THE BEHAVIOUR OF PRELOADED ANCHORS IN NORMALLY CONSOLIDATED SANDS

LE COMPORTEMENT D'ANCRAGES PRECONTRAINTS SOUS CONDITIONS NORMALES DE TASSEMENT DU SABLE

РАБОТА ПРЕДВАРИТЕЛЬНО-НАГРУЖЕННЫХ АНКЕРОВ В НОРМАЛЬНО УПЛОТНЕННЫХ ПЕСКАХ

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SYNOPSIS. The paper presents observations of the behaviour of large scale plate anchors tested in the laboratory in beds of homogeneous and normally consolidated dry sand and examines in detail the effects which the initial prestressing of such an anchor can have on its subsequent loading behaviour.

The displacements of the sand at 16 positions above and near to the anchor plate were measured by mechanical gauges. During the preloading phase the surface stressing plate was loaded against the anchor plate by means of a special jack. After the preloading stage the anchor system was test loaded to failure. In summary the results of these tests show that: (1) The magnitude of the preload value has a significant effect on the ultimate pull out resistance of the anchor. (2) The sand movements associated with a preloaded anchor are quite different from those observed with a "dead" anchor. (3) During the test loading of a preloaded anchor the drop off in stressing plate load is dependent on the magnitude of the initial prestress load value.

INTRODUCTION

Many foundation problems such as retaining walls, dry dock floors and excavations where uplift loads occur, have been solved by the use of preloaded or prestressed anchors. However, the behaviour of a loaded anchor and the behaviour of the soil near it are not well understood principally because very little analytical, field or laboratory

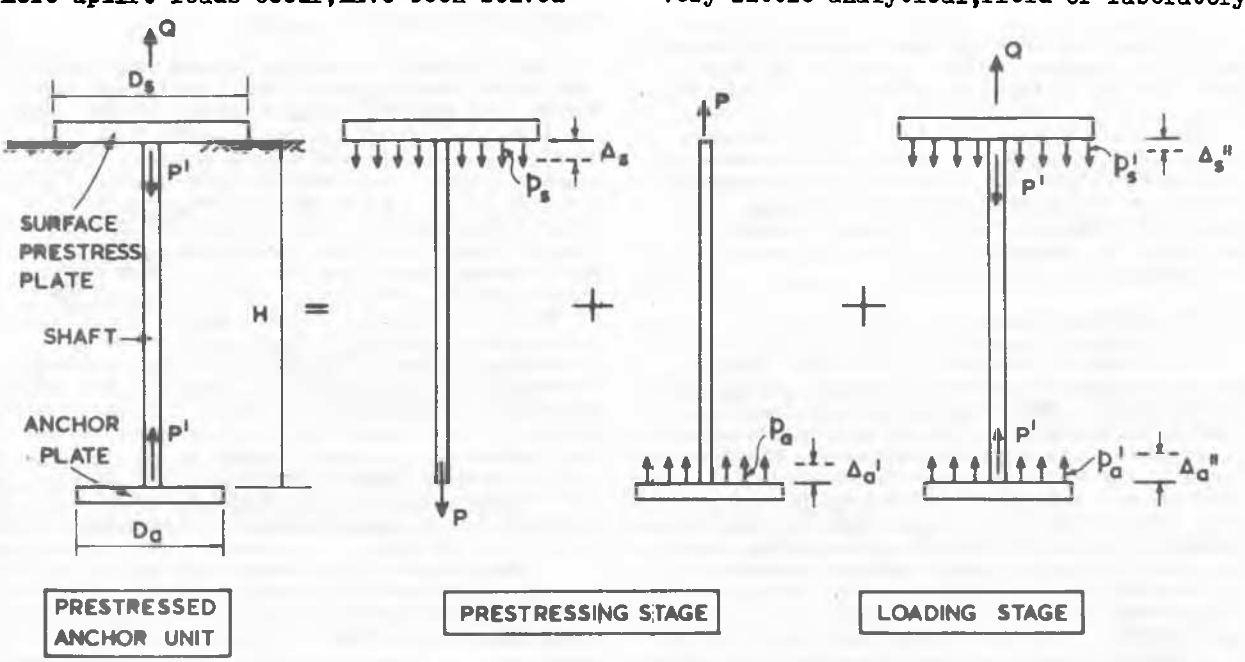

FIG. 1. THE PRESTRESSED ANCHOR SYSTEM.

scale studies have been carried out. Consequently the prediction of anchor behaviour from the results of laboratory tests on small soil elements is impossible at this stage. In this paper the results of two series of laboratory tests on pre-loaded plate-shaped anchors are described.

Because an anchor requires a finite displacement to mobilize an applied load, its usefulness is restricted in problems where movements may be critical. To extend the use of an anchor to such conditions it may, initially, be preloaded to a predetermined value and it is known that very small movements will occur until the applied external load exceeds the preload value. The principle of the preloaded anchor is illustrated by Figure 1.

The prestressed anchor behaviour may be divided, for convenience, into three parts. First, the surface prestress plate is loaded in compression by a load P. The plate settlement is Δ_s and a stress and displacement field is set up in the soil. Secondly, the anchor plate is loaded in uplift by a load P causing an upward displacement, Δ_a. A stress and displacement field is generated in the soil in the vicinity of the anchor plate. Thirdly, when the two loading systems are combined the recorded displacements under the pre-stress load P are Δ' and Δ' and the stress and the individual displacement fields are modified due to overlapping of the zones of influence. Application of the external load, Q, causes further modification to the already complex stress and displacement distribution in the soil mass and the displacements of the surface prestress plate and the anchor plate become Δ''_s and Δ''_a respectively where $\Delta''_s < \Delta'_s$ and $\Delta''_a > \Delta'_a$.

In use, whether in the support of basement slabs against uplift loads or in the tying back of retaining walls, it is important to have an appreciation of the interrelationships between anchor plate and prestress plate diameters, depth of embedment, prestress load P and pull-out resistance Q, and the corresponding movements of the anchor systems and the soil mass in which the anchor is embedded. This is the primary purpose of this paper.

THE TEST APPARATUS

The mode of action of the test equipment is indicated schematically in elevation in Figure 2. The anchor plate of 0.15 m. diameter is connected to the surface prestress plate by a "rigid" shaft. The prestress plate had diameters between 0.15 m. and 0.45 m.. A special loading jack with load transducer, fixed above the surface prestress plate, permitted the preloading of the anchor plate against the surface prestress plate. The anchor shaft extended through the surface prestress plate to the load lever. The load lever was levelled by an adjustable bearing used with special lever

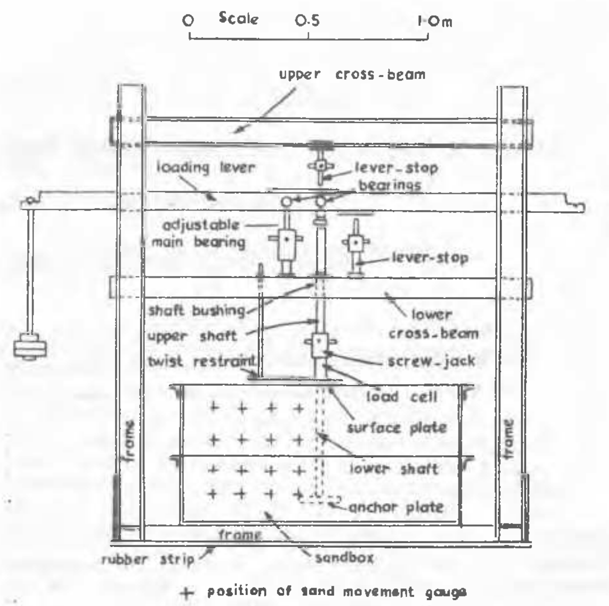

FIG.2 AN ELEVATION VIEW OF THE TEST APPARATUS

stops. Mechanical sand movement gauges similar in principle of operation to those used by Carr and Hanna (1971), but about one quarter of the size, provided a record of sand movements at sixteen predetermined positions as shown in Figure 2.

The sand was placed in 75mm layers and each layer was carefully stirred to give an average bulk density of 1543 Kg/m^3 and relative density 0.47. Drained triaxial tests gave an angle of internal friction, ϕ, of 36°. The sand was well graded between sieve numbers 10 and 72.

The surface stressing plate was lowered into contact with the level sand surface, and all the gauges were zeroed. The prestress force P was applied by jacking the surface prestress plate against the anchor plate, the loading lever being allowed to "float". The magnitude of the initial load P_i was predetermined with respect to the ultimate pull out resistance of a non-prestressed plate anchor, P_u. Nominal values of 25, 50, 75 and 100 per cent of P_u were chosen and these initial prestress loads were applied in increments and a period of about 10 minutes was maintained between each increment to take all the sand movement gauge readings and the anchor movements. Subsequent to the prestress stage the anchor system was loaded in increments to failure by dead weights via the lever, the change in prestress load P and the corresponding sand movements being recorded.

Comparator tests were carried out on surface plates of diameter 0.15 m. to 0.3 m. which were loaded in compression, sand movements being recorded. Several tests were performed on the comparator non-prestressed or "dead" anchor which was of 0.15 m.diameter embedded at 0.45 m.

The first test series comprised four tests on 0.15 m diameter surface stressing and anchor plates with initial prestress load ratios, P_i/P_u, of 0.26, 0.48, 0.72 and 1.0. In the second series the surface prestress plate was of 0.15 m., 0.23 m. and 0.31 m. diameter, the initial prestress load ratio, P_i/P_u, being 0.48. The depth of embedment, H, was 0.45 m..

TEST RESULTS

Figure 3 shows load settlement relationships for the surface prestress plates and the values of P_i, the initial prestress load used in the main tests, are indicated. Sand movements for the 0.30 m. diameter plate are given in Figure 4 for applied loads P equal to 1980 N (the value of P_u) and 6260 N. Generally the directions of

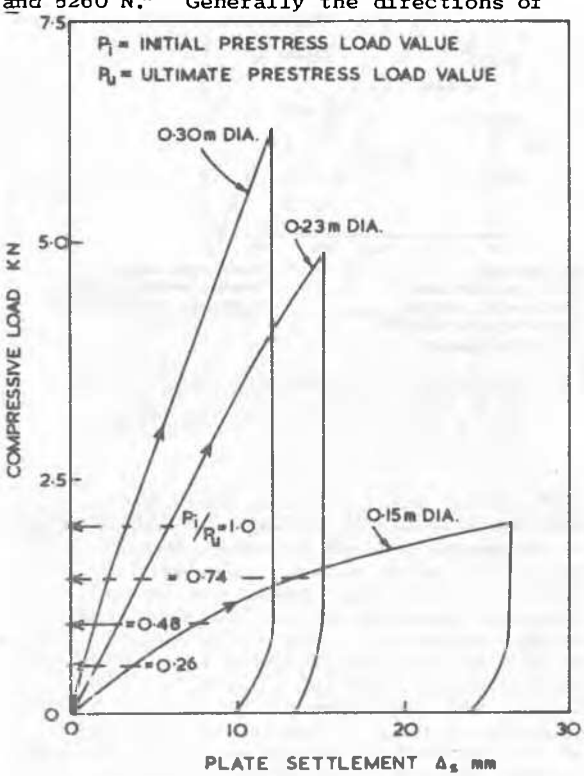

FIG. 3. LOAD - SETTLEMENT RELATIONSHIPS FOR THE SURFACE PRESTRESS PLATES

these displacements are in agreement with the experimental findings of Eggestadt (1963). The recorded sand movements for the dead anchor at the failure load of 1980N are presented in Figure 5. The vector movements are shown as straight lines and it will be recalled that the vectors are almost unidirectional up to the anchor pull out load, Carr and Hanna (1971), for a particular location.

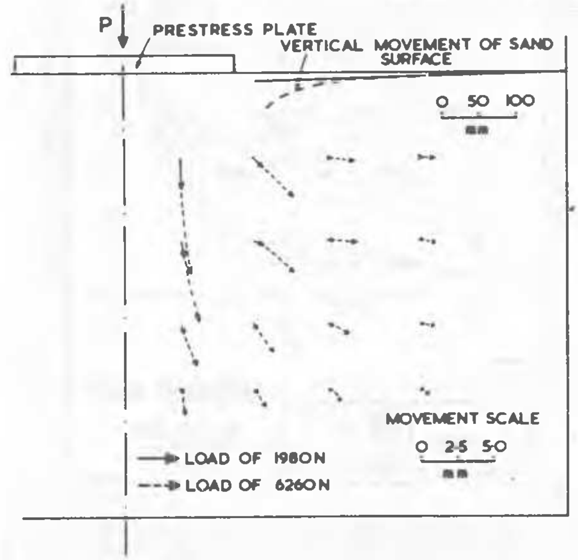

FIG.4. RECORDED SAND MOVEMENTS BENEATH A 0.3M DIAMETER SURFACE PRESTRESS PLATE.

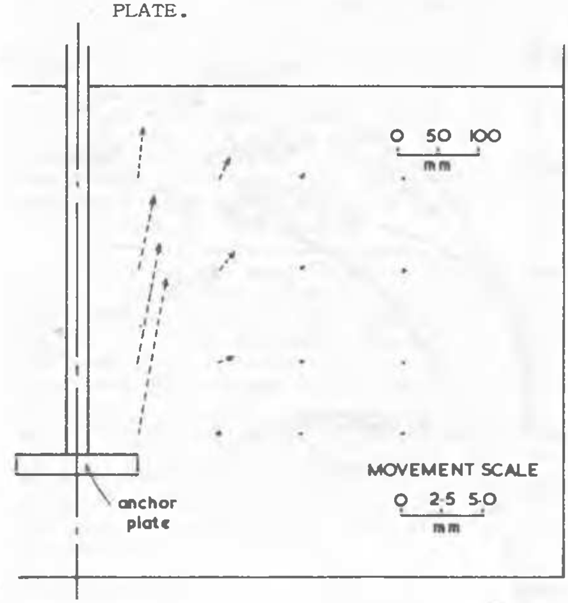

FIG. 5. RECORDED SAND MOVEMENTS ABOVE A 0.15 M. DIAMETER "DEAD" ANCHOR.

Under the condition of prestress loading the behaviours of the anchor components were different from their individual behaviours demonstrated above. Generally the surface prestress plate settled further and the anchor plate displaced less than in the dead anchor case. This was an expected result and demonstrates the effects of stress change in the sand above the anchor plate. The sand movements were dependent on the initial prestress load ratio, P_i/P_u, and the diameter of the surface prestress plate and Figure 6 shows sand movements for one test in Series 1

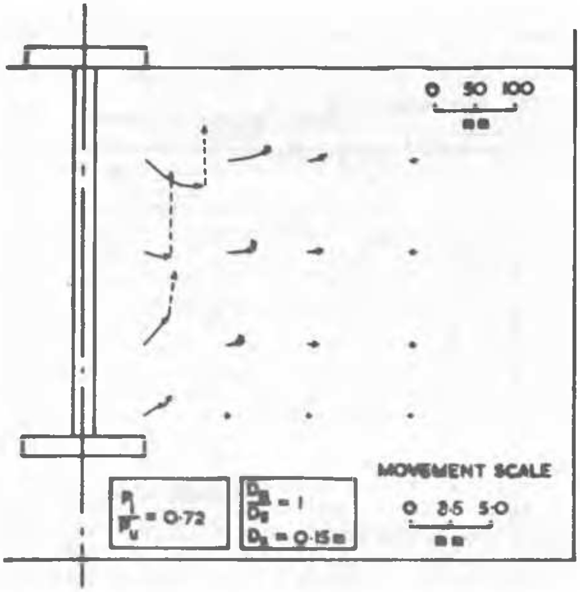

FIG.6. RECORDED SAND MOVEMENTS DURING PRESTRESS AND PULL OUT LOADING FOR 0.15 M. DIAMETER SURFACE PRESTRESS AND ANCHOR PLATES AT 0.45 M. DEPTH.

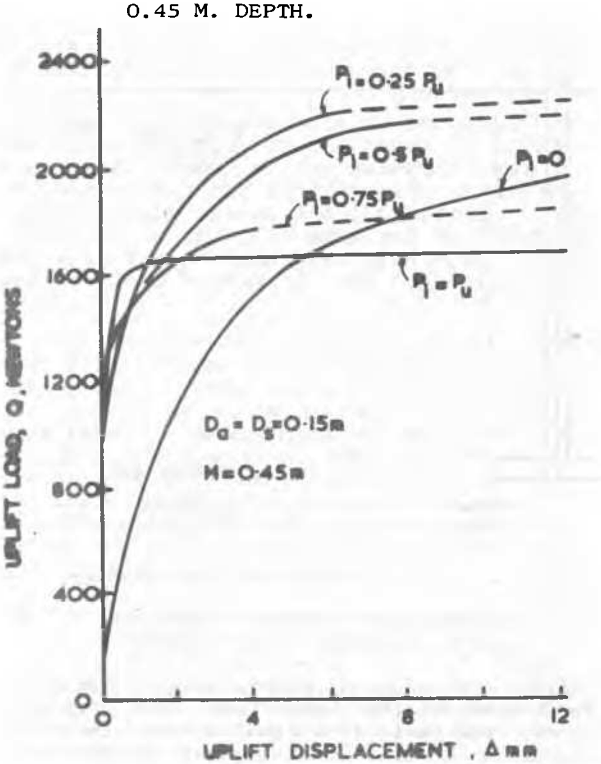

FIG. 7. PULL-OUT RESISTANCE - ANCHOR DISPLACEMENT RELATIONSHIPS FOR ANCHORS WITH DIFFERENT INITIAL PRESTRESS LOAD RATIOS (P_i/P_u).

For all prestressed anchors a large reduction in anchor displacement resulted on subsequent load testing. Figure 7 compares the pull-out load/displacement behaviours. The shapes of these relationships were not dependent on the value of P_i until an applied load greater than about 70 per cent of the ultimate was reached. Up to a tenfold decrease in displacement has been caused by the application of the prestress force. During pull-out loading the load carried by the surface prestress plate decreased. Data for the 0.15 m. diameter surface prestress plate are shown in Figure 8 in the dimensionless plot of applied load ratio, Q/Q_u, against prestress load ratio, P/P_i, with initial prestress load ratio, P_i/P_u as variable. For this series of tests the reduction in prestress load depended on applied load and initial prestress load ratio. In general the prestress load remaining in the anchor system was highest for the anchors subjected to the largest initial prestress load ratios.

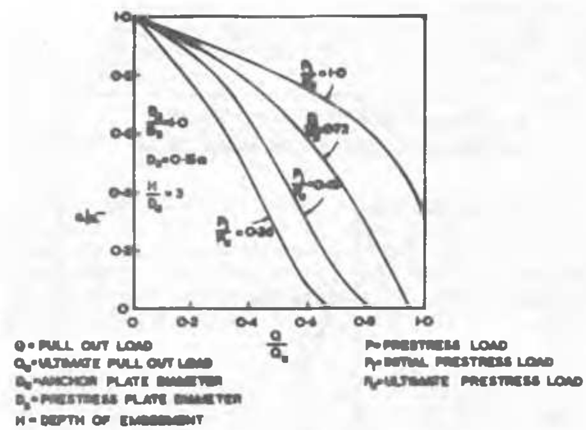

FIG 8. DECREASE IN PRESTRESS RATIO (P/P_i) WITH APPLIED LOAD RATIO (Q/Q_u) FOR A RANGE OF INITIAL PRESTRESS LOAD RATIOS (P_i/P_u)

Throughout all pull-out tests the anchor plate and the surface prestress plate were displaced upwards by equal amounts, the anchor shaft being rigid. The sand in the vicinity of the anchor plate was loaded whilst that beneath the surface prestress plate was unloaded. The direction and the magnitude of the sand movements recorded are superimposed on Figure 6. The movements increased with decrease in initial prestress load ratio, P_i/P_u. Increase in the diameter of the surface prestress plate did not alter the general sand movement pattern except in detail. The ultimate pull-out resistance of the prestressed anchors with $D_a/D_s = \frac{1}{2}$ and $\frac{1}{3}$ were almost equal to that for the anchor whose prestress and anchor plates were of equal diameter. For these limited test geometries it was found that the diameter of the surface prestress plate had little effect on the ultimate pull out resistance for the same initial prestress load value, P_i.

DISCUSSION

Figure 7 showed that the ultimate pull-out resistance of a prestressed anchor depended on the magnitude of the initial prestress load ratio. Qualitatively this was an expected result because the shearing strength of an element of sand increases with increase in normal stress on the plane of potential failure. The surface pre - stress plate applies a surcharge to the sand surface but over a finite area only. This causes a stress state change in the sand mass. During uplift loading this surcharge pressure is reduced whilst the stresses in the sand above the anchor plate increase. The behaviour of the anchor system therefore will be dissimilar to either that of a dead anchor or that of a dead anchor with a uniform surface surcharge. Tests by Hanna and Carr (1971) showed that the presence of a uniform surface surcharge increased pull-out capacity in almost direct proportion to the surcharge intensity. Figure 9 shows

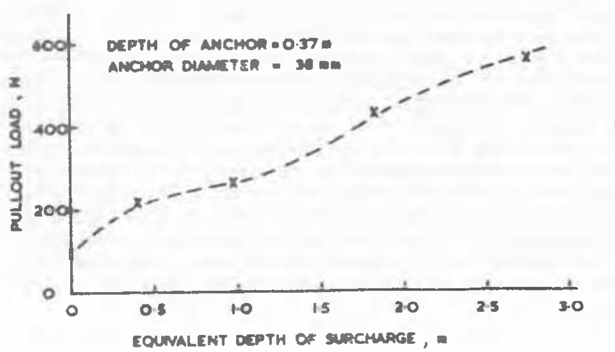

FIG. 9. PULL OUT RESISTANCE OF A 38 MM DIAMETER ANCHOR EMBEDDED AT 0.37 M FOR DIFFERENT INTENSITIES OF UNIFORM SURCHARGE PRESSURE.

data for a 38 mm. plate anchor embedded 0.37 m. in a normally consolidated sand of the same density and properties used in the present tests. The sand surface was loaded through a membrane and the ultimate pull-out resistance of the anchor increased in a near linear manner with surcharge intensity increase. With the prestressed anchor, however, because (a) the surcharge is applied over a finite area and (b) it is reduced with applied external load increase, such an anchor will not display the same behaviour as the anchor in a sand stratum under a uniform surcharge. The trend shown in Figure 7 is an expected one but, at the moment, can be explained only in qualitative terms.

The anchor system was stiffened by the prestressing operation and the effectiveness of prestressing an anchor to control its subsequent behaviour is illustrated by the data of Figure 10. As the initial prestress load ratio, P_i/P_u, increased the movement of the prestressed anchor to that of a dead anchor decreased provided Q/Q_u 0.8. At low applied load ratios, Q/Q_u, the reduction in anchor movement is up to tenfold.

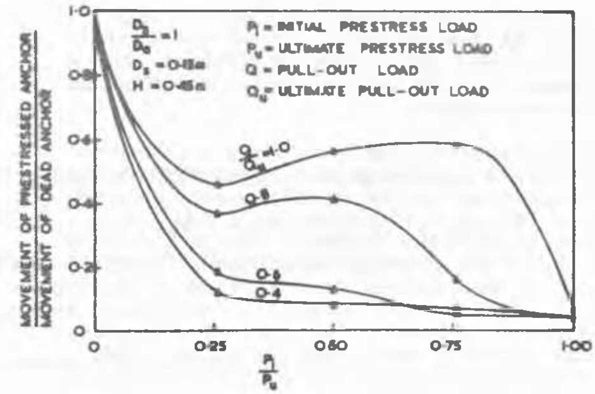

FIG. 10. COMPARISON OF PRESTRESS AND DEAD ANCHOR MOVEMENTS WITH INITIAL PRESTRESS LOAD RATIO (P_i/P_u) AND APPLIED LOAD RATIO, (Q/Q_u).

Returning to the associated sand movements, the prestress loading stage caused the sand in the vicinity of the plates to be squeezed. A predominantly lateral displacement of the sand resulted and the magnitude of the displacements was controlled by the initial prestress load, P_i, and the diameter of the surface stressing plate, D_s. When the anchor system was loaded the volume of sand which was subjected to further deformation was much smaller than that during the prestress loading stage or for a corresponding dead anchor. Also the sand movements were in a near vertical direction which suggests that a cylinder of sand is strained and lifted by the anchor.

Based on the very limited test data from the present study it is clear that prestressed anchors do not behave in a similar manner to dead anchors. The use of test data on dead anchors for the design of anchored structures which rely on the pre-stressed principle requires caution and high factors of safety. When used in groups prestressed anchors will interact at much wider spacings than groups of dead anchors (e.g. Meyerhof and Adams (1968)), but during the loading stage the grouping spacing may be smaller.

CONCLUSIONS

In spite of the fact that the conditions and variables which decide the behaviour of prestressed anchors have not yet been entirely studied, the influence of anchor prestress loading on its pull-out behaviour can be given according to the results of the experiments as follows :

(a) Prestressing of a plate anchor in sand produces a significant decrease in subsequent movement under loading, thus confirming the validity of modern ground anchor practice. The ultimate pull out capacity of a prestressed anchor, for the limited range of variables tested, was less than the pull-out resistance of a dead anchor at high initial prestress load ratios and greater at low ratios. It is not certain if this trend will apply at greater anchor embedment depths and in sands of different stress histories.

(b) Prestressing caused a zone of sand to strain in a predominantly lateral direction, the magnitude of the displacements depending on the applied prestress load. The extent of the displacement fields was larger than that observed with the loading of either a dead anchor or a surface stressing plate. Subsequent loading of the prestressed anchor caused a vertical sand displacement field of much smaller extent than that recorded during the prestress loading stages, the magnitude of the displacements depending on the initial prestress load.

(c) In use the separation between the surface stressing plate or structure and the anchor must be important and until detailed results are available to quantify the influence of stress and strain field overlapping, conservative designs based on current analysis methods are required.

ACKNOWLEDGEMENT

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