SECTION III

FIELD INVESTIGATIONS

SUB-SECTION III a

BORING AND SAMPLING

III a 1 FIELD TESTS WITH NEW COMBINED LOADING TEST SAMPLER FOR HARBOUR EXTENSION WORK

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SUMMARY.

In heterogeneous samples from deep waterfilled borings the porewater may migrate from sandy to clayey parts of the sample and sandy samples may be lost in the casing or damaged during the lifting operations or shipment due to lack of capillary pressure.

E new combined loading test sampler with short piston rod for undisturbed sampling in cohesive soils and for test loading f. inst. in cohesionless soils is described.

The measured values for shear, τ_s (skin friction on outside of cylinder) and vertical soil pressure, σ_v, in uniform heavy-textured late glacial clay with thin layers of sand (Yoldia clay), in heterogeneous glacial chalky clay and in chalk are compared with results from sample tests in the field and on the laboratory.

The average values for all tests of the relation between τ_s and σ_v, respectively, and the natural soil pressure (geostatic soil pressure = weight less buoyancy) $p_n = \Sigma(\gamma - 1) . \Delta h$ (Δh is the stratum thickness) were for Yoldia clay:

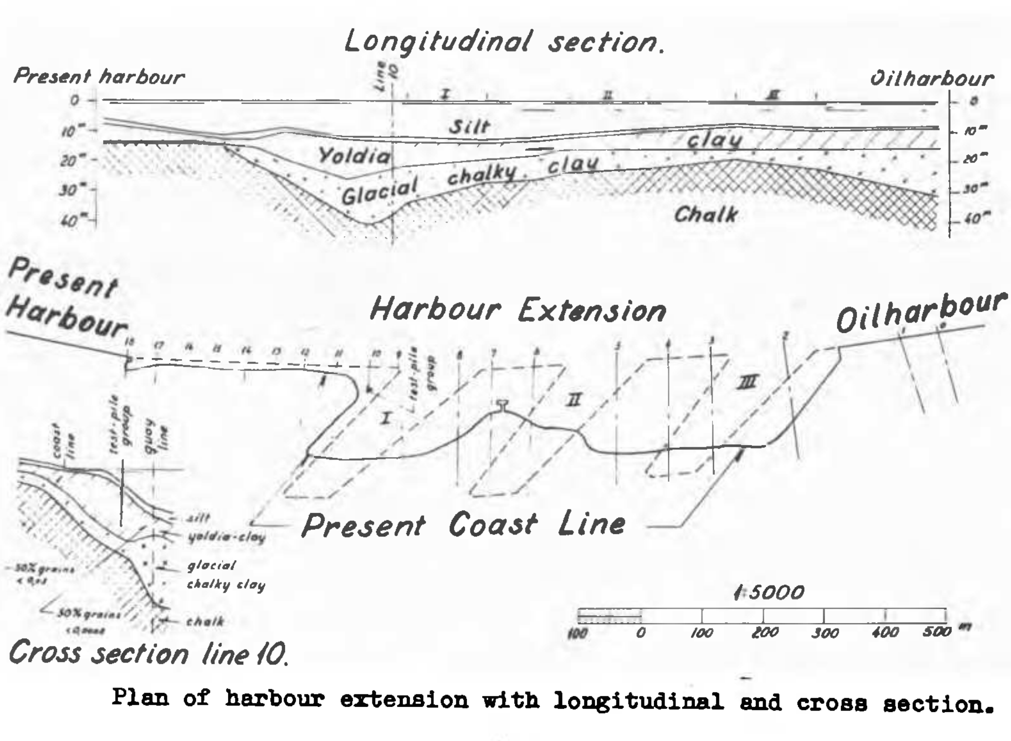
$$\tau_a = 0.5 + 0,5\ p_n \text{ kg/cm}^2 \text{ for } p_n < 1 \text{ kg/cm}^2$$
$$\tau_a = 0,8 + 0,2 \cdot p_n \quad - \quad - \quad p_n > 1 \quad -$$
$$\sigma_a = 12,5 + 7,4 \cdot p_n^2 \quad - \quad - \quad p_n > 1 \quad -$$

) average for 169 samples from 40 hectars harbour extension area

for glacial clay:

$$\tau_a = 0,5 + 0,5 \cdot p_n \text{ kg/cm}^2 \text{ for } p_n > 1 \text{ kg/cm}^2$$
$$\sigma_a = 12 + 45 \cdot p_n \quad - \quad - \quad p_n > 1 \quad -$$

) average for 114 samples (same area)



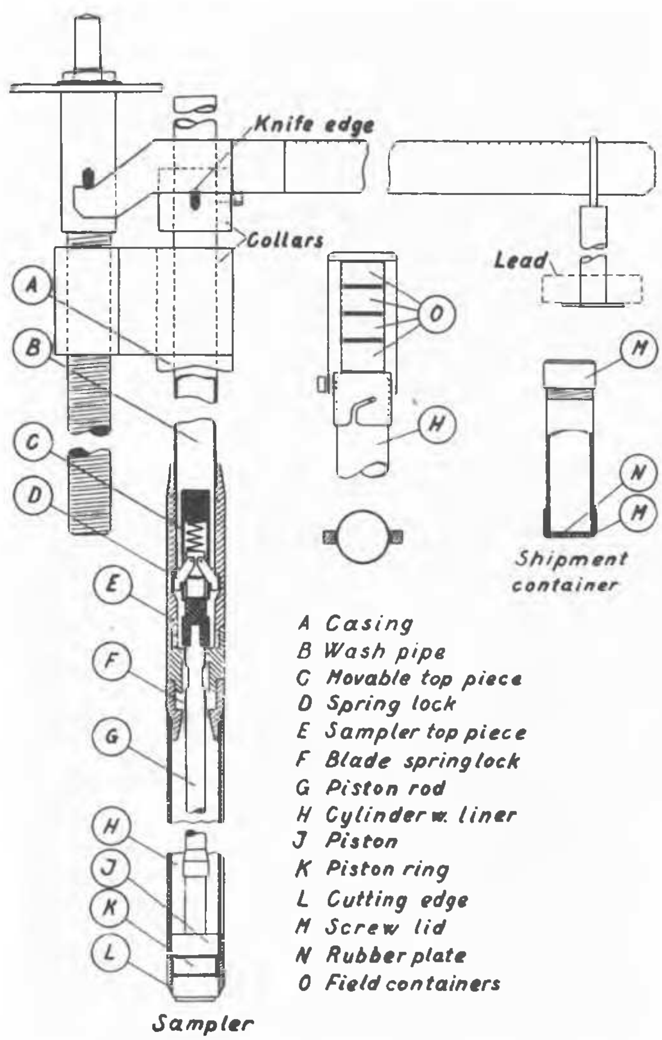
Plan of harbour extension with longitudinal and cross section.

FIG. 1

INTRODUCTION:

On a coast stretch of 1,3 km (fig.1) plans were in 1943-45 prepared for the extension of Aalborg Harbour with 3 bassins outside the coastline. Old wash borings (73) with dry sampling to 15 m depth in 21 lines perpendicular to the coast gave by individual judgement the result, that the bottom consisted of solid clay of good bearing capacity but from later pile-driving results suspicion arose about the reliability of these results. The borings were then supplemented by 37 new borings to until 40 m depth with undisturbed samples (1,5 - 2 m intervals for determination of the shear strength and other soil properties, but in order to eliminate errors from changes in pressure and consistency it was decided simultaneously to carry out loading tests just below the casing shoe.

A combined loading test sampler was constructed - fig.2 -



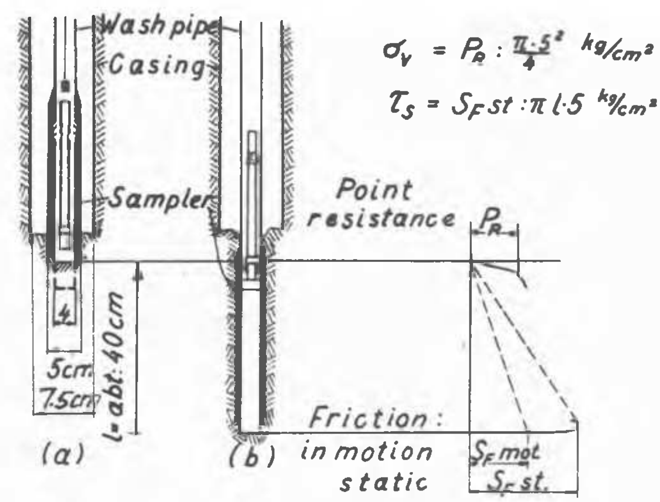
Combined sampler and loading tests cylinder

FIG. 2

with a short piston, locked in bottom position by a helical spring lock D, which may by released by sinking a lead suspended in a string down on the top of a tubular top piece C. When loading the top spring the two lock levers D. are pulled back from the lock grooves in the top piece through the two slots in the top pipe and the piston is then released and ready for sampling.

After the sampler is filled (40 cm) two blade springs E. lock the piston in upper position, because an enlargement of the piston rod G. passes between the two blade springs.

When the casing has been brought down to the wanted depth, the sampler is screwed on the wash pipe and sunk down to rest on the bottom of the borings (fig. 3 a). To the casing top is fastened a collar with a lever knife with a downwards turning edge, movable by a helical screw, and to the wash pipe is fixed a collar with an upwards turning knife edge (fig. 2) A 2 m lever with movable lead is used to press the sampler 2 - 5 cm down into the soil. The lever is kept level by turning the helical screw and moving the lead simultaneously. Corresponding values of load and depression are read on the lever scale and on the screw scale. When the initial static point resistance, P_R, thus has been determined - fig. 3 a & c - the piston is released and the sampler by the lever pressed 40 cm down until the blade springs are heard locking the piston in upper position. The lever is then turned opposite and the sampler withdrawn. The corresponding values of the pulling force and the lift are measured, and the static skin friction, S_F, determined - fig. 3 b & c. The sampler is then brought up and the sample taken out for field and laboratory tests.



Loading test.

FIG. 3

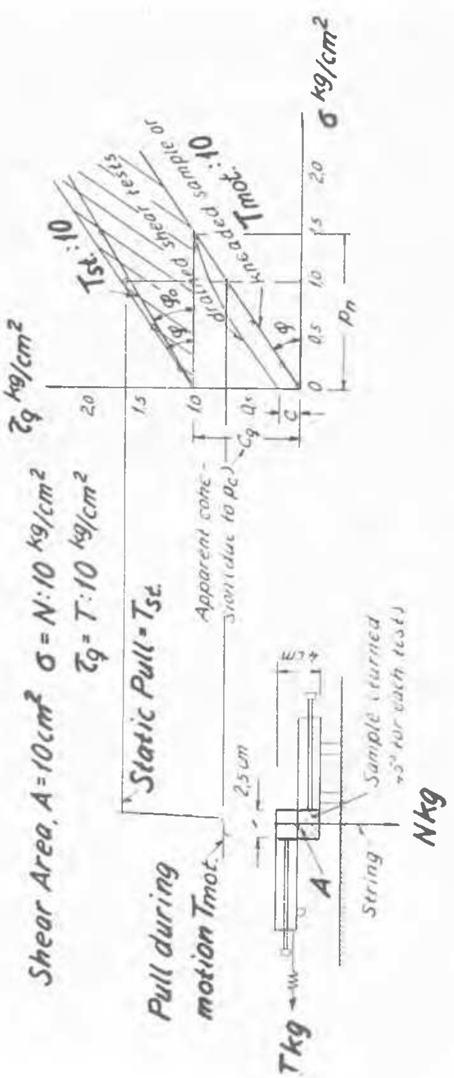
The loading test skin friction, τ_s, is compared with the following field tests on samples under capillary pressure:

1) spring scale cone test by which the cone load, K_{sc}, for a 10 mm steady impress of a 60° steel cone in a sample in natural state is measured on the spring scale. The drop cone weight, K_3, is the cone load, that gives a 10 mm imprint after a 10 mm drop. The former (size of a fountain pen) is practical for field testing, and the relation between K_{sc} and K_3 is for Yoldia-clay $K_{sc} : K_3 = 2,3$ and for glacial chalky clay $K_{sc} : K_3 = 1,4$. K_1 denotes in the same way the drop cone weight, when the clay structure has been broken by kneading without change in natural water content. The ratio $K_3 : K_1$ is for Yoldia-clay 2,1 and for hetereogeneous glacial clay about the same value but ranging between wider limits. The relation between K_3 and the ultimate shear stress, τ_{sc}, due to the capillary pressure (p_c) was found to be:

for Yoldia-clay $\tau_{sc} = \frac{K_3}{4{,}3} = \frac{K_{sc}}{4{,}3 \cdot 2{,}3} = \frac{K_c}{10}$

glacial chalky clay $\tau_{sc} = \frac{K_3}{4{,}3} = \frac{K_{sc}}{4{,}3 \cdot 1{,}4} = \frac{K_c}{6}$

2) Quick shear tests with the apparatus fig. 4 a gave the

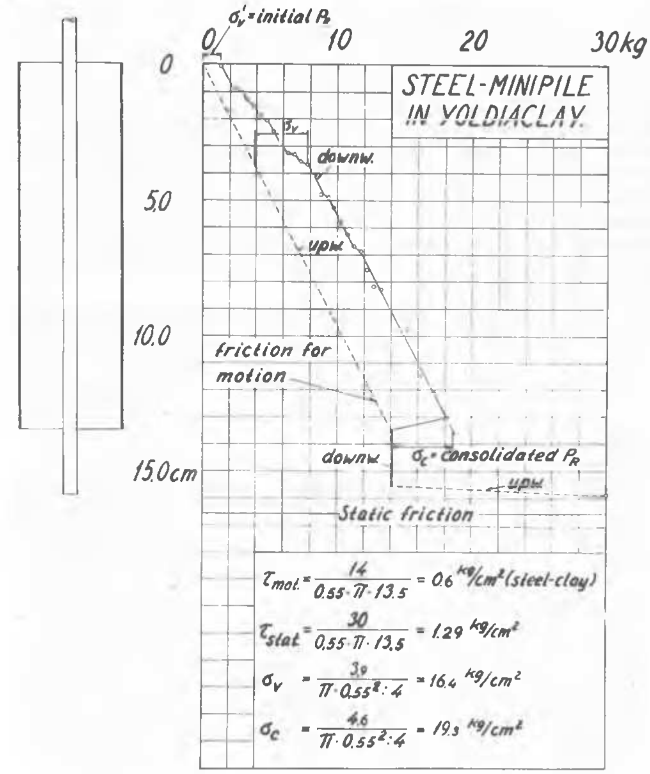


Quick shear test.

FIG. 4

result, that the shear value, c_q corresponding to the capillary pressure p_c (in Yoldia-clay same as the geostatic pressure p_n) could be determined from the $\sigma_v - c_q$ graph - fig. 4 b - as the apparent cohesion. A minimum value, φ_o, for the angle of internal friction, φ, was found by turning the sample 45° and varying the vertical pressure. Generally φ_o was found on or near the upper limit φ (τ_q in upper part of cross hatched section.) for sandy and chalky clay was practically found $\varphi_o = \varphi$ and $\tau_q = c + \sigma tg\varphi$ as in Casagrande shear tests.

For some of the samples τ further was controlled by 3) cork screw tests: the shear, τ_c, corresponding to the capillary pressure p_c, was determined by $\tau c = \frac{P}{\pi \, dl}$, where P is the pull in the cork screw, d is the outside screw diameter and l the length screwed into the sample. The cork screw shear value was the same as by the quick shear test or slightly higher. The same result was obtained 4) by pulling a model or MINI-pile (d = 5 mm) out of a clay sample in a container.



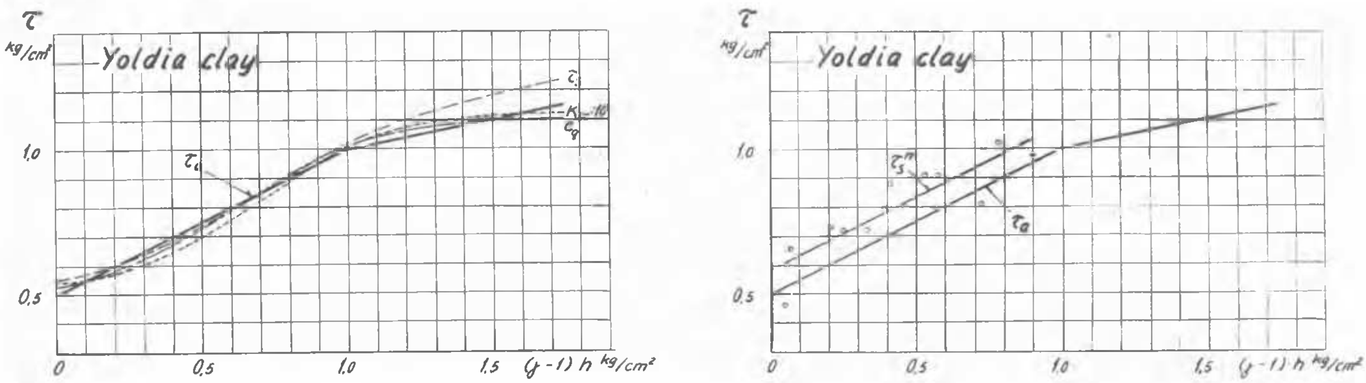
Model of Mini-pile test

FIG. 5

The point resistance, σ_v, found by the loading tests, was checked by the Mini-Pile tests as the initial point resistance in 2-3 cm depth or as the drop in pressure σ_c - fig. 5 - when the pile breaks through the sample (consolidated point resistance). The ratio $\sigma_c : \sigma_v$ for a Mini-Pile is a measure for the consolidation during the penetration of a pile.

In fig. 6 a is given the average τ_a-p_n - graph in Yoldia-clay for the relation between the soil pressure $p_n = \Sigma(\gamma - 1) \cdot \Delta h$ and the shear τ_c^m, determined by average curves for 1) loading test τ_s, 2) spring scale cone tests, $K_{sc}/10$, and 3) quick shear tests, c_q, each determined from about 200 uniform tests results in homogeneous Yoldia-clay. The average shear value corresponds to the straight line $\tau_a = 0{,}5 + 0{,}5\ p_n$ kg/cm² for $p_n < 1$ kg/cm² and $\tau_a = 0{,}8 + 0{,}2\ p_n$ kg/cm² for $p_n > 1$ kg/cm² and seems also to include same clay type outside the new harbour area - cf. tests results for τ_s^m in fig. 6 b from a quay 1000 m from the investigated area. The point resistance found by loading tests and Mini-piles gave for the harbour extension area the average value $\sigma_a = 12{,}5 + 7{,}4\ p_n^2$ kg/cm² and for the quay in question $\sigma_v^m = 12{,}5 + 9{,}2\ p_n^2$ kg/cm².

This late glacial Yoldia-clay has 50 % - 70 % grains less than 0,002 mm, specific gravity 1,92, voids ratio ε = 0,95, coefficient of permeability $k = 3.10^{-7}$ cm/min and for σ = 1 kg/cm² is the confined compression modulus of elasticity $E_2 = \frac{\Delta\sigma}{\Delta\varepsilon}(1 + \varepsilon_m)$ = 40 - 80 kg/cm². The grain size decreases with the water depth and above water is the Yoldia-clay very sandy



(a) τ_a - p_n graph (determined from all tests τ_s, $K_{sc}/10$ and c_q)

(b) τ_s^m - p_n graph for 250m quay

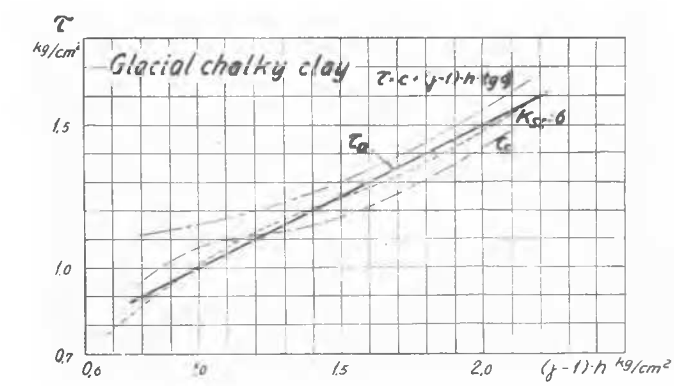
Average τ_a — p_n graph (a) and test results from a quay on Yoldia-clay 1000 m away (b).

FIG. 6

(50 % over 0,05 mm).

For a chalky glacial clay with 10-20 % grains less than 0,002 mm (50 % over 0,05 mm), specific gravity 2,23, voids ratio $\varepsilon = 0,35$, $k = 5.10^{6}$ cm/min, $E_2 \approx 100 - 200$ kg/cm², the average shear τ_a was found $\tau_a = 0,5 + 0,5 \cdot p_n +$ -cf.(fig.7) - and the average point resistance $\sigma_a = 12 + 45 \cdot p_n$ kg/cm², but the individual test results are here more spread due to the heterogeneous character of glacial clay and the varying capilary pressure, and this applies still more to chalk, where K_3/K_1 is about 10, $K_{sc}/10$ about 1,20 and $\tau_s = 0,85^{at}$ and $\sigma_a = 40 + 15\ p_n$.

In clay types with high fragmental content - as chalky glacial clay - an onion-shaped consolidated body is formed under the loading test sampler as under piles, and an increase in the point resistance thereby produced. This important soil property for piles



Average τ_a - p_n for tests in glacial chalky clay.

FIG. 7

TABLE I

FIELD TESTS

Boring 1234 February 1946		same day			n days later				$\frac{K_{sc}^n}{K_{sc}^8}$	$\frac{c_q^n}{c_q^8}$	Loss Δ w in W % water content
depth m	Yoldia-clay with sand layers.	K_{sc}^o	c_q^o	φ^o	n	K_{sc}^n	c_q^n	φ^o			%
1,98	fine lay	8,8	1,1	30	11	7,0	1,1	30	0,8	1,0	0
2,93	thick -	1,8	0,42	31	7	9,0	0,88	27	5,0	2,1	3
4,45	- -	12	0,8	30	10	7,5	0.8	30	0,6	1,0	4,7
6,12	few & fine lay	9,5	0,87	33	8	6,5	0,77	33	0,7	0,9	2,3
8,40	thick -	9,0	0,7	30	7	10,2	0,8	32	1,1	1,1	2,4
10,0	- -	9,0	1,08	29	8	8,0	1,0	30	0,9	0,9	2,4
13,97	few thinner layers	7,3	1,2	27	5	10,0	1,95	27	1,4	1,6	4
15,72	-	11,0	1,3	24	5	12,0	1,67	29	1,1	1,3	4

TABLE II

Field tests.					Laboratory tests, Copenhagen.							
Boring	depth	Late glacial Yoldia-clay.	K_{sc}^{o}	quick shear tests c_q^o	γ t/m³	w % water	after days	K_3^L	K_{sc}^L	quick shear test c_q^L	$\frac{K_{sc}^L}{K_{sc}^o}$	$\frac{c_q^L}{c_q^o}$
1046	- 7,94	thin sand layers	5,5	0,60	1,97	25,2	8	4,8	(11,2)	1,58	2,04	2,63
-	-16,54	- " -	8,0	0,60	1,91	31	8	2,7	(6,3)	0,51	0,79	0,64
-	-18,65	- " -	8,0	1,00	1,96	30,1	9		10	1,73	1,25	1,73
1248	-16,35	Yoldiaclay	2,0	0,30	1,91	30,9	8	4,3	10	1,50	5,00	5,00
-	-19,60	-	6,0	0,70	1,93	31,8	-	5,7	13	1,65	2,17	2,36
-	-23,31	Heavy Texture	11,0	0,85	1,98	33,7	-	6,1	14	1,66	1,28	1,96
1048	-17,70	traces of sand	8,5	0,68	1,93	31,1	9	5,4	(12,7)	1,79	1,50	2,63
-	-19,96	Spots sand & chalk	10	0,74	1,92	30,7	22	6,15	(14,3)	1,70	1,43	2,30
-	-21,78	homogeneous	10	0,48	1,91	32,1	-	6,95	(16,2)	2,56	1,62	5,36
-	-23,60	many thin sand layers.	11	0,31	1,99	31,8	-	4,9	(11,3)	1,52	1,03	4,90
							Average . . .				1,81	2,56

may be determined by cone tests in the upper part of a loading test sample, where the cone weight K_{sc} in chalky clay may be increased with 50 - 100%, gradually decreasing to the normal value in a depth of abt. 4 x the point diameter, and ordinary tests should only be taken from the lower 15 cm of the sample.

The loading tests in Yoldia-clay give very uniform results and only in greater depth are the loading test results slightly higher than the cone and quick shear sample tests, probably due to insufficient capillary pressure on the samples to develop the natural pressure from overlying weight. The importance of testing the samples as soon as possible - even in tight containers with rubber cushions between the lids and the container - was confirmed by repeating the cone tests (K_{sc}) and quick shear tests (c_q and φ) 5 to 11 days later - of table I - and by comparing the field tests with laboratory tests 8 - 22 days later - table 2. The greater changes in table 2 may be due to damage during shipment of containers and difference in testing outfit and procedure, but in both tables are found cases of drying out and cases of migration of porewater from sandy layers to clayey parts of the sample, which is the most common cause to a decrease in shear strength of a heterogeneous sample.

In glacial chalky clay the loading test results are lower than the cone and quick shear test results, which for the shear value may be explained by the fact, that while there in Yoldia-clay always is found a thin clay skin on the outside of the sampler, this is not the case in glacial chalky clay. In fragmental soil is proposed to weld a helical groin on the outside cylinder surface and in order to prevent loosing samples is proposed to surround the wash pipe with a rubber collar near the sampler.

CONCLUSION.

The described loading test is simple, speedy and reliable and gives 1) the skin friction and point resistance under actual conditions without depending on a certain capillary pressure, 2) samples of test loaded soil (upper sample) for investigation of consolidation and 3) undisturbed soil sample (lower part).

The shear stress τ_s^m is for each sample determined as an average of 1) a loading test and 2) 8 - 10 sample tests (spring-cone, quick shear, Mini-pile and cork screw tests) immediately after it has been brought up. The vertical soil stress σ_v^m is found as an average of a loading test and a Mini-pile-test.

In heavy-textured homogeneous Yoldia-clay the deviations of the individual tests from the $\tau_s^m - p_n$ and $\sigma_v^m - p_n$ - curves are insignificant. The stresses increase uniformly downwards with the weight p_n and the curves are generally parallel to the average curves (τ_a and σ_a) for all borings in the area.

By comparing the individual tests with τ_s^m and σ_v^m and these again with τ_a and σ_a, errors are eliminated and important historic informations about the clay (earlier overburden, disturbances etc.) obtained.

In chalky glacial clay and in chalk same procedure is used, but the deviations are greater due to the inhomogeneous character, but the loading test results may here replace lost or insufficient samples.

The loading test results were found more reliable than the other field tests and these-especially the shear tests - again more reliable than Laboratory tests a week or more later due to drying out or migration of porewater.

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