PULLOUT BEHAVIOUR OF SUPERPILE ANCHORS IN SOFT SATURATED CLAY

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CERTIFICATE

This is to certify that the thesis entitled " **PULLOUT BEHAVIOUR OF SUPERPILE ANCHORS IN SOFT SATURATED CLAY** " being submitted by **Mr. BALESHWAR SINGH** to the Indian Institute of Technology, Delhi , India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other University or Institute, for the award of any degree or diploma.

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ABSTRACT

For the recovery of petroleum resources from the offshore environment, compliant offshore structures are finding increasing acceptability in deeper waters in place of conventional jacket-type fixed offshore structures because of lower costs. The tension leg platform (TLP) is one type of compliant structure which is being adopted at several deep water sites.

A TLP is held in position by anchors or anchoring systems which resist sustained static tension as well as wave-induced cyclic tension. Conventional anchoring systems used as foundations of TLPs are long tubular piles and gravity anchors. The superpile anchoring system is a new type of TLP foundation system which was proposed by Albert et al.(1989). A superpile anchor differs from the long tubular pile in three ways :

(i) The superpile is a large-diameter short pile with a closed top whereas the conventional pile is a much smaller diameter long pile with an open top.

(ii) On account of the closed top of the superpile, soil within the pile is visualized 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.

(iii) Conventional pile anchors are installed by driving whereas superpile anchors are installed with the help of a suction system at the top of the superpile.

This thesis examines the suitability of superpile anchors as foundations of TLPs in soft clays through laboratory tests.

The objectives of the present study are :

(i) To study the pullout behaviour of model superpile anchors installed in soft clay under static and cyclic vertical pullout loading.

(ii) To identify the influence of ratio of pile length to diameter and water content of soil on the pullout behaviour.

(iii) To identify the influence of cyclic loading on subsequent static pullout behaviour.

(iv) To compare the static and cyclic pullout behaviour of model superpiles with that of similar large-diameter piles having open tops.

(v) To study the pore water pressures which develop at the bottom of model superpiles and at the top of the soil plug in model superpiles during static and cyclic pullout.

(vi) To understand the mechanisms which govern the stability of a soil plug inside a model superpile.

Pullout behaviour of superpile anchors in clays under static loading has been studied through two laboratory investigations. Results of field model tests under inclined static and inclined cyclic loading have been reported by an investigating team.

Model superpiles were installed in soft clay in model test tanks and subjected to static and cyclic pullout tests using a specially designed and fabricated mechanical-pneumatic loading frame. Tests were also conducted on similar large-diameter piles having open tops to simulate the behaviour of conventional piles. Circular steel tanks of 55 cm internal diameter and 45 cm height were used as model test tanks. Model superpiles and model open-top piles made of perspex, having an internal diameter of 11 cm, wall thickness of 5 mm and lengths of 16.5 cm and 8.3 cm were used. The soil used in the model tests was Dhanauri clay, a river bed clay deposit having liquid limit of 45%, plastic limit of 28% and plasticity index of 17.

Static pullout tests were conducted with three different pullout rates, with two different ratios of pile length to diameter (L/D) and with two different water contents of soil. Cyclic pullout tests were carried out with different maximum cyclic stress levels, with different ratios of pile length to diameter and with different water contents of soil.

The results of the laboratory investigation on model superpiles under static pullout loading are as follows:

(i) Model superpiles do not show any distinct failure and the pullout load continues to increase with displacement upto as much as 60% of the superpile diameter. In all the tests, it was observed that the soil plug moved up with the superpile.

(ii) Significant resistance is developed beneath model superpiles during static pullout. This resistance (though of a short term nature)results in the following effects:

    (a) gives added uplift capacity, and

    (b) prevents sudden failure as observed in the case of model large-diameter piles having open tops.

(iii) When the model superpile is pulled out at a rapid rate, the pullout load is higher because of the development of higher resistance at the bottom.

(iv) A reduction of ratio of length to diameter from 1.5 to 0.75 does not cause significant change in pullout load-displacement behaviour and the trends observed for the lower L/D ratio are similar to those obtained for the higher L/D ratio.

(v) When the water content is increased, there is no change or transition in the pullout load-displacement behaviour except that the pullout loads are smaller for the same magnitude of model superpile displacement.

(vi) At a pullout load less than the sum of the weights of the model superpile, soil plug and water above the soil plug, the magnitude of displacement is very small.

(vii) The pore water pressure at the bottom decreases to a minimum value at low displacement and increases gradually thereafter. The pore water pressure at the top of soil plug continues to decrease with displacement.

The results of the laboratory investigation on model superpiles under cyclic pullout loading are presented below:

(i) During cyclic loading, model superpiles show upward displacement. The rate of increase of displacement per cycle of model superpiles is maximum in the first few cycles and it decreases thereafter except in those cases where the maximum cyclic stress level exceeds a critical value. Beyond this critical max. cyclic stress level, the rate of increase of displacement per cycle initially decreases by a small amount and then increases with number of cycles leading to failure. A zero rate of increase of displacement per cycle is achieved after a few hundred cycles when the maximum cyclic stress level is equal to the sum of the weights of the model superpile, soil plug and water above the soil plug. When the maximum cyclic stress level is equal to the sum of the weights of the model superpile, soil plug and water above the soil plug, and skin friction on the external pile wall, the magnitude of displacement at the end of 1000 cycles is very small. The presence of an additional resistance at the bottom of the model superpiles ensures that any sudden failure does not occur. In contrast, model open-top piles fail suddenly without any warning when the maximum cyclic stress level is equal to the sum of the weight of the pile and 90% of the total skin friction as no bottom resistance exists.

(ii) When model superpiles do not fail, the amplitude of movement per cycle is almost constant throughout the test.

(iii) There is no significant difference on account of change of L/D ratio on the overall magnitude of total displacement at the end of 1000 cycles. However, when the L/D ratio is reduced, the amplitude of movement per cycle is higher.

(iv) At a higher water content, after the initial few cycles, the rate of increase of displacement per cycle as well as the amplitude of movement per cycle are higher. However, the overall accumulated displacements at the end of 1000 cycles are similar at the two water contents.

(v) It has also been observed that as long as a model superpile does not fail during cyclic loading, the subsequent post-cyclic static pullout capacity is of the same order as that obtained in static tests.

(vi) The pore water pressure at the bottom attains a high negative value in the first few cycles. With increasing number of cycles, the pore water pressure levels at the bottom become less negative. The pore water pressure at the top also attains a high negative value in the initial few cycles. Thereafter, the cyclic pore water pressure levels at the top remain almost constant throughout the test.

The mechanisms which govern the stability of a soil plug inside a model superpile have been determined and are as follows :

(i) The soil plug remains in position in the absence of a flow path connecting the top of the plug to the outside environment under static conditions as well as under impact and vibrations.

(ii) The soil plug also remains in position under the above three conditions when there is presence of a gap at the top of the soil which is not connected to the outside environment.

(iii) The soil plug does not remain in position and moves down slowly under static conditions when a flow path is present. Impact and vibrations cause the plug to move down rapidly.

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