PULLOUT BEHAVIOUR OF PILE ANCHORS IN SOFT SATURATED CLAY

by

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ABSTRACT

The recovery of petroleum products from offshore environment i moving into regions of greater water depths. New platfor concepts have emerged in the form of compliant structures sinc jacket type fixed offshore structures are exorbitantly expensiv in deeper waters. One type of compliant structure that is findin increasing acceptability is the tension-leg platform (TLP).

The TLP requires anchoring of its foundations to the seabed i order to resist sustained static tension as well as wave-induce cyclic tension. Piles are considered to be a viable means o providing such anchorage.

Presence of significant petroleum resources has been registere off the east coast of India - at the mouth of the river Godavar where water depths are of the order of 200 metres and the seabe soil comprises of very soft to soft clay. TLPs with pil foundations are envisaged as one feasible type of productio structure for this location. An understanding of the pullou behaviour of offshore piles in very soft to soft clays, unde static as well as cyclic uplift loading is, therefore, of grea interest for the design of TLP foundations in the Indian context

A review of literature indicates that:

(i) Pullout behaviour of piles in very soft clays has no been a subject of detailed study,

(ii) Under static pullout loading, the influence of loadin

rate, the influence of pile surface characteristics and the influence of variation in water content on pullout behaviour requires further investigation, and

(iii) Under one-way stress-controlled cyclic tension loading there are no studies reported on pullout behaviour of piles in soft to very soft clays.

In view of the prohibitive cost of full scale pile load tests in the marine environment, research must begin with laboratory model tests. The present research work is, therefore, directed to understanding the pullout behaviour of pile anchors under static and cyclic loading conditions in very soft clays by means of model tests in the laboratory.

The objectives of the present study were as follows:

(i) to understand the load-displacement behaviour of model pile anchors - embedded in very soft clay under static vertical pullout loads; and to identify the influence of various parameters such as pullout rate and water content on the soil-pile adhesion factor, α ,

(ii) to understand the influence of wave-induced cyclic loading on pullout behaviour; particularly to identify (a) the movement of piles under cyclic loading, and (b) the influence of the cyclic loading on subsequent static pullout behaviour,

(iii) to compare the static and cyclic pullout behaviour of pile anchors with that of plate anchors - a type of anchor which has been extensively studied by various investigators.

Model pile anchors were buried in very soft clay in test tanks and subjected to static and cyclic pullout loads using a specially designed and fabricated mechanical - pneumatic loading frame. Over 200 model tests were conducted in the present study. Circular steel tanks of 30 cm internal diameter and 50 cm height were used as model test tanks. Model pile anchors were made of tubular aluminium sections having an outside diameter of 50 mm, wall thickness of 5 mm and, lengths of 200 mm and 350 mm. Model piles with either smooth or knurlled surfaces were used.

The static pullout tests were conducted at different water contents of soil, for different natures of applied loading (stress-controlled and strain-controlled), with different speeds of pullout and with varying surface characteristics of model piles.

Cyclic pullout tests were carried out at different water contents of soil, with varying the number of load cycles and using different cyclic stress levels.

The soil used for model tests was Dhanauri clay, a river bed clay deposit having liquid limit of 51 percent, plastic limit of 30 percent and plasticity index of 21 percent. The range of water content used for the tests varied from 30 to 45 percent. In this range the undrained strength of the soil varied from 0.016 to 0.07 kg per sq.cm.

Static pullout tests, both stress-controlled as well as strain-controlled, were conducted on model pile anchors at water contents of approximately 30, 35, 40 and 45 percent. Unde strain-controlled testing, the piles were pulled out at pullou strain rates of 0.2 and 5.0 mm/min, whereas in stress-controlle pullout tests, stress increments of 1/8 th of the pullou capacity obtained in strain-controlled tests were applied, eac for a duration of 30 min.

From the results obtained in static model tests the followin observations are made about the pullout behaviour of pile anchor under static loading:

(i) The values of the adhesion factor, α , observed i laboratory tests are substantially less than 1.0 an lie in the range of 0.25 to 0.40. Data in literatur correborates this information.

(ii) An increase in water content and the consequen decrease in undrained strength does not influence α values significantly.

(iii) Increase in pullout rate does not appear to have an appreciable influence on α - values.

(iv) Pullout loads are found to be comparable in bot stress-controlled and strain-controlled tests.

(v) Failure occurs at displacements of less than 10 percer of the pile diameter.

Cyclic tests consisted of applying 500 cycles of pullout loac with a cyclic time period of 15 sec., between pre-specifie maximum and minimum load limits and observing the correspondir upward movement of the pile. At the end of 500 cycles, tr pullout load applied to the pile was reduced to zero. The pil was then pulled out statically.

From the results obtained in cyclic model tests, the following observations are made about the pullout behaviour of pile anchors under cyclic loading:

(i) The upward movement of model pile anchors at low cyclic stress levels was observed to be less than 0.4 percent of the pile diameter. Whereas at high stress levels, for same water contents, the pile moved-up rapidly to failure after showing low movement in the initial few load cycles.

(ii) The critical maximum cyclic stress level beyond which failure of the pile occurs appears to be about 70 percent of its static pullout capacity in soils at low water content and about 85 percent at high water content for the range of water contents investigated.

(iii) No degradation of pile capacity due to cyclic loading is observed in post-cyclic static behaviour so long as the pile does not actually fail under cyclic loading itself.

This thesis also presents a comparative study of the pullout behaviour of pile and plate anchors in soft to very soft clays under static as well as cyclic loading. Significant conclusions from this comparison are as follows:

(i) When no suction forces develop below plate anchors, the behaviour of plate anchor is similar to that of pile anchor in that it is not influenced by water content or pullout rate.

(ii) The displacement that is necessary to generate maximum skin friction in case of pile anchors is very low as compared to a much larger displacement required for full mobilisation of the vertical breakout resistance in case of plate anchors.

(iii) Plate anchors show much larger movement under cyclic loading than pile anchors.

(iv) For both, plate and pile anchors, the total movement under cyclic loading is governed by the maximum cyclic stress level.

(v) Pile anchors show low initial movement but in some cases, at some stage, the movement increases very rapidly leading to total failure. In contrast, plate anchors do not show sudden failure.

(vi) One-way (tension) cyclic loading does not result in any degradation in the static pullout capacity of either pile or plate anchors so long as failure under cyclic loading does not occur.

The present study indicates that for the design of pile anchors of TLPs, one would have to use a factor of safety higher than that adopted for the design of pile foundations of steel jacket type fixed offshore platforms. To ensure that a pile anchor does not show any movement under cyclic uplift loading induced by environmental forces as well as that sudden pile failure does not occur, it is recommended that the static pullout capacity of such an anchor must be atleast 3.0 times the maximum cyclic load induced during extreme environmental conditions. A factor of safety of 3.0 is thus the minimum acceptable factor of safety which must be adopted for pile anchors to resist vertical loads.

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