Evaluation of sample disturbance of three Norwegian clays

Évaluation de la qualité de trois échantillons d'argile molle Norvégienne

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ABSTRACT: The quality and reliability of laboratory test data in sensitive clay can significantly be affected by sample disturbance. In turn, sample disturbance may affect key design parameters such as compressibility, preconsolidation stress and undrained shear strength. In this work, samples obtained from a 72 mm thin walled fixed-piston sampler are compared to Sherbrooke Block samples with diameter (Ø) of 160 mm (mini) and 250 mm (standard) for clays from three different locations in Norway (Skatval, Koa and Nybakk-Slomarka). All three clays have plasticity indices varying between 8-25 and water contents varying between 30-40%. Results from triaxial tests (CAUC) and oedometer tests (CRS) are used to study the influence of sampler type and disturbance effect. Sample disturbance from both block samplers is further evaluated using measurements of shear-wave velocity (Vs) performed in the field and in the laboratory. The measurements are correlated to volumetric change values during triaxial testing as a form of evaluating quality of the laboratory tests.

RÉSUMÉ : Il est reconnu que les méthodes d'échantillonnage peuvent fortement affecter la qualité des échantillons d'argile molle. De ce fait, les perturbations dues à l'échantillonnage peuvent affecter les paramètres de conception en géotechnique tels que la compressibilité de l'argile, la contrainte de pré-consolidation et la résistance au cisaillement. Dans cette étude, les résultats de laboratoire sur des échantillons obtenu à l'aide d'un échantillonneur à piston de 72 mm sont comparés avec ceux d'échantillons en bloc de 160 mm et 250 mm. Les tests ont été faits sur trois argiles Norvégienne provenant de Skatval, Koa et de Nybakk-Slomarka. Chacune des argiles a un indice de plasticité variant entre 8 et 25, et une gamme de teneur en eau entre 30-40%. Les résultats d'essai triaxiaux en compression (CAUC) ainsi que d'œdomètre (CRS) sont utilisés pour évaluer l'effet des différents échantillonneurs ainsi que la qualité des échantillons. De plus, la qualité des échantillons en bloc est évalué à partir de résultats d'ondes de cisaillement recueillis sur le terrain et au laboratoire. Ces mesures sont aussi corrélées aux changements volumétrique pendant le stade de consolidation dans les essais triaxiaux.

KEYWORDS: clay, sample quality, shear-wave velocity.

1 INTRODUCTION

The quality and reliability of laboratory test data in sensitive clay can significantly be affected by sample disturbance. Research has shown that sample disturbance decreases the measured values of preconsolidation stress (p_c') (Landon et al. 2007) and affects estimates of shear strength (s_{uC}) on soft clays (Lunne et al. 2006).

Sample disturbance effects can be mitigated by improved sampling methods, geometry of sampler and equipment; however, sample quality should be assessed as part of the geotechnical designed prior to selection of parameters. Two well know approaches to evaluate sample quality for clay are change of volumetric strain (Δe) (Kleven et al. 1986) and the normalized change in void ratio ($\Delta e/e_o$) (Lunne et al. 1997). These approaches require reconsolidation to *in situ* stresses, which require time and sample destruction.

Landon et al. (2007) describe a nondestructive field method of sample quality assessment by using a bender element device and taking measurements of shear-wave velocity (Vs). Donohue and Long (2010) present the use of unconfined shear-wave velocity (Vs-0) and suction to assess the quality of soft clay samples, and proposed a criterion for sample quality assessment.

This paper presents field and laboratory test results of samples obtained from a 72 mm thin-walled fixed-piston sampler and Sherbrooke Block samples (Ø160 and Ø250 mm) to study the influence of sampler type and disturbance effect. Sample disturbance is further evaluated using measurements of shear-wave velocity performed in the field and in the laboratory at various stages. The Vs measurements are correlated to volumetric changes during the consolidation phase of the triaxial tests.

2 DESCRIPTION OF TEST SITES

Piezocone tests (CPTU) and soil sampling were performed at Skatval, Koa and Nybakk-Slomarka in Norway. The sites consist of both sensitive and non-sensitive marine clays. Cone resistance (q_t) and pore pressure ratio (B_q) vary between 600-1000 kPa and 0.8-1.1, respectively, for the clay deposit on each site (see Figure 2). Table 1 presents basic soil parameters for each site. All three clays have plasticity indices varying between 8-25 and water contents varying between 30-40%.

Table 1. Basic site properties.

Parameter	*Skatval*	*Koa*	*Nybakk-Slomarka*
Unit weight γ (kN/m^3)	19.4	19.4	18.5
Water content *w* (%)	32	30	35
Sensitivity S_t (-)	5-50	13-63	5-150
Plasticity index *IP* (-)	11-17	8-25	8-17
Overconsolidation ratio *OCR* (-)	2-4	3-4	2-6
Clay content *CC* (%)	35-43	50-53	40-47

Figure 1. Location of test sites.

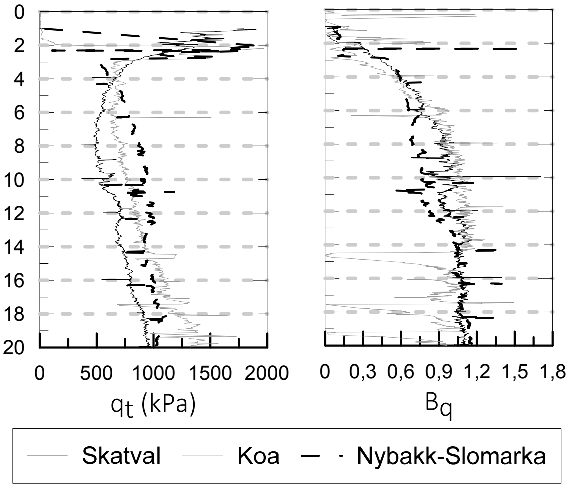

Figure 2. CPTU tests at each site.

3 FIELD & LABORATORY TESTS

The 72 mm samples, Sherbrooke Block samples (Ø250 mm) and miniblock samples (Ø160 mm) were collected at each site. At each of the sites the different samples were taken at similar depths. Measurements of shear-wave velocity in the field ($Vs_{\text{-MASW}}$) were obtained from multichannel analysis of surface waves (MASW). Unconfined measurements of shear-wave velocity (Vs-0) were collected on site and in the laboratory using the bender element device described by Landon et al. (2007). For this, samples were carefully trimmed from block sample size to a cube about 70x70x70 mm size due to restrictions in the equipment size.

The laboratory program included index testing, grain size distribution and more advanced tests such as triaxial tests (CAUC & CAUE) and oedometer tests at constant rate of strain (CRS). Additional measurements of Vs were acquired after sample consolidation during CAUC & CAUE tests ($Vs_{\text{-lab}}$).

Table 2. Evaluation of sample quality, after Lunne et al. (1997).

OCR	$\Delta e/e_o$			
1 to 2	< 0.04	0.04-0.070	0.070-0.14	> 0.14
2 to 4	< 0.03	0.03-0.050	0.050-0.10	> 0.10
4 to 6	< 0.02	0.02-0.035	0.035-0.07	> 0.07
Quality	1: very good to excellent	2: good to fair	3: poor	4: very poor

Shear-wave travel time (i.e. arrival time), for both $Vs_{\text{-0}}$ and $Vs_{\text{-lab}}$, was calculated as the difference between two peaks of the transmitted signal minus the system calibration time.

The quality of the samples tested is evaluated based on the initial void ratio and the axial strain at the in-situ stress according to the classification proposed by Lunne et al. (1997) (see Table 2). The corresponding criteria used from Table 2 applies for OCR values varying between 2 to 4 for Koa and Skatval, and between 2 to 6 for Nybakk-Slomarka.

4 RESULTS

4 .1 *Skatval site*

Figure 3 shows the CAUC and CRS results for the samples taken at Skatval. The Ø250 mm and Ø160 mm samples tested in CAUC show quality 1 (i.e. very good to excellent) according to Lunne et al. (1997). The 72 mm sample shows quality 2 (i.e. good to fair) for the same type of test. The measured shear strength is 3% and 8% lower for the 72 mm sample than the values obtained with the Ø160 mm and Ø250 mm samples, respectively (see Table 3). The axial strain at failure is highest for the 72 mm sample, followed by the Ø250 mm sample and the Ø160 mm sample, which gives the lowest value.

The 72 mm sample tested in CRS tests show poor quality (i.e. quality 3) according to the classification proposed by Lunne et al. (1997). The Ø250 mm shows quality 2 and the Ø160 mm shows quality 1. The preconsolidation stress value does not show strong variations (about 8%) for Ø160 and the Ø250 mm samples (see Table 3), while the preconsolidation stress could not be determined for the 72 mm sample due to sample disturbance effects.

4 .2 *Koa site*

Figure 4 shows the CAUC and CRS results for the samples taken at Koa. The deepest Ø160 mm samples tested in CAUC show quality 2, while all 72 mm samples and the rest of the Ø160 mm samples show quality 1. The measured shear strength is 8-28% lower for the 72 mm samples than the values obtained with the Ø160 mm samples (see Table 3). The axial strain at failure is highest for the 72 mm samples than for the Ø160 mm samples.

Table 3. Ratio of s_{uC} and p_c' between block samples (Ø160 and Ø250) and 72 mm samples, taking block samples as true value. Values are calculated for each depth were laboratory tests were performed.

Parameter		*Skatval*	*Koa*	*Nybakk-Slomarka*
Undrained shear strength ratio	72/160 mm	0,97	0,92 0,72*	-
	72/250 mm	0,92	-	0,92 0,94 0,85
	160/250mm	0,95	-	-
Preconso-lidation stress ratio	72/160 mm	not possible	0,86*	-
	72/250 mm	not possible	-	0,83 0,94 0,74
	160/250 mm	0,92	-	-

*Samples are not at the same depth.

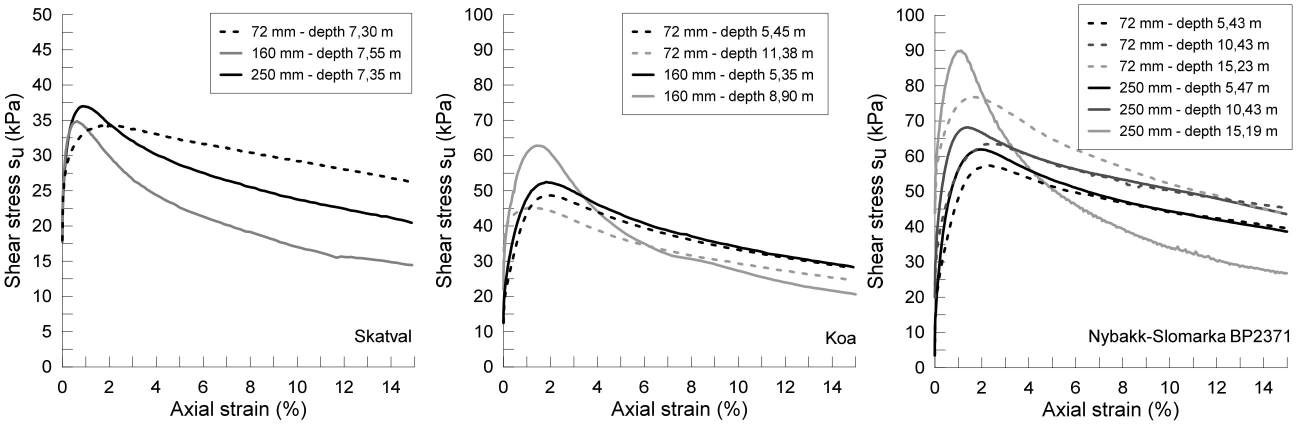

Figure 3. Results for CAUC at Skatval, Koa and Nybakk-Slomarka.

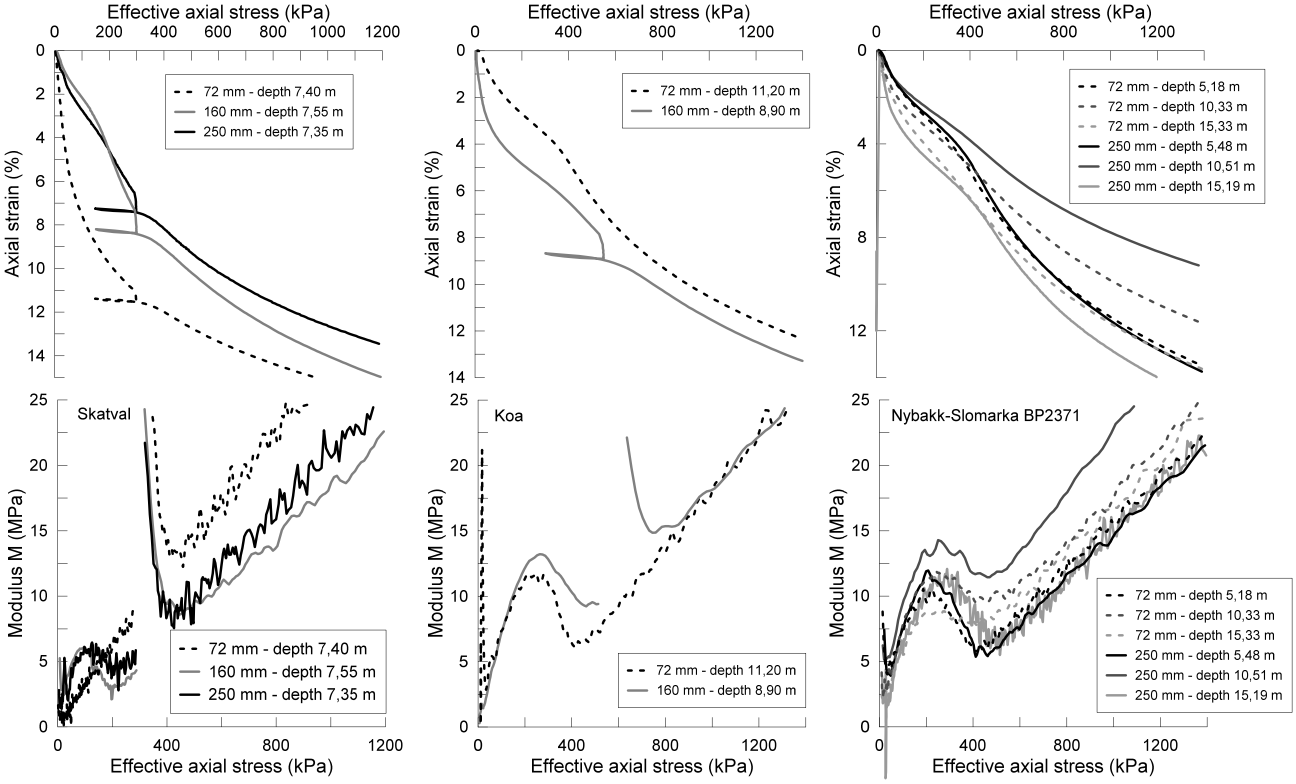

Figure 4. Results for CRS at Skatval, Koa and Nybakk-Slomarka.

Both the 72 mm and Ø160 mm samples tested in CRS tests show poor quality (i.e. quality 3) according to the classification proposed by Lunne et al. (1997). The preconsolidation stress value shows a 14% deviation between the tests, however, samples are not from the same depth (see Table 3).

4 .3 *Nybakk-Slomarka site*

Figure 3 shows the CAUC and CRS results for the samples taken at Nybakk-Slomarka site. The Ø250 mm and 72 mm samples tested in CAUC show quality 1 (i.e. very good to excellent) according to Lunne et al. (1997). The Ø250 mm samples show higher undrained shear strength and lower peak axial strain than the 72 mm samples. The difference Ø250 mm and 72 mm samples for undrained shear strength values varies between 6-15%.

The deepest samples tested in CRS tests show poor quality (i.e. quality 3) for both 72 mm and Ø250 mm samples where the material is more sensitive. However, for the rest of the samples, the Ø250 mm gives better quality (i.e. quality 1) than the 72 mm samples according to the classification proposed by Lunne et al. (1997). The preconsolidation stress value is higher in all depths for the Ø250 mm samples than the 72 mm samples. The difference Ø250 mm and 72 mm samples for preconsolidation stress values varies between 6-26%.

4 .4 *Measurements of Vs at Skatval and Koa sites*

MASW measurements performed at Skatval and Koa are shown in Figure 5. They are compared to two correlations for shear-wave velocity proposed by L'Heureux and Long (In Press) which are based on CPTU results. Both correlations fit well with MASW measurements.

Individual Vs measurements are plotted in Figure 5 which correspond to: a) unconfined measurements on block samples right after sampling ($V_{s\text{-}0f}$); b) unconfined measurements on block samples after transport to Lab 1 (Vs-1); c) unconfined measurements on block samples after transport to Lab 2 (Vs-2) which is located further away from the site than Lab 1; and d) measurements after consolidation for CAUC and CAUE tests ($V_{s\text{-lab}}$) in Lab 2. Samples were transported by a vehicle to Lab 1 in Trondheim and Lab 2 in Oslo. There are no Vs measurements relating to the 72 mm samples.

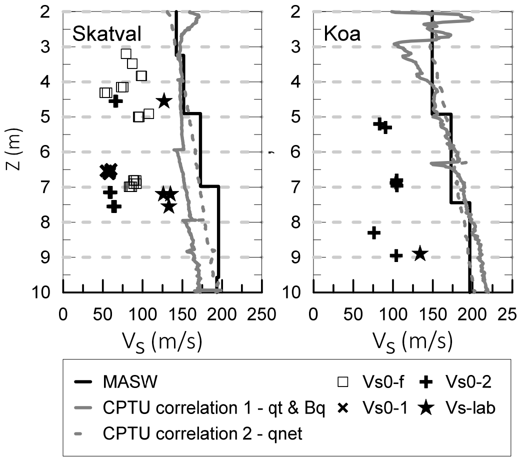

Figure 5. Results for Vs at Skatval and Koa.

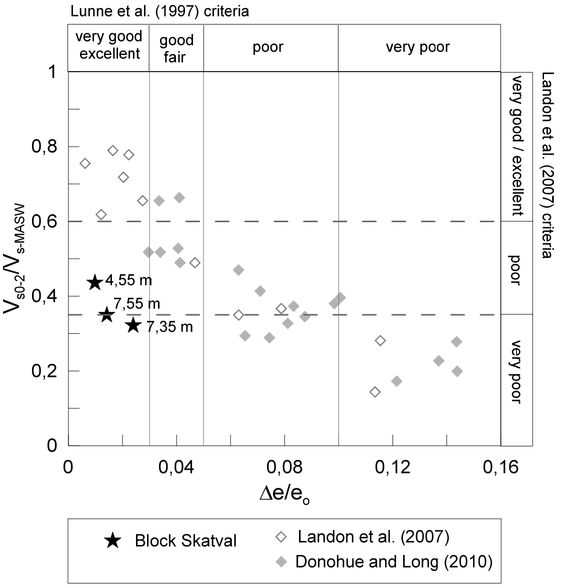

Figure 6. Comparison of shear-wave velocity ratio and normalized void ratio for block samples from Skatval (CAUC), and data collected by Landon et al. (2007) and Donohue and Long (2010) for soft clays.

5 DISCUSSION

Results from the CAUC tests on the three clays show that the clays collected with block samplers have a more brittle behaviour and higher shear strenght than those collected with the 72 mm piston sampler. Preconsolidation stress values determined after CRS tests are higher for the block samples than the 72 mm samples. This shows that even though most of the samples show good quality (i.e. quality 1 and 2 according to the Table 2), undrained shear strength and preconsolidation values show a variation associated with change in block sampler diameter and sampler type, Sherbrooke versus 72 mm diameter fixed piston sampler. These changes are as a result of associated disturbance effects due to the sampler and sample method. Baligh et al. (1987) states that disturbance in tube sampling might be due to the effect of mechanical destructuration as the soil experiences compression and extension straining while entering the sampling tube.

In situ Vs from MASW tests agrees well with correlations for Vs based on CPTU values. Unconfined mesurements of Vs-0 on site are lower than the *in situ* values and transport resulted in a reduction in Vs-0 between field and laboratory measurements, see results for Skatval between 6.5 and 7.5 m.. There was good agreement on results for these tests between the two laboratories despite the difference in distance. Hence it is thought that greater travel distance does not play a role in Vs-0 reduction.

There is some scatter in field Vs-0 values at Skatval between 4.0 m and 5.0 m. These might be due to disturbance while sampling cutting, since a big stone was hit by the Sherbrooke Block sampler between these depths that made shorter samples and that the material was partly wash out.

Reconsolidation to *in situ* stresses prior to testing seems to reduce sampling disturbance and gives the highest measured Vs values (Vs-lab). However the Vs values are about 33% lower than Vs-MASW at 7.5 m in Skatval and 32 % at 9 m at Koa both on block samples.

Figure 6 shows the relationship between the consolidated shear-wave velocity ratio (unconfined/*in situ*) and the normalized change in void ratio. The data disagrees with previous experience from Landon et al. (2007) and Donohue and Long (2010) for soft clays. These relationships show that very good to excellent quality samples have high Vs-0/Vs-*insitu* ratio. Landon et al. (2007) recommend that very good to excellent and fair to good quality samples have a shear-wave velocity ratio ≥ 0.60, poor quality samples have a ratio varying between 0.35-0.60 and very poor quality samples show a ratio lower than 0.35. It should be noted that Landon et al. (2007) uses Vs-*insitu* based on seismic CPTU which gives a continuos record of Vs and in this paper we are using *in situ* values based on MASW that gives constant values of Vs for depth intervals. Additionally, the Vs-0 measurements were done in trimmed sections (i.e. 70x70x70 mm cubes) of the block samples that could add some additional disturbance to the testing samples and therefore, the disagreement in the data.

6 CONCLUSIONS

Results from CAUC and CRS tests are used to study the influence of sampler type and disturbance effect. Block samples give a more brittle behaviour, higher undrained shear strenght and preconsolidation stress values. Sample disturbance from block samplers is evaluated using measurements of shear-wave velocity performed in the field and in the laboratory. Good quality samples have higher Vs-0/Vs-*insitu* ratio.

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