Performance of Prestressed Anchors under Slow Repeated Loadings

L'Accomplissement d'Ancrages Précontraints sous des Charges Lentes et Répétées

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SYNOPSIS The use of prestressed ground anchors is widespread. They are now being used in situations where repeated loading effects have to be considered. This paper presents recent data on long term repeated load testing of laboratory scale anchors and reviews the sensitivity of the various factors which influence the life of an anchor. It is shown that the pre-stressing of an anchor increases its life significantly but that with increase in the number of load cycles the initial pre-stress load is lost and the anchor reverts back to a dead anchor. The effect of repeated loading on ultimate static pull out resistance and the effects of alternating loading are also discussed.

INTRODUCTION

A prestressed anchor consists of an anchor unit in the ground which is stressed against a surface slab or structure via a tie-rod. The main advantages of a prestressed anchor over a dead anchor are that the movements of the anchor and the surrounding ground are greatly reduced, Hanna and Sparks (1973), and the anchor is also load tested during the prestressing operation. The behaviour of a prestressed anchor system is governed by the prestressing load stage and the uplift stage and consequently a highly redundant problem exists.

In many design situations anchors are subjected to slow repeated loads. The question which is often posed is how does repeated loading affect an anchor under load. Research into this topic commenced in 1970 with extensive studies on the behaviour of dead anchors under slow repeated loading, Hanna, Sivapalan and Senturk (1978), and on long piles, under repeated loads, Chan and Hanna (1980). Some engineers believe that prestressing an anchor automatically takes care of repeated loading effects, Littlejohn (1977).

The research work reported in this paper is part of a systematic study of ground anchors and piles under static and repeated loads. To achieve the control necessary in such work many idealisations were necessary and consequently all tests were performed in a dry sand medium with plate-shaped anchor units.

Test Apparatus

The requirements of the test apparatus were that the anchor could be prestressed and that a repeated load could also be applied. The apparatus lay-out is shown in Fig. 1 and is the evolution of equipment designed and used by De Hoxar (1980), Sivapalan (1976) and Senturk (1977). The surface stressing plate, 75mm diameter, is connected to the 38mm diameter anchor plate via an anchor rod which passed through the surface plate and permitted the prestressed load to be applied through a special yoke with proving ring, Al-Mosawe (1979). Thus it was possible to apply a prestress load to the anchor as well as an external uplift load and to record these values and their change with time along with the movements of the anchor system. All anchors were located at a depth of 380mm to give an anchor depth/width ratio of 10.

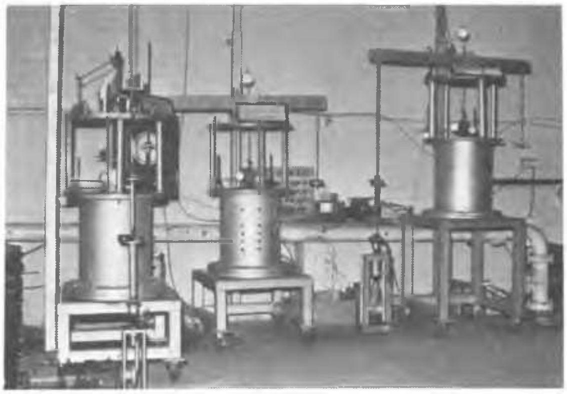
The repeated loading of the anchor followed the procedure of Hanna, Sivapalan and Senturk (1978) and involved the lifting of the repeated load component on and off the load lever to give a square-shaped load pulse of frequency one cycle per minute. Great care was taken in the design and the use of the test equipment to ensure that friction effects in the loading lever system were small and that there was no "dynamic effect" during application of load.

The sand bed was prepared by pouring dry sand from a fixed height of 160mm through a Number 10 sieve to give a density of 1720 kg/m^3. The sand of specific gravity 2.67 had minimum and maximum void ratios of 0.442 and 0.846 and was of medium gradation with a uniformity coefficient of 2.2. Consolidated drained triaxial tests on fully saturated samples gave an angle of shearing resistance of 39^o.

With the test system used it was possible to overconsolidate the sand stratum to give any desired stress history. Details of the apparatus, test technique and precautions taken are given by Al-Mosawe (1979).

Test Programme

The test programme had two main objectives - to investigate the effect of load level and amplitude on the behaviour of a prestressed anchor subjected to repeated and alternating loads and to examine the effect of prestress load level on the life span of an anchor.



a

b

Figure 1. (a) The prestressed anchor test apparatus showing three test rigs with lever systems and lifting systems for applying repeated loads.

(b) Detail of surface stressing plate showing proving ring for prestress load measurement and central rod leading to lever loading system.

Details of the tests performed are given in Table 1. All tests were carried out in sand at an overconsolidation ratio of 4 at anchor plate level. The prestress load was applied in three equal increments and during the setting up of the test and connecting the external load system great care was taken to prevent any change in the prestress load. Full details of all precautions taken are given by Al-Mosawe (1979).

TABLE 1

Test No	Loading	Load Levels % Pu	Initial Prestress Load (% Pu)
1	R	40 - 0	30
2	R	60 - 0	30
3	R	80 - 0	30
4	R	25 - 10	30
5	R	45 - 20	30
6	R	80 - 30	30
7	R	90 - 15	30
8	A	5 - (-3)	30
9	A	8 - (-7)	30
10	A	10 - (-10)	30
11	A	15 - (-15)	30
12	R	60 - 0	0
13	R	80 - 30	0
14	R	90 - 15	0
15	A	15 - (-15)	0
16	A	8 - (-7)	0
17	R	60 - 0	15
18	R	80 - 30	15
19	R	60 - 0	50
20	R	80 - 30	50
21	A	15 - (-15)	50
22	A	8 - (-7)	50

Pu = Ultimate pull out static load value

Overconsolidation ratio = 4

Surface plate diameter = 75mm

Anchor plate diameter = 38mm

R = Repeated loading test

A = Alternating loading test

Test Results

The prestressing stage resulted in movement of both the anchor and surface stressing plates and a small loss in prestress load value occurred with time being up to 6%. Such trends have been observed by others, e.g. Hanna and Sparks (1973). To overcome such losses the initial prestress load was increased by 6% in all cases, a technique which is used very often in anchoring practice. The primary purpose of the present study was to assess the beneficial effects of prestressing an anchor on its repeated loading behaviour. The comparator used was a similar dead anchor and Fig.2 presents the displacement - number of load cycle relationships for anchors with an initial prestress load of 30% Pu and for a range of repeated loadings. From the results of this figure it is clear that prestressing an anchor increases its life significantly and reduces the amount of movement which occurs during repeated loading.

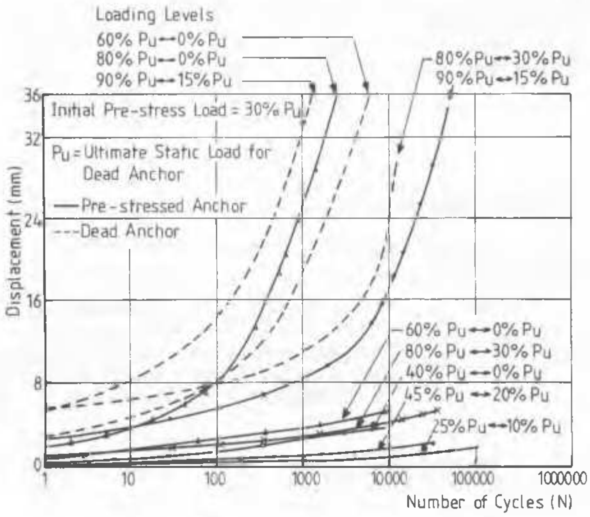


Figure 2. Displacement - log number of load cycles for anchor with initial prestress load of 30% Pu compared with dead anchor performance - repeated loading.

It will also be noted that the prestressing of an anchor also significantly reduces the movements under first loading. The rate of anchor displacement per cycle relationships are shown in Fig. 3. A similar trend to that for dead anchors results, see Hanna, Sivapalan and Senturk (1978) but the displacement rate values were much less than those for a dead anchor. It is clear therefore that the effect of the prestressing of an anchor is to increase the life span by causing a reduction in displacement at any load cycle when compared with a dead anchor. The larger loading amplitude resulted in higher displacement rates, while with small load amplitudes the life span of the anchor was very great. The effect of initial prestress load level on an anchor cycled between 80% and 30% Pu and 60% and 0% Pu is shown in Fig. 4. Here it is clearly demonstrated that the prestressing level increased the life of the anchor significantly, and a more stable behaviour with a reduced rate of displacement occurred as the initial prestress load was increased.

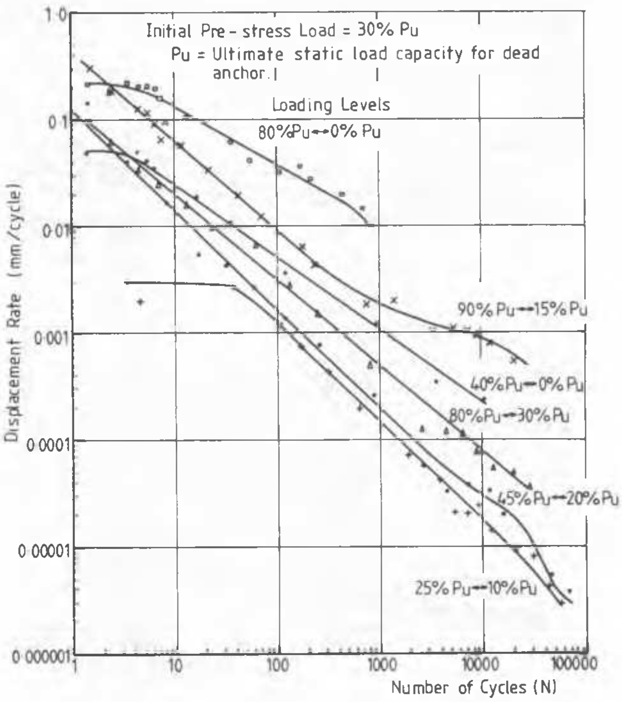


Figure 3. Rate of anchor displacement - number of load cycles relationship for anchors with an initial prestress load of 30% Pu.

The figure also demonstrates the importance of loading level and it will be noted that 60% to 0% Pu is a much more severe loading system than 80% to 30% Pu.

Because all anchors move when subjected to a repeated load it was expected that a loss in prestress load would occur. In all tests when the application of repeated loading starts the anchor and surface plates both move upwards with the result that there was a continuous loss in the prestress load with the number of load cycles.

Fig. 5 shows the loss in prestress as a function of load cycles for a loading level less than that of the initial prestress value. Where the applied load was greater than the initial prestress load the prestressing load was lost in a few cycles only and this appears to be related to the very high displacement caused by a high repeated load level which in turn causes a large upwards movement of the prestressing plate with a loss in contact pressure between the sand surface and the plate. For example where the initial prestress value was 30% Pu and the repeated load range was 60% - 0% Pu complete loss of prestress occurred after five cycles of loading. In very special cases it is possible for an anchor to be subjected to an alternating load.

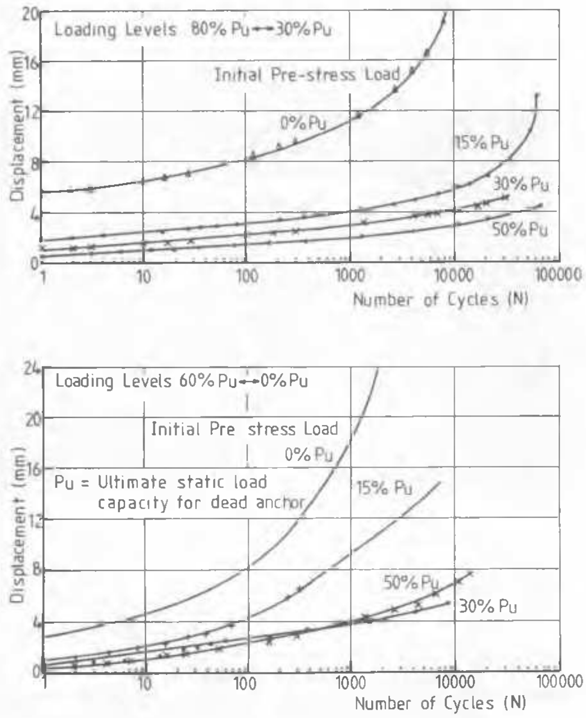


Figure 4. Displacement - log number of cycles for different values of initial prestress load.

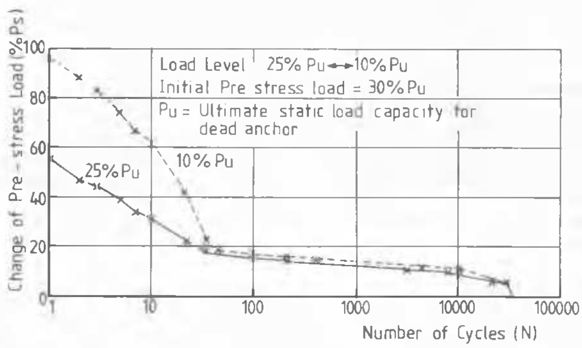


Figure 5. Loss of prestress load with number of load cycles - repeated load tests.

Fig. 6 presents comparative data for dead and prestressed anchors in which the initial prestress load was 30% Pu. The life of a prestressed anchor is seen to be considerably greater than that of a dead anchor for all load levels. During repeated loading there was also a gradual loss in prestress load, the rate of loss being dependent on the applied load level relative to the initial prestress value.

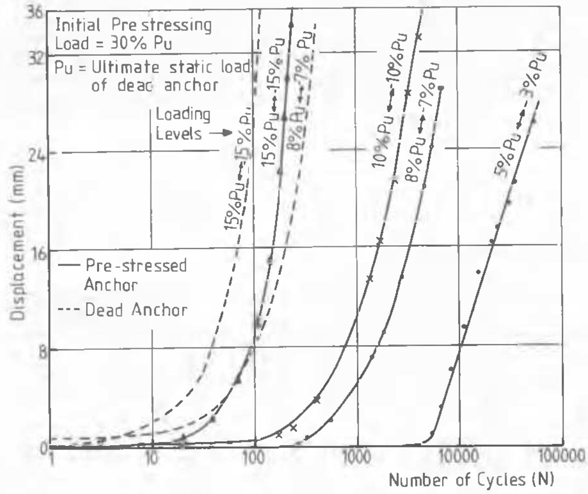


Figure 6. Displacement - log number of load cycles for anchors with initial prestress load of 30% Pu. compared with dead anchor performance - alternating loading.

Fig. 7 gives typical data for an anchor loaded cyclically between +5% and -3% Pu.

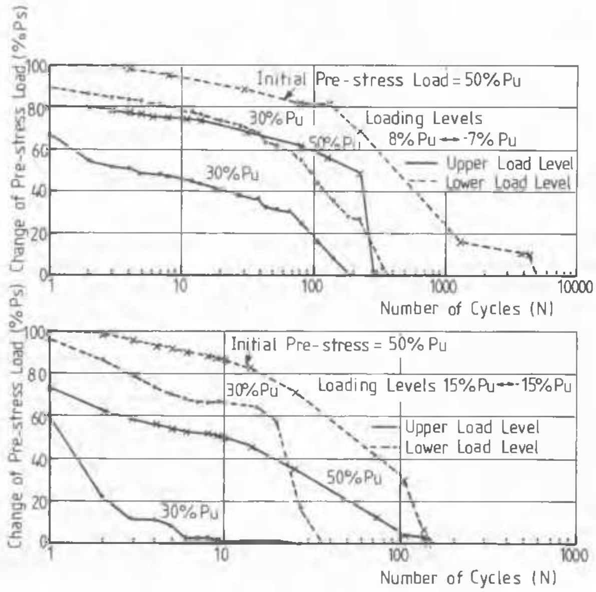


Figure 7. Loss of prestressed load with number of load cycles - alternating load tests.

A questions which often arises in ground anchor use is the effects of repeated or alternating loads on the pull out resistance of a prestressed anchor. Static tests were performed at the end of all repeated load programmes and typical test results are given in Fig.8. Here it will be noted that after repeated loading there was a stiffening effect with an increase in pull out resistance for repeated loading but there was a reduction in pull out for anchors subjected to alternating load tests. It should be noted that when these tests were performed the initial prestress loads had been lost through the effects of previous loading. Consequently the static loading performances were the results of repeated and alternating loading effects. Little is known about the mechanics of progressive failure of an anchor or pile under repeated loading, Chan and Hanna (1980). One possible explanation is the gradual breakdown of the sand grain corners under repeated loading.

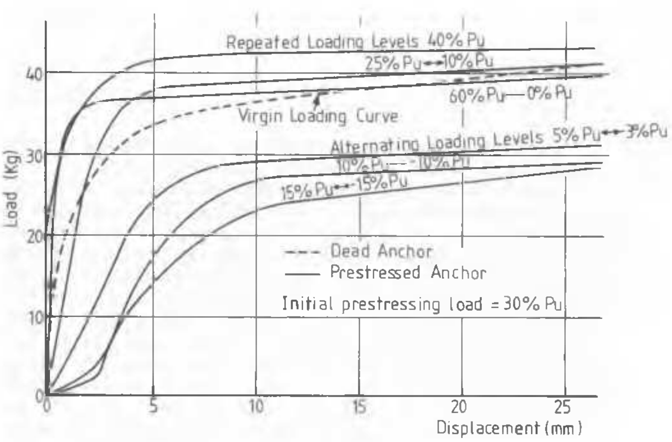


Figure 8. Effect of repeated and alternating loading on the static pull out resistance of anchors.

After each test the sand just above and surrounding the anchor plate was sampled and carefully sieved and in every case it was found that the sand had become finer with the greatest amount of breakdown being directly above the plate, Fig. 8. The amount of breakdown depended on the number of load cycles and the applied load level. Most of the changes in grading were with the coarser sizes. This finding is supported by the work of Youd (1972) who showed that additional densification of sands during repeated loading was due to crushing of the individual particles. It will be noted that the stress levels are very low and consequently grain breakdown is most likely due to attrition and grinding of the grain contacts. From these observations it is reasonable to suggest that at least part of the progressive movement of the anchor was due to attrition and grinding at the grain contacts. This in turn will lead to a density increase which partly explains the high static load capacity result for tests on anchors after repeated loading. Further supporting evidence is provided by Maddox (1978) who noticed dust particles collected around the sand grains above an anchor which had been subjected to 5000 load cycles.

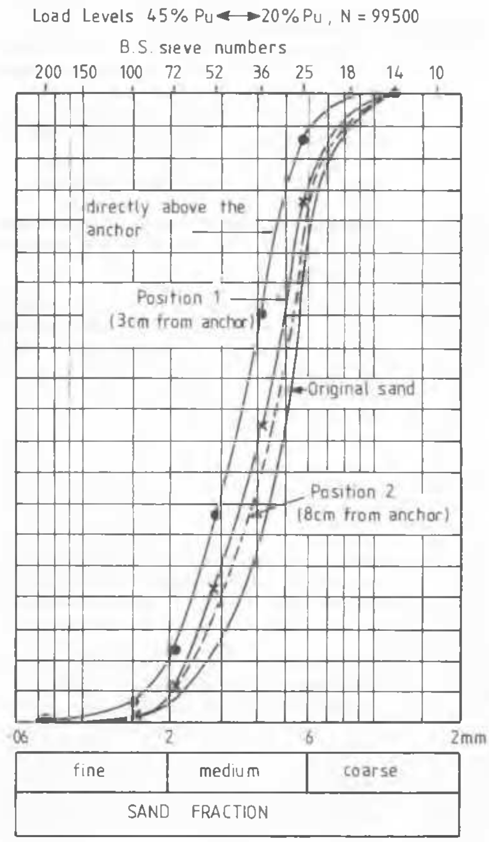


Figure 9. Grain size distribution of sand in the vicinity of anchor after a repeated loading test.

DISCUSSION

The test data presented refer to plate-shaped anchor tests performed in a dry sand at laboratory scale. It is not possible to translate these findings to field scale directly because of the very different boundary conditions which apply. For example, with a field anchor the stretch of the tendon may be several tens of mm and thus the prestress losses with repeated loading are expected to be much smaller than the present tests have shown. Also, the loading conditions used in the present work are very severe and it is unlikely, save in very special cases, that such extreme loads would occur in practice. Despite these general shortcomings, several very positive conclusions may be drawn from this work as follows:

(i) the prestressing of an anchor whilst improving its "life" with respect to repeated or alternating loads does not automatically prevent deterioration under repeated loading as claimed by Littlejohn (1977). Essentially the life span of the anchor is increased but the same general trends found for dead anchors apply;

(ii) as repeated loading continued there was a gradual loss of the initial prestress load in the anchor and eventually the anchor reverted to a dead one. The higher the prestress value the greater was the life of the anchor provided that the applied repeated loads were small and less than the initial prestress load values;

(iii) alternating loading is a much more severe loading condition than repeated loading but with prestressing the life of an anchor was considerably greater than that of a dead anchor;

(iv) repeatedly loading an anchor did not lead to a reduction in its static pull-out capacity. In effect there was significant increase in capacity for repeatedly loaded anchors but a decrease for alternately loaded anchors;

(v) the sand near the anchor changed gradation during repeated loading due to grain grinding and crushing. In turn this led to an increase in density and a decrease in effective normal stress which permitted the anchor to slowly pull through the sand with repeated loading.

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