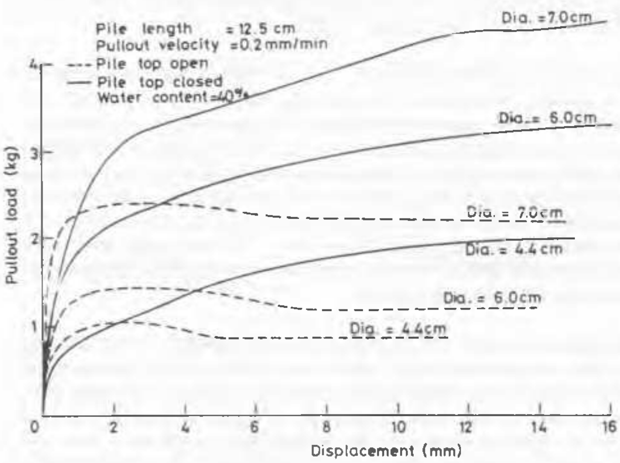

Fig. 4 Pullout load-displacement behaviour

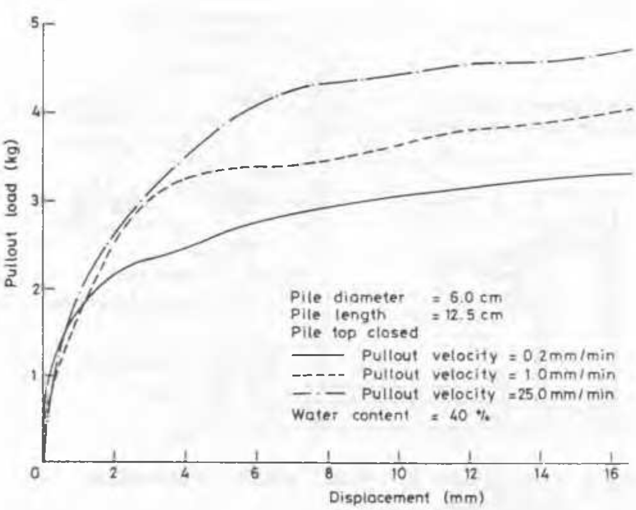

Fig. 5. Pullout load-displacement behaviour

Table 3. Suction Breakout Factors Observed at the Tip of Model Superpiles

Pullout Velocity	Pile Diameter (cm)		
mm/min.	4.40	6.00	7.00
0.2	0.97	1.33	-
1.0	1.87	2.12	1.81
25.0	3.63	3.02	3.31

The suction force (P_{su}) which developed at the superpile tip was evaluated as (Ultimate pullout load) - (Wt. of superpile) - (Wt. of soil plug) - (Friction on external wall). The ultimate pullout load was taken as the pullout load at a displacement of 20% of superpile diameter.

The breakout factors on account of the suction force were also calculated as $[P_{su}/(\text{Base area x } S_u)]$ where S_u is the undrained strength of the soil. These are listed in Table 3. One notes from the table that the breakout factors increase with pullout velocity and lie in the range reported by Baba et.al.(1989) for suction beneath plate anchors.

CONCLUSIONS

The following are the conclusions based upon the tests conducted to study the movement of a clay plug in superpiles.

(a) The plug does not fall out in the absence of an air path connecting the top of the plug to the outside environment.

(b) The plug also does not fall out when there is presence of an air gap at the top of the soil which is not connected to the outside environment.

(c) The plug falls slowly under static conditions when an air path is present. Impact and vibrations cause the plug to fall rapidly.

For a sand plug, the plug does not fall out in the absence of an air path under static conditions. However, it falls when impact or vibrations are given. For all other situations studied, it falls out.

The study of pullout load-displacement behaviour of superpiles in soft clays indicates that superpiles behave differently from conventional piles. Superpiles do not show failure at low displacements but the pullout load continues to increase with displacement upto 30% of the diameter. In contrast, conventional piles show distinct failure at a much lower displacement of about 5%-10% of pile diameter. The ultimate pullout load for superpiles is significantly greater than that of conventional piles.

The pullout load of superpiles increases with pullout velocity. This is on account of the presence of a significant suction force at the superpile tip, which increases with pullout velocity.

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