STATENS GEOTEKNISKA INSTITUT
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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

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Varia 637

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Photo on cover: SGI large-diameter sampler, Helen Åhnberg (SGI)

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PREFACE

In this project the differences in test results from samples taken by the SGI large-diameter sampler ("Block sampler") and the Swedish standard piston sampler have been studied. A test site in the Göta River valley with both normally sensitive clay and quick clay has been used. Investigations were carried out within the Göta River Commission and by MiljöGeo AB in conjunction with sampling in another project. The laboratory investigations were carried out at the SGI laboratory. The report has been reviewed by Rolf Larsson, Helen Åhnberg and Martin Holmén, SGI.

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The Author

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1 SUMMARY

To obtain good quality samples even in easily disturbed clay, a new large-diameter sampler, ”Block sampler”, has been designed at SGI (Larsson, 2011). The sampler is a hybrid between the Laval sampler and a modified NGI 200 mm sampler.

The aim of this project is to study the differences in test results from samples taken by this SGI “Block sampler” and the Swedish standard piston sampler, particularly in highly sensitive clay and quick clay, but also in normally sensitive clay.

A test site in the Göta River valley that covers both normally sensitive clay and quick clay has been used. At the test site one block sample (of 0,5-1 m) was taken of normally sensitive clay and one block sample of the quick clay. With the standard piston sampler samples of normally sensitive clay and quick clay were taken at the same levels as with the block sampler. On the samples were carried out routine analyses, CRS oedometer tests, direct simple shear tests and active and passive triaxial tests.

The results from the CRS oedometer tests and the direct simple shear tests indicate that specimens of higher quality can be obtained from the ”Block sampler” than from the standard piston sampler, particularly in highly sensitive and quick clays.

The main difference valid for all clays is the stiffness of the samples at small strains and any investigation of this property in the laboratory should use “block” samples.

The differences in evaluated undrained shear strength in this investigation were so moderate, if any, that they hardly motivate block sampling for this purpose in general.

From the results of the triaxial tests it is difficult to draw any conclusions about sample quality.

During the work within this study it became evident that the sensitivity of the stored quick clay samples decreased faster than anticipated. How fast this process is and if it differs between different types of clay needs to be investigated.

2 INTRODUCTION

2.1 Background

Undisturbed sampling for examination and testing of specimens in the laboratory is in Sweden routinely done with the standard piston sampler StI or StII, which are considered equivalent. In soil that is very sensitive to disturbance, such as quick clay, these samplers provide in some cases, samples of insufficient quality and in extreme cases, it is not possible to get any samples at all. Various types of so-called block samplers for collecting samples of high quality are available, (eg the Laval sampler and the Sherbrooke sampler) and the former has been tested in a couple of sites in Sweden. A comparison in Norway between samples from the Sherbrooke sampler, the Norwegian 54 mm sampler and a Japanese sampler, shows differences in the test data that can be very large, especially in sensitive low-plastic clay (Lunne et. al. 1999, Tanaka, 2008). Sampling with block samplers is expensive, laborious and requires considerable resources, why it should be limited to soils sensitive to disturbance or when very high quality samples or almost equal samples are needed.

Samples of high quality are required in laboratory studies on strength- and deformation characteristics and on factors that influence degradation of soil. Today's knowledge is mainly based on samples taken with the Swedish standard piston sampler, why possible differences in test results must be clarified through a comparative study of the properties obtained from the samples taken with the standard piston sampler and some type of block sampler.

In a collaboration between SGI and the University Laval in the early 80's the Laval sampler was tested. This sampler turned out to provide samples of good quality even in easily disturbed quick clay where no samples could be picked up with the standard piston sampler. In normally sensitive clay, the results on samples from the standard piston sampler and the Laval sampler were almost equivalent (Larsson, 1981).

To obtain good quality samples even in easily disturbed clay, a new large-diameter sampler, "Block sampler", has been designed at SGI (Larsson, 2011). The sampler is a hybrid between the Laval sampler and a modified NGI 200 mm sampler. The sampler was used and further developed in conjunction with sampling in another project regarding disturbance effects from cyclic loading (Åhnberg, 2009).

2.2 Purpose and scope of the study

The aim of the project is to study the differences in test results from samples taken by the SGI "Block sampler" and the standard piston sampler, particularly in highly sensitive clay and quick clay, but also in normally sensitive clay.

A test site in the Göta River valley that covers both normally sensitive clay and quick clay has been used. Investigations were carried out within the Göta River Commission and in conjunction with sampling in the above mentioned project (Åhnberg, 2009).

At the test site one block sample (of 0,5-1 m) was taken of normally sensitive clay and one block sample of the quick clay. With the standard piston sampler samples of normally sensitive clay and quick clay were taken at the same levels as with the block sampler. On the samples were carried out routine analyses, CRS oedometer tests, direct simple shear tests and active and passive triaxial tests.

3 TEST SITE TORPA

The Torpa test site is situated on the east side of the Göta Älv River, north of Slumpån river about 10 km south of the municipality of Trollhättan and 60 km north of Gothenburg. The area is used for agriculture. The soil consists of about 2 m dry crust and there under clay to more than 40 m depth. At this site, previous investigations have been carried out within the Göta River Commission. The sampling boreholes in the current study are located close to borehole U07044 along section E22/570 of Subarea 7 (DO7) between Trollhättan and Lilla Edet in the Göta River Commission investigation. This location was chosen because laboratory results from the previous investigation showed quick clay and normally sensitive clay in the same borehole. In borehole U07044 a layer of quick clay was found at about 3 to 4 m depth, there under highly sensitive clay to about 6 m depth and under this normally sensitive clay to about 30 m depth. The sensitivities (S_t) of the quick clay varied between 65 and 85 and the remoulded undrained shear strength τ_R was 0,25 kPa. The normally sensitive clay had sensitivities between 15 and 29.

4 SAMPLING

4.1 Sampling program

4.1.1 Torpa

Sampling has been carried out at two depths in borehole U07044, at 3.5 m depth in the highly sensitive clay and at 8 m depth in the normally sensitive clay. With the block sampler one sample has been taken at 3.5 m depth and one sample at 8 m depth. With the standard piston sampler 7 boreholes with one sampling at 3.5 m depth and one sampling at 8 m depth were carried out close to the borehole for the block samples.

4.2 Standard piston sampler StII

The standard piston sampler and its operation is described in the method description (SGF, 2009). The standard piston sampler StII is about 1 m long. It has an inner diameter of 50 mm and a close-fitting sliding piston, which is slightly coned at its lower face. The detachable cutting edge has a cutting angle of 5º except for the very edge where it is blunted to 45º over maximum 0.3 mm. Inside the sampler are placed five plastic tubes of which three are sample tubes with a length of 170 mm. The piston is locked in the cutting edge while the sampler is pushed down to the sampling level and then hold stationary at the further driving of the sampler during the sampling operation.

4.3 SGI large-diameter sampler (“Block sampler”)

The SGI block sampler and its operation is described in the method description (Larsson, 2011). The sampling tube is about 1 m long with an inner diameter of 200 mm. It is manufactured from a prefabricated seamless “stainless” steel tube with smooth inner surface. The outside of the tube is threaded at both ends. The cutting edge is manufactured from the same prefabricated tube and has the same inner diameter. It has a cutting angle of 5º except for the very edge where it is blunted to 45º over maximum 0.3 mm. At the inside of the edge there is a 3 mm wide and deep groove with a cutting cord pressed into it. One end of the cord is fixed and the other is led through a plastic tube for compressed air to the ground surface. The top part is a round steel plate which can be screwed onto the upper end of the sampling tube. At the centre of the plate, there is a circular hole through which bentonite slurry and soft lumps of soil can flow out when the sampler is pushed down.

At operation the sampler is lowered in a predrilled hole stabilized with bentonite slurry until the edge reaches the carefully prepared bottom. The sampler is then pushed further the total length of the tube and the edge minus 10-20 mm. The hole in the top plate is then sealed and after a suitable rest period the sample is cut off with the cord. At the same time a pneumatic pressure is introduced in the tube and slot created by the cord, which prevents suction below the sample and helps to lift the sample when the sampler is retracted.

5 LABORATORY TESTS

5.1 Test program

At Torpa test site the following laboratory tests have been carried out:

- Index tests; density (ρ), water content (w_N), liquid limit (w_L), plasticity limit (w_P), undrained and remoulded shear strength by fall cone test (τ_k, τ_R), sensitivity (S_t), and organic content by the colorimeter method.
- CRS oedometer tests to determine the compression properties as preconsolidation pressure (σ'_c), oedometer/constrained modulus at stresses below the preconsolidation pressure (M_0), oedometer/constrained modulus at stresses just above the preconsolidation pressure (M_L) and modulus number (M').
- direct simple shear test for determination of undrained shear strength
- active and passive triaxial test for determining the stress-strain relationships, active and passive undrained shear strength and preconsolidation pressure.

At each of the test sites, three tests of each type have been carried out on specimens from block samples and three tests of each type on specimens from standard piston samples.

5.2 Handling of block samples

The handling of the block samples in the laboratory is described in detail in the method description of the block sampler (Larsson, 2011).

As the same laboratory equipment is used for the block samples as for the standard piston samples, the samples have to be divided and trimmed to 50 mm diameter. A specially designed rig is used where the block samples can be cut both vertically and horizontally. The samples are cut in a pattern as shown in Figure 5-1.

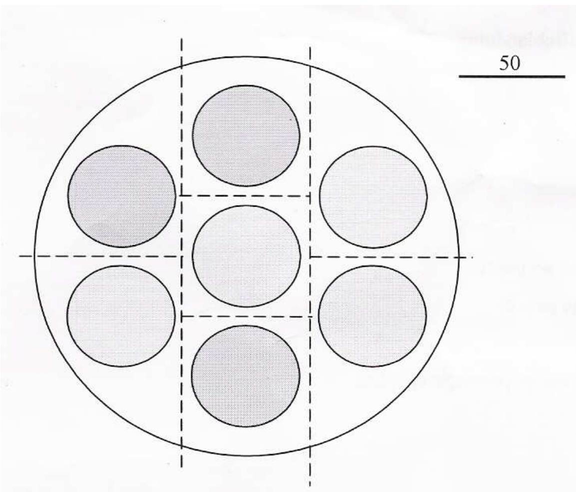


Figure 5-1: Cutting pattern for optimal removal of specimens with 50 mm diameter (Larsson, 2011).

After the block samples have been cut according to Figure 5-1, the subsamples for triaxial tests are trimmed to the right dimension with a wire cutter by placing the sample on a soil lathe. When the specimen has been trimmed to the right diameter, the specimen is placed in a cradle, adapted to the actual diameter and length of the specimen. The ends of the specimen are cut with the wire cutter to have the right length and parallel and plane ends. A special trimming device is used for specimens for oedometer and direct simple shear tests.

5.3 Laboratory tests

CRS oedometer tests were carried out according to the Swedish Standard SS 027126:1991. The CRS oedometer test and evaluation of parameters are also described in Larsson (2008). The parameters obtained are the preconsolidation pressure σ'_c, the effective stress where the modulus starts to increase again, σ'_L, the oedometer modulus M_L and the modulus number M'. Also the modulus before the preconsolidation pressure, M_0, have been evaluated. The permeability, k, and the parameter β_k are also obtained.

Direct simple shear tests were carried out according to the guidelines for direct simple shear tests (SGF, 2004). The parameter obtained is the undrained shear strength.

Anisotropic consolidated undrained active and passive triaxial tests (CAUC-active and CAUC-passive) were in principle carried out according to the Technical Specification SIS-CEN ISO/TS 17892-9, with paraffin oil instead of water as pressure medium. The parameters obtained are apart from the stress-strain relationship, the active and passive undrained shear strengths and the vertical and horizontal preconsolidation pressures. Also Youngs modulus may be evaluated, but the registration have to be done more frequently for the results to be sufficiently accurate.

6 LABORATORY TEST RESULTS FROM TORPA TEST SITE

6.1 Index test results

The index tests of the clay at 3.5 m depth show that it has a water content (w_N) of about 70%, a liquid limit (w_L) of about 60% and a plastic limit (w_P) of about 27%. The density is about 1.58 t/m^3 and the organic content is about 1.2%. It can be seen that, at 3.5 m depth, both in specimens from the standard piston sampler and the block sampler, the sensitivity of the clay (S_t) is between 37 and 47 and the remoulded undrained shear strength (τ_R) between 0.42 and 0.56 kPa. For the clay to be classified as quick the sensitivity should be higher than 50 and the remoulded undrained shear strength should be lower than 0.4. Thus, the clay at 3.5 m depth is not classified as quick, although it is classified as a highly sensitive clay.

The index tests of the clay at 8 m depth show that it has a water content (w_N) of about 76%, a liquid limit (w_L) of about 74% and a plastic limit (w_P) of about 29%. The density is about 1.55 t/m^3 and the organic content is about 1.0 %. The sensitivity of the clay (S_t) is between 16 and 26, and the clay is then classified as medium sensitive. The remoulded undrained shear strength (τ_R) is between 1.84 and 1.50 kPa.

6.2 Results from CRS oedometer tests

6.2.1 Volume change at reconsolidation

The volume change during reconsolidation up to the preconsolidation pressure has been measured for all specimens used in the CRS oedometer tests. It can be seen that all specimens except one fall in the category for good samples. It can also be noted that the volume change of the specimens from the block sampler in general is smaller than the volume change of the specimens from the standard piston sampler, see Figure 6-1. This is an indication of better quality of the block samples.

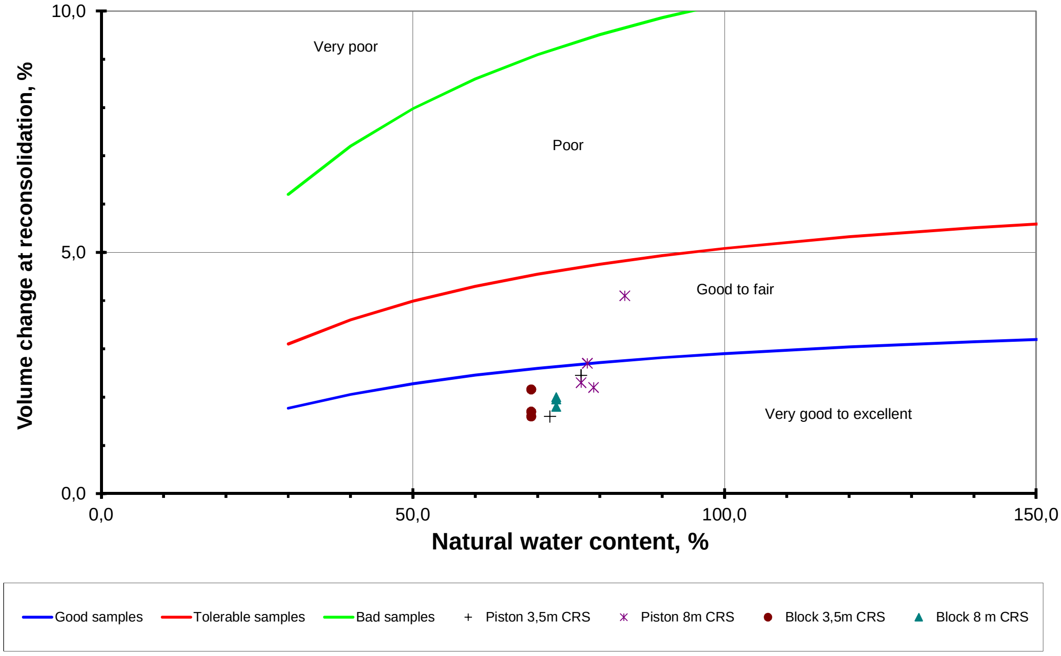


Figure 6-1: Volume change at reconsolidation of the specimens for CRS oedometer tests (from Lunne et. al., 1999).

6.2.2 Preconsolidation pressure and constrained modulus

Figure 6-2 shows axial strain versus effective vertical stress from the CRS oedometer tests on block samples as well as from standard piston samples at 3.5 m depth and 8 m depth. The curves have been adjusted to take initial deformation due to seating problems into consideration. Figure 6-3 shows curves of the constrained modulus versus effective vertical stress, from which the modulus for stresses below the preconsolidation pressure (M_0) and the modulus for stresses just above the preconsolidation pressure (M_L) can be estimated.

A comparison of results of estimated preconsolidation pressure on the highly sensitive clay at 3.5 m depth (Figure 6-2), show both higher preconsolidation pressures and more uniform stress - strain curves from the block samples. However, it should be noted that the empirical estimation of preconsolidation pressure from CRS oedometer tests is based on specimens from the standard piston sampler. Therefore, it is not quite accurate to call the estimated “preconsolidation pressure” from block samples by this method for preconsolidation pressure. Furthermore, it was only possible to estimate the preconsolidation pressure from two of the three CRS-tests on specimens from piston samples at 3.5 m depth. However, this was probably due to other reasons than sample quality.

Also on the normally sensitive clay at 8 m depth a comparison of the results show that also on this normally sensitive clay higher “preconsolidation pressures” and more uniform stress-strain curves were obtained from the block samples.

The “preconsolidation pressure” estimated from the CRS oedometer tests on block and piston samples at 3.5 m and 8 m respectively are shown in Table 6-1.

A comparison of the preconsolidation pressures estimated from CRS oedometer tests with preconsolidation pressures estimated from empirical relations from the undrained shear strength by fall cone tests and field vane tests have been done. At 3.5 m depth the preconsolidation pressures from CRS tests on piston samples are slightly lower than the empirical values and the "preconsolidation pressures" from the block samples are somewhere in the middle. The scatter of the empirical values is quite large. At 8 m depth the preconsolidation pressures from both the block and the piston samples are in the upper range of the empirical values.

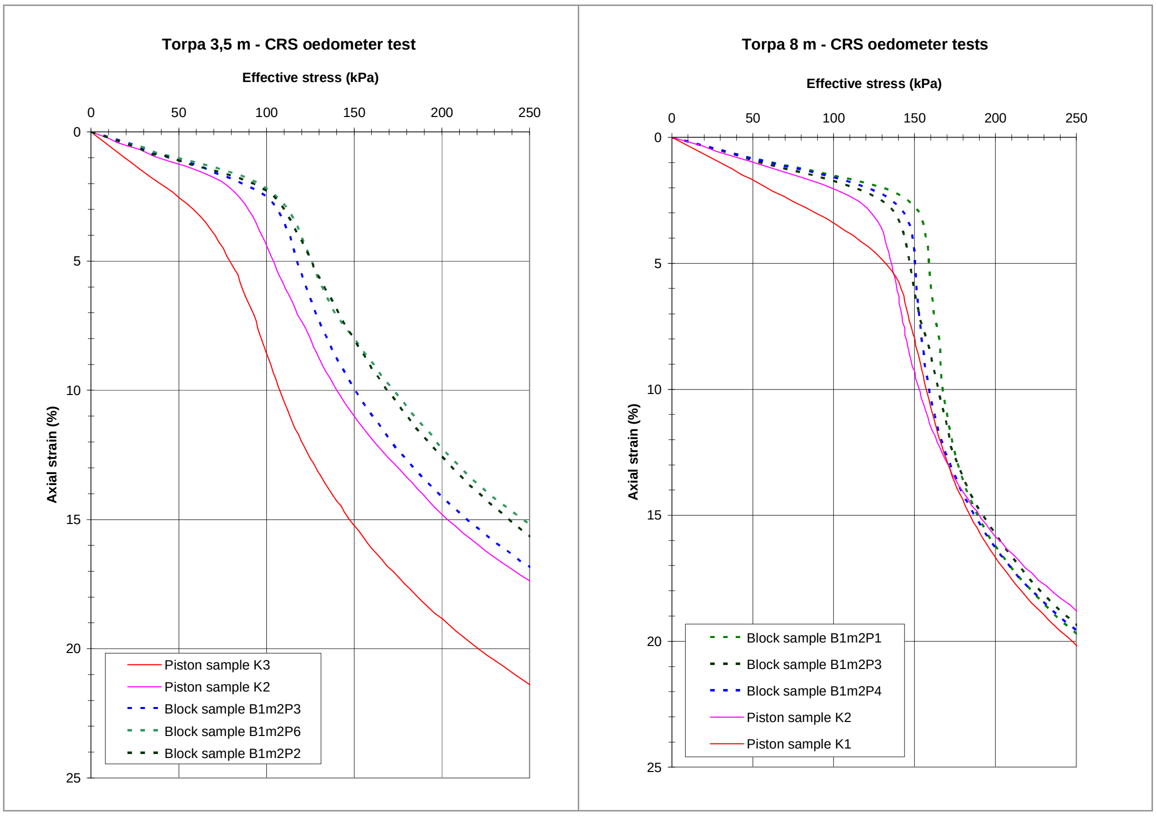


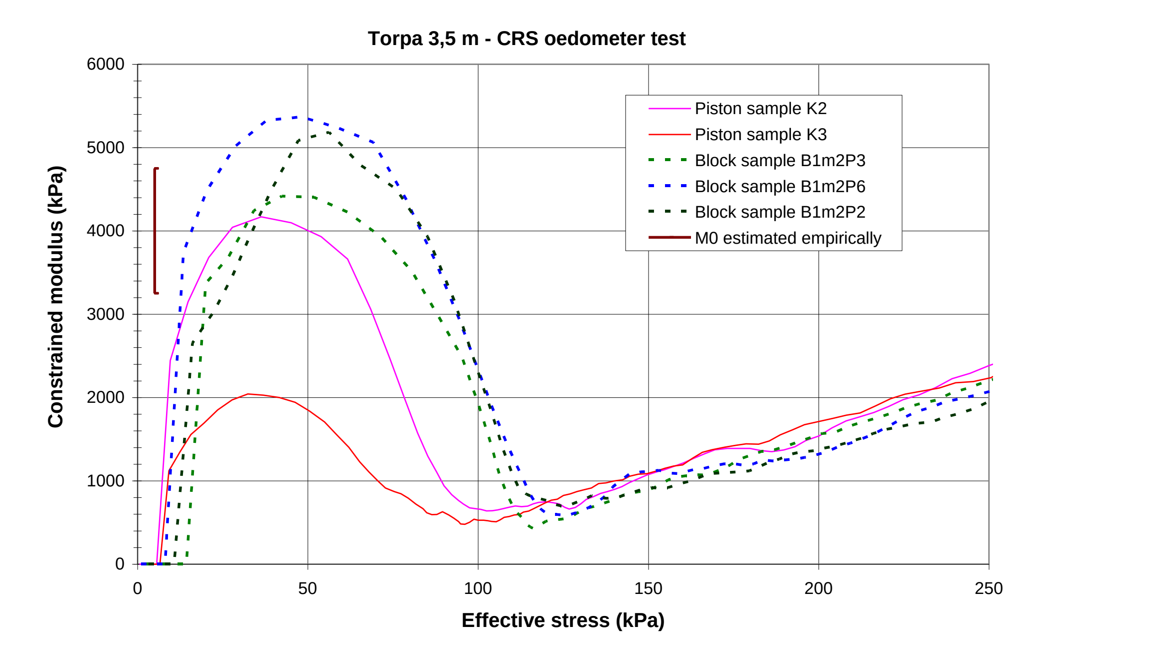
Figure 6-2: Effective vertical stress versus axial strain results from CRS oedometer tests 3.5 m and 8 m depth at Torpa.

Table 6-1: ”Preconsolidation pressure” and constrained modulus estimated from CRS oedometer tests on piston samples and block samples.

Depth (m)	Sample type	σ'c (kPa)	M_0 (kPa)	M_L (kPa)
3.5	piston	72	4100	690
3.5	“	60	2000	520
3.5	“	-	-	-
3.5	block	95	4400	500
3.5	“	93	5100	760
3.5	“	94	5350	645
8	piston	123	5000	375
8	“	114	3000	300
8	“	-	-	-
8	block	127	6600	340
8	“	144	7200	165
8	“	133	5900	135

Comparing the constrained modulus (M_0) for stresses below the preconsolidation pressure, the modulus estimated from tests on block samples are higher than the modulus from the tests on piston samples, both in the highly sensitive clay at 3.5 and the normally sensitive clay 8 m depth, see Figure 6-3. At 8 m depth the modulus M_0 from CRS oedometer tests on block samples are also higher than M_0 estimated from the empirical relation ($M_0 = 250c_u$). At 3.5 m depth M_0 from two of the three CRS oedometer tests on block samples are higher than M_0 from the empirical relation. The modulus M_0 estimated from tests on piston samples show a larger variation both at 3.5 and at 8 m depth. The test with the highest modulus are within the interval of the empirical relation whereas the test with the lowest modulus are below the empirical values at both 3.5 and 8 m depth.

The estimated constrained modulus for stresses above the preconsolidation pressure, M_L, from tests on the block samples are equal or slightly lower than the modulus M_L from piston samples. The lowest value of the constrained modulus above the preconsolidation pressure, i.e. M_L, is obtained at a higher stress level for the block samples than for the piston samples, which is in agreement with the higher preconsolidation pressures of the block samples. However, the same restrictions for the relevance of the evaluation of this stress level also applies.



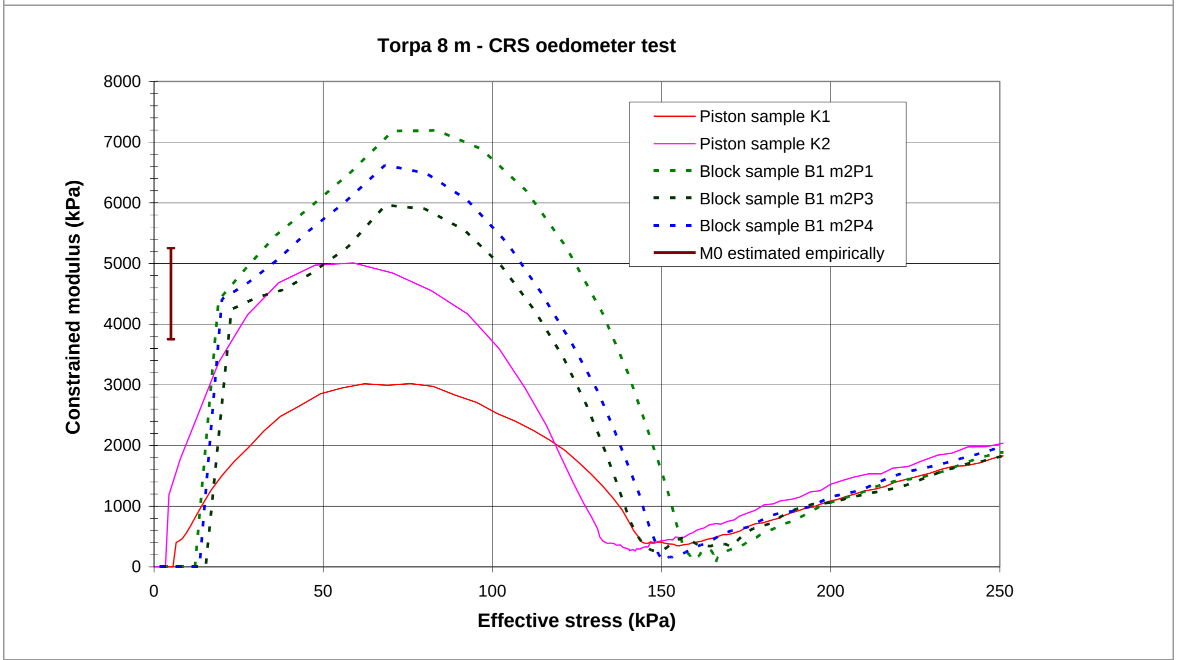


Figure 6-3: Constrained modulus from CRS oedometer tests at 3.5 m and 8 m at Torpa.

6.3 Results from direct simple shear tests

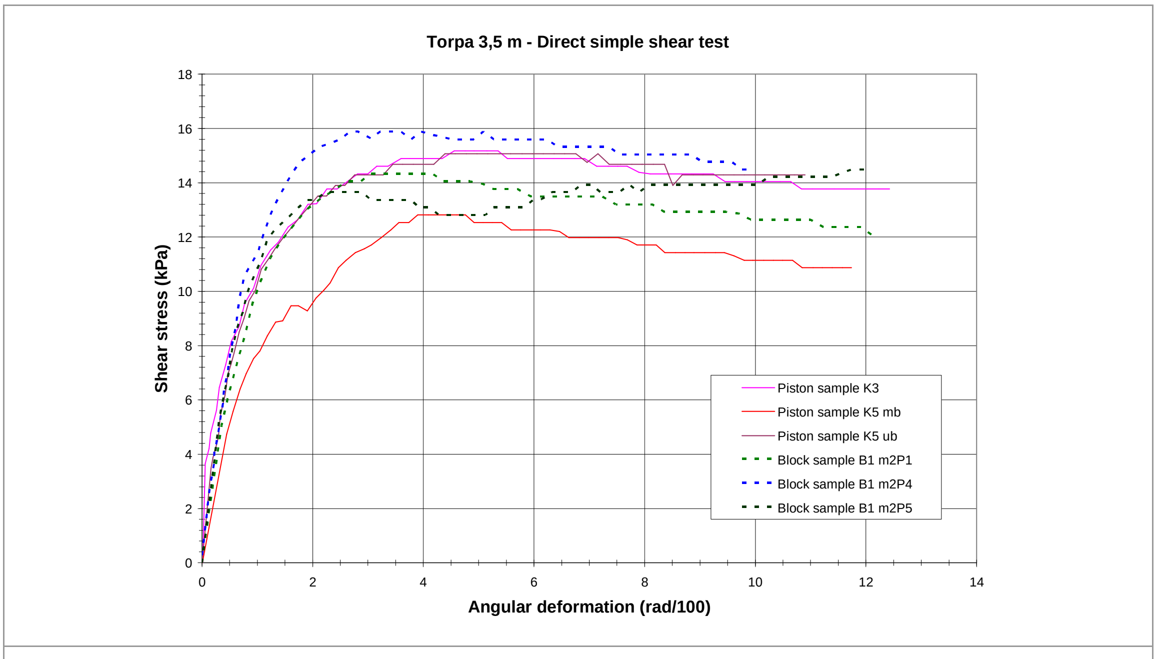
The undrained shear strength estimated from the direct simple shear tests at 3.5 m and 8 m depth are shown in Table 6-2, below.

Table 6-2: Undrained shear strength from direct simple shear tests

Depth (m)	Undrained shear strength Piston samples (kPa)			Undrained shear strength Block samples (kPa)		
3,5	15	12	15	13	14	15
8	24	22	22	22	24	23

Figure 6-4 shows diagrams of the shear stress versus angular deformation for 3.5 m and 8 m depth. There is no great difference in evaluated undrained shear strength between the standard piston samples and the block samples. However, the deformation at failure for the piston samples is generally larger than the deformation at failure for the block samples, which indicates higher quality of the block samples.

The undrained shear strength determined by these direct simple shear tests are in the same range as the undrained shear strength determined by CPT, field vane, fall cone and direct simple shear tests at the same location carried out within the Göta Älv Commission.



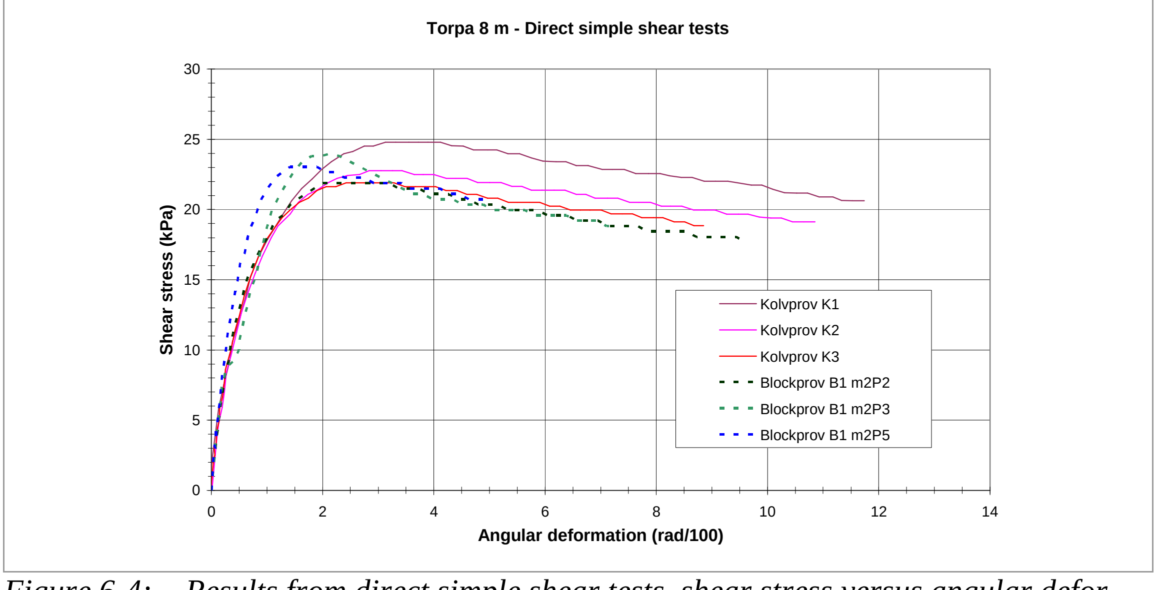


Figure 6-4: Results from direct simple shear tests, shear stress versus angular deformation, at 3.5 m and 8 m depth at Torpa.

6.4 Results from triaxial tests

6.4.1 Volume change at reconsolidation

The volume change and axial strain during reconsolidation have been measured for all specimens used in the triaxial tests. The volume changes are plotted against axial strain in Figure 6-5.

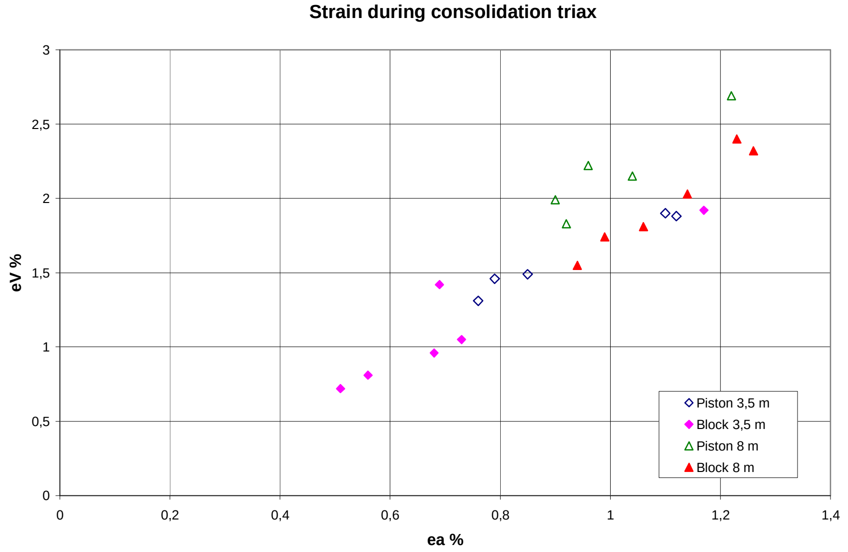


Figure 6-5: Volume change and axial strain during reconsolidation of samples for triaxial tests.

The volume change during reconsolidation of the specimens for triaxial tests have also been plotted in the diagram for estimation of the quality of the specimens, see Figure 6-6. It can be seen that also the specimens for the triaxial tests fall in the category for good samples. The volume change of the specimens from the block samples are in general slightly lower than the volume change of the specimens from the piston samples indicating a slightly better quality of the block samples.

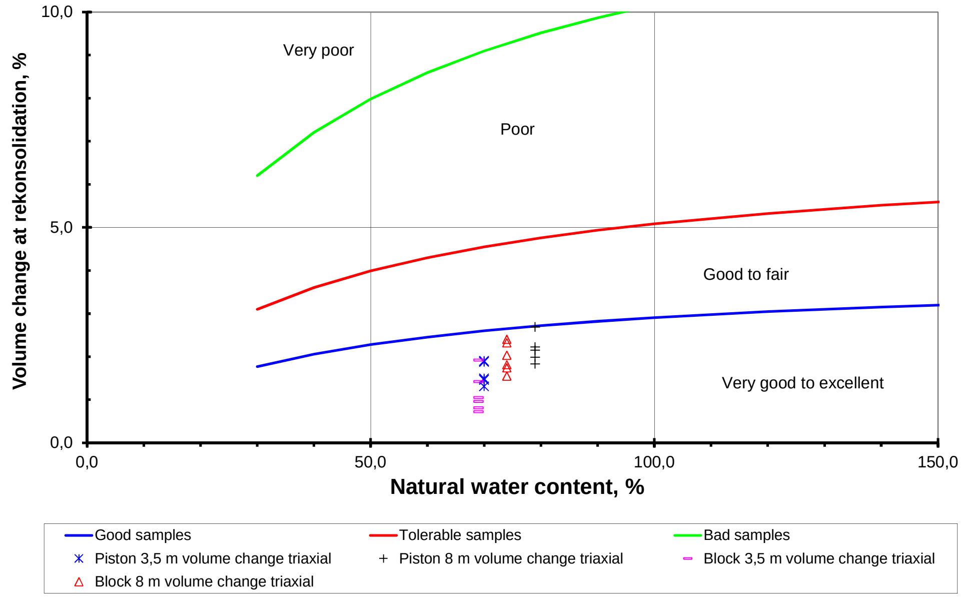


Figure 6-6: Volume change during reconsolidation of specimens used in triaxial tests (from Lunne et.al. 1999).

6.4.2 Results from anisotropically consolidated undrained triaxial compression tests (CAUC-tests)

Figure 6-7 and Figure 6-8 show the shear stress versus axial strain for the CAUC triaxial tests on block samples and standard piston samples at 3.5 m and 8 m depth respectively. The stress paths for these tests are plotted in Figure 6-9 and Figure 6-10.

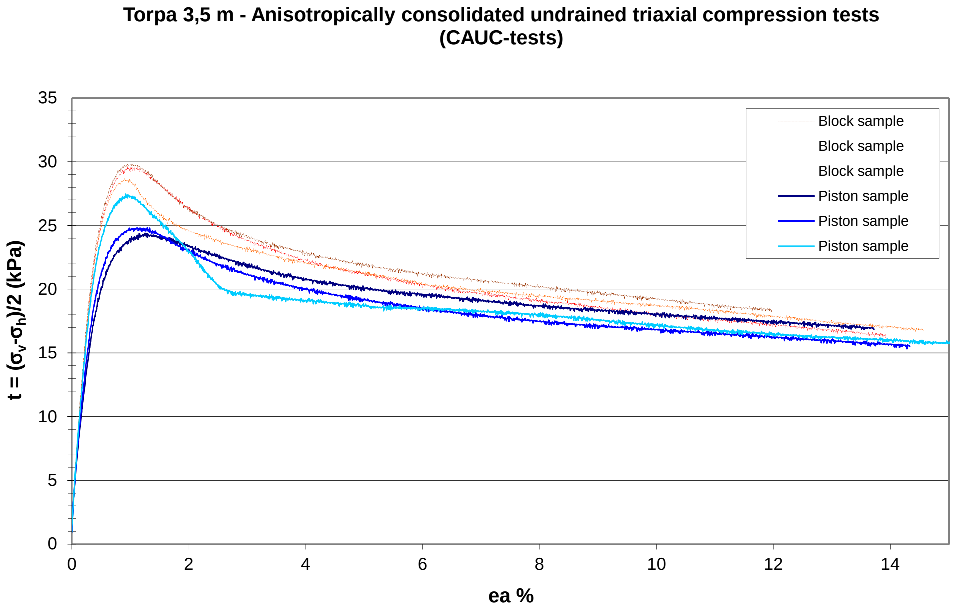


Figure 6-7: Shear stress versus axial strain for the CAUC triaxial tests on block samples and standard piston samples at 3.5 m depth.

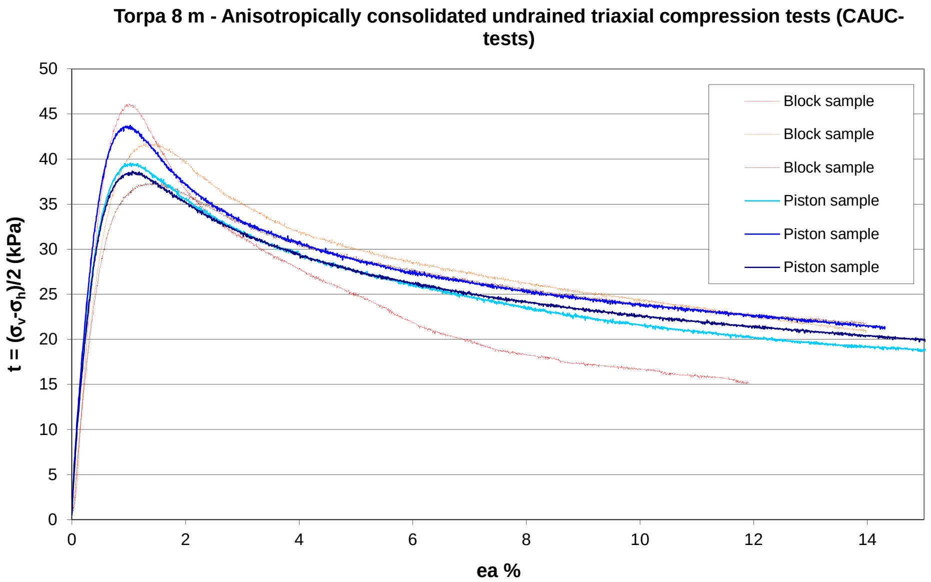


Figure 6-8: Shear stress versus axial strain for the CAUC triaxial tests on block samples and standard piston samples at 8 m depth.

From the tests on specimens of the highly sensitive clay at 3.5 m depth it can be noted that the tests on block samples give higher undrained shear strength than the tests on piston samples. Also the stress paths of the block samples follow each other more closely than the stress paths of the piston samples. The scatter in estimated undrained shear strength between the three specimens is about the same for the piston samples and the block samples.

Looking at the tests at 8 m depth on the normally sensitive clay, there are both higher and lower values of the undrained shear strength from the tests on block samples than from the tests on piston samples. Also an equal difference of the stress paths can be noted for both the tests on block samples and the piston samples.

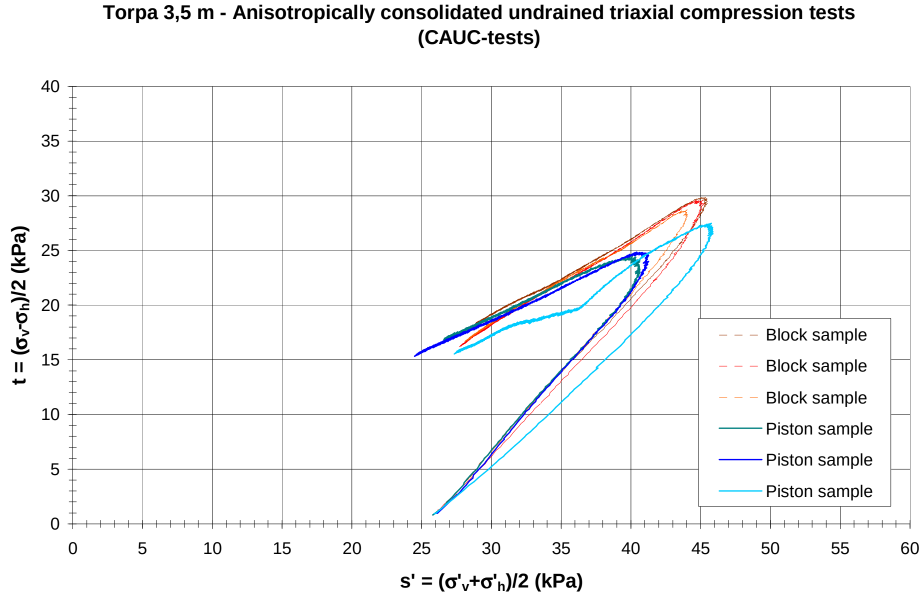


Figure 6-9: Stress paths for the CAUC triaxial tests on block samples and standard piston samples at 3.5 m depth.

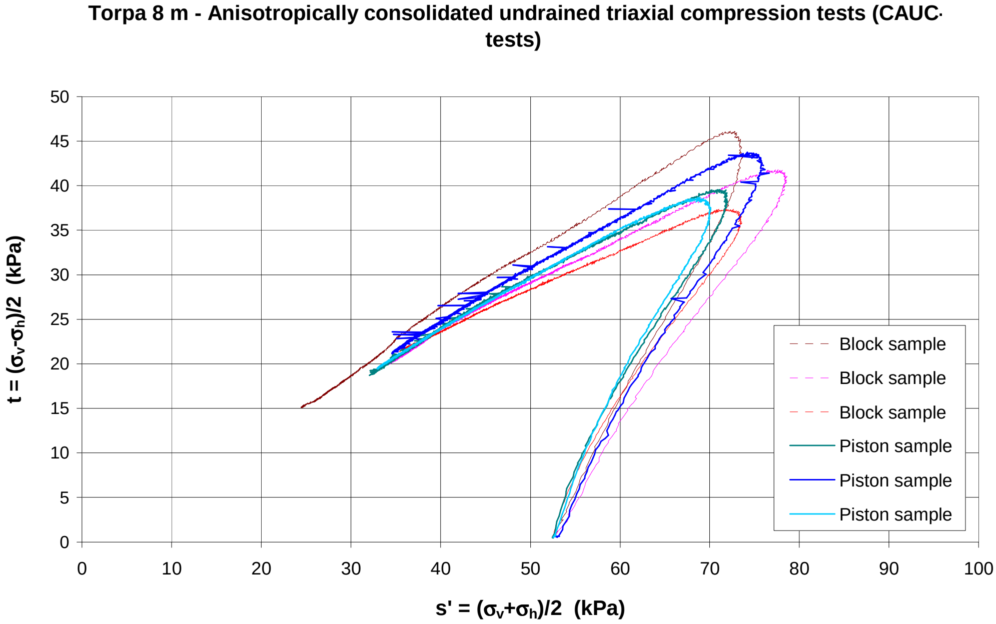


Figure 6-10: Stress paths for the CAUC triaxial tests on block samples and standard piston samples at 8 m depth.

Similar to the results of the CRS oedometer tests on the highly sensitive clay at 3.5 m depth, the estimated vertical preconsolidation pressures from the CAUC triaxial tests on block samples are higher than the preconsolidation pressures from the triaxial tests on piston samples.

The CAUC triaxial tests on normally sensitive clay at 8 m depth give vertical preconsolidation pressures in the same range from the block samples as from the piston samples.

The undrained shear strength and preconsolidation pressures estimated from the triaxial tests are compiled in Table 6-3, Section 6.4.4.

6.4.3 Results from anisotropically consolidated undrained triaxial extension tests (CAUE-tests)

The shear stress versus axial strain for the CAUE triaxial tests on block samples and standard piston samples at 3.5 m and 8 m depth are shown in Figure 6-11 and Figure 6-12. In Figure 6-13 and Figure 6-14 the stress paths from these tests are plotted.

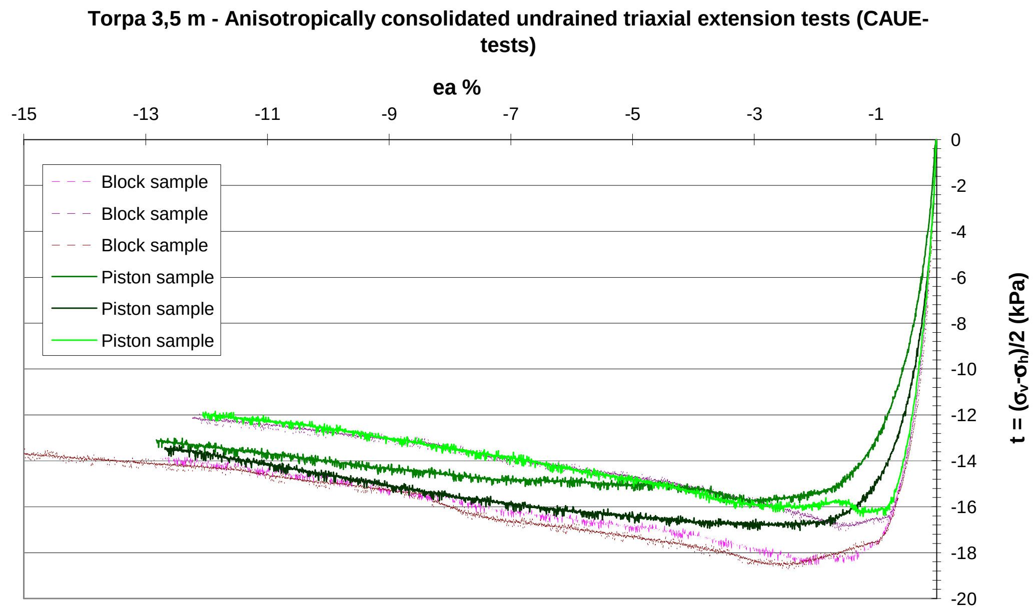


Figure 6-11: Shear stress versus axial strain for the CAUE triaxial tests on block samples and standard piston samples at 3.5 m depth.

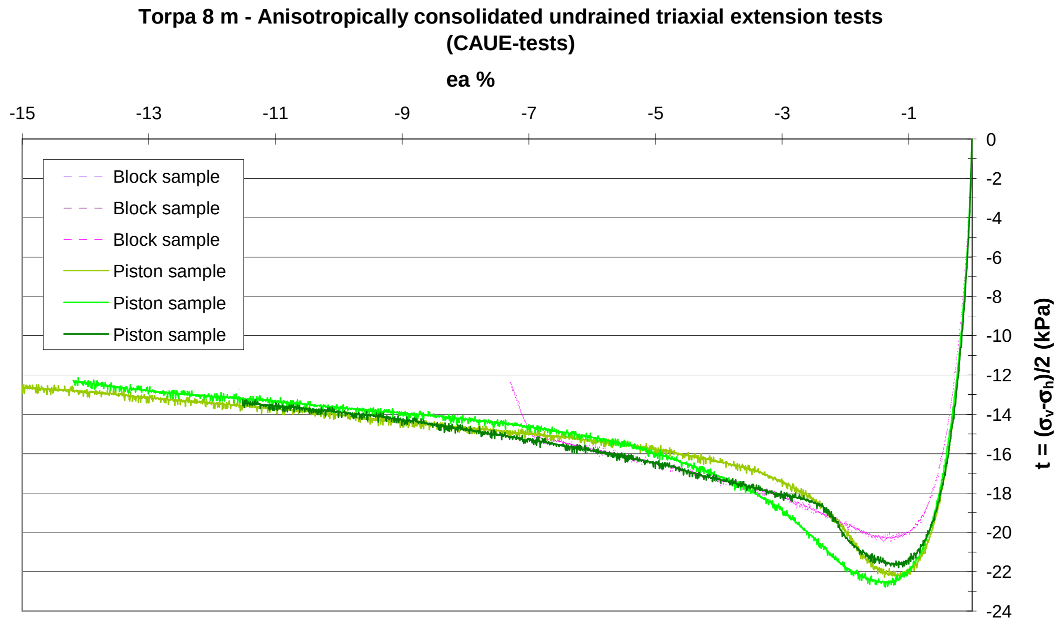


Figure 6-12: Shear stress versus axial strain for the CAUE triaxial tests on block samples and standard piston samples at 8 m depth.

The CAUE triaxial tests in the highly sensitive clay at 3.5 m depth gave higher values of the passive undrained shear strength of the block samples than of the piston samples. On the contrary, in the normally sensitive clay at 8 m depth the tests on piston samples give slightly higher passive undrained shear strengths than the tests on block samples.

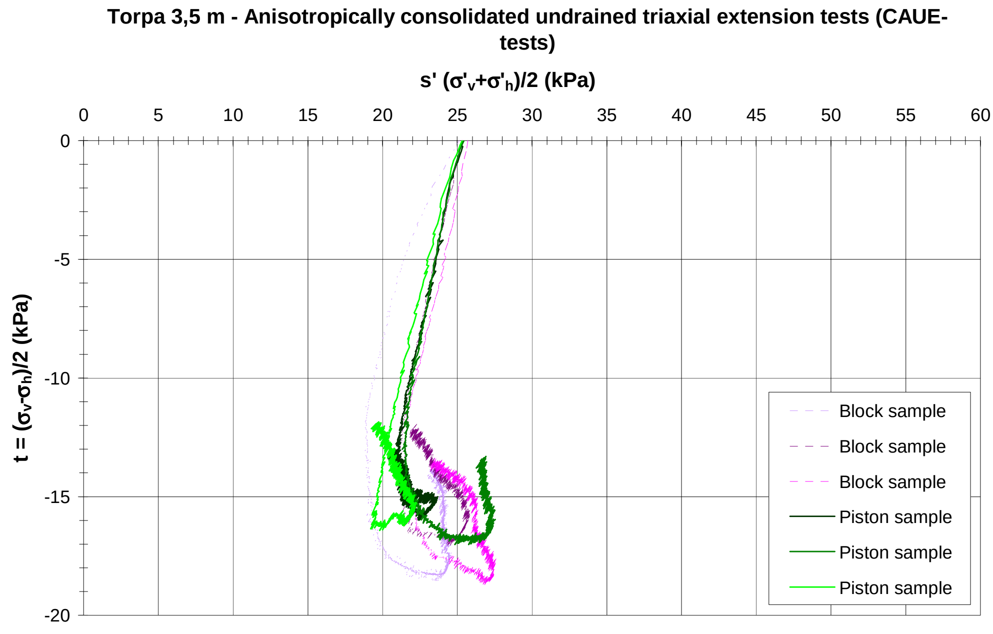


Figure 6-13: Stress paths for the CAUE triaxial tests on block samples and standard piston samples at 3.5 m depth.

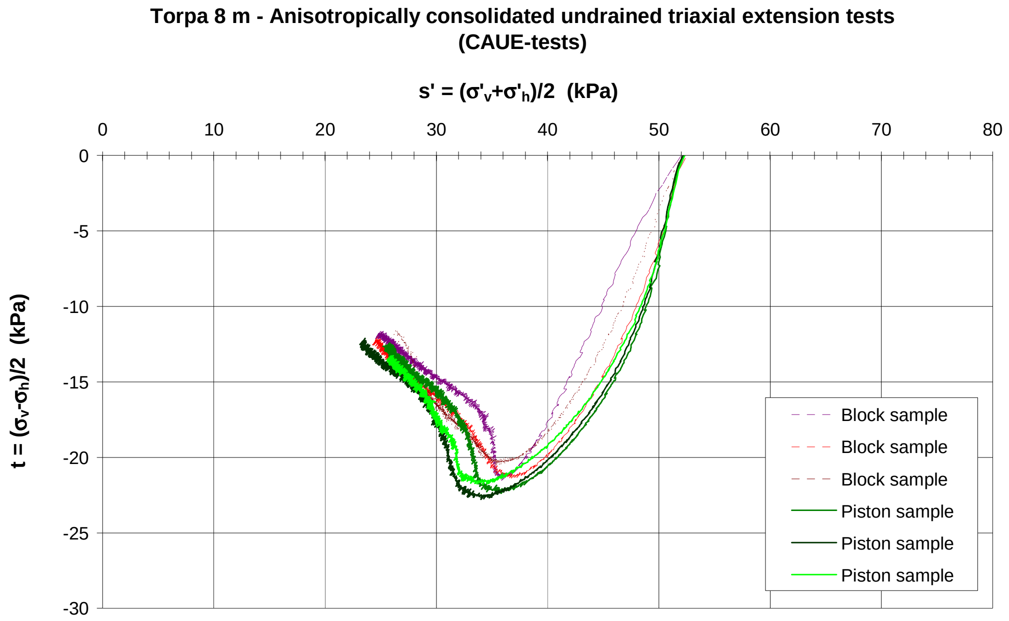


Figure 6-14: Stress paths for the CAUE triaxial tests on block samples and standard piston samples at 8 m depth.

Horizontal preconsolidation pressures estimated from the CAUE triaxial tests in the highly sensitive clay at 3.5 m depth on the block samples are slightly higher than the preconsolidation pressures estimated from tests on piston samples.

At 8 m depth, in the normally sensitive clay, the estimated horizontal preconsolidation pressures from block and piston samples are almost equal.

6.4.4 Compilation of results

Active and passive undrained shear strength and vertical and horizontal preconsolidation pressures estimated from the anisotropically consolidated undrained triaxial tests are shown in Table 6-3, below.

Table 6-3: Active and passive undrained shear strength and vertical and horizontal preconsolidation pressures estimated from the anisotropically consolidated undrained triaxial tests.

Depth (m)	**τ_{fu}^{Active} (kPa)**		**$\tau_{fu}^{Passive}$ (kPa)**		**σ'_{cv} (kPa)**		**σ'_{ch} (kPa)**	
	Piston	**Block**	**Piston**	**Block**	**Piston**	**Block**	**Piston**	**Block**
3.5	27	30	17	18	73	75	44	46
3.5	25	29	16	18	66	74	39	43
3.5	25	28	16	17	65	72	38	42
8	43	46	22	21	162	164	62	60
8	39	42	22	21	150	161	61	59
8	38	37	22	20	145	147	60	58

A comparison of the coefficient of earth pressure at rest in normally consolidated conditions, K_{0NC}, estimated from the vertical and horizontal preconsolidation pressures from the triaxial tests and empirically estimated K_{0NC} has been done. The empirical estimation of K_{0NC} has been based on the relations:

$K_{0NC} \approx 0{,}31 + 0{,}7(w_L - 0{,}2)$ (Larsson, 1977)

The estimated value of K_{0NC} at 3.5 m depth based on this empirical relations is K_{0NC}^{emp} = 0.59. The corresponding value based on the preconsolidation pressures estimated from both the piston and the block samples is K_{0NC} = 0.59.

At 8 m depth, the estimated value of K_{0NC} based on the empirical relations is K_{0NC}^{emp} = 0.69. The corresponding value based on the preconsolidation pressures estimated from the piston samples is K_{0NC} = 0.40 and from the block samples K_{0NC} = 0.37. The most likely reason for these very low K_{0NC} values is that the stress paths for the passive triaxial tests (CAUE tests) at 8 m depth bent off before reaching the horizontal preconsolidation pressure.

7 DISCUSSION

When comparing test results from different types of samplers it must be observed that not only the sampling operation but also the subsequent handling of the samples is different. In this case the piston samples were transported and stored within their plastic sample tubes and extruded from these directly into the oedometer rings and mounting rings for direct simple shear tests or to be cut off in the proper lengths for the triaxial tests. The block samples were transported and stored on a rigid plate and sealed with a mixture of wax and paraffin. They were then opened and cut into subsamples and often resealed again in the laboratory. The specimens for oedometer and direct simple shear tests were trimmed and punched into the rings by special equipment and the specimens for triaxial tests were trimmed to both the right diameter and length using a wire saw and trimming apparatuses.

When comparing the results from the large-diameter ”Block sampler” and the standard piston sampler in this investigation, it should also be observed that all specimens from "block" sampling at a certain level originate from one and the same sampling operation. On the other hand, the specimens from piston sampling originated from a number of sampling operations carried out at the same level in adjacent boreholes.

The observed differences in test results are thus not solely effects of the sampling operations and equipments in themselves but the whole chain of sampling, transport, storing and handling of the samples. This should be kept in mind when looking at the possible differences in test results and at evaluation of the quality of the obtained samples.

The results of the CRS oedometer tests on block samples, both at 3.5 m depth in the highly sensitive clay and at 8 m depth in the normally sensitive clay, show higher values of the estimated preconsolidation pressure and more uniform stress-strain relationships.

The constrained modulus (M_0) estimated from block samples both at 3.5 m and 8 m depth are higher than M_0 estimated from piston samples. M_0 estimated from block samples are also higher than M_0 estimated from the empirical relation ($M_0 = 250\tau_{fu}$).

It should be remembered that the method for estimation of the preconsolidation pressure is based on piston samples. Nevertheless, the results of the CRS oedometer tests are an indication that specimens of higher quality can be obtained from the “Block sampler” than from the standard piston sampler.

The estimated undrained shear strengths from the direct simple shear tests are in the same range for both block and piston samples at both levels. However the deformation at failure is larger for the specimens from piston samples than those from block samples, which may be due to higher quality of the block samples.

The volume changes at reconsolidation of samples for triaxial tests are equal or slightly less for block samples than for piston samples.

Both the active (CAUC) and the passive (CAUE) triaxial tests in the highly sensitive clay at 3.5 m depth give higher values of the undrained shear strength and the preconsolidation pressures in the block samples. In the clay with normal sensitivity at 8 m depth there are both higher and lower values of the undrained shear strength from the active (CAUC) triaxial tests on block samples than from the piston samples. The preconsolidation pressures from block samples are higher or equal. There is also a larger difference in estimated undrained shear strength within the three block samples than within the piston samples. The undrained shear strengths estimated from the passive (CAUE) triaxial tests at 8 m depth are even higher from piston samples than from block samples, whereas the values of the preconsolidation pressures are about equal.

These results from the triaxial tests indicate that in the highly sensitive clay at 3.5 m depth the specimens from the block sampler are of higher quality. On the contrary, in the clay with normal sensitivity at 8 m depth, the specimens from the piston samples are of about equal quality.

Other studies comparing different types of piston samplers with block samplers have in principle come to similar results but often with larger differences. Lunne et.al. (2008) compared results from CRS oedometer tests on samples from the NGI 54 mm piston sampler with the Sherbrooke block sampler, taken in soft marine clay from four test sites in Norway. They concluded that, in general, the preconsolidation pressure estimated from the 54 mm tube sampler were 20-30% lower compared to the block sampler. The constrained modulus (M_0) for stresses below the preconsolidation pressure were about 40% lower for the 54 mm piston sampler. Similarly, Long, et.al. (2009) compared results from CRS oedometer tests and triaxial tests on soft marine Norwegian clay taken by the NGI 54 mm sampler and the Sherbrooke sampler. The block samples were found to be significantly superior to the 54 mm specimens and yielded e.g. up to 50% higher preconsolidation pressures and M_0 values twice as high. The undrained shear strength estimated by triaxial tests on block samples were typically 30% higher than those of the 54 mm piston sampler.

8 CONCLUSIONS

The results from the CRS oedometer tests and the direct simple shear tests indicate that specimens of higher quality can be obtained from the ”Block sampler” than from the standard piston sampler, particularly in highly sensitive and quick clays.

The main difference valid for all clays is the stiffness of the samples at small strains and any investigation of this property in the laboratory should use “block” samples.

The differences in evaluated undrained shear strength in this investigation were so moderate, if any, that they hardly motivate block sampling for this purpose in general. The exception is extremely sensitive soils where it proves to be impossible to take undisturbed samples of high quality with the standard piston sampler.

From the limited number of triaxial tests it is difficult to draw any conclusions about sample quality.

The differences in evaluated preconsolidation pressures were considerable, particularly from the CRS oedometer tests. However, the method for evaluation of preconsolidation pressure and the handling of other parameters from these tests is based on results from piston samples and follow ups of full-scale field cases. A possible use of results from the same type of test performed on block samples should require a similar large research program to be carried out.

9 FURTHER WORK

During the work within this study it became evident that the sensitivity of the stored quick clay samples decreased fast. That the sensitivity decreases with time during storage in the laboratory is known. However, how fast this process is and if it differs between different types of clay needs to be investigated.

Investigations in a second test site needs to be conducted to clarify the difference in sample quality between the standard piston sampler and the ”Block sampler” in quick clay with high sensitivity ($S_t > 200$).

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