Some Investigations Concerning Salt in Clay

Quelques Études sur la Salinité de l'Argile

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Summary

In order to explain the peculiar shear strength curves of some organic clays from the surroundings of Stockholm, a study was made of the influence of the salt content on some geotechnical properties, e.g. the sensitivity. A new method of salinity determination has been evolved. This method consists in measurements of the salinity of the pore water squeezed out of clay samples in combination with conductivity measurements made directly in the soil; in the laboratory with a small penetration electrode and in the field with a special sounding device. Data from some sites are presented and discussed. In one case it is shown that a leaching process is still going on and is accompanied by a sensitivity increase. This is in close agreement with the present theories of the formation of 'quick' clays. A short study of the influence of the salinity on the liquid limit concludes the paper.

Sommaire

Afin d'expliquer forme bizarre de la courbe de résistance au cisaillement de quelques argiles provenant du voisinage de Stockholm, on a étudié l'influence de la salinité sur quelques qualités géotechniques, par exemple la sensibilité. On a élaboré une méthode nouvelle pour la détermination de la salinité. Cette méthode combine les mesures de la salinité de l'eau interstitielle exprimée des échantillons d'argile et les mesures de la conductibilité effectuées directment dans le sol avec un instrument de sondage special. Les résultats relatifs à quelques places sont présentés et discutés. Dans un cas, on montre que le processus de délavage continue toujours et qu'il est accompagné du'une augmentation de la sensibilité, ce qui s'accorde bien avec les théories de la formation de 'l'argile fluide'. En outre, on a fait une courte étude de l'influence de la salinité sur la limite de liquidité.

Introduction

The geotechnical significance of salt in clay has not yet been completely elucidated. Rosenqvist (1946, 1955a) has done pioneer work in this field and has found that many important geotechnical properties can be explained by, among other things, the present salt content of the pore water and the sedimentation environment of the clay.

At the Swedish Geotechnical Institute, the question of salt and its influence upon clay arose in explaining some 'peculiar' shear strength curves, especially from a place near Stockholm (Enköping*), in which the shear strength does not increase rectilinearly with the depth but decreases in some parts.

Tests Made by Means of Common Methods

Tests were first made by means of a common conductivity method. The clay was dried, and 2 g were mixed with 20 ml of distilled water. The solid particles were leached out and permitted to sediment, and the conductivity was measured in the clear water phase in equilibrium with the clay particles. If the clay particles did not sediment, they were filtered off. The salt content of the pore water was then calculated, Fig. 1. The curve in this figure gives salt contents as high as 25 parts per thousand but, since this clay, according to geologists, has sedimented in water having a maximum salinity of 15 parts per thousand (Littorina Sea), it is obvious that our values of the salt content are too high, there being some source of error.

We found that different values of the salt content were obtained according to the time during which the clay was in contact with water, and according to the concentration of the dispersion. Furthermore, it seems confusing to use values relating to pre-dried clay. Some check tests were therefore made by evaporating pore water from a natural material, and then we got a very uniform salt content curve ranging from 3 to 7 parts per thousand. (This curve is shown in Fig. 3, on the left.) The peak value at 12 m does not exist here.

The latter determinations seem to give safer values because we have only evaporated pore water without contact with the clay mineral, and we can draw the conclusion that leaching methods cause a disturbance due to the adsorbed ions, and do not give the salt content of the pore water in the natural clay.

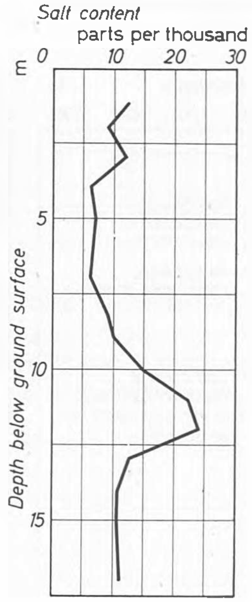

Fig. 1 Results of salt determinations by means of leaching and conductivity method

Résultats des déterminations de la salinité au moyen de la méthode utilisant le délavage et les mesures de la conductibilité

Method for Quick Determination of the Pore Water Salt Content

Main features—The greatest difficulty in using free pore water in salt analyses seems to have been the imperfectness of the squeezing method. We have therefore constructed a special press based on the principle of a filter press for testing drilling mud. With this press we work with an air-pressure of 10 kg/cm², and it takes in normal cases about 20 minutes to get

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* The clay at Enköping has earlier been extensively investigated from certain points of view (Jakobson, 1954). Some of the data in the present paper, e.g. the Atterberg limits and the unit weight, are taken from this publication.

from a clay sample, about 6 cm in height and 6 cm in diameter, an amount of pore water sufficient for an analysis. The pore water can be analysed by means of common physical and chemical methods; the simplest ways are to evaporate it or to measure its conductivity.

It can be stated that the most accurate methods for the determination of the salt content of the pore water are the two last mentioned methods. As, however, all methods working with extracted samples are rather expensive and time-consuming and cannot give a continuous picture of the profile, which is very often wanted, it would be desirable to get a simplified method; a method which should permit measurement directly in the ground. The simplest would then be to measure the conductivity directly in the clay and determine if there is a relation between its conductivity and the salinity of the pore water.

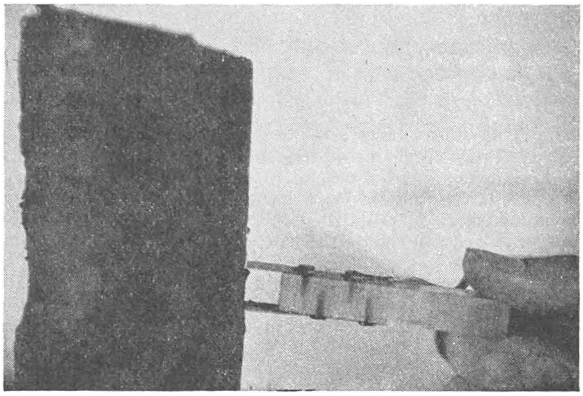

Fig. 2 Laboratory penetration electrode
Électrode de pénétration pour les essais de laboratoire

For this purpose we extracted long undisturbed clay cores of about 15 m length by means of the soil sampler with metal foils (Kjellman, Kallstenius and Wager, 1950). On these cores we made laboratory tests to give comparisons between conductivity measurements directly in the clay and salinity determinations on squeezed pore water. The conductivity measurements were made by means of a small penetration electrode, shown in Fig. 2, in points with spaces of about 3 cm. The salinity determinations were made from samples cut out from the core about each m. A resistance curve and a salt content curve from these investigations on a clay from Enköping are shown in Fig. 3 (on the left). If we disregard the dry crust and compare the two curves, we find that they are roughly reflections of each other. The same fact can be shown by using another clay of different type, viz. a high-resistance clay, i.e. a clay of very low salt content, from the surroundings of Uppsala (Marsta, Fig. 4). The salt content curve in this case is also in agreement with the resistance curve. All our present investigations indicate that we can form a general idea of the salt distribution in a clay profile by measuring the resistance directly in the clay. The numerical value of the salt content can then be obtained by calibration of the resistance curve by evaporation of pore water (see Figs. 3 and 4).

Our adopted method for salt determination in clay is therefore: Resistance measurements in the clay are made at points which are as close spaced as possible. The resistance curve is then calibrated by the squeezing method on samples at distances of, say, 1 m. In many cases the squeezing process is not necessary.

The new method in the field—The conductivity measurement directly in a clay is easily adapted for use *in situ*. Rosenqvist (1955b) has designed a sounding tool for measuring the corrosive properties of the soil; this tool can preferably be used to measure the conductivity of the soil. After this prototype we

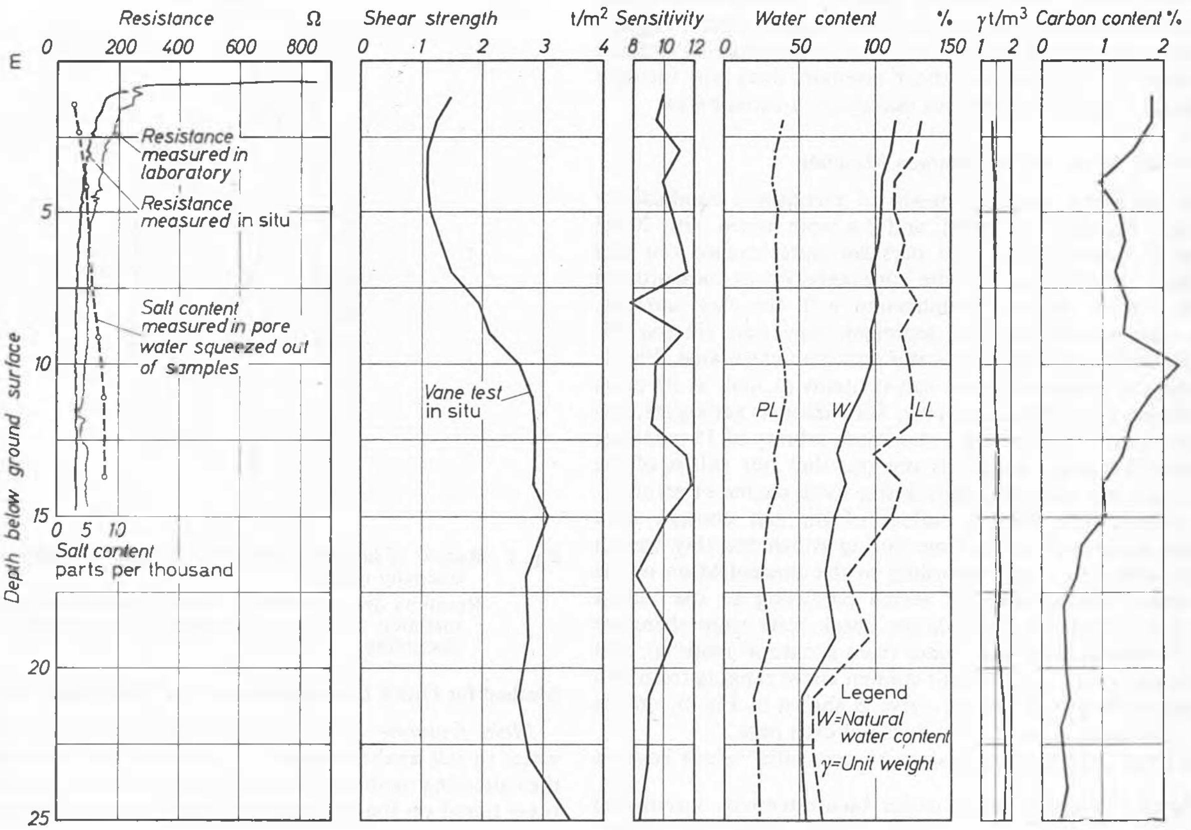

Fig. 3 Geotechnical data including results of salinity determinations on pore water in a clay profile from Enköping
Données géotechiques, y compris les résultats des déterminations de la salinité de l'eau interstitielle dans un profil d'argile à Enköping

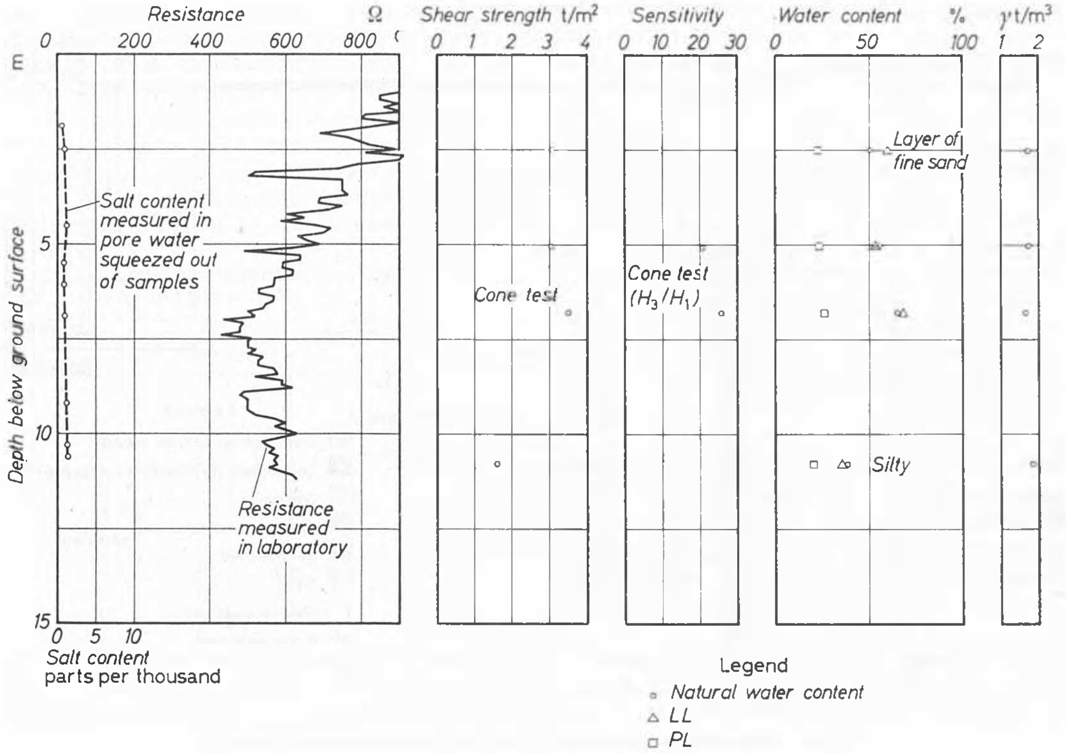

Fig. 4 Geotechnical data including results of salinity determinations in pore water in a clay profile from Marsta
Données géotechniques, y compris les resultats des déterminations de la salinité de l'eau interstitielle dans un profil d'argile à Marsta

designed and constructed the apparatus shown in Fig. 5. The values obtained *in situ* with this apparatus are in agreement with the values observed in the laboratory by the aid of the small penetration electrode, except that the former are somewhat smaller (see Fig. 3). With this apparatus we have made some investigations of clays near Stockholm (only the two most interesting places* are treated in this paper). We found that a clay from one place can be salty, while a clay from another place in the immediate vicinity can be completely free from salt, although both originally were sedimented in saline water. This can be explained by a leaching process going on. By studying the geology of the sites we can see that sites free from salt are situated rather higher than 'salty' sites. In fairly recent time the latter have been sea bottom (salt water) and the leaching process cannot have been going on for as many years as in higher situated sites.

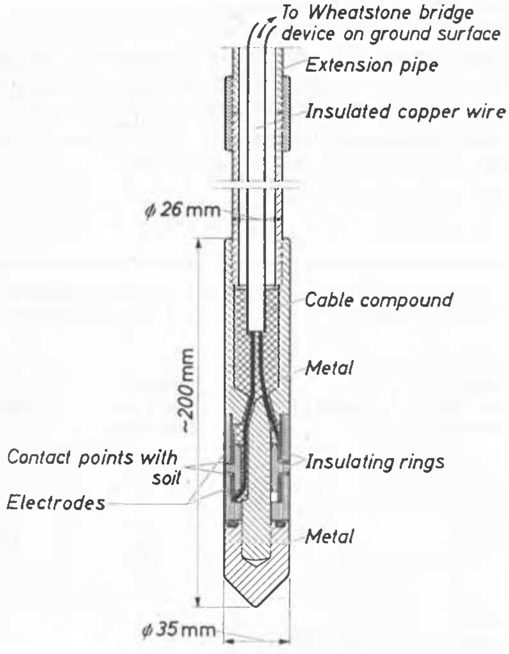

Fig. 5 Sounding tool for direct measurements of conductivity in the soil
Instrument de sondage pour les mesures directes de la conductibilité dans le sol

Effect of the Salt on Some Geotechnical Properties

Sensitivity—Rosenqvist (1955a) has compared salt content curves and sensitivity curves. Similar curves for a Swedish clay from Enköping (deposited in salt water) are shown in Fig. 6 (bore hole 4).

Considering the resistance curve, which is the reflection of the salt curve (see bore hole 2 in Fig. 6), we see that the salt content is small at the ground surface but increases slowly with depth to about 5 m, where it reaches a maximum. After this the curve deviates, showing a slow decrease in salt content: below about 8 m, the clay has a very low salt content, while lower still (at about 11 m) there is a layer having a very low conductivity, and it seems from the slope of the curve as if there is a continuous slow salt diffusion from the overlying salt layers, and that the salt is probably washed away by the flowing water in the lower layer (a certain overpressure in the ground water together with high permeability in the lower layer have been observed in bore holes on this site). One thing which indicates that a salt diffusion cycle is going on here is that bore hole 2 shows a higher salt content because of its great depth to a layer of high permeability. The leaching process is probably going on also from above.

Now if we compare the sensitivity curve in bore hole 4 with

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* Enköping and Marsta, see Figs. 3, 4 and 6.

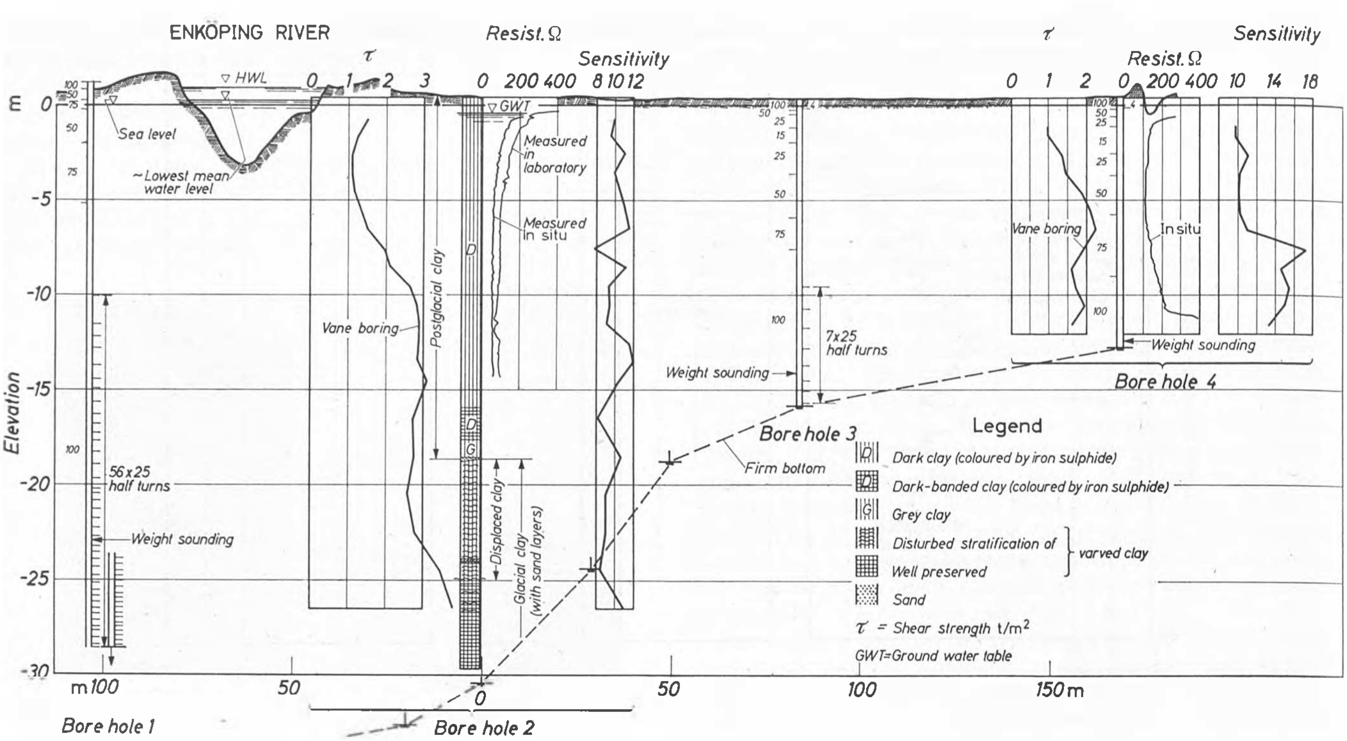

Fig. 6 Results of investigations of the clay profile from Enköping
Résultats d'examens du profil d'argile à Enköping

the corresponding resistance curve, we find that the sensitivity increases much just at the point where the resistance curve deviates. This affords evidence that a leaching process is accompanied by an increasing sensitivity of the clay in accordance with the Norwegian theories.

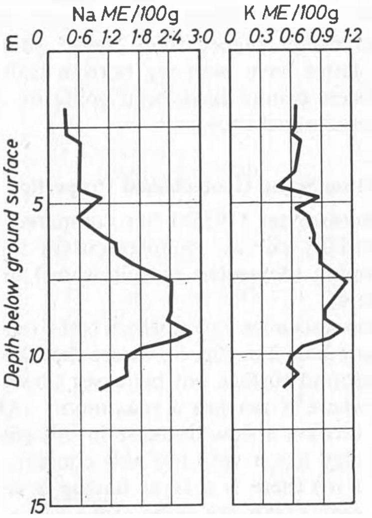

Fig. 7 Spectrographic salt determination on a clay from Marsta (made by B. Järnefors, Geological Survey of Sweden)
Determination spectrographique de la salinité d'une argile de Marsta (faite par B. Järnefors, Institut National Geologique Suédois)

We have, however, also found cases where the sensitivity curve and the salt curve do not agree with each other. Fig. 4 shows a sensitivity curve on a few samples from Marsta and a salt content curve. The whole clay profile is here almost free from salt (about 1 g/l.). The sensitivity, on the other hand, has a maximum at 7 m. This seems a little strange, but is due to the fact that only the clay in the middle layers was originally deposited in salt water, and has then been almost completely washed out by a leaching process. This can be detected by means of, for instance, spectrographic methods (see Fig. 7).

Liquid limit—Rosenqvist (1955a, p. 70 *et seq.*) made an investigation on the variation of the liquid limit with the salt content. We have made similar tests on a glacial clay from the Stockholm district and a glacial clay from the Province of Värmland, about 300 km west of Stockholm: the results are shown in Table 1. They exhibit the same typical increase at small salt contents which is characteristic of an inorganic clay. Pre-drying and re-wetting caused on the Stockholm clay a decrease of the liquid limit from 51 to 47, i.e. a very small change.

Table 1

Glacial clay from Värmland		*Highly organic clay from Huddinge*	
Salinity parts per thousand	*Liquid limit*	*Salinity* parts per thousand	*Liquid limit*
0	47·5†	0	231*
5	52†	0	208†
20	51·5†	5	228†
50	52†	20	222†
from Stockholm		50	217†
		100	211†
Salinity parts per thousand	*Liquid limit*		
0	41		
10	53		
15	53		
20	51		

* Salt mixed in by hand
† Salt mixed in by means of a Turmix apparatus

From experience it is known that organic matter has a great influence on the common geotechnical properties of Swedish clays. Therefore we made corresponding investigations on such clays in order to determine the influence of the salt. The sample was a highly organic clay from Huddinge, and the results are given in Table 1. As was to be expected, the liquid limit is here very high (231). It seems as if increased salt contents will decrease the liquid limit; unfortunately the mixing apparatus will also cause a decrease of the liquid limit because of the very unstable structure of the organic material and the values must be taken with care.

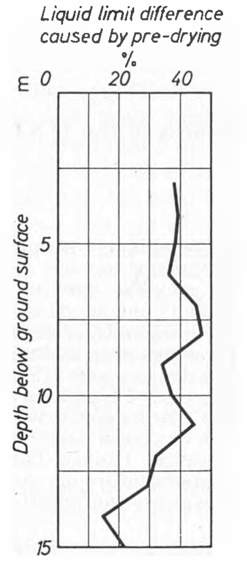

Fig. 8 Influence of pre-drying and re-wetting on liquid limit of Enköping clay

Influence du préséchage et de la réimbibition sur la limite de liquidité d'une argile d'Enköping

The very great difference between inorganic and organic clays is due to the effect of the drying on the liquid limit. The drying process carried out in the same manner as in the case of the glacial clay caused in one test a decrease of the liquid limit from 236 to 90. This immense change must be due to the structural disturbance of the organic material which has been described by Casagrande (1939, p. 42). In order to completely eliminate the effect of the organic material we treated the sample with hydrogen peroxide: after renewed drying and swelling we observed a further decrease of the liquid limit to 64; thus, the total decrease of the liquid limit caused by drying was 167.

In order to examine the conditions in an ordinary Swedish organic clay, tests were made on samples from Enköping whose organic matter content (carbon content) is shown in Fig. 3; they were taken at every m, were subjected to the above treatment, and the result is the curve shown in Fig. 8. This curve has a certain similarity to the organic content curve, though the former deviates from the latter at some points. It is conceivable that in this way we can estimate the structure-forming power and the shear-strength-developing power of organic matter, but this point remains to be investigated more thoroughly.

Conclusions

From the above results obtained by various methods it seems as if we can draw the conclusion that the shear strength of clays of such a type as in Enköping is not influenced so much by the salt content: it seems also as if the organic content has a greater importance.

The work in this report was carried out at the Research Department of the Royal Swedish Geotechnical Institute; the field tests were conducted by Mr. N. Flodin and the laboratory investigations made by Mrs. A. Schöldström: the author is grateful to them for their valuable contribution.

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