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Dissipation tests in saline environment

E. Imre
Obuda University BMF, Bp., Hungary,

D. Bishop, L. Bates, S. Fityus
University of Newcastle, Newcastle, Australia,

Z. Bakacsi, K. Rajkai
MTA ATK TAKI, Budapest, Hungary

M. Juhász
Taupe Kft Budapest, Hungary

ABSTRACT: The results of two research projects are presented here. The first is based on soil exploration down to 20 m indicating that a difference exist horizontally in Szeged City, Hungary, possibly due to the variation of saline and non-saline soils in depth. The geotechnical laboratory and in situ data are treated by some statistical tests. In addition, chemical and some special, new tests (simple local side friction and cone resistance dissipation tests and multistage oedometric relaxation tests) are mentioned to characterize the fabric instability and composition of the saline layers. The second is based on the results of some geotechnical laboratory and in situ dissipation tests related to a saline spot up a depth down to 66 m.

1 INTRODUCTION

1.1 *The aim of research*

There is a hilly area with a divider between the Duna and the Tisza Rivers in Hungary, where the groundwater moves downwards, in the low areas along the two large rivers the soil water is moving upwards (Figs 1, 2, Arany, 1956; Bakacsi and Kuti, 1998, Simon et al. 2011). A statistical study made by Rétháti and Ungár (1978), based on soil physical parameters of 11000 laboratory tests determined from 2600 soil samples taken in the western side of Szeged (Figs 1 to 3) revealed that the layering is the same, however, the soil conditions are worse on part C in comparison with parts A and B. The aim of the research is to explain this difference, based on existing data.

1.2 *Content of paper*

In this work it is assumed that in area C some saline groundwater may move upwards in some spots from a very deep, old clay marine deposit, and, as a result, the soil may be altered in a different degree at various depths and locations.

Concerning this, the results of two research projects are presented. In the first borings, laboratory and CPT data were produced in Szeged down to 20 m depth, which was completed by chemical and special dissipation tests.

In the second one, a site in area C was investigated down to 70 m depth using conventional laboratory tests and CPTu u_2 dissipation tests.

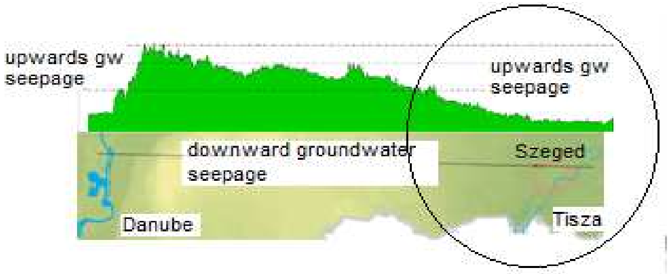


Figure 1. The Duna -Tisza Rivers section

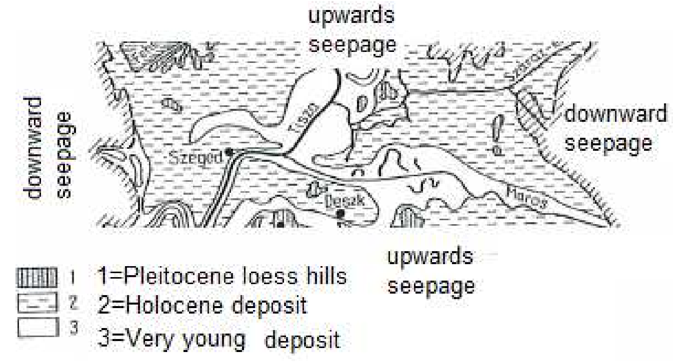


Figure 2. The Szeged environment of the section

2 METHODS

2.1 *Analysis in large area down to 20 m*

2.1.1 *Statistical and soil science tests*

In the frame of the OTKA research on in situ test modelling seven, approximately 15 to 20 m deep borings with undisturbed samples and CPT's with simple dissipation tests were made at locations indicated in Figure 1 (Imre, 1995). All geotechnical data (classification tests, chemistry tests, continuous or dissipation type CPT) were separated into horizontal and vertical groups on the basis of soil classification and area (i.e. area A, B and C). The data sets were statistically compared. Chemical tests and double compression tests were made on a few samples. The less usual dissipation type CPT and the double compression tests can be described as follows.

2.1.2 *Simple (rheological) dissipation test*

The CPT can be used in a logging and a rheological testing mode. In the ‘‘simple rheological test” the time variation of the local side friction and the cone resistance are measured for a few minutes.

135 simple rheological type CPT were made with the CPT Sz832 (with a shaft sensor of 350 cm^2) in Szeged. These were divided into 10 groups on the basis of soil classification and site A, B and C. Tests made in the vicinity of layer boundaries were not included into these groups. Tests made in an eolian sand layer 6 in Debrecen city were used as a reference with two groups on the basis of the d<0.1 mm grain content (Tables 1a and b).

2.1.3 *Double oedometer tests*

In the multistage oedometric relaxation test the displacement load is increased with 0.1 mm, the rate of strain is 1e-3 to 5e-2 %/s during the load imposition. This rate is slightly greater than the laboratory testing rates and may cause some load reversal due to the error of the control system.

The non-monotonic loading at the beginning of the stage changes the soil response (which will depend on the energy stored in the solid phase). As a results, the compression curve point changes.

It can be noted that oedometric relaxation test and the simple CPT dissipation tests are similar in terms of boundary conditions, similar models can be used for the modelling (Imre et al, 2010).

It can also be noted that there is a partial unloading effect along the shaft surface when the penetration stops due to the stress release of the equipment entailing a decrease in the penetrometer diameter.

The double compression test results were the by-product of the basic research on the similarity. Both conventional multistage compression tests (MCT) and multistage oedometer relaxation tests (MRT) were made on all soil samples.

2.2 *Analysis of a saline spot down to 66 m*

2.2.1 *Dissipation test*

The pore water pressure dissipation tests were evaluated using three methods. Methods I and II (slow and fast methods) were precise Least Squares fittings of a 1D consolidation model. Method I was numerically more expensive than II. Method III – the one of Teh and Houlsby (1988) - was based on a two-dimensional model and a one-point-fitting at the t_{50} determined according to Sully et al. (1999).

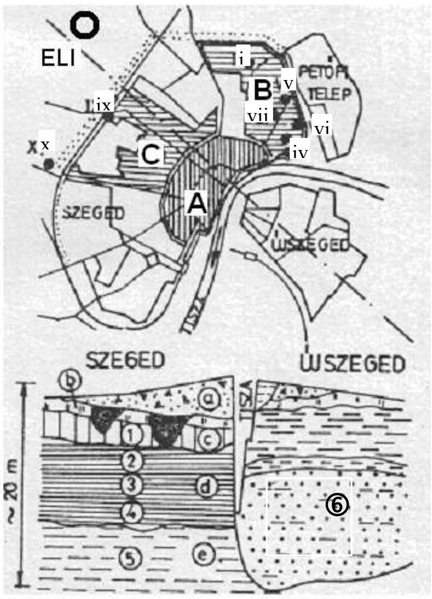


Figure 3. Site plan with explorations of OTKA (closed symbols) and the saline spot denoted by ELI. Layers 1 to 5 (or a to e) are shown in Table 1 (or Réthári and Ungár, 1978).

Table 1a. Layers in the OTKA research.

Notation	soil
1	Loess
2	Upper yellow lacustrine clay
3	Silty inclusion
4	Lower yellow lacustrine clay
5	Blueish fresh-water deposit
6	Sand

Table 1b. Category limits and notations OTKA research

Notation	Category limits
a	> 25 I_p [%]
b	15-25 I_p [%]
c	10-15 I_p, [%]
d	5-10 I_p, [%]
e	d_{30}>0.1mm
f	d_{30}<0.1mm

Table 2. Soil chemistry tests (Site X is at part C, site VI is at part B.)

Site,depth	pH(H_2O)	Electric conductivity mS/cm	ESP	Salt %
X-12,3m	8.02	0.66	3.94	0.15
VI-12,5m	8.29	0.30	1.536	0.06
X-10,0m	7.96	0.86	5.142	0.17
VI-5,0m	8.46	0.36	3.117	0.06
VI-6,5m	8.53	0.34	1.93	0.05

2.2.2 *Conventional oedometer tests*

The conventional oedometric compression tests was evaluated with the modified Terzaghi and Bjerrum models (a constant term for the immediate compression was added, Imre et al, 2013, 2014). The immediate, primary and secondary consolidation settlements were separated.

3 RESULTS

3.1 *Analysis in large area down to 20 m*

3.1.1 *Rheological dissipation test*

The mean simple CPT dissipation test records shown in Figure 4 generally show an immediate stress drop (or discontinuity) at the stop of the steady penetration, possibly since the loading type changes from basically dynamic to quasi-static.

After the stress drop, the rate of the cone resistance dissipation is larger in sand and is smaller in clay, it can be related to soil plasticity. The sign of the shaft resistance change during dissipation, in the first two minutes (measured with a 350 cm2 element for the shaft) is strongly dependent on the soil type. For sands the local side resistance increases with time and for clays it decreases with time in the first two minutes.

Concerning the horizontal inhomogenity (Fig 4), the stress decrease after 2 minutes was larger in part C than in parts A or B possibly since the normalization unit was less in area C than in area A and B. In addition, a non-zero final tangent was observed in area C which may indicate an unstable fabric.

It can be noted that the plasticity dependent results of the mean simple CPT dissipation test records were qualitatively reproduced by some multistage oedometric relaxation test both experimentally and in terms of modelling (Imre, 1985, Imre et al, 2010).

3.1.2 *Double oedometer tests*

By plotting the MCT and MRT compression curves together, some difference, reflecting the fabric and plasticity, was observed (Imre at al, 2015, Imre and Singh, 2012).

No deviation occurred for soft, intact, plastic clays. For small plasticity soils there was an increasing difference. For saline silts, zero MRT compression curve was measured (Imre et al., 2013) indicating the collapse lack of the fabric structure (Fig 5).

3.1.3 *Statistics and soil science*

The bluish-grey deposit has lower plasticity index I_P at C than at A and B. The montmorillonite + illite content of the lower yellow clay layer was less on unit C than A and B. According to the results of the chemistry tests (see Table 2) saline soil with high salt content was found at various depths in part C.

The lower yellow clay and the bluish-grey deposit has considerably less undrained shear strength c_u, and ultimate cone resistance q_{cu}, on area C than on areas A, B (see Table 3). This result supported the result of the statistical study made by Réthát and Ungár (1978).

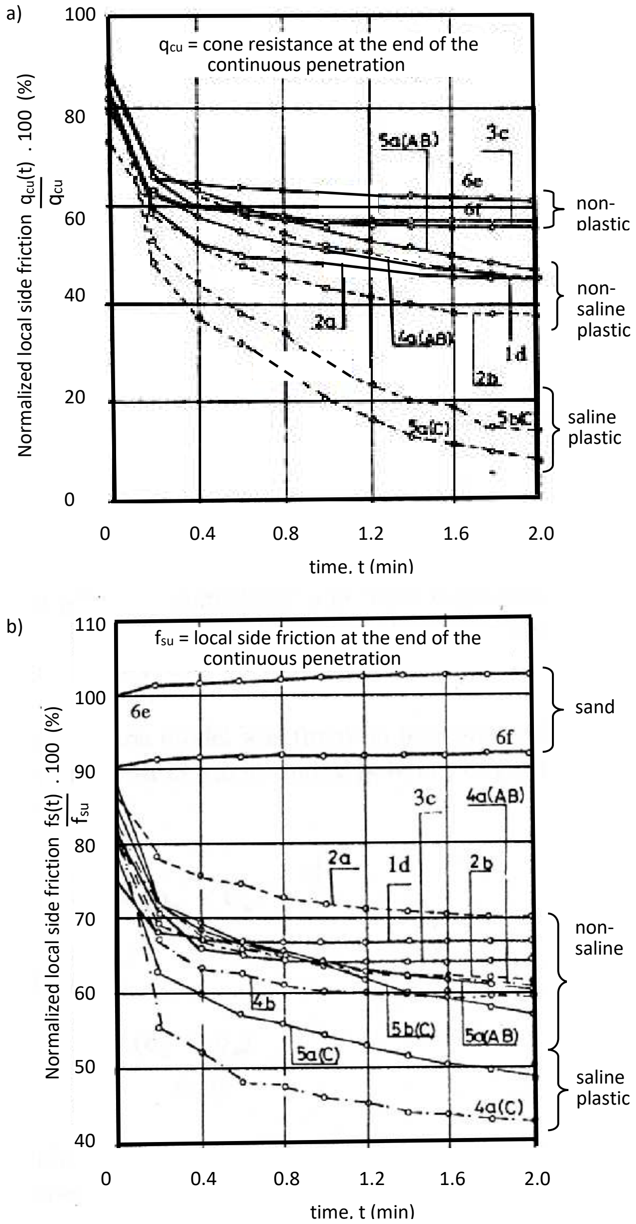
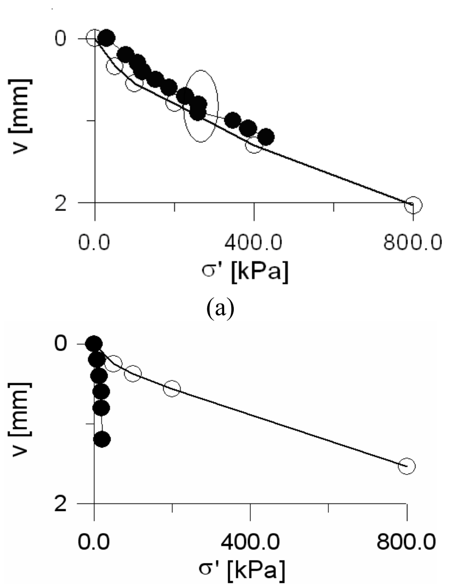


Figure 4. Average dissipation test records (OTKA research) a) cone resistance b) local side friction (on the basis of CPTs I to X shown in Fig 3) Area A, B or C is indicated in bracket. (The sand shows f_s increase, the saline soils show the largest stress drops.)



(a)

(b)

Figure 5 OTKA research, the usual and the relaxation test compression curves determined with a slight partial unloading (MRT: full circle, MCT: open circle). (a) Ip =23%, area A. (b) Ip =10%, saline, area C

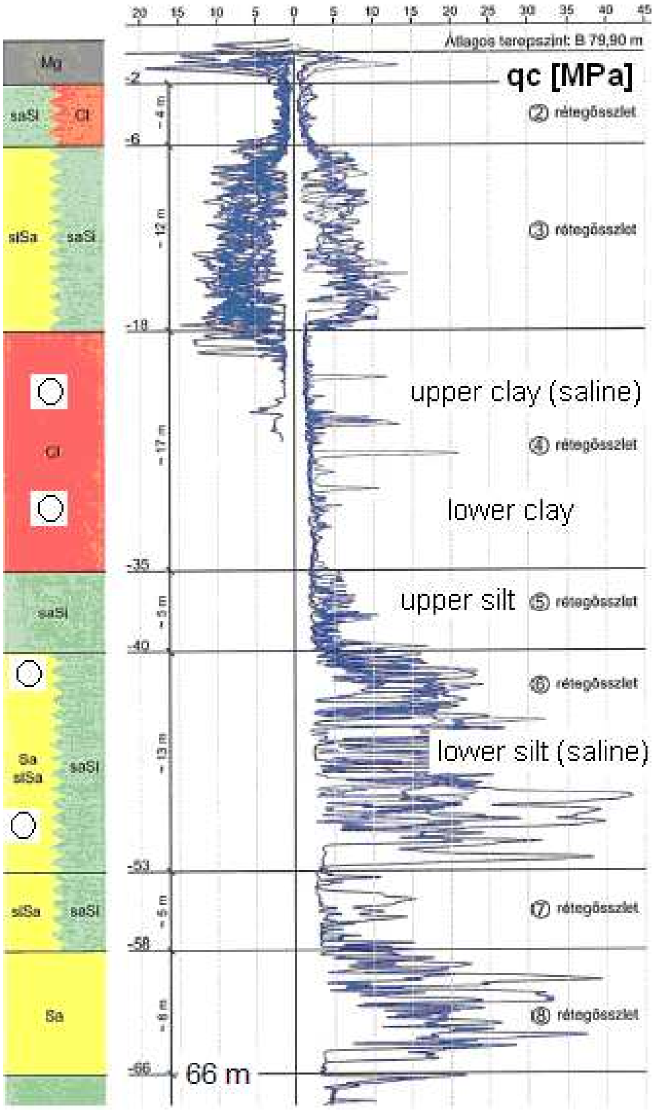


Figure 6. Mean profile indicating location of the dissipation tests.

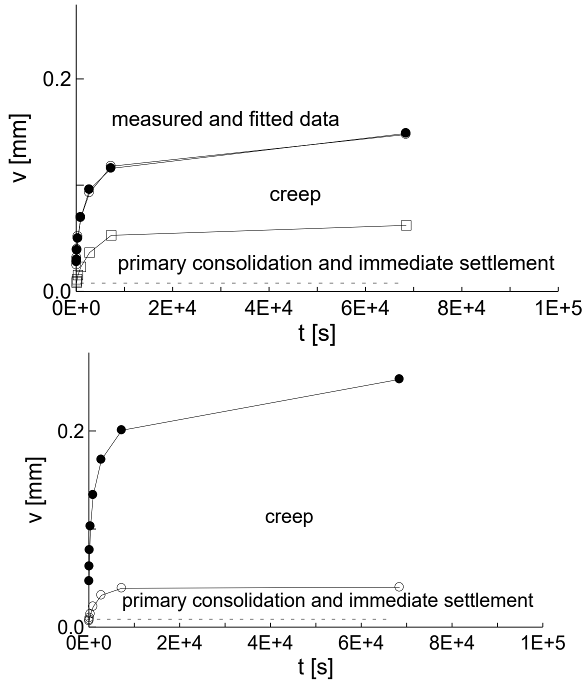


Figure 7. ELI-site, Compression test evaluation for non-saline and saline Szeged soils, upper: Non-saline clay e = 0,74, lower: Saline clay e = 1.06.

Table 3. OTKA; mean of relative shear strength parameters.

Layer Group	s_u [%]	q_c [%l	f_s [%l
4AB	100	100	100
4C	88	67	62
2	80	68	71
5AB	79	91	91
3	58	51	53
5C	32	31	51

3.2 *Analysis a saline spot down to 66 m*

The results are shown in Figs 6 to 10, Tables 4 and 5 which can be summarized as follows.

3.2.1 *Oedometer tests*

The coefficient of consolidation *c* identified from oedometer test data was considerably smaller than the dissipation test values, as expected. By evaluating the stages of the compression tests with the modified Bjerrum (1967) model, the ratio of the primary consolidation settlement was smaller and the creep settlement was larger for the saline soils than for the non-saline soils at the end of the stages (Fig 7). The immediate compression was zero for the sand-silt.

3.2.2 *Measured dissipation test data*

The upward flow was proven by the 100% long, measured dissipation curve data which resulted in various groundwater levels on the same location. An approximate equilibrium groundwater level was also defined for each location, the evaluation of measured data was made for both the approximate equilibrium and the actual non-equilibrium groundwater levels.

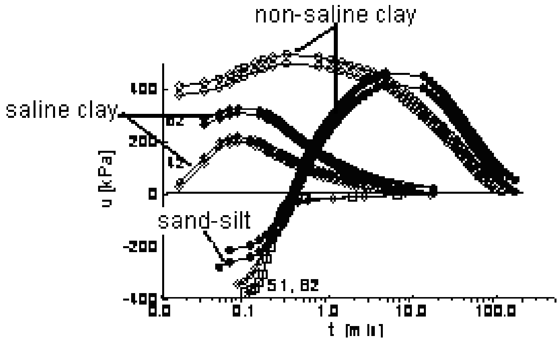


Figure 8. Pore water pressure dissipation curves at ELI-site

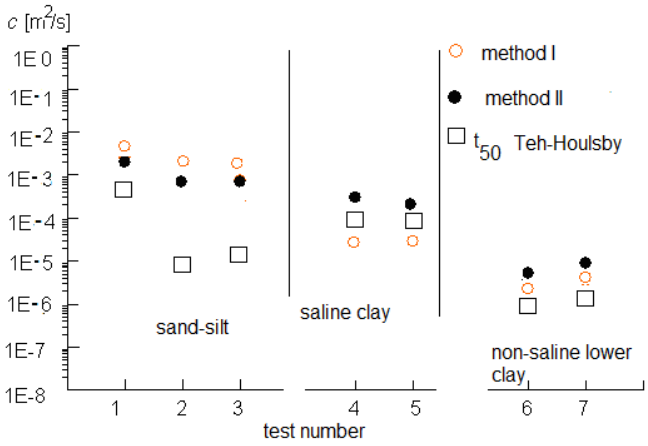


Figure 9. The coefficient of consolidation c values identified from dissipation tests, with correction factors.

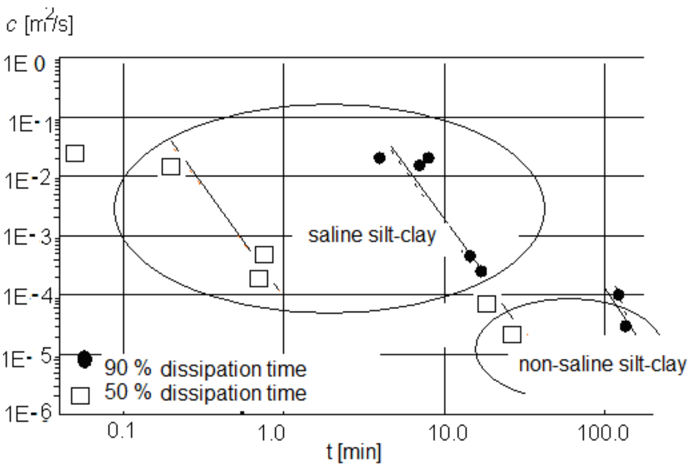


Figure 10. The relation between c and time (with t50 or t90), with correction factors, method I.

Table 4. Dissipation testing time

Site/ depth m	Test id	Test id for Fig 9	t_{50}[min]	t_{90}[min]
52/22	41/42/5	4	0,62	14,5
53/22	61/62/6	5	0,78	22,5
52/30	91/92/8	6	27,73	135
53/30	71/72/9	7	20,05	122
51/50	33/1	1	0,05	4
52/40	51/2	2	1,97	7
53/40	82/3	3	2,37	8,5

Table 5. The identified *c* without correction factors (*c* in m^2/s)

Test id for Fig 9	Compression test	Method III	Method I	Method II
4	5E-8	7,00E-05	6,00E-05	6,00E-04
5	5E-8	5,00E-05	9,00E-05	4,00E-04
6	3E-8	1,00E-06	4,00E-06	7,00E-06
7	3E-8	2,00E-06	1,00E-05	2,00E-05
1		5,00E-04	1,00E-02	8,00E-03
2		1,00E-05	4,00E-03	2,00E-03
3	1E-7	1,00E-05	3,00E-03	3,00E-03

The dissipation curves were non-monotonic in the NC clays (type III and IV), similarly to the case of quick clays in Australia.

The dissipation curves were negative, monotonic in the silty sand (type V). This result can be explained by the small compressibility of the particles and, the nearly drained penetration around the tip. At the shaft the sand layer becomes highly overconsolidated due to the effect of the compression made by the penetrometers tip.

The incompressibility of the sand grains can be linked with the results of the evaluation of the oedometer test: the immediate compression was zero for the sand-silt in each case.

3.2.3 *Dissipation test evaluation*

The u_2 data were evaluated using three methods. The first and second methods were Least Squares fittings of a coupled consolidation model using two initial conditions. The third method was suggested by Teh and Houlsby (1988) as a one-point-fitting-method based on the t_{50} determined according to Sully et al, 1999 being valid for undrained penetration.

The results are shown in Figs 9 to 10, Tables 4 and 5. The method I gave better fit than method II but the solution was not unique (double, larger the c-valued solution was accepted). The solution of the methods I and II needed to be corrected with a factor of 0.49 to 0.86 for the clays and silts (see e.g. in Imre and Bates, 2015).

For clays, the c solution of method II was larger than the one of method I. The solution of method I was close to the one of method III if a correction factor of 0.5 was used.

In silts and sands the *c* values determined by method III seemed to be too large since method is not precise in partly drained case. The *c* values identified from oedometer tests were smaller than the dissipation test values, as expected (Table 4, Bjerrum, 1967).

4 DISCUSSION, CONCLUSION

4.1 *Analyses in large area down to 20 m*

The results of the statistical analyses showed a considerable reduction in the CPT data in area C with respect to areas A and B. The chemical tests showed saline soils at various depth in area C.

The simple CPT dissipation tests results showed dependence on soil plasticity on the one side which can be explained as follows. The simple CPT dissipation tests (and the oedometer relaxation tests) can be modelled in terms of *c* and the relaxation coefficient *s* both determined by soil plasticity.

The simple CPT dissipation tests (and the oedometer relaxation tests) revealed some fabric instability tests in area C.

4.2 *Analysis of a saline spot down to 66 m*

The u_2 dissipation tests were evaluated by methods I and II (slow and fast methods) which were precise, automatic methods and by method III which was a one-point-fitting method valid for undrained penetration. The *c* values identified by these methods were similar in clays and were different in silts-sands possibly due to error of method III in case of partly drained of penetration.

The conventional oedometric compression tests was evaluated with the modified Terzaghi and Bjerrum model (a constant term for the immediate compression was added). The *c* identified from compression tests was considerably smaller than the in situ test values. The salinity caused an increase in the compressibility and creep as follows. The compression tests showed smaller primary consolidation, larger creep settlements for saline-like than non-saline-like soils. The void ratio was larger for the saline-like soils than for the non-saline-like soils. The immediate compression was zero for silts which can be linked with the incompressibility of the grains. This result may explain that the dissipation curves were negative, monotonic in the silty sand (type V).

Different c - t_{50} or t_{90} relations were obtained for saline-like and non-saline-like clays in both the in situ and the laboratory tests, reflecting larger permeability for the saline-like soils.

The presence of upward flow was proven by both the 100% long, measured dissipation curve data which resulted in various groundwater levels on the same location and by the compression test data which resulted under-consolidated state otherwise.

4.3 *Summary*

The effect of the upwards groundwater flow with saline content in spots causes a change in the chemistry of the soils leading to unstable fabric, larger void ratio, less clay content, a reduction in shear strength, an increase in the compressibility and creep. It can be noted that similar results can be found in quick clay deposits (Bates et al, 2012, Bishop, 2009).

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