Effects of storage on 54 mm piston samples of soft sensitive clay

Effets de stockage sur échantillons d'argile molle sensitive dans des pistons 54 mm

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ABSTRACT: Effects of storage on low plasticity sensitive soft clay were studied by means of laboratory tests. The 54 mm fixed piston sampler was used, and the samples were stored in stainless steel tubes. When comparing the preliminary results on fall-cone and triaxial tests performed shortly after sampling and the following months, it is observed that there is a decrease in the undisturbed shear strength. In addition, storage reduces the measured preconsolidation pressure together with the constrained modulus. It is therefore recommended to carry out the triaxial and oedometer testing as soon as possible after the sampling. However, determination of the remoulded strength, water content and Atterberg limits may be delayed, assuming that the sample is properly sealed in the tube.

RÉSUMÉ : Les effets de stockage sur une argile molle sensitive de faible plasticité ont été étudiés au moyen d'essais au laboratoire. L'échantillonneur à piston fixe de diamètre 54mm a été utilisé, et les échantillons conservés dans des tubes en acier inoxydable. Lors de la comparaison des résultats préliminaires du cône à chute libre et des essais triaxiaux effectués juste après l'échantillonnage et les mois suivants, il a été observé une diminution de la résistance au cisaillement non drainée. De plus, le stockage réduit la pression de préconsolidation mesurée ainsi que le module de contraintes. Il est par conséquent recommandé d'effectuer l'essai triaxial et l'essai œdométrique le plus tôt possible après l'échantillonnage. Cependant la détermination de la résistance remaniée, la teneur en eau et les limites d'Atterberg, peut être retardée en assumant que l'échantillon est proprement scellé dans le tube.

KEYWORDS: sensitive clay, disturbance, storage, piston sample

1 INTRODUCTION

Engineering characterisation of sensitive clays is a challenging task and it is important to establish methods of measuring the proper material properties. Sampling and testing of sensitive clays without the influence of sample quality has been studied by many researchers, e.g. Hvorslev (1949), Berre et al. (1969), Hight et al. (1992), Lunne et al. (1997a), (2006), Ladd and DeGroot (2003) and Long et al. (2009).

The type of sampler is the main contributor to the disturbance of a soil sample. The disturbance is minimal for large diameter samples, such as 160-250 mm block samples (Lefebvre and Poulin 1979, La Rochelle et al. 1986, Emdal et al. 2016), but it may be critical for small diameter tube and piston samples. In Norwegian sensitive clays even large diameter samples, like the 95 mm fixed piston sampler, may exhibit poor quality (Lacasse et al. 1985).

After sampling, a piston soil sample may experience an additional disturbance during handling, transport, storage and preparation prior to testing. Disturbance may be caused by several factors, including the following:

- Inadequate sealing (e.g. Hvorslev 1949)
- Vibration and shock loads (e.g. Kallstenius 1963)
- Stress relief and pore pressure equalisation (e.g. Ladd and Lambe 1963, Schjetne 1971, Amundsen et al. 2016)
  - Migration of water from one type of soil to another
  - Migration of water at the periphery
  - Swelling
- Temperature (Kallstenius 1963, Sallfors and Tidfors 1989)
- Chemical changes (e.g. Bjerrum and Rosenqvist 1956, Lessard and Mitchell 1985)

In geotechnical practice, the storage of samples is common; the samples may be stored for weeks or for months before testing. The main objectives of this paper are to examine and evaluate the influence of storage on the sample quality and various material parameters.

This paper presents some preliminary results of an ongoing study on a soft sensitive clay. The samples were retrieved with the most common sampler in Norway, the 54 mm fixed piston sampler. Thereafter, the samples were stored for up to five months in steel tubes, which were used during sampling, as recommended by Ladd and DeGroot (2003). The obtained results are compared to a reference block sample (Amundsen et al. 2016) and similar studies in the literature. Finally, the effects of storage on the material parameters are discussed and some recommendations are proposed.

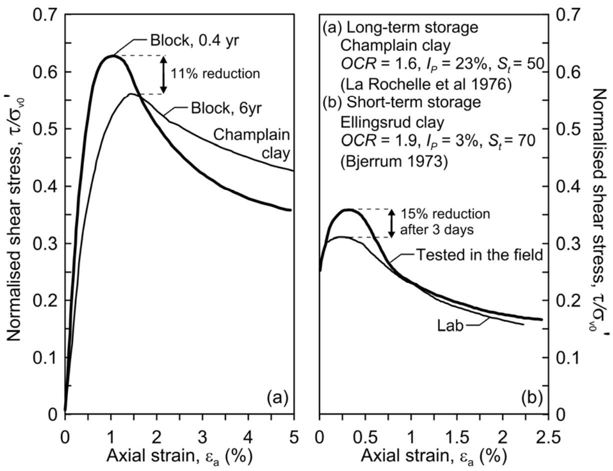

Figure 1. Illustration of the reduction in peak undrained shear strength in active triaxial tests due to (a) the long-term storage and (b) the short-term storage. OCR – overconsolidation ratio; I_p – plasticity index; S_t – sensitivity, τ – shear stress, σ'_{v0} – in situ effective vertical stress.

2 STORAGE OF NATURAL SOIL SAMPLES

Significant changes in sensitivity, plasticity, strength, preconsolidation pressure and pore water chemistry in natural sensitive soft soil samples during a various storage periods have been reported in the literature.

Bozozuk (1971) conducted a series of oedometer tests on block samples of sensitive clay (I_P=12%) which were stored for over a year. He noticed that the preconsolidation pressure decreased with 4.9% during that time. La Rochelle et al. (1976) conducted a similar study, but did not observe any changes. However, they registered a decrease in peak undrained shear strength of the order 10 to 15% (I_P=23%) and 13 to 21%

(I_P=11%) after up to 6 years in storage, see Figure 1a. Short-term storage was studied by Bjerrum (1973). He observed that already after three days the peak shear strength reduced with 15%, illustrated in Figure 1b.

Lessard and Mitchell (1985) studied the physicochemical properties of a sensitive clay (I_P=6%) and concluded that samples stored in the laboratory showed signs of aging, such as an increase of remoulded strength and liquid limit, as well as a decrease in sensitivity, liquid index and pH. Similar observations were done on a Swedish soft clay (Henriksson and Carlsen 1994). To avoid these signs of weathering La Rochelle et al. (1986) presented a technique for sealing and storing clay samples for long periods. The results showed that parameters such as Atterberg limits and the pH values remained constant in the tested clays (I_P=27% and I_P=6%) during a three-year period.

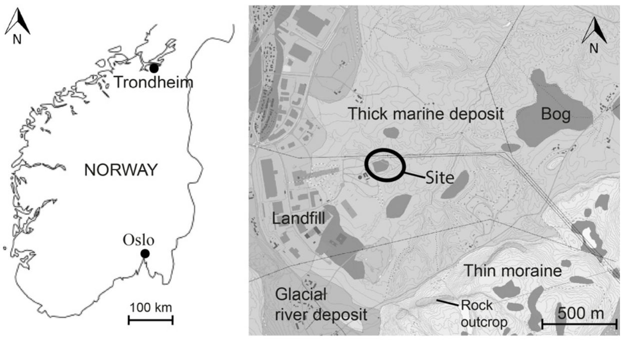

Figure 2. Location of the Tiller site, about 12 km from Trondheim (map: www. ngu.no).

3 TEST SITE

The Geotechnical Division at Norwegian University of Science and Technology (NTNU) has established a research site at Tiller, about 12 km from Trondheim, shown in Figure 2. The area near the site is covered with a thick marine deposit, which is characterised by erosion (Reite et al. 1982).

The marked area in Figure 2, enclosing about 0.01 km^2, has been heavily investigated by NTNU over the years (e.g. Gylland et al. 2013), the geotechnical profile is shown in Figure 3. The upper 4 m is a weathered clay, between 4 and 8 m there is a non-sensitive clay layer and from 8 m until at least 15 m the clay is highly sensitive with remoulded strength of 0.1 kPa, plasticity index (I_P) of about 8% and overconsolidation ratio (OCR) of 1.7. The clay deposit is dominated by many thin (2-15 mm) shifting layers of clay. The clay content in the layers varies between 42% and 58% (Amundsen et al. 2016).

4 GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations at the site, carried by NTNU, included a total of three piezometers, four RCPTU soundings and 17 boreholes with 54 mm piston sampling and eight boreholes with block samples. The laboratory testing at NTNU consisted of index tests, Constant Rate of Strain (CRS) oedometer and Consolidated Anisotropically Undrained triaxial Compression (CAUC) tests. The study included 44 triaxial tests and 61 oedometer tests, based on 46 piston samples. See the paper of Amundsen and Thakur (2017) for more details.

The samples were stored in stainless tubes. The top and bottom of the tubes were sealed with a rubber plug and rubber cups. The samples were transported about 12 km to the NTNU laboratory, where they were stored in a humid room with a constant temperature of 4^{o}C for a period up to five months.

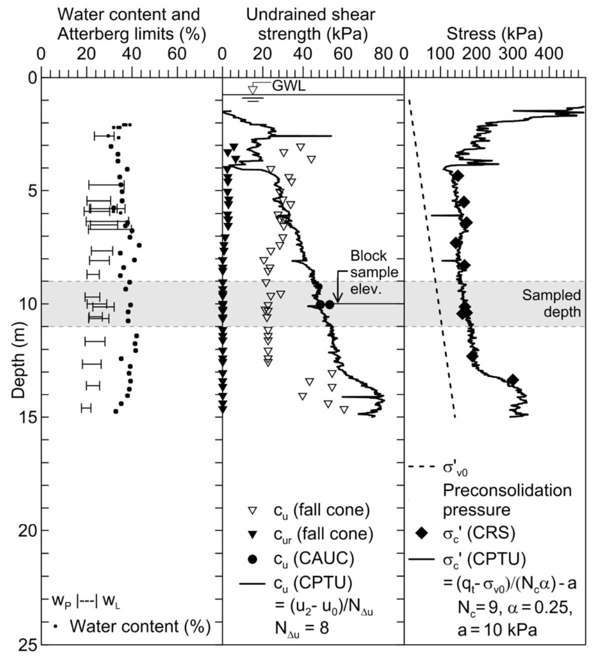

Figure 3. Geotechnical profile of the Tiller site (after Amundsen et al. 2016). CPTU correlations of the undrained shear strength and preconsolidation pressure are based on work of Lunne et al. (1997b) and Sandven (1990).

5 RESULTS

The results presented in this paper are from sensitive clay samples from 9.0 to 10.8 m. Various material properties were measured during the storage of the samples. Figure 4a shows how the water content (w) of the samples was relatively unchanged, 37-42%, compared to the natural variation at day zero.

The undrained shear strength (c_u) and remoulded strength (c_r) were determined by means of the Swedish fall-cone test, and are presented in Figure 4b and 4c.

Figures 5 and 6 show the results of four sets of oedometer and triaxial tests. One of the sets are from a block sample (test no. 1) and the rest are from 54mm piston samples (tests no. 2-4). The reference samples (tests no. 1-2) were tested shortly after sampling, one sample was stored for a month (test no. 3) and one for five months (test no. 4).

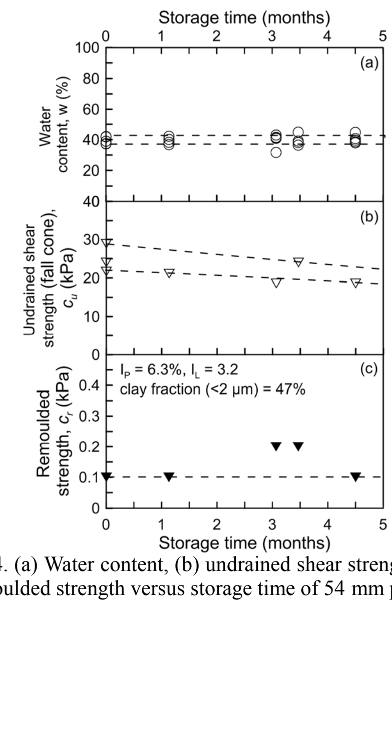

Figure 4. (a) Water content, (b) undrained shear strength (fall-cone) and (c) remoulded strength versus storage time of 54 mm piston samples.

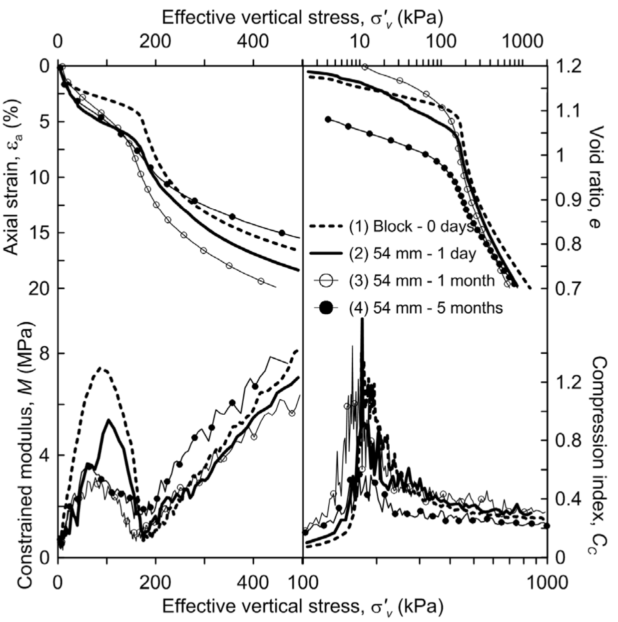

Figure 5. Results from CRS oedometer tests from one block sample and three 54 mm piston samples from Tiller clay, which were stored for up to five months.

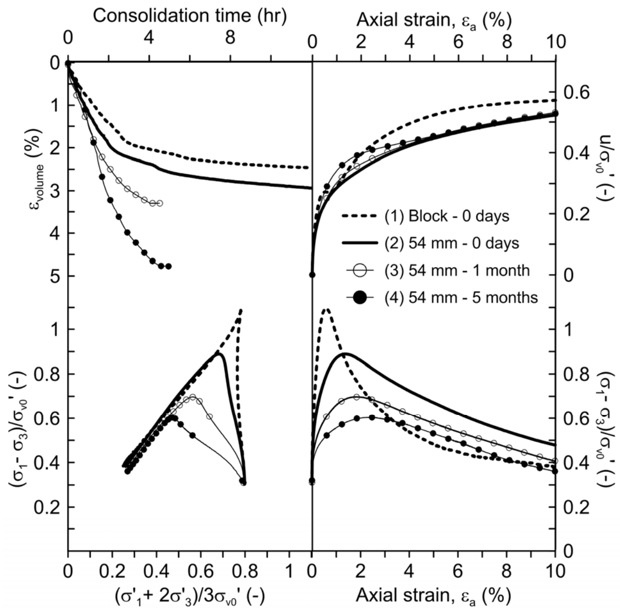

Figure 6. Results from CAUC oedometer tests from one block sample and three 54 mm piston samples from Tiller clay, which were stored from up to five months.

Table 1. Results from CRS tests on Tiller clay conducted with a strain rate of 1.0%/hr.

CRS no.	Storage time	w (%)	I_p (%)	σ'_c (kPa)	M_0/M_L (-)	ε_{v0} (%)	$\Delta e/e_0$ (-)
(1)	0 days	41.9	9.4	167	8.7	3.0	0.055
(2)	1 day	42.3	6.5	167	5.0	5.1	0.094
(3)	1 month	43.3	4.7	150	3.4	4.3	0.078
(4)	5 months	38.7	5.7	147	2.0	4.7	0.090

Table 2. Results from CAUC tests on Tiller clay conducted with a shear strain rate of 1.5%/hr.

CAUC no.	Storage time	w (%)	I_p (%)	c_u/σ'_{v0} (-)	ε_f (%)	ε_{v0} (%)	$\Delta e/e_0$ (-)
(1)	0 days	40.0	9.0	0.55	0.59	2.5	0.047
(2)	0 days	40.7	6.0	0.44	1.41	3.3	0.061
(3)	1 month	40.5	4.7	0.35	1.83	3.3	0.062
(4)	5 months	40.9	5.7	0.30	2.57	4.8	0.089

The oedometer specimens were trimmed to a cross sectional area of 20 cm^2 and a height of 2 cm. The triaxial specimens were trimmed to a diameter of 54 mm and a height of 10 cm. Tables 1 and 2 summarise the results from CRS and CAUC tests, which are shown in Figures 5 and 6.

6 DISCUSSION

As expected, the results from the block sample are superior compared to the 54 mm piston samples. The difference is especially large in the normalized peak undrained shear strength; it decreases with 20% for samples tested shortly after sampling. The preconsolidation pressure remains constant.

During the storage period of five months, the water content, plasticity index, liquidity index and remoulded strength values seem to be unchanged. The scatter in Figure 4 is due to the natural variation for the Tiller clay. It was also previously observed by Lessard and Mitchell (1985) that only unsealed samples show large signs of aging at that point. Hence, the samples were sufficiently sealed.

6 .1 *Preconsolidation pressure and stiffness*

The preconsolidation pressure (σ'_c) reduces with 10.2% after one month in storage. However, further storage does not lead to a significant additional decrease, with the reduction totalling at 12% after five months. Compared to the stiff sensitive clay Bozozuk (1971) tested, the σ'_c of the lightly overconsolidated (OCR=1.7) sensitive Tiller clay reduces much faster with storage.

The constrained modulus (M) in oedometer tests, see Figure 5, decreases with 42% after one month of storage. After five months, it increases slightly, however the stress-strain curve indicates a poor sample quality.

6 .2 *Undrained shear strength*

The undrained shear strength (c_u) from the fall-cone tests decreases with storage with an average of about 18%. However, the remoulded strength remains constant. This is consistent with no changes in the water content and Atterberg limits during storage.

The normalised c_u from the CAUC tests decreases with 20.5% during the first month of storage. After an additional 4 months, the strength decrease had amounted to 31.8%. However, all samples exhibit a strain softening regardless of the age. La Rochelle et al. (1976) observed a similar behaviour in Canadian sensitive clays.

6 .3 *Sample quality*

Results from the block sample are of the highest sample quality compared to piston samples, based on the volumetric strain (ε_{v0}, Andresen and Kolstad 1979), normalised void ratio ($\Delta e/e_0$, Lunne et al. 1997a) and the constrained modulus ratio (M_0/M_L, Karlsrud and Hernandez-Martinez 2013) criteria.

The quality of the CRS tests decreases with storage, according to the M_0/M_L-criterion, together with the σ'_c. There is however, no clear trend with the ε_{v0} and $\Delta e/e_0$ criteria see Table 1.

The sample quality of the CAUC tests decreases with storage due to the increase in volumetric strain during storage, see

Table 2. In addition, the strain at failure increases from 1.4% to 2.6% during five months, which indicates a deterioration of the sample quality with storage.

The results indicate a general decrease in sample quality, followed by a decrease in strength and consolidation parameters. The water content and Atterberg limits were within the natural variation. However, the stress relief and the pore pressure equalisation, which lead to water migration and swelling, presumably have happened. This is especially could have happened between the thin clay layers, which the Tiller clay deposit is dominated by. In addition, after the sampling, the core of the sample is surrounded by the remoulded clay. The remoulded clay contains free water, and so swelling of the core and reconsolidation of the remoulded clay at the periphery may have occurred.

7 CONCLUDING REMARKS

In this paper, an attempt was made to study the effects of storage of a low plasticity sensitive soft clay. In summary, the following results were found:

- The preconsolidation pressure decreased with 10.2% after the first months of storage and 12% after five months.
- The constrained modulus decreased with 42% after first month of storage.
- The undrained shear strength (fall-cone) decreased with 17.7% on average during the five months of storage.
- The remoulded strength remained constant.
- The peak undrained shear strength in active triaxial tests decreased with 20.5% during the first month, becoming 31.8% after five months in storage.

The concluding remarks to be drawn from this study is that sensitive clay samples stored in 54 mm stainless steel tubes should be opened and tested during the first month after the sampling if the undisturbed strength and consolidation parameters need to be determined. The samples may be stored in sealed tubes for a longer period if only parameters such as remoulded strength, water content and Atterberg limits need to be determined.

The authors would like to emphasize that the effects of storage are visible in samples of sensitive soft clay of good quality. In disturbed samples, the effect of storage may not be seen. In high quality block samples, stress relief could be the main effect of short-term storage (Amundsen et al. 2016). Long-term storage may instead be dominated by the weathering processes and chemical changes. The effects of storage on sample quality is the topic of the current research at NTNU.

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