STATENS GEOTEKNISKA INSTITUT

SWEDISH GEOTECHNICAL INSTITUTE

No. 45

SÄRTRYCK OCH PRELIMINÄRA RAPPORTER

REPRINTS AND PRELIMINARY REPORTS

Supplement to the "Proceedings" and "Meddelanden" of the Institute

Quality in Soil Sampling

1. Secondary Mechanical Disturbance. Effects in Cohesive Soil Samples

Torsten Kallstenius

2. Sampling of Sand and Moraine with the Swedish Foil Sampler

Bengt Broms & Anders Hallén

STOCKHOLM 1972

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Reprinted from Proceedings of Specialty Session on Quality in Soil Sampling. Bangkok, July 1971

STOCKHOLM 1972

PREFACE

Sweden is represented in the International Group on Soil Sampling (IGOSS) by Dr Bengt Broms and Dr Torsten Kallstenius, the latter being one of the founders of IGOSS. At the Specialty Conference on the Quality in Soil Sampling in Bangkok in 1972 in connection with the Fourth Asian Conference on Soil Mechanics and Foundation Engineering two Swedish papers were presented.

The papers, which are included in this publication, are dealing with disturbance effects at sampling in general and with experience with the Swedish Foil Sampler, at sampling in friction material.

Stockholm, February 1972

SWEDISH GEOTECHNICAL INSTITUTE

SECONDARY MECHANICAL DISTURBANCE. EFFECTS IN COHESIVE SOIL SAMPLES

Torsten Kallstenius, Geotechnical Consultant, K-Konsult, Sweden

SYNOPSIS. Disturbance effects in soil samples were studied. Certain after-effects from sampling give a time-dependent influence. In addition, damage from deformation of samples, shocks, heavy vibrations and changes in water content after sampling are major sources of disturbance. Small vibrations and temperature changes in the region + 5 - + 30° C do not affect sample strength seriously. Disturbance may give higher or lower strength and affects different laboratory tests differently. This can be used as a means of detecting disturbance.

I. INTRODUCTION

During sampling primary disturbances of the soil samples are caused by the sampling tool. They depend on the type of soil, the shape and quality of the sampler and the manner in which it is handled. After sampling secondary disturbance effects occur. Such secondary effects may be time-dependent after-effects from disturbance initiated by the sampling procedure but they may also be caused by incorrect handling and storage of samples after sampling.

At the Swedish Geotechnical Institute the Author studied primary and secondary disturbance effects in soil samples (cf. Kallstenius, 1958 and 1963). During some years of consulting practice, experience was gained on the ways to detect sample disturbance.

Swedish clay soils are seldom heavily overconsolidated and not frequently of a swelling type. The basic clay minerals are illites with some content of kaolinite and organic detritus or humic acids. The content of in-active matter such as crushed rock (quartz, feldspar, mica and iron hydroxide) is normally of the order of 50 %.

Most samples used for the actual studies were taken with the Swedish standard piston sampler (cf. Standard Piston Sampling, 1961). This sampler was developed with the aim to get correct strength values in the laboratory after due calibration. Still it should be economical and intended for ordinary routine practice.

Some other samplers are also mentioned in the following and Fig. 1 shows the samplers arranged after the degree of disturbance effects. The Helical Sounding Borer gives the highest degree of disturbance and the Piston-Foil Sampler the lowest.

II. FIELD EXPERIENCE

(a) Helical Sounding Borer at Ultuna and Löddeköpinge

By means of the Helical Sounding Borer (Sökjer, 1961) a sample of soil can be obtained by extrusion of a helical screwed into the soil. The samples are locally much disturbed but their least disturbed parts can be tested with respect to strength by means of the Swedish fall-cone test.

At Ultuna (about 60 km north of Stockholm) the clay is slightly organic (cf. Fig. 2). Samples were tested by the fall-cone test at the site immediately after sampling and in the laboratory in Stockholm about 24 hours later. The transport was very carefully done without strong vibrations or shocks.

Laboratory testing showed much lower strength values and a time effect was suspected to be the main reason for the strength reduction (cf. Fig. 3 a). Such a time effect can be explained by water migrating from the more disturbed parts of the samples to the less disturbed parts. The time influence was smaller where the clay had dried slightly near the soil surface. It was decided to avoid transport effects by testing samples on the boring site at different times after sampling. Such tests were performed in clay by Sökjer and collaborators at Löddeköpinge in southern Sweden. As samples were taken from different depths, the total results (Fig. 3 b) show great scatter but a clear tendency could be observed for these slightly overconsolidated samples to decrease in strength with time.

(b) Old Swedish Piston Samplers in Normal-Sensitive Clay and Quick-Clay near Gothenburg

Tests were performed by the Swedish State Railways on samples taken with three different samplers, called SJ, GH[1] and Gk, shown in Fig. 1. The samplers used gave a degree of disturbance which were a little higher than the Swedish Standard Piston Sampler.

Tests were performed in normal-sensitive clay and in quick clay. Testing was performed on the site and after about 500 km of railway transport.

The samples tested in the laboratory showed about 20 % lower strength values than those tested at the site. (By courtesy of the Geotechnical Department of the Swedish State Railways the Author could study their laboratory

1) Sampler GH is a development of Sampler SJ with sample tubes.

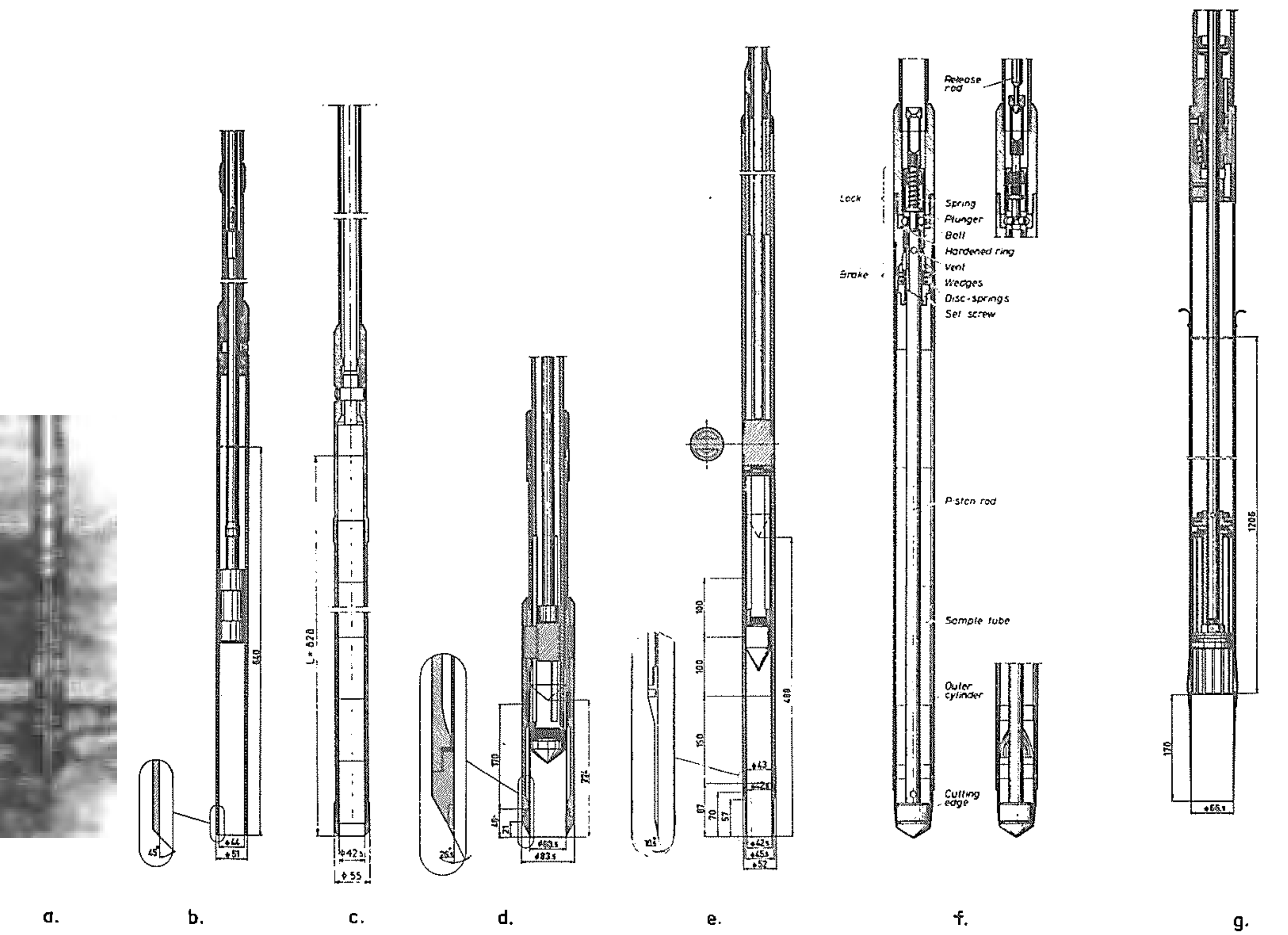

Fig. 1. - Various samplers for taking "undisturbed" soil samples, a. Helical Sounding Borer, b. Sampler SJ, c. Sampler GH, d. Sampler SGI IV, e. Sampler Gk, f. Swedish Standard Piston Sampler, St I, g. Foil Piston Sampler SGI IX.

journals. It was found that testing in the field had been performed at varying times after sampling.)

Fig. 4 shows median strengths with respect only to time elapsed after sampling. As can be seen, there is a reduction of strength with time. Even if disturbances due to vibrations during shipment by railway could have had some influence, the influence of time only can explain the main decrease in strength.

The greatest decrease in strength was found for samples from the smallest and greatest depths, respectively. Here the soil samples would lose most of their strength by swelling if excess water from remoulded parts of the samples could reach the least disturbed part.

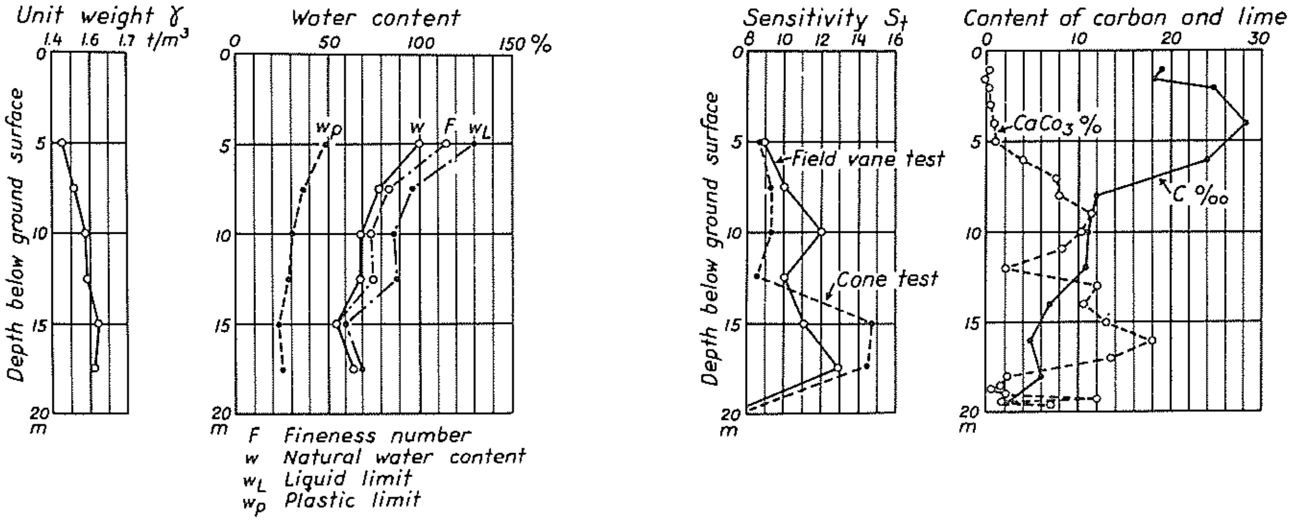

Fig. 2. - Soil data from Ultuna 1956

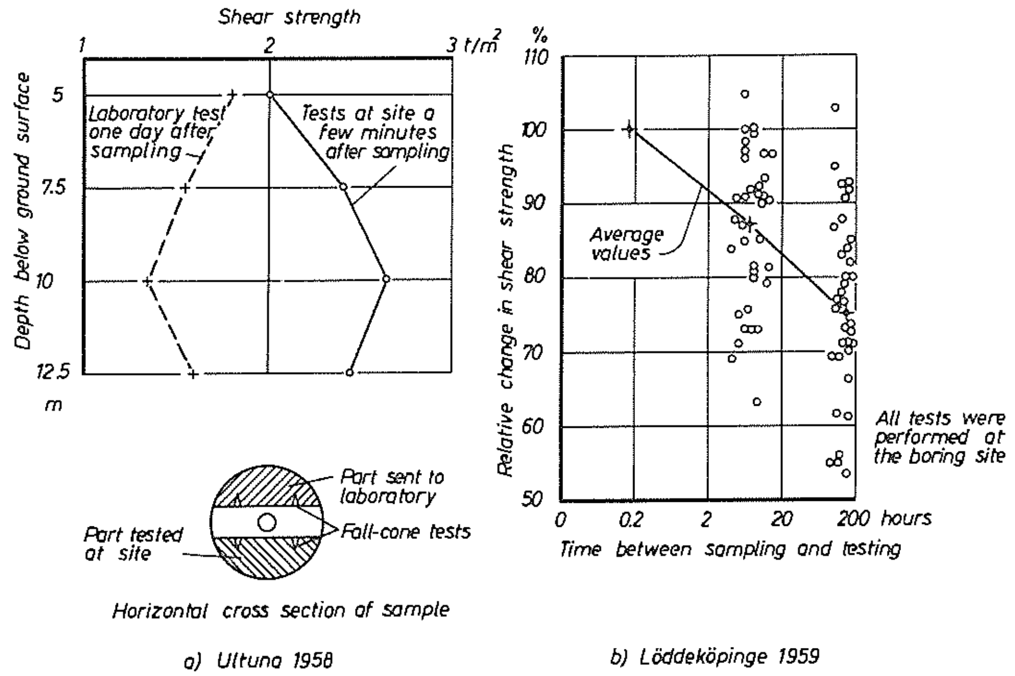

Fig. 3. - Time effects in fall-cone tests on samples taken with the Helical Sounding Borer, a. Ultuna 1958, b. Löddeköpinge 1959

(c) Standard Piston Sampler at Various Sites

(i) Quick clay samples from Vesten

The place Vesten is situated in western Sweden in the Göta River Valley. The clay is here locally of the extremely sensitive, "quick" type (cf. Fig. 5). The sampler is shown in Fig. 1.

Samples from 2 - 26 metres depth were tested at different occasions after the start of withdrawal of the sampler. At the site, strength testing was performed after ten minutes, one hour, two hours, one day and one week. In the laboratory, after about 500 km railway transport, testing was performed one day, one week, one month and two months after sampling.

The transport was made by train but the samples were not subjected to shocks or extreme temperatures. Fig. 6 summarizes the test results. The samples were stronger immediately after sampling than later. Transport seems to have had a strengthening effect when samples were tested by identical methods equally long time after the withdrawal from the soil was started.

The fall-cone penetration depth in different parts of the samples shows distributions as is indicated in Fig. 7. A weakening of the upper part of the samples can be proven to depend on the extrusion of the samples but the strengthening effect caused by transport is difficult to explain otherwise than by an effect similar to that obtained when vibrating concrete.

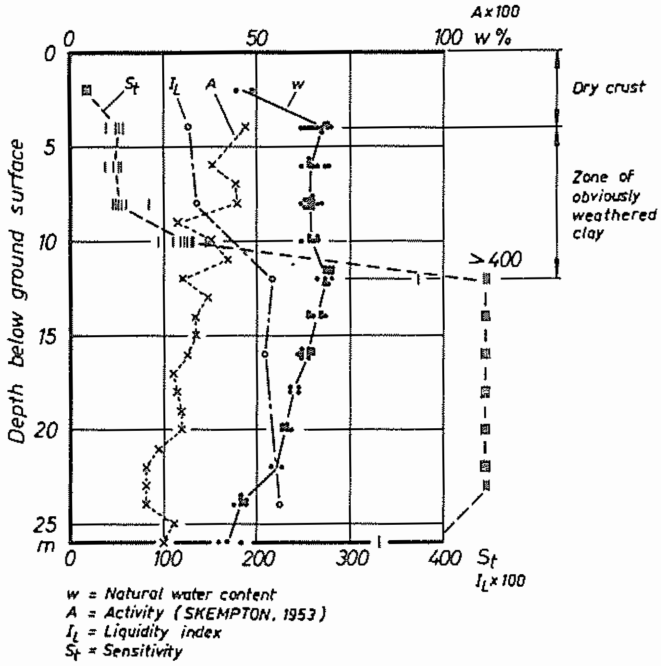

Fig. 5.- Soil data, Vesten 1961

(ii) Clay samples from Skå Edeby. Consolidation tests

Consolidation tests were run with the aim to check the influence of storage time and test temperature.

Samples were taken at night at Skå Edeby, a site close to Stockholm. Sample temperature was permitted to deviate at the most 2° C from the temperature in situ. Some samples were tested in a field laboratory immediately after sampling. Thus, time and swelling factors should have minimum influence. Other samples were transported carefully to the Institute and stored under approximately the same temperature as in the field (8° C). After one day, consolidation tests were performed on some samples without any change in temperature and other samples at 22° C.

Influence of temperature was negligible but six comparisons out of ten showed less compression values in the site tests when temperature was kept constant. When temperature was changed in the laboratory, 12 comparisons of 15 gave smaller compression in the field. No reliable assessments could be made as to water content distribution in the samples. Some results are shown in Table 1. They scatter too much to permit detailed evaluation, but this seems to be typical of consolidation tests in some types of soil.

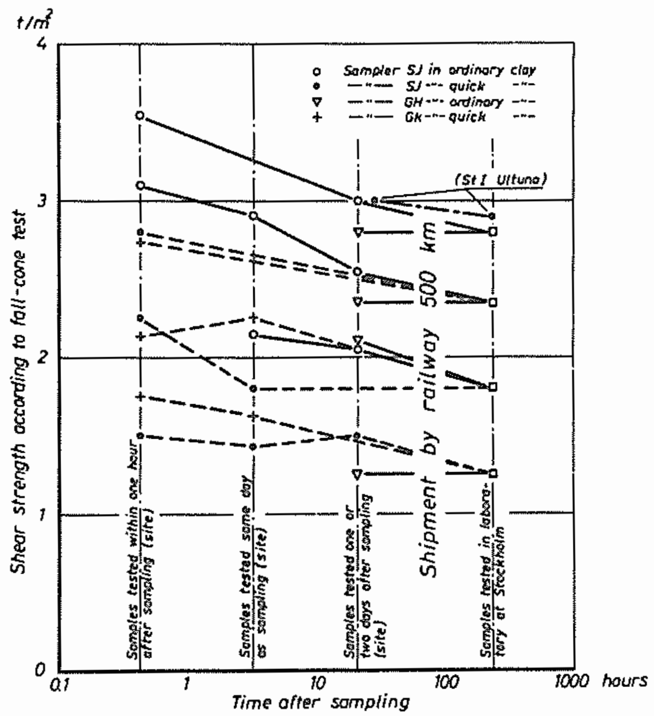

Fig. 4.- Time dependence of the tests performed by SJ 1954 (0 - 30 m depths)

(iii) Clay samples from Ultuna

Standard Piston samples of clay from Ultuna were tested in the Stockholm laboratory. Some were tested 1.5 - 3 days after sampling and others 6 - 13 days after sampling. The test results are shown in Fig. 8. Also here samples taken from the smallest depths and the greatest depths showed the largest decrease in strength with time. This is contrary to the experience with the Helical Sounding Borer where, however, the disturbances of the samples were locally much greater than for piston samplers.

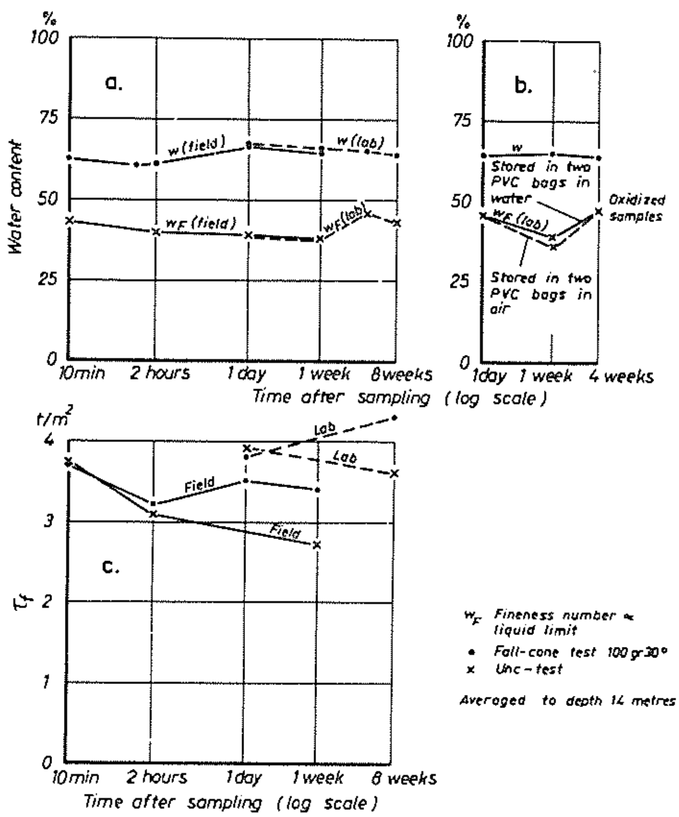

Fig. 6. - Influences of storage and transport, Vesten 1961. a. undisturbed samples stored in their ordinary tubes, classification data, b. remoulded samples stored in double plastic bags, classification data, c. undisturbed samples stored in their ordinary tubes, strength test results

(d) Piston-Foil Sampler in Layers of Clay and Silt

During 1958 - 1959 a research sampler SGI IX (cf. Kallstenius, 1958, p. 68) with extremely sharp cutting edge, very thin wall and with inside friction eliminated by means of foils (Fig. 1) was tested in soil consisting of alternating layers of silt and clay.

In uniform clay this sampler had given extremely good sample quality. Samples were tested immediately after withdrawal from the soil and also after transport to the laboratory a few days later. The results scattered much but no clear tendency could be found. It was concluded that rapid changes in strength and water content must have occurred in the soil layers already during the operations of sampling and withdrawal of the sampler. As the sampler was of an extremely little disturbing type it seems to be impossible to avoid quick disturbance effects when punching in layered soils.

(e) Conclusions from Field Experience

Table 2 gives a comparison between strength tests immediately after sampling and 200 hours after sampling. A time influence is obvious for all types of sampler and all actual soils.

Influence of transport may have either a strengthening or a softening effect (Vesten, Skå Edeby).

Temperature changes had some influence but not a very important one.

III. TESTS ABOUT THE INFLUENCE OF SOME FACTORS DISTURBING AFTER SAMPLING

It was decided to test the probable factors of disturbance in separate tests after sampling. The following factors were considered as important:

TABLE 1. Consolidation tests in field and laboratory 0-1 day after sampling, Skå Edeby, 1962

Hole	Depth	Speci-men height	Water content (approx.)	Compression, in mm, for load in t/m²								
				5 t/m²			10 t/m²			15 t/m²		
	m	mm	%	Field[2] 7°C[3]	Lab. 7°C	Lab. 22°C	Field 7°C	Lab. 7°C	Lab. 22°C	Field 7°C	Lab. 7°C	Lab. 22°C
N 5 ex	10	20	67	1.04	-	0.75	2.18	-	1.82	4.5	-	4.6
N 6-7[1]	10	20	67	0.48	0.79	0.64	0.99	1.68	1.52	2.06	3.23	3.12
N 8-9	7.5	20	64	1.11	0.74	0.81	2.5	1.83	2.55	3.92	3.17	4.22
N 8-9	7.5	20	64	1.44	-	-	3.07	-	-	4.25	-	-
N 5 ex	10	12	67	0.57	-	0.61	1.38	-	1.73	2.4	-	2.90
N 6-7[1]	10	10	67	0.42	0.50	0.39	0.91	1.29	1.12	1.69	2.05	1.98
N 8-9	7.5	10	64	-	0.59	0.75	-	1.89	1.96	-	2.84	2.61

[1] Load applied in increments of 1 t/m² and rested 15 min.

[2] Four field tests could not be accepted due to primitive arrangements.

[3] 7° C indicates that the soil was handled and tested all the time at the same temperature as in situ.

TABLE 2. Loss in strength in clay samples, tested at site, during 0.2 - 200 hours after sampling

Site	Sensitivity	Sampler	τ_f fall-cone after 200 hours t/m^2	Loss in strength per cent of original strength
Löddeköpinge, 1959	~ 5	Helical sounding borer	~ 1.8	25
Gothenburg, 1954	10–15	SJ	2.35	24
	10–15	SJ	2.8	21
	100	SJ and Gk	2.35	16
	100	SJ and Gk	1.8	22
	100	Gk	1.25	28
	100	SJ	1.25	17
Vesten, 1961	400	St I	3.4	13

1. a. Deformation of sample
   b. Shocks
   c. Vibrations

2. a. Temperature
   b. Temperature variations
   c. Frost

3. a. Swelling due to increase in water content
   b. Swelling without change in water content

4. Thixotropic recovery of strength in remoulded samples

5. Water content redistribution in undisturbed samples.

In all types of tests, the samples were cut length-wise in halves. One half was then treated in different ways before strength testing. The other untreated half was tested for reference at the same time.

(a) Deformation of Sample

Samples were compressed axially in unconfined state and tested with respect to strength. The average loss in strength for Skå Edeby clays increased rapidly for small deformations but slower as strain increased. Even for a 40 % uniaxial compression samples of a sensitivity of 10 lost only about 40 % of their original strength.

(b) Remoulding

Remoulding gives a type of disturbance quite different from uniaxial compression as is shown by ordinary tests with respect to sensitivity. Therefore friction seems to be a major source of damage as it causes remoulding of the peripherical parts of undisturbed samples and, possibly, secondary redistribution of pore water.

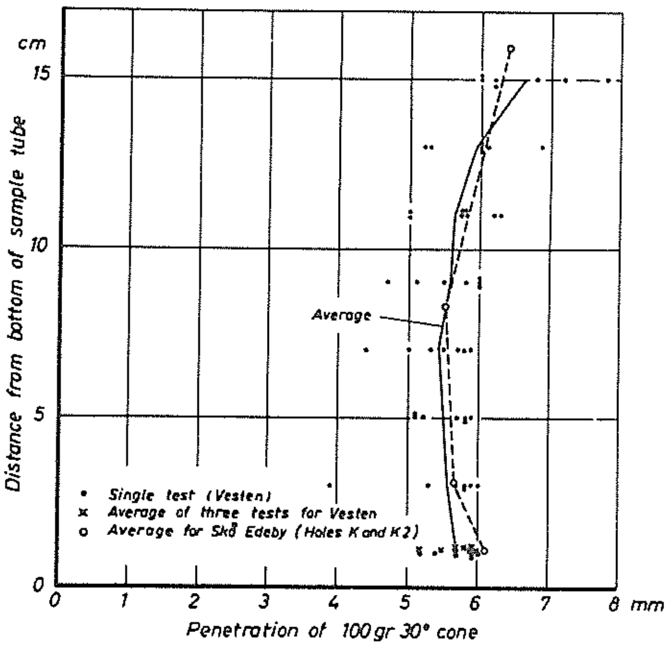

Fig. 7.- Fall-cone penetration in different parts of standard samples from various depths, Vesten and Skå Edeby 1961

(c) Shocks

Sample halves from different samples were put together (insulated by a plastic sheet), enclosed in a sample tube and then permitted to fall freely with horizontal axis one metre against a floor of soft asphalt. The maximum retardation force was judged to be about 500 times the acceleration of gravitation. A decrease in strength occurred for Skå Edeby samples which was greater at higher liquidity index. For $I_L = 1.3$ the decrease in strength for such a shock had the order of 30 %. Some samples of quick clay showed no such decrease but it was assumed that they had already been damaged during transport. Shocks may give transport disturbances of a considerable degree.

(d) Vibrations

To test the influence of vibrations, samples in tubes were vibrated on a laboratory vibrator. The frequency was 50 p/s and the amplitude ± 0.025 to ± 0.05 mm. The effect used was about 150 watt. Vibration time was ten minutes, which was considered to correspond to a railway transport of about 500 km. Samples were tested one day, one week and two months after sampling. The influence of vibration varied from 22 % loss of strength to 26 % increase in strength. This variation was greater than test scatter and indicates a variable influence.

If samples were put on the vibrator without confining cylinder and with a load on their top they collapsed quickly. "Quick" clays collapsed earlier than ordinary clays. The influence of vibrations is therefore most probably dependent on soil type, original sample disturbance, sample length, sample protection and if samples are shipped standing or in horizontal position.

(e) Thermal Disturbance Effects

To check the influence of viscosity, fall-cone tests were performed on remoulded clays from Skå Edeby and Dalsland in western Sweden at temperatures 20° and 8° C. They indicated slightly increased strength with decreased temperature.

The thermal influence in undisturbed samples of clay was investigated for the temperature interval 10 - 50° C. At the lower temperature the strength was about 4 % higher. In general, the influence of storage temperature seems to be negligible as far as drying out of the samples is avoided. In a similar way the influence of regular temperature variations between 6° C and 22° C was found to be negligible in fall-cone tests, unconfined compression tests, laboratory vane tests, shear box tests and consolidation tests on Skå Edeby clay.

(f) Freezing

Freezing tests were performed on samples, also from Skå Edeby. When samples had been fully frozen and then thawed up, they lost 80 - 90 % of their original strength. The structure was thus destroyed almost as completely as by remoulding. In other tests when freezing was not complete it could happen that only 5 - 20 % of the original stength was lost. Partial freezing of soil samples may be difficult to discover by visual observation.

(g) Disturbance due to Swelling

Some samples were kept unprotected in water from 24 hours and reference halves were stored in the same way but protected by plastic bags. Samples taken from 8.5 and 9.5 m depth at Skå Edeby (I_L = 1.06 and 1.21) lost 27 % and 41 % of their strength by taking up water during this time.

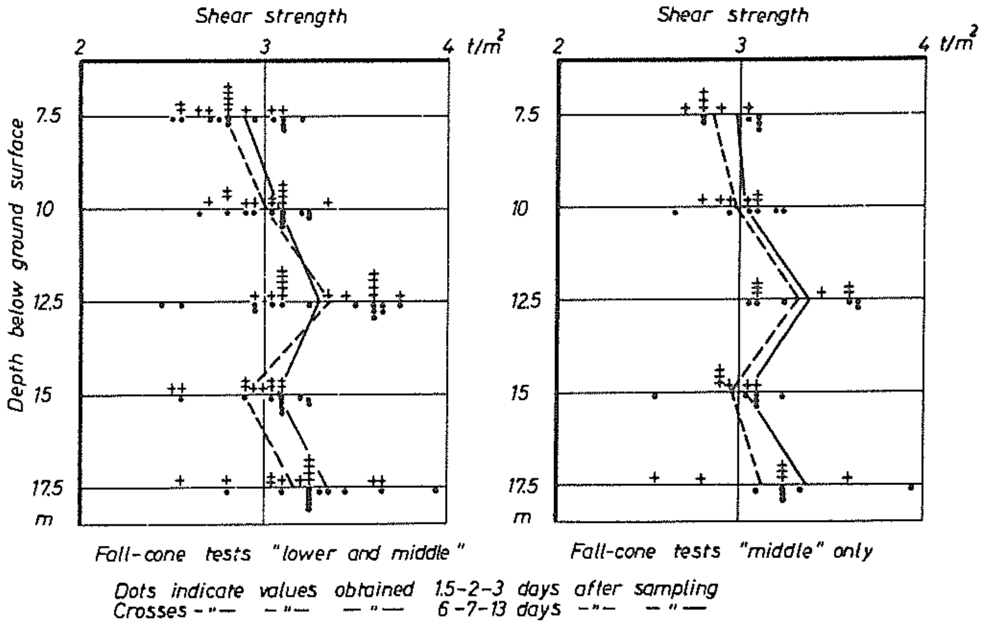

Fig. 8.- Time effects, Ultuna 1960

Only little water needs to enter the sample to cause great reduction of effective stresses. Consolidation tests on Skå Edeby clay (unloading path) indicate a 90 % reduction of stresses for only 1 - 2 % axial swelling. Such swelling requires, on the other hand, a pressure gradient between the water in the actual spot and that of its surroundings. Besides, water must be free to flow. In partially disturbed samples with locally high water content these conditions are fulfilled.

Swelling of standard piston samples protected from external water was also measured and its influence was checked on Skå Edeby clay. Immediately after taking a sample the sample tube was provided with rigid end plates and covered with rubber caps. The caps had holes to permit direct measurement of axial sample swelling. As long as samples were not pressed axially and contained no open fissures, changes in length were smaller than one per mille during several days.

In one case where swelling had been about twice as great as normal, the sample was found to contain an open fissure.

Swelling without change in water content seems to be small for most normal Swedish clays and has small disturbance effect. When swelling was observed to be greater than usual it was found to influence the fall-cone test very little but had a visible effect on the unconfined compression test. It seems therefore to affect the structure of a fissured clay only locally.

(h) Thixotropic Effects

Samples of normally sensitive clay from Skå Edeby and a few samples of quick clay from Dalsland were remoulded to homogeneous consistency and then divided into small specimens contained in sealed jars. The specimens were then tested with the fall-cone test at different times after remoulding. The curves of thixotropic regain of strength in Fig. 9 indicate three different stages. In the first stage strength was almost constant. During the second stage a normal thixotropic build-up of a microstructure occurs.

TABLE 3. Water content distribution in samples from Skå Edeby, 1962

Bore-hole	Depth m and sample tube	Elapsed time after sampling days	Water content %					I_L	Penetration of 100 gr 30° cone mm		Difference in water content between centre and periphery %
			w			w_L	w_P		Average in centre	Close to parts used for w_L-test	
			Average in centre	Average in outer part	Close to parts used for w_L and w_P-tests						
N 4	2.5 U	0							8.0		
N 5	2.5 U	0							8.0		
	2.5 M	1	117.6	116.2	116	135	38	0.81	8.21	8.25	1.4
	2.5 L	7	114.9	113.3	117.3	145	41	0.73	8.43	8.25	1.6
N 4	2.5 M	77	117.2	115.3	115.3	142	40	0.74	8.66	8.85	1.9
N 5	2.5 U	84	122.8	121.2	129	162	48	0.71	8.43	8.45	(1.6)
N 4	7.5 U	0							10.0		
N 5	7.5 U	0							10.0		
	7.5 M	1	66.4	64.9	71	68	23	1.07	10.5	10.2	1.5
	7.5 L	7	64.9	63.3	56.7	52	20	1.15	9.67	9.45	1.6
N 4	7.5 M	84	72.1	67.1	65.7	61	22	1.12	10.21	9.7	5.0
N 4	12.5 U	0							7.5		
N 5	12.5 U	0							7.5		
	12.5 M	1	55.6	55.3	56.5	54	21	1.07	8.47	8.8	0.3
	12.5 L	7	64.8	64.3	58.8	57	22	1.05	7.45	7.45	0.5
N 4	12.5 M	84	60.8	59.9	57.7	56	21	1.05	8.80	9.6	0.9

During the third stage the clay showed cracks and free water and seems to form a macro-structure affected by syneresis. In the third stage strength values scattered much.

Thixotropic regain of strength was much slower in the quick clay than in the ordinary clay.

In ordinary "undisturbed" samples of clay the thixotropic effects ought to be relatively smaller and show less time-dependence than in remoulded clay. Anyway, disturbed but not remoulded quick clay seems to build up its bounding forces slower than ordinary clay and may therefore react differently to mechanical influences in the beginning.

(i) Water Content Redistribution in Undisturbed Clay Samples

Samples from Skå Edeby from various depths were studied with regard to the water content in the central parts and the peripherical parts. The water content was always higher in the central parts (cf. Table 3). Most of this difference existed already at the first determination one day after sampling, but the difference increased slightly with time. This points towards an internal redistribution of water in the samples. Disturbance during sampling liberates water at the periphery and this water then moves inwards and also towards the sample ends and causes swelling and softening effects.

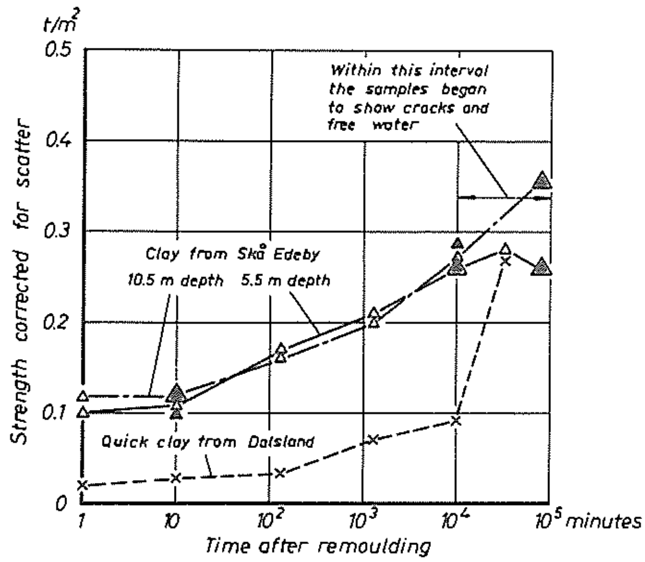

Fig. 9.- Strength of remoulded clay as dependent on time

IV. COMMENTS

(a) Main Disturbing Factors

Of the secondary disturbances or changes of samples which may occur during transport and storage the greatest and most easily avoided are shocks, frost and great deformation of the soil. Of great importance are further partial remoulding and redistribution of water within samples, partial freezing and strong vibrations.

Insulation against shocks and frost and non-disturbing sampling methods including early trimming off the most disturbed parts of samples are remedies.

Temperature or thermal expansion of samples is seldom a great source of disturbance under Swedish conditions as far as samples are protected against drying.

Different soils react differently to bad treatment and it is difficult to find out correction factors because they will be different for different laboratory tests. It is therefore very important to avoid unnecessary sample disturbance by proper protection.

(b) Detection of Sample Disturbance

According to the Author's opinion, errors appear even in the best quality sampling. Therefore, all samples should be regarded as being "suspect". This does not mean, however, that the majority of good samples is not of sufficient quality to be used for practical purposes.

Sample disturbance is not uniform in any sample of soil. Certain systematical patterns may develop due to treatment (e.g. extrusion) of samples but frequently disturbance appears locally and irregularly. Detection of locally disturbed parts may be achieved by careful scrutinizing, observation of macrostructure and judgement of stratification influences. Sometimes a sharp and thin needle can be used as a probe to check disturbed zones and sometimes one can bend or break part of the sample to discover macrostructure features, softer parts or failures.

In many cases, however, it is not possible to detect sample disturbance by direct observation. One may then use other ways.

Sample strength can be determined on the sampling site by means of a fall-cone apparatus for field use. This strength is then compared with fall-cone test values in the laboratory. If they differ much, disturbance must be considered.

The classification data of the soil may be compared with its sensitivity and shear strength. There should exist some relationship between the liquidity index and the sensitivity of clays. If the values differ too much from general knowledge of similar soils one must study the soil behaviour more in detail.

One may apply different types of strength test on the soil sample. If e.g. the unconfined compression test shows much smaller strength values than the fall-cone test or the laboratory vane test, a system of fissures or weak zones probably exists in the sample. If the unconfined compression test gives higher strength values than the fall-cone test, the latter has possibly been influenced by reduction of effective stresses near the tested sample surface.

It is very important to gather a statistical knowledge of the general behaviour of different soils and the normal relationship between classification data and mechanical properties.

If one's observations in a certain case deviate from the normally expected, one may make additional laboratory tests to get a more detailed view of the behaviour of the soil. Application of the effective stress theory in connection with empirical data on the angle of friction for typical soils is a quick way of judgement which frequently may be applied.

Sample disturbance, if discovered, may give valuable information about the behaviour of a soil in the practical building process. If a soil is very easily disturbed in the sampling procedure it may also be sensitive to disturbance during the performance of foundation work, etc. Sometimes it is in such cases advisable to use higher factors of safety in calculations or to give special instructions regarding the treatment of such soils.

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SAMPLING OF SAND AND MORAINE WITH THE SWEDISH FOIL SAMPLER

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SYNOPSIS A drilling method is described by which it is possible to obtain long cores of sand, silt and moraine above and below the ground water table with the Swedish foil sampler. By using rotary drilling, even hard strata can be penetrated.

INTRODUCTION

The original Swedish foil sampler (Kjellman et al. 1950) was developed at the Swedish Geotechnical Institute (SGI) between 1943 and 1950. It is a piston sampler and its function is illustrated in Fig. 1. Very long soil cores can be taken with this sampler since the wall friction between the sample and the sampling tube is reduced with steel foils.

Two types of samplers exist, with either 68 mm or 40 mm core diameter. In the sampler head of the 68 mm sampler there are 16 rolls of very thin foils of high strength steel. The width of each foil is 12.5 mm and the thickness can be varied between 0.12 mm and 0.08 mm depending on the anticipated length of the samples and on the friction along the sampling tube. The maximum length of the foils which are stored in the sampler head is 30 m. The foils are attached to a piston which is held stationary during the sampling operation by a chain and a rod, attached to a rigid frame as shown in Fig. 1. As the sampler is pushed down into the soil, the foils completely surround the sample.

The maximum length of the cores which can be taken is governed by the tensile strength of the foils which have to carry the weight of the sample and overcome the friction in the sampler head along the sampler wall. The wall friction can in clay be decreased by lubrication. (In sand the lubricating oil will penetrate into the samples and thus affect the properties of the soil.) With the 68 mm foil sampler it has been possible to obtain over 20 m long cores in soft to very soft clays. The maximum length of the cores which can be obtained in clay with the 40 mm foil sampler is 12 m due to the limited length of the foils.

In soft cohesive soils the sampler is generally pushed down by a hand-driven device with a maximum capacity of 6 tons. In silty or sandy soils ramming is frequently used instead of pushing. Water jets are sometimes utilized in such material to reduce the driving resistance. When ramming or jetting is used, the samples will, however, be more disturbed. In order to obtain undisturbed samples in hard clays, sand or moraines, rotary drilling and drilling mud are as a rule required. In hard clays and in sand, compressed air instead of drilling mud has been used

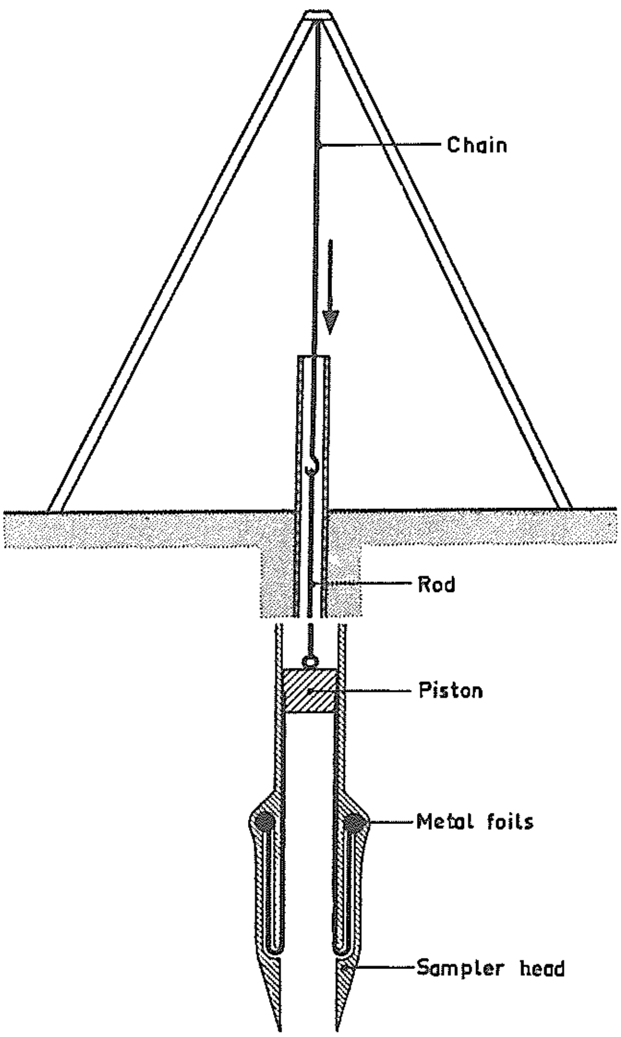

Fig. 1. Principle of the Swedish foil sampler

successfully during rotary drilling to prevent changes of the natural water content of the soil above the ground water table.

For rotary drilling in connection with foil sampling a special rotary drilling rig has been developed at the Swedish Geotechnical Institute. With this drill rig it has been possible to obtain undisturbed samples both above and below the ground water table. Up to 12 m long cores have been obtained in sand. The quality of these samples is usually very high.

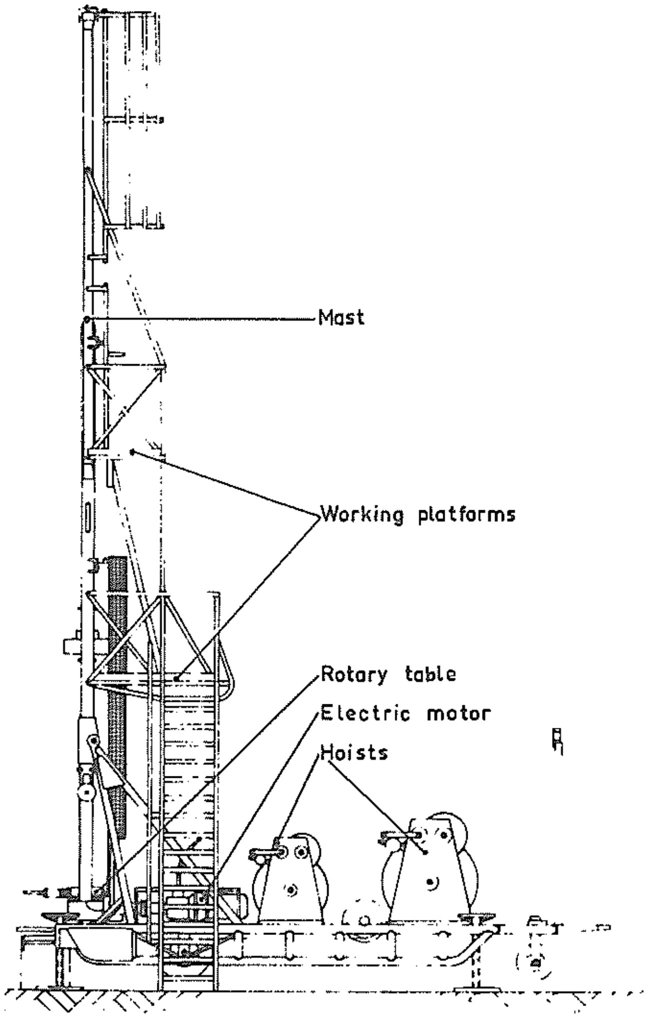

Fig. 2. Drilling rig

DRILLING EQUIPMENT

The drill rig consists of a mast, an electrically driven rotary table and several hoists. Auxiliary equipment, such as pumps for circulation of drilling mud, mud container, mixing devices and a generator, is also required for the drilling. The total weight of the drill rig, shown in Fig. 2, is about 4.000 kg and it can easily be towed by a truck or tractor since the rig is mounted on wheels.

The light weight foldable mast has a total height of 10 m. To facilitate the handling of drill tubes and of the foil sampler, there are two working platforms in the mast. The mast is raised to its upright position by a hand-operated hoist, mounted on the drilling rig as shown in Fig. 3. This hoist is also used for the lowering and the raising of the foil sampler. The drill rig is in addition provided with two electrically driven hoists for the handling of the drill tubes, the swivel and the hoses for the drilling mud.

Fig. 3. Raising of mast

The drill tube is rotated with the rotary table at a rate which can be varied between 10 and 70 rpm. The rotation can also be reversed in order to unscrew the drill tube sections. The rotation rate, the circulation of the drilling mud and the tension in the foils is regulated from a central console unit. In order to decrease the disturbance of the soil sample, guide arms on the swivel prevent the sampling head and sampling tubes from rotating during the sampling operation.

The head of the foil sampler which is used for sampling in hard clays, sand and moraines is shown in Fig. 4. Outside the sampler is a rotating drilling tube with an outside diameter of 138 mm (5.5 in) and a wall thickness of 6.35 mm (0.25 in). The length of each tube section is 2.5 m. The drill tubes are usually connected two lengths at a time in order to facilitate the handling. The drill string has at the bottom an over-size circular drill bit with an outside diameter of 175 mm. The drill bit is provided with three teeth of hard carbide inserts around its perimeter (Fig. 5.).

Under normal drilling conditions the cutting edge of the sampler extends approximately 10 mm in front of the drill bit. A somewhat larger length is generally required in loose sand. In hard, stony materials the edge should, to be protected, be flush with the drill bit.

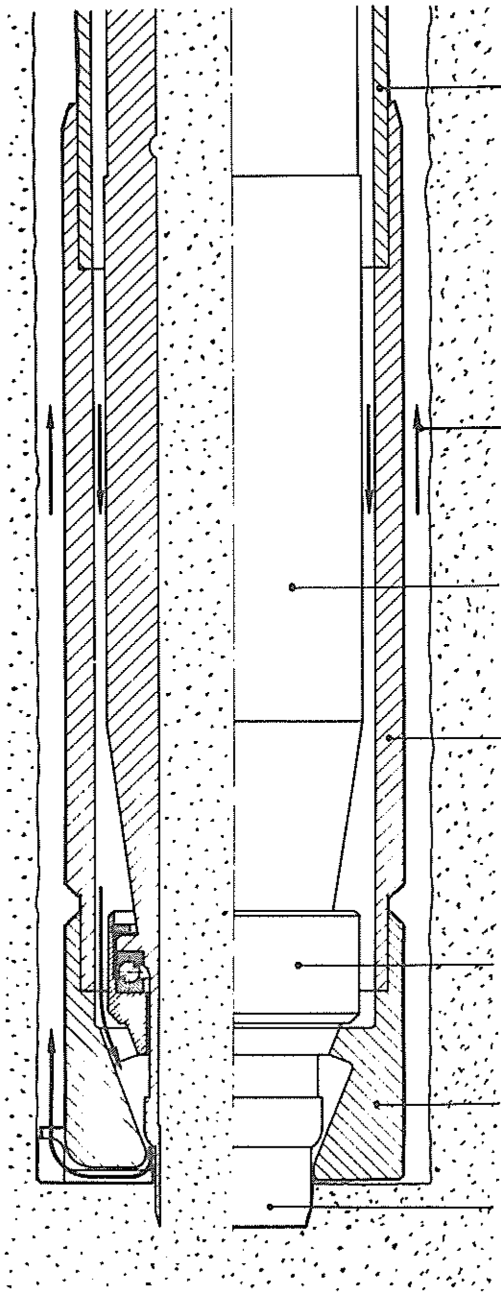

Fig. 4. Foil sampler and drill bit

The mud pump, the mud container and the mixer are placed beside the drilling rig during normal drilling operations. The mud container is frequently partly buried in the ground. A mud pit is required in order to recover the drilling mud. In temperatures below 0° C it is generally necessary to provide a heated enclosure for the mud pump, the mud containers, and the mixer. This heated enclosure can also be used to store the samples so that they will not freeze.

A surface casing with 250 mm diameter and a length of 2.5 m is normally used to stabilize the borehole near the ground surface. The lower end of the casing is provided with approximately 8 cm long teeth. The casing is usually rotated and driven down by the rotary table to a depth of about 1.5 m below the ground surface. In fills and in loose sand it is sometimes necessary to use a much longer surface casing which is driven about 5 m into the ground.

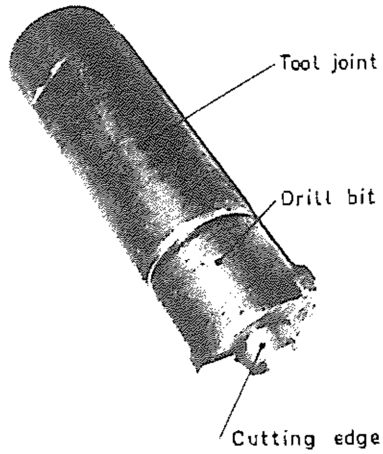

Fig. 5. Drill bit

The drilling mud is pumped from the container, through the swivel and down through the drill tube. The mud and the cuttings return to the surface through the annulus between the drill tube and the bore hole walls. From the surface casing the drilling mud flows through a sieve into the mud pit as shown in Fig. 6. Normal circulation is thus used.

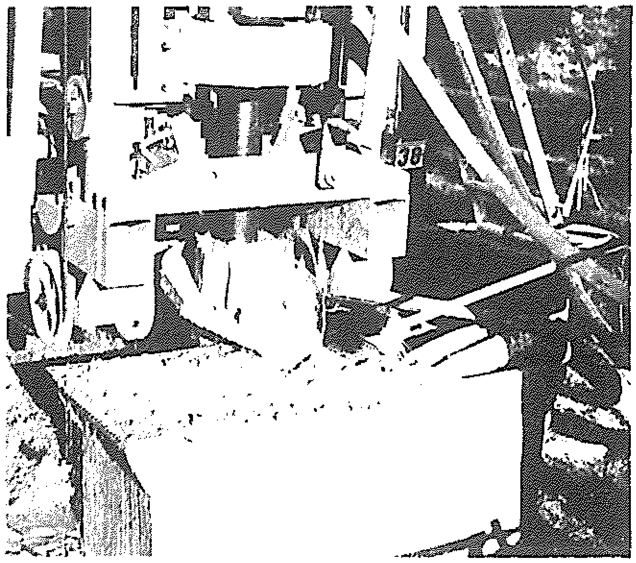

Fig. 6. Drilling mud

A drilling crew of one foreman and three helpers is normally required for operation of the drilling rig.

SAMPLING

When the sampler head has reached the intended sampling depth, the piston of the foil sampler is locked in place by a chain and a rod attached to a hook at the top of the mast. The load in the chain and thus the tension in the metal foils is measured by a hydraulically operated load cell attached to the hook. This load is read on a manometer mounted on the central console unit. The tension in the foils can be adjusted manually.

In Fig. 7 is shown the joining of the drill tubes. The swivel has been unscrewed and raised by the hoist. The piston which carries the foils has been locked in place so that the chain and the rod which holds the piston can be unhooked. Additional lengths of drill and sampling tubes can then be added. Thereafter, the swivel is screwed on to the drill tube and the chain is attached to the piston. The foils are tensioned to the same value as before the release of the chain.

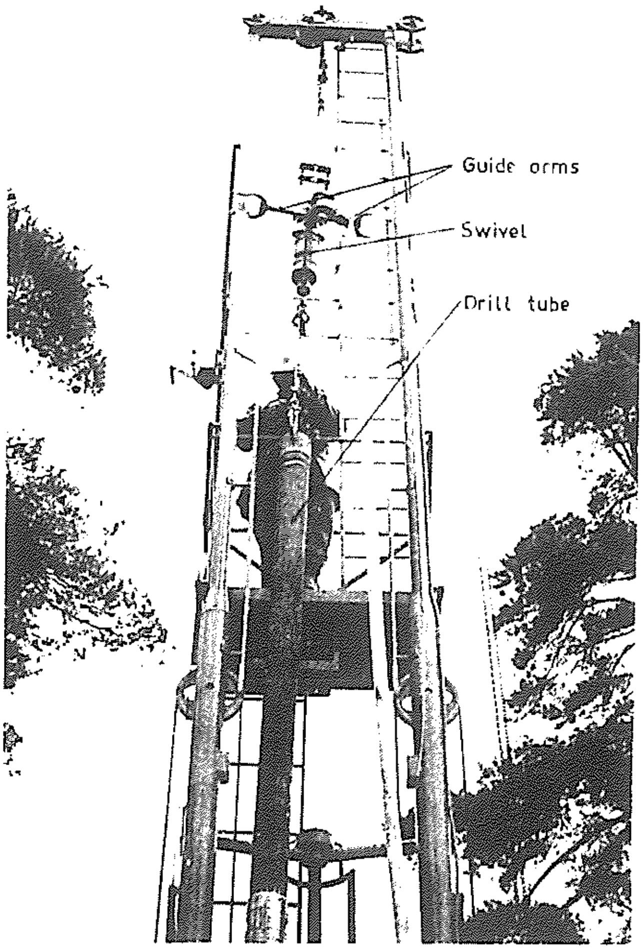

Fig. 7. Joining of the drill tube

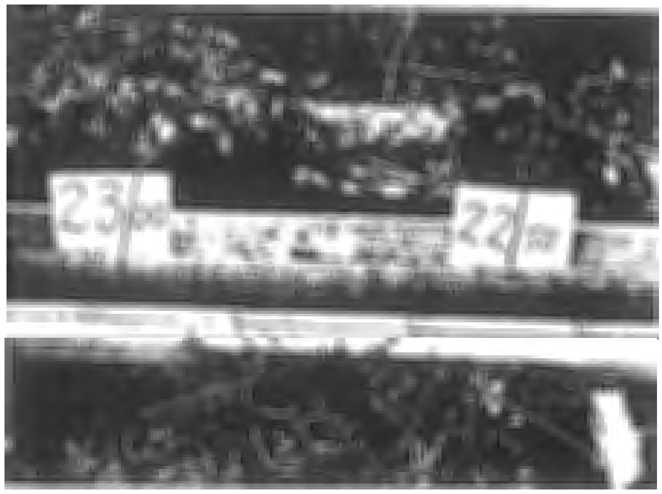

Fig. 8. Sand sample

The weight of the drilling rig is generally sufficient to resist the required pull-down force during the sampling. If the weight is not sufficient, the drilling rig can be anchored by earth screws. These screws can also be used to stabilize the mast. When the sampler has been driven to the intended depth, the drill assembly is raised about 1 m to prevent sticking due to sedimentation of the cuttings in the borehole. The drill string is locked in this position. The swivel can then be unscrewed and raised and the foil sampler be lifted with a hoist and unscrewed in 5 m lengths. After the sampler head and the sample tubes have been removed, the sampler is reloaded and reassembled. It can then be reinserted into the drill tube and additional samples be taken. By rotary drilling it is seldom possible to recover cores in sand with the 68 mm sampler which are longer than 10 m. Under difficult sampling conditions as in stony soils and moraines, the maximum length is only one to two metres.

The sampling tubes with the soil cores are generally shipped to the laboratory for testing. Both ends of each sampling tube are sealed by tight fitting lids with rubber packings. However, cores are sometimes extruded in the field for classification purposes. The cores are in that case placed in shorter tubes and transported to the laboratory. In Fig. 8 is shown a sample of sand which has been extruded in the field. The stratifications in the sand can clearly be seen. In cold weather it is important to prevent the samples from freezing.

The drilling rate varies normally between 2 and 5 m/hour. The costs for the coring depend on the soil conditions as well as on the drilling depths. But considering quality of the cores, the costs are relatively low.

DRILLING MUD

The drilling mud consists mainly of water and bentonite with a unit weight between 1.0 and 1.4. Various chemicals are usually added to fit the consistency of the drilling mud to the different soil conditions. The consistency of the drilling mud is usually checked with a filter press before and during the drilling. A filter paper is placed at the bottom of the press which is filled with drilling mud. The water in the drilling mud is forced through the filter paper with air pressure. The thickness of the mud-cake which gradually builds up on the filter paper at an air pressure of $5 N/cm^2$ ($0.5 kp/cm^2$) is measured. The thickness should after half an hour be less than 1 mm, otherwise it is necessary to recondition the mud.

SUMMARY

By combining rotary drilling with sampling with the Swedish foil sampler it is possible to obtain up to 10 m long cores of cohesionless soils and moraines even below the ground water table. Drilling mud is used to stabilize the borehole and to prevent loss of the sample during the withdrawal. The drill tube which is provided with an over-size drill bit with hard carbide inserts is rotated by an electrically driven rotary table. The drilling rate varies normally between 2 and 5 m/hour. The drill rig is operated by one foreman and three helpers.

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