# Soil Anchors in clay till using post-grouting

## Ancrages dans argile glaciaire utilizing injections repetés

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ABSTRACT

GEO - Danish Geotechnical Institute has carried out a series of pull out tests on vertical soil anchors in overconsolidated clay till to examine the effect of post-grouting of anchors in overconsolidated clay till in combination with time effect. The test results show that the post-grouted anchors have a much higher resistance than the anchors installed using conventional techniques. The time effect on the post-grouted anchors seems to be very small.

RÉSUMÉ

L'Institut géotechnique danois (GEO) a réalisé une série de tests de traction sur des ancrages de sol verticaux dans une argile glaciaire surconsolidée en vue d'examiner l'effet de post-injection des ancrages dans la moraine argileuse combiné à l'effet temporel. Les résultats des tests montrent que les ancrages post-injectés présentent une résistance beaucoup plus grande que les ancrages installés à l'aide de techniques conventionnelles. L'effet temporel sur les ancrages post-injectés semble très réduit.

Keywords: soil anchors, post-grouting, clay till, in-situ tests

## 1 INTRODUCTION

At the north coast of Zealand GEO - Danish Geotechnical Institute has carried out a series of pull out tests on soil anchors. The anchors are installed in overconsolidated clay till. The purpose of the tests is to examine the effect of post-grouting of anchors in overconsolidated clay till in combination with time effect.

## 2 TESTS AND SOIL CONDITIONS

Three series each of three anchors (a total of nine) were included. Each series included anchors with fixed length of 3, 5 and 7 m. All the anchors fixed length started 5 m below ground level. All three series were installed using conventional techniques (pulling back the casing successively) with an injection pressure between 6 and 8 bar (600 and 800 kN/m$^2$).

All the anchors were installed in vertical boreholes with a borehole diameter of 114 mm in a borehole pattern with a distance of minimum 5 m.

The anchors were steel bars (DYWIDAG) with a diameter of 26, 32 and 36 mm and a yield/ultimate strength of 460/568, 671/828 and 1099/1252 kN per anchor.

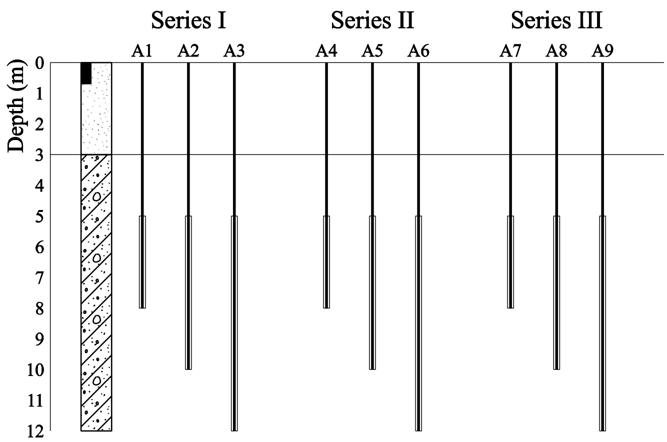


Figure 1. Anchor configuration. Principle

One series (No. I) was a reference series without post-grouting. Two series (Nos. II and III) were post-grouted under higher pressure 24 and again 48 hours after installation using pressure up to 20 bar.

During the post-grouting there has been used between 65 and 227 kg of cement per anchor.

The post-grouting has been possible because series II and III were installed with a post-grouting system as shown in figure 2.

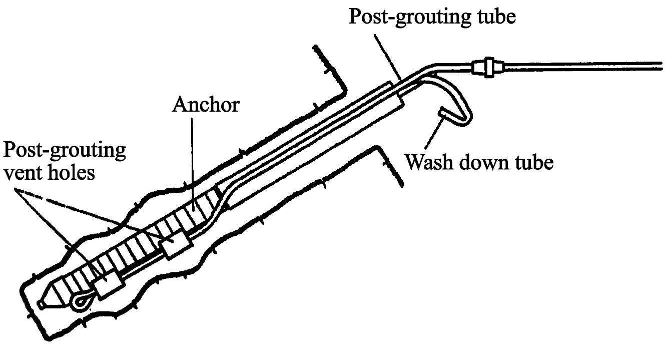


Figure 2. Post-grouting system (DYWIDAG).

One to two weeks after installation of the anchors, pull out tests were carried out on the reference series and on one (No. II) of the post-grouted series. Approximately two weeks later series No. III was tested.

The soil conditions consisted of clay till and sand till with an approximate 3 m thick layer of postglacial marine sand on top of it. With a clay content of 14 to 18 % and a plasticity index <5,1 % the till was a soil with characteristics between clay and sand. An example of the grain size distribution is shown in figure 3.

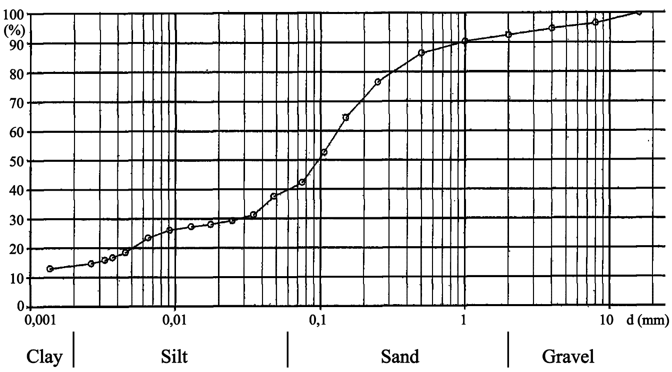


Figure 3. Grain size distribution in the clay till.

The undrained shear strength ($c_u$) has been measured by vane tests ($c_v$) in the boreholes to 100 to 250 kN/m$^2$ increasing slightly with depth. According to Danish experience $c_u = c_v$ in clay tills.

## 3 RESULTS AND THEORY

An example of the pull out tests is shown in figure 4.

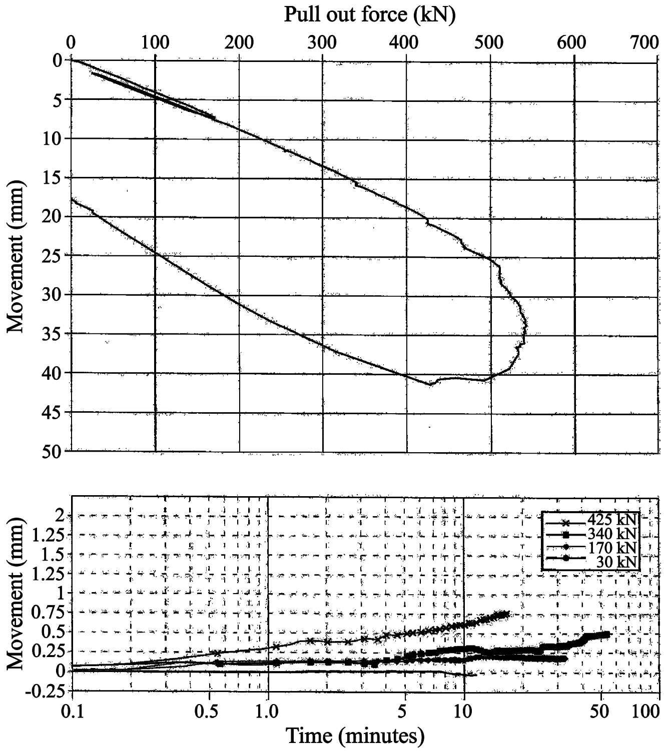


Figure 4. Pull out test.

The results of all the pull out tests are shown in figure 5 as the pull out resistance versus the fixed length of the anchor.

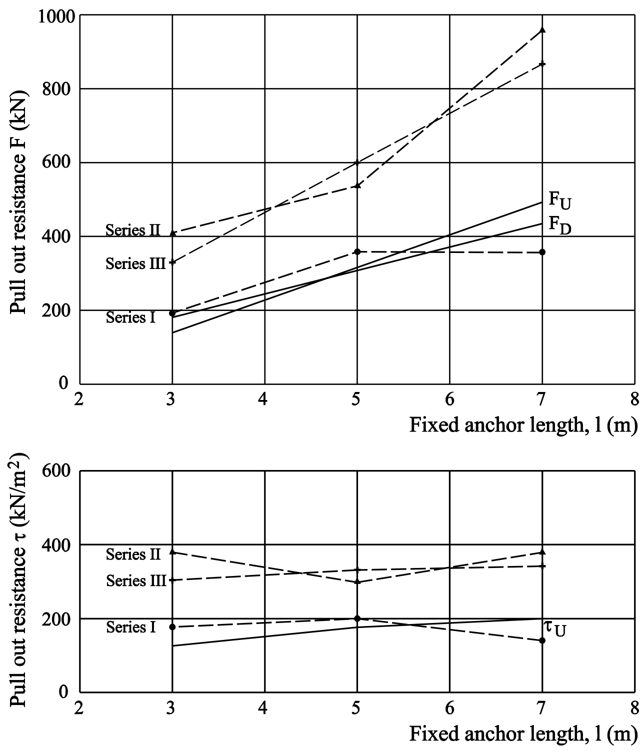


Figure 5. Pull out resistance of anchors as a function of the fixed length.

The tests in series II and III have more than 50 % higher pull out resistance than the reference series No. I. Tests in series II and III give approximately the same values for equal fixed length of anchor. This shows that the time effect on the post-grouted anchors seems to be very small.

The algorithm for the pull out resistance F for the contact between soil and anchor can be expressed

$F = \pi \cdot d \cdot L \cdot \tau$

Where

d is the effective diameter of the borehole (114 mm)

L is the fixed length (3, 5 and 7 m)

$\tau$ is the shear strength between the soil and the anchor (= $\sigma' \cdot \tan \varphi + c$)

Becaurce the actual soil (clay till and sand till) is a soil with characteristics between clay and sand we have to consider undrained as well as drained failure.

Undrained failure can be calculated as:

$F_U = \pi \cdot d \cdot L \cdot r \cdot c_u$

Where

r is the regeneration factor for the clay around the anchor

In figure 5 the resistance $F_u$ calculated for undrained failure on the basis of the borehole results has been shown using a regeneration factor r = 1.

Drained failure can be expressed by the formula:

$F_D = \pi \cdot d \cdot L \cdot (\sigma' \cdot \tan \varphi' + c')$

Where

$\sigma'$ is the effective mean stress in the soil perpendicular to the fixed part of the anchor

$\varphi'$ is the effective friction angle of the soil

$c'$ is the effective cohesion of the soil

In figure 5 the resistance $F_D$ calculated for drained failure on the basis of the borehole results has been shown using a horizontal mean stress $\sigma'$ = 250 kN/m$^2$. This value has been used due to an assumed vertical overconsolidation pressure from the ice of $\sigma_{pc}$ = 500 kN/m$^2$. The curve $F_D$ in figure 4 is based on the effective parameters ($\varphi'$; $c'$) = (32°; 0,1 · $c_u$ ). The parameters ($\varphi'$; $c'$) = (38°; 0) yield 5 to 10 % higher pull out resistance.

The calculated pull out resistance for undrained ($F_U$) and drained conditions ($F_D$) gives for all practical purposes the same values in good agreement with the test results from the reference tests, series I. The resistance for the 7 m long anchor gives a low value compared to the theory. This could be due to the fact that the resistance decreases with the fixed length of the anchor. Though this effect is not seen in series II and III.

In figure 6 the resistance for the tests results are plotted against the grouting pressure $\sigma_{gp}$ during post-grouting. The experience from BS8081 has been indicated in the figure.

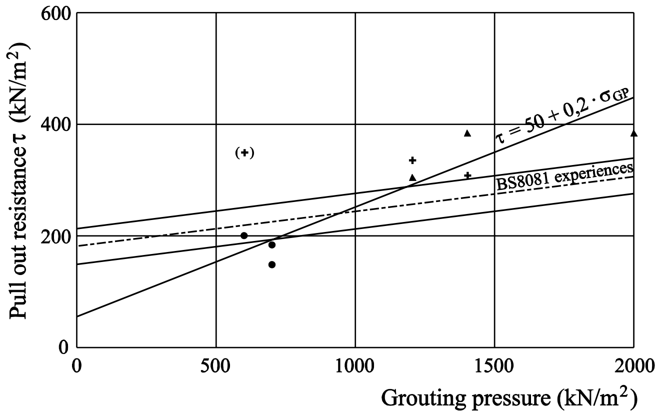


Figure 6. Pull out resistance as a function of the post-grouting pressure.

The test results show that post-grouting yields higher resistance and that the resistance increases with the grouting pressure.

The number of tests is few, but it looks as if the best fit for a strait line could be:

$\tau = \sigma'_r + 0.2 \cdot \sigma_{gp}$

Where

$\sigma'_r$ is the lowest horizontal effective stress the soil has experienced until today (here 50 kN/m$^2$).

## 4 GAINING OF RESISTANCE

Obviously the gaining of resistance has something to do with the post-grouting pressure effect on the grout and on the soil around the anchor.

The anchors are installed in a overconsolidated, but not very firm soil. During drilling the soil around the borehole will be relieved. Maybe the drilling will even generate small cracks in the soil around the borehole. Moreover the borehole will locally be a little wider than the theoretical diameter because of play in the drilling tools and the loss of stones.

When installing the anchors a grouting pressure of 6 to 8 bar is probably high enough to restore the conditions (strength) in the soil around the anchor if the excess pore water pressure has the time to drain away. Due to shrinkage in the grout during the drying process some small cracks will develop and reduce the resistance to a level as calculated with the theoretical diameter and not with the actual diameter.

The post-grouting process using a higher grouting pressure after the grout has started gain strength will generate a higher pressure on the soil and fill out the cracks in the grout between the soil and the grout. This gives a higher effective diameter of the anchor. The failure between soil and anchor will be forced a little further away from the anchor wall.

## 5 CONCLUSIONS

The test results show that the post-grouted anchors have a much higher resistance than the anchors installed using conventional techniques.

The time effect on the post-grouted anchors in the actual soil seems to be very small.

Further tests have to be carried out with other types of soil.

## 6 ACKNOWLEDGEMENT

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