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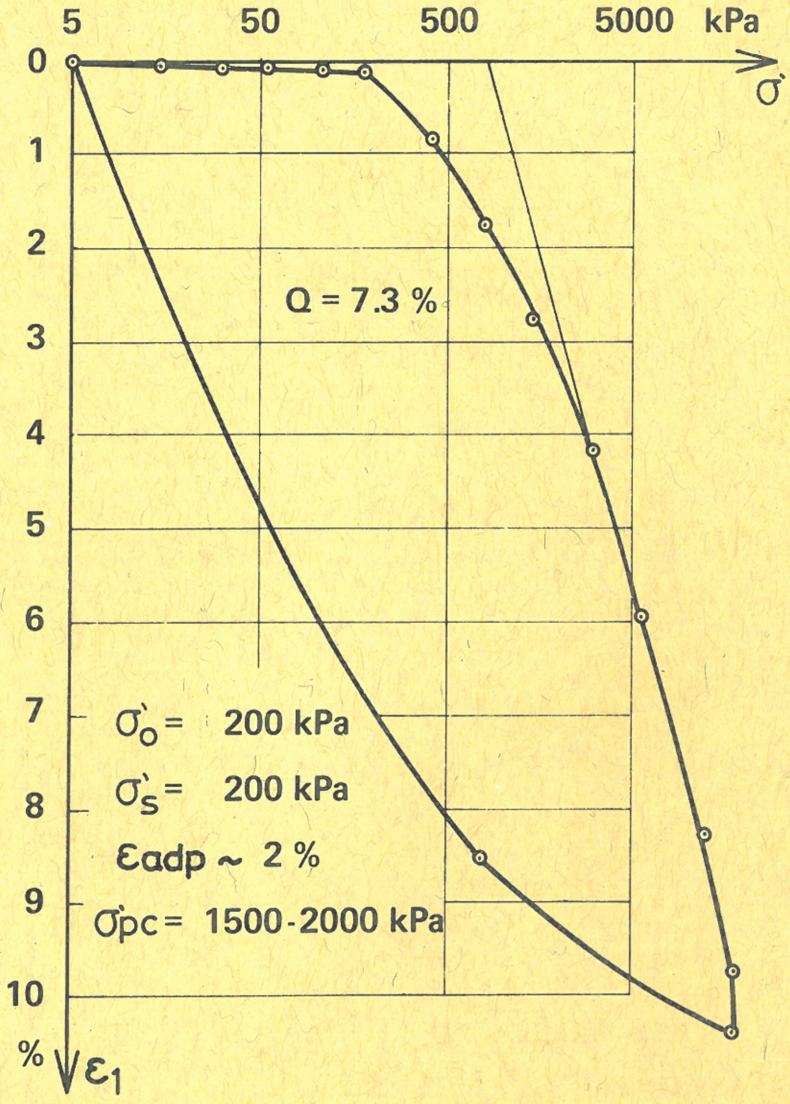
INSTITUTE OF CIVIL ENGINEERING
AALBORG UNIVERSITY CENTRE
DENMARK

Test no 1. Sample no B3-9



RAPPORT
NO 14
SEPT. 79

SOME TESTS ON HEATHER FIELD MORAINE CLAY

MOUST JACOBSEN

Some tests in Heather Field moraine clay

This report deals with oedometer tests and triaxial tests on three samples of moraine clay from the Heather Field in the English part of the North Sea. The tests have been carried out in the very un-elastic apparatus used in Denmark and with special test procedures differing from the ones used elsewhere.

In Denmark moraine clay covers a large part of the surface, and it has therefore been investigated extensively in the field and in the laboratories during the last 25 years. It is to day - from a geotechnical point of view - the best known clay in Denmark. It could therefore be of some interest to compare the English North Sea moraine clays with the corresponding Danish Moraine clays.

The Danish test procedures are explained in details and some comments are given in the hope that they may not be banalities all of them.

The main results are that the sandy moraine clay from depths of 4-17 m seems to be very similar to the strongest Danish moraine clays and that it should be possible to use many of the Danish results.

Laboratory tests

Three samples of diameter 55 mm and lengths 100-120 mm have been investigated:

Borehole	Sample no	Depth
B3	9	16.9 m
B3	17	36.1 m
B1	10	7.0 m

The grain size distribution envelopes for the English moraine clays as determined in England are compared with the distribution of the best known Danish moraine clays in Fig. 1.

It is seen that the distribution envelope for moraine clay from a depth of 4-17 m in the North Sea (corresponding to sample B3-9 and B1-10) covers the distribution envelope for the investigated Danish moraine clays.

The pore water has been analysed for salt concentration (1.9% NaCl) and water with that salt concentration has been used in swelling tests.

In Fig. 2 is shown a summary of samples and tests described in this report, including the natural water content w_n corresponding to $S_w = 1$, the specific gravity d_s and the void ratio.

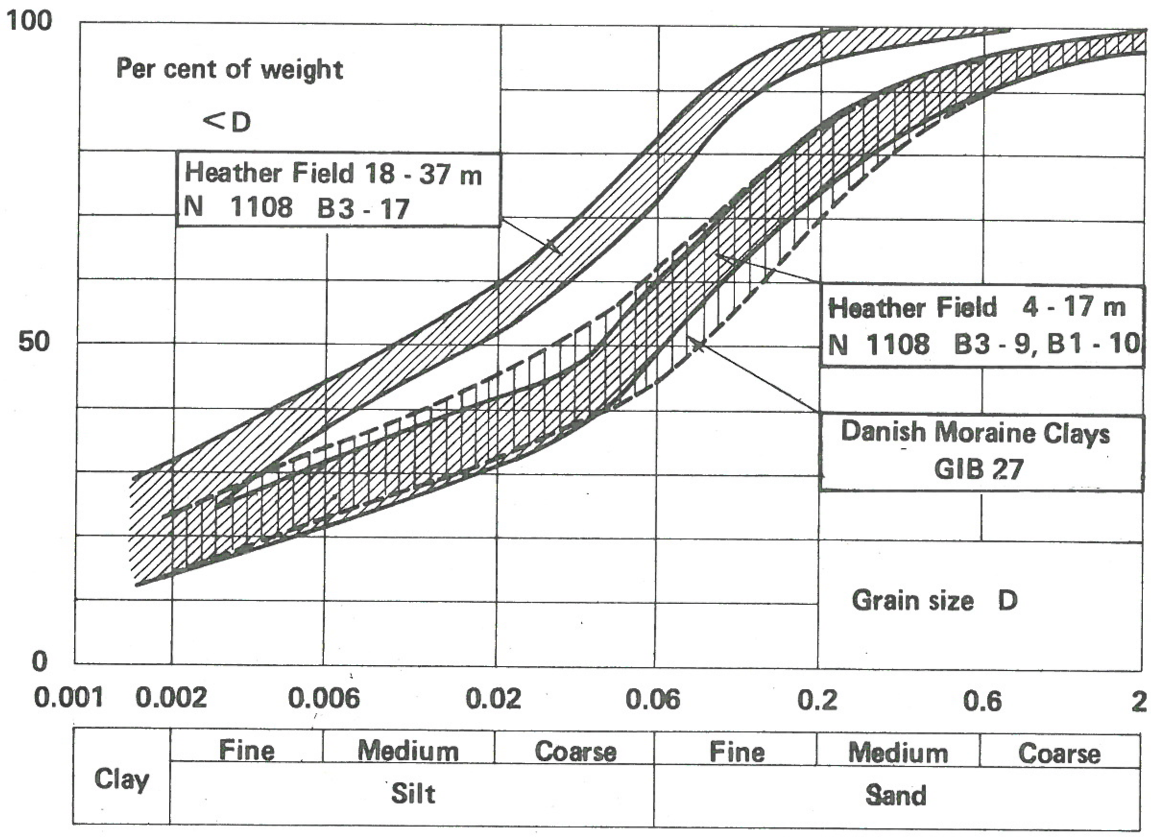


Fig. 1. Grain Size Distribution Envelopes.

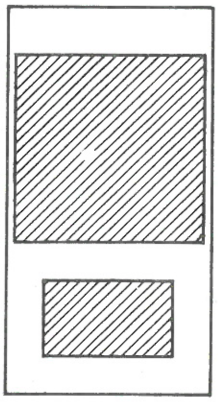
Borehole B3, Sample no 9, Depth 16.9 m, over burden pressure $\sigma'_o \sim 200$ kPa

Moraine clay,
sandy, very silty

w_n = 9.6 %

e = 0.25

d_s = 2.66



Test no 8. Triaxial test
Measurement of undrained shearing strength

Test no 1. Oedometer test
Measurement of preconsolidation pressure σ'_{pc}
and swelling pressure σ'_s

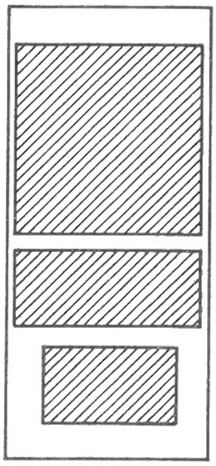
Borehole B3, Sample no 17, Depth 36.1 m, over burden pressure $\sigma'_o \cong 400$ kPa

Moraine clay,
rather fat,
silty

w_n = 18.5 %

e = 0.5

d_s = 2.70



Test no 7. Triaxial test
Measurement of undrained shearing strength

Test no 4. Oedometertest
Measurement of strain properties.
Reloading curves

Test no 2. Oedometertest
Measurement of preconsolidation pressure σ'_{pc}
and swelling pressure σ'_s

Borehole B1, Sample no 10, Depth 7.0 m, over burden pressure $\sigma'_o \cong 85$ kPa

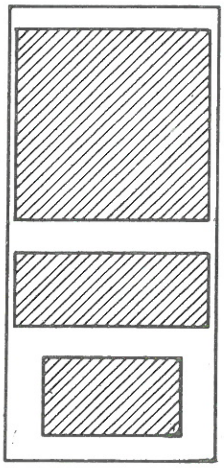
Moraine clay,
very sandy,
silty
many stones

Difficult to
prepare for
testing

w_n = 10.1 %

e = 0.27

d_s = 2.68



Test no 6. Triaxial test
Measurement of undrained shearing strength

Test no 5. Oedometer test
Measurement of strain properties.
Reloading curves

Test no 3. Oedometertest
Measurement of preconsolidation pressure σ'_{pc}
and swelling pressure σ'_s

Fig. 2. Samples and tests mentioned in the report.

The preconsolidation pressure σ'_{pc}

The vertical preconsolidation pressure σ'_{pc} is determined in ordinary oedometer tests by means of very "unelastic" oedometers, described in [3].

Three tests with $A_0 = 10\ cm^2$ and $h_0 = 2$ cm have been carried out at pressures as much as 18000 kN/m^2. In such tests the preconsolidation pressure σ'_{pc} is exceeded by a factor 5-10 compared even to the most heavily preconsolidated natural clay deposits. The compression curves are plotted with σ' on a logarithmic scale in Fig. 3.

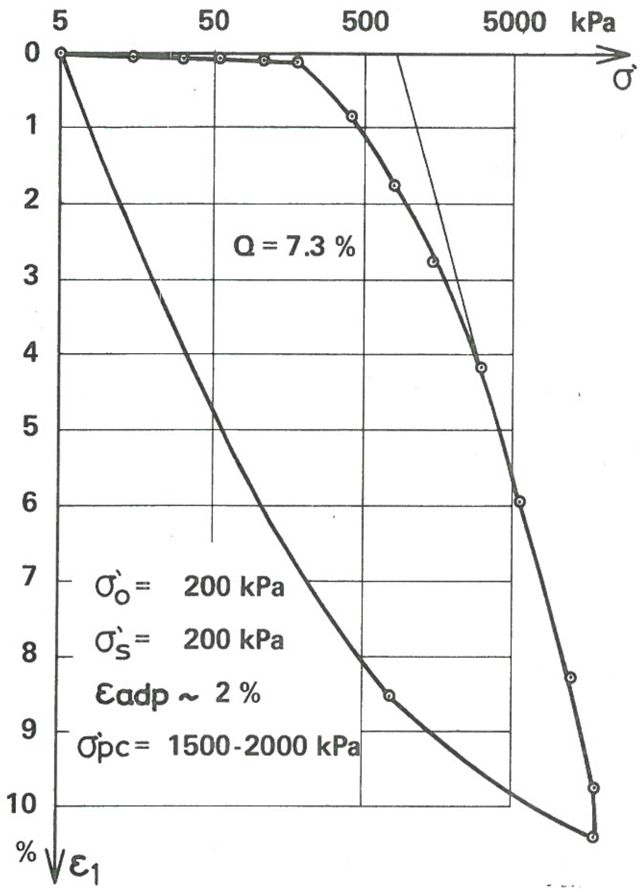
The slope of the virgin compression line (the compression strain index Q) can be determined as accurately as for normally consolidated clays. This quantity can of course not be used in practice because of the heavy preloading, but it is not possible to find the preconsolidation pressure σ'_{pc} without the virgin line.

The compression index $C_c = Q(1 + e_0)$ can be compared with some Danish results on moraine clays and Fig. 4 shows close agreement between the moraine clays from Denmark and the North Sea.

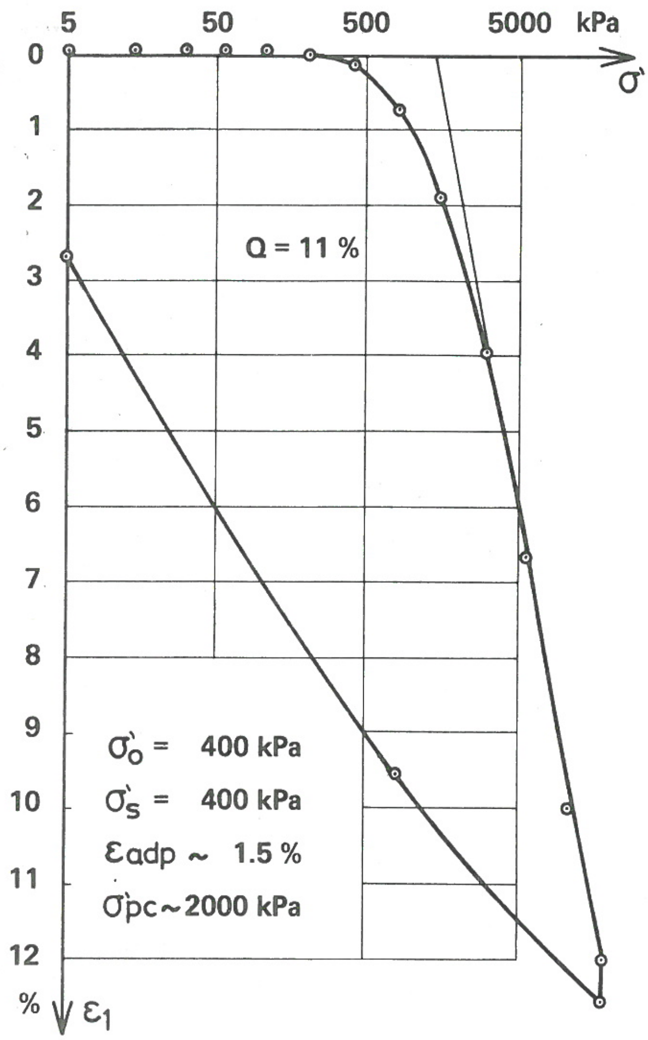
The preconsolidation pressure σ'_{pc} can not be determined accurately because of adaption deformations which take place at the first part of the primary compression curve. The adaption deformation is estimated and the pressure corresponding to the virgin compression line is taken as the preconsolidation pressure. The main results of the three tests are:

Sample	Depth (m)	Test no	σ'_{pc} (kN/m^2)	OCR
B 1-10	7	3	1500-2000	~30
B 3- 9	17	1	1500-2000	~10
B 3-17	36	2	~2000	~5

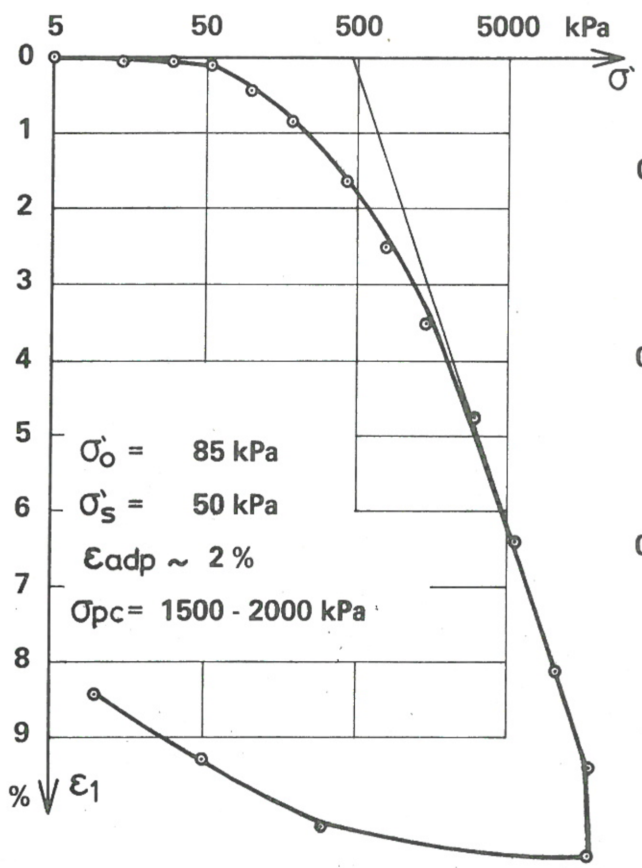
Test no 1. Sample no B3-9



Test no 2. Sample no B3-17



Test no 3. Sample no B1-10



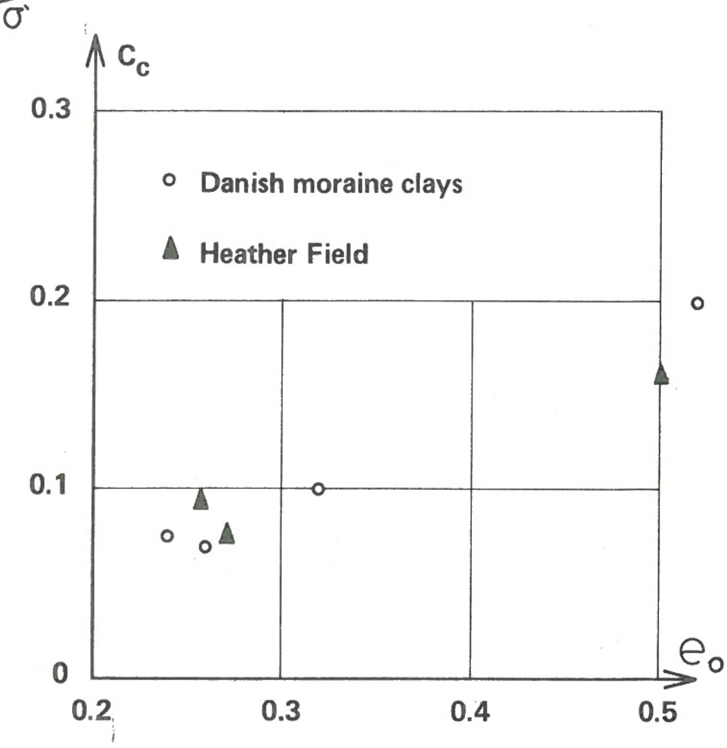


Fig. 3. High pressure oedometer tests. *Fig. 4. Compression index.*

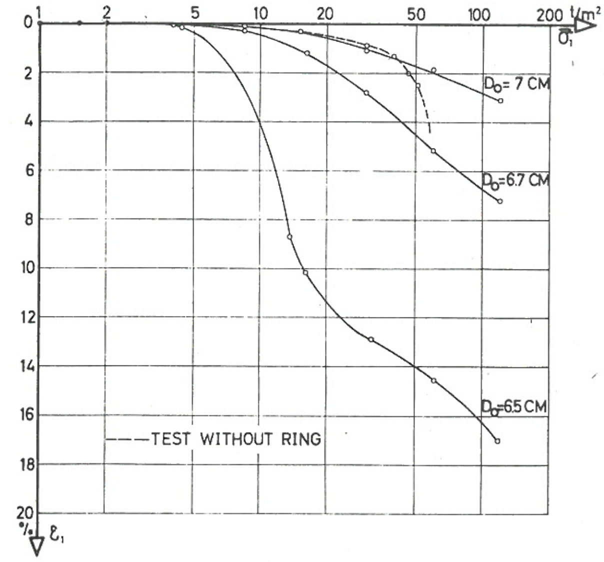


Fig. 1.6 Some primary curves found in the same oedometer for the same kind of moraine clay, but with different diameters of the samples. The diameter of the ring is seven cm. Kratbjerg moraine clay.

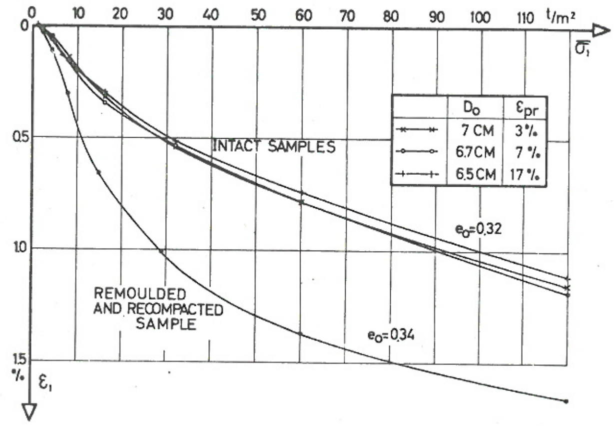


Fig. 1.9 The effect of the preparation of the sample on the reloading curves. Kratbjerg moraine clay.

Comments

The shape of the primary compression curve is influenced very much by the precision of the preparation of the sample. Morain clay samples contain sand grain and small stones which make the surface of the sample rough. The sample therefore had to be prepared with a somewhat smaller diameter than that of the oedometer ring.

The first part of the primary compression curve does not represent an oedometer test with no lateral deformation, but rather a kind of a compression test. Fig. 1.6 (from GIB 27) shows the influence of sample preparation on the primary compression curve. The maximum pressure load σ'_{max} equals the preconsolidation pressure σ'_{pc}. It is obvious, that the use of a sophisticated method e.g. Casagrandes, does not lead to a relevant result.

Therefore the three preliminary tests have been carried out mainly to determine the preconsolidation pressure.

Since the virgin curve is a straight line in figur 3 the oedometer ring must function at pressures exceeding σ'_{pc}. The reconstruction of the stress history ensures a perfect adaption of the sample to the testing apparatus.

Recompression curves can not be used, because σ'_{max} exceeds σ'_{pc} by a factor of 5-10.

Swelling pressure

The three above mentioned tests were performed just after the unpacking of the samples with their natural water content.

The tests were set up with dry filters and a small vertical pressure was applied. Then the filters were filled with water and swelling of the sample prevented by applying vertical pressure to balance the swelling pressure.

Test no 1 and 2 show, that the swelling pressure nearly equals the vertical in situ pressure. It means, that the horizontal and vertical stresses are equal, when OCR = 5-10, which seems reasonable (Fig. 2.22 in GIB 27).

Test no 3 was performed with a very sandy moraine clay, and shows a swelling pressure less than the in situ pressure. This is probably due to the low capillarity of the sample.

Comments

By sampling, the effective overburden pressure will partly be transferred into suction in the pore water. The mean effective pressure will remain nearly constant.

The suction, however, can not exceed the maximum capillary forces in the sample. In very sandy Danish moraine clays the capillarity normally does not exceed 100 kN/m^2. The measurements are mentioned in [2], which has not been published in English. Since test no 3 is carried out on a very sandy moraine clay, very similar to Danish moraine clays, the very low swelling pressure could correspond to the capillarity of the sample.

Storage or preparation of the sample will increase the suction due to partical exsiccation, and the swelling pressure is therefore measured on fresh samples only.

Recompression curves

Two oedometer tests have been carried out with samples with $A_0 = 19.6\ cm^2$ and $h_0 = 2$ cm.

The stress history was reconstructed by using a maximum load of $\sigma'_{max} = 2000\ kN/m^2$, which equals the preconsolidation pressure σ'_{pc}. Then the sample was unloaded to σ'_u and recompressed until

σ'_{max} = 2000 kN/m^2. This procedure was repeated 3 times in test no 4 and 5 times in test no 5, but with different values of σ'_u. One value of σ'_u equals the in situ pressure σ'_0.

The vertical load doubled at each step of the recompression and decreased by a factor of 2-10 at each step of the unloading. Test no 4 consists of 22 steps, test no 5 of 42 steps. These tests are shown in the normal way in Fig. 5, and further details are shown in a special way in Fig. 7 and 8, using strain increments as defined in Fig. 6.

All unloadings in a test can be represented by the same curve - $\Delta\varepsilon_u$ versus σ' - since the maximum load σ'_{max} is constant. During unloading friction can develope between the pistons and the oedometer ring. The value of $\Delta\varepsilon_u$ then corresponds to a pressure bigger than measured and the point would be placed below the curve. Therefore the curve has to be drawn through points with the relatively largest strains.
The recompression curves are shown in a $\Delta\varepsilon_r$ versus σ' diagram. The curve is found to be upwards concave for OCR $\geq$ 5 and upwards convexe for OCR $\leq$ 5 for Danish moraine clays in case no friction occurs [2].

The curves can be influenced by friction developed during unloading (see test no 4, recompression no 3) or reloading during the first steps, but friction seems not to be important for the rest of the curve.

The black lines in Fig. 7-8 have not been fitted to the observations, but take friction into account. The curve used is nearly the same as that for Danish moraine clay.

In settlement analysis the recompression curves should be used, but using test results from the very stiff apparatus used in Denmark, we found that the recompression curves underestimate the settlement because lateral movements are prevented in the oedometer.

It was also found, that if the initial tangent modulus K_t is used, we got close agreement between settlement observations and calculations (GIB 27, pp 42-44). In table 1 is shown the unloading pressure σ'_u, σ'_{uc} corrected for friction, OCR and K_t.

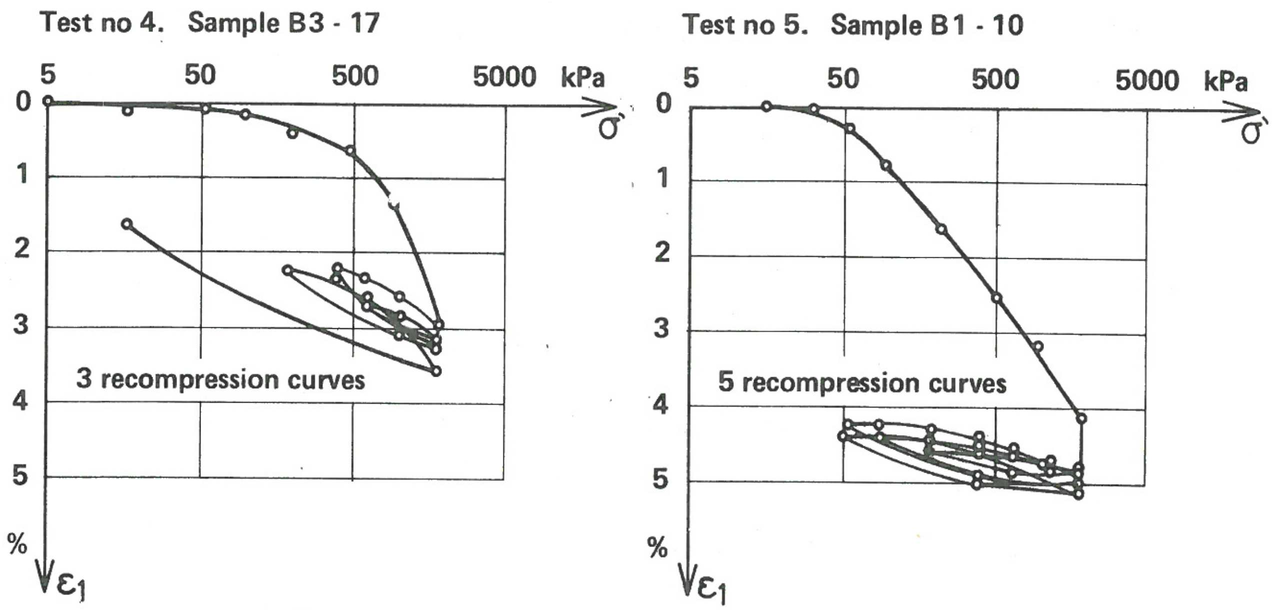


Fig. 5. Oedometer tests with recompressions.

The moraine clay used in test no 5 seems to be very similar to the Danish Carlsberg moraine clay. They have nearly the same grain size distribution, preconsolidation pressure and natural water content.

K_t can be expressed by

$$K_t = K_t^0 + \Delta K_t \cdot \sigma'_{uc} \qquad (1)$$

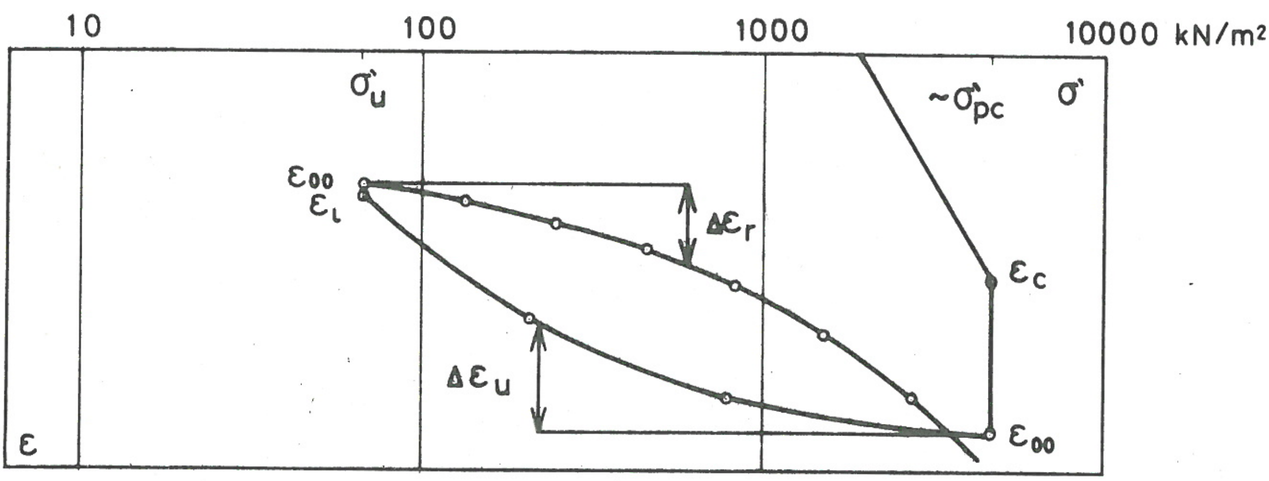


Fig. 6. Definition of stresses and strains.

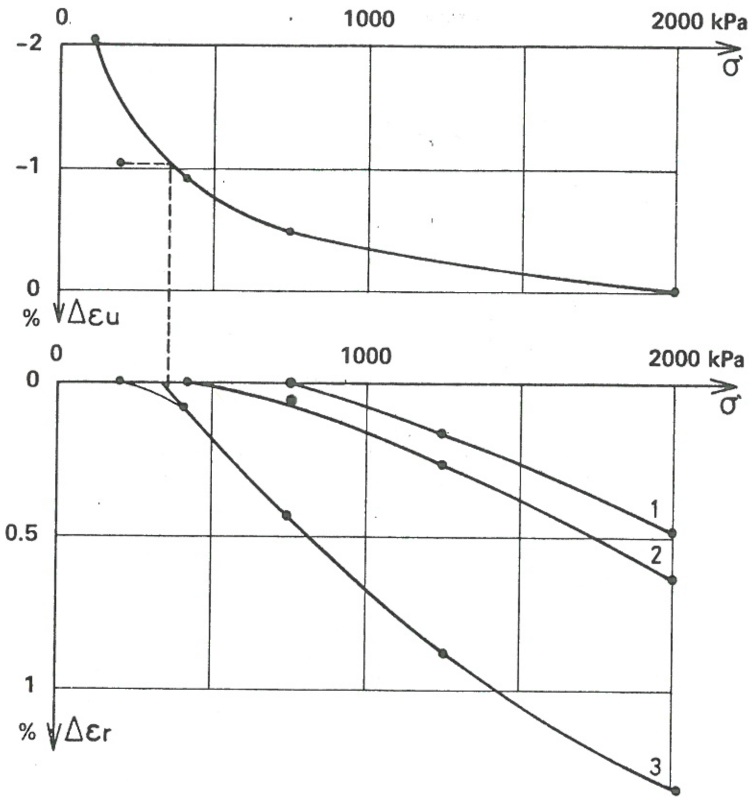


Fig. 7. Unloading and recompression curves for test no 4.

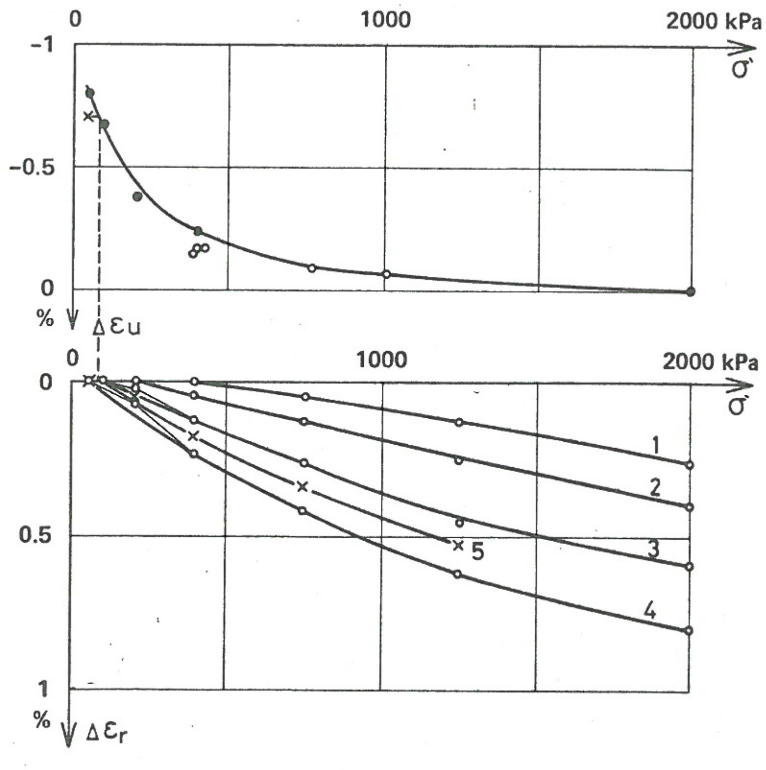


Fig. 8. Unloading and recompression curves for test no 5.

Table 1

	Recom-pression no	σ'_u kN/m²	σ'_{uc} kN/m²	OCR	K_t MN/m²
Test no 4	1	755	755	2.6	520
σ'_0 = 400 kN/m²	2	405	405	5	520 ?
	3	205	330	6	195
Test no 5	1	405	405	5	800
σ'_0 = 85 kN/m²	2	205	205	10	400
	3	105	105	20	225
	4	55	80	25	185
	5	55	55	36	150

For Carlsberg moraine clay K_t^0 is 57 MN/m² and ΔK_t = 1700. In Fig. 9 the values from the table 1 are plotted and compared with the line, eq. (1) for Carlsberg moraine clay and the agreement is perfect.

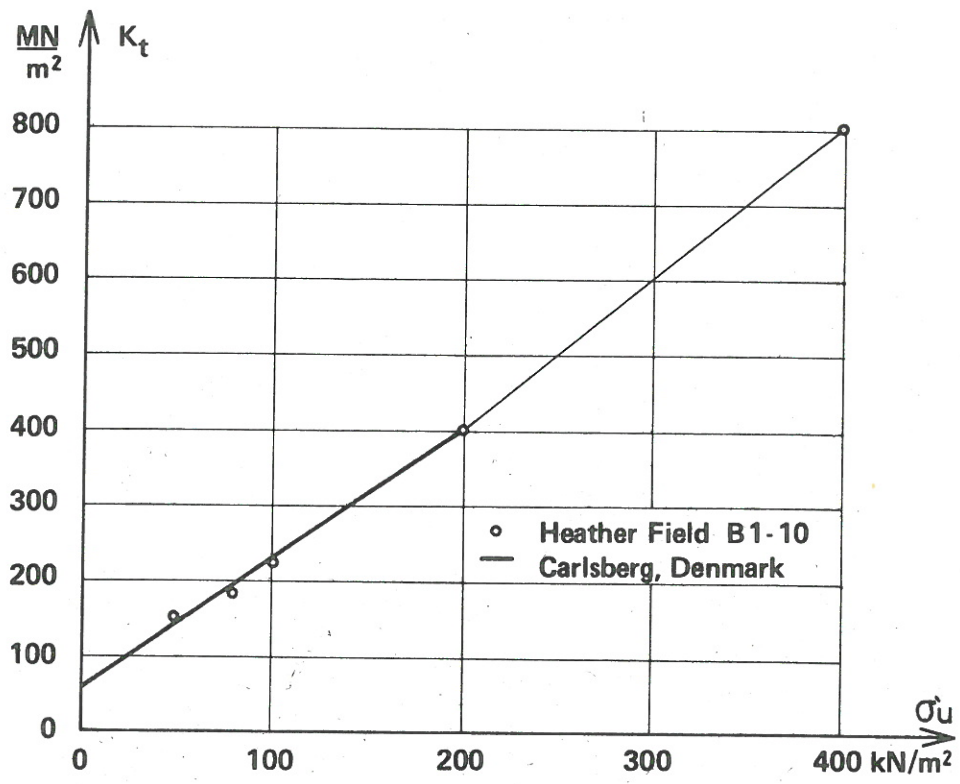


Fig. 9. K_t from test no 5 compared with K_t from tests on Carlsberg moraine clay.

The moraine clay used in test no 4 has a higher clay content than I am familar with. The results seem not to be in accordance with eq. (1), but this formula has never been used for OCR < 8 for Danish moraine clays and the two identical K_t values in recompression 1 and 2 could be a consequence of the low OCR values.

Comments on sample preparation

In Fig. 1.6 was shown the influence of the adaption deformations on the primary compression curve. The samples were afterwards unloaded to the same value of σ'_u and recompressed. The result is shown in Fig. 1.9 and shows that the adaption deformations are "forgotten" during reconstruction of the stress history.

Comments on maximum load σ'_{max}

The influence of maximum loads was measured on another moraine clay with a preconsolidation pressure of 120-160 kN/m^2. Fig. 1.10 shows that when overloading the sample (here $\sigma'_{max}/\sigma'_{pc}$ = 15) the recompression curve shows remoulding effects. After some months at maximum load the normal behaviour of the sample was reestablished.

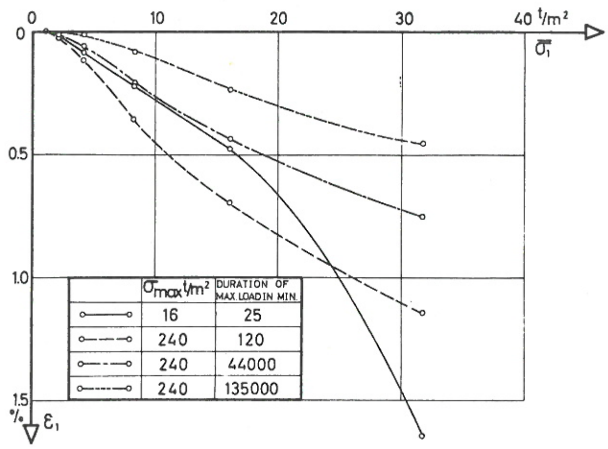


Fig. 1.10 Remoulding and ageing effects. Sabro moraine clay.

It means, that remoulding is due to large volume changes, which have taken place in the tests described in Fig. 1.10, but not in Fig. 1.6 and 1.9.

Another result, which has not been published in English, shows that when $\sigma'_{max}/\sigma'_{pc} \sim$ 0.8-1 the recompression curve is not influenced by σ'_{max}. Therefore it is better to use a maximum load σ'_{max} which is a little bit less than σ'_{pc} than to use a maximum load exceeding σ'_{pc}.

Comments on test procedures

Tests have been performed with many recompressions and the influence of decreasing or increasing values of σ'_u have been investigated. The influence of repeated compressions have been investigated too.

The result was, that it is possible to make as many recompressions as wanted and in arbitrary order. But it is necessary to load the sample until σ'_{pc} in every recompression.

The undrained shear strength c_u

Undrained triaxial tests have been carried out with samples of diameter and height equal to 50 mm.

The pressure heads are smooth and with 80 mm diameter. Special membranes were made as the diameter of the sample was 20 mm smaller than normally used. To ensure an effective connection between the pore water and the measuring system the filter consisted of four surface drains extending from one pressure head to the other. The water can be washed through the drains and air bubbles effectively removed. Further details are given in [3].

Undrained triaxial tests consist of two parts. First the stress history is reconstructed isotropically under drained circumstances by loading the sample stepwise to a certain pressure σ'^m_{pc} and then unloading to the pressure σ'^m_u corresponding to the in situ pressure. In the second part of the test the undrained deviatoric loading takes place.

The procedure used in Denmark is different from the one used elsewhere. Instead of measuring the pore pressure at constant cell pressure, the cell pressure is varied at constant volume.

A very fine capillary tube is used to measure the volume in order to keep it constant. Since no water flows from the sample to the capillary tube the pore pressure is equal to the atmospheric pressure [1]. The effective pressures are therefore measured directly.

The isotropic preconsolidation pressure σ'^m_{pc} is smaller than the vertical preconsolidation pressure σ'_{pc} as determined from oedometertests. It has been shown previously that only the mean normal stress causes preconsolidation [6] (creep effects are not included in that argument). And the coefficient of earth pressure at rest K_0 has been determined to 0.3-0.4 in the normally consolidated state. It means that σ'^m_{pc} can be calculated as

$$\sigma'^m_{pc} \simeq \frac{1}{3}(1 + 2 \cdot 0.4)\sigma'_{pc} \simeq 0.6\ \sigma'_{pc}$$

which means that in present tests $\sigma'^m_{pc} = 1200\ kN/m^2$.

During unloading the horizontal stresses decrease more slowly than the vertical stress, and for OCR ∿ 5-10 an isotropic state occurs. That means, that for a certain OCR value, it is correct to use undrained tests with initial isotropic stress conditions. The stress condition corresponding to the natural state can be determined in the laboratory by means of either a special oedometer or a conventional triaxial apparatus, in which case though, the procedure is very cumbersome. In Denmark the undrained tests start from the isotropic state.

Reconstruction of the stress history has the main effect of erasing the memory of the sample. It means, that it is possible to repeat the undrained test procedure with the same sample and get the same result, since the void ratio is unchanged. Undrained multiple stage tests could therefore be performed on preconsolidated clays. It is valid only for small deformations ($\varepsilon_1 <$ 5-10%).

Three undrained tests have been carried out (Fig. 10), Test no 6 stage 1 has to be rejected because the upper pressure head tilted, causing the sample to move sidewards in stead of getting compressed. Stage 2 gives too small shear stresses because of the large deformations in stage 1. In test no 8 two stages were carried out, and the deformations in stage 1 exceeded 15%.

The main results are

Sample	Depth (m)	Test no	Fig. no	c_u (kN/m²)
B 1-10	7	6	10	>600
B 3-9	17	8	10	∿1000
B 3-17	36	7	10	≥530

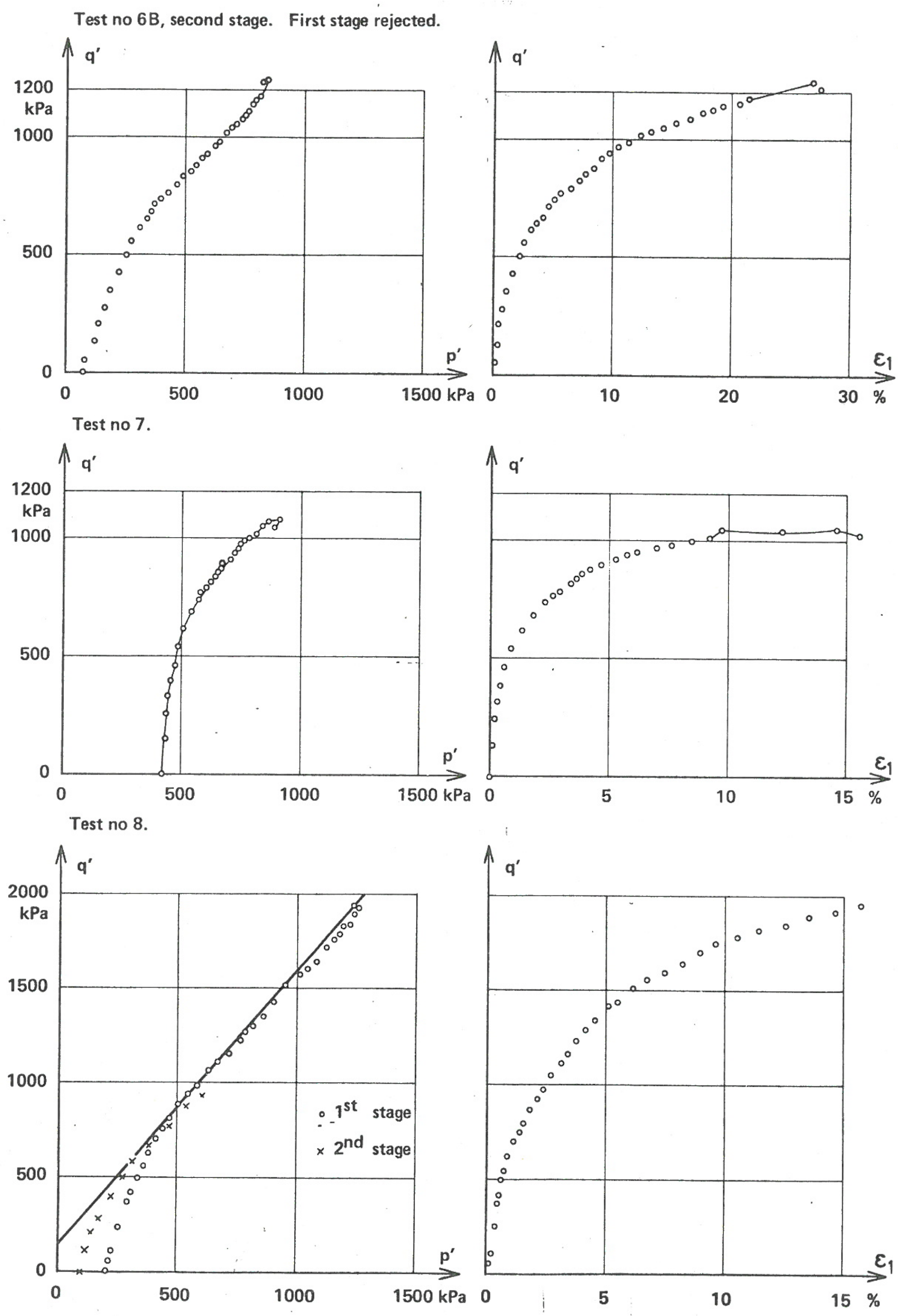


Fig. 10. Undrained triaxial tests.

Some comparison can be made with Danish results.

1. Danish moraine clays have a c_u/σ'_{pc} ratio of $\sim$0.25. [5]. The best test (B 3-9) shows, that c_u is relatively high, but B 3-17 seems to be in accordance with Danish results.

2. The Carlsberg moraine clay has c_u = 750 kN/m², $\phi' \sim 33^\circ$ and c' = 72 kN/m². In undrained tests the stress path can be used to find ϕ' and c' if it is assumed that the failure condition is represented by an asymptote. Fig. 10 then gives: c_u = 1000 kN/m², $\phi' = 36^\circ$ and c' = 64 kN/m².

The sandy moraine clay from Heather Field seems to be a little bit stronger than the Carlsberg moraine clay, but the deformation properties seem to be equal.

References

Moust Jacobsen:

[1] The Undrained Shear Strength of Preconsolidated Boulder Clay. Proc. Geot. Conf. Oslo 1967.

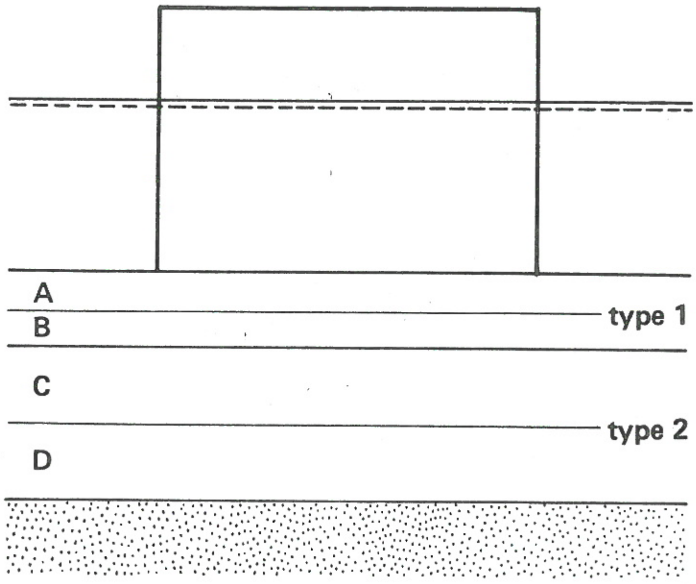
[2] Moranelers deformationsegenskaber. Ph.D. thesis DTH 1967.

[3] New Oedometer and New Triaxial Apparatus for Firm Soils. Danish Geotechnical Institute, Bulletin no 27, 1970.

[4] Strength and Deformation Properties of Preconsolidated Moraine Clay. Danish Geotechnical Institute, Bulletin no 27, 1970.

[5] Nogle danske moranelerers styrke- og deformationsegenskaber. NGM 1975, Copenhagen.

[6] Stress-strain relationship of preconsolidated clay. Proc. Ninth intern. conf. on soil mech. and found. eng. Tokyo 1977.



layer	mid-depth	in situ pressure	preconsolidation pressure	overcompression ratio	initial tangent	transmitted load	settle-ment
	z	σ'_0	σ'_{pc}	OCR	K_t	$\Delta\sigma'$	δ
	m	kN/m^2	kN/m^2		MN/m^2	kN/m^2	mm
A	5	60	1800	30	160	250	16
B	15	180	1800	10	360	270	7
C	30	360	1800	5	330	280	17
D	50	600	1800	3	330	250	15

$\delta_t = \delta_i + \delta_c = 55$

Example
Settlement analysis. The initial tangent method.

A simple off shore construction is shown in the figure. It is circular, has a diameter of 100 m, and transmits a mean load of 500 kN/m^2 to the ground. The geological structure consists of an upper layer of moraine clay like that in sample no B3-9 of thickness 20 m and a layer of moraine clay like that in sample no B3-17 of thickness 40 m. Below the moraine clay are sand deposits.

The total settlement is calculated, including the initial settlement.

The stress distribution corresponds to an infinite elastic layer. The real stress distribution is more concentrated and the real settlement is somewhat bigger than calculated in the example.

Oedometer tests

	Test no 1		Test no 2	Test no 3		Test no 4		Test no 5	
load no	σ' kN/m²	ε_1 %	ε_1 %	σ' kN/m²	ε_1 %	σ' kN/m²	ε_1 %	σ' kN/m²	ε_1 %
1	5	.08	-.11	5	.0	5		17.5	.0
2	15	.09	-.13	15	.01	17.5	.03	30	.18
3	30	.10	-.14	30	.01	30		55	.37
4	55	.02	-.09	55	.07	55	.09	105	.77
5	105	.09	-.07	105	.45	105	.14	255	1.65
6	205	.11	.00	205	.85	255	.33	505	2.51
7	405	.83	.14	405	1.60	505	.64	1005	3.13
8	805	1.75	.75	805	2.50	1005	1.39	2005	4.18/4.861
9	1505	2.75	1.92	1505	3.50	2005	2.90/3.15	1005	4.797
10	3005	4.15	3.98	3005	4.75	775	2.662	405	4.633/4.566
11	6005	5.95	6.65	6005	6.35	1255	2.831	755	4.597
12	12005	8.25	10.0	12005	8.10	2005	3.153/3.281	1255	4.692
13	18005	9.73/10.42	12.0/12.55	18005	9.4/10.6	405	2.376/2.273	2005	4.831/4.942
14	805	8.51	9.5	300	10.15	755	2.331	755	4.869
15	5	.02	2.65	50	9.25	1255	2.537	205	4.569/4.504
16				10	8.4	2005	2.898/3.220	405	4.536
17						205	2.209	755	4.631
18						405	2.303	1255	4.758
19						755	2.639	2005	4.903/5.043
20						1255	3.092	405	4.881
21						2005	3.531/3.675	105	4.603/4.371
22						105	1.656	205	4.386
23								405	4.497
24								755	4.644
25								1255	4.825
26								2005	4.967/5.074
27								405	4.906
28								55	4.258/4.200
29								105	4.197
30								205	4.264
31								405	4.431
32								755	4.619
33								1255	4.819
34								2005	5.003/5.089
35								405	4.936
36								55	4.417/4.370
37								105	-
38								205	4.408
39								405	4.551
40								755	4.703
41								1255	4.883
42								55	4.446