Block sampling of sensitive clays

Echantillonnage bloc des argiles sensibles

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SYNOPSIS The quality of block samples 300-mm in diameter is compared to the quality of 95-mm fixed piston samples of three Norwegian marine clays with plasticities between 5 and 40%. The laboratory test results are compared in terms of preconsolidation stress, oedometer curves, and stress-strain-strength behaviour from unconfined compression, triaxial and direct simple shear tests. For two of the clays tested, the quality of the block samples is superior to that of the large piston samples. In the case of lean quick clays, block sampling results in higher peak shear stress at lower failure strain. Shear modulus values are much higher. In the case of a plastic moderately sensitive clay, the blocks and the 95-mm samples had very similar characteristics.

INTRODUCTION

Even the best tube sampling techniques disturb the structure of a clay and may result in significant differences in mechanical properties. The effect is most important for brittle and sensitive clays. The quality of samples generally increases with the diameter of the sampling equipment, but previous studies agree that even large diameter tube samplers damage the structure of the clay as compared to block samplers. La Rochelle et al. (1981) have shown however that the quality of 200-mm tube samples is comparable to that of block samples.

In cooperation with the University of Sherbrooke, the Norwegian Geotechnical Institute undertook to compare the behaviour of block samples of Norwegian marine clays to the behaviour of 95-mm tube samples. The investigation aimed at: (1) assessing the importance of sampling disturbance caused by 95-mm piston samplers; (2) evaluating the performance of a new block sampler in Norwegian sensitive clays; and (3) identifying how the degree of sample disturbance depends on clay type and how it affects the mechanical properties determined from different laboratory tests.

To this effect, 300-mm diameter block samples and 95-mm fixed piston samples were taken in three Norwegian marine clays. The laboratory test programme included oedometer, fall cone, unconfined compression, triaxial compression and extension, and direct simple shear tests. Some of the results and the main conclusions of the investigation are presented in this paper.

SAMPLING

The block samples were taken with the University of Sherbrooke cylindrical block sampler for sensitive clays (Lefebvre and Poulin, 1979). This special sampler allows the carving of a block at depth from the surface, using cutting procedures similar to those employed in shallow trenches. At the Norwegian sites, the sampler was operated from a drilling rig with mud circulation, which pressure was monitored to avoid hydraulic fracturing in the soil mass. The vertical thrust and the sampler rotation were controlled continuously. Block samples 35 and 40 cm high were recovered without difficulty down to depths of 13 m. The blocks, wrapped with cheeze cloth and waxed, were transported in padded cases. The handling and trimming in the laboratory required much time because of the logistics associated with large samples to be treated with the greatest care possible.

The tube samples were obtained with the NGI 95-mm fixed piston sampler, with the same field crews and procedures as for conventional sampling jobs. Andresen (1981) and Berre et al. (1969) described the sampler and the sampling techniques. The piston samples were taken less than 10 m from the blocks, and either immediately or only a few months after the block sampling. In the laboratory the tube samples were extruded vertically with an hydraulic piston and trimmed with the methods normally used at NGI (Berre, 1981; Sandbækken et al., 1985).

TEST SITES

Two quick clays sites, Emmerstad and Ellingsrud, and one sensitive clay site, Onsøy, were used for the investigation. Table 1 summarizes some of the index characteristics of each clay.

Emmerstad clay is a marine quick clay with 10% sand and gravel particles. As shown on Fig. 1,

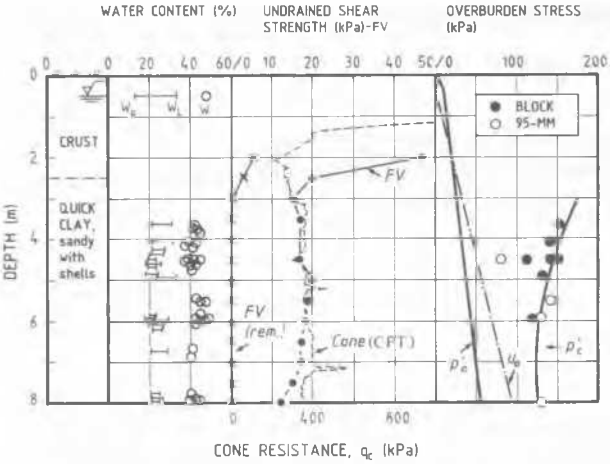


Fig. 1 Soil profile at Emmerstad site

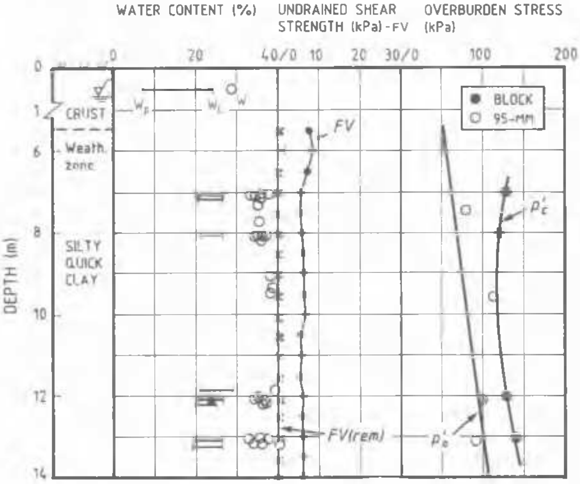


Fig. 2 Soil profile at Ellingsrud site

the natural water content varies between 40 and 48% and the plasticity index between 3 and 12%. The in situ pore pressure is slightly artesian. Below a 2 m crust, the field vane undrained shear strength in the top 6 m averages 18 kPa, while the remoulded undrained shear strength is essentially zero. Cone penetration tests with the Wissa piezocone indicate a fairly homogeneous clay below 3 m. Bedrock is found at about 13 m. The overconsolidation ratio of Emmerstad clay is higher than generally encountered for Norwegian quick clays.

In Ellingsrud, the marine quick clay is very homogeneous below a 5 to 6 m crust. The natural water content varies between 34 and 40% and the plasticity index is only 5 to 8% (Fig. 2). The clay is silty with some sand. The undisturbed field vane undrained shear strength between 7 and 15 m ranges from 5 to 7 kPa. The sensitivity, as for Emmerstad clay, is very high. Bedrock is found at about 24 m.

TABLE I Description of three clays tested

Site	Emmerstad	Ellingsrud	Onsøy
Depth sampled (m)	3 - 8	7 - 13	3 - 10
Water content (%)	40 - 48	34 - 40	58 - 70
% > 60 μ % < 2 μ	10 40	9 37	0 60
Liquid limit (%)	24 - 32	25 - 29	56 - 74
Plasticity index (%)	3 - 12	5 - 8	30 - 44
Sensitivity (FV)	60 - ∞	60 - ∞	6 - 9
Overconsolidation ratio	5 at 4 m 3 at 7 m	2.4 at 7 m 1.4 at 13 m	3 at 3 m 1.5 at 10 m

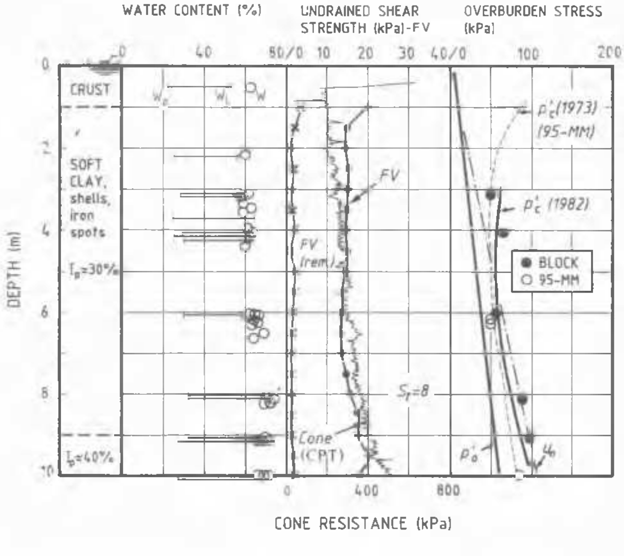
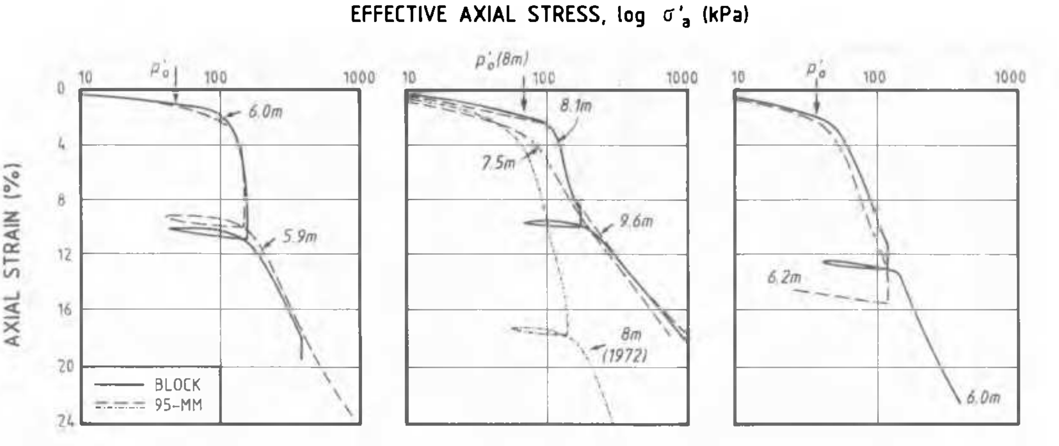


Fig. 3 Soil profile at Onsøy site

The non-quick Onsøy deposit (Fig. 3) consists of a one-meter crust underlain by 44 m of homogeneous soft plastic clay with iron-colour spots, organic matter and shell fragments. The natural water content in the top 10 m varies between 58 and 70%, with a plasticity index between 30 and 44%. The average field vane sensitivity, S_t, is 8. Figure 3 compares the undrained shear strength based on field vane and a typical profile of cone penetration resistance.



a) Emmerstad b) Ellingsrud c) Onsöy

Fig. 4 Comparison of oedometer stress-strain curves for block and 95-mm piston samples

RESULTS OF LABORATORY TESTS

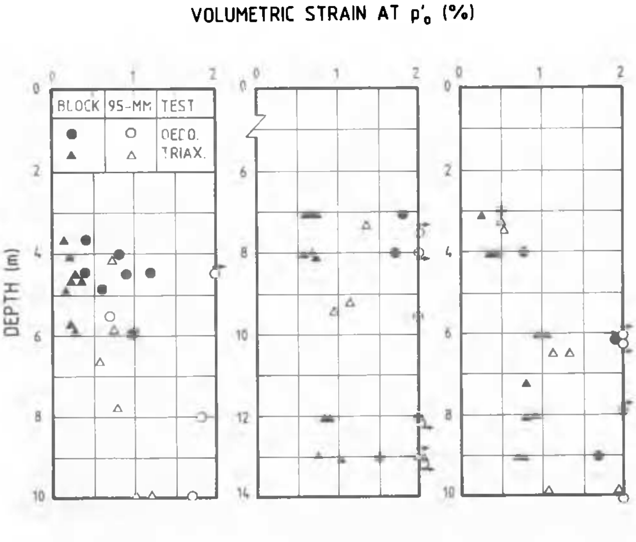
Oedometer tests

Figure 4 compares the stress-strain curves for block and 95-mm piston samples. Incremental loading oedometer tests were carried out. In Emmerstad and Onsøy, very small differences are observed in the curves, except for slightly larger strains at the effective overburden stress p'_o. The values of preconsolidation stress, p'_c, are approximately the same. In the case of Ellingsrud clay, the 95-mm piston samples generally show more signs of disturbance, with lower p'_c-value and higher recompression index during first loading.

The 95-mm Ellingsrud sample denoted 1972 in Fig. 4b is disturbed. However, the unload-reload loops for this sample and the better quality block specimens are parallel and correlate well to the slope of the initial recompression of the block sample. This observation lends confidence to the unload-reload procedure proposed for oedometer tests by Sandbækken et al. (1985) to correct for the effects of sample disturbance.

A useful index to sample disturbance is the volume change of the specimen during recompression to p'_o (Andresen et al., 1969). Figure 5 presents the volumetric strains at p'_o recorded from oedometer and one-dimensionally consolidated triaxial tests. In the case of the quick clays, the 95-mm samples tend to give higher strains than the block samples. On the other hand, in Onsøy, the strains of the block specimens are not significantly lower than the strains of the 95-mm specimens. The strains at p'_o increase with depth as one would expect, since sampling disturbance tends to increase with deeper samples. The Onsøy block samples between depths of 7 to 10 m are probably of better quality than the 95-mm samples, based on the strains at p'_o, but the stress-strain oedometer curves are very similar.

Figures 1, 2 and 3 compare the preconsolidation stress determined from oedometer tests on block and 95-mm specimens (both incremental and constant rate of strain tests were used). The p'_c-values are determined from stress-strain curves plotted after one or two-hour consolidation. Except for a few isolated obviously disturbed 95-mm specimens, the two types of samples lead to about the same p'_c profile for Emmerstad and Onsøy clays. The Ellingsrud 95-mm samples suggest lower p'_c-values than the block samples.



a) Emmerstad b) Ellingsrud c) Onsöy

Fig. 5 Volumetric strain during reconsolidation to the in situ effective stresses

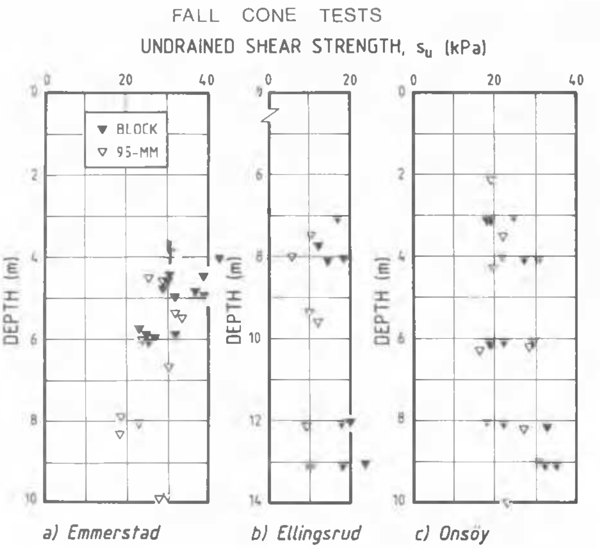


Fig. 6 Comparison of results from fall cone tests on block and 95-mm piston samples

Fall cone tests

Figure 6 compares the results from fall cone tests run on the specimens before trimming for oedometer or shear testing. In general the results from fall cone tests on 95-mm tube samples plot on the lower bound of the fall cone results on block samples. A few of the tube samples have fall cone strengths that agree with that of block samples, and oedometer tests on these same tube samples give p'_c-values comparable to the p'_c-values derived from oedometer tests on block samples. The Ellingsrud tube samples, for which oedometer tests showed more important signs of disturbance than the other two clays, have much lower fall cone strengths than the block samples. The lower values observed for the tube samples at 8 m in Emmerstad clay probably only reflect soil variability, since the field vane strength is also lower at that depth.

Unconfined compression tests

Figure 7 summarizes 5 unconfined compression tests run on Emmerstad clay specimens. The results indicate clearly the much higher peak strength and lower failure strain of the block samples. A factor of two in the peak strength is not unusual. The structure of quick clays is definitely preserved more intact by block sampling than by fixed piston sampling. The undrained shear strength of the Emmerstad block specimens in unconfined compression is higher than the peak shear stress measured in consolidated-undrained triaxial compression tests (see next paragraphs for these results). This is due to the high rate of imposed shear strain in the unconfined test.

Triaxial tests

Triaxial compression and extension tests were carried out with the test procedures described by Berre (1981). The specimens were anisotropically consolidated to the in situ effective stresses.

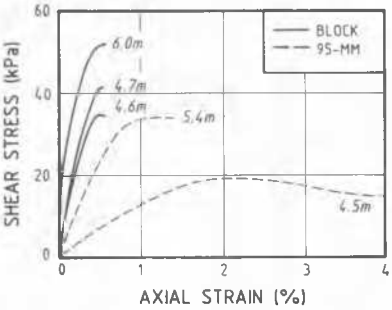


Fig. 7 Unconfined compression tests on Emmerstad clay samples

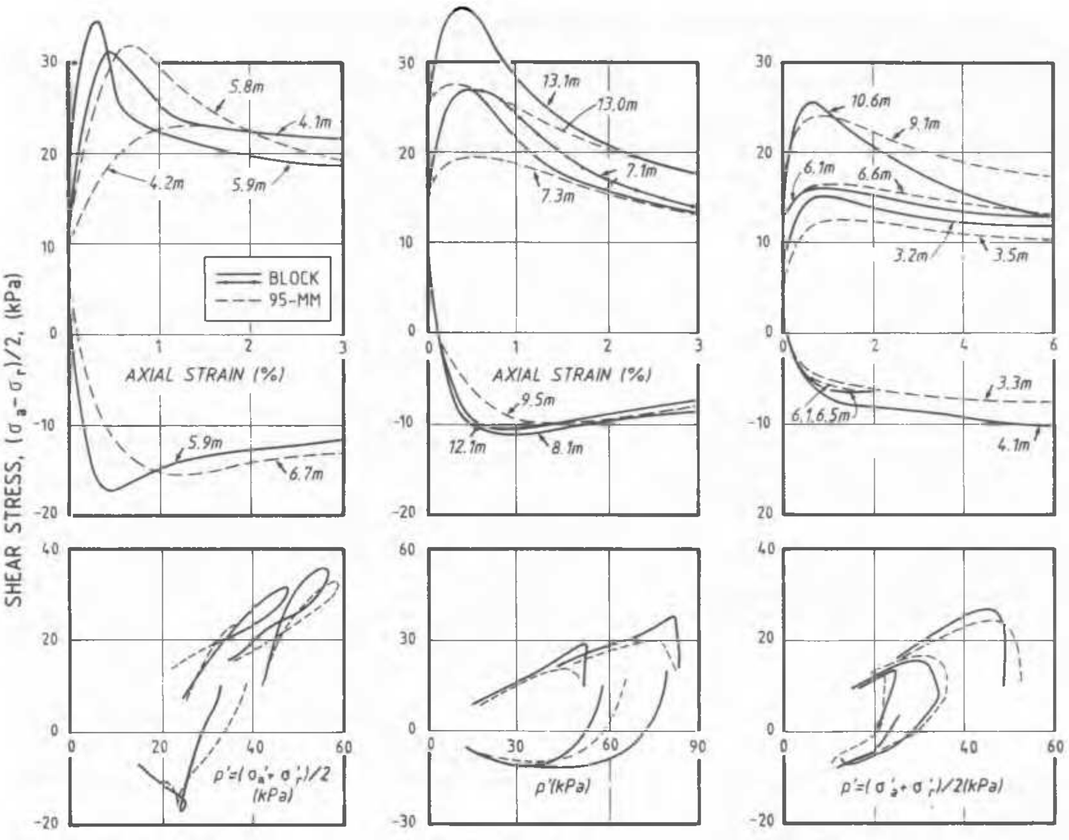
Figure 8 presents typical stress-strain curves and effective stress paths for Emmerstad, Ellingsrud and Onsøy clays. Although the effects on the stress-strain curves are not as dramatic as for the unconfined compression tests, important differences are seen for quick clays. In triaxial compression, the block samples of quick clay are of better quality than the 95-mm fixed piston samples, since the undrained shear strength from tests on block samples are 10 to 33 per cent higher than the strength from tests on 95-mm samples. The failure strains are lower for the block samples, especially in the case of Emmerstad. Because of the higher peak stress and lower failure strains, Young's modulus at 50 per cent of the peak shear stress from block samples can be larger by a factor of 4. Smaller differences are observed in the non-quick Onsøy clay. The extension tests do not exhibit large differences for the two types of samples, except perhaps for Onsøy clay.

The effective stress paths reflect the different pore pressures developed in the block and piston samples. In the overconsolidated Emmerstad quick clay, the excess pore pressures of the block samples are generally lower than those for the 95-mm samples. The Emmerstad clay exhibits unusual effective stress paths (Fig. 8a), compared to other Norwegian clays. In the very soft Ellingsrud and Onsøy clays, the excess pore pressures are similar for both sample types.

To check test repeatability, two triaxial compression tests were run on the Ellingsrud block sample from 7 m. The two tests agree very well and have nearly identical stress paths (Fig. 8b).

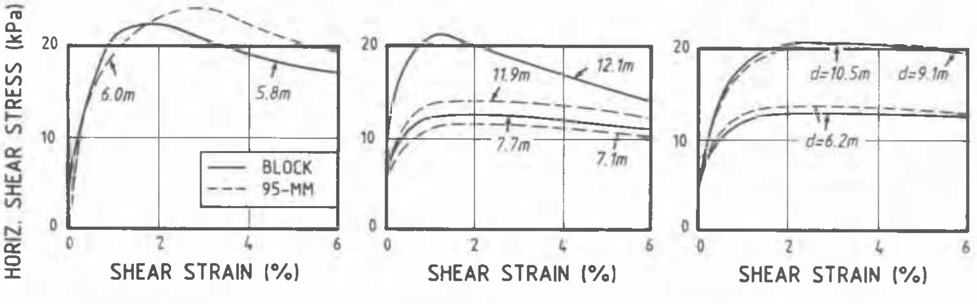
Direct simple shear tests

Only one test series on Ellingsrud clay (12 m) shows important differences between block and 95-mm samples (Fig. 9). Direct simple shear tests may behave differently from triaxial and unconfined compression tests because of the different stress and strain systems imposed, and the stress and strain concentrations particular to simple shear testing.



a) Emmerstad b) Ellingsrud c) Onsöy

Fig. 8 Results of triaxial tests on block and 95-mm samples



a) Emmerstad b) Ellingsrud c) Onsöy

Fig. 9 Results of direct simple shear tests on block and 95-mm samples

Discussion

Tube sampling leads to various degrees of disturbance for different types of clay. The quick clays underwent a loss of peak strength and resistance to deformation due to disturbance during tube sampling, but such was not experienced by the non-quick, more plastic Onsøy clay. The smaller degree of disturbance may be due to the plasticity of Onsøy clay, but it may be also due to the presence of sand and gravel particles in the quick clay deposits. Onsøy clay had no sand sizes, but sand and gravel particles were encountered during sampling of the Emmerstad and the Ellingsrud deposits. The coarse particles could force the sampling tube to move laterally and impose a lateral straining of the clay during sampling.

The effect of sampling disturbance on the test results varies with the type of test. The disturbance effect appears smaller in tests which offer larger confinement. The effect of sampling disturbance is indeed the smallest in the oedometer test, intermediate in consolidated triaxial test and the largest in unconfined compression tests. For a medium-plastic clay, Holm and Holtz (1977) came to similar conclusions for tube samples with diameters between 50 and 127 mm.

Comparisons of unconfined compression tests with undrained triaxial compression tests reconsolidated to the in situ stresses, confirms that the reconsolidation corrects for a large portion of sampling disturbance. Even after reconsolidation however, Young's moduli of tube samples remain lower than those of block samples by a significant factor. Once the natural soil structure is damaged by sampling, it seems that it cannot be restored by reconsolidation to p'_o in the laboratory.

The testing program has clearly indicated that intact Norwegian quick clays are extremely brittle, with axial strains at failure in the triaxial test lower than 0.5% for the "undisturbed" block samples.

CONCLUSIONS

The quality of the block samples was superior to the quality of the 95-mm fixed piston samples. However, the degree of disturbance due to tube sampling varies for different types of clays. In the case of lean quick clays, block sampling resulted in 30% higher peak shear stress and 4 times higher Young's modulus. In the case of the plastic, non-quick, but sensitive Onsøy clay, the blocks and the 95-mm samples had very similar characteristics.

Only small differences were observed in the preconsolidation stress profiles derived from tests on both types of samples, although some sample disturbance effects are seen on the recompression index.

The experience in the Norwegian clays demonstrates the ability of the cylindrical block sampler to obtain samples of excellent quality, even at depths greater than 10 m.

ACKNOWLEDGEMENT

The authors thank their NGI colleagues who contributed to this investigation, especially B. Thune, B. Fjell, G. Olsen, J. Rosenkrantz, and B. Raadim. The assistance of Geonor A/S with the drilling rig is gratefully acknowledged. The authors also thank K. Høeg, O. Eide, K. Karslrud, and G. Aas, for their helpful comments to this paper.

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