On engineering characterisation of a low plastic sensitive soft clay

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ABSTRACT
In central Norway, the soft clays can be extremely sensitive to disturbance during sampling and preparation for laboratory testing. In this paper a low plastic sensitive soft clay from Klett is presented. It is challenging to retrieve samples from the site and good quality samples are rare.
For this study, two different laboratories participated in testing the samples taken with a downsized (160 mm) Sherbrooke block sampler. The block samples were opened in Lab. 1 and transported to the other laboratory. The observations indicate a reduction in measured preconsolidation pressure and undrained shear strength in the time delayed tests carried out at Lab. 2. The observed differences in the results from the two laboratories may be explained by the transport of samples, stress release due to delayed testing, handling of samples and dissimilarities in laboratory procedures.

RÉSUMÉ
Dans le centre de la Norvège, les argiles molles peuvent être extrêmement sensibles aux perturbations durant l'échantillonnage et la préparation pour des essais de laboratoire. Dans cet article, une argile molle sensible à faible plasticité provenant de Klett est présentée. Il est difficile de récupérer des échantillons sur le site, et ceux de bonne qualité sont rares.
Pour cette étude, deux laboratoires différents ont participé aux essais sur les échantillons pris à l'aide d'un échantillonneur à bloc Sherbrooke de taille réduite (160 mm). Les blocs d'échantillons ont été ouverts au laboratoire 1 et ont été transportés dans l'autre laboratoire. Les observations montrent une réduction de la pression de préconsolidation mesurée et de la résistance au cisaillement non drainée dans les essais retardés effectués au laboratoire 2. Les différences observées dans les résultats entre les deux laboratoires peuvent être expliquées par le transport des échantillons, les pertes en contraintes dues aux essais retardés, la manipulation des échantillons et les différences de procédure entre les laboratoires.

1 INTRODUCTION

In the coastal regions of Eastern Canada, Norway, Sweden and Japan, to name a few, sensitive soft clays are encountered. Sampling of sensitive soft clays is challenging, often resulting in samples of low quality. This issue has gained much attention for many years e.g., Berre et al. (1969), La Rochelle and Lefebvre (1970), Bjerrum (1973), Leroueil et al. (1979), Nagaraj et al. (1990), (2003), Lunne et al. (1997), Ladd and DeGroot (2003), Leroueil and Hight (2003) and Karlsrud and Hernandez-Martinez (2013).

Literature confirms that low plastic sensitive soft clays such as Norwegian sensitive soft clays are prone to sample disturbance - especially when sampled using tube samplers. On the contrary, block sampling in such materials is considered a relatively gentle approach, but is still challenging due to, for instance, the stress release when the recovered sample is withdrawn from a great depth e.g., Hvorslev (1949), Skempton and Sowa (1963), Ladd and Lambe (1963), Leroueil and Vaughan (1990) and Hight et al. (1992). This effect may change the geotechnical properties measured by the laboratory tests. On top of all this, poor handling, testing procedures and transportation also complicate the issue. To illustrate these aspects this paper presents some laboratory test results on block (160 mm diameter) and tube samples (75 mm diameter) on a low plastic sensitive soft clay. In doing so, two independent laboratories were involved in the testing of the freshly taken block samples. The time difference between the tests at the laboratories were from 0.4 to 6.5 hours. This paper presents an assessment, along with a detailed discussion, regarding the possible sources of disturbance behind the triaxial and oedometer test results, as they were significantly different from each other. Finally, this paper makes an attempt to highlight the significance of careful sampling and handling of low plastic sensitive soft clay.

2 ON SAMPLE DISTURBANCE

Sample disturbance causes differences between laboratory-measured parameters and the in-situ conditions in the ground. The origin and effect of sample disturbance has been discussed by Hvorslev (1949), Bjerrum (1954), Skempton and Sowa (1963), Ladd and Lambe (1963) and Noorany and Seed (1965). The disturbance may be caused by several factors, including the change when a recovered sample is withdrawn from a great depth and transferred to the laboratory. These changes may include:

a) Disturbance of the soil due to sampling, during which the soil is subjected to loads following a compression-extension-compression cycle (Baligh 1985).
b) Transportation, storage, trimming and handling during preparation for testing.
c) Changes in effective stresses caused by removal of in situ stresses during sampling.
d) Development of negative pore pressure followed by swelling.

Effects of sample disturbance have been observed by many researchers, e. g., Leroueil et al. (1979), Lacasse et al. (1985) and Hight and Leroueil (2003). It can cause, among other things, a reduction of clay stiffness, peak shear strength, preconsolidation pressure and compression index.

2.1 Stress release

Changes in total and effective stresses during sampling is unavoidable and the strength and deformation properties of the soil may be affected by this. The effect was originally addressed by Skempton and Sowa (1963) on a high plastic clay which had a sensitivity of two. It was found that there was a small difference between the undrained strengths. Later on, Noorany and Seed (1965) showed that the difference can be significant in the case of sensitive clays. In addition, Adams and Radhakrishna (1971) observed significant loss of strength due to sampling and the loss of effective stresses (suction) with slight swelling.

To reduce the effects of stress release and thereby a possible swelling Bjerrum (1973) brought a triaxial cell into the field and trimmed, mounted and consolidated a clay specimen at the site next to the drilling rig. A second specimen was tested in the laboratory 3 days after sampling. Bjerrum (1973) concluded that the internal swelling which had occurred had reduced the undrained shear strength by 15 %.

The release of stress may lead to a breakdown of the bonds between particles and thus to a general decrease in strength of the material. Also Locat and Lefebvre (1985) showed that it is impossible to reproduce the effect of the lost microstructure in laboratory samples.

The response of artificially consolidated clays, like kaolin and illite, to sampling stress release was studied by Kirkpatrick and Khan (1984). The tests on both clays showed that when compared with the in situ soil the samples suffered considerable loss in strength, increase in failure strain and produced appreciably different effective stress paths to failure. The loss of undrained shear strength was found to be about 34% of the in situ strength after 5-6 hours for illite, and 47% for kaolin. The losses increase with time, reaching about 50% and 72% respectively for the two clays after 50 days storage.

2.2 Long-term storage

La Rochelle et al. (1976) presented a study of the influence of storage time on the strength and consolidation characteristics of sensitive medium to strongly-cemented clays from eastern Canada.

During long-term storage the clays suffered a reduction in undrained shear strength in the order of 10 to 20%. However, the preconsolidation pressure appeared unchanged by the storage.

A study by Arman and McManis (1976) on clays from Louisiana showed that an extended storage reduced the preconsolidation pressure by about 30%, with a significant decrease in the undrained shear strength after ten days. Bozozuk (1971) observed only a 4.8% reduction of the preconsolidation pressure in a similar study on marine clay from Ottawa.

Lessard and Mitchell (1985) studied the physicochemical properties of Champlain clays 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.

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 during storage.

3 ASSESSMENT OF SAMPLE QUALITY

Sample quality assessment is essential in order to assign a confidence level to laboratory test results regardless of the sampling methods and types, depth of extraction or the soil type. Okumara (1971) pointed out that a method of sample quality assessment should be simple and accurately determine the deviations from perfectly undisturbed conditions, as caused by disturbance.

Assessments of sample quality or methods for correcting values derived from poor quality samples have been proposed by many researchers, e.g., Nagaraj et al. (1990); Onitsuka and Hong (1995) and Shogaki (1996). However, these methods are strongly dependent on local differences in geotechnical properties.

Norwegian Geotechnical Institute (NGI) carried out sampling on Norwegian soft medium plastic clay (I_P=14-20%), called Lierstranda clay. Lunne et al. (1997) used the results to develop a new criterion for evaluation of sample disturbance. Laboratory analysis from Lierstranda site are used in this paper to illustrate the quality assessment criteria that were proposed by Lunne et al. (1997) and by Karlsrud and Hernandez-Martinez (2013).

3.1 Volumetric strain, ε_{v0}

Andresen and Kolstad (1979) described a quality assessment criterion that NGI followed for soft clays. The criterion is based on the relative volume decrease of the test specimen during consolidation, called volumetric strain (ε_{v0}). The criterion is shown in Table 1.

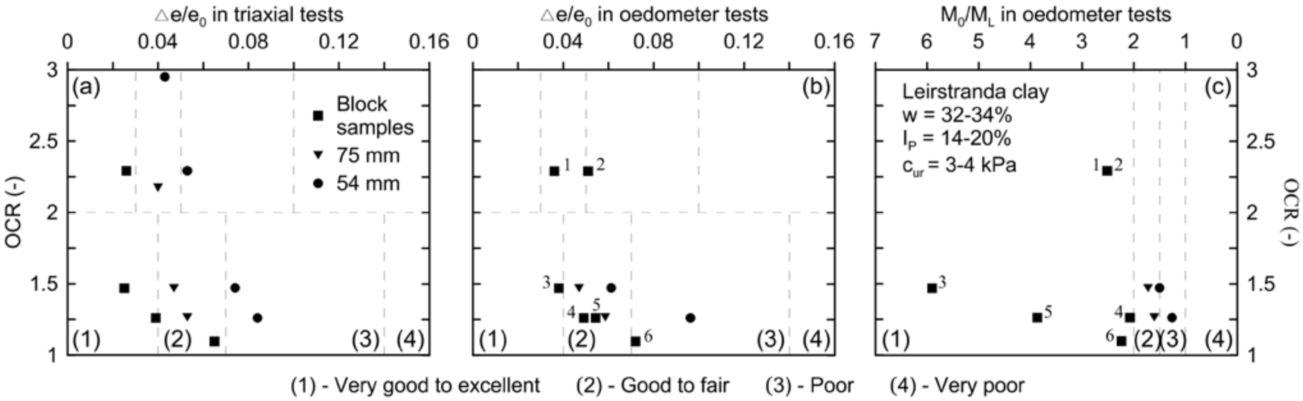

Figure 1. Assessment of sample quality based on triaxial and oedometer tests on Lierstranda clay, after Lunne et al. (1997) and (Karlsrud and Hernandez-Martinez 2013)

3.2 Change in the void ratio, $\Delta e/e_0$

Based on volume change during reconsolidation, Lunne et al. (1997) modified the ε_{v0}-criterion to a ratio of the change in void ratio (Δe) and the initial void ratio (e_0) at the start of reconsolidation with the assumption that the specimen is fully saturated. The criterion shown in Table 1 take OCR into account.

Table 1. Sample quality assessed on basis of $\Delta e/e_0$ (Lunne et al. 1997) and M_0/M_L (Karlsrud and Hernandez-Martinez 2013) values from oedometer tests.

Sample quality	Vol. strain ε_{v0} (%)	Ratio $\Delta e/e_0$ for OCR 1-2	Ratio $\Delta e/e_0$ for OCR 2-4	Ratio M_0/M_L
1 - Very good to excellent	<1	<0.04	<0.03	>2
2 - Good to fair	1-4	0.04-0.07	0.03-0.05	1.5-2
3 - Poor	4-10	0.07-0.14	0.05-0.10	1-1.5
4 - Very poor	>10	>0.14	>0.10	<1

Lunne et al. (1997) based the $\Delta e/e_0$-criterion on laboratory tests on block samples and parallel tube samples from Lierstranda. Figure 1a shows the triaxial tests that were used. Three of four tests on block samples were categorised as "very good to excellent" quality, all of the 75 mm tube samples were of "good to fair" quality and three of four 54 mm samples were of "poor" quality.

The $\Delta e/e_0$-criterion is also used for quality assessment of oedometer tests. Oedometer tests shown in figure 1b were carried out on the same block and tube samples as triaxial tests mentioned previously. There is no consensus between the criteria and oedometer tests, in contrast to triaxial tests.

Norwegian Geotechnical Society (NGF 2013) recommends the $\Delta e/e_0$-criterion for assessment of sample quality for oedometer and triaxial tests.

3.3 The stiffness ratio

Based on the shape of the oedometer curve, Karlsrud and Hernandez-Martinez (2013) have proposed a new criterion, see Table 1. It uses the oedometer stiffness ratio M_0/M_L, where M_0 ($M = d\sigma'/d\varepsilon$, Janbu (1963)) is the maximum constrained modulus in the overconsolidated stress range and M_L is the minimum constrained modulus after preconsolidation stress, shown in Figure 2.

Figure 1c shows the oedometer tests on Lierstranda clay assessed with the M_0/M_L-criterion. According to the criterion, all of the block samples are of "very good to excellent" quality, all of the 75 mm tube samples are of "good" quality and all 54 mm tube samples are of "poor" quality.

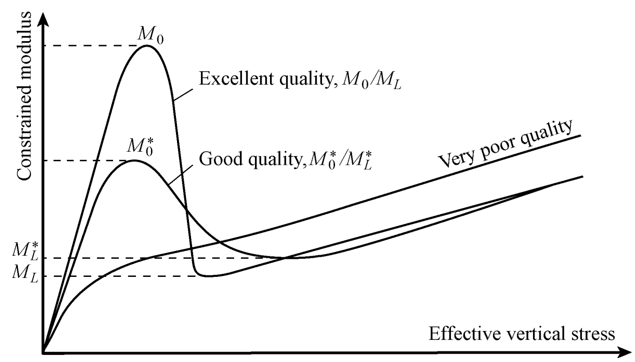

Figure 2. Definition of constrained modulus relationships from oedometer tests (Amundsen et al. 2015)

4 LABORATORY TESTING

Norwegian Public Road Administration (NPRA) initiated an extensive field investigation to the south of Trondheim, at the Klett site, as part of a proposed development of a new highway. The program for laboratory tests was designed to evaluate the importance of sample disturbance, transport and handling of samples on the soil parameters. Marine low plastic sensitive soft clay from Klett exhibits a fabric of silt layers evenly distributed in the soil profile. A down sized Sherbrooke (160 mm) block sampler developed by Norwegian University of Science and Technology (NTNU) were used to sample this challenging material.

Two different laboratories, Lab 1 and Lab 2, participated in the testing of the block samples. The samples were opened in Lab 1, divided into smaller pieces which were wrapped in plastic film. The samples for Lab 2 were transported on a rigid plate and tested on the same day. All of the specimens were trimmed right before testing. The difference between testing in the laboratories was between 0.4 to 4.5 hours, listed in Table 2. The laboratory tests include:

a) Constant Rate of Strain (CRS) oedometer tests with strain rate of 0.7 %/hr
b) Consolidated Anisotropically (*K_0*'=0.8) Undrained Compression tests (CAUC) on specimens trimmed to 54 mm in diameter, with 1.2 %/hr rate of shear strain

Table 2. The time of testing after opening of block samples in the laboratories

	Test No.	Lab	Block depth (m)	Time after opening of block (hr)
Oedometer tests	1	Lab 1	10	0.4
	2	Lab 2	15	0.7
	3	Lab 1	10	2.0
	4	Lab 2	15	6.5
Triaxial tests	1	Lab 1	10	1.0
	2	Lab 2	15	2.0
	3	Lab 1	10	1.0
	4	Lab 2	15	5.0

Table 3. Material properties of quick clay from Klett

Characteristics	
Depth interval, m	10-19
Ground water level, m	1
Water content w, %	32-36
Unit weight, γ, kN/m^3	19.1
Plasticity index I_P, %	3.6-5.1
Liquidity index I_L	4.0-4.2
Void ratio e_o	0.88-0.93
Porosity n, %	46-48
Particles <2 μm, %	27-36
Particles 2-50 μm, %	64-73
Remoulded undrained shear strength, c_{ur}, kPa	0.1-0.2
Sensitivity S_t	120-304
Overconsolidation ratio, OCR	1.2-1.4
Storage time after sampling, days	≤3

The physical properties of the Klett clay measured at the elevations where the block samples were taken are given in Table 3. The soil profile is shown in Figure 3 with parameters obtained from block samples. The salt content of the pore water is very low, about 1 g/L.

The variations in water content and undrained shear strength may reflect geological differences in the specimens, such as silt layers.

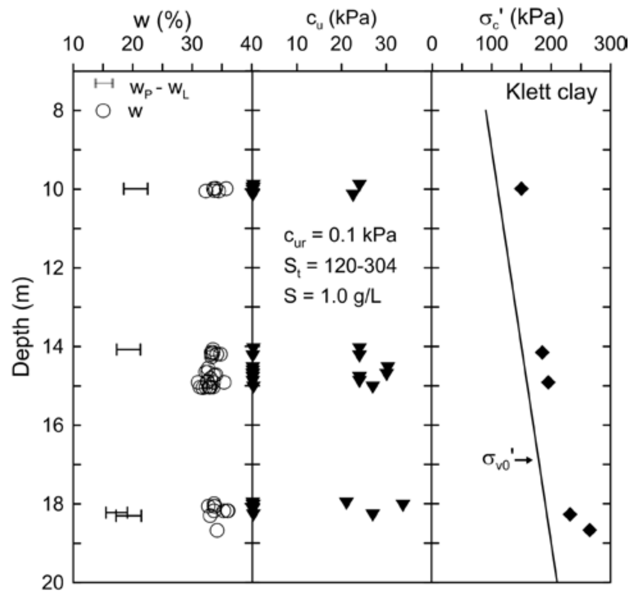

Figure 3. Soil profile of Klett clay

4.1 Oedometer test results

Figures 4 and 5 show CRS results carried out according to Table 2. The tested samples were cut into an oedometer ring with a diameter of 50 mm and height of 20 mm.

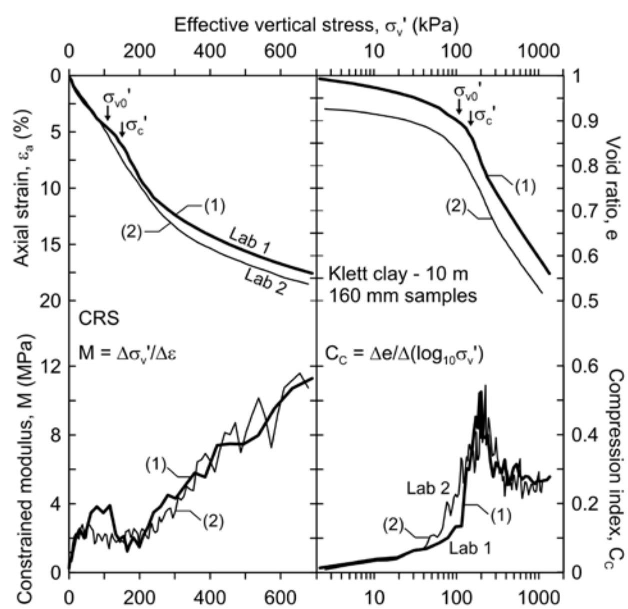

Figure 4. Oedometer tests on block sample, Klett 10 m

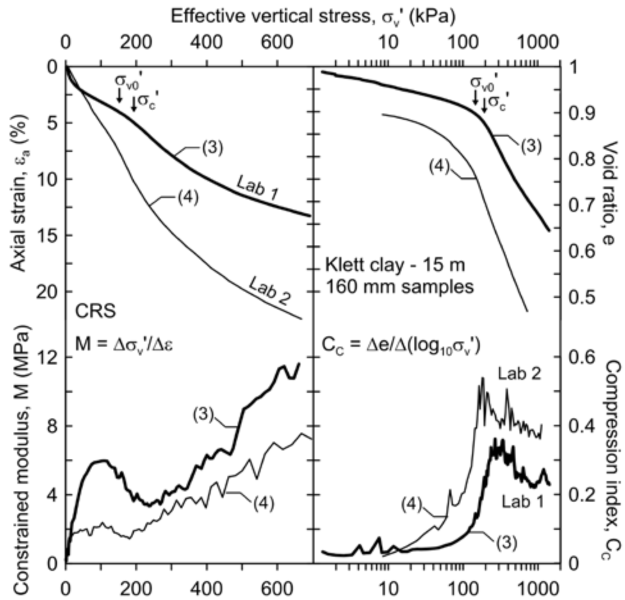

Figure 5. Oedometer tests on block sample, Klett 15 m

Table 4. Results of CRS and CAUC tests on Klett clay

CRS test No.	1	2	3	4
Depth (m)	10	10	15	15
w (%)	35.7	33.7	35.4	32.6
σ_c' (kPa)	150	93	190	150
Test interpretation:				
m	17.2	19.8	20.5	12.1
σ_{ref}' (kPa)	23.6	90.5	95.4	52.6
M_0 (MPa)	3.50	2.58	6.00	2.20
M_L (MPa)	1.23	1.84	3.29	1.45
κ	0.02	0.02	0.02	0.03
λ	0.11	0.11	0.10	0.17
ε_{v0} at σ_{v0}' (%)	4.77	5.62	4.24	8.31
$\Delta e/e_0$	0.098	0.118	0.086	0.176
M_0/M_L	2.85	1.40	1.82	1.52
CAUC test No.	**1**	**2**	**3**	**4**
Depth (m)	10	10	15	15
w (%)	33.6	34.0	31.0	32.6
σ_{v0}' (kPa)	109.9	109.9	159.1	159.1
σ_{ac}' (kPa)	110.2	107.4	162.1	157.8
Test interpretation:				
φ (°)	26.9	27.8	27.9	26.4
D	-0.26	-0.38	-0.23	-0.40
c_u / σ_{ac}'	0.44	0.34	0.42	0.34
ε_f (%)	1.26	0.85	1.14	0.68
u_f / σ_{ac}'	0.40	0.39	0.34	0.37
ε_{v0} at σ_{ac}' (%)	3.28	4.35	4.78	4.22
$\Delta e/e_0$	0.069	0.091	0.104	0.089

4.2 Triaxial test results

Lab 1 and Lab 2 carried out one triaxial test each on both block samples. The consolidation procedures were similar in both laboratories, however there are small dissimilarities, such as how the consolidation stress is applied and the duration and value of the back pressure. The results for blocks from 10 and 15 meters are shown in Figure 6 and 7. Lab 1 tested specimen no. 1 and 3 and Lab 2 tested no. 2 and 4 with a time delay which is listed in Table 2. All stresses are normalised with axial consolidation pressure (σ_{ac}'), see, Table 4.

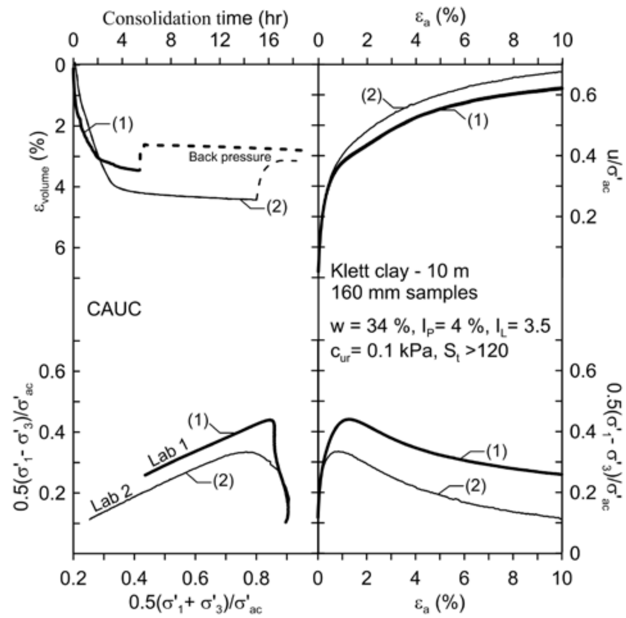

Figure 6. Triaxial tests on block sample, Klett 10 m

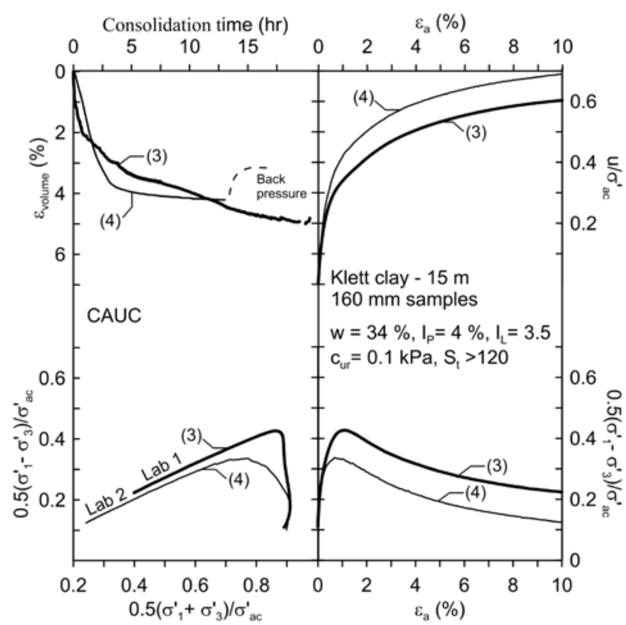

Figure 7. Triaxial tests on block sample, Klett 15 m

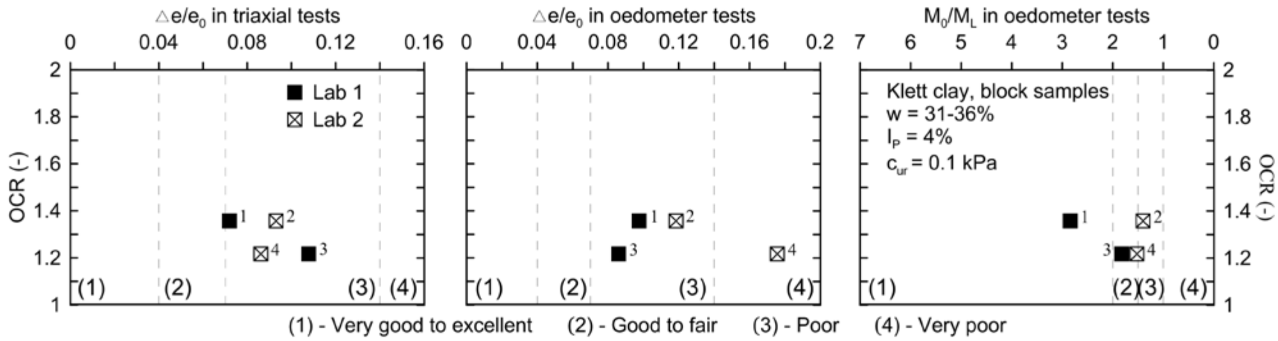

Figure 8. Assessment of sample quality based on triaxial and oedometer tests on Klett clay

5 DISCUSSION

5.1 Sample quality

The results presented herein indicate that the downsized (160 mm diameter) Sherbrooke block sampler provides mostly good to fair samples on a low plastic sensitive soft clay from Klett. It is interesting to look at sample quality criteria in view of this.

The sampling quality has been examined with regards to the normalised void ratio change ($\Delta e/e_0$) and the oedometer stiffness ratio (M_0/M_L), with the criteria listed in Table 1. For the soil samples investigated, which have OCR less than two, the $\Delta e/e_0$-values are found to lie in the range 0.069-0.176. For this reason, all the triaxial and oedometer tests are categorised as of poor quality. In view of the presented results, this is surprising, and a higher quality rating was expected. In contrast, the M_0/M_L-criterion gives a quality rating of “very good to excellent” and “good to fair” based on measured M_0/M_L-values between 2.85 and 1.40.

These methods for assessment of sample quality show clear discrepancies. For the medium plastic non-sensitive clay from Lierstranda, shown in Figure 1, the $\Delta e/e_0$-criterion does produce expected results, however the criterion may not be well suited for low plastic sensitive soft clays – as exemplified by Figure 8. Tanaka et al. (2002) observed something similar, that the sample quality criterion proposed by Lunne et al. (1997) cannot be unconditionally applied to all types of soils.

5.2 Oedometer and triaxial tests

The shape of the oedometer curve of four tests in Figures 4 and 5 show that tests carried out in Lab 1 are easier to interpret and indicate less sample disturbance than the parallel results from Lab 2. The Lab 1 tests have considerably larger constrained modulus (M_0), with an increase of between 35 and 170% for samples from depths of 10 and 15 meters. Also, the recompression index (C_s) and compression index (C_c) indicate sample disturbance in the tests from Lab 2. Disturbance usually increases the C_s and decreases the C_c (Leroueil and Hight 2003), but this is not the case in test 4, where large deformations cause the high C_c value.

A reduction in preconsolidation pressure, 26-38%, is observed in samples no. 2 and 4, see Table 4.

All four results of the CAUC triaxial tests tend to show that the clay from Klett is a strain softening material. A reduction in undrained shear strength of 23%, as observed in Figures 4 and 5, is found in tests no. 2 and 4. The same samples also show higher pore pressure response and lower dilatancy parameter (D). However, these samples have the lowest strain at failure. The friction angle varies between 26.4^o and 27.9^o independently of testing laboratories. The results of these tests are summarised in Table 4.

The observed differences in oedometer and triaxial test results between the laboratories may be explained by the transport of samples, short time storage, handling and dissimilarities in laboratory procedures. During transport and delayed testing, the specimens experience vibrations combined with a stress release. A reduction in effective stress contains an inherent risk that the cementation bond structure may be partially or completely destroyed. Once the microstructure is destroyed it will be impossible to reproduce during testing,

These observations exemplifies the seriousness of the challenges related to low plastic sensitive soft clays. Careful handling of this type of material is essential to obtain good quality test results because even a small amount of disturbance can be significant.

5.3 Stress release

Stress-strain curves from two CAUC tests on specimens from the Klett clay, trimmed from a block sample and a 75 mm tube sample from 18 m, are plotted against axial strain in Figure 9c. The effect of disturbance on peak undrained shear strength is about 15 %. Similar observations were made by Berre et al. (1969) where a 95 mm sampler was compared to a 54 mm sampler, with improvements in the stress-strain relationship. Additionally, Lefebvre (1970), Bozozuk (1971) and Löfroth (2012) investigated the effect of sample diameter and concluded that a larger diameter sampler provides better quality samples in soft marine clay.

Figure 9 shows a comparison between triaxial tests carried out on three different clays, two from Norway and one from Canada. Clays from Klett and Ellingsrud are low plastic quick clays, the former is slightly more overconsolidated. The Champlain clay is a high plastic sensitive clay, slightly overconsolidated. Table 5 summarises some of the properties of these clays.

The effect of sampler diameter is illustrated in Figures 8a and 8c, larger block samples provide higher undrained shear strength.

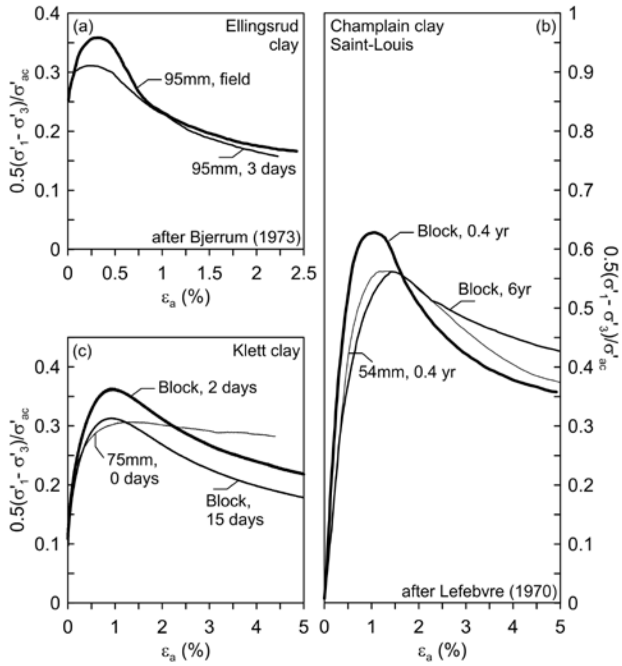

Figure 9. Comparison between triaxial tests on block and tube samples. (a) Ellingsrud clay, Norway (Bjerrum 1973), (b) Champlain clay, Saint-Louis, Canada and (Lefebvre 1970) (c) Klett clay, Norway

Table 5. Results of CAUC triaxial tests

Site	Tested after	OCR	w (%)	I_P (%)	I_L
(a) Ellingsrud clay		1.4-2.4	38.0	3.0	5.3
95 mm	Field				
95 mm	3 days				
(b) Champlain clay		1.6	69.0	23	1.8
54 mm	0.4 years				
Block	0.4 years				
Block	6 years				
(c) Klett clay 75 mm	0 days	1.3	33.9	4.3	1.8
Block	2 days		33.7		
Block	15 days		33.9		

The effect of stress release is illustrated in Figure 9a, where one of the samples were consolidated immediately after sampling and the other was stored for 3 days. A similar observation was also made for the Klett clay where a sample that was stored for 15 days decreased its undrained shear strength with 14%, shown in Figure 9c.

Observations that were made in Figures 6 and 7, where the samples were tested in different laboratories, show a decrease in peak strength by 21 %.

Triaxial tests on Champlain clay illustrate the effect of long-term storage on the undrained shear strength, which had decreased by 10% after 6 years. The comparison with a test performed on a 54 mm tube sample indicates that the effect of storage is somewhat similar to the disturbance resulting from tube sampling, but not that severe (La Rochelle et al. 1981). Similar behaviour was observed for the Klett clay in Figure 9c for a 75 mm tube sample and a block sample that was stored for 15 days.

6 CONCLUDING REMARKS

From the limited number of test results on block samples, as well as 75 mm tube samples on a low plastic sensitive soft clay from Klett, the following conclusions may be drawn:

a) Sampling of sensitive soft clays with layers of silt can lead to extensive sample disturbance. Careful handling of the material is essential to prevent further disturbance.
b) Short term storage or a delay in the laboratory testing of an open sample may reduce the measured preconsolidation pressure and undrained shear strength. This implies that the sample should be tested as soon after sampling as possible.
c) A comparison between results of tube and block samples showed a significant effect of sample disturbance on peak undrained shear strength for low plastic sensitive clays.
d) Observations presented in this paper exemplify the detrimental effect of sample disturbance, and the importance of skillful sampling and proper handling.

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REFERENCES

Adams, J. I. and H. S. Radhakrishna 1971. Loss of Strength Due to Sampling in a Glacial Lake Deposit. *Sampling of Soil and Rock*, ASTM. STP 483: 109-112.

Amundsen, H. A., V. Thakur and A. Emdal 2015. Comparison of two sample quality assessment methods applied to oedometer test results. *15th Pan-American Conf. on Soil Mechanics and Geotechnical Engineering*. Buenos Aires.

Andresen, A. and P. Kolstad 1979. The NGI 54-mm samplers for undisturbed sampling of clays and representative sampling of coarser materials. *Int. Symp. on Soil Sampling*. Singapore: 13-21.

Arman, A. and K. L. McManis 1976. Effect of Storage and Extrusion on Sample Properties. *Soil Specimen Preparation for Laboratory Testing*, ASTM. STP 599: 66-87.

Baligh, M. 1985. Strain Path Method. *Journal of Geotechnical Engineering* 111(9): 1108-1136.

Berre, T., K. Schjetne and S. Sollie 1969. Sampling disturbance of soft marine clays. *Proc. of the 7th ICSMFE, Special Session*. Mexico. 1: 21-24.

Bjerrum, L. 1954. Geotechnical Properties of Norwegian Marine Clays. *Géotechnique* 4(2): 49-69.

Bjerrum, L. 1973. Problems of soil mechanics and construction on soft clays. State-of-the-art report. *Proc., 8th ICSMFE*. Moscow. 3: 111-159.

Bozozuk, M. 1971. Effect of Sampling, Size, and Storage on Test Results for Marine Clay. *Sampling of Soil and Rock*, ASTM. STP 483: 121-131.

Hight, D. W., R. Böese, A. P. Butcher, C. R. I. Clayton and P. R. Smith 1992. Disturbance of the Bothkennar clay prior to laboratory testing. *Géotechnique* 42(2): 199-217.

Hight, D. W. and S. Leroueil 2003. Caracterisation of soils for engineering purposes. *Characterisation and Engineering Properties of Natural Soils*. T. S. Tan et al. 1**:** 255-360.

Hong, Z. and K. Onitsuka 1998. A method of correcting yield stress and compression index of Ariake cays for sample disturbance. *Soils and Foundations* 38(2): 211-222.

Hvorslev, M. J. 1949. Subsurface exploration and sampling of soils for civil engineering purposes, Report on soil sampling, U.S. waterways experiment station, Vicksburg. 521.

Janbu, N. 1963. Soil compressibility as determined by oedometer and triaxial tests. *European Conf. on Soil Mechanics and Found. Engrg.* Wiesbaden. 1: 19-25.

Karlsrud, K. and F. G. Hernandez-Martinez 2013. Strength and deformation properties of Norwegian clays from laboratory tests on high-quality block samples. *Can. Geotech. J.* 50(12): 1273-1293.

Kirkpatrick, W. M. and A. J. Khan 1984. The reaction of clays to sampling stress relief. *Géotechnique* 34(1): 29-42.

La Rochelle , P. and G. Lefebvre 1970. Sampling disturbance in Champlain clays. *Proc. of the Symp. on Sampling of soil and rock*, ASTM. STP 483: 143-163.

La Rochelle, P., S. Leroueil and F. Tavenas 1986. A technique for long-term storage of clay samples. *Can. Geotech. J.* 23(4): 602-605.

La Rochelle, P., J. Sarrailh, M. Roy and F. A. Tavenas 1976. Effect of Storage and Reconsolidation on the Properties of Champlain Clays. *Soil Specimen Preparation for Laboratory Testing*, ASTM. STP 599: 126-146.

La Rochelle, P., J. Sarrailh, F. Tavenas, M. Roy and S. Leroueil 1981. Causes of sampling disturbance and design of a new sampler for sensitive soils. *Can. Geotech. J.* 18(1): 52-66.

Lacasse, S., T. Berre and G. Lefevbre 1985. Block sampling of sensitive clays. *Proc. of the Int. Conf. on Soil Mechanics and Foundation Engineering, 11*. San Francisco. 2: 887-892.

Ladd, C. C. and D. J. DeGroot 2003. Recommended practice for soft ground site characterization: Arthur Casagrande Lecture. *Proc. of the 12th Pan American Conf. on Soil Mechanics and Geotechnical Engineering*. MIT, Cambridge, Massachusetts.

Ladd, C. C. and T. W. Lambe 1963. The strength of undisturbed clay determined from undrained tests. *Symp. on Laboratory Shear Testing of Soils*, ASTM. STP 361: 342–371.

Lefebvre, G. (1970). Contribution à l'étude de la stabilité des pentes dans les argiles cimentées Ph.D. thesis, Université Laval, Quebéc, Canada.

Leroueil, S. and D. W. Hight 2003. Behaviour and properties of natural soils and soft rocks. *Characterisation and Engineering Properties of Natural Soils*. T. S. Tan et al. 1**:** 29-254.

Leroueil, S., M. Roy, P. L. Rochelle and F. A. Tavenas 1979. Behavior of Destructured Natural Clays. *Journal of the Geotechnical Engineering Div.* 105(6): 759-778.

Leroueil, S. and P. R. Vaughan 1990. The general and congruent effects of structure in natural soils and weak rocks. *Géotechnique* 40(3): 467-488.

Lessard, G. and J. K. Mitchell 1985. The causes and effects of aging in quick clays. *Canadian Geotechnical Journal* 22(3): 335-346.

Locat, J. and G. Lefebvre 1985. The compressibility and sensitivity of an artificially sedimented clay soil - The Grande-Baleine marine clay, Quebec, Canada. *Marine Geotechnology* 6(1): 1-28.

Lunne, T., T. Berre and S. Strandvik 1997. Sample disturbance effects in soft low plastic Norwegian clay. *Conf. on Recent Developments in Soil and Pavement Mechanics*. Rio de Janeiro: 81-102.

Löfroth, H. 2012. Sampling in normal and high sensitive clay - a comparison of results from specimens taken with the SGI large-diameter sampler and the standard piston sampler St II. *SGI Varia*. 637: 26.

Nagaraj, T. S., N. Miura, S. G. Chung and K. N. Prasad 2003. Analysis and assessment of sampling disturbance of soft sensitive clays. *Géotechnique* 53(7): 679-683.

Nagaraj, T. S., B. R. S. Murthy, A. Vatsala and R. C. Joshi 1990. Analysis of Compressibility of Sensitive Soils. *Journal of Geotechnical Engineering* 116(1): 105-118.

NGF 2013. Sampling guidelines (in Norwegian), Norwegian Geotechnical Society: 1-30.

Noorany, I. and H. B. Seed 1965. In-Situ Strength Characteristics of Soft Clays. *Journal of the Soil Mechanics and Foundations Division* 91(2): 49-80.

Okumara, T. 1971. The variation of mechanical properties of clay samples depending on its degree of disturbance. *Proc. Spec. Session on Quality in Soil Sampling, 4th Asian ISSMFE*. Bankok: 73-81.

Onitsuka, K. and Z. Hong 1995. A new nethod of correcting unconfined comressive strength of natural clays for sample disturbance. *Soils and Foundations* 35(2): 95-105.

Shogaki, T. 1996. A method for correcting consolidation parameter for sample disturbance using volumetric strain. *Soils and Foundations* 36(3): 123-131.

Skempton, A. W. and V. A. Sowa 1963. The Behaviour of Saturated Clays During Sampling and Testing. *Géotechnique* 13(4): 269-290.

Tanaka, H., F. Ritoh and N. Omukai 2002. Quality of samples retrieved from great depth and its influence on consolidation properties. *Canadian Geotechnical Journal* 39(6): 1288-1301.