Field Scale Tests for Determination of Pullout Capacity of Suction Pile Anchors under Varying Loading Conditions

Vijaya Ravichandran[1], R. Ramesh[2], S. Muthukrishna Babu[3], G.A. Ramadass[4], .M.V.Ramanamoorthy[5] and M.A. Atmanand[6]
National Institute of Ocean Technology, Chennai, India
E-mail: vijaya@niot.res.in

ABSTRACT: Full scale tests have been conducted on suction pile anchors for testing the pullout behaviour under various loading conditions for mooring applications. Suction pile anchors with varying diameters and constant length to diameter ratios have been used in the tests. The tests have been carried out in the field within breakwaters where natural environmental factors like wind, lower waves and tidal influence exists. Comparison has been made between static pullout and dynamic loading on the suction pile. It is found that the pullout capacity of the suction pile anchors is influenced by pile geometry, angle of pullout and nature of pull (static / dynamic loading).

1. INTRODUCTION

Suction anchors are widely used in mooring applications for floating production units and find widespread applications in the offshore oil industries. Suction caissons or anchors are large cylindrical (inverted bucket type structure) open at the bottom and closed at the top. Presently these caissons are being increasingly used for offshore foundations in deep waters.

National Institute of Ocean Technology, (NIOT), India, proposes to install a desalination plant offshore in 1000m water depths and therefore there is a requirement to test feasibility of providing anchoring through suction pile foundation. Objective of the field tests is to assess the response of suction pile anchors to various loading conditions so that design criteria for mooring rope and prototype suction pile is established.

The mooring / pullout capacity of the suction pile anchors is influenced by suction pile dimensions, length to diameter (L/D) i.e., aspect ratio and installation methods. Suction pile anchor pullout capacities are generally determined from scaled model tests in the laboratory as field tests using larger piles are expensive and highly involved with respect to pile handling requirements in vessels in offshore conditions, sea state like high winds/waves etc.. statutory approvals with respect to testing etc. The instrumentation and equipment requirements for field tests do not significantly vary between model and prototype. The variations in environmental parameters like waves, currents, winds and tides can severely impact the performance of suction piles.

Several scaled down model tests are conducted in clay as there is no requirement for modeling the overburden pressure in clays. Review of literature reveals that several laboratory tests have been carried out on pullout behaviour primarily with focus on soil resistance offered to the suction pile during pullout. Generally, the impact of environmental conditions has not been tested in the laboratory. Goldberg (1994) has conducted laboratory scale model tests on small instrumented tubes (4.29 and 5 inch diameter) for assessing pullout capacity of pile and concluded that suction forces contribute over 75% of the pullout resistance. Tjelta (2001) suggested design methods to predict capacities for suction piles, which are not standardized, to the same extent as for ordinary piles. While it is possible to design suction piles in a variety of soil conditions using the present knowledge, combined (horizontal & vertical) capacity prediction is a coupled problem. According to Tjelta (2001) low aspect ratio of suction pile is required in sands and hard clays in order to limit extremely high suction values during installation. Aspect ratio greater than 1.5 is recommended in dense sands.

Higher aspect ratios may be adopted in soft clays as the anchor provides large penetration for the same weight thus reaching stronger clay strata.

Higher aspect ratio anchors may be easy to handle and more robust but often limited by resistance to penetration due to high. external friction and upward movement of soil plug. Optimal aspect ratio for a suction pile with inclined load may theoretically be when the failure mode is combined vertical and horizontal translation with no rotation, which requires an aspect ratio in the range 2-3. Luke et al. (2005) have conducted laboratory scale model tests for measurement of uplift capacity of suction piles in normally consolidated clay. Pull out tests were carried out with and without internal soil plug and the axial uplift capacity was evaluated. Axial capacities were considerably larger when the caisson was sealed during extraction, because of the large end bearing capacity and the weight of the interior soil plug.

Bang et al. (2005) have investigated the relationship between applied positive pressure inside the pile and the resulting pile movement. This was used to calculate the mobilized effective and friction angle ratios, which describes the reduction of the interface friction between pile and soil during retrieval.

Bang et al. (2006) have developed an analytical solution to estimate the vertical pullout capacity of embedded suction anchors. They found that the primary factors influencing the vertical pullout capacity include loading point, load inclination angle, the soil type, embedment depth and addition of flanges. Narasimha Rao (2006) studied the effect of inclination of the mooring chain. Inclination is found to significantly influence the uplift capacity of the suction anchor. It is found that as inclination changes from 0 to 90 degrees, with respect to horizontal, the resistance changes from passive earth pressure to skin friction.

2. DESCRIPTION OF FIELD TESTS

2.1 Site Description

Testing of piles was carried out at the Royapuram fishing harbour located in Chennai, Tamil Nadu, India. The test site was located within breakwaters where water depths of 4 to 5 m were available at all times. The variation in water depths was due to tidal variations off Chennai coast. Since the site was located within breakwaters, tests could be carried out with minimum impact of environmental conditions like wave action, rolling of deployment boat, currents and other uncertainties normally encountered in offshore locations. Waves of up to 0.3 m could be experienced within the breakwater and winds of up to 2 m/sec velocities were experienced during the trials. Tidal difference of up 0.6 m to 1.0 m was observed within the breakwater at the test location.

2.2 Soil data

Soil at the site was predominantly soft clay in the top 0 to 1.5 m layers followed by clayey silt. Undisturbed soil samples were collected at the test site and characterized in the laboratory. Hydrometer analysis and unconsolidated undrained triaxial tests were conducted on the soil. The soils are classified as CI (clays of medium compressibility) according to IS classification. The undrained shear strength was 7.5 kPa and Soil Modulus, E_s was 1500 kPa.

2.3 Suction pile geometry

Studies have been carried out on piles of four different diameters (300 mm, 500 mm, 750 mm and 1000 mm) by keeping the length to diameter (L/D) ratio constant. As the trials were carried out in shallow waters, the major penetration force was the applied suction pressure of the pump as the water head available was not sufficient to drive piles of higher L/D ratio. L/D ratio of 1.5 was used for all the piles based on available pump capacity. A pad eye is placed on both the side walls of the pile at a distance of 1/3 of the pile length from bottom, for enabling attachment of mooring rope using which pullout load is applied.

2.4 Deployment methodology

The pump skid is a frame structure for housing the pump and related electronics used for the deployment. The pump has been designed for providing a suction pressure of upto 300 kPa when working underwater. A motor is also provided for delivering water into pile at a rate of 720 litres / minute. Pump is pressure compensated and is therefore capable of operating underwater in water depths of upto 300m.

The electronics arrangement for operating the pump and motor are provided within enclosures which are also pressure compensated and capable of working underwater.

The suction pile assembly was deployed at the test location using a winch operated barge. Schematic diagram of the deployment procedure is shown in Figure 1 and Figures 2 and 3 show the assembly of suction pile and deployment arrangements from the shore at the Royapuram test site.

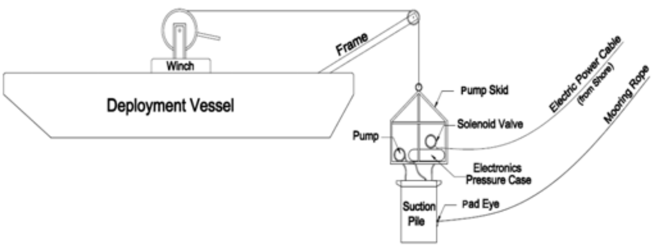

Figure 1 Schematic arrangement for deployment

The assembly of electronics and pump / motor was carried out onshore and completely housed on the pump skid. Power supply is provided from the shore using diesel generator using an aramid umbilical cable. The entire assembly was lowered into the deployment barge using a shore crane and attached to the suction pile using hooks. Pump / motor were connected through hoses and then the entire assembly was lowered into water.

Installation is carried out by pumping out water from the inside of the pile using the suction pump. Once lowered into water the excess air was removed using relief valve and then entire assembly was lowered into water and the suction pile was placed on the seabed.

Divers were sent in to assess the verticality of the pile when seated on the seabed. After initial penetration was achieved under self weight, the pumping out was started and monitored onshore using computer software exclusively developed for this purpose. The entire data acquisition system is shown in Figure 4. The pumping was continued till the suction pile completely penetrated the seabed. At the end of each test, divers where sent in to ensure complete penetration of the pile. During all tests, the mooring ropes were held away on a smaller boat.

Figure 4 shows the control panel developed for data acquisition during installation. This system was kept onshore and was used for two-way communication between the electronics pressure case which was underwater during installation and testing. It was used for controlling the pump and solenoid valve operations and reading out the suction and delivery pressures and issuing commands for reversal of pump operations.

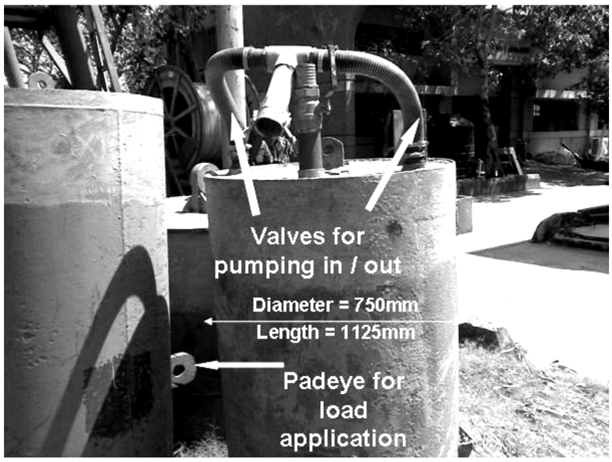

Figure 2 Suction pile geometry and accessories

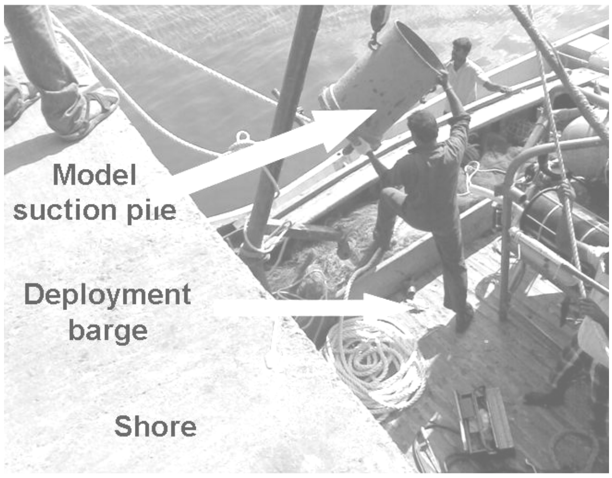

Figure 3 Arrangements for transfer at test site

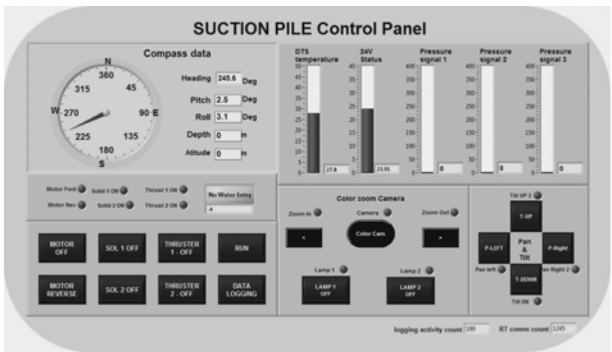

Figure 4 Data Acquisition System developed

2.5 Pullout testing methodology

Pullout load is applied using the mooring rope which is attached to the sides at the pad eye location at 1/3rd distance from the bottom of the first suction pile. In order to test the response of the piles to various loading conditions, following types of loads were applied.

1. Pumping in water into the suction pile using the motor in the pump skid arrangement.

2. Static pullout from the shore using a shore crane (static loading).
3. Pull is applied from the deployment barge which is subjected to the environmental conditions at the site like wave loading. Response of the deployment barge to wave action induces a dynamic effect on the pullout due to heaving action of the boat. Under wave action it is not possible to keep the deployment vessel stationary and the pullout angle varied upto 5° during the testing. (a) Loading is applied at an angle of 20° to horizontal and (b) angle of 75° to horizontal from the deployment vessel.

A calibrated load cell of 50 MT capacities with a least count of one kg was used for measuring the pullout load. The load cell was placed along the mooring rope between the pullout load application point and the rope.

After the pullout load is applied using the delivery pump, the connections between the pump skid and pile are completely removed before applying mooring load from a static shore crane and dynamic loading using deployment vessel..

Figure 5 shows the schematic arrangement of various load application points for the pullout tests. For pullout using the barge, the barge position was calculated and placed exactly to achieve the required degree of pullout.

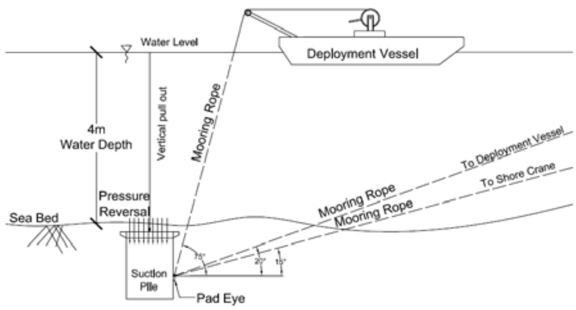

Figure 5 Schematic of various pullout angles during pullout tests

Table 1 Summary of pullout capacity tests

Pile Diameter (m)	Penetration (m)	Uplift capacity (kN) during pump reversal	Lateral capacity using shore crane (kN) (Static loading)	Max. lateral capacity from barge (kN) (Dynamic loading)	
				20°	75°
0.3	0.45	2.83	4.7	9.3	4.7
0.5	0.75	7.85	22	18	8.6
0.75	1.125	20	58.3	36.6	22.5
1.0	1.5	31.42	63	40	33

2.6 Results and discussion

Figure 6 shows results of ultimate pullout load versus degree of pullout for tests carried out on the suction pile of various diameters. In all cases the L/D remained constant at 1.5. The ultimate capacity decreases as the pull angle increases from 20° (to horizontal) to 90°.

From the test results it can be observed that as diameter increases the variation in pullout capacity with angle of pullout is negligible.

There is negligible difference in uplift capacity obtained from reverse pumping (vertical pull at 90°) and lateral pullout at 75° angle. Maximum load is obtained when the angle of pullout is 20° to horizontal. For lower diameter suction pile, the difference between static pullout using shore crane and dynamic pull applied from the deployment vessel (7-8 cycles/second) is found to be negligible / inconsistent.

It is possible to theoretically predict that lateral capacity for 15° pullout (static pull applied from shore crane) is equal to the sum of weights suction and pile and net soil resistance. The uplift resistance offered by suction pile is found to be theoretically equal to the sum of external skin friction and weights of soil plug and suction pile.

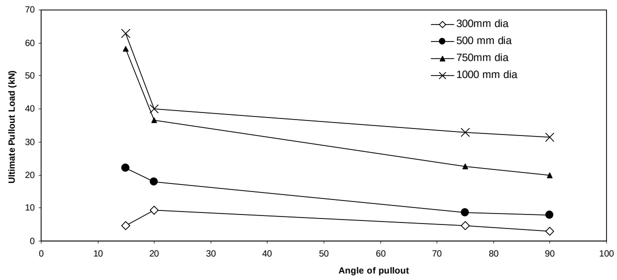

Figure 6 Ultimate pullout capacity of suction pile for varying load applications

3. CONCLUSION

The suction pile has been tested for ultimate pullout capacity under various loading conditions under marine environmental conditions like waves, tides and currents. It is generally observed that for larger diameter piles the influence of angle of pullout on the dynamic capacity is negligible

It is observed that the ultimate pull out capacity increases as the angle of pull out changes from vertical to horizontal position up to 15° for suction piles of 750 mm and 1000 mm diameter. Decrease in pull out capacity is observed from the results of static pullout (using shore crane) and dynamic pullout (applied from the deployment barge) which is prominent in the case of larger diameter piles (750mm and 1000mm). A reduction in lateral pullout capacity of 35% between static pull of 15° (applied from shore crane) and 20° pull from deployment barge due to response of deployment barge to wave action.

4. ACKNOWLEDGEMENTS

The tests have been carried out by NIOT under the project 'Development of components for offshore structures' funded by the Ministry of Earth Sciences, Govt. of India. Significant contributions to the fieldwork provided by Arokia Prabhu, E. Chandrasekaran, G. Chandrasekar, V. Doss Prakash, A. Vadivelu, K. Venkatesan, B. Ravikiran, N.Sureshkumar and P. Jayaprakash is gratefully acknowledged.

5. REFERENCES

Adam M. Luke, Alan F. Rauch, Roy E. Olson, Elliott C. Mecham, (2005) Components of suction caisson capacity measured in axial pullout tests, Ocean Engineering 32, 878 – 891.

Aaron D. Goldberg (1994), Design and construction of a model suction pile, Offshore Technology Research Centre, Texas A& M University.

Bang S., Jones K., and Cho Y., (2005) Transition of Soil Strength during Suction Pile Retrieval in Sand, International Journal of Offshore and Polar Engineering Vol. 15, No. 2 , 155-159.

Bang S., Jones K., Kim Y.S., Kim K.O. and Cho Y. (2006) Vertical Pullout Capacity of Embedded Suction Anchors in Sand, Proceedings of the 16th ISOPE, California Paper No.206-JSC-166.

Narasimha Rao S., Hema Latha K., Pallavi B, Surendran S.(2006) Studies on pullout capacity of anchors in marine clays for mooring systems, Applied Ocean Research 28 103-111.

Tor Inge Tjelta (2001) Suction Piles: Their Position and Application Today, Proceedings of the 11th ISOPE, Norway, 1-6.