CONTRIBUTION TO LOADING TEST PROCEDURE OF GROUND ANCHORS

Contribution à la méthode d'essais des tirants d'ancrage

by

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SOMMAIRE

La communication contient les principaux renseignements sur la technologie de construction et sur les méthodes d'essais de la résistance d'ancrages temporaires ou permanents installés dans la structure d'une cale sèche. Des analyses particulières furent faites pour le choix de la meilleure méthode de perforation et son influence sur la résistance obtenue pour des ancrages dans des sols sableux intercalés de lits d'argile. Les essais de tirants ont été faits à partir d'un programme modifié de la norme DIN 4125, cependant qu'une comparaison des résultats obtenus en utilisant différentes méthodes connues dans le monde, a permis de définir la meilleure. Au cours des essais, on a cherché à obtenir des informations sur l'influence du temps qui s'écoule entre la construction des ancrages et l'essai de chargement sur l'amplitude des déformations et la résistance des ancrages. Le frottement sur la longueur libre de l'ancrage et la préservation de cette longueur ont aussi été étudiés en fonction de la méthode de construction. Enfin, des chargements répétés des mêmes ancrages ont été faits qui permettent de donner des conclusions sur l'influence de ce facteur.

D'après les observations et les résultats des essais in situ, une analyse théorique est présentée de la stabilité des murs de soutènement ancrés et des fondations soumises à des tractions.

SUMMARY

The paper contains basic data on the technology of construction and on the testing methods of bearing capacity of ground anchors, temporary and permanent, installed in the structure of a dry dock. Particularly analyses were made concerning the choice of a proper drilling method and its influence on the bearing capacities obtained of anchors in sandy soils with clay interbeddings. The tests of the bearing capacity of the ground anchors were made according to a modified program based on the results of an analysis of the method given by DIN 4125, whilst a comparison of results obtained using different methods known in the world, has offered the possibility of definirs the most adequate one. During the tests, efforts were made to obtain data on the influence on the magnitude of deformations and bearing capacities of the anchors of the time period, between the construction of the ground anchor and the loading test. Also the magnitude of friction of the free part of the anchor and the preservation of this length as dependent on the construction method were considered. Additionally repeated loadings of the same anchors were made, and conclusions made concerning the influence of this factor.

The theoretical analysis concerns the problem of the stability of anchored retaining walls and of foundation subjected to tension forces, based on observations and test results made on the site.

1. INTRODUCTION

During construction of a dry dock, ground anchors were used as permanent anchors of sheet walls of the dry dock wall and as temporary anchors of special foundations used for erection of a heavy gantry crane. Analyses were particularly made concerning the choice of a proper drilling method and its influence on the bearing capacity of the above anchors in sandy soils with clay interbeddings. All anchors were tested by means of loading tests made according to a modified program based on the result of an analysis of the (German standard DIN 4125) method. A comparison of results obtained using different methods known throughout the world has shown that the chosen method can be the most adequate one.

The performed tests, described in the paper, were made with an assumption that the results obtained would deliver information about the influence of the time period which elapsed between the construction of the ground anchor and the loading test, on the magnitude of deformations and bearing capacities of the ground anchors. Also the magnitude of friction of the free part of the anchor and the preservation of this length as dependent on the construction method were considered, whilst repeated loadings of the same anchors should bring results on the influence of these loadings on the bearing capacity.

2. CONSTRUCTION OF GROUND ANCHORS

The permanent ground anchors investigated were made using the rotary-percussive drill method called «Alvik-X». Casing tubes 3.5 and flushing water were introduced on the free length equal to 17.0 m. The crawler drill on wheels was of the Atlas Copco type BVB-33 whilst the tubes and extension rods were placed in the soil by power rotated drill (top hammer) of the BBE 57-01 type. Number of of blows = 1950/60 s, torque moment = max. 80 kpm, inclination = 1:3. The boring along the length bond to ground, equal to 10.0 m, was performed using the same method but without casing tube and with bentonit flushing. After the assumed depth has been reached the bentonit suspension was pressed out by cement grout (aqueous colloidal dispersion) with $w/c = 0.4$ to 0.5 Through raising the grout from the hole bottom level concreting of the borehole took place whilst at the same time through the upper end of the tube there was a discharging of the ground and bentonit. The pressing of grout was stopped about 5 min after a total removal of bentonit flushing occured. Immediately after grouting a 7.5 ∅ Bridon wire strand with centralisers placed in 2.0 m distance along the whole anchoring length was pressed in the grout. Grouting tubes were also installed. To avoid concreting of steel strands along the free length special packers were used.

Once the strands in the grout the anchor head was closed and the pressure was raised to about 15 at (1.5 N/mm^2) to increase the bond of the anchor to the ground. One week after concreting of the anchor a prestressing tests was made by means of a hollow ram multi strand jack VSL for a force of 88 Mp on one anchor. The loading force was then lowered to working load of 59 Mp.

The temporary anchors were made using the overburden drilling method (OD) with a very rich water flushing. Reaching the assumed depth, the water flushing was replaced by cement grout of $w/c = 0.4$. The hole was filled with grout from the bottom level using flexible tubes. The reinforcement consists of 7.5 ∅ wire strands but without centralisers. The pulling out of casing tubes was connected with addition of grout to keep a constant grout level in the hole. Once the casing tube pulled out a 6.0 m long injection pipe with one way valve was placed. By means of this pipe the injection was performed under a pressure of 7 at (0.7 N/mm^2). Seven days later the anchors were prestressed to 90 Mp. After prestressing the loading was lowered to 72 Mp.

Both methods used for construction of permanent and temporary anchors, belong to the rotary-percussive drill method. The action of the bit is a combination of torque and impact with a high frequency, and of axial thrust. It causes a very effective remoulding of the ground whilst the removal of the remoulded ground is assured by water flushing. To obtain an optimum interaction between the ground and the anchor, the remoulding of the ground around the casing tube should extend as low as possible whilst the water flushing should be limited as much as possible. These conditions are fulfilled using the Alvik-X system, depending on the action of an eccentric bit boring a hole which has a diameter slightly bigger than the diameter of the casing tube. The tube penetrates by following the bit but it does not rotate. This causes a lesser remoulding of the soil along the tube shaft. The bit, because of the impact and torque, cuts the soil simultaneously by the bit part and the reamer. The water flushing is discharged through extension rods and holes in the bit which has a special constructed guide. This guide protects the pipe from inflow of soil what means that a certain amount of grains is pressed back into the soil whilst through the tube only water flushing is discharged. In sandy soils it gives a big increase of density.

In the OD-method the bit and the tube are in the tip protected by a ring. They are under a torque and impact transmitted by a common part, namely the shank adapter. In the described cases, however, a simplified OD-method was used. The penetration took place using only casing tube whilst the soil from the tube was removed by water flushing.

Analyzing both methods and the bearing capacities of anchors obtained it can be stated that the OD-method which seems to be simpler and needs less work, does not give any significant increase of efficiency when compared with the Alvik-X method. The remoulding of the ground when using water flushing and casing pipes, as occurs in the OD-method, has very small influence on the bearing capacities obtained. However, in the existing conditions the soil conditions have had the most important influence existing around the grouted body.

It was additionally stated that if boring in layered subsoil it is very important to observe the whole time what kind of soil is removed from the casing tube. Only such an observation gives the possibility to adjust the length of the anchor being installed. It should also be mentioned that it was found that the bearing capacity of an anchor is strictly dependent on the removal of bentonit.

3. LOADING TESTS

Loading tests of the permanent anchors by a force of 88 Mp were performed in a simple way in the following stages (fig. 1):

a) Prestressing of the anchor to 60 Mp with simultaneously measuring of the jack ram extension.

b) Locking-off the loading force through loosening of the jack. The moving back wire strands placed in the anchor block of the VSL system pull the gripping wedges and block the pulling system.

c) Moving back of the piston and further prestressing to 88 Mp. The piston, when moving, is pulling out the strand wires together with the stressing head. Measuring of piston displacement for the maximum load.

d) Measuring of prestressing losses one hour after application of maximum force.

e) Releasing of prestressing load. The strand wires together with the stressing head are moving back to the bearing plate.

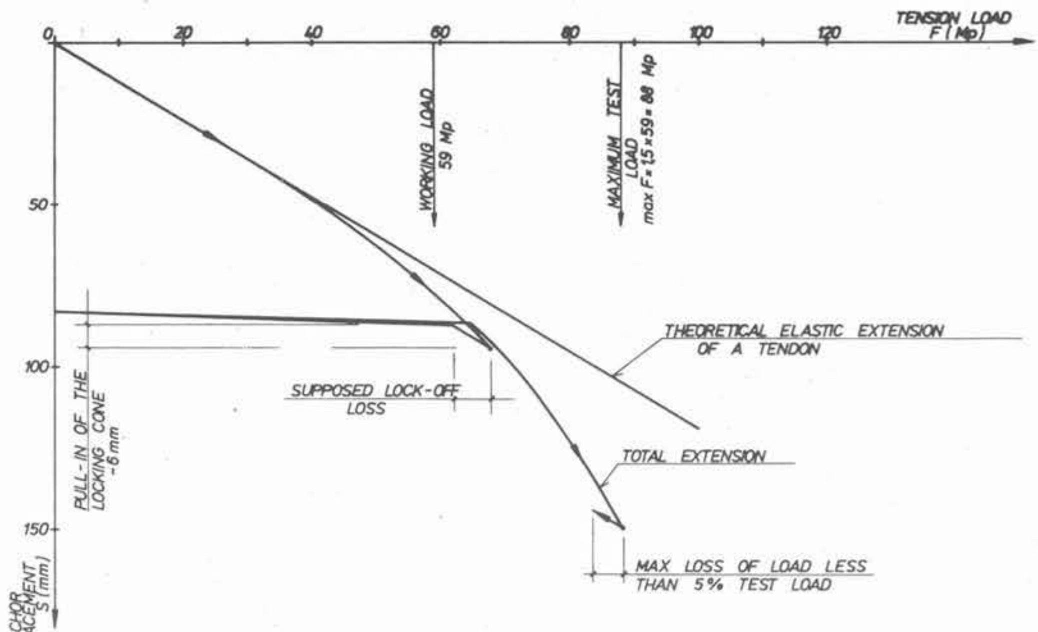

Fig. 1. — **Permanent anchors test loading scheme.**

The applied test loading method is a two-stage method in which reaching of a load equal to 150% of the working load is foreseen. Measurements of the magnitude of the creep displacement for this load should take place. The basic fault of this system is the small amount of measuring points which gives a very schematic loading diagram. Because no loading and unloading cycles are available it is not possible to determine the elastic and permanent displacements of an anchor. It is also impossible to find the conformity between the designed and actual free length of the ground anchor. Also the displacement measuring system of the anchor is simplified because it is assumed that this displacement is equal to the extended length of the piston. These values can be found to be different when analyzing for instance the backward movement of the anchored wall.

The necessity of a two stage prestressing method results also from the fact that the maximum outgoing of the piston depending on the structural solution of the jack is smaller than the total displacement of the free anchor length (17.0 m) for the applied load (88 Mp).

When testing the temporary anchors which were used for temporary foundations loaded by a vertical or inclined tensile force the following new test loading procedure was introduced (fig. 2):

a) Prestressing of the anchor in steps to reach 125% of the working load. The increase of load for each step is equal to 15 Mp starting from the initial load $F_o = 15$ Mp,
b) Unloading after each loading step to F_o. Unloading is starting from 30 Mp.
c) Keeping the observation time for loads of 45 Mp equal to 15 min, for loads of 60 and 75 Mp — 30 min, and for the maximum load $F_{max} = 90$ Mp equal to 60 min.
d) Measuring of anchor displacements by means of measuring of the outgoing of the piston and settlements of foundations.
e) Measuring of displacements immediately after loading at a certain step (about 1 min) and at the end of the loading steps to obtain the creep displacement. The resulting prestressing losses were equalized by increasing of oil pressure in the jack.

The results obtained made it possible to present diagrams of the load-displacement curves using a new elaborated method which is an extension of the method given in the German standard DIN 4125. These diagrams are made as follows:

a) Axis of a load-total displacement curve and a load-elastic and permanent displacement curve are drawn.
b) Measured results corresponding to all loading and unloading steps are plotted.
c) The real zero coordinate is introduced by shifting the loading axis to a distance equal to the measured outgoing of the piston on the beginning of test for zero increase of loading. It corresponds to the magnitude of the effect in the strand wires.
d) An auxiliary axis is placed through the measuring point which corresponds to the load $F_o = 15$ Mp.
e) Values are plotted on the permanent displacement curve which correspond to following unloading steps measured in relation to the auxiliary axis. It is assumed here that the permanent displacements for F_o are equal to zero.
f) In relation to the load-permanent displacement curve the total displacement s is plotted while it is measured from the axis going through the real zero. Points of the curve of elastic displacement s_{el} are obtained.
g) A straight line is made through the above points which indicates the elastic displacements taking friction into consideration. This straight line intersects the loading axis in a point of a coordinate which is the sum of initial friction causing displacements lower than should be expected according to Hook's law. Distances between this line and a parallel line plotted through the beginning of the coordinate system correspond to the friction losses on the following steps of the prestressing load.
h) If during the tests the ultimate bearing capacity has not been reached, dependent on the pulling out of the anchor from the soil, an extrapolation is proposed according to two schemes. In the first the change of the curvature of the permanent displacement curve is used. The second depends on the increase of the load which corresponds to the permanent displacement of the anchor

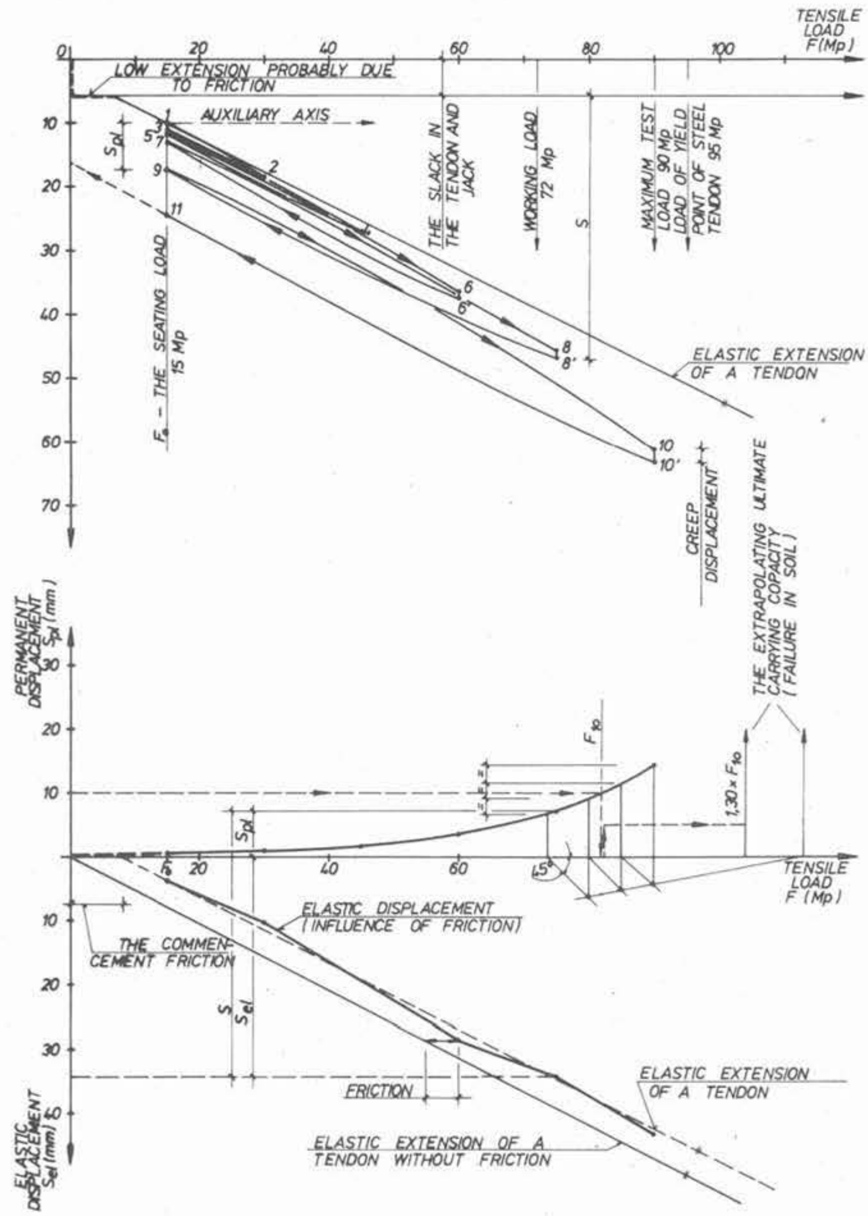

Fig. 2. — **Temporary anchors test loading scheme.**

equal to 10 mm whilst this load is multiplied by 1.30. Such a value was reached during failure loading tests of ground anchors in similar soil conditions.

Because of slight friction in the jack and on the free length of the anchor, mainly due to the straight arrangement of wires in the VSL wedge system, a simplified version of the proposed method was also used (fig. 3). It is based only on one unloading step after the maximum test load is reached and on presentation of the two curves in the way shown on fig. 3.

The conclusion that the anchors fulfill all requirements and may be used for permanent or temporary structures can be drawn analyzing:

- the designed free anchor length in relation to the stated real one, calculated from the inclination of the curve of elastic displacements;
- the difference between the ultimate bearing capacity and the working load;
- the allowable values of friction which are causing lower deformations of wires on the free length in the region of the anchor head an jack,
- the value of creep depending on time (for permanent anchors).

It should be stated that the free lengths obtained from these curves were much lower than designed. It was probably the result of the simplified way of reaching the free displacement of wires in the free length using the flushing out of grout by water. The grout mixed with water came back to the hole and made up an additional part of grouted body. The strand wires in the free length were not isolated or placed in plastic tubes which could allow them to move along this distance. Consequently a significant decrease of safety factor was obtained (fig. 4).

Repeated prestressings indicated a small increase of elastic displacements of anchors. It resulted probably by cracking due to cycle loadings and unloadings of the additional porous part of the grouted body, which caused the increase of the free length of the anchor. Loading tests of 10 anchors have been made twice, after 7 and 130 days from concreting date. The differences in displacements for the same prestressing load were not higher than + 6% to — 3%. This indicates that there is no influence of time on the results of loading tests.

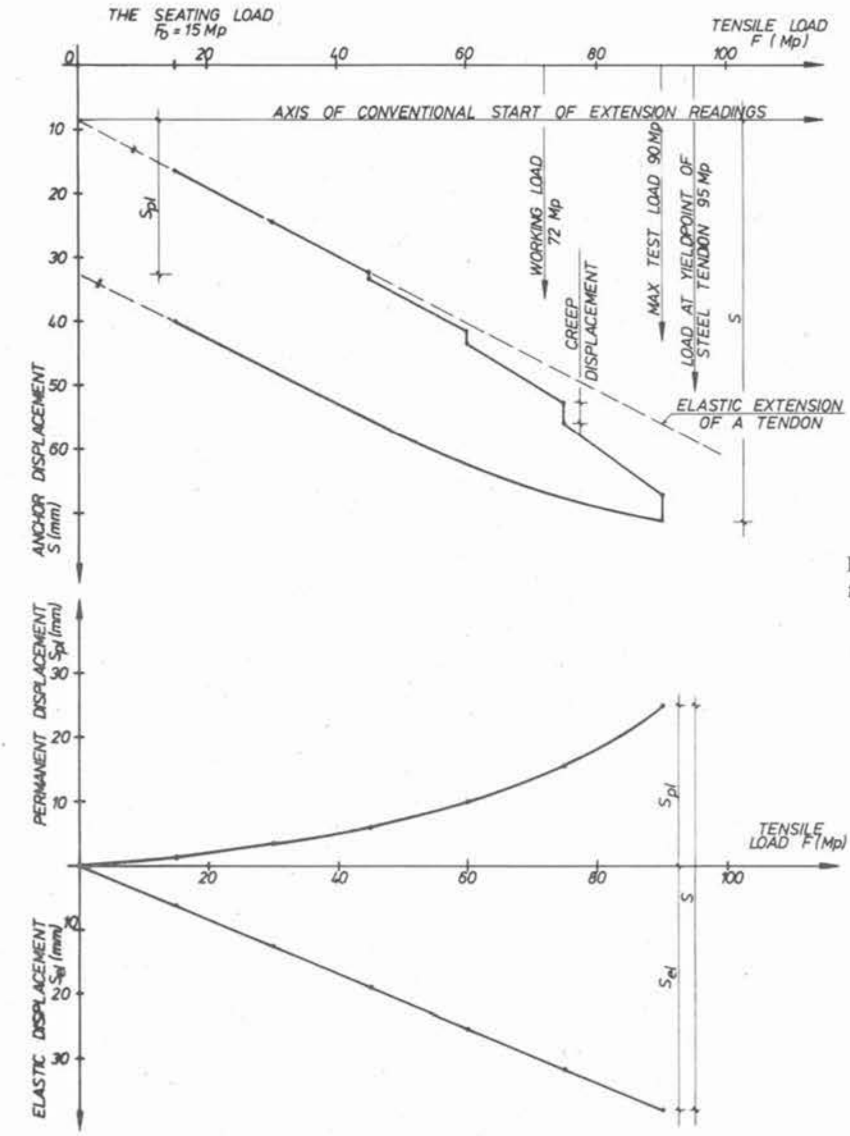

Fig. 3. — **Simplified method of ground anchors prestressing.**

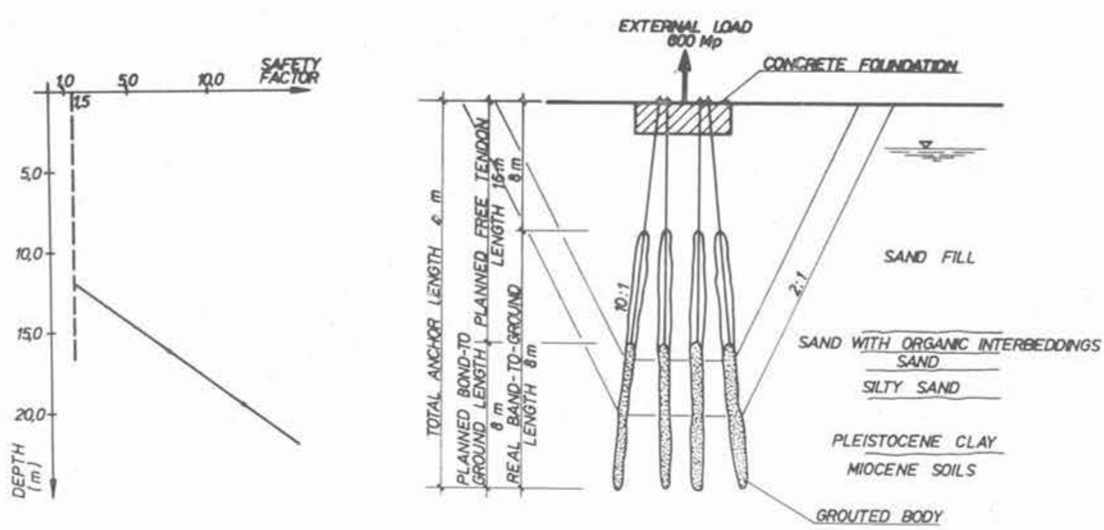

Fig 4. — **Safety factor variation in relation to anchor length.**

During loading tests the magnitude of prestressing losses as a result of moving back of selfbraking wedges during blocking was also measured. It was stated that the back movement of wedges was from 3 to 8 mm, whilst its magnitude depended on the pressing of wedges by a hammer during preparation of the stressing head for blocking and on its cleanliness. The calculated lock-off losses were in the range of 5 Mp. They were confirmed during later measurements.