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Sherbrooke Block Sampler

Time Effect in Ordinary Sherbrooke Block Sampler contra Mini-block Sampler

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Abstract:
Laboratory work is one of the key factors when gathering information used in geotechnical engineering. It is therefore of great value to have good quality samples, so that the geotechnical parameters determined are as representative as possible to avoid overly conservative design. Sampling in sensitive clays is very challenging. It has been shown that sampling with an ordinary tube sampler gives less reliable results when evaluating the soil conditions compared to results from a block sampler. Sampling using the original Sherbrooke block sampler requires elevation of the drill rig above ground level, due to the large size of the sampler, and the method is relatively costly and time consuming. Modifications of the sampler was therefore done by simply downscaling the original sampler to enable sampling at ground level. The difference in sampler size opens the question if the downscaled sampler, the mini block sampler, retrieves samples of the same quality as the original Sherbrooke sampler, and if the mini block samples survive storage as well as the original.

To answer these questions, extensive laboratory work was carried out at the geotechnical laboratory at NTNU. Index tests, oedometer and triaxial tests were performed at samples from both mini block and the original Sherbrooke block samplers, retrieved at the NGTS quick clay site at Flotten, Trondheim. An XRD analysis was also done by the Department of Geoscience and Petroleum at NTNU to determine the mineral composition of the soil.

Based on the sample quality criteria and the results from the laboratory investigations it may be concluded that the mini block samples are of the same quality as the Sherbrooke block samples. Results from triaxial tests conclude the same; the peak undrained shear strength s_u and the strain at failure ε_f are the same for both mini block and Sherbrooke block samples. However, oedometer results may conclude the opposite; specimens from the mini block sampler are more disturbed than those from the Sherbrooke block sampler, considering lower values of preconsolidation stress p'_c, overconsolidation ratio *OCR* and oedometer modulus for overconsolidated clay M_{OC}. These oedometer results should be treated with caution considering difficulties experienced during testing. Evaluation of the effect of storage shows that mini block samples survives storage just as well as the Sherbrooke block samples based on the sample quality criteria. Regarding the index properties, mini block samples survives almost as well as the Sherbrooke block samples. The main differences before and after storage for the mini block samples are the water content, unit weight and the undrained shear strength s_u determined from the falling cone test. Almost no change was detected for the oedometer and triaxial tests before and after storage for the mini block samples, except for the triaxial tests from 7 m.

Keywords:

1. Sherbrooke block sampler
2. Mini block sampler
3. Laboratory testing
4. Effect of storage on block samples

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Sherbrooke Block Sampler

Time effect in Ordinary Sherbrooke Block Sampler contra Mini-Block Sampler

Tidseffekter i ordinær Sherbrooke blokkprøvetaker kontra mini blokkprøvetaker

The original Sherbrook block sampler (Lefebvre and Poulin 1979) was developed to minimize the sampling disturbance and has shown great success, e.g. in Norway used as base information in NGI's database for CPTU – interpretation, (Karlsrud et. al. 2005).

Sampling in sensitive clays, as in Canada and Norway, is very challenging. The shortcomings of the ordinary tube sampling often mask the real information on the soil characteristics and results from block sampling are therefore considered far more reliable in evaluation of soil conditions.

The original block sampler is large and in practical use it requires elevation of a standard drill rig about 1 meter above ground. This was the reason to do the modification into the mini block sampler, simply by downscaling the original version to enable sampling by the drill rig at the ground surface.

Samples taken with the mini block sampler show very good results, but the difference in sampler size opens the question if the quality is comparable to the quality of samples taken with the original Sherbrooke sampler. Further, do the mini block samples survive storage as well as the original Sherbrooke samples, and if not, what are the differences?

These questions are the background for the thesis work. The issue shall be investigated on clays from the NGTS (Norwegian Geo Test Sites) site for quick clay at Flotten in Tiller in Trondheim.

NTNU Geotechnical engineering will provide samples and background information on the Flotten clay. The sampling program shall cover soils in non-sensitive and sensitive clay, with samples taken with original Sherbrook sampler and mini block sampler in different depths at the site.

The samples shall be tested 1) immediately (i.e. as soon as possible) and 2) after a period of two weeks. The testing program shall include index testing, XRD, CRS and CAUC.

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Lefebvre G, Poulin C. 1979. A new method of sampling in sensitive clay. Canadian Geotechnical Journal **16**(1): 226-233
Karlsrud, K., Lunne, T., Kort, D.A. and Strandvik, S. (2005) CPTU correlations for clays. ICSMFE 16, Osaka, 2, pp. 693-702

Preface

This master's thesis in geotechnical engineering is a part of the MSc in Civil and Environmental Engineering at the University of Science and Technology (NTNU), Trondheim, Norway. The work presented herein was conducted in the fall of 2017.

Trondheim, 2017-12-31

Pernille Rognlien

Pernille Rognlien

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Finally, I would like to thank PhD Candidate Helene Alexandra Amundsen and NTNU Research Assistants Dirk van Oosterhout and Johannes Osorio Mydland for their help and support throughout this fall.

P.R.

Summary and Conclusions

Laboratory work is one of the key factors when gathering information used in geotechnical engineering. It is therefore of great value to have good quality samples, so that the geotechnical parameters determined are as representative as possible to avoid overly conservative design. Sampling in sensitive clays is very challenging. It has been shown that sampling with an ordinary tube sampler gives less reliable results when evaluating the soil conditions compared to results from a block sampler. Sampling using the original Sherbrooke block sampler requires elevation of the drill rig above ground level, due to the large size of the sampler, and the method is relatively costly and time consuming. Modifications of the sampler was therefore done by simply downscaling the original sampler to enable sampling at ground level. The difference in sampler size opens the question if the downscaled sampler, the mini block sampler, retrieves samples of the same quality as the original Sherbrooke sampler, and if the mini block samples survive storage as well as the original.

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Based on the sample quality criteria and the results from the laboratory investigations it may be concluded that the mini block samples are of the same quality as the Sherbrooke block samples. Results from triaxial tests conclude

the same; the peak undrained shear strength s_u and the strain at failure ε_f are the same for both mini block and Sherbrooke block samples. However, oedometer results may conclude the opposite; specimens from the mini block sampler are more disturbed than those from the Sherbrooke block sampler, considering lower values of preconsolidation stress p'_c, overconsolidation ratio OCR and oedometer modulus for oveconsolidated clay M_{OC}. These oedometer results should be treated with caution considering difficulties experienced during testing. Evaluation of the effect of storage shows that mini block samples survives storage just as well as the Sherbrooke block samples based on the sample quality criteria. Regarding the index properties, mini block samples survives almost as well as the Sherbrooke block samples. The main differences before and after storage for the mini block samples are the water content, unit weight and the undrained shear strength s_u determined from the falling cone test. Almost no change was detected for the oedometer and triaxial tests before and after storage for the mini block samples, except for the triaxial tests from 7 m.

Sammendrag og Konklusjoner

Laboratoriearbeid er en av nøkkelfaktorene når det kommer til innhenting av informajson som brukes i geotekniske beregniner og prosjektering. Det er derfor viktig å ha god kvalitet på prøvene som skal testes, slik at de geotekniske parameterne som skal bestemmes blir så pålitelige som mulig, for å unngå overdimensjonerte, overkonservative og kostbare løsninger.

Prøvetaking i sensitiv leire er veldig utfordrende. Det har blitt vist at prøvetaking med en vanlig 54 mm sylinderprøvetaker gir mindre pålitelige resultater når en evaluerer in situ forholdene i jorda, sammenlignet med resultater fra blokkprøver. Prøvetaking med en Sherbrooke blokkprøvetaker forutsetter at borriggen installeres over bakkeflatenivå, da størrelsen på denne blokkprøvetakeren er veldig stor. Denne metoden er meget kostbar og tidkrevende. Derfor ble det utviklet en nedskalert versjon av denne blokkprøvetakeren som var liten nok til borriggen kunne stå på bakken. Forskjellen i blokkstrørrelsen mellom de to prøvetakerne setter spørsmålstegn ved om blokkprøvene tatt med den nedskalerte blokktakeren gir prøve av like god kvalitet som de som er tatt med den originale Shebrooke blokkprøvetakeren. Det settes også spørsmålstegn ved om blokkene fra en mini blokkprøvetaker tåler lagring like godt som prøver tatt med den originale blokkprøvetakeren.

For å svare på disse spørsmålene har det blitt gjort grundige laboratorieforsøk. Indeks tester og ødometer og treaksiale forsøk har blitt utført på prøver fra både mini blokkprøvetakeren og Sherbrooke blokkprøvetakeren. Alle prøvene er tatt fra NGTS' test område på Flotten i Trondheim. En XRD analyse har også blitt utført for å bestemme mineralsammensetningen av jorda.

Basert på kriterier om prøvekvalitet og resultatene fra laboratoreforsøkene kan det konkluderes med at mini blokkprøvene er av samme kvalitet som Sherbrooke blokkprøvene. Resultater fra de treaksiale forsøke konkluderer med det samme; de udrenerte skjærstyrkene og tøyningsnivåene ved brudd er de samme for prøver fra begge prøvetakerne. Ødometer resultatene derimot konkluderer med det motsatte; mini blokkprøver synes å være mer forstyrret ettersom basert på prekonsolideringsspenninger, overkonsolideringsforhold og ødometermodulen for overkonsoliderte leirer. Resultatene fra ødometertestene bør likevel behandles og vurderes med aktsomhet ettersom det oppsto flere problemer under testing.

Vurdering av effekten av lagring viser at mini blokkprøvene tåler lagring like godt som Sherbrooke blokkprøvene når man ser på kriteriene for prøvekvalitet. Basert på resultater fra indeks tester så ser det ut som at mini blokkprøvene får noen endringer i vanninnhold, enhetsvekt og skjærstyrke.

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Chapter 1

Introduction

1.1 Background

1.1.1 Problem Formulation

Laboratory work is one of the key factors when gathering information used in geotechnical engineering. It is therefore of great value to have good quality samples, so that the geotechnical parameters determined are as representative as possible to avoid overly conservative design. The quality of samples generally increases with the diameter of the sampling equipment (Lacasse et al., 1985) and research shows that Sherbrooke block samples are usually of superior quality compared to other sampling methods (Poirier et al., 2005; Tanaka et al., 1996).

Sampling in sensitive clays is very challenging, and especially difficult in highly sensitive, low plastic clays (Karlsrud and Hernandez-Martinez, 2013). Retrieving high quality samples in material like this is therefore important if reliable results when evaluating the soil conditions should be achieved.

Sampling using the original Sherbrooke block sampler requires elevation of the drill rig above ground level, due to the large size of the sampler, and the method is relatively costly and time consuming. Modifications of the sampler was therefore done by simply downscaling the original sampler to enable sampling at ground level. The difference in sampler size opens up for to main questions:

- Does the downscaled sampler, known as the mini block sampler, retreiev samples of the same quality as the original Sherbrooke block sampler?
- Does the mini block sampler survive storage as well as the original Sherbrooke block sampler?

1.1.2 Literature Survey

In Chapter 2 the results of the literature survey are presented. The survey presents a description of the test site where the samples tested in this thesis are retrieved from. Next, a brief description of the original Sherbrooke block sampler (Lefebvre and Poulin, 1979) and the downscaled mini block sampler (Emdal et al., 2016) is presented. The literature survey does also include sample disturbance (DeGroot et al., 2005; Emdal et al., 2016; Amundsen et al., 2015) and sample quality criteria (Lunne et al., 1997; Andresen and Kolstad, 1979).

1.1.3 What Remains to be Done?

At the current time, there are no data available which compares the effect of storage between mini block and Sherbrooke block samples. Little information comparing sample quality of the two methods exists. In general, very few articles and other sources of information concerning the mini block sample and its performance compared to the original sampler exists.

1.2 Objectives

A large amount of work remains to be done on the topic of mini block samplers and how they perform compared to the original Sherbrooke block sampler. This master's thesis is therefore limited to the following objectives:

1. Literature survey on block sampling
2. Review literature on sample quality criteria of Lunne et al. (1997) and Andresen and Kolstad (1979)
3. Perform index tests on specimens from the NGTS quick clay site at Flotten, retrieved with both mini block and Sherbrooke block sampler
4. Perform CRS oedometer tests on specimens from the NGTS quick clay site at Flotten, retrieved with both mini block and Sherbrooke block sampler
5. Perform CAUc triaxial tests on specimens from the NGTS quick clay site at Flotten, retrieved with both mini block and Sherbrooke block sampler
6. Perform XRD analyses on one specimen from the NGTS quick clay site at Flotten
7. Compare p'_c, M_{OC}, OCR and sample quality criteria of oedometer specimens from mini block and Sherbrooke block samples, tested both immediately and after two weeks of storage
8. Compare s_u, ε_f and sample quality criteria of triaxial specimens from mini block and Sherbrooke block samples, tested both immediately and after two weeks of storage

9. Correlate the results from oedometer tests to NGI's database for CPTU-interpretation (Karlsrud et al., 2005)

1.3 Limitations

The main limitation for this thesis has been time, since the master's thesis is restricted to a certain amount of weeks. Only certain depths was therefore chosen when it came to retrieving block samples; above and within the assumed depth of a possible quick clay layer.

1.4 Approach

To answer the main two questions presented in the problem formulation above, extensive laboratory work was carried out at the geotechnical laboratory at NTNU. Index tests, oedometer and triaxial tests were performed at samples from both mini block and the original Sherbrooke block samplers, retrieved at the NGTS quick clay site at Flotten, Trondheim. An XRD analysis was also done by the Department of Geoscience and Petroleum at NTNU to determine the mineral composition of the soil. The approach of objective 1 and 2 is to find and study the literature proposed by supervisor Arnfinn Emdal, as well as other relevant literature. Objective 3, 4 and 5 will be approach by performing laboratory investigations. Objective 6 will be met by ordering and XRD analysis and sending a representative sample of the Flotten clay to the chemical/mineralogical laboratory at NTNU. Objective 7 and 8 will be met through comparing all the results found in objective 3, 4 and 5. Objective 9 will be met by plotting the values of OCR and s_{uc}/σ'_{v0} found through laboratory investigations, into the OCR vs. s_{uc}/σ'_{v0} plot presented by Karlsrud et al. (2005).

1.5 Structure of the Report

The rest of the thesis is divided into five chapters. Chapter 2 presents the literature survey on block samples and sample quality, as well as a brief description of the NGTS quick clay test site where all samples are retrieved from. Chapter 3 describes the laboratory investigation carried out on the samples, chapter 4 presents the results found from laboratory investigations and chapter 5 discusses and evaluates the results from the laboratory investigations. Finally, chapter 6 gives a summary of the findings in this thesis as well as recommendations for further work.

Chapter 2

Background

2.1 Norwegian Geo-Test Sites

Norwegian Geo-Test Sites (NGTS) is a research and development program supported by the Research Council and Norway Infrastructure program. It is led by NGI and also includes NTNU, SINTEF/UNIS and the Norwegian Public Roads Administration. The program has five national test sites in Norway, which are representative for specific soil types. These five soil types include; soft clay, quick clay, silt, sand and permafrost (NGI, 2017). The quick clay site is located at Flotten in Trondheim and is the area where all soil samples treated in this master thesis are retrieved from.

Figure 2.1: NGTS quick clay site location at Flotten in Trondheim, Norway (Kartverket, 2017).

2.1.1 Site Description

Flotten is located at Tiller, approximately 10 km south-east of Trondheim, Norway. The marine limit in the area lies at + 171 m above sea level according to NGU (2017). The site which lies at ca. + 125 m above sea level (Kartverket, 2017) is located within a quick clay hazard zone (NVE, 2017). Fig. 2.2 shows today's soil situation, which is primary characterized as thick marine deposits with ravines and slide scars. The most known landslide in the Tiller area in historical times was the Tiller quick clay landslide in 1816, where 550.000 m^2 of soil slid out killing 15 people (Reite, A. J. and Sveian, H. and Erichsen, E., 1999). The slide took place approximately 1 km north-west of where the samples were retrieved (NGU, 2017).

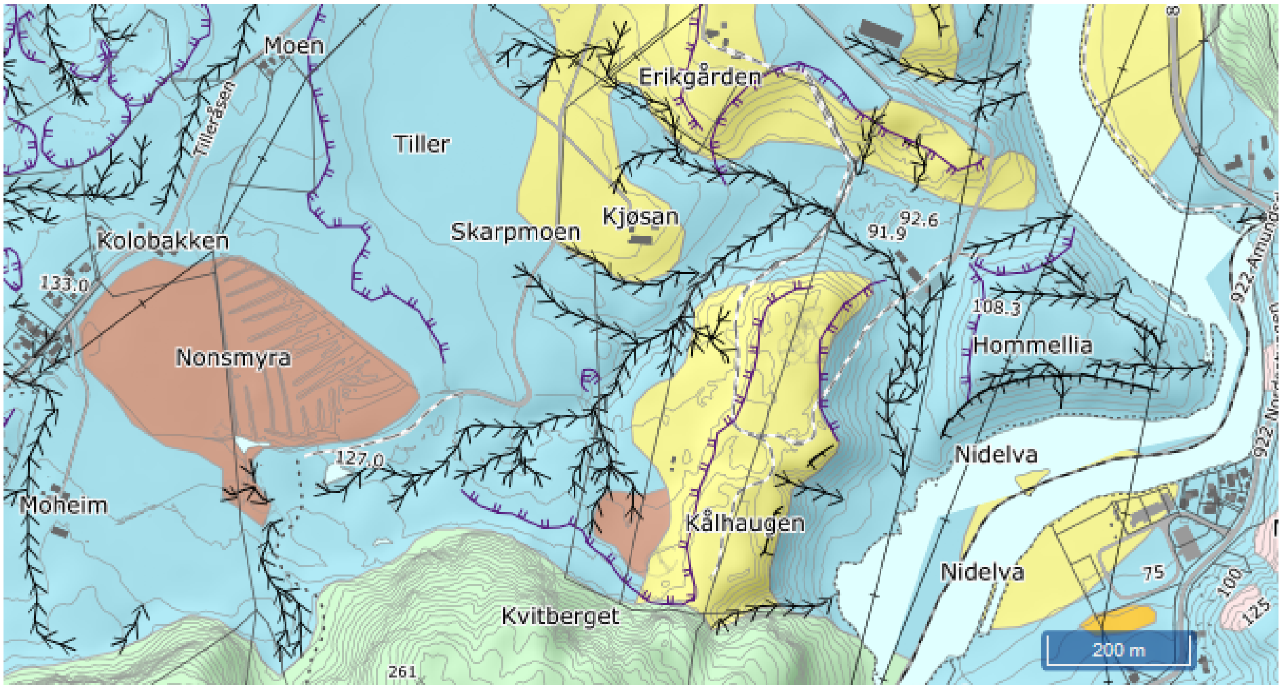


Figure 2.2: Detailed map of superficial deposits. The red arrow indicates the approximate location of where the samples are retrieved from. Blue color indicates thick marine deposits, brown symbolizes peat and swamp and yellow is fluvial deposits. Modified after (NGU, 2017).

According to Gylland et al. (2013), most of the material which were deposited, derived from glacial erosion of metamorphosed greenstones, meta-sediments and volcanic rock types. 40 % of the clay fraction are quartz and feldspar (mostly K-feldspar and plagioclase), while illite and chlorite dominate the clay fraction. Only normal sedimentation processes are known for the area, no outstanding loading events are known except for the overburden of the inland glacier, thus one should expect the soil strata to be overconsolidated (Gylland et al., 2013).

2.2 Sampling Methods

The original Sherbrooke block sample was developed to minimize sampling disturbance. According to DeGroot et al. (2005, p. 97), "research has shown that block sampling, such as that with the Sherbrooke sampler, is considered the best method of collecting high quality samples of soft clays". The sampling methods used in this thesis are sampling with a Sherbrooke block sampler (250 mm diameter) and a mini block sampler (160 mm diameter). The two samplers will be described briefly in the following sections.

2.2.1 Sherbrooke Block Sampler

The development of what is now known as the Sherbrooke block sampler started in 1975 at the University of Sherbrooke in Quebec, Canada. The motivation for developing this block sampling method was that the existing method involved carving out blocks in a deposit at the bottom of an open trench. This method was often limited to shallow depths of 3 - 4 m due to cost and difficulties related to deep excavations, as for instance the clay's resistance to bottom heave, to mention one (Lefebvre and Poulin, 1979). The Sherbrooke block sampling method requires a pre-drilled borehole large enough to fit the sampler, which has an outside diameter of 410 mm, see Fig. 2.3.

Figure 2.3: Block sampling at Flotten using a Sherbrooke block sampler.

Because of the size of the sampler, elevation of the drill rig above ground level is required, see Fig. 2.4

Figure 2.4: The drill rig was elevated above ground level using a trailer.

The sampling method is basically using water jets with an annular motion to flush and carve out a cylinder of soil with a diameter of 250 mm. Water exits through openings on the bottom of three hollow arms and if sufficient water pressure and flow is present, the water can carve out a cylinder of soil as the sampler is rotating. This water helps stabilize the borehole wall and the water jets transport cutting debris. After a soil cylinder of full length, approximately 350 - 400 mm, is carved out, horizontal bottom cutters are released, cuts the bottom of the soil cylinder and form a support under the sample when retrieving it from the borehole (Emdal et al., 2016; Lefebvre and Poulin, 1979). The sample is cleaned for surface debris after it is retrieved, before it is sealed with plastic film and packed upright in boxes that provide damping of vibrations, see Fig.

2.5. Styrofoam pellets are used between the container wall and the sample to absorb vibrations and shocks and to support the sample during transportation and storage (DeGroot et al., 2005).

(a) (b) (c)

Figure 2.5: Block samples retrieved from the ground at Flotten using a Sherbrooke block sampler. a) Sample with debris, b) Sample cleaned for debris and c) Sample wrapped in plastic foil in container.

2.2.2 Mini Block Sampler

The mini block sampler was developed at the Geotechnical Division of the Norwegian University of Science and technology (NTNU) in Trondheim, Norway, motivated by issues relating to the high costs and time consumption of the Sherbrooke block sampler. It is important to emphasize that NTNU did not invented the block sampler - it is simply a down-scaled version of the Sherbrooke block sampler. The main difference between the two samplers is that the outer diameter of the mini block sampler is reduced to 230 mm, which gives a sample diameter of 160 mm (Emdal et al., 2016). Otherwise, the sample height is not much different, a maximum of 300 mm, and the operating principles stay the same. See Fig. 2.6 for a technical drawing of the mini block sampler. Experience shows that the sampler is efficient in use when it comes to soil material more sensitive to sample disturbance. According to Emdal et al. (2016, p. 1237), one can achieve the following advantages by reducing the outer diameter: efficient rigging and sampling, elevation of the drill rig above ground level is not required, favourable health and safety aspects, simple and fast pre-augering, small and easy to handle casing, off-the-shelf casing size, two operators sufficient, and easy sample handling due to relatively low size and weight. For further elaboration about the mini-block sampler, see Emdal et al. (2016).

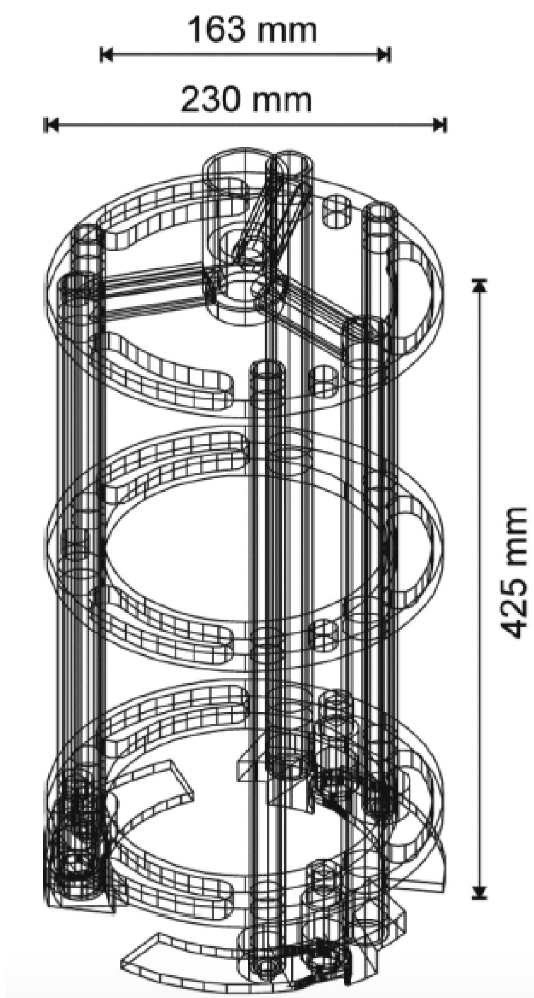


Figure 2.6: Technical drawing of the mini block sampler (Emdal et al., 2016).

2.3 Correlations for Clays Tested on Sherbrooke Block Samples

A database containing correlations between CPTU factors, undrained shear strength and overconsolidation ratio has been developed for soft to medium stiff clays based on results from testing on Sherbrooke block samples (Karlsrud et al., 2005). The results from oedometer and triaxial testing carried out in this master's thesis will be correlated to the OCR vs. s_{uc}/σ'_{v0} plot presented by Karlsrud et al. (2005). The plot is shown in Fig. 2.7.

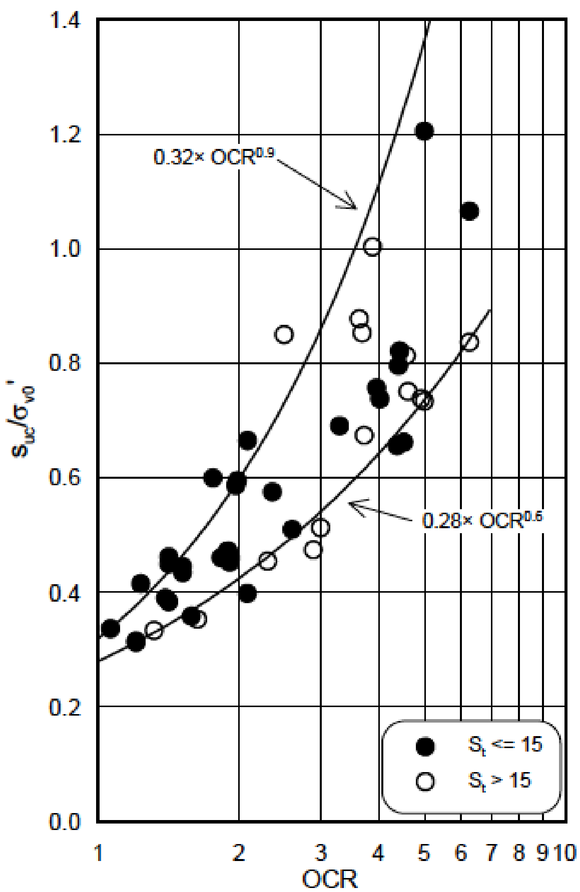


Figure 2.7: Normalized CAUc strength values, s_{uc}/σ'_{v0}, for block samples in relation to OCR (Karlsrud et al., 2005).

2.4 Sample Disturbance

A sample is potentially prone to disturbance in each stage of the sampling process to final preparation in the laboratory (DeGroot et al., 2005; Emdal et al., 2016). Differences between in situ conditions and parameters found in the laboratory are usually caused by sample disturbance (Amundsen et al., 2015).

2.4.1 Disturbance due to Sampling and Handling of Samples

According to Amundsen et al. (2017) as well as Karlsrud and Hernandez-Martinez (2013), DeGroot et al. (2005) and Carrubba (2000), sample disturbance is primarily caused by borehole drilling, sampler type, sealing, transportation, thermal variations, storage method, trimming and handling during preparation for testing, stress relief during and after sampling and changes in the physicochemical properties. When drilling the open borehole, the total vertical stress is reduced and the sample experiences stress relief (DeGroot et al., 2005). It is impossible to not have any changes in total and effective stress during sampling (Amundsen et al., 2015). After a block sample is taken out of the ground, negative pore water pressure develops (Amundsen et al., 2017) followed by swelling, as well as change in strength and deformation properties (Amundsen et al., 2015). Swelling may also impact the volume change during consolidation of the sample to in situ conditions, which is used as an indicator in the $\Delta e/e_0$-criterion for sample quality (Amundsen et al., 2016).

Samples may be exposed to vibration and temperature variations during transportation and storage (DeGroot et al., 2005). According to Amundsen et al. (2016), will the suction in the sample reduce with time, causing swelling, if a block sample is stored. Arman and L. (1976, p. 86) states that "long-term storage of soil cores results in serious deterioration of the shear strength and lowering of the measured preconsolidation pressure". When preparing the sample for laboratory testing, stress relief while trimming and disturbance while trimming and mounting of the sample may occur. Even if the sample is reconsolidated to in situ stresses, unrealistic stress-strain behavior may occur due to disturbance which causes significant volumetric changes (DeGroot et al., 2005). Sharp cutting tools and wire saws should be used when trimming or cutting into the samples. Also potentially disturbed material should be removed.

2.4.2 Sample Disturbance in Relation to Sample Diameter

Lacasse et al. (1985) compared results from oedometer and triaxial tests on block samples and 95 mm piston samples, finding that the block samples gave the best quality and that sample quality in general increases with the diameter of the sampling equipment. The results differed the most for the sensitive, low plasticity clays, which indicates that sampling of such materials should preferably be carried out using a block sampler. Norwegian Geotechnical Insitute (NGI) also confirms that good quality samples cannot be produced with a 54 mm piston sampler at depth of 10 - 20 m, and that "high-sensitivity low-plasticity clays are the worst" (Karlsrud and Hernandez-Martinez, 2013, p. 1274). Clays with layers of silt or sand are prone to reduction of soil suction due to internal drainage of pore water (Amundsen et al., 2016). It has been concluded that a larger diameter sampler provides better quality samples in soft marine clay (Amundsen et al., 2015). Small specimens trimmed from large samples in the laboratory increases the sample quality and provide better test results (Arman and L., 1976; Emdal et al., 2016).

When clay samples are disturbed, the preconsolidation stress p'_c and the undrained shear strength s_u decrease, while the failure strain increases. These are the most significant effects of sample disturbance. (Emdal et al., 2016). At small strains the shear stress decreases with increasing sample disturbance, and at large strains the shear stress increases (Lunne et al., 2006).

2.4.3 Sample Quality Criterion

Two criterions for sample quality are used in this thesis; $\Delta e/e_0$-criterion and ε_{vol}-criterion. Lunne et al. (1997) proposed the $\Delta e/e_0$-criterion for evaluating sample disturbance, which can be found in Tab. 2.1. The criterion is based upon the change in pore volume divided the initial pore volume when a sample is consolidated to the assumed in situ effective stress level (Karlsrud and Hernandez-Martinez, 2013). The initial void ratio is calculated using values from index tests and can be calculated using Eq. 2.1.

$$e_0 = \frac{V_p}{V_s} = \frac{\gamma_s(1+w)}{\gamma} - 1[-] \tag{2.1}$$

where V_p is the volume of voids, V_s is the volume of solids, γ_s is the unit weight of solids, w is the water content and γ is the unit weight. The water content was determined from spare material after trimming the sample, both for triaxial and oedometer test. The change in void ratio Δe can be found using Eq. 2.2.

$$\Delta e = \frac{\Delta V_p}{V_s}[-] \tag{2.2}$$

Due to not determining the water content from the actual sample, but from the spare material after trimming, V_s could not be found using the relation $V_s = (m_s \cdot g)/\gamma_s$, since m_s was not measured. Therefore another method was used to determine Δe. The change in volumetric strain $\Delta\varepsilon_{vol}$ can be calculated using Eq. 2.3.

$$\Delta\varepsilon_{vol} = \frac{\delta \cdot A}{h_0 \cdot A} = \frac{\Delta V_p}{V} = \frac{\Delta V_p}{V_p + V_s} = \frac{\Delta e}{e_0 + 1}[-] \tag{2.3}$$

where δ is the deformation at the in situ stress, h_0 is the initial sample height and A is the area of the cross section of the sample. For the oedometer test h_0 = 20 mm and $A = 20\,\text{cm}^2$ were used. Calculation of $\Delta\varepsilon_{vol}$ from triaxial testing was calculated based on the ratio between the change in volume in the consolidation phase and the initial volume of the sample, $V_0 = 229\,\text{cm}^3$. The change in volume was based on the total amount of expelled water measured by the burette. The reason why the cross section area of the triaxial sample was not used to calculate the volumetric strain is because the sample does not have an entirely circular area due to trimming. Rearranging Eq. 2.3, the change in void ratio Δe can determined, see Eq. 2.4.

$$\Delta e = \Delta\varepsilon_{vol}(e_0 + 1)[-] \tag{2.4}$$

Table 2.1: Criterion for sample disturbance proposed by Lunne et al. (1997).

	$\Delta e / e_0$			
OCR	Very good to excellent quality	Good to fair quality	Poor quality	Very poor quality
1 - 2	<0.04	0.04 - 0.07	0.07 - 0.14	>0.14
2 - 4	<0.03	0.03 - 0.05	0.05 - 0.10	>0.10

The other criterion for sample quality was described by Andresen and Kolstad (1979). The criterion uses volumetric strain ε_{vol}, which is based on the ratio between the change in pore volume and the initial total volume, to evaluate the sample quality, see Eq. 2.5. The criterion is shown in Tab. 2.2.

$$\varepsilon_{vol} = \frac{\Delta V}{V_0} \tag{2.5}$$

where V_0 is $40\,\mathrm{cm}^3$ and $229\,\mathrm{cm}^3$ for oedometer and triaxial samples, respectively. ΔV for triaxial test is the total amount of expelled water measured by the burette, and for oedometer test $\Delta V = \delta \cdot A$.

Table 2.2: Criterion for sample disturbance described by Andresen and Kolstad (1979).

OCR [-]	Depth [m]	Perfect quality epsvol < [%]	Acceptable quality <epsvol < [%]	Disturbed quality eps vol > [%]
1 - 1.2	0 - 10	3.0	3.0 - 5.0	5.0
1.2 - 1.5	0 - 10	2.0	2.0 - 4.0	4.0
1.5 - 2	0 - 10	1.5	1.5 - 3.5	3.5
2 - 3	0 - 10	1.0	1.0 - 3.0	3.0
3 - 8	0 - 10	0.5	0.5 - 1.0	1.0

Chapter 3

Laboratory Investigations

This chapter gives a brief description of the laboratory investigations performed on the block samples, as well as how the block samples were treated after sampling. The laboratory investigations include index tests, oedometer tests and triaxial tests. Many pilot tests were run in advance, before the block samples from Flotten were retrieved. This was done to establish a better execution of the testing procedures, giving more accurate results for comparison. All tests were carried out by the author at the geotechnical laboratory at NTNU Trondheim.

3.1 Storage and Treatment of Block Samples

The mini block samples were sampled between the 20th of September and the 23rd of October 2017, and the Sherbrooke block samples were sampled between the 23rd and 27th of November 2017. The distance between the mini block and Sherbrooke block sample series are approximately 5 m. After the block samples were extracted from the ground, surface debris were removed before wrapping the samples with plastic foil. The samples were placed in containers and the void between the container walls and the sample was filled with Styrofoam pellets for damping of vibrations during transportation. When arriving at the laboratory, the samples were stored in a temperature regulated room, holding an average of 4 - 5 ° C. The samples were tested as soon as possible after sampling and then again after 2 weeks of storage.

In theory, there is room for four triaxial samples in the plane on the mini block sample, in two levels. In other words, it would be possible to get eight triaxial samples from one mini block sample. However, it was decided to only retrieve two triaxial samples from two levels, giving a total of four triaxial samples from each mini block sample. The rest of the material from each block was used for index testing and oedometer testing. For the Sherbrooke block samples, four triaxial samples were retrieved from each level, giving a total of eight triaxial samples from each Sherbrooke block sample. The mini block and Sherbrooke block samples were divided as shown in Fig. 3.1 and Fig. 3.2, respectively.

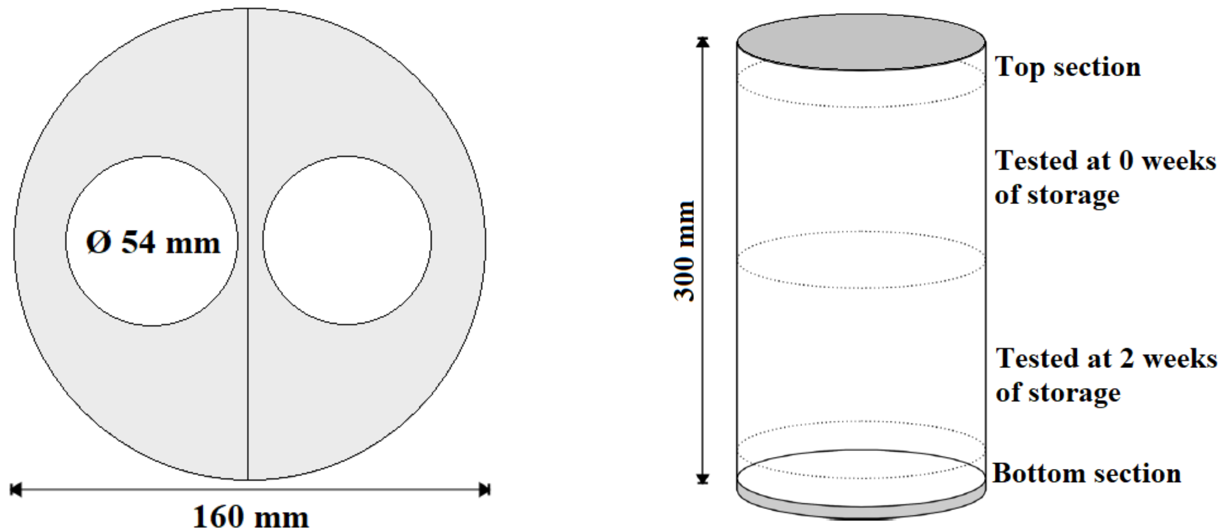


Figure 3.1: Subdivision of mini block sample. Left figure shown plan view and right figures shown elevation view.

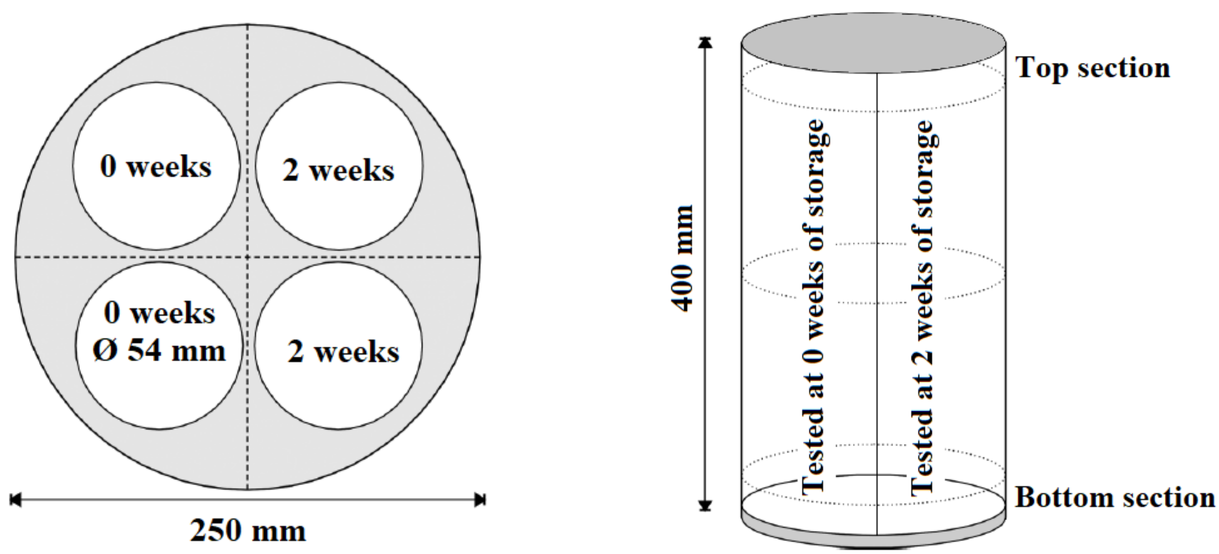


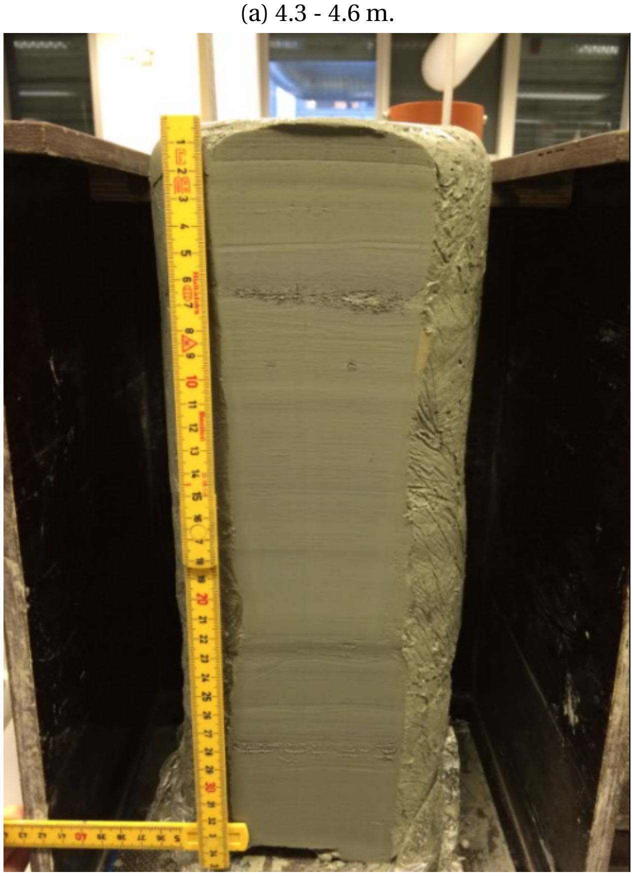
Figure 3.2: Subdivision of Sherbrooke block sample. Left figure shown plan view and right figures shown elevation view.

3.2 Visual Description of the Block Samples

All of the mini and Sherbrooke block samples seemed to be clay with layers and/or lenses of fine sand and/or silt. The top and bottom section, as well as the surface was assumed to be disturbed and not used in the laboratory tests. The shallower samples at depth of 4 m contained some coarser grains of sand and gravel. No visible plant fibres were found in any of the samples. See Fig. 3.3a to 3.3d and Fig. 3.4a to 3.4d for layering of the mini block samples, and figure 3.5 for layering of the Sherbrooke block samples.

(a) 4.3 - 4.6 m.

(b) Gravel found in mini block sample 4.3 - 4.6 m.



(c) 4.6 - 4.9 m.

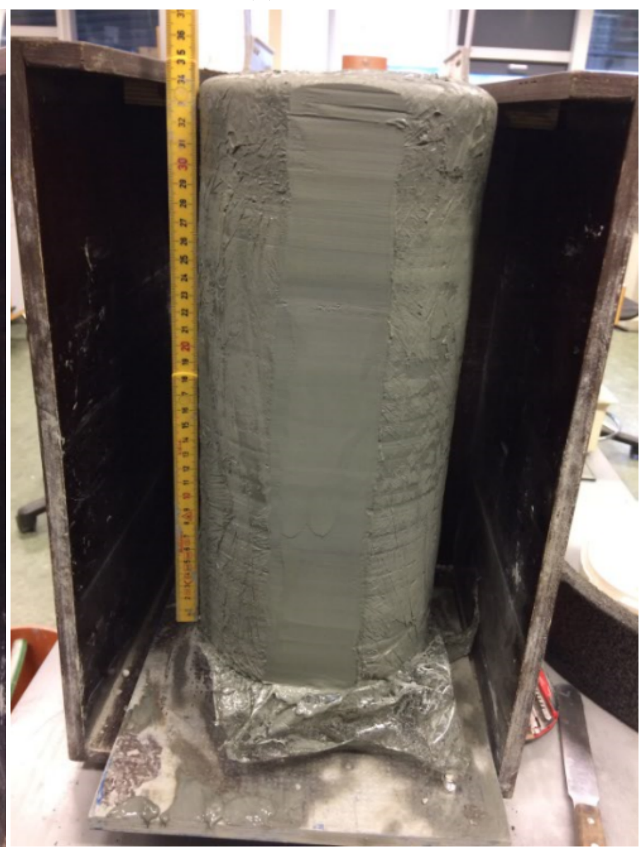
(d) 4.95 - 5.30 m.

Figure 3.3: Visual inspection of mini block samples from depth 4.3 to 5.30 m.

(a) 7.0 - 7.3 m.

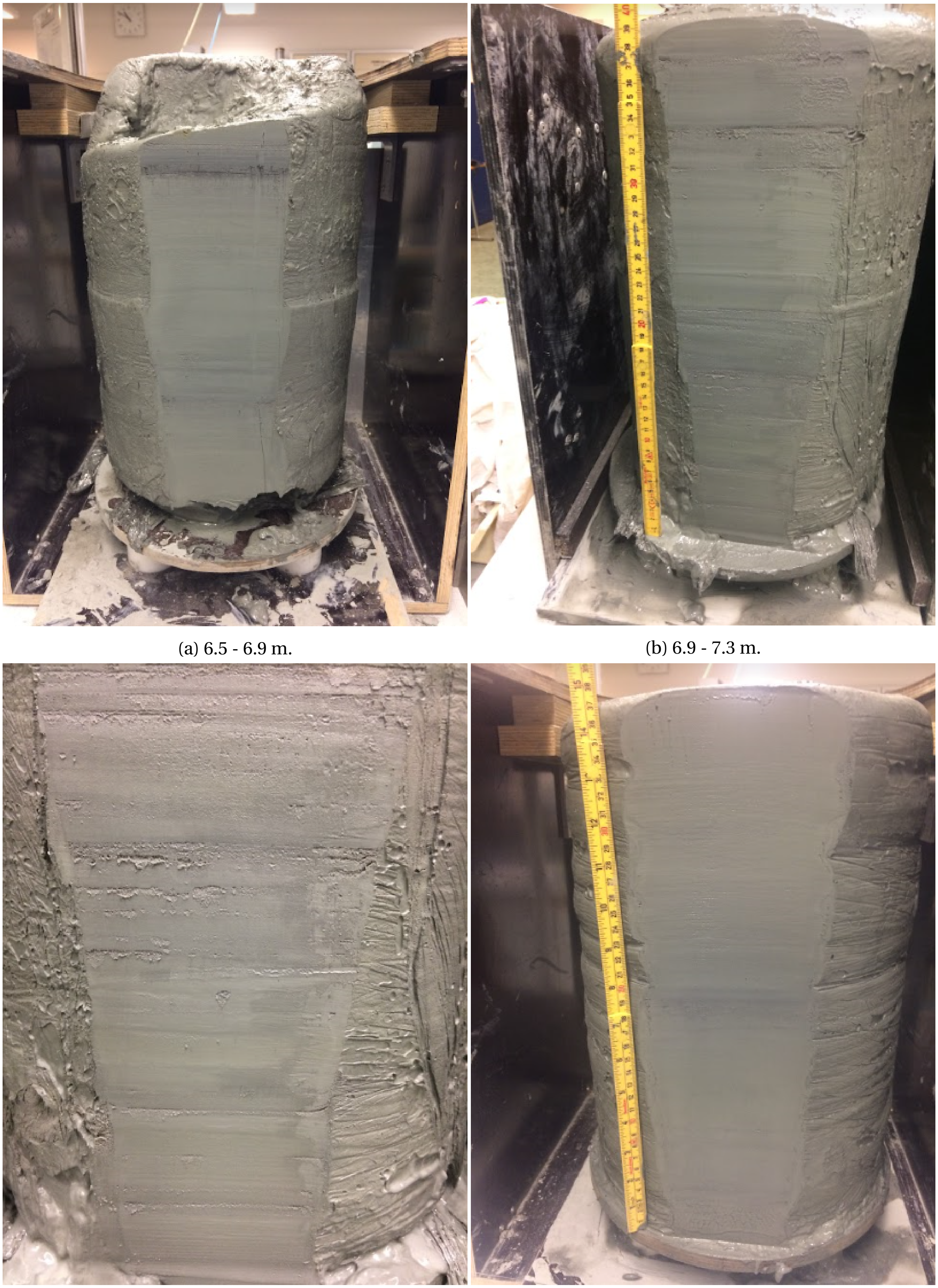
(b) 7.3 - 7.6 m.

(c) 7.6 - 7.9 m.



(d) 7.9 - 8.2 m.

Figure 3.4: Visual inspection of mini block samples from depth 7.0 to 8.2 m.



(a) 6.5 - 6.9 m.

(b) 6.9 - 7.3 m.

(c) 6.9 - 7.3 m close up. Notice the layers.

(d) 7.66 - 8.04 m.

Figure 3.5: Visual inspection of Sherbrooke block samples from depth 6.5 to 8.04 m.

3.3 Index Testing

Results from index tests can be used to classify and identify the soil, and some of the data can be used as input parameters in other laboratory tests, such as triaxial testing. The index tests were performed on each block sample immediately after sampling and two weeks after sampling. Index tests were carried out two times for each block. All tests were performed by the author according to the Norwegian Standard (NS) or International Organization for Standardization (ISO). The index tests include water content, Atterberg limits, bulk density, grain density, falling cone, salinity and grain size distribution. Unconfined compression tests and determination of organic content were not carried out in this thesis. Only a brief description of the test procedures will be given in the following sections.

3.3.1 Water Content

The water contents were determined according to ISO 17892-1 (ISO, 2014a) and calculated using Eq. 3.1

$$w = \frac{m_1 - m_2}{m_2 - m_c} \cdot 100\% = \frac{m_w}{m_s} \cdot 100\% \tag{3.1}$$

where w is the water content in percent, m_1 is the mass of the container and moist soil specimen, m_2 is the mass of the container and the dry soil specimen, m_c is the mass of the container, m_w is the mass of water and m_s is the mass of the dry soil specimen.

3.3.2 Atterberg Limits

Clay can be liquid, plastic,crumbling or dry, and the water content in the transition from one of these states to another are known as the Atterberg limits. The liquid limit w_L is the water content in the transition between liquid and plastic, and the plastic limit w_P is the water content in the transition between plastic and crumbling. The liquid limit w_L was determined according to section 5.3 in NS 8001 (Standard Norge, 1982) with 25 as the number of drops. The plastic limit w_P was found according to section 5.3 in ISO/TS 17892-12 (ISO, 2004a).

Knowing the water content and the plastic and liquid limit, the plasticity and liquidity indices can be determined using Eq. 3.2 and Eq. 3.3 respectively (ISO, 2004a). The Norwegian Geotechnical Society (NGF) presents a classification system for Norwegian clays based on the plasticity index, see Tab. 3.1.

$$I_P = w_L - w_P \tag{3.2}$$

$$I_L = \frac{w - w_P}{w_L - w_P} \tag{3.3}$$

Table 3.1: Classification system for Norwegian clays based on the plasticity index (NGF, 2011).

Classification of clay	Classification of plasticity	I_P [%]
Low plastic	Low plasticity	<10
Medium plastic	Medium plasticity	10 - 20
Highly plastic	High plasticity	>20

Quick clay behaviour can often be indicated if the liquidity index is larger than 1 at the same time as the water content is larger than the liquid limit (NTNU Geotechnical Division, 2015).

3.3.3 Bulk Density

The bulk density of the samples were found using two linear measurement methods. The linear measurement method according to section 5.1.2.3 in ISO 17892-2 (ISO, 2014b) for cylindrical block samples was used in connection with trimming samples for triaxial testing. The bulk density found by pushing a cylindrical cutter into a smaller sample according to section 5.1.4 in ISO 17892-2 was the other method used.

The bulk density can be calculated using Eq. 3.4 and the unit weight can be determined using Eq. 3.5.

$$\rho = \frac{m_s + m_w}{V} = \frac{m}{V}\left[\frac{g}{cm^3}\right] \tag{3.4}$$

$$\gamma = \frac{(m_s + m_w)\cdot g}{V} = \frac{m \cdot g}{V}\left[\frac{kN}{m^3}\right] \tag{3.5}$$

where ρ is the bulk density, m_s is the mass of the solid particles, m_w is the mass of water, m is the total mass of the sample, V is the total volume of the sample and g is the acceleration due to gravity, which is 9.81 $\mathrm{m/s^2}$.

3.3.4 Grain Density

The grain density ρ_s used to calculate the unit weight of solids γ_s was found using pycnometers with volumes of ~ 100 ml. The tests were carried out in accordance with ISO 17892-3 (ISO, 2015). The grain density and the unit weight of solids can be calculated using Eq. 3.6 and Eq. 3.7 respectively

$$\rho_s = \frac{m_3}{m_1 - m_2 + m_3} \cdot \rho_w \left[\frac{g}{cm^3}\right] \tag{3.6}$$

$$\gamma_s = \rho_s \cdot g \left[\frac{kN}{m^3}\right] \tag{3.7}$$

where ρ_s is the density of the soil particles, m_1 is the mass of the pycnometer filled with distilled water, m_2 is the mass of the pycnometer filled with distilled water and soil, m_3 is the mass of the dry soil, ρ_w is the density of distilled water and γ_s is the unit weight of solids.

3.3.5 Falling Cone

Determination of undrained shear strengths of both undisturbed s_u and remoulded s_r samples was carried out according to ISO 17892-6 (ISO, 2017). The sensitivity S_t was calculated after Eq. 3.8.

$$S_t = \frac{s_u}{s_r} \tag{3.8}$$

The samples were classified after Tab. 3.2 and Tab. 3.3. According to NGF (2011); if a clay has a remoulded shear strength below 0.5 kPa, it is defined as a quick clay.

Table 3.2: Classification according to undisturbed shear strength (NGF, 2011).

Classification of clay	Classification shear strength	s_u [kPa]
Very soft	Very low	<10
Soft	Low	10 - 25
Medium stiff	Medium	25 - 50
Stiff	High	>50

Table 3.3: Classification according to sensitivity (NGF, 2011).

Classification of clay	Classification of sensitivity	St [-]
Low sensitive	Low sensitivity	<8
Medium sensitive	Medium sensitivity	8 - 30
Highly sensitive	High sensitivity	>30

3.3.6 Salinity

The salinity of the sample was found by remoulding the sample and pouring it into a small container with a filter at the bottom. The sample was then mounted into an air compressor and air pressure was turned on to expel pore water from the sample. The electric conductivity was measured and by using a diagram, the salinity could be found. If the salt content in the pore water of a marine clay drops below 5 g/l, the clay might possess quick clay behaviour (NTNU Geotechnical Division, 2015).

3.3.7 Grain Size Distribution

The grain size distributions was found by hydrometer analyzes, which is a method based on Stoke's law for equivalent spheres sedimenting freely in a liquid or gas. A calibrated hydrometer was lowered into a suspension of water, sample and a dispersive matter and the consentration the suspension is measured at predetermined time intervals. The test was done according to NS8005 (Standard Norge, 1990).

3.4 Oedometer Testing

The oedometer test is the most frequently used method to determine the deformation parameters in geotechnical testing (NTNU Geotechnical Division, 2015). The block samples were tested immediately after sampling and then again after two weeks of storage. The chosen method of testing was the CRS-procedure and the testings were conducted according to NS 8018 (Standard Norge, 1993), with some modifications. The oedometer rings used had a height of 20 mm and an inner area of 20 cm^2. The standard recommends a strain rate between 0.25 and 0.75 %/hr when testing on clay. The oedometer tests were run at a strain rate of 1 %/hr on the mini block samples which were tested immediately after sampling, in addition to those samples from a depth of 4 m. The samples from 7 to 8 m depth tested immediately after sampling experienced an upward squeezing of material, and it was then decided that all future oedometer test carried out in this thesis would be run at a strain rate of 0.5 %/hr.

The results from the oedometer tests were plotted diagrams which can be found in Appendix B.

The preconsolidation stress p'_c was found using the σ'_m vs. ε plot, as proposed by Janbu (1963). The stress at where the slope of the oedometer curve changes corresponds to the preconsolidation stress, see fig 3.6.

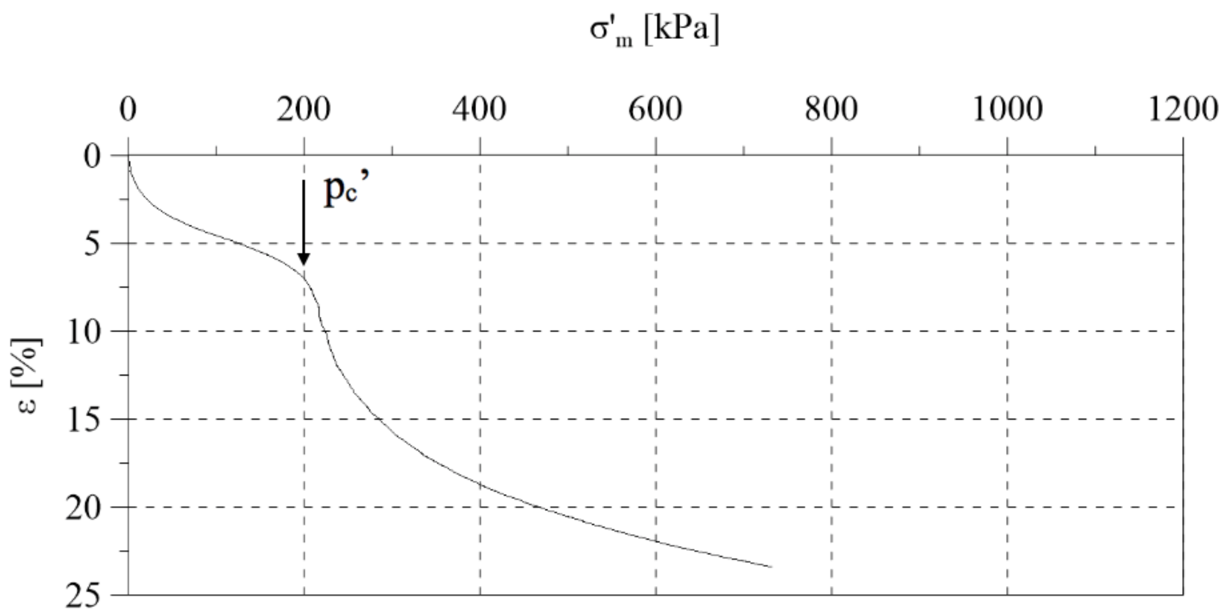
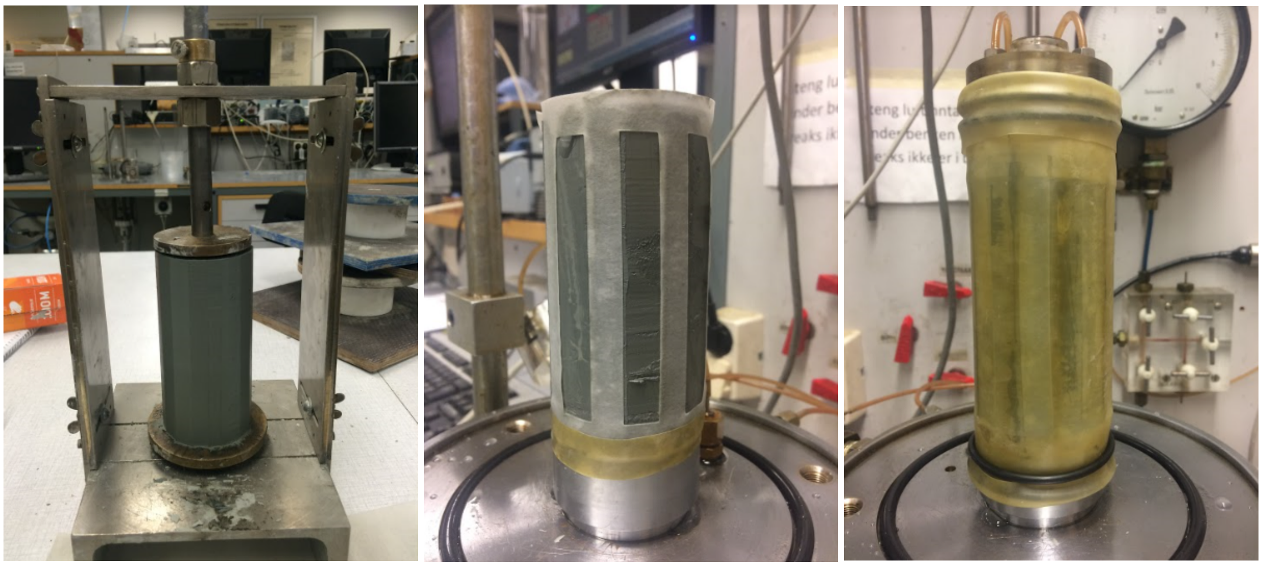


Figure 3.6: Determination of preconsolidation p'_c stress from oedometer results.

The sample quality was determined using both the $\Delta e/e_0$- criterion and the ε_{vol}-criterion, see section 2.4.3. Equations used to process the data and result from the oedometer tests can be found in Appendix B.

3.5 Triaxial Testing

The triaxial testing were conducted according to ISO 17892-9 (ISO, 2004b) and Håndbok R210 (Vegdirektoratet, 2016), and the test procedure chosen was the Consolidated Anisotropically Undrained compression (CAUc) test. The purpose for conducting the triaxial tests was to determine the strength parameters as basis for comparison between the samples from mini blocks and Sherbrooke blocks. To get a 54 mm sample from a block sample, a frame as shown in Fig. 3.7a was used. A piece of sufficient size from the block sample was placed on the circular bottom piece of the frame. A wire saw was used to trim the sample until it obtained a cylindrical shape. Filter paper for side drain were used as well as small membrane rings. These rings were mounted on the joint between the bottom of the filter paper, porous disk and the pedestal and the joint between the top of the filter paper, porous disk and the top cap.



(a) (b) (c)

Figure 3.7: a) Triaxial spesimen trimmed from block sample, b) Sample with porous disks and filter paper on pedestal with small membrane ring and c) Sample with filter paper, membrane, membran rings, porous disks, o-rings and top cap.

The sample was consolidated to in situ conditions by applying the cell pressure in steps of 10 kPa/min and adding the vertical anisotropic stress at the end. When the curve in the $\sqrt{T}$-ΔV-plot had flattened out, after consolidating over night for approximately 12 - 14 hours, back pressure was applied after the consolidation phase to determine the B-value. This procedure was done according to Håndbok R210 (Vegdirektoratet, 2016). A back and cell pressure of approximately 300 kPa was applied at a rate of 10 kPa/min until 300 kPa was reached. After this, the sample was resting for 30 min. before the B-test. The B-test was conducted by applying a cell pressure of 10 kPa at the same time as the burette was closed. The value of Δu was recorded within 2 min and the B-value was determined. After this the additional cell pressure was reduced with 10 kPa and the sample was set to rest for 1 hour before the the shear phase was started.

The first two triaxial tests that were run (mini block sample at a depth of 4.45 m) were conducted assuming that the ground water level was at 0 m, due to uncertainties. The ground water level was later found to be approximately 1.5 - 2 m below ground level, and the rest of the triaxial test were run ausing a ground water level at a depth of 2 m. The coefficient of earth pressure at rest K_0' used was set to 0.7 for the majority of the triaxial tests conducted, except for the mini block samples from a depth of 4 - 5 m.

All of the tests were run at a strain rate of 1.5 %/hr in the shear phase until a deformation of 10 mm was reached. The sample quality was determined using both the $\Delta e/e_0$- criterion and the ε_{vol}-criterion, see section 2.4.3. Equations used to process the data and result from the triaxial tests can be found in Appendix C. The results from the triaxial tests were plotted in diagrams which can be found in Appendix C.

Chapter 4

Results

This chapter presents the result from the index tests, oedometer tests and the triaxial tests from both the mini block and Sherbrooke block samples.

4.1 Index Testing

Plots and tables of all the results from index testing can be found in A. In general, three plots for each tests are made, one for mini block samples, one for Sherbrooke block samples and one where all the results are plotted together.

4.1.1 Water Content and Atterberg Limits

Fig. A.1 present the water content, liquid limit and plastic limit with depth. The water content varies between 39 and 57 %, and shows a decreasing trend with depth. There is no distinct difference between the water contents from the mini block and Sherbrooke block samples, neither is it apparent that the water content decreases after 2 weeks of storage, as one might expect.

The liquid and plastic limit do not vary much; approximately 52 and 30 %

respectively for the mini block samples at depth 4 - 5 m. For the deeper mini block and Sherbrooke block samples, 6.6 - 8.2 m, the liquid limit varies between 31.7 and 39.5 % and the plastic limit varies between 20.5 and 25.3 %. The Atterberg limits decreases with depth, and also the span between the liquid and plastic limit seems to decrease with depth. There is no evident difference between the measurements from mini block and Sherbrooke block samples. The plasticity and liquidity indices are plotted with depth in Fig. A.2 and A.3. Based on the plasticity index, the clay is classified as highly plastic at a depth of 4 to 5 m, medium plastic at a depth of 5 to 7 m and low plastic from 7 m and deeper.

4.1.2 Bulk Density

In Fig. A.4, the unit weight is plotted with depth. The unit weight is calculated from the density found from pushing the small ring through a clay specimen. For the shallower samples, the unit weight varies between approximately 16.6 and 17.4 kN/m^3, and Fig. A.4 shows an increasing trend with depth. There is no distinct difference between the mini block and Sherbrooke block samples, neither when it comes to duration of storage.

4.1.3 Grain Density

Fig. A.5 shows the grain density plotted with depth. The grain density varies mainly between 2.85 and 2.90 g/cm^3. A sample was also sent to the chemical/mineralogical laboratory at the Department of Geoscience and Petroleum at NTNU for an XRD-analysis, and the results from the analysis fitted well with the values determined using a pycnometer. 37 % of the sample consisted of mica, which has a density of approximately 2.95 g/cm^3. The results from the XRD-analysis is shown the end of Appendix A.

4.1.4 Falling Cone

In Fig. A.6, both the undisturbed s_u and remolded s_r shear strength is plotted with depth. For the mini block samples, s_u varies between 30 and 50 kPa, and seems to decrease with depth, and increase after 2 weeks of storage. s_r decreases with depth and is below 0.5 kPa for the deeper samples, which indicates quick clay. For the Sherbrooke block samples, there is little variation in s_u (between 30 and 40 kPa); neither with depth or duration of storage. s_r is below 0.5 kPa from depths 7.20 m and below, which indicates quick clay. The s_u at 5 m depth is approximately 50 kPa, and for the deeper samples, s_u varies between approximately 30 ad 45 kPa. Based on the classification of clay, the clay is classified as a medium stiff clay (NGF, 2011). Based on the sensitivity, the clay is medium sensitive down to 6.5 m and highly sensitive from 6.5 m and deeper.

4.1.5 Salinity

The salt content of the samples are plotted with depth in Fig. A.8, and is 0.5 g/l for all the samples. According to NTNU Geotechnical Division (2015, p. 153), "marine clays will exhibit quick clay behaviour if the salt content in the pore water drops below ca. 5 g/l pore water".

4.1.6 Grain Size Distribution

The grain size distributions in plotted in Fig. A.10 to A.12. The plots show no distinct differences with depth, nor with the type of block sampler used. The samples consist of about 53 to 72 % clay, except for one sample, with an average clay content of about 60 %, see Fig. A.9. Based on the grain size distribution, the material is defined as clay (NGF, 2011).

4.2 Oedometer Testing

All the oedometer tests are plotted in Appendix B, and Tab. 4.1 and 4.2 gives an overview of the results from the tests. The oedometer test that were run on highly sensitive clay at a strain rate of 1 %/hr squeezed, see Fig. 4.1. As seen from the plots of σ'_m vs M in Appendix B, M_{OC} seems to be higher for the Sherbrooke block samples than for the mini block samples. The average M_{OC} for the Sherbrooke samples are approximately 6,7 MPa, while for mini block samples M_{OC} is ca. 5.1 MPa.

Note that all oedometer samples are classified as disturbed or of poor quality according to the ε_{vol} and $\Delta e/e_0$-criterion respectively. This will be discussed in Chapter 5.

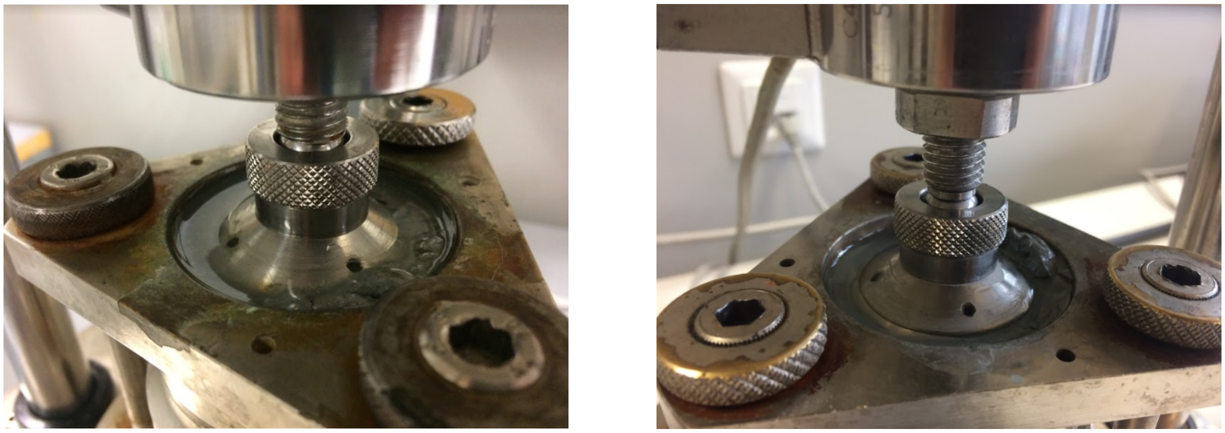


Figure 4.1: Squeezing of material on oedometer tests run at highly sensitive samples at a strain rate of 1 %/hr.

Table 4.1: Overview of results from oedometer tests from mini block samples.

Test ID	Storage time [weeks]	Depth [m]	Strain rate [%/hr.]	p'_c [kPa]	OCR [-]	$\Delta e/e_0$ [-]	ε_{vol} [%]	Fig. no.
CRS-1.1	0	7.20	1	180	2.3	0.08	4	B.3
CRS-1.2	0	7.20	1	200	2.6	0.08	4	B.4
CRS-2.1	0	7.95	1	250	3.0	0.07	4	B.5
CRS-2.2	0	7.95	1	200	2.4	0.07	4	B.6
CRS-3.1	2	4.52	1	200	3.8	0.05	3	B.7
CRS-3.2	2	4.56	1	175	3.3	0.05	3	B.8
CRS-4.1	2	7.38	0.5	180	2.3	0.06	3	B.9
CRS-4.2	2	7.38	0.5	180	2.4	0.05	3	B.10
CRS-5.1	2	7.84	0.5	190	2.4	0.09	5	B.11
CRS-5.2	2	7.84	0.5	190	2.4	0.07	4	B.12

Table 4.2: Overview of results from oedometer tests from Sherbrooke block samples.

Test ID	Storage time [weeks]	Depth [m]	Strain rate [%/hr.]	p'_c [kPa]	OCR [-]	$\Delta e/e_0$ [-]	ε_{vol} [%]	Fig. no.
CRS-S1.1	0	6.75	0.5	250	3.2	0.05	3	B.17
CRS-S1.2	0	6.75	0.5	225	3.0	0.05	3	B.18
CRS-S2.1	0	7.05	0.5	210	2.9	0.06	4	B.19
CRS-S2.2	0	7.05	0.5	210	3.0	0.05	3	B.20
CRS-S3.1	0	7.20	0.5	200	2.6	0.09	5	B.21
CRS-S3.2	0	7.20	0.5	200	2.6	0.07	4	B.22
CRS-S4.1	0	7.82	0.5	225	2.8	0.07	4	B.23
CRS-S4.2	0	7.82	0.5	200	2.5	0.07	4	B.24
CRS-S5.1	2	6.75	0.5	250	3.2	0.06	3	B.25
CRS-S5.2	2	6.75	0.5	200	2.8	0.06	3	B.26
CRS-S6.1	2	7.05	0.5	200	2.9	0.06	3	B.27
CRS-S6.2	2	7.05	0.5	210	2.9	0.06	3	B.28
CRS-S7.1	2	7.20	0.5	290	3.4	0.07	4	B.29
CRS-S7.2	2	7.20	0.5	180	2.4	0.05	3	B.30
CRS-S8.1	2	7.82	0.5	200	2.6	0.06	4	B.31
CRS-S8.2	2	7.82	0.5	200	2.6	0.05	3	B.32

The average preconsolidation stress p'_c is about 195 kPa for the mini block samples and 215 kPa for the Sherbrooke block samples. The average OCR is about 2.7 and 2.8 for the mini block and Sherbrooke block samples, respectively.

4.3 Triaxial Testing

All the triaxial tests are plotted in Appendix C, and Tab. 4.3 and 4.4 gives an overview of the results from the tests. All of the samples have a clear failure pattern at about 45 ° after the shear phase was completed, see Fig. 4.2 for three of the samples. The peak undrained shear strength is approximately in the interval 50 to 60 kPa for the samples. The failure strain ε_f varies between 0.70 and 0.8 %. There is no apparent difference in s_u or ε_f between the mini block and Sherbrooke block samples, nor when it comes to duration of storage except for the mini block samples from a depth of 7 m. Note that only two of the samples classifies as being of perfect quality according to the ε_{vol}-criterion. Also note that only one of the triaxial tests meets the B-value requirement of B-value ≥ 0.95.

Figure 4.2: Failure patterns for three of the triaxial samples. All samples had a similar pattern.

4.3.1 Correlations for Clays Tested on Sherbrooke Block Samples supplied with New Values

Values of s_u and σ'_{v0} determined from triaxial testing and values of OCR determined from oedeometer testing on Sherbrooke block samples are plotted in the same OCR vs. s_{uc}/σ'_{v0} plot presented by Karlsrud et al. (2005), see Fig. 4.3. As seen in the plot, the values for OCR, s_{uc} and σ'_{v0} correlates fairly well with the rest of the values.

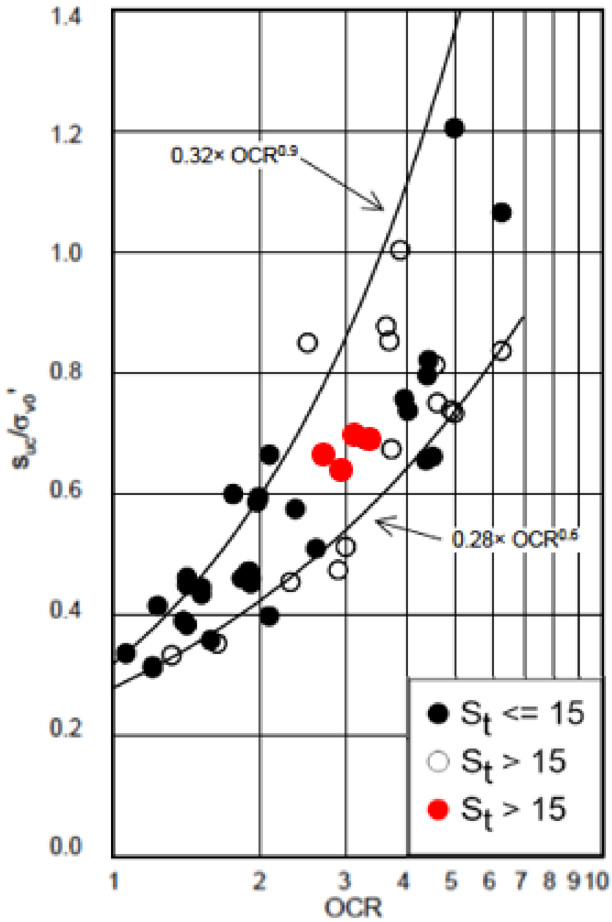


Figure 4.3: Normalized CAUc strength values, s_{uc}/σ'_{v0}, for block samples in relation to OCR presented by Karlsrud et al. (2005). Values determined in this master's thesis are also plotted, marked in red color.

Table 4.3: Overview of results from triaxial tests from mini block samples.

Test ID	Storage time [weeks]	Depth [m]	σ'_{v0} [kPa]	K'_0 [-]	GWL [m]	$\Delta e/e_0$ [-]	ε_{vol} [%]	B-value [-]	Fig. no.
CAUc-1.1	0	4.45	33.8	0.6	0	0.02	1.44	0.90	C.4
CAUc-1.2	0	4.45	32.2	0.6	0	0.02	1.19	0.91	C.5
CAUc-2.1	0	7.08	80.5	0.7	2	0.06	3.01	0.88	C.6
CAUc-2.2	0	7.08	80.7	0.7	2	0.04	1.93	0.91	C.7
CAUc-3.1	0	8.05	82.2	0.7	2	0.04	2.09	0.77	C.8
CAUc-3.2	0	8.05	82.9	0.7	2	0.03	1.63	0.87	C.9
CAUc-4.1	2	4.70	57.6	0.8	2	0.13	7.18	0.77	C.10
CAUc-4.2	2	4.70	57.1	0.8	2	0.03	1.88	0.21	C.11
CAUc-5.1	2	5.10	58.7	0.8	2	0.10	5.78	0.84	C.12
CAUc-5.2	2	5.10	58.7	0.8	2	0.04	2.30	0.82	C.13
CAUc-6.1	2	7.20	76.8	0.7	2	0.05	2.82	0.82	C.14
CAUc-6.2	2	7.20	76.8	0.7	2	0.05	2.65	0.87	C.15
CAUc-7.1	2	8.15	86.1	0.7	2	0.10	5.66	0.99	C.16
CAUc-7.2	2	8.15	84.9	0.7	2	0.04	2.21	0.91	C.17

Table 4.4: Overview of results from triaxial tests from Sherbrooke block samples.

Test ID	Storage time [weeks]	Depth [m]	σ'_{v0} [kPa]	K'_0 [-]	GWL [m]	$\Delta e/e_0$ [-]	ε_{vol} [%]	B-value [-]	Fig. no.
CAUc-S1.1	0	6.65	72.7	0.7	2	0.04	2.65	0.92	C.22
CAUc-S1.2	0	6.65	71.6	0.7	2	0.05	2.67	0.66	C.23
CAUc-S2.1	0	7.05	79.7	0.7	2	0.04	2.23	0.94	C.24
CAUc-S2.2	0	7.05	78.9	0.7	2	0.04	2.34	0.85	C.25
CAUc-S3.1	0	7.20	84.0	0.7	2	0.04	2.15	0.94	C.26
CAUc-S3.2	0	7.20	85.0	0.7	2	0.07	3.63	- 0.31	C.27
CAUc-S4.1	0	7.72	85.6	0.7	2	0.05	2.88	0.75	C.28
CAUc-S4.2	0	7.72	86.1	0.7	2	0.05	2.46	0.55	C.29
CAUc-S5.1	2	6.65	73.2	0.7	2	0.05	3.05	0.94	C.30
CAUc-S5.2	2	6.65	73.3	0.7	2	0.04	2.30	0.82	C.31
CAUc-S6.1	2	7.05	78.1	0.7	2	0.05	2.45	0.92	C.32
CAUc-S6.2	2	7.05	79.1	0.7	2	0.04	2.14	0.87	C.33
CAUc-S7.1	2	7.20	82.3	0.7	2	0.05	2.81	0.88	C.34
CAUc-S7.2	2	7.20	83.3	0.7	2	0.04	2.02	0.81	C.35
CAUc-S8.1	2	7.72	86.4	0.7	2	0.11	5.68	0.86	C.36
CAUc-S8.2	2	7.72	86.7	0.7	2	0.05	2.70	0.77	C.37

Chapter 5

Discussion

In this chapter, the results from the laboratory work will be discussed. The main focus is to look at possible differences in quality between the mini block and Sherbrooke block samples, as well as consider if the duration of storage has altered the samples.

5.1 Index Testing

Plots and tables of all the results can be found in A. The tests which are most prone to disturbance are of main interest; water content w, undrained shear strength s_u, bulk density ρ, since the aspect of this thesis is mainly sample quality.

5.1.1 Water Content

The water content seems to decrease with depth based on Fig. A.1. The average water content at 4.5 to 6.5 m is about 52 %, and at 7 to 9m w varies between 39 and 48 % with an average value of about 43 %. The difference in water content before and after 2 weeks of storage is larger for mini block samples than for Sherbrooke block samples. w for the mini block samples seems to vary about 5 %, and the Sherbrooke block samples seems to vary less than 1%. One might expect the water content to decrease with storage time, but in these cases there are no evident indication of this; for some of the samples the water content is higher before storage, and opposite for others. This might be due to difference in the exact location of where in the samples the specimens for water content were retrieved from considering layering. It is reasonable to assume that the content of permeable materials, such as silt and sand, decreases with depth considering the decrease in water content, but also the visual inspection of the samples.

5.1.2 Atterberg Limits

The plastic and liquid limits are also plotted in Fig. A.1. The limits seems to decrease with depth, as well as the span between the plastic limit w_P and liquid limit w_L. Looking at the plasticity indices I_P (Fig. A.3), they decrease with depth, while the liquidity indices I_L (Fig. A.2) increase with depth. The liquidity indices varies mainly between 1 and 2 at the same time as the $w > w_L$, whch indicates quick clay behaviour (NTNU Geotechnical Division, 2015). When considering results before and after storage, I_L from mini block samples vary more than those from Sherbrooke block samples, which almost don't vary at all. This is probably due to the more evident difference in w for the mini block samples than for the Sherbrooke block samples. Little variation in I_P before and after storage, both for the mini block and Sherbrooke block samples. In regards to I_P, the clay is classified as medium plastic down to a depth of approximately 7 m, and low plastic from 7 m and deeper.

5.1.3 Bulk Density

The bulk density ρ was determined in three different ways; pushing a small ring into a specimen, bulk density from oedometer samples and from triaxial samples. Fig. A.4 shows the unit weight γ with depth based on the bulk density determined only from the little density ring. Since the triaxial samples were trimmed using a wire saw, the cross section is not perfectly circular, as well as variations in trimming of samples are more likely. The oedometer tests were run using two different oedometer rings, which is why the small density ring was the chosen method, since only one density ring was used for all tests. Based on Fig. A.4, the unit weight seems to increase with depth, from about 16.5 kN/m^3 at 4.5 m to 18 kN/m^3 at 8 m. The variation in unit weight, when taking storage time into account, is greater for the mini block samples compared to the Sherbrooke block samples. This might be due to the variation in water content, which were more evident for the mini block samples.

5.1.4 Grain Density

Fig. A.5 shows the grain density ρ_s with depth, which varies between 2.85 and 2.9 g/cm^3 independent of the depth, sampling method and storage time. At first these values seemed to be a bit too high considering that most Norwegian clays have a $\rho_s = 2.75$ g/cm^3 $\pm$ 3 % (NTNU Geotechnical Division, 2015). A sample was therefore sent to the chemical/mineralogical laboratory at NTNU for an XRD analysis, which showed that 37 % of the sample consisted of mica, which has a density of approximately 2.95 g/cm^3. A quick estimate of ρ_s based on the mineralogy gave a ρ_s of 2.86 g/cm^3, which correlates well with the values measured using pycnometers.

5.1.5 Falling Cone

Undrained shear strength with depth is shown in Fig. A.6. s_u seems to decreases with depth from approximately 50 kPa at 5 m to 30 to 45 kPa at 7 to 8 m. s_r also decreases with depth from 5 kPa to below 0.5 kPa at about 7 m depth, which indicates that quick clay is present from 7 m (NGF, 2011). s_u seems to increase after 2 weeks of storage for the mini block samples, while for Sherbrooke block samples s_u appear to be constant. Duration of storage does not seem to impact s_r for any of the samples. The sensitivity increases with depth as seen in Fig. A.7, and becomes highly sensitive at 7 m. It is important to keep in mind that the falling cone test is not the most accurate method to determine the undrained shear strength, since the method is affected by inaccuracies, conceptual limitations and sources of errors (NTNU Geotechnical Division, 2015), and the results should be used with caution.

5.1.6 Salinity

Fig. A.8 shows the salt content of the clay with depth. The salinity is 0.5 g/l for all of the samples, which can indicate that the clay may exhibit quick behavior (NTNU Geotechnical Division, 2015).

5.1.7 Grain Size Distribution

Based on the grain size distributions plotted in Fig. A.10 to A.12, the material is defined as clay (NGF, 2011). The hydrometer analyses used to determine the grain size distribution is also affected by inaccuracies. The results correlates well with results presented by Gella (2017), but deviates slightly from those presented by Gylland et al. (2013). The deviations may be due to local variations in the clay strata. The cite where Gylland et al. (2013) retrieved their samples lies approximately 2 km south west of where the samples treated in this thesis are retrieved from.

5.1.8 Comments

The results from index tests seems to correlate well with those presented by Gella (2017). I_P, S_t and s_r indicates distinct changes in the clay at 7 m, where there is assumed to be quick clay, which corresponds well findings presented by Lindgård and Ofstad (2017).

5.2 Oedometer Testing

Results from all of the 26 oedometer tests are plotted in Appendix B. Section 5.2.1 discusses the results from testing mini block samples, while section 5.2.2 discusses the results from testing Sherbrooke block samples. At last, section 5.2.3 will compare the results from mini block and Sherbrooke block samples. For a significant amount of the oedometer tests, it seems like something went wrong, and several "bumps" occurs on the oedometer curve in the $\sigma'_m - \varepsilon$ plot.

The reason for this behavior is yet not know.

5.2.1 Evaluation of the Results from Mini Block Samples

A total of ten oedometer tests were run at the specimens sampled using a mini block sampler. The first six samples were run at a strain rate of 1 %/hr; for the specimens from 4.5 m depth it was difficult to determine a preconsolidation stress p'_c, but a value of 175 and 200 kPa was estimated, with an OCR of 3.3 and 3.8. These samples had been stored for two weeks before testing. For the highly sensitive samples from 7 to 8 m, the specimens experienced squeezing of material, and it was therefore decided to run the rest of the samples at a strain rate of 0.5 %/hr. Although the samples squeezed, it was possible to find a good estimate for p'_c for two of the samples; 180 and 200 kPa. These samples were tested immediately after sampling. Even though, the samples run at a strain rate of 1 %/hr were from different depths, and tested immediately and after two weeks of storage, p'_c did not seem to differ much. The remaining four oedometer test, which were run at a strain rate of 0.5 %/hr and tested after two weeks of storage had an estimated p'_c of 180 and 190 kPa. These specimens did not experience squeezing even though the clays were retrieved from a depth of 7.4 and 7.8 m, and were classified at highly sensitive. When evaluating the preconsolidation stress, it might seem like the p'_c decreased after two weeks of storage, but it is important to note that these samples were run at different strain rates. The differences might be due to creep because the tests were run at a lower strain rate, but to strengthen this statement more tests are required.

M_{OC} varies between 4 and 6 MPa, with an average value of 5.1 MPa, regardless of whether the samples are stored or not. The overconsolidation ratio OCR varies between 2.3 and 2.6 for the samples from 7 to 8 m, with an average value of 2.4. When considering the sample quality based on the $\Delta e/e_0$-criterion (Lunne et al., 1997), all of the samples fall into the category of *poor quality*. The same applies when the ε_{vol}-criterion (Andresen and Kolstad, 1979) is used; all of the samples are classified as *disturbed*. The reasons for this can be discussed, but one reason might be how the samples were build into the oedometer ring. When pushing the oedometer ring into the clay specimen, the outermost material might have become remolded or disturbed.

5.2.2 Evaluation of the Results from Sherbrooke Block Samples

All of the 16 oedometer tests from blocks sampled with the Sherbrooke block sampler were run at a strain rate of 0.5 %/hr. p'_c for the samples tested immediately after sampling varies between 200 and 250 kPa, and for those tested after two weeks of storage p'_c varies essentially between 180 and 210 kPa, except for one sample which had a p'_c of about 290 kPa and an OCR of 3.4. OCR varies mainly between 2.6 and 3.2, and 2.4 and 2.9 for the samples tested immediately and after two weeks of storage, respectively. It may seem like both p'_c and OCR decreases after two weeks of storage. The M_{OC} seems to be independent of whether the samples are stored or not, and varies between 5 and 8 MPa with an average value of 6.7 MPa. Also for the Sherbrooke block samples, all of the specimen fall into the category of *poor* or *disturbed quality*.

Table 5.1: Overview of p'_c, OCR and M_{OC} for mini block and Sherbrooke block samples.

	p'_c [kPa]	OCR [-]	M_{OC} [MPa]
Mini Block: 0 weeks	180 - 200	2.3 - 2.6	5 - 6
Mini Block: 2 weeks	180 - 190	2.3 - 2.4	4 - 6
Sherbrooke Block: 0 weeks	200 - 250	2.6 - 3.2	6 - 8
Sherbrooke Block: 2 weeks	180 - 210	2.4 - 2.9	5 - 7

5.2.3 Oedometer Results: Mini Block vs. Sherbrooke Block Sample

Comparing the results from the oedometer tests carried out on specimens from mini block and Sherbrooke block samples, some differences are discovered. It seems like the samples from the mini block gives lower values of p'_c, OCR and M_{OC}, than those from Sherbrooke block, both for those which are tested immediately and for those stored for two weeks. For the samples tested immediately after sampling, the mini block samples had a p'_c of 180 to 200 kPa and an OCR of 2.3 to 2.6, while the Sherbrooke block samples had a p'_c of 200 to 250 kPa and an OCR of 2.6 to 3.2. For the samples which were stored for two weeks, the mini block samples had a p'_c of 180 to 190 kPa and an OCR of 2.3 to 2.4, while the Sherbrooke block samples had a p'_c of 180 to 210 kPa and an OCR of 2.4 to 2.9. Tab. 5.1 gives an overview of the differences in p'_c and OCR.

All of the samples, independent on storage time or sampler type, fell into the categories of *poor* or *disturbed quality*, even if the oedometer curve in the $\sigma'_m - \varepsilon$ plot seemed to be reliable and a good estimation of p'_c was easy to find. As mentioned above, one reason might be how the samples were build into the oedometer ring; the outermost material might have become remolded or disturbed during build-in. Another reason might be that several of the oedometer tests run, had problems making contact with the deformation measuring device, which can be indicated by studying the $\sigma'_m - u_b$ plots. For many of the samples, the pore pressure at base u_b stayed constant in the beginning of the test before a sudden increase occurred, even though the average effective stress σ'_m increased. The criteria are also dependent of the water content of the actual samples, which were not measured. The water content used in the calculations were based on the water content of the spare material after pushing the oedometer ring into the sample, which may differ slightly from the water content of the actual sample. On the other hand, no material were lost when measuring w which is common for oedometer tests as some clay tend to stick to the filters and inside the oedometer apparatus. One can raise the question if the criteria are suited for highly sensitive, low plastic clays, as also pointed out by Amundsen et al. (2015). Observations done by Tanaka et al. (2002) shows that the criterion of sample quality proposed by Lunne et al. (1997) cannot be unconditionally applied to all types of soils.

5.3 Triaxial Testing

Results from all of the 30 triaxial tests are plotted in Appendix C. Section 5.3.1 discusses the results from testing mini block samples, while section 5.3.2 discusses the results from testing Shebrooke block samples. At last, section 5.3.3 will compare the results from mini block and Sherbrooke block samples. For most of the B-tests carried out in the triaxial tests, the B-value did not meet the criterion of ≥ 0.95.

5.3.1 Evaluation of the Results from mini Block Samples

A total of 14 triaxial tests were run at the specimens sampled using a mini block sampler. At a depth of approximately 5 m the peak undrained shear strength s_u equals ca. 50 - 60 kPa while the strain at this point, the failure strain ε_f, is 0.8 %. These samples were run using different input parameters; an assumed ground water level at 0 m and K_0' at 0.6 and 0.8. At approximately 7 m, the s_u is ca. 40 - 50 kPa when tested immediately after sampling and ca. 55 kPa when tested after two weeks of storage while ε_f = 0.8 % independent of storage time. At a depth of ca. 8 m, s_u equals ca. 50 - 55 kPa and ε_f equals 0.7 %, both for those samples tested immediately and after storage. There is no evident difference in s_u when taking duration of storage into account, except for the samples at 7 m, where s_u seems to have decreased with 8 kPa after two weeks of storage. The criteria for sample quality varies between *acceptable* and *disturbed quality* using the ε_{vol}-criterion, and mainly between *good to fair* and *poor quality* using the $\Delta e/e_0$-criterion. For the latter one, two of the samples fall into the category of *very good to excellent quality* and one falls into the category of *very poor quality*.

5.3.2 Evaluation of the Results from Sherbrooke Block Samples

16 triaxial tests were run at the specimens sampled using a Sherbrooke block sampler. At a depth of approximately 6.6 m the peak undrained shear strength s_u equals ca. 50 kPa, while ε_f is 0.8 %. At approximately 7 m, the s_u is ca. 55 kPa, while ε_f = 0.8 % and at a depth of ca. 8 m, s_u equals 57 kPa and ε_f equals 0.7 %. There is no distinct difference in s_u when taking duration of storage into account. The criteria for sample quality is mainly *acceptable* and *good to fair*

quality for all samples, independent of storage time. There a few samples which falls into the category of *disturbed* and *poor quality*.

5.3.3 Triaxial Results: Mini Block vs. Sherbrooke Block Sample

When comparing the results from the triaxial tests carried out on specimens from mini block and Sherbrooke block samples, there are close to no difference in s_u except for the triaxial samples from the mini block sampler at a depth of 7 m which seems to have lost almost 13 % of it's shear strength during storage. There is no distinct difference when it comes ε_f which is approximately 0.8 % at depths between 5 and 7 m and 0.7 % at 8 m. When evaluating s_u and ε_f in the shear phase, it is important to keep in mind that measurements are only made at the top and bottom of the sample and not in-between. What happens in-between with the pore pressure and strains when the sample has gone to failure is not known. Hence the calculated ε_f after failure is not reliable. What is really measured is the deformation as the sample "slides down" at the failure plane. It is also impossible to know anything about the shear strength inside the sample after failure. When plotting the values of s_u into the $OCR - s_{uc}/\sigma'_{v0}$-diagram presented by Karlsrud et al. (2005), the peak undrained shear strength is used. Tab. 5.2 gives an overview of the differences in s_u and ε_f.

Table 5.2: Overview of s_u and ε_f for mini block and Sherbrooke block samples

	s_u [kPa]	ε_f [%]
Mini Block: 4.45 - 5.10 m	50 - 60	0.8
Mini Block: 7.08 - 7.20 m	40 - 50 (0 weeks) 55 (2 weeks)	0.8
Mini Block: 8.05 - 8.15 m	50 - 55	0.7
Sherbrooke: 6.65 m	50	0.8
Sherbrooke Block: 7.05 - 7.20 m	55	0.8
Sherbrooke Block: 7.72 m	57	0.7

Most of the samples, independent on storage time and sampler type, fell into the categories of *good to fair* or *acceptable quality*. The ε_{vol}-criterion have more samples of *disturbed quality*, both for mini block and Sherbrooke block samples. This might be due to that the criterion uses expelled water measured by a burette as the change in volume, assuming the samples are fully saturated. One might wonder if ε_{vol} is suited for all types of clay considering clays with higher water content have the ability to expel more water than samples of lower water content. High sensitive clays are more prone to sample disturbance and can therefore expel more water if the clay structure has partly collapsed due to disturbance. This might be the reason why more of the samples evaluated after this criterion are of *disturbed quality*.

5.3.4 Comment on the Sample Quality Criteria for Oedometer and Triaxial Samples

It seems like the triaxial samples are of better quality than the oedometer samples, even though they came from the same block sample. This might be due to the different methods of trimming the samples; triaxial samples are trimmed to the proper size using a wire saw and oedometer samples are trimmed by pushing an oedometer ring into the sample and removing the spare material. Maybe using a wire saw disturbs the sample less since only small parts of the spare material is removed at a time and not all at once. One can raise the question if the criteria are suited for highly sensitive, low plastic clays, as mentioned in section 5.3.3 and 5.2.3.

Chapter 6

Summary and Recommendations for Further Work

6.1 Summary and Conclusions

Laboratory work is one of the key factors when gathering information used in geotechnical engineering. It is therefore of great value to have good quality samples, so that the geotechnical parameters determined are as representative as possible to avoid overly conservative design. Sampling in sensitive clays is very challenging. It has been shown that sampling with an ordinary tube sampler gives less reliable results when evaluating the soil conditions compared to results from a block sampler. Sampling using the original Sherbrooke block sampler requires elevation of the drill rig above ground level, due to the large size of the sampler, and the method is relatively costly and time consuming. Modifications of the sampler was therefore done by simply downscaling the original sampler to enable sampling at ground level. The difference in sampler size opens the question if the downscaled sampler, the mini block sampler, retrieves samples of the same quality as the original Sherbrooke sampler, and if the mini block samples survive storage as well as the original.

To answer these questions, extensive laboratory work was carried out at the geotechnical laboratory at NTNU. Index tests, oedometer and triaxial tests were performed at samples from both mini block and the original Sherbrooke block samplers, retrieved at the NGTS quick clay site at Flotten, Trondheim. An XRD analysis was also done by the Department of Geoscience and Petroleum at NTNU to determine the mineral composition of the soil.

The results from the laboratory investigations show that the water content is approximately the same for specimens tested immediately from both samplers. After two weeks of storage, the water content changed with about 5 % for the mini block samples (increased for some samples and decreased for others), while it stayed approximately constant for the Sherbrooke block samples. There is little variation in the plasticity index I_P before and after storage for specimens from both samplers. The unit weight γ varies also more for the mini block samples than the Sherbrooke block samples when considering storage time. The grain density ρ_s determined using a pycnometer varies between 2.85 and 2.9 g/cm^3. As mentioned above, an XRD analysis was conducted and an estimate of ρ_s based on the mineral composition was found to be 2.86 g/cm^3. ρ_s seems to be unaffected of sampler type used and duration of storage. The undrained shear strength determined from the falling cone test shows that s_u is approximately the same for both types of samples that were tested immediately after sampling. After two weeks of storage s_u increased for the mini block samples, while s_r was constant. The Sherbrooke block samples showed little to no change after storage. The salinity for all samples, regardless of sampler type and storage time, was determined to be approximately 0.5 g/l. Clay which have a salinity below 0.5 g/l may obtain quick behavior. Results from grain size distribution using the hydrometer method, shows that the material is defined as clay, with an average clay content of about 60 %.

For a significant amount of the oedometer samples, it seems like something went wrong as several "bumps" occurred on the oedometer curve in the $\sigma'_m - \varepsilon$ plot. Some differences are discovered between the mini block and Sherbrooke block samples; the mini block samples gives a lower value of p'_c, OCR and M_{OC}, than those form the Sherbrooke block sampler, regardless whether the samples have been stored or not. All of the oedometer samples are classified as being of *poor* or *disturbed quality*. For the triaxial samples, there are close to no difference in s_u or ε_f, regardless of sampler type and whether the samples were stored or not. Only the specimens from the mini block sampler at 7 m showed a decrease in s_u after storage. Most of the triaxial samples fell into the categories of *good to fair* and *acceptable quality*. The difference in quality between for the oedometer and triaxial samples may be due to the difference of trimming the samples. In Chapter 5 it is pointed out whether the sample quality criteria proposed by Lunne et al. (1997) and Andresen and Kolstad (1979) are suited for all types of soils, especially for highly sensitive, low plastic clays.

Based on the sample quality criteria of Lunne et al. (1997) and Andresen and Kolstad (1979) and the summary above it may be concluded that the mini block samples are of the same quality as the Sherbrooke block samples. Results from triaxial tests conclude the same; s_u and ε_f are the same for both mini block and

Sherbrooke block samples. However, oedometer results may conclude the opposite; specimens from the mini block sampler are more disturbed than those from the Sherbrooke block sampler, considering lower values of p'_c, OCR and M_{OC}. These oedometer results should be treated with caution considering the difficulties experienced during testing. Evaluation of the effect of storage shows that mini block samples survives storage just as well as the Sherbrooke block samples based on the sample quality criteria. Regarding the index properties, mini block samples survives almost as well as the Sherbrooke block samples. The main differences before and after storage for the mini block samples are the water content, unit weight and the undrained shear strength s_u determined from the falling cone test. Almost no change was detected for the oedometer and triaxial tests before and after storage for the mini block samples, except for the triaxial tests from 7 m. To strengthen the findings and conclusion of this master's thesis, more tests should be carried out.

6.2 Recommendations for Further Work

First of all, more laboratory tests should be carried out, especially oedometer tests. Ideally, two sets of samples series right next to each other, both for mini block and Sherbrooke block samples, should be retrieved. One series would be opened and tested immediately and the other series after being stored for two weeks. This way samples are not opened and cut and then stored again for two weeks. One could also consider to change the storage time for the block samples; do the mini block samples survive as well as the Sherbrooke samples after four weeks?

Mini block samples and Sherbrooke samples should be retrieved continuously to greater depths, to obtain a better profile of the soil strata and to gain a wider basis for comparison of the two types of block samples. Triaxial tests from the same depth should be consolidated to the same stress conditions, and not based on the sample's specific unit weight as done in this thesis. A better practice of how to conduct the B-test in the triaxial test should be explored, since most B-tests carried out here did not meet the criterion for acceptable B-values for most of the tests. Also more piezometers should be installed at the test cite to have a better understanding how the pore pressure develops with depth. Other field investigation methods should be carried out to give more information about the layering and compare this to results from the block samples. One might consider to carry out all the tests in a temperature controlled room, which holds the same temperature and humidity as the in situ conditions for the samples. Regarding the sample quality criteria; the oedometer and triaxial test should also be evaluated after the M_0/M_L-criterion by Karlsrud and Hernandez-Martinez (2013).

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Appendix A

Index Testing

The results from the index tests performed on the block samples are presented in this appendix as plots. A table containing the water contents and the plasticity and liquidity indices is also presented herein. The results from the XRD-analysis carried out by the Department of Geoscience and Petroleum at NTNU can be found at the end of this appendix.

A.1 Water Content and Atterberg Limits

Table A.1: Results from water content and Atterberg limits measurements

Sample type	Storage time [weeks]	Depth [m]	w [%]	w_P [%]	w_L [%]	I_P [%]	I_L[-]
Mini	0	4.45	54.86	29.21	53.44	24.22	1.06
Mini	0	7.08	44.05	23.17	32.54	9.37	2.23
Mini	0	8.05	42.72	24.51	33.12	8.61	2.11
Mini	2	4.70	48.11	29.35	51.37	22.02	0.85
Mini	2	5.10	57.61	32.74	51.64	18.90	1.32
Mini	2	7.20	39.33	24.03	34.30	10.27	1.50
Mini	2	8.15	47.71	24.09	31.72	7.63	3.17
Sherbrooke	0	6.65	50.08	24.47	40.25	15.78	1.62
Sherbrooke	0	7.05	44.44	23.23	35.26	12.04	1.76
Sherbrooke	0	7.20	40.83	21.04	31.98	10.94	1.81
Sherbrooke	0	7.72	43.46	22.30	32.05	9.75	2.17
Sherbrooke	2	6.65	49.49	21.84	39.46	17.63	1.57
Sherbrooke	2	7.05	45.99	25.34	39.06	13.71	0.98
Sherbrooke	2	7.20	42.13	21.74	32.66	10.93	1.87
Sherbrooke	2	7.72	43.28	20.53	31.87	11.34	2.01

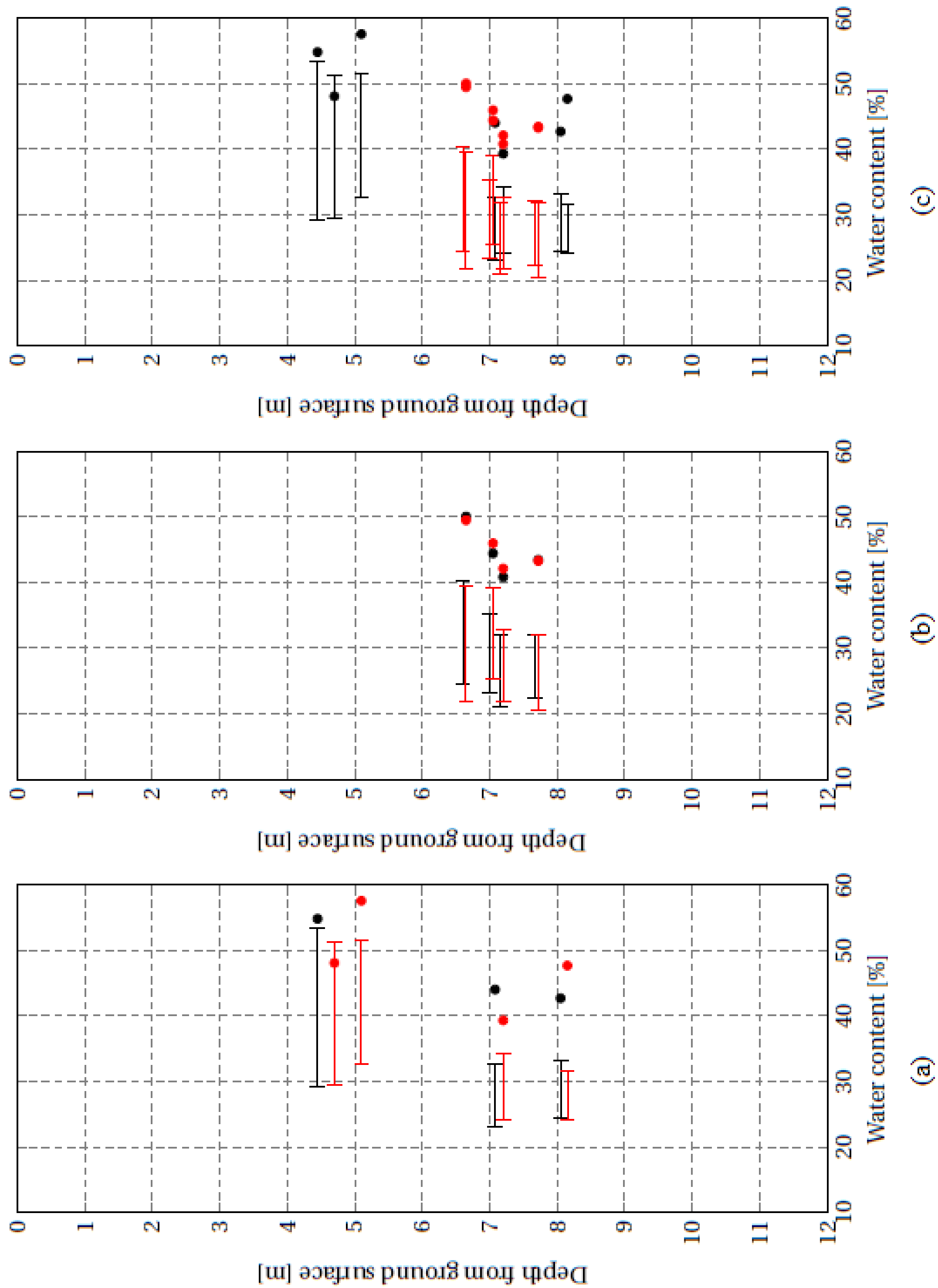

Figure A.1: Water content and Atterberg limits. Fig. (a) and (b) shows water contents at 0 weeks after sampling (black) and 2 weeks after sampling (red) for mini block samples and Sherbrooke block samples, respectively. Fig. (c) shows the water contents for all mini block samples (black) and Sherbrooke block samples (red).

A.2 Liquidity and Plasticity Index

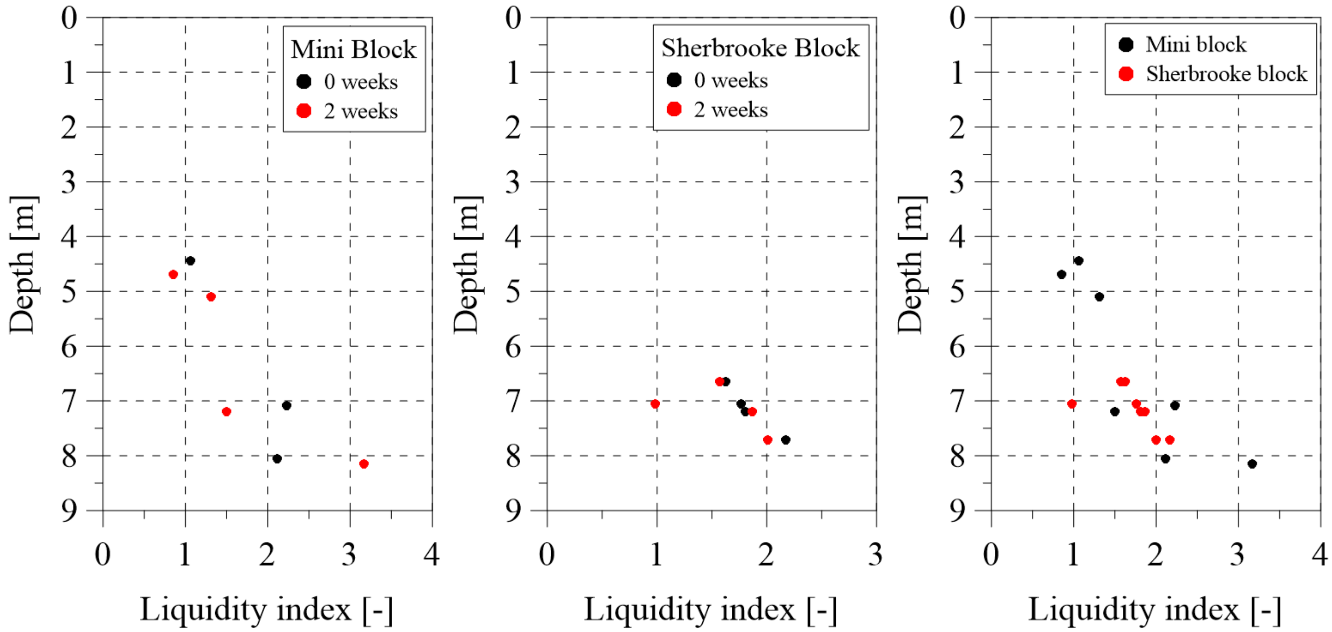

Figure A.2: Liquidity index.

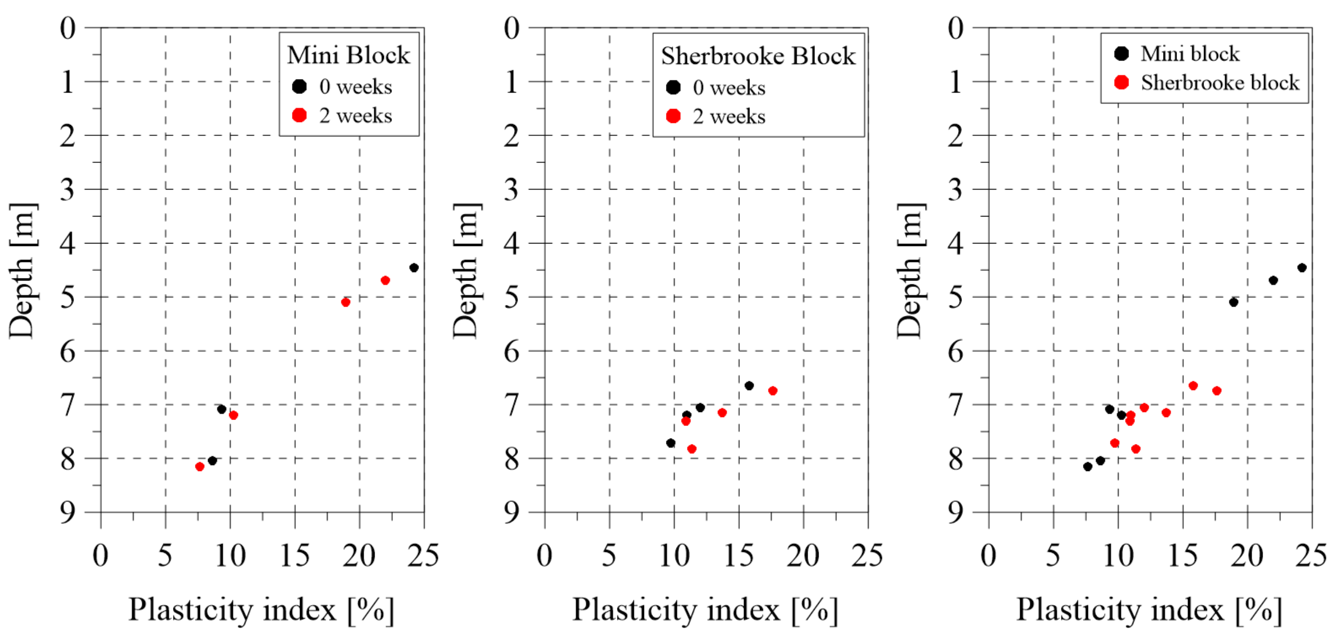

Figure A.3: Plasticity index.

A.3 Unit Weight and Grain Density

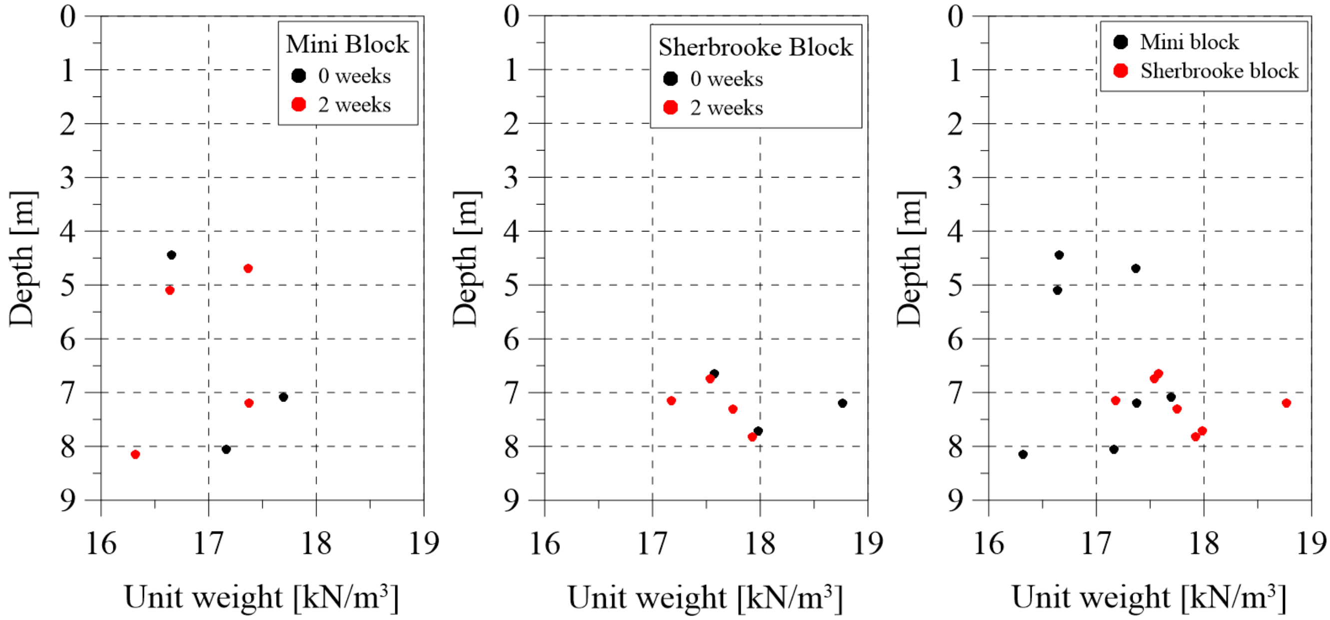

Figure A.4: Unit weight.

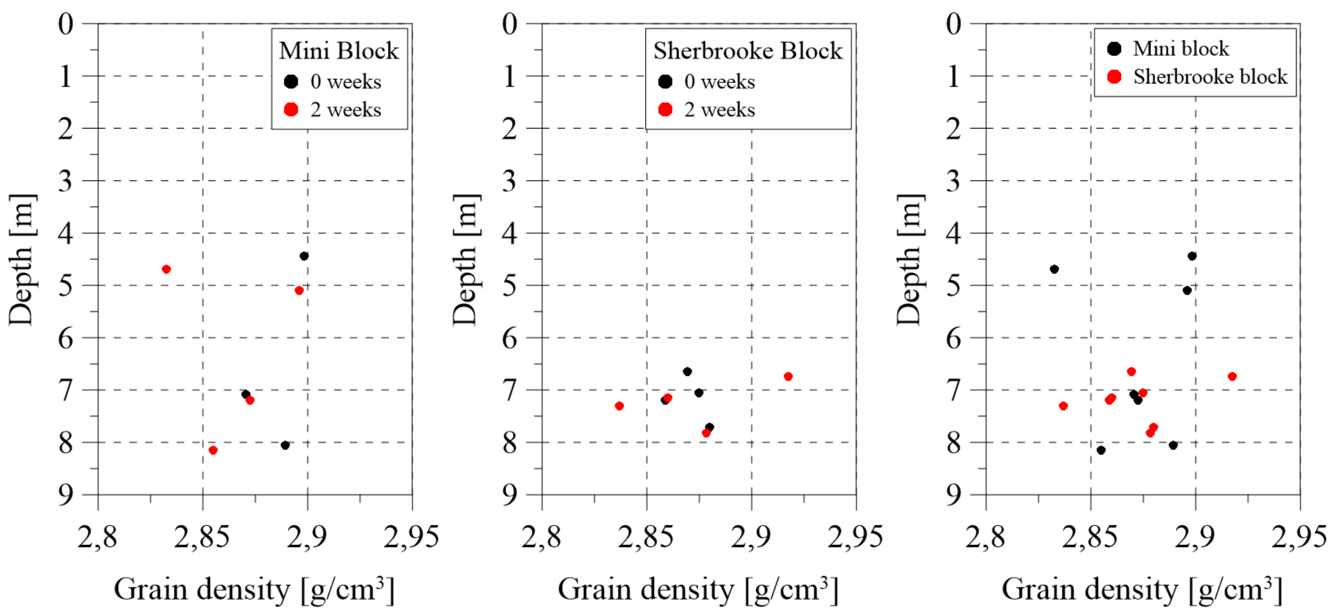

Figure A.5: Grain density.

A.4 Falling Cone

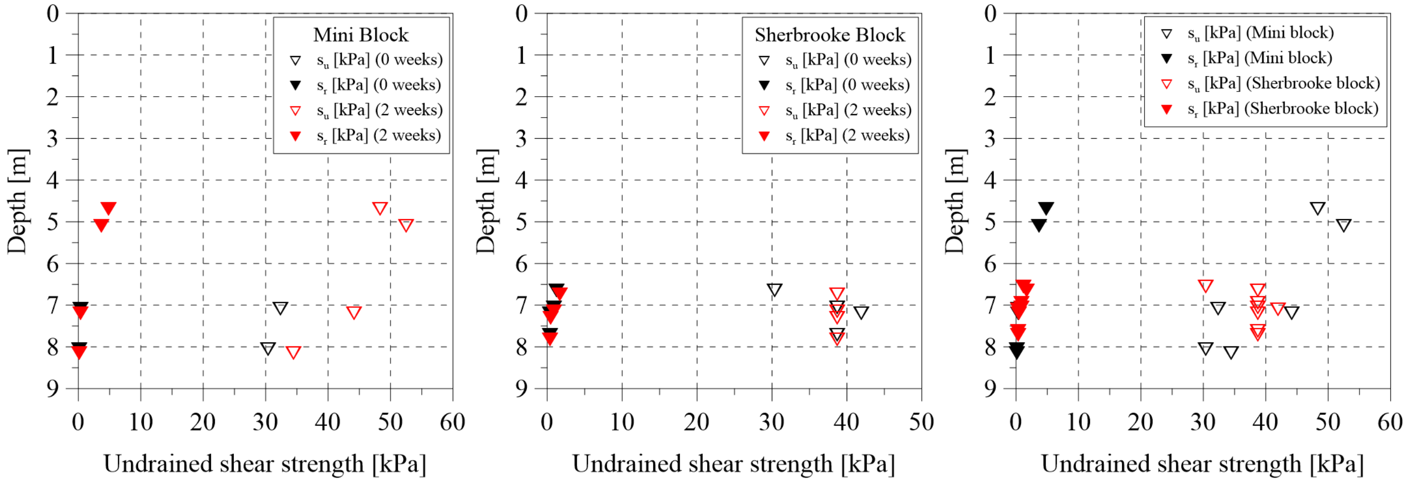

Figure A.6: Undrained shear strength.

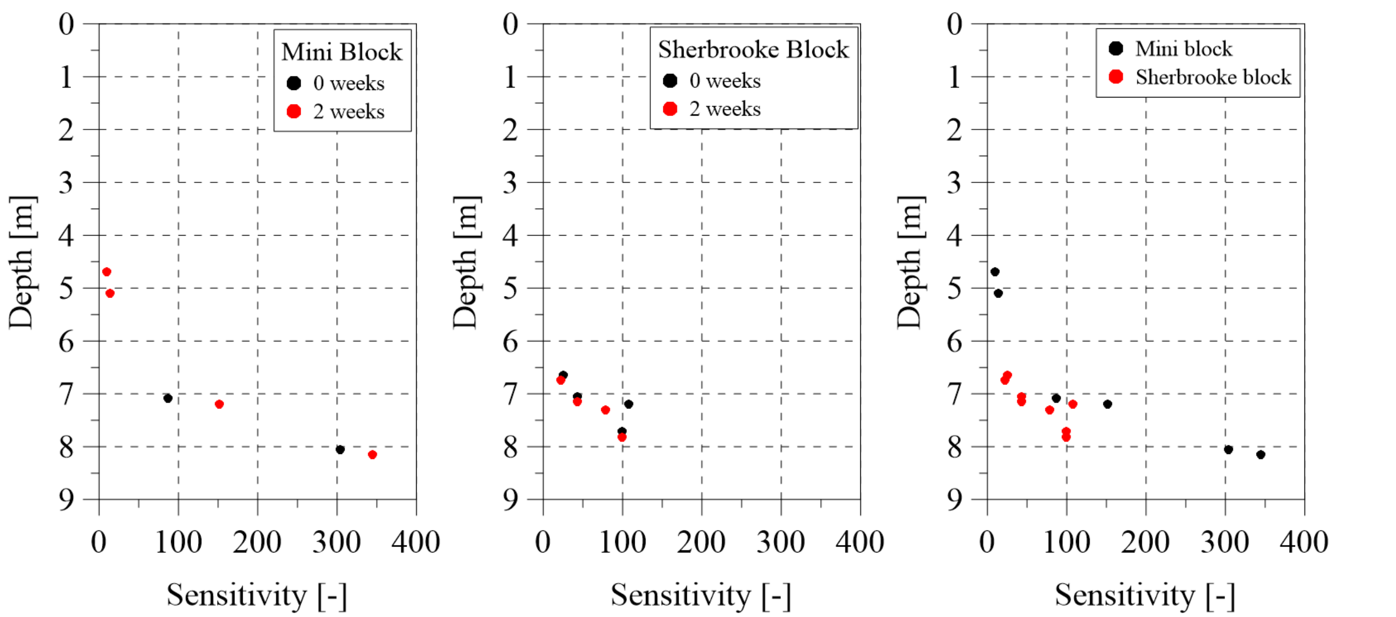

Figure A.7: Sensitivity.

A.5 Salt Content and Clay Percentage

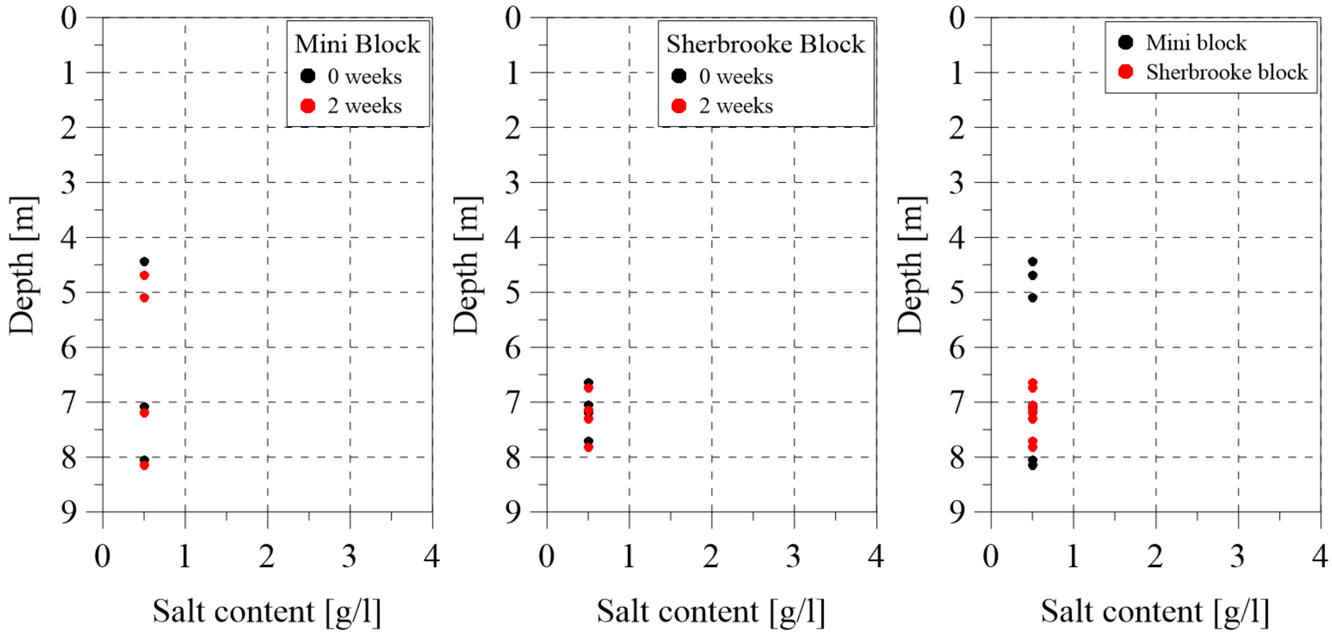

Figure A.8: Salinity.

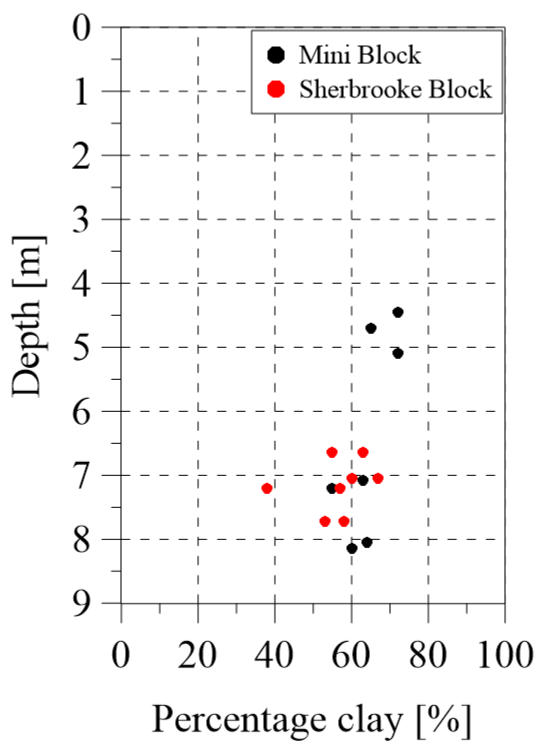

Figure A.9: Clay content.

A.6 Grain Size Distribution by Hydrometer Method

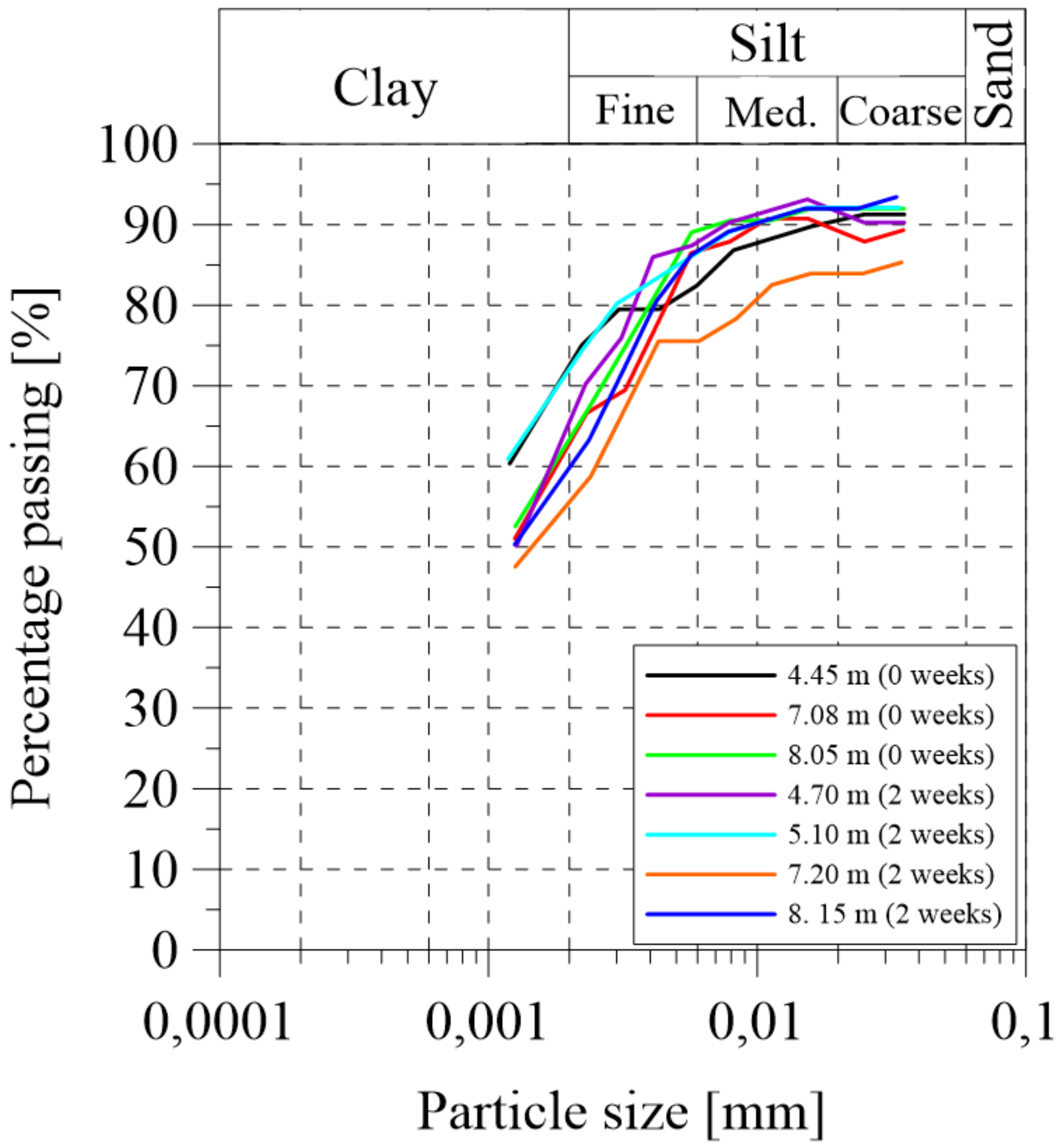

Figure A.10: Grain size distribution from hydrometer analysis, mini block sample.

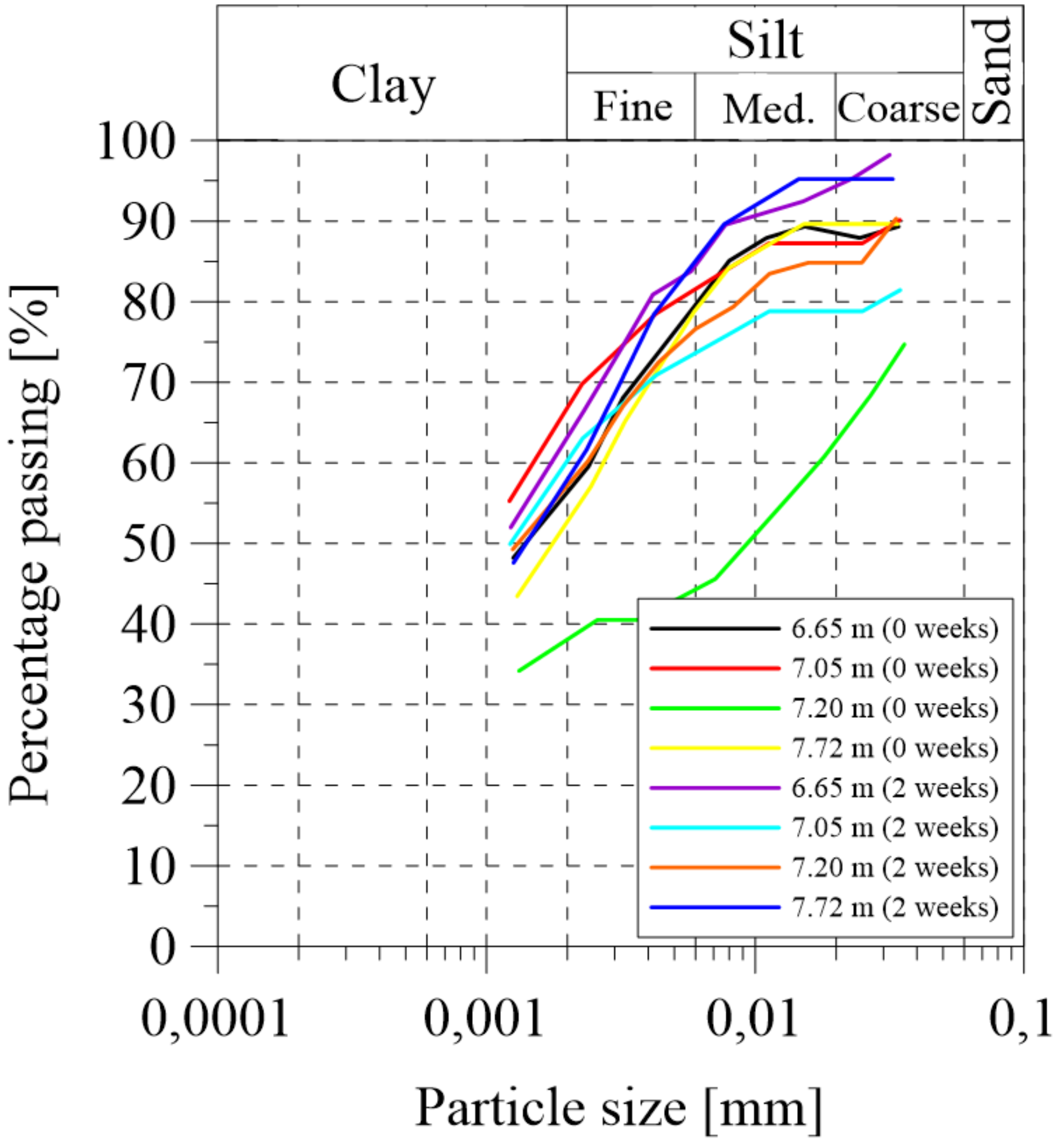

Figure A.11: Grain size distribution from hydrometer analysis, Sherbrooke block sample.

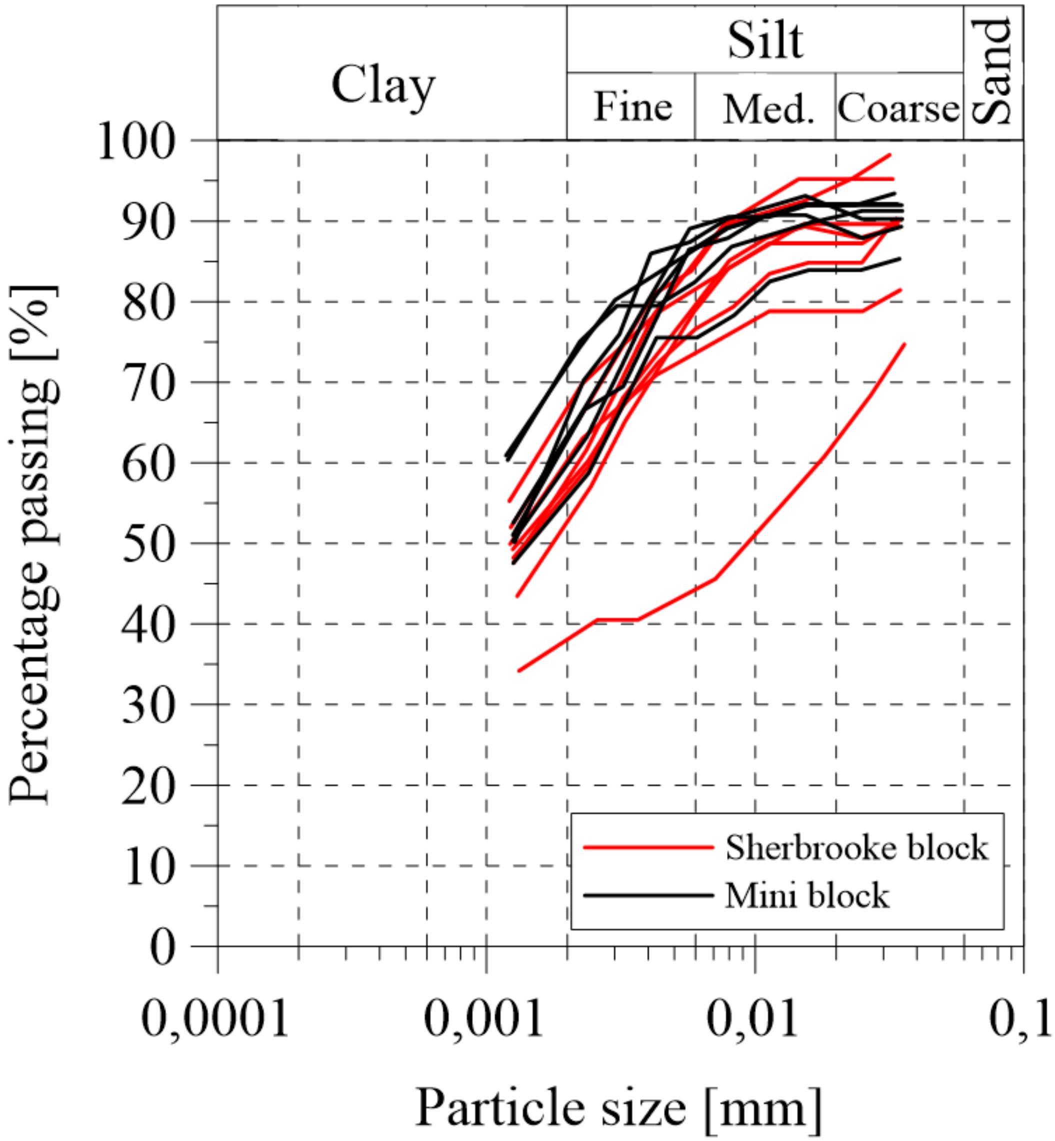

Figure A.12: Grain size distribution from hydrometer analysis, mini block (black) and Sherbrooke block (red) sample.

NTNU
Fakultet for ingeniørvitenskap
Institutt for geovitenskap og petroleum

Vår dato	Vår referanse
17.11.2017	LT / 17-160
Deres dato	Deres referanse
15.11.2017	90160900

NTNU Institutt for bygg- og miljøteknikk
Høgskoleringen 7a
7491 Trondheim
v/Pernille Rognlien

XRD-analyse av 1 prøve fra Flotten

Analysen er utført på en Bruker D8 ADVANCE. DIFFRAC.SUITE.EVA programvare i kombinasjon med databasen PDF-4+ foreslår følgende mineralfaser.
Rietveld (Topas 4) er brukt til mineral-kvantifisering.

Prøve mrk.	NGTS/P.R.
J.nr.	**170846**
Kvarts	17 %
Glimmer	37 %
Plagioklas	18 %
Alkalifeltspat	7 %
Pyroksen	2 %
Amfibol	6 %
Kloritt	11 %
Kalkspat	1 %
Dolomitt	< 1 %

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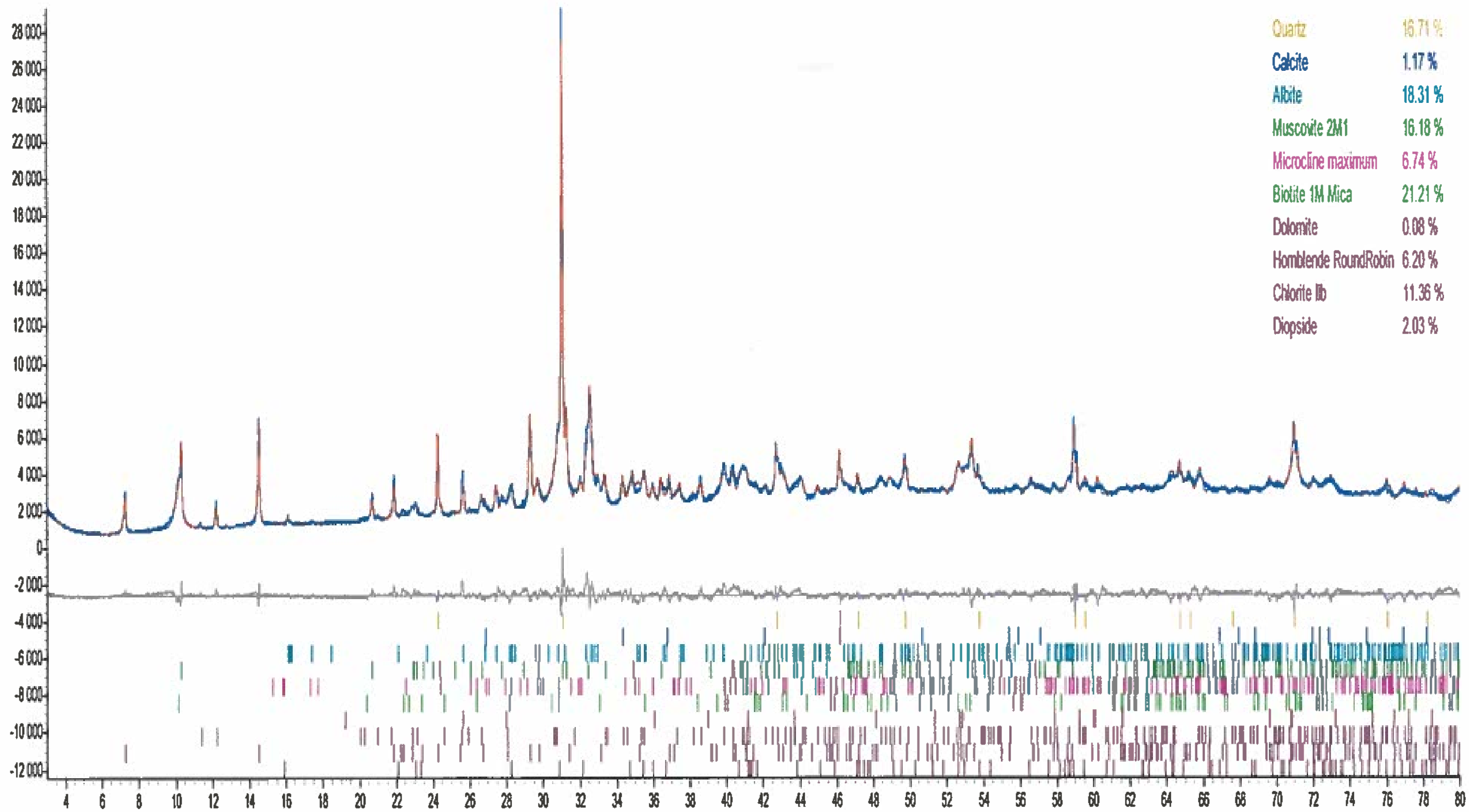
Vår dato 17.11.2017 | Vår referanse LT / 17-160

170846: NGTS/P.R.



Appendix B

Oedometer Testing

Time t, deformation δ, vertical stress σ_v and pore pressure at the base of the oedometer u_b were logged with a 5 second sampling interval. Processing of these data were done in Microsoft Excel and plots where made in Grapher. The equations used in the processing will be presented here. The strain was calculated after Eq. B.1

$$\varepsilon = \frac{\delta}{h_0} \tag{B.1}$$

where δ is the recorded deformation and h_0 is the initial height of the soil sample, which for all tests where 20 mm.

The average effective stress σ'_m was calculated using Eq. B.2

$$\sigma'_m = \sigma_v - \frac{2}{3} u_b \tag{B.2}$$

where σ_v and u_b are the recorded vertical stress and pore pressure at the sample base respectively.

The modulus M was calculated after Eq. B.3

$$M = \frac{d\sigma'_m}{d\varepsilon} \tag{B.3}$$

where $d\sigma'_m$ and $d\varepsilon$ are the differences between two trailing data points for the calculated σ'_m and ε respectively.

The coefficient of consolidation was calculated using Eq. B.4

$$c_v = \frac{d\sigma'_m}{dt}\frac{[h_0(1-\varepsilon)]^2}{2u_b} \tag{B.4}$$

where $d\sigma'_m$ and dt are the differences between two trailing data points for the calculated σ'_m and the recorded time t respectively.

B.1 Oedometer Results from Mini Block Samples

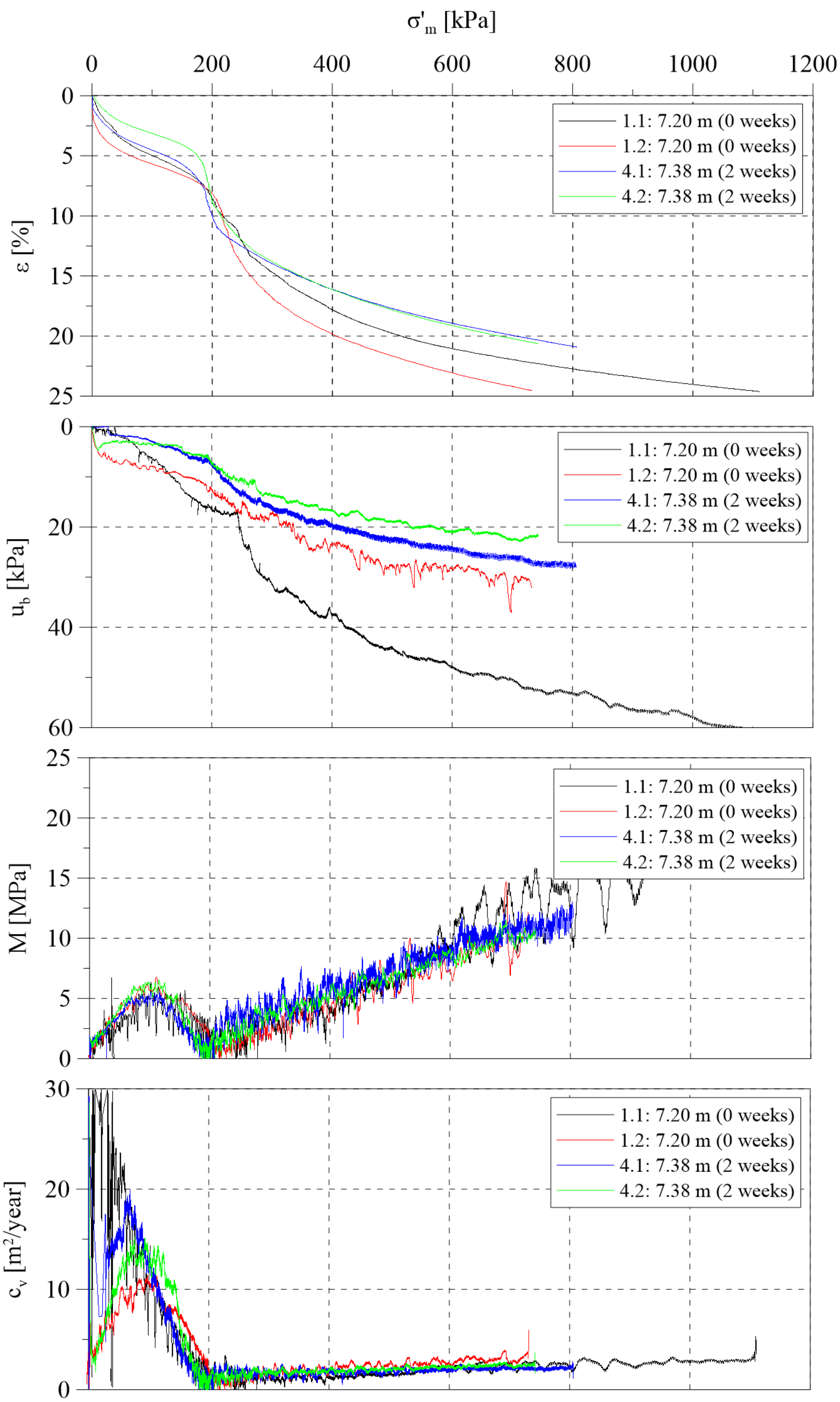


Figure B.1: CRS results from oedometer tests from depths 7.20 to 7.38 m, mini block sample.

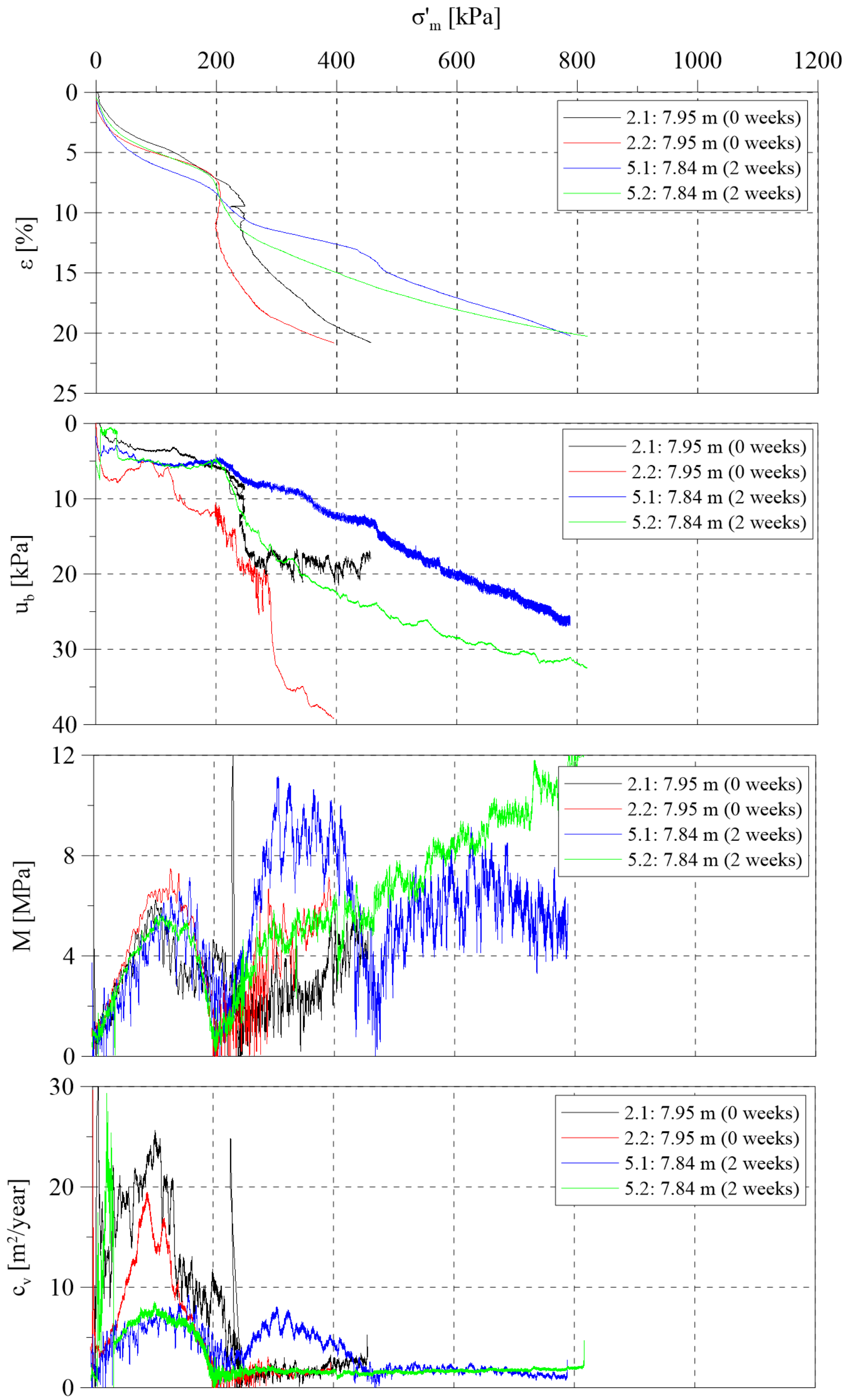


Figure B.2: CRS results from oedometer tests from depths 7.84 to 7.95 m, mini block sample.

CRS-1.1 **Mini Block Sample** **Flotten, Trondheim**					**0 weeks after sampling**
Depth	7.20 m	Strain rate	1 %/hr		
Sampling date	20.10.17	σ'_{v0}	77.3 kPa	$\Delta e/e_0$	0.08
Opening date	20.10.17	w	44.1 %	p'_c	180 kPa
Testing date	21.10.17	γ	18.0 kN/m^3	OCR	2.3

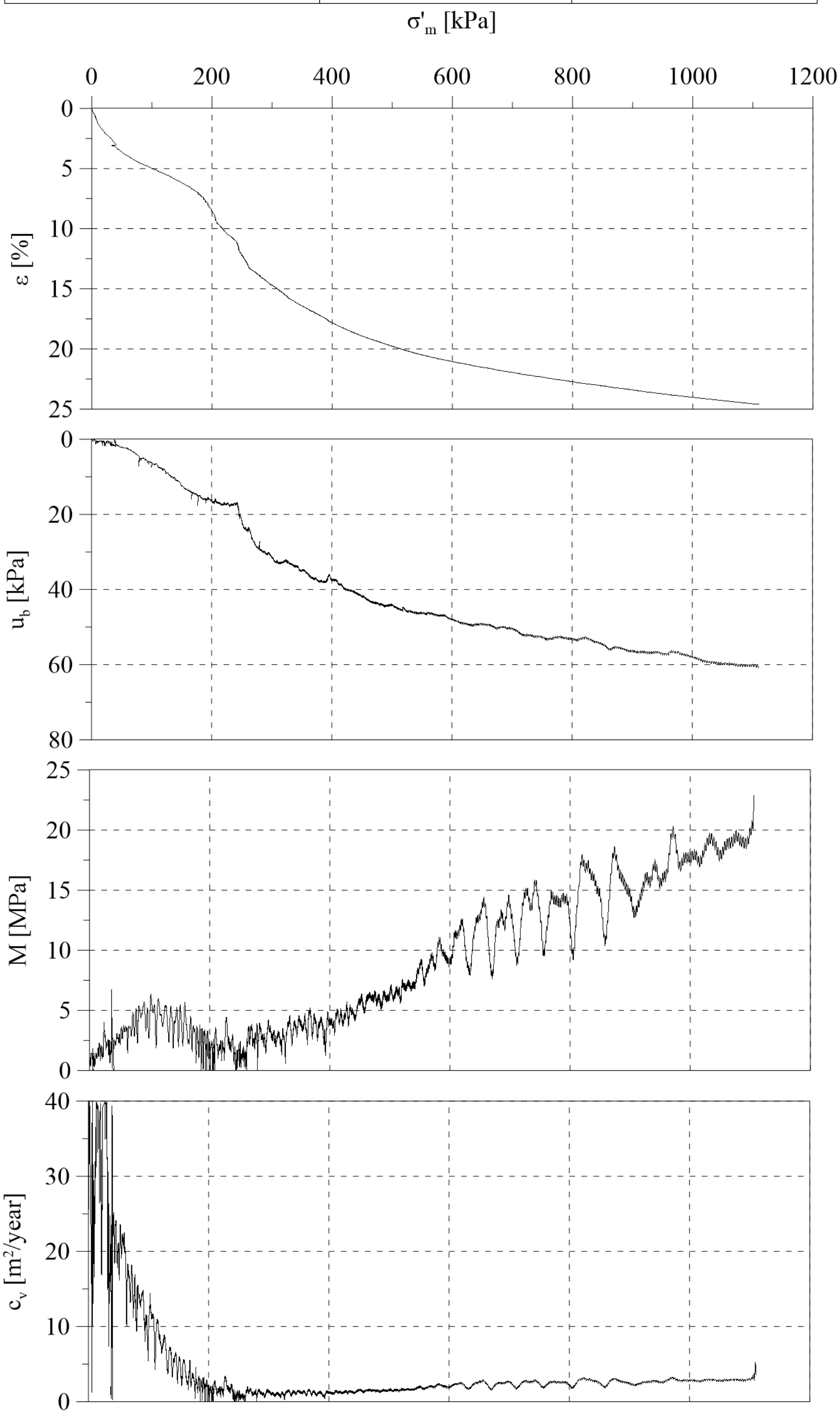


Figure B.3: CRS results from oedometer test no. 1 at depth 7.20 m.

CRS-1.2 **Mini Block Sample** **Flotten, Trondheim**					**0 weeks after sampling**
Depth	7.20 m	Strain rate	1 %/hr		
Sampling date	20.10.17	σ'_{v0}	78.2 kPa	$\Delta e/e_0$	0.08
Opening date	20.10.17	w	44.1 %	p'_c	200 kPa
Testing date	21.10.17	γ	18.1 kN/m^3	OCR	2.6

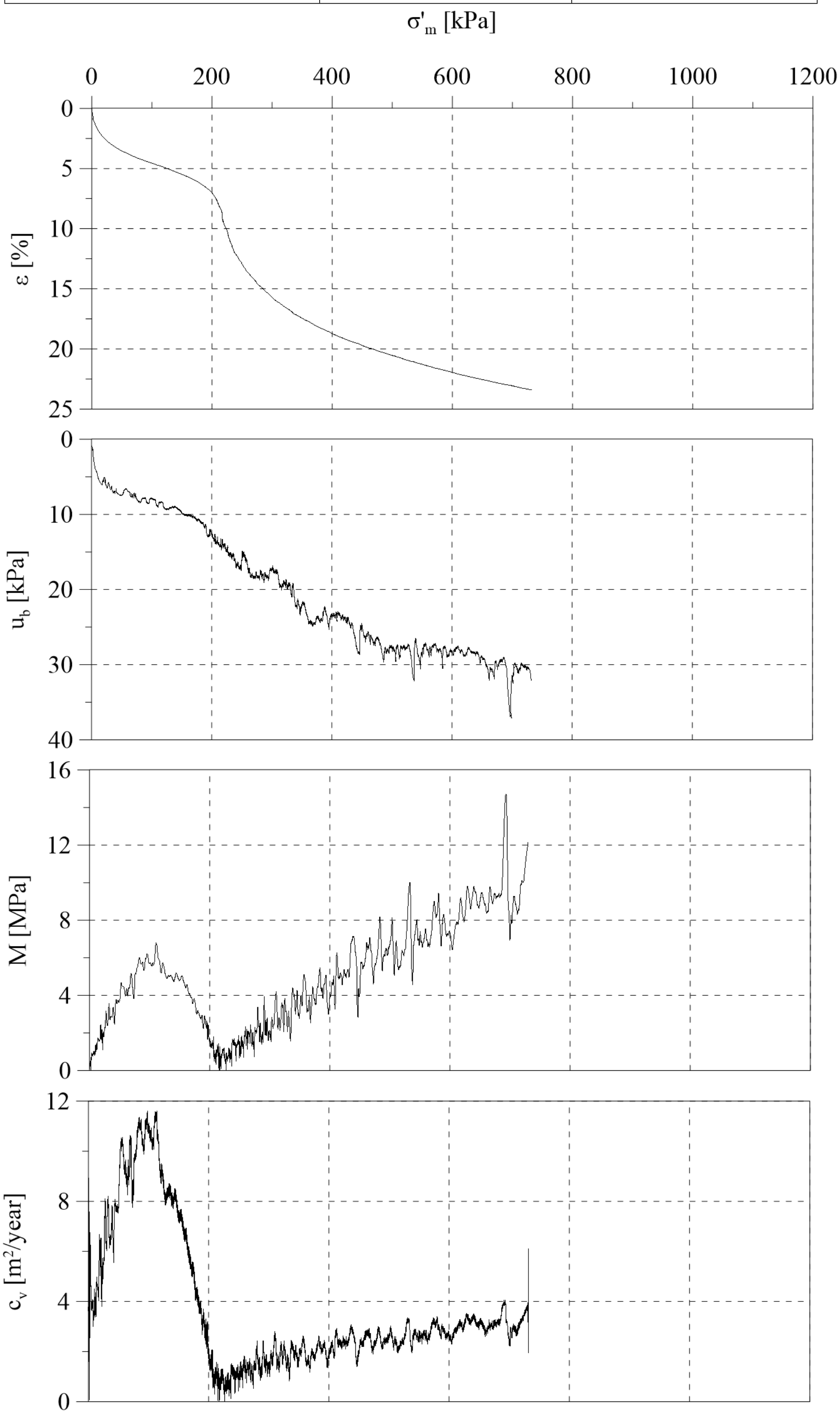


Figure B.4: CRS results from oedometer test no. 2 at depth 7.20 m.

CRS-2.1					**0 weeks after sampling**
Mini Block Sample					
Flotten, Trondheim					
Depth	7.95 m	Strain rate	1 %/hr		
Sampling date	23.10.17	σ'_{v0}	82.2 kPa	$\Delta e/e_0$	0.07
Opening date	23.10.17	w	46.7 %	p'_c	250 kPa
Testing date	23.10.17	γ	17.8 kN/m^3	OCR	3.0

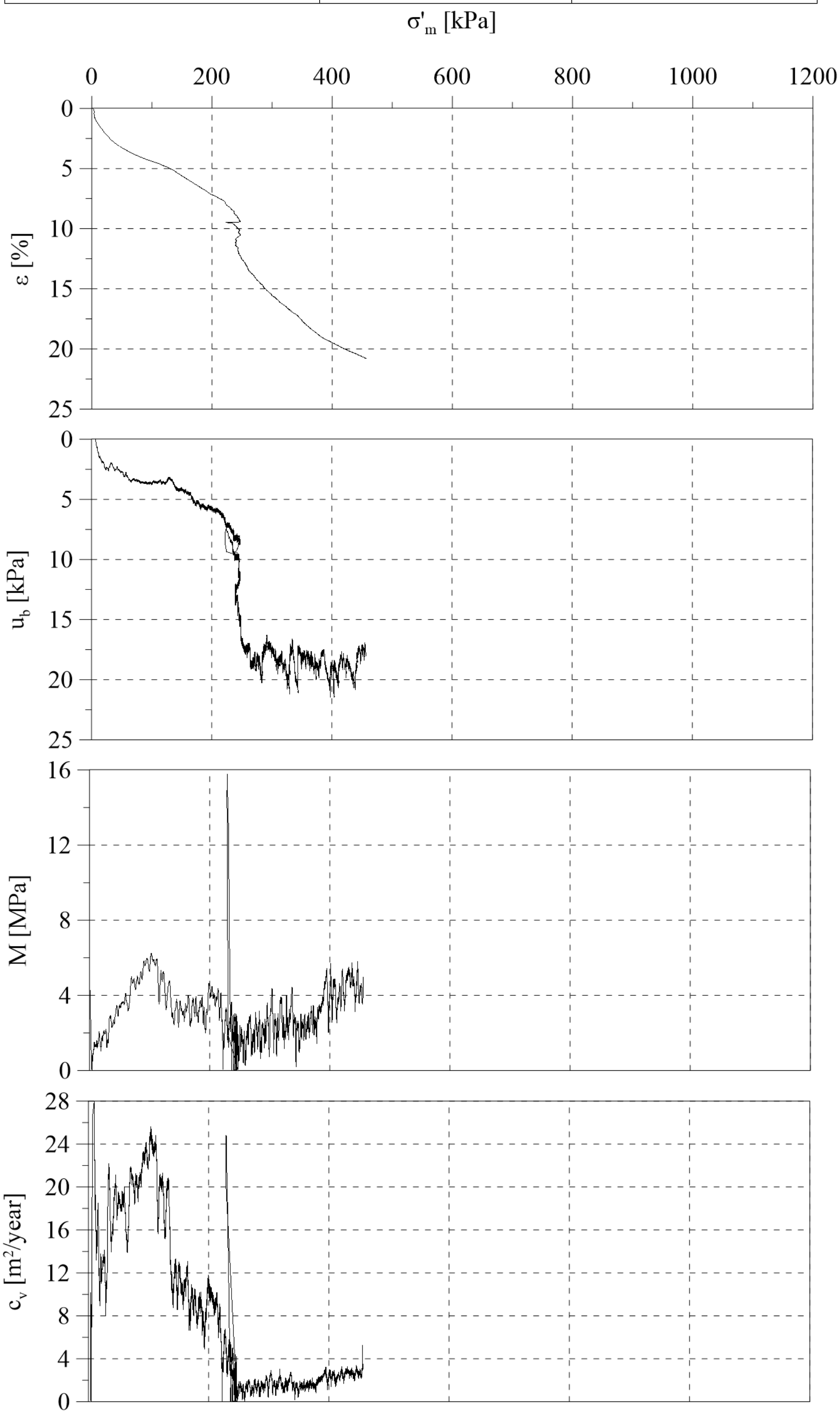


Figure B.5: CRS results from oedometer test no. 1 at depth 7.95 m.

CRS-2.2 **Mini Block Sample** **Flotten, Trondheim**					**0 weeks after sampling**
Depth	7.95 m	Strain rate	1 %/hr		
Sampling date	23.10.17	σ'_{v0}	82.8 kPa	$\Delta e/e_0$	0.07
Opening date	23.10.17	w	46.7 %	p'_c	200 kPa
Testing date	23.10.17	γ	17.9 kN/m^3	OCR	2.4

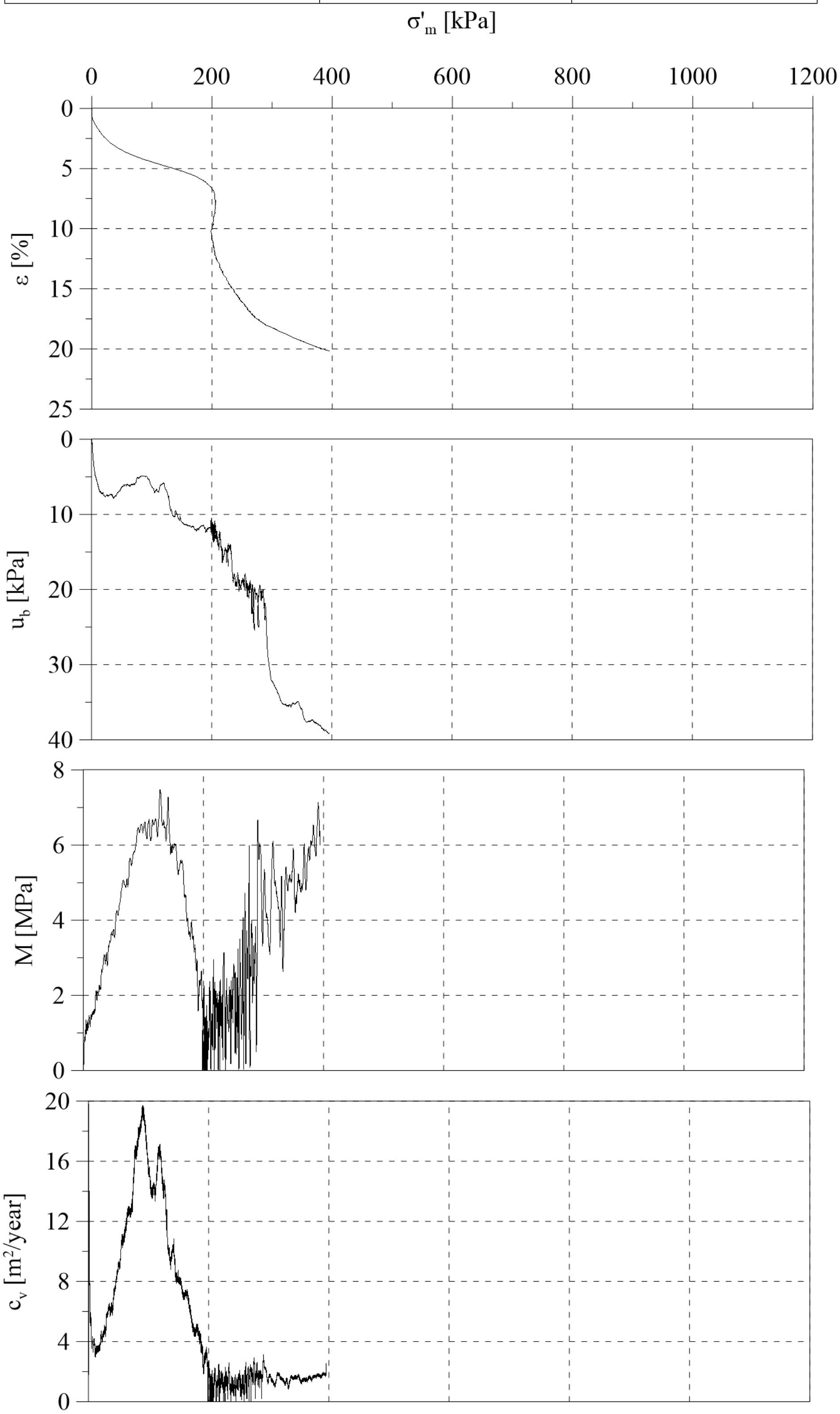


Figure B.6: CRS results from oedometer test no. 2 at depth 7.95 m.

CRS-3.1 **Mini Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	4.52 m	Strain rate	1 %/hr		
Sampling date	20.09.17	σ'_{v0}	53.1 kPa	$\Delta e/e_0$	0.05
Opening date	21.09.17	w	54.9 %	p'_c	200 kPa
Testing date	06.10.17	γ	17.3 kN/m^3	OCR	3.8

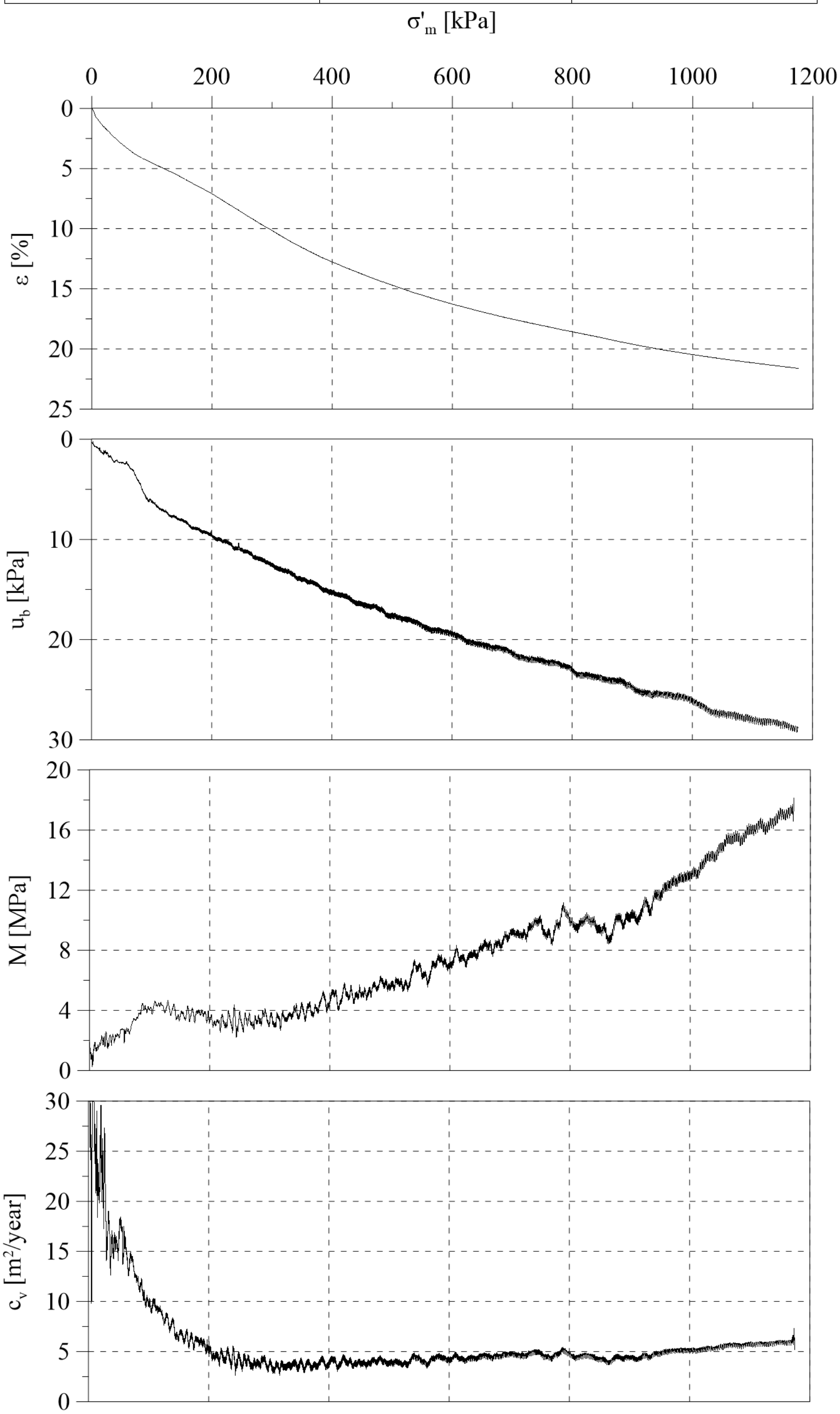


Figure B.7: CRS results from oedometer test at depth 4.52 m after 2 weeks of storage.

CRS-3.2					**2 weeks after sampling**
Mini Block Sample					
Flotten, Trondheim					
Depth	4.56 m	Strain rate	1 %/hr		
Sampling date	20.09.17	σ'_{v0}	52.8 kPa	$\Delta e/e_0$	0.05
Opening date	21.09.17	w	54.9 %	p'_c	175 kPa
Testing date	06.10.17	γ	17.2 kN/m^3	OCR	3.3

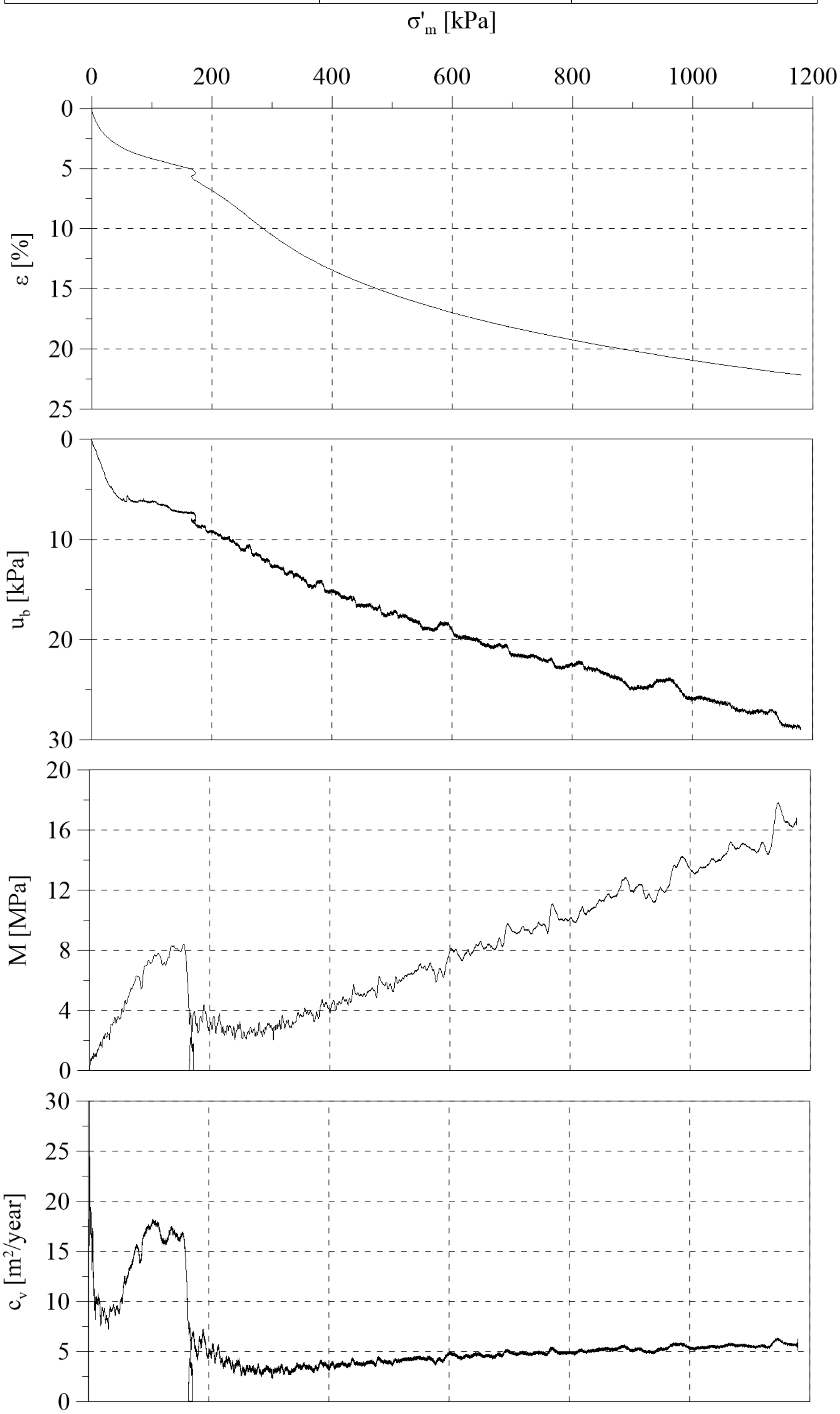


Figure B.8: CRS results from oedometer test at depth 4.56 m after 2 weeks of storage.

CRS-4.1 **Mini Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	7.38 m	Strain rate	0.5 %/hr		
Sampling date	20.10.17	σ'_{v0}	77.9 kPa	$\Delta e/e_0$	0.06
Opening date	21.10.17	w	46.0 %	p'_c	180 kPa
Testing date	02.11.17	γ	17.8 kN/m^3	OCR	2.3

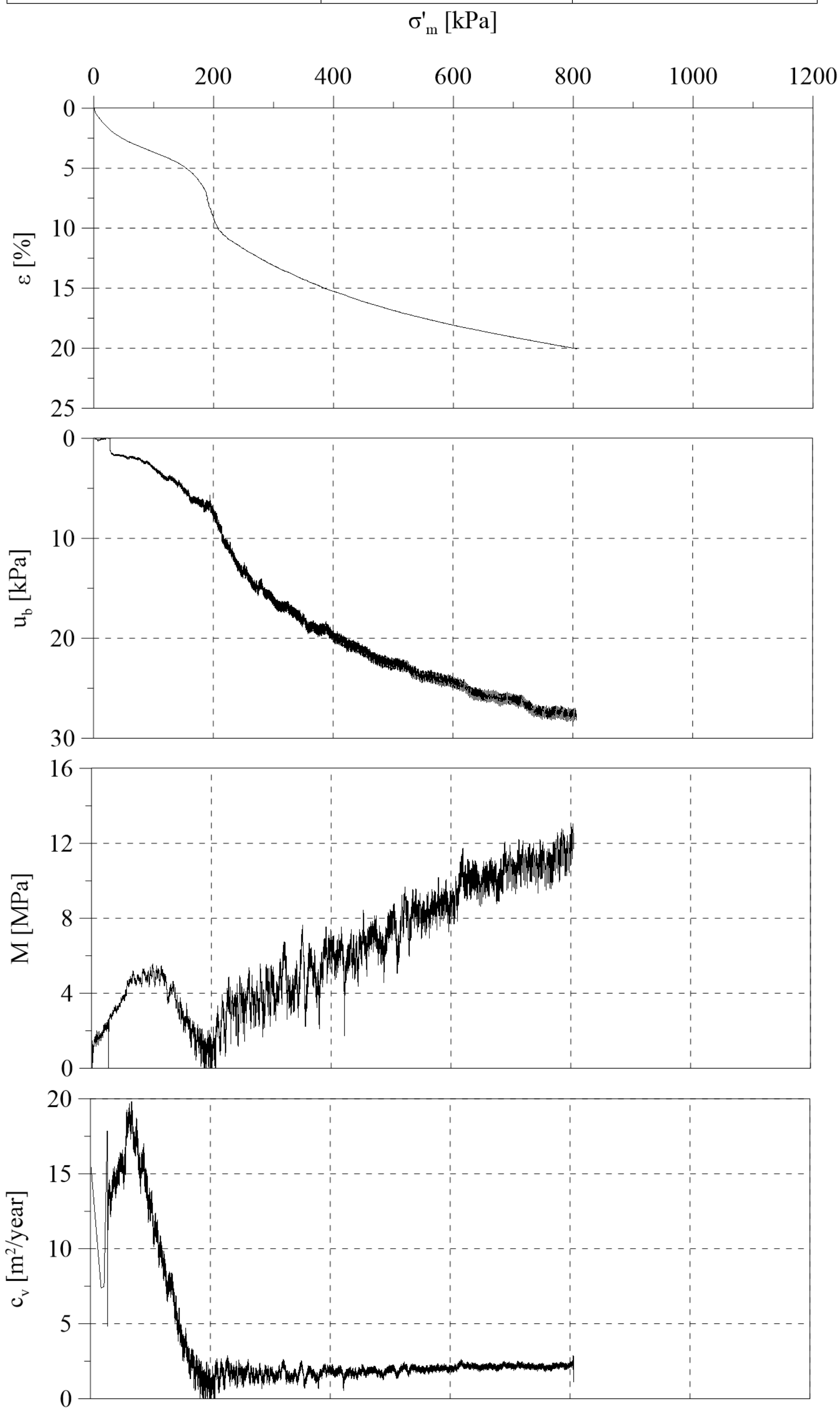


Figure B.9: CRS results from oedometer test no. 1 at depth 7.38 m after 2 weeks of storage.

CRS-4.2 **Mini Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	7.38 m	Strain rate	0.5 %/hr		
Sampling date	20.10.17	σ'_{v0}	74.8 kPa	$\Delta e/e_0$	0.05
Opening date	21.10.17	w	46.0 %	p'_c	180 kPa
Testing date	02.11.17	γ	17.4 kN/m^3	OCR	2.4

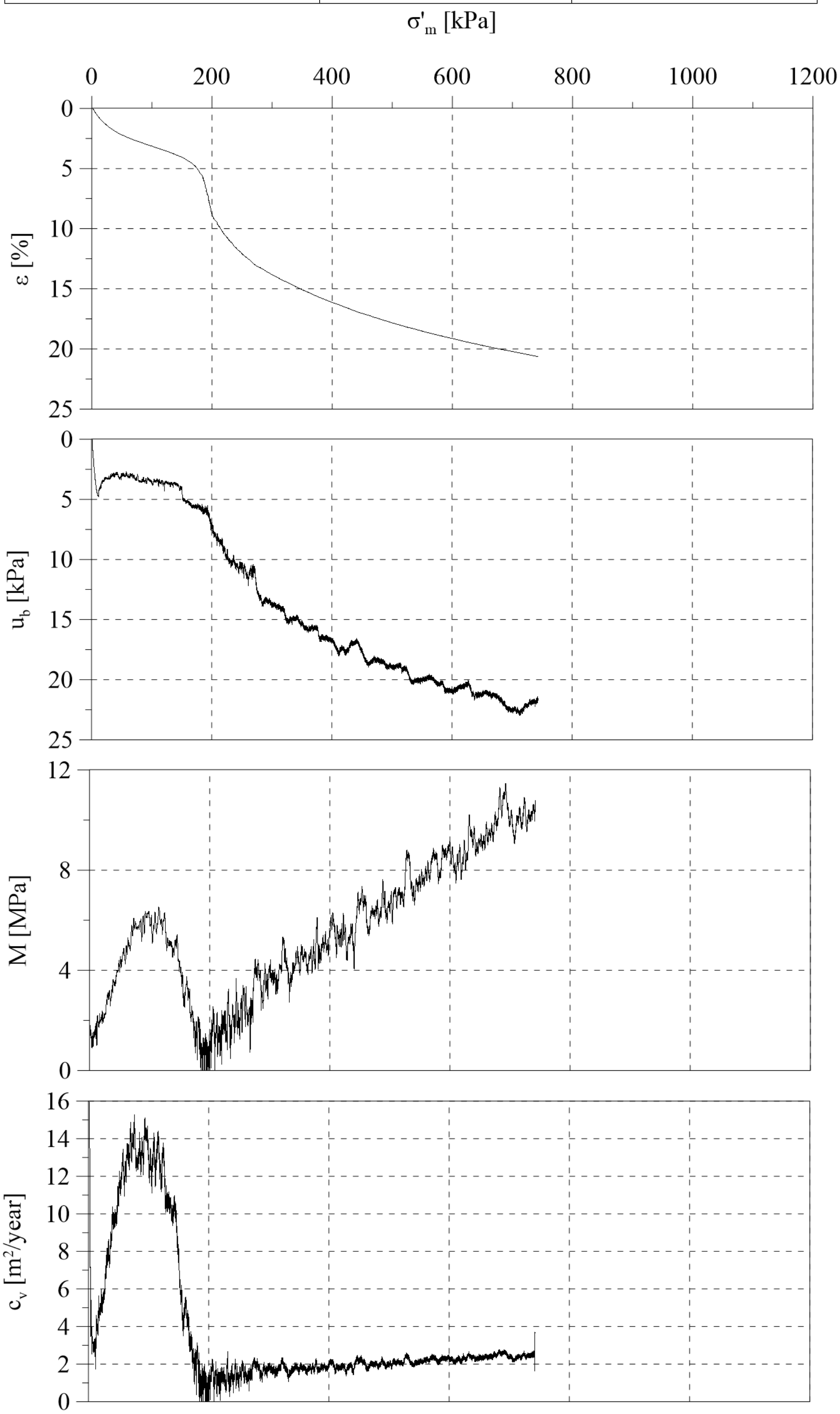


Figure B.10: CRS results from oedometer test no. 2 at depth 7.38 m after 2 weeks of storage.

CRS-5.1 Mini Block Sample Flotten, Trondheim					**2 weeks after sampling**
Depth	7.84 m	Strain rate	0.5 %/hr		
Sampling date	23.10.17	σ'_{v0}	80.3 kPa	$\Delta e/e_0$	0.09
Opening date	04.11.17	w	47.3 %	p'_c	190 kPa
Testing date	04.11.17	γ	17.7 kN/m^3	OCR	2.4

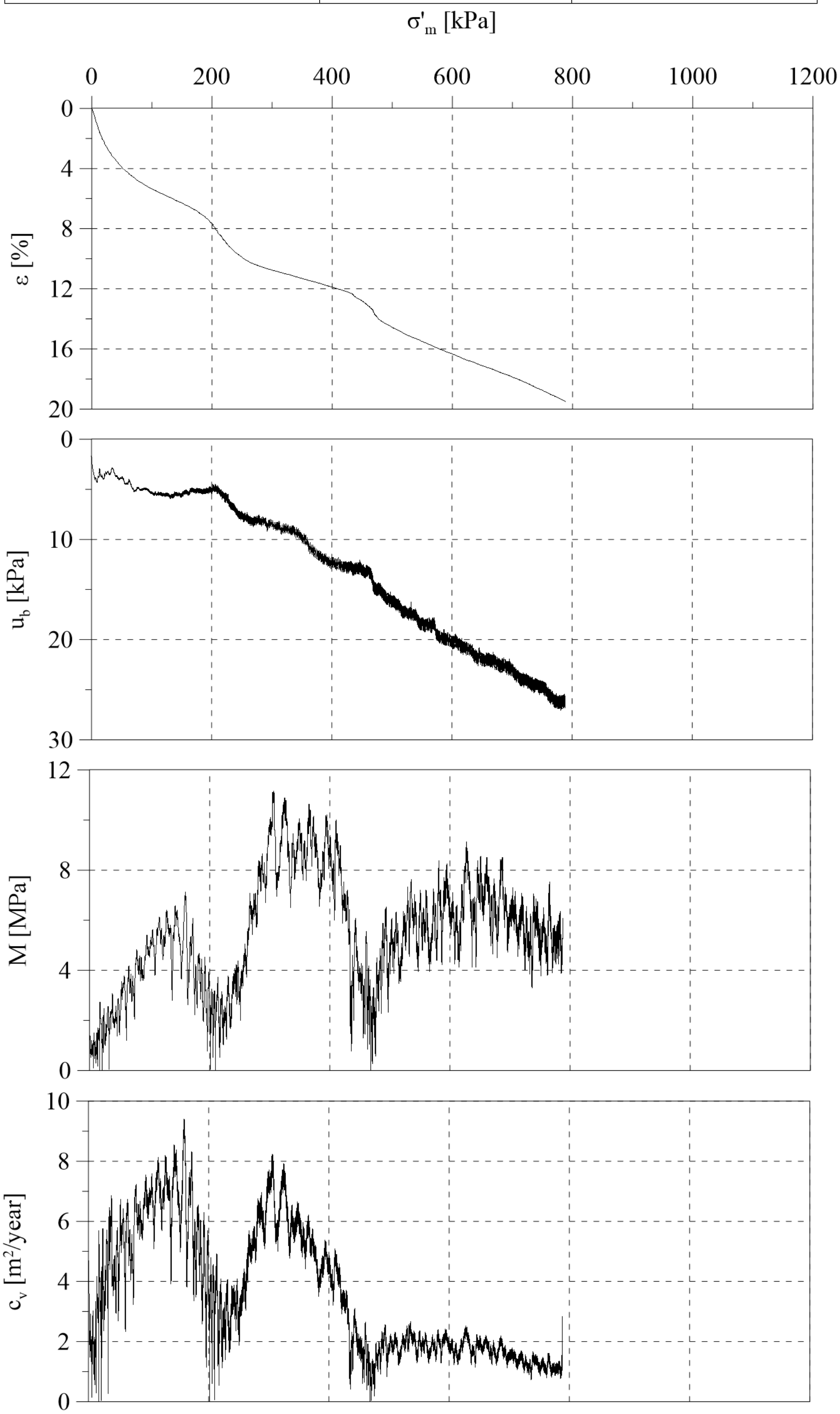


Figure B.11: CRS results from oedometer test no. 1 at depth 7.84 m after 2 weeks of storage.

CRS-5.2					**2 weeks after sampling**
Mini Block Sample					
Flotten, Trondheim					
Depth	7.84 m	Strain rate	0.5 %/hr		
Sampling date	23.10.17	σ'_{v0}	80.2 kPa	$\Delta e/e_0$	0.07
Opening date	04.11.17	w	47.3 %	p'_c	190 kPa
Testing date	04.11.17	γ	17.7 kN/m^3	OCR	2.4

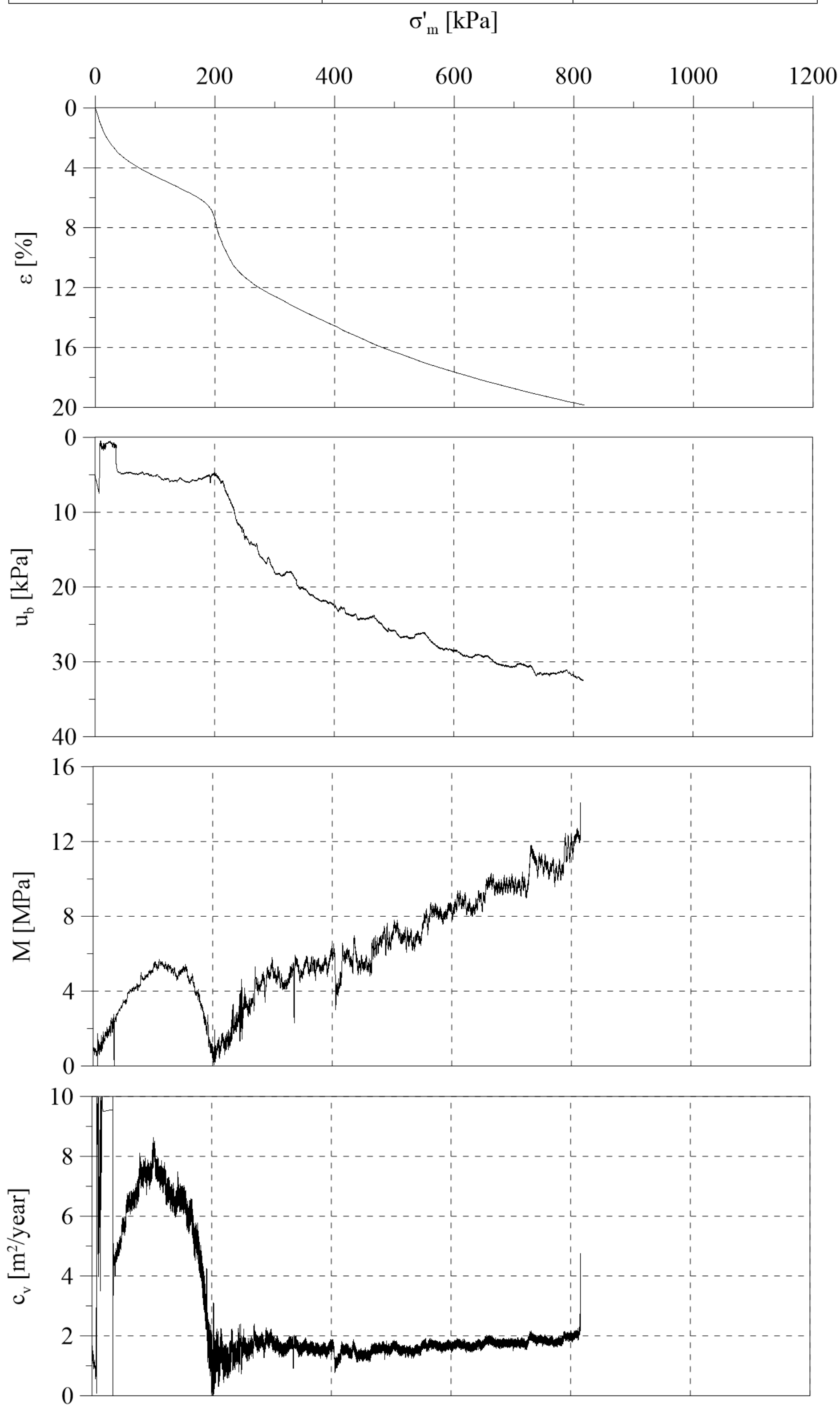


Figure B.12: CRS results from oedometer test no. 2 at depth 7.84 m after 2 weeks of storage.

B.2 Oedometer Results from Sherbrooke Block Samples

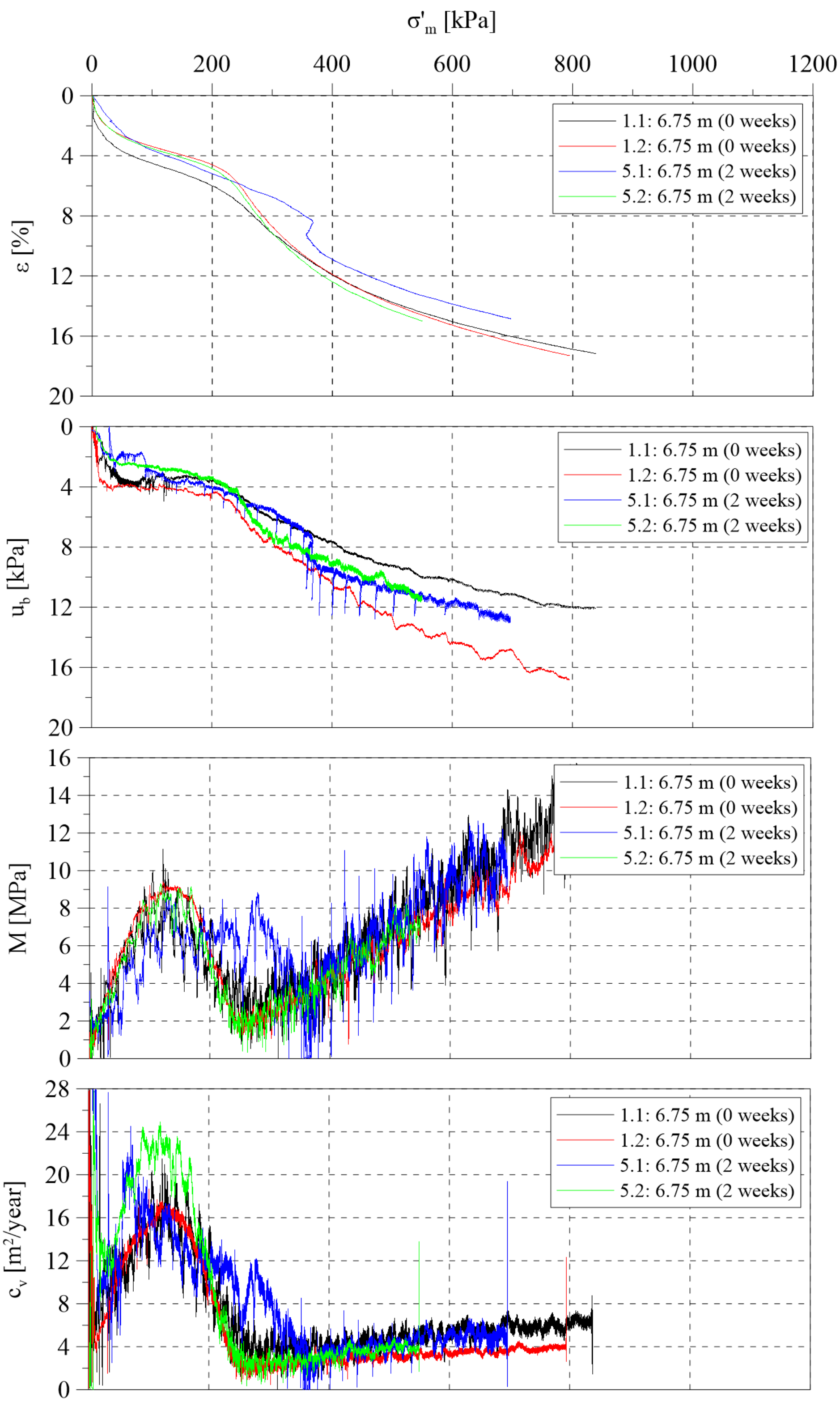


Figure B.13: CRS results from oedometer tests from depth 6.75 m, Sherbrooke block sample.

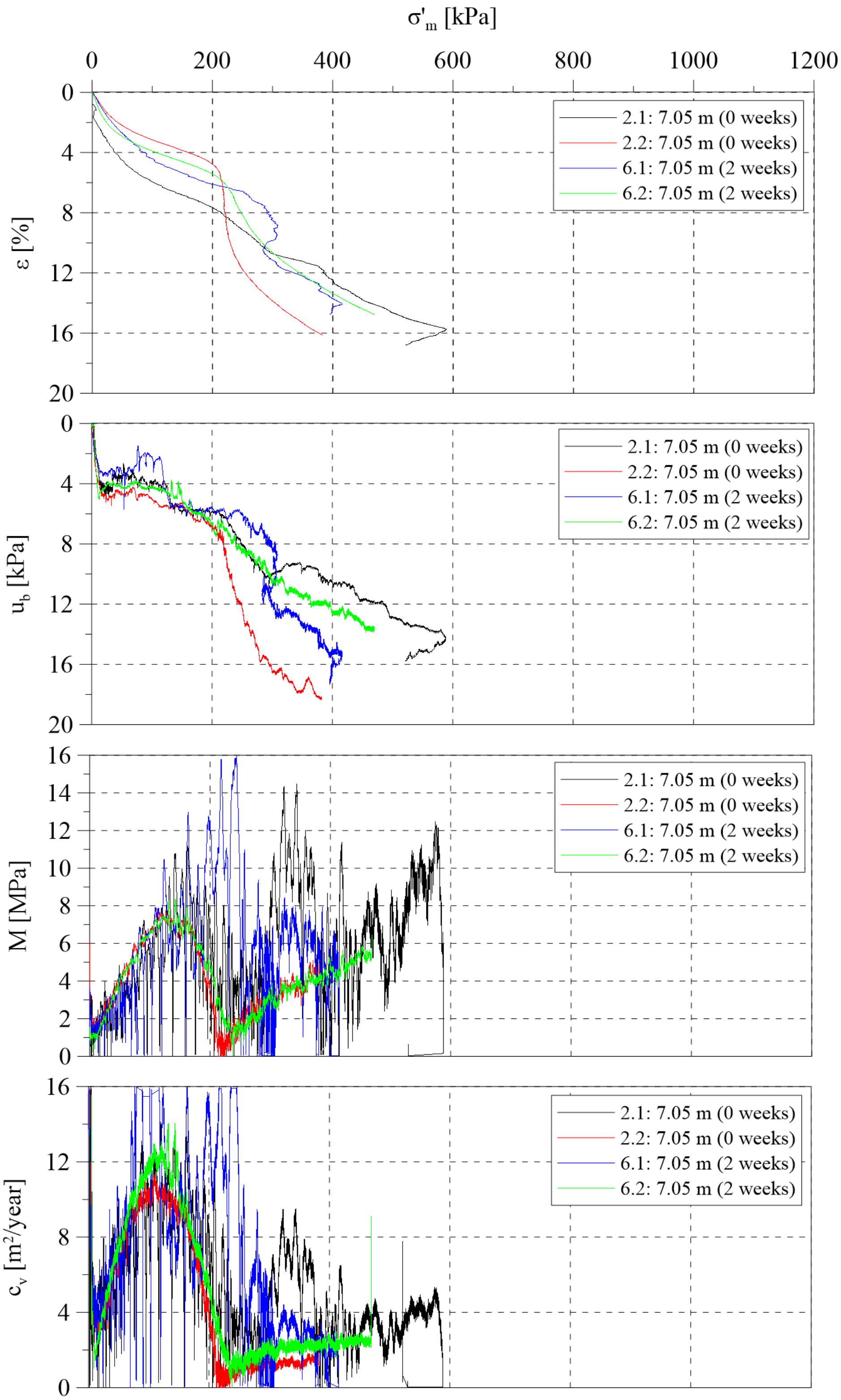


Figure B.14: CRS results from oedometer tests from depth 7.05 m, Sherbrooke block sample.

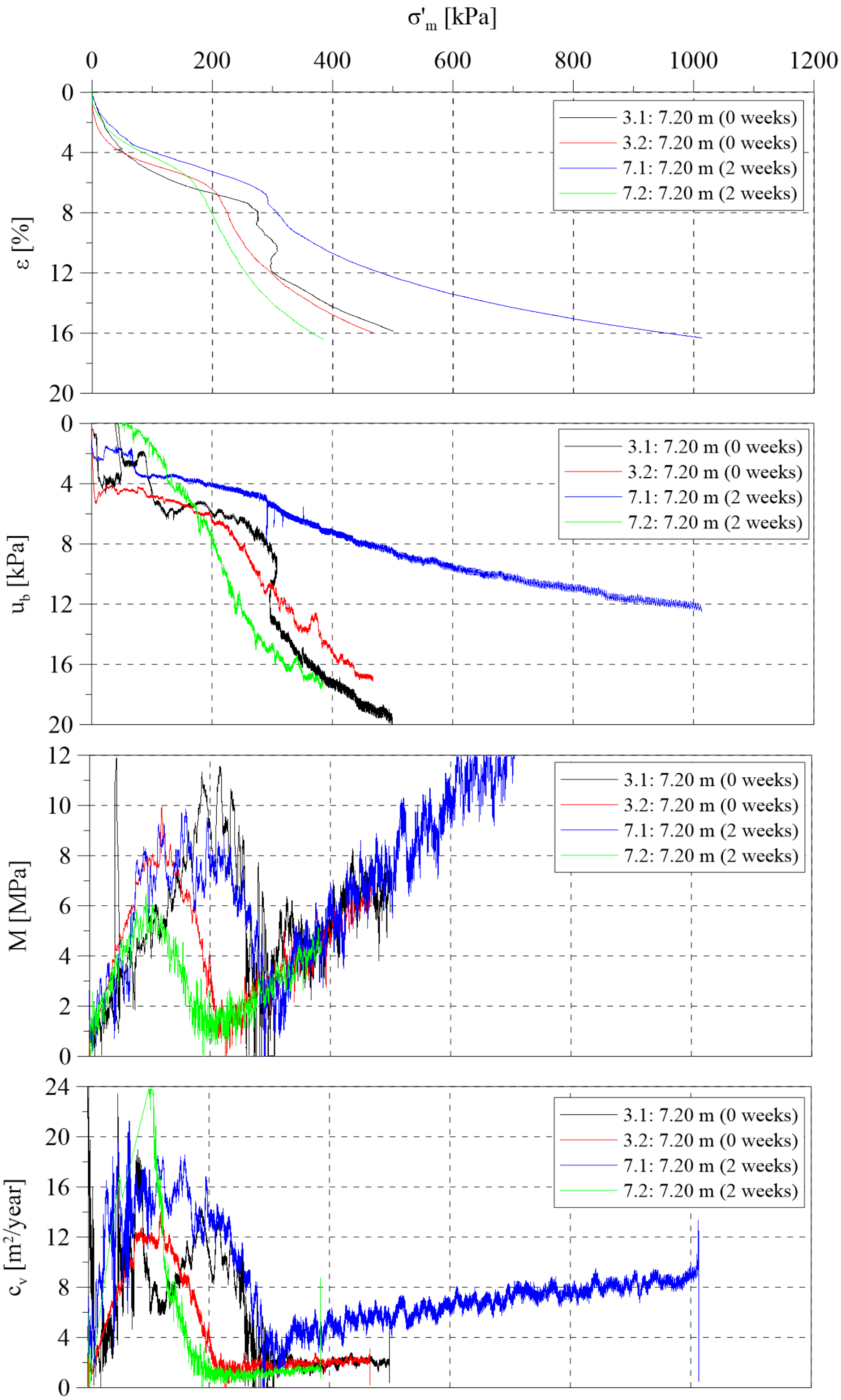


Figure B.15: CRS results from oedometer tests from depth 7.20 m, Sherbrooke block sample.

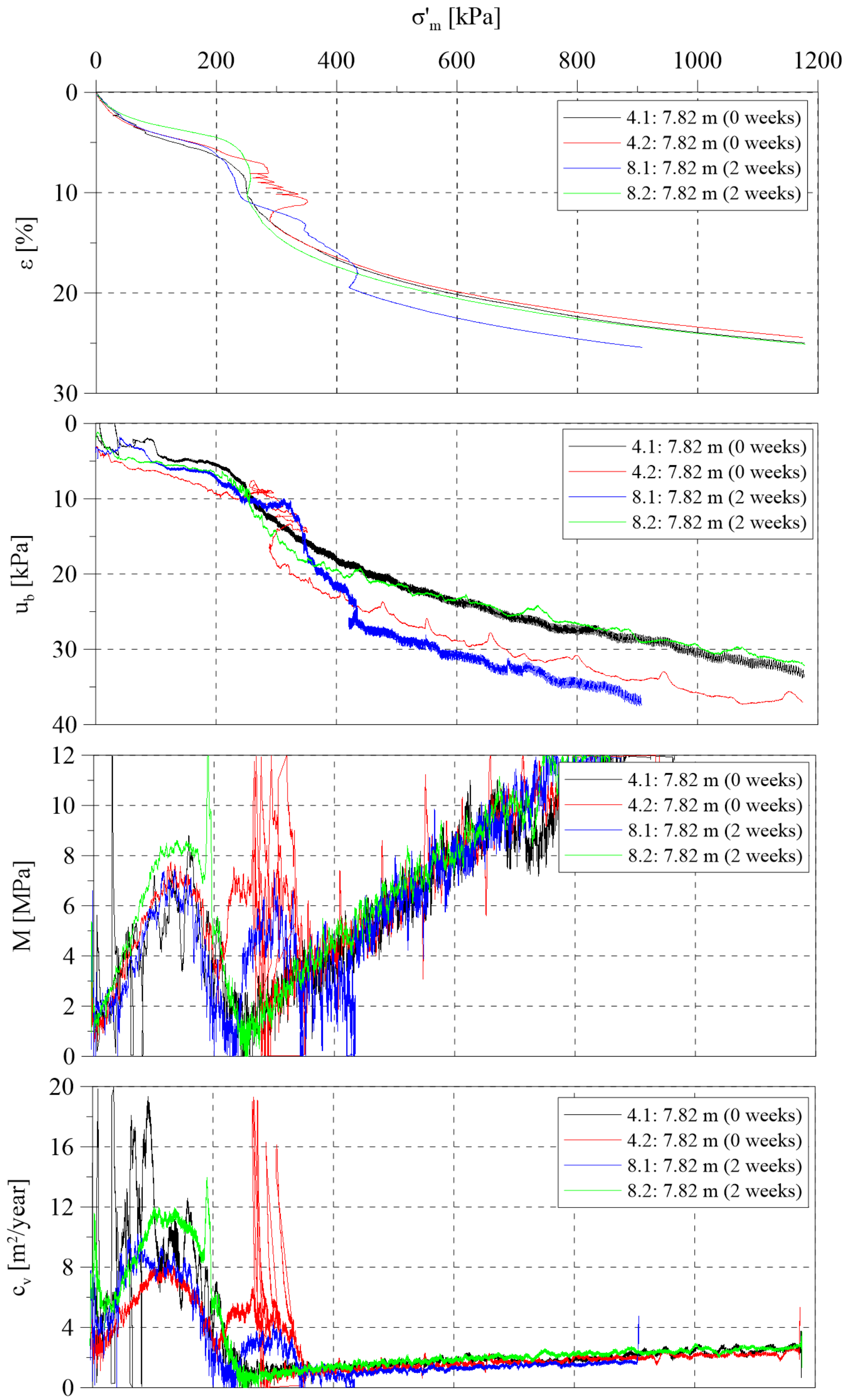


Figure B.16: CRS results from oedometer tests from depth 7.82 m, Sherbrooke block sample.

CRS-S1.1					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	6.75 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	78.1 kPa	$\Delta e/e_0$	0.05
Opening date	26.11.17	w	50.1 %	p'_c	250 kPa
Testing date	26.11.17	γ	18.6 kN/m^3	OCR	3.2

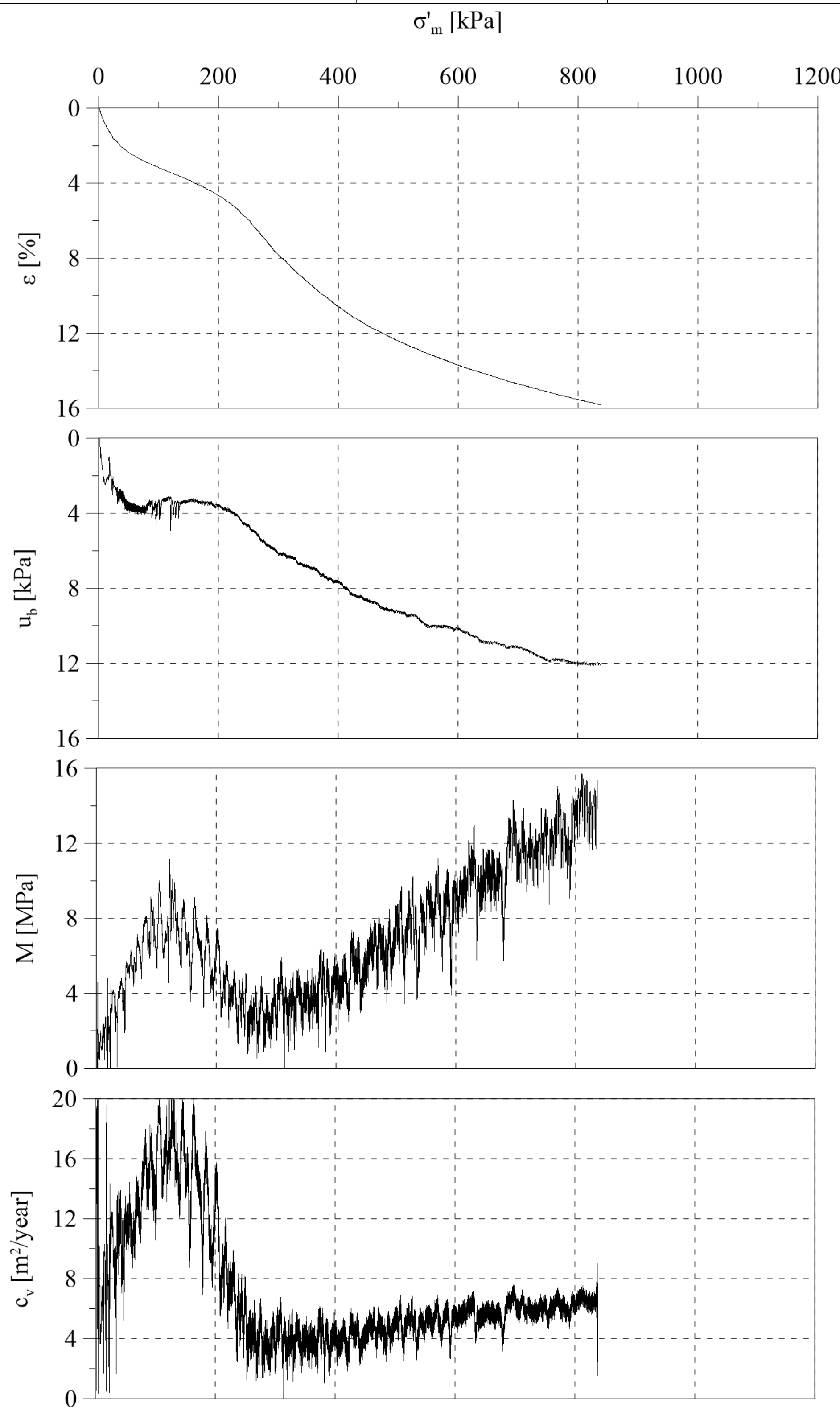


Figure B.17: CRS results from oedometer test no. 1 at depth 6.75 m, Sherbrooke block sample.

CRS-S1.2					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	6.75 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	74.9 kPa	$\Delta e/e_0$	0.05
Opening date	26.11.17	w	50.1 %	p'_c	225 kPa
Testing date	26.11.17	γ	18.1 kN/m^3	OCR	3.0

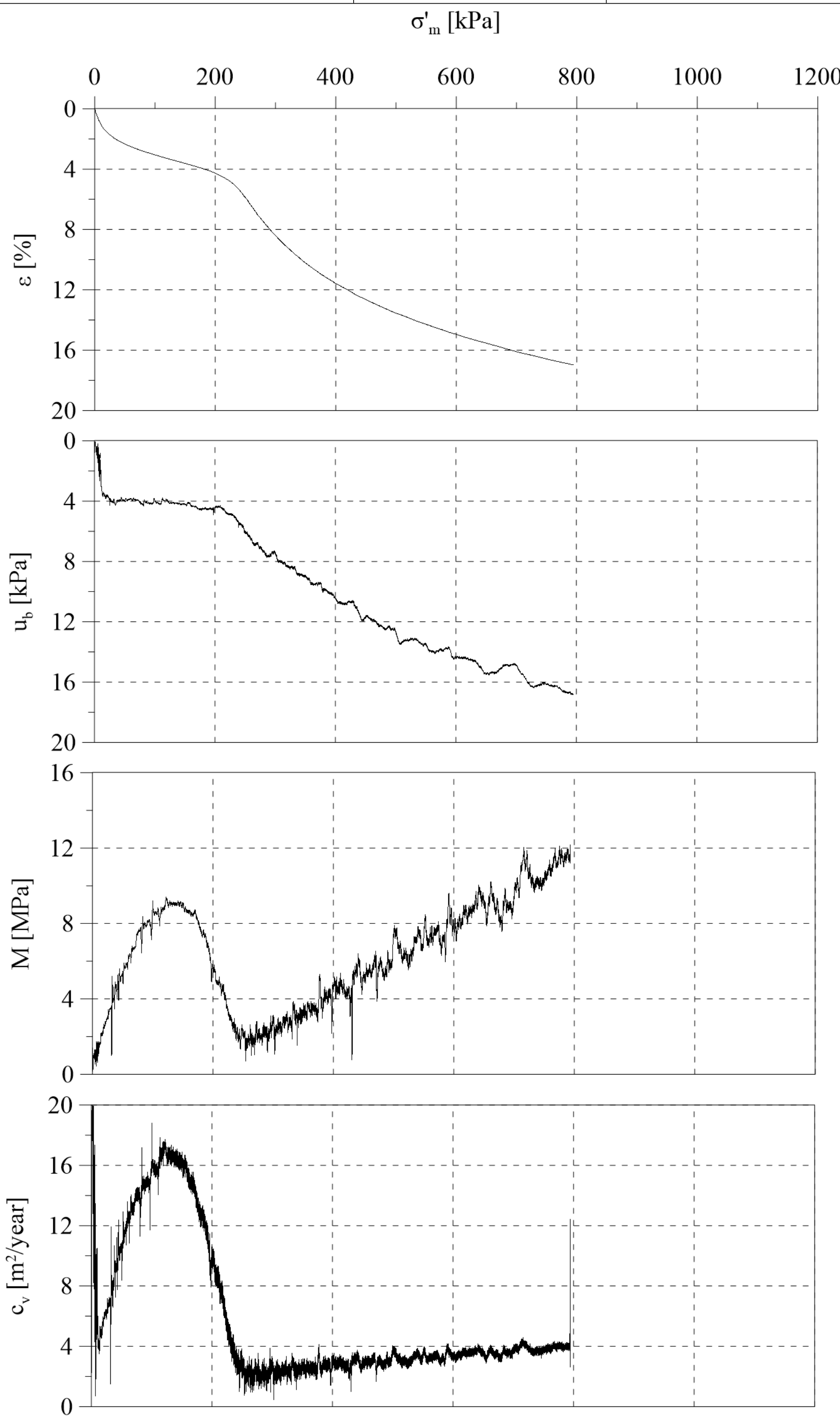


Figure B.18: CRS results from oedometer test no. 2 at depth 6.75 m, Sherbrooke block sample.

CRS-S2.1					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.05 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	72.5 kPa	$\Delta e/e_0$	0.06
Opening date	23.11.17	w	44.4 %	p'_c	210 kPa
Testing date	23.11.17	γ	17.4 kN/m^3	OCR	2.9

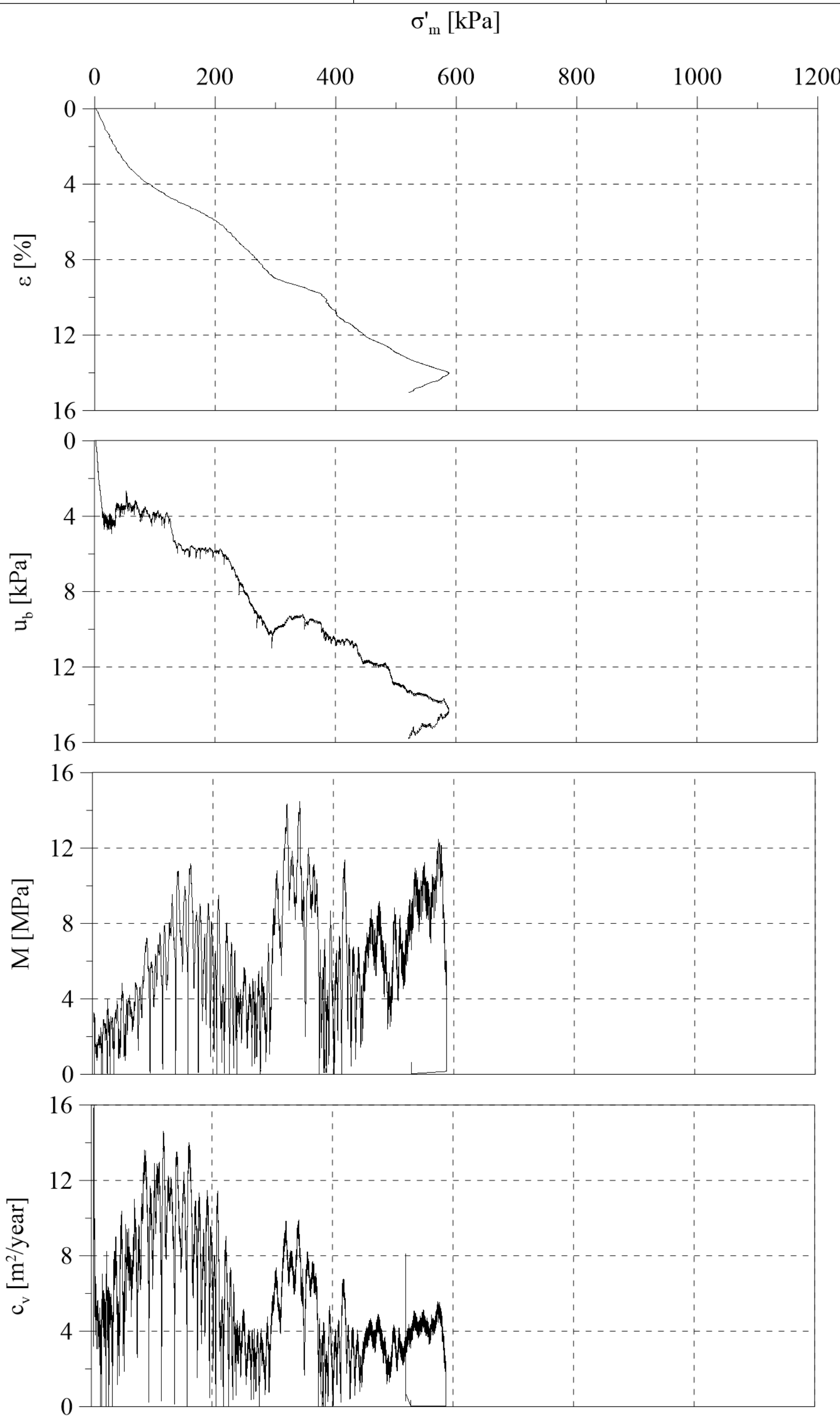


Figure B.19: CRS results from oedometer test no. 1 at depth 7.05 m, Sherbrooke block sample.

CRS-S2.2					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.05 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	70.5 kPa	$\Delta e/e_0$	0.05
Opening date	23.11.17	w	44.4 %	p'_c	210 kPa
Testing date	23.11.17	γ	17.2 kN/m^3	OCR	3.0

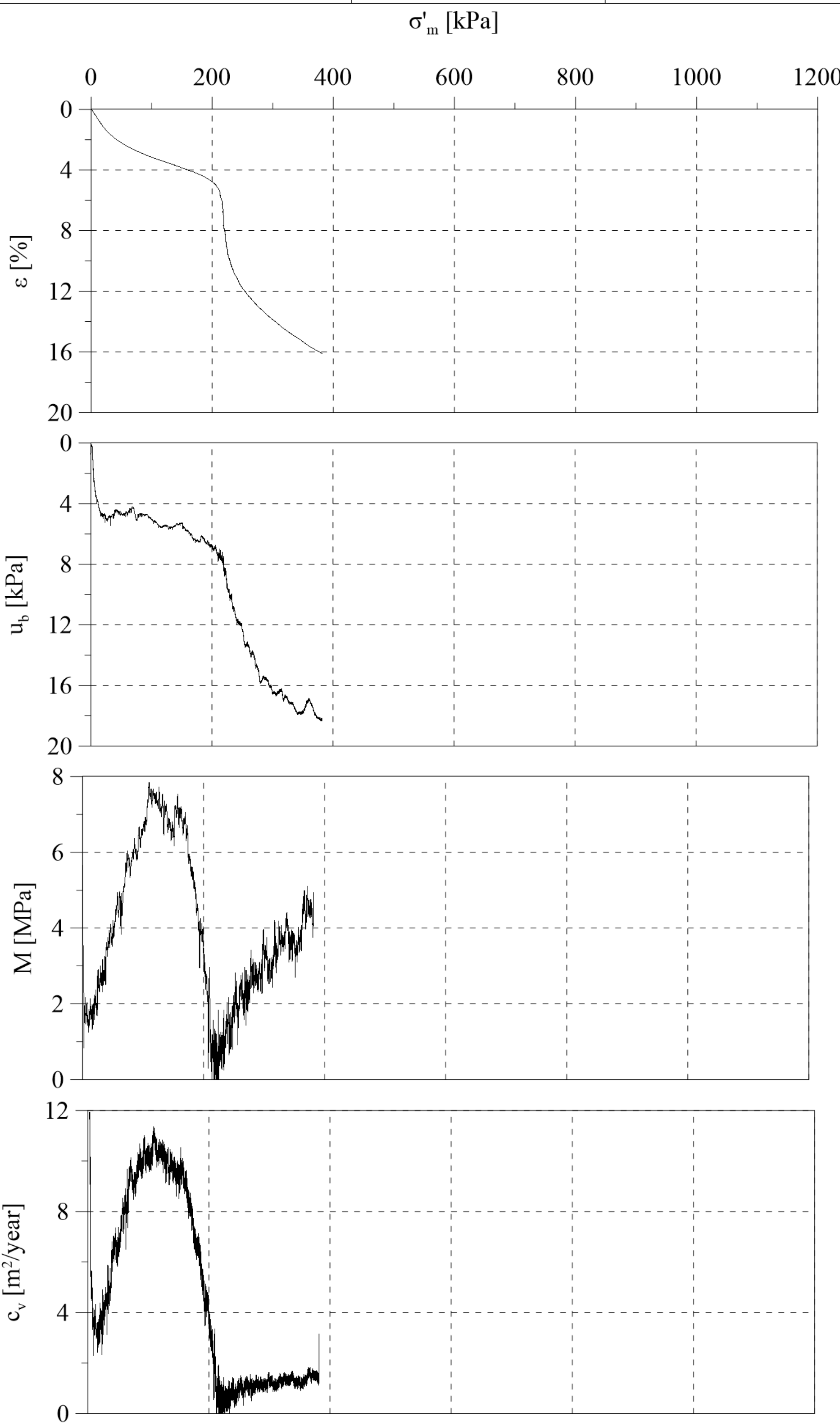


Figure B.20: CRS results from oedometer test no. 2 at depth 7.05 m, Sherbrooke block sample.

CRS-S3.1					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.20 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	78.0 kPa	$\Delta e/e_0$	0.09
Opening date	23.11.17	w	40.8 %	p'_c	200 kPa
Testing date	25.11.17	γ	18.1 kN/m^3	OCR	2.6

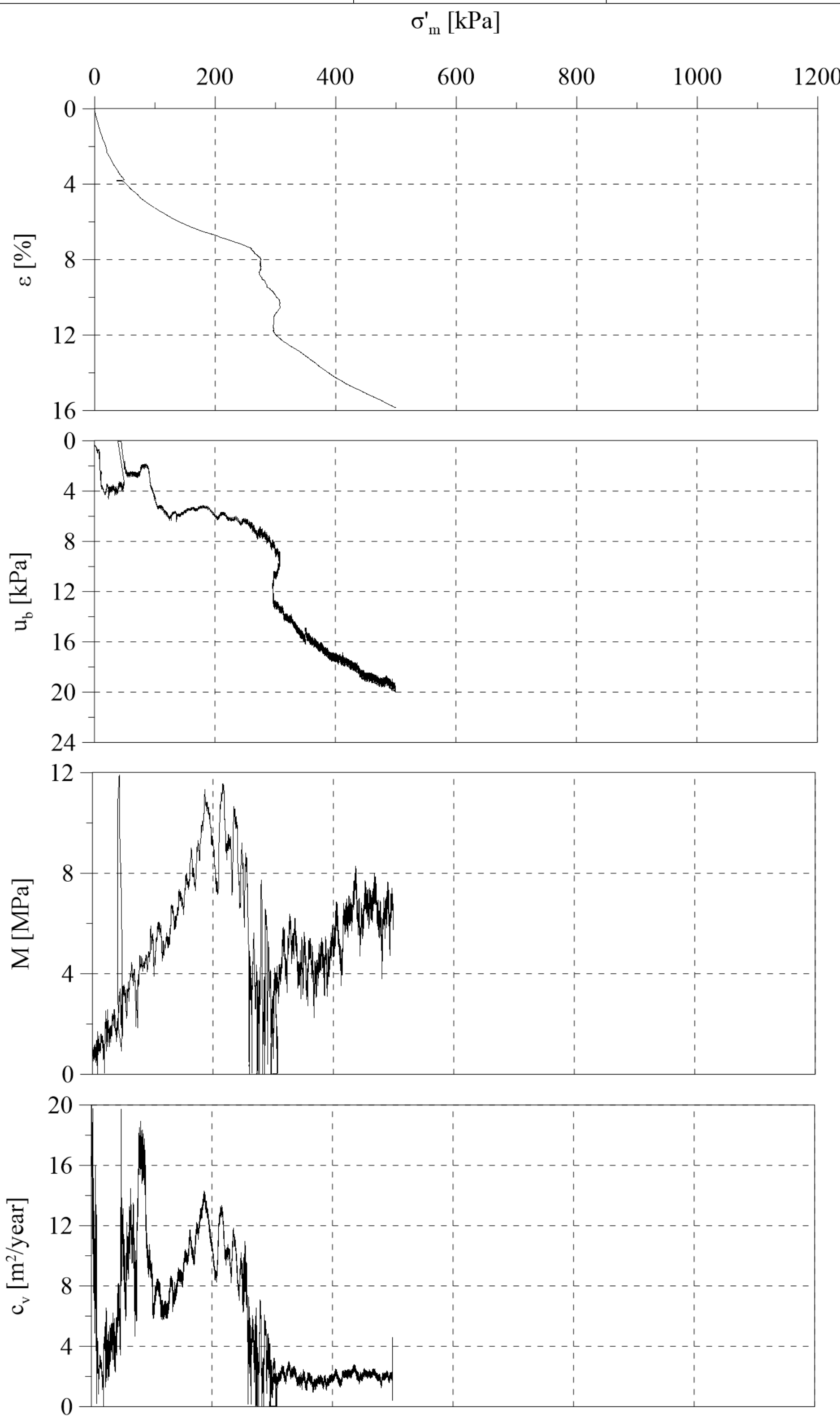


Figure B.21: CRS results from oedometer test no. 1 at depth 7.20 m, Sherbrooke block sample.

CRS-S3.2 Sherbrooke Block Sample Flotten, Trondheim					**0 weeks after sampling**
Depth	7.20 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	77.7 kPa	$\Delta e/e_0$	0.07
Opening date	23.11.17	w	40.8 %	p'_c	200 kPa
Testing date	25.11.17	γ	18.0 kN/m^3	OCR	2.6

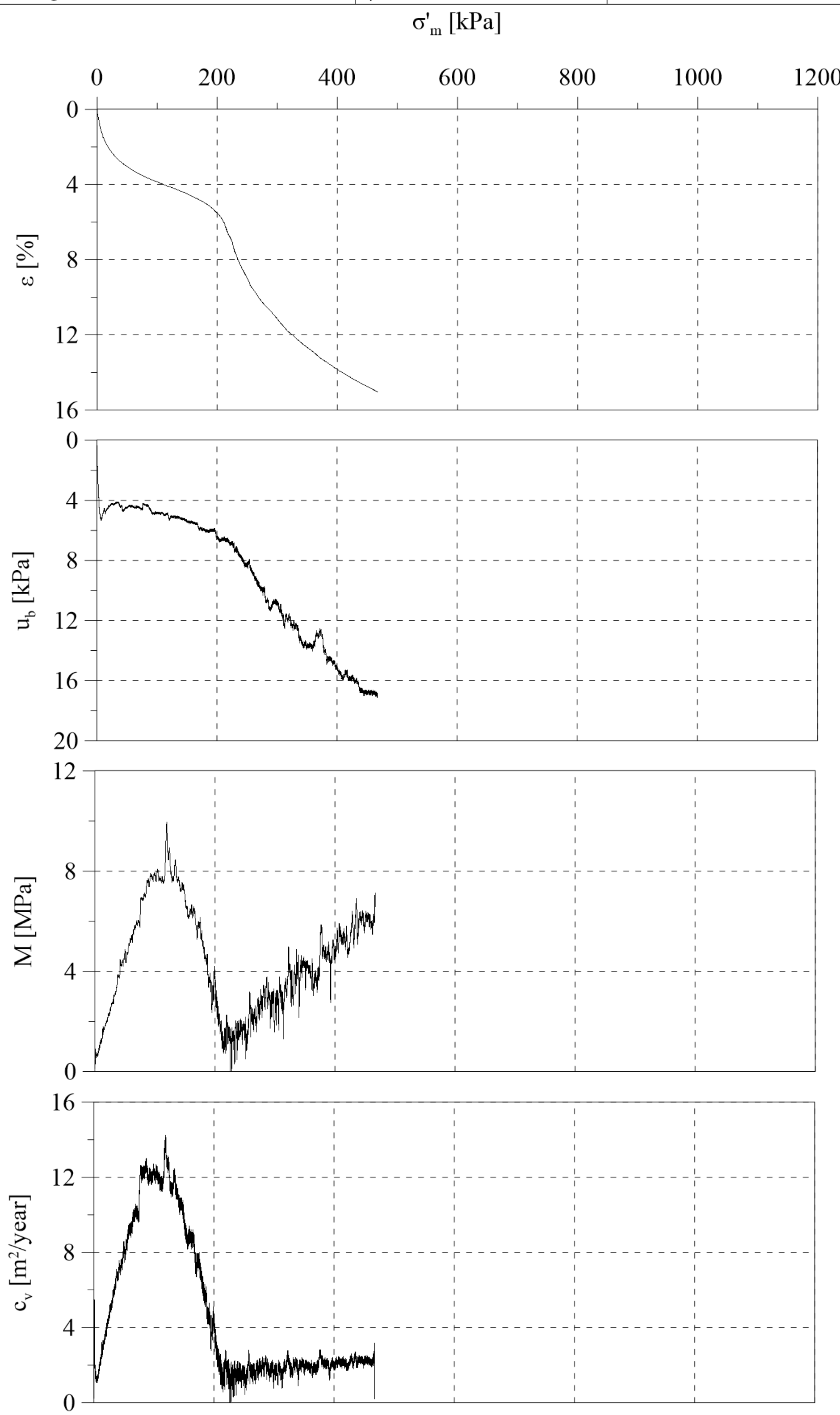


Figure B.22: CRS results from oedometer test no. 2 at depth 7.20 m, Sherbrooke block sample.

CRS-S4.1 **Sherbrooke Block Sample** **Flotten, Trondheim**					**0 weeks after sampling**
Depth	7.82 m	Strain rate	0.5 %/hr		
Sampling date	27.11.17	σ'_{v0}	80.5 kPa	$\Delta e/e_0$	0.07
Opening date	27.11.17	w	43.5 %	p'_c	225 kPa
Testing date	28.11.17	γ	17.7 kN/m^3	OCR	2.8

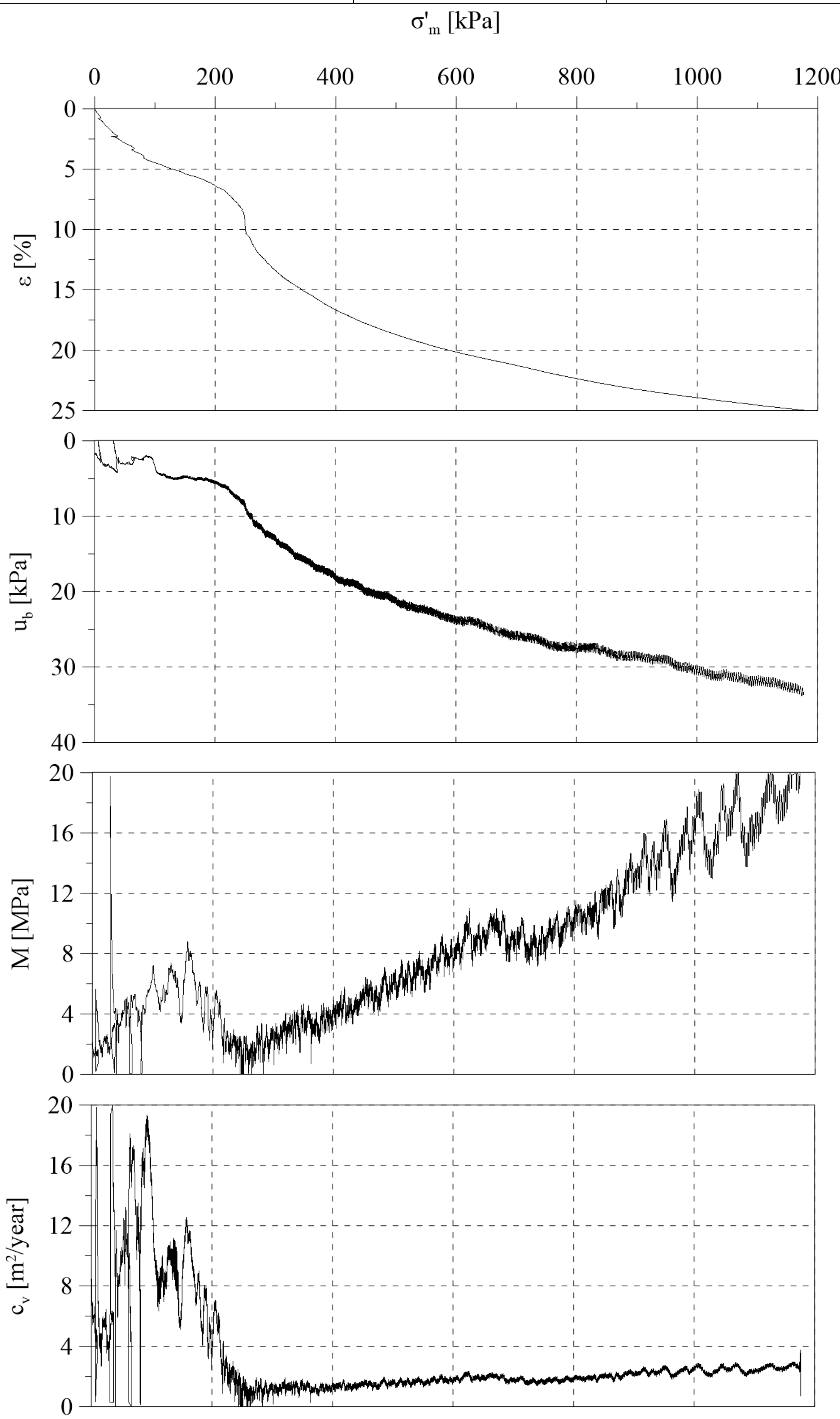


Figure B.23: CRS results from oedometer test no. 1 at depth 7.82 m, Sherbrooke block sample.

CRS-S4.2					**0 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.82 m	Strain rate	0.5 %/hr		
Sampling date	27.11.17	σ'_{v0}	79.8 kPa	$\Delta e/e_0$	0.07
Opening date	27.11.17	w	43.5 %	p'_c	200 kPa
Testing date	28.11.17	γ	17.7 kN/m^3	OCR	2.5

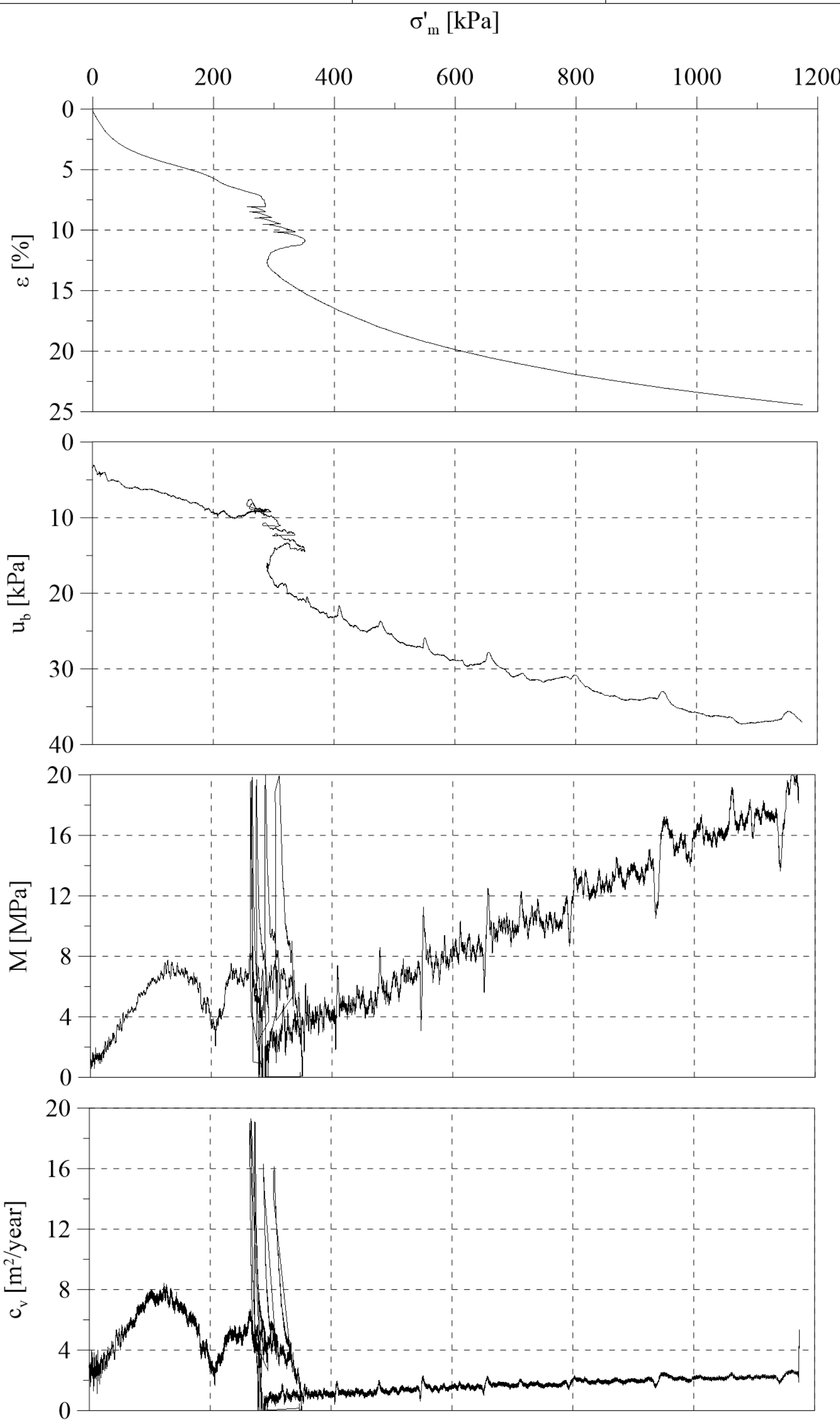


Figure B.24: CRS results from oedometer test no. 2 at depth 7.82 m, Sherbrooke block sample.

CRS-S5.1					**2 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	6.75 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	78.3 kPa	$\Delta e/e_0$	0.06
Opening date	26.11.17	w	49.5 %	p'_c	250 kPa
Testing date	10.12.17	γ	18.6 kN/m^3	OCR	3.2

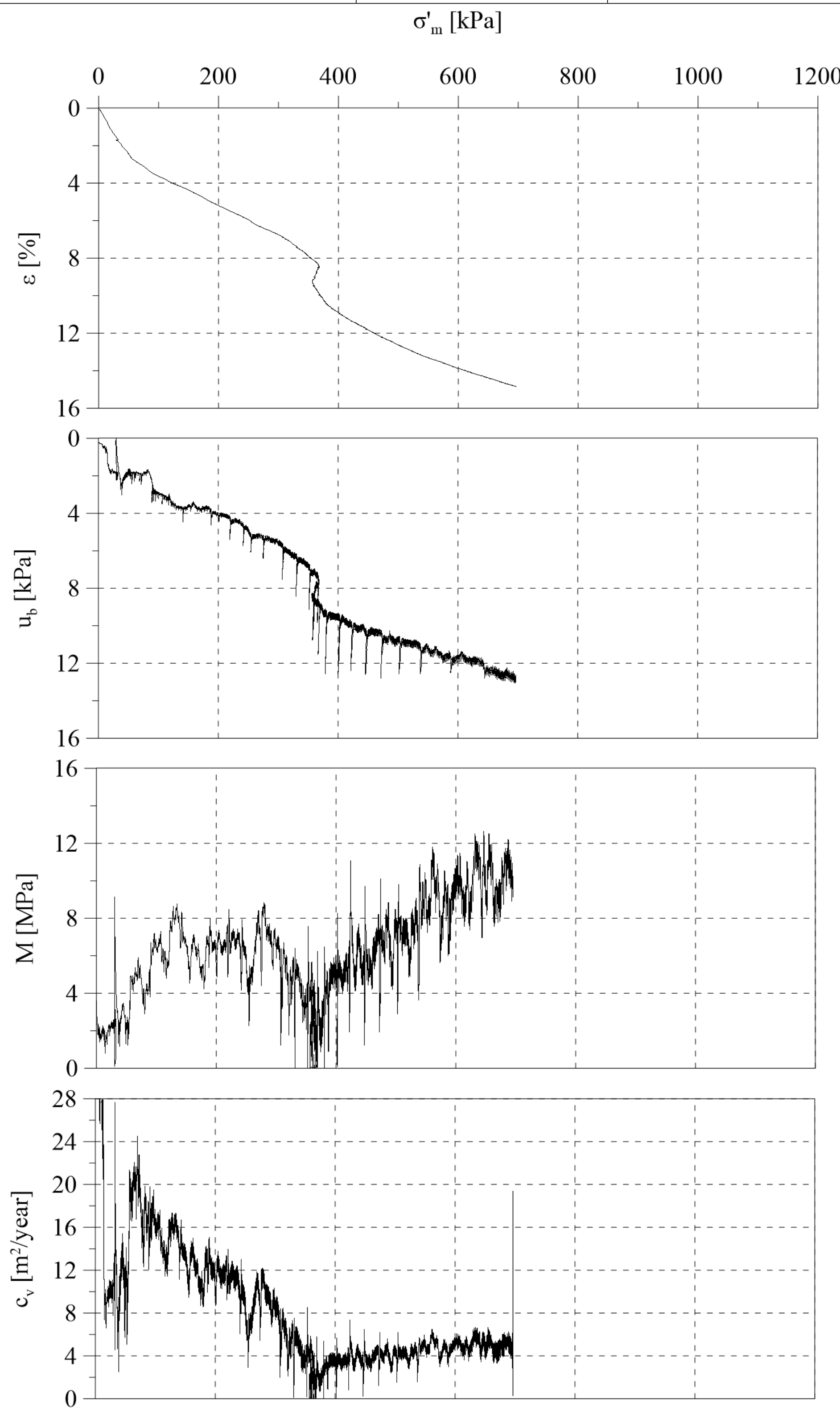


Figure B.25: CRS results from oedometer test no. 1 at depth 6.75 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S5.2 **Sherbrooke Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	6.75 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	75.3 kPa	$\Delta e/e_0$	0.06
Opening date	26.11.17	w	49.5 %	p'_c	200 kPa
Testing date	10.12.17	γ	18.2 kN/m^3	OCR	2.8

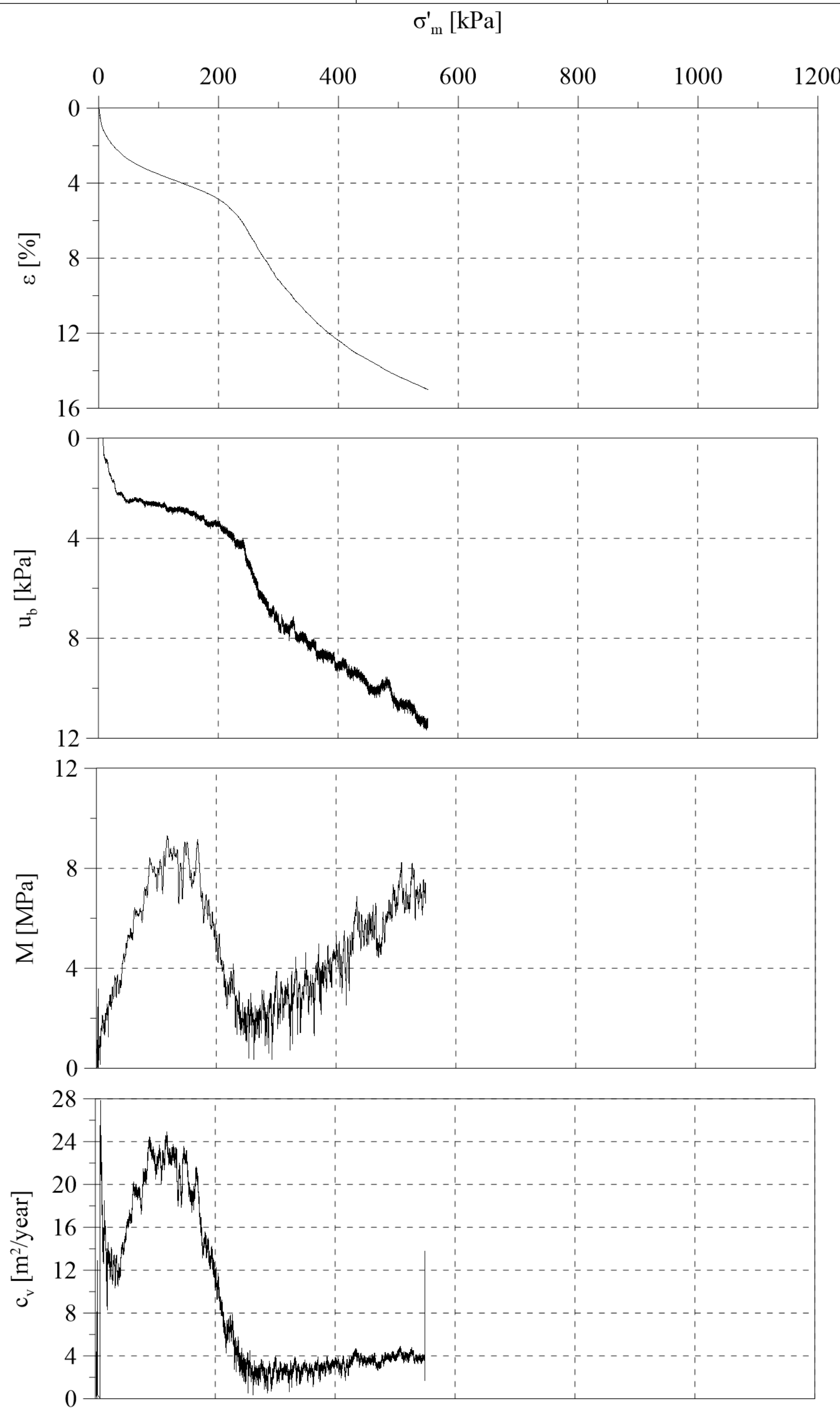


Figure B.26: CRS results from oedometer test no. 2 at depth 6.75 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S6.1					**2 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.05 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	69.4 kPa	$\Delta e/e_0$	0.06
Opening date	23.11.17	w	38.8 %	p'_c	200 kPa
Testing date	07.12.17	γ	17.0 kN/m^3	OCR	2.9

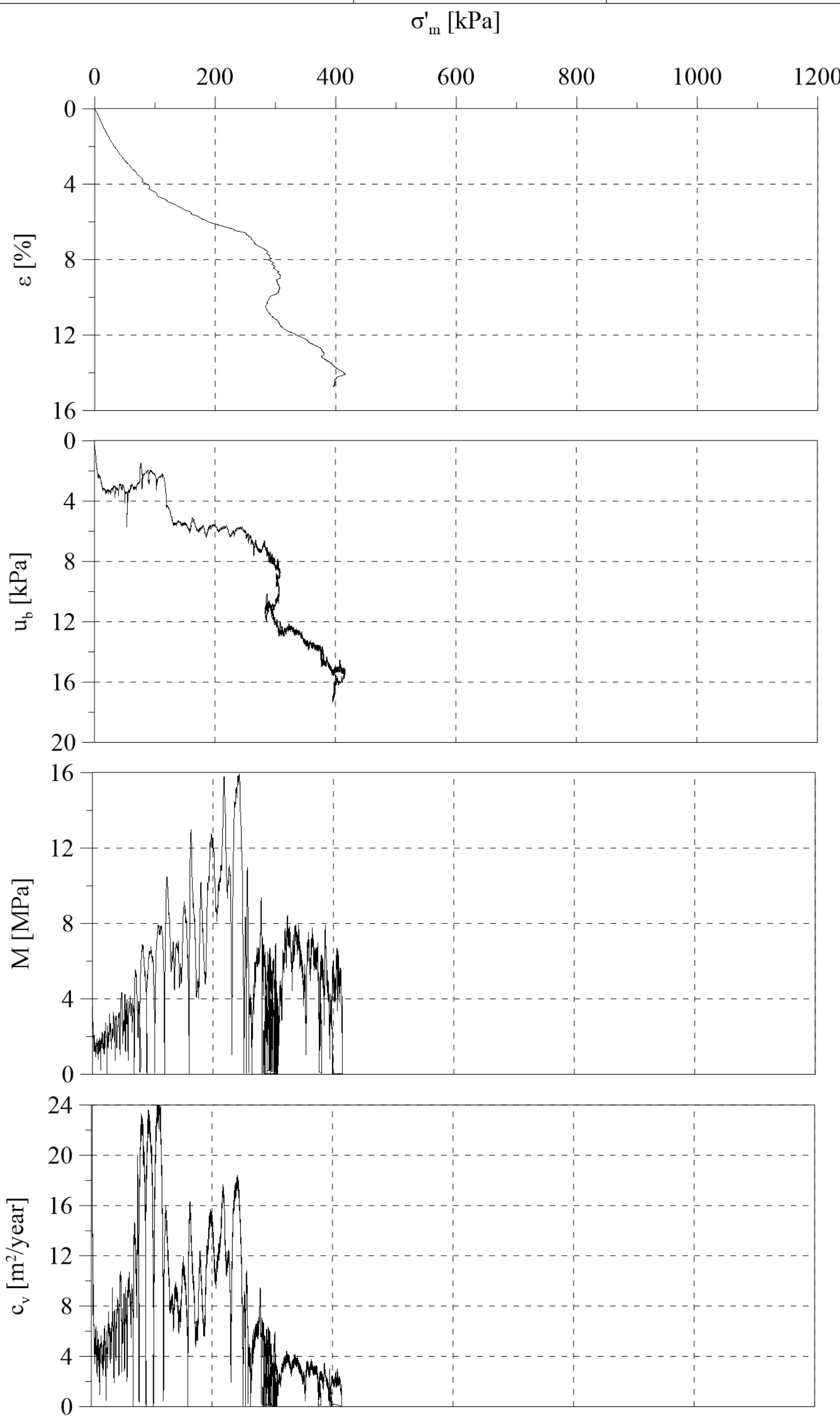


Figure B.27: CRS results from oedometer test no. 1 at depth 7.05 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S6.2					**2 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.05 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	72.2 kPa	$\Delta e/e_0$	0.06
Opening date	23.11.17	w	38.8 %	p'_c	210 kPa
Testing date	07.12.17	γ	17.4 kN/m^3	OCR	2.9

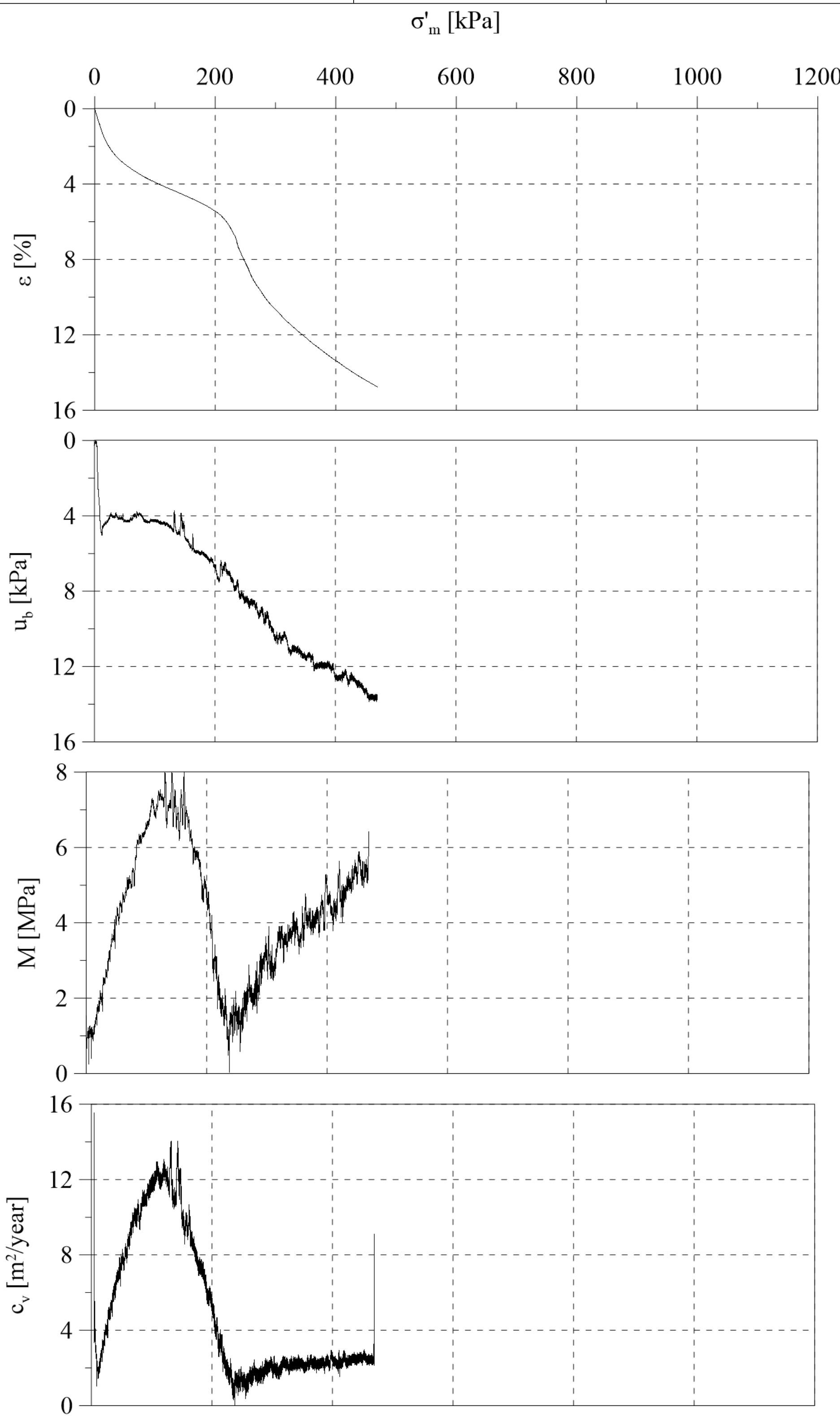


Figure B.28: CRS results from oedometer test no. 2 at depth 7.05 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S7.1					**2 weeks after sampling**
Sherbrooke Block Sample					
Flotten, Trondheim					
Depth	7.20 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	84.9 kPa	$\Delta e/e_0$	0.07
Opening date	23.11.17	w	42.1 %	p'_c	290 kPa
Testing date	08.12.17	γ	19.0 kN/m^3	OCR	3.4

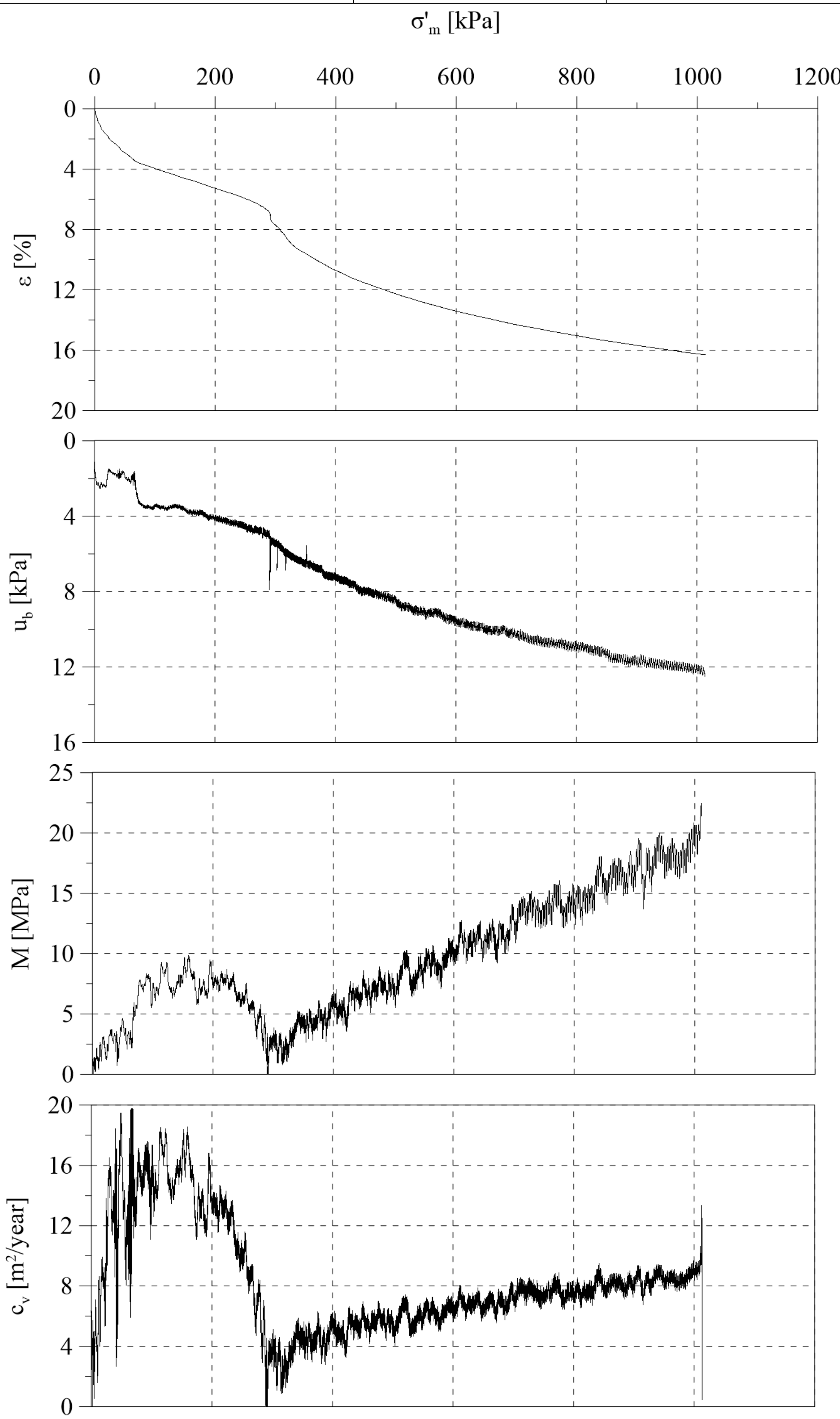


Figure B.29: CRS results from oedometer test no. 1 at depth 7.20 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S7.2 **Sherbrooke Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	7.20 m	Strain rate	0.5 %/hr		
Sampling date	23.11.17	σ'_{v0}	74.9 kPa	$\Delta e/e_0$	0.05
Opening date	23.11.17	w	42.1 %	p'_c	180 kPa
Testing date	08.12.17	γ	17.6 kN/m^3	OCR	2.4

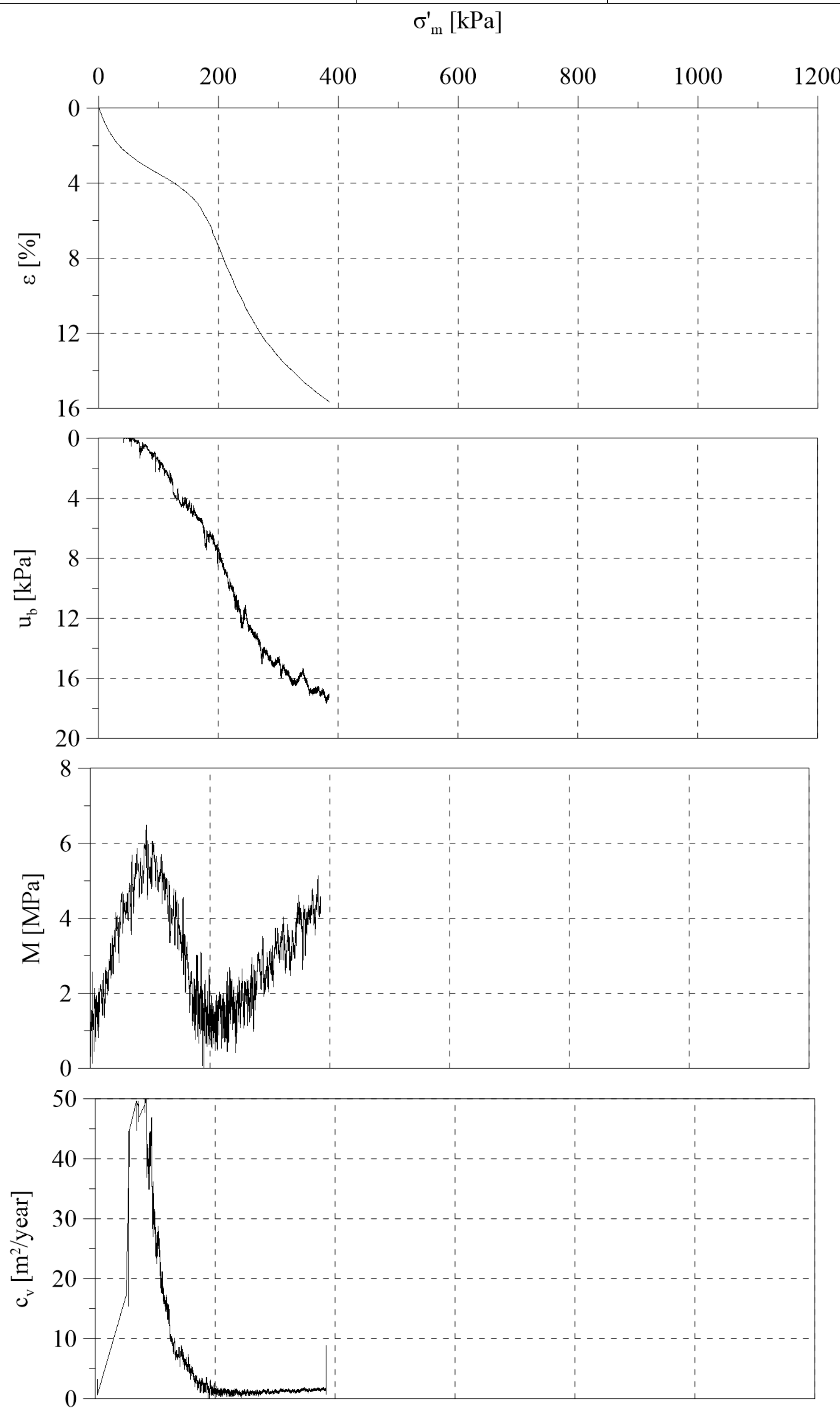


Figure B.30: CRS results from oedometer test no. 2 at depth 7.20 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S8.1 **Sherbrooke Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	7.82 m	Strain rate	0.5 %/hr		
Sampling date	27.11.17	σ'_{v0}	76.1 kPa	$\Delta e/e_0$	0.06
Opening date	27.11.17	w	43.3 %	p'_c	200 kPa
Testing date	11.12.17	γ	17.2 kN/m^3	OCR	2.6

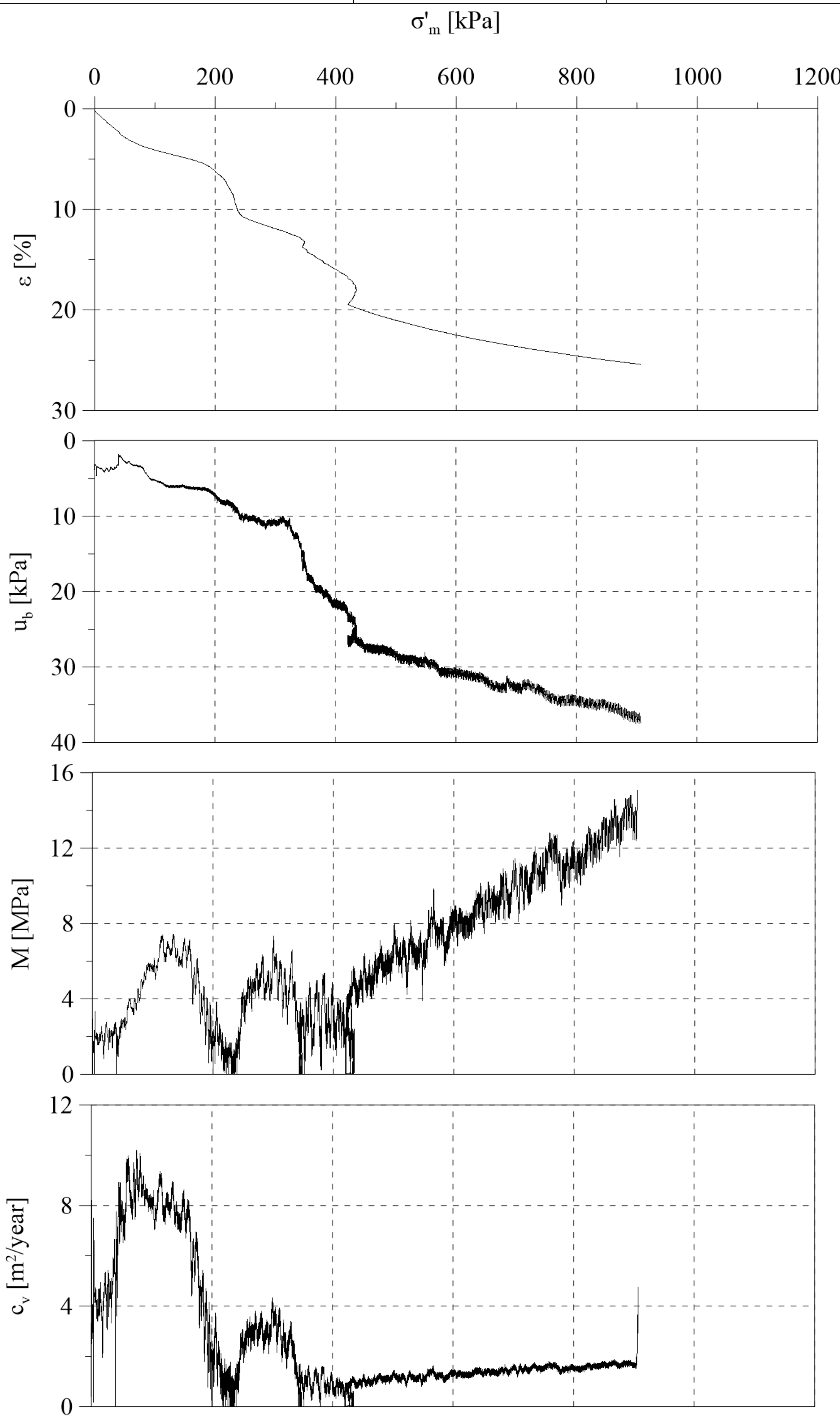


Figure B.31: CRS results from oedometer test no. 1 at depth 7.82 m after 2 weeks of storage, Sherbrooke block sample.

CRS-S8.2 **Sherbrooke Block Sample** **Flotten, Trondheim**					**2 weeks after sampling**
Depth	7.82 m	Strain rate	0.5 %/hr		
Sampling date	27.11.17	σ'_{v0}	77.3 kPa	$\Delta e/e_0$	0.05
Opening date	27.11.17	w	43.3 %	p'_c	200 kPa
Testing date	11.12.17	γ	17.3 kN/m^3	OCR	2.6

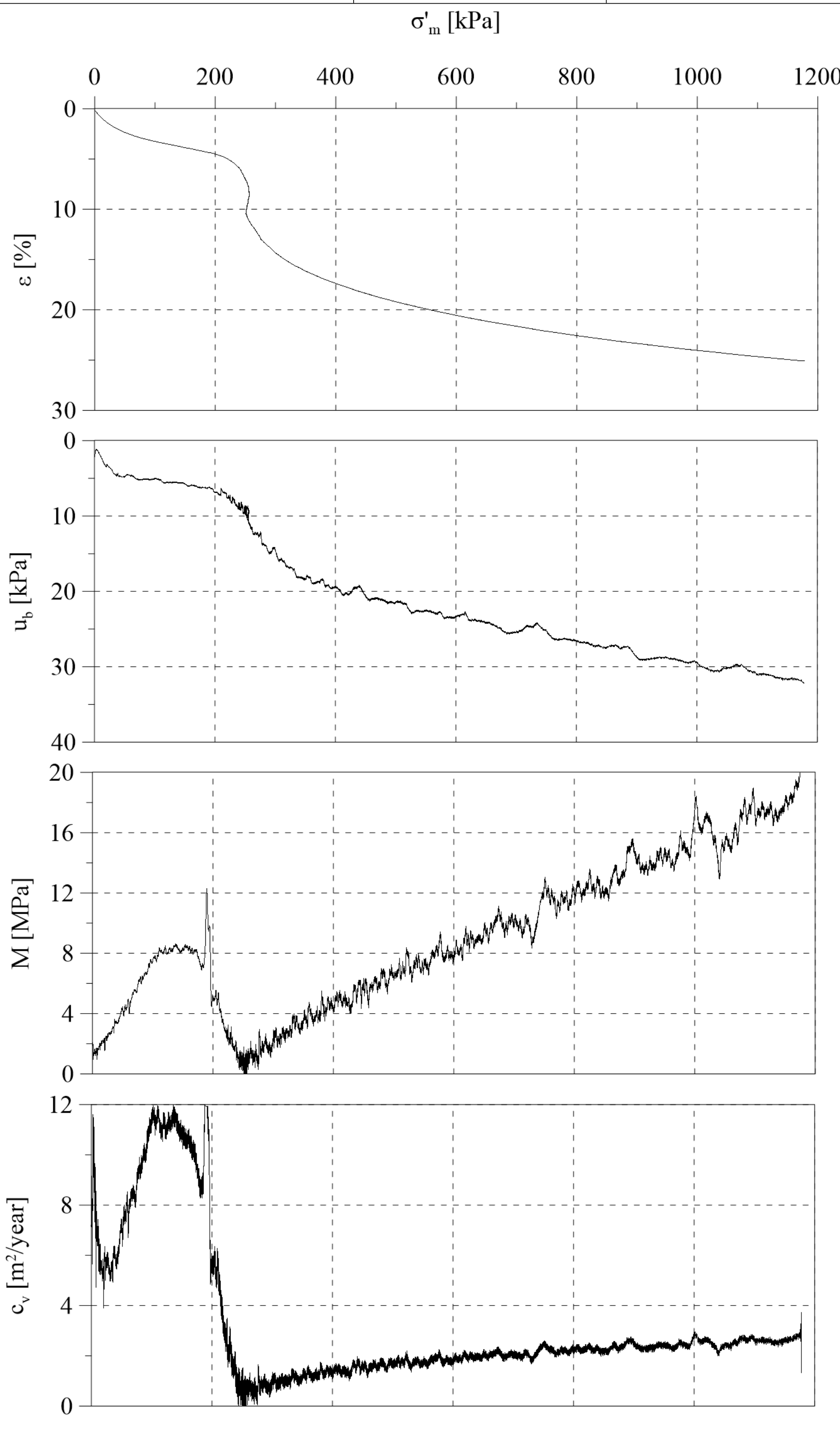


Figure B.32: CRS results from oedometer test no. 2 at depth 7.82 m after 2 weeks of storage, Sherbrooke block sample.

B.3 Oedometer Results from both Mini Block and Sherbrooke Block Samples

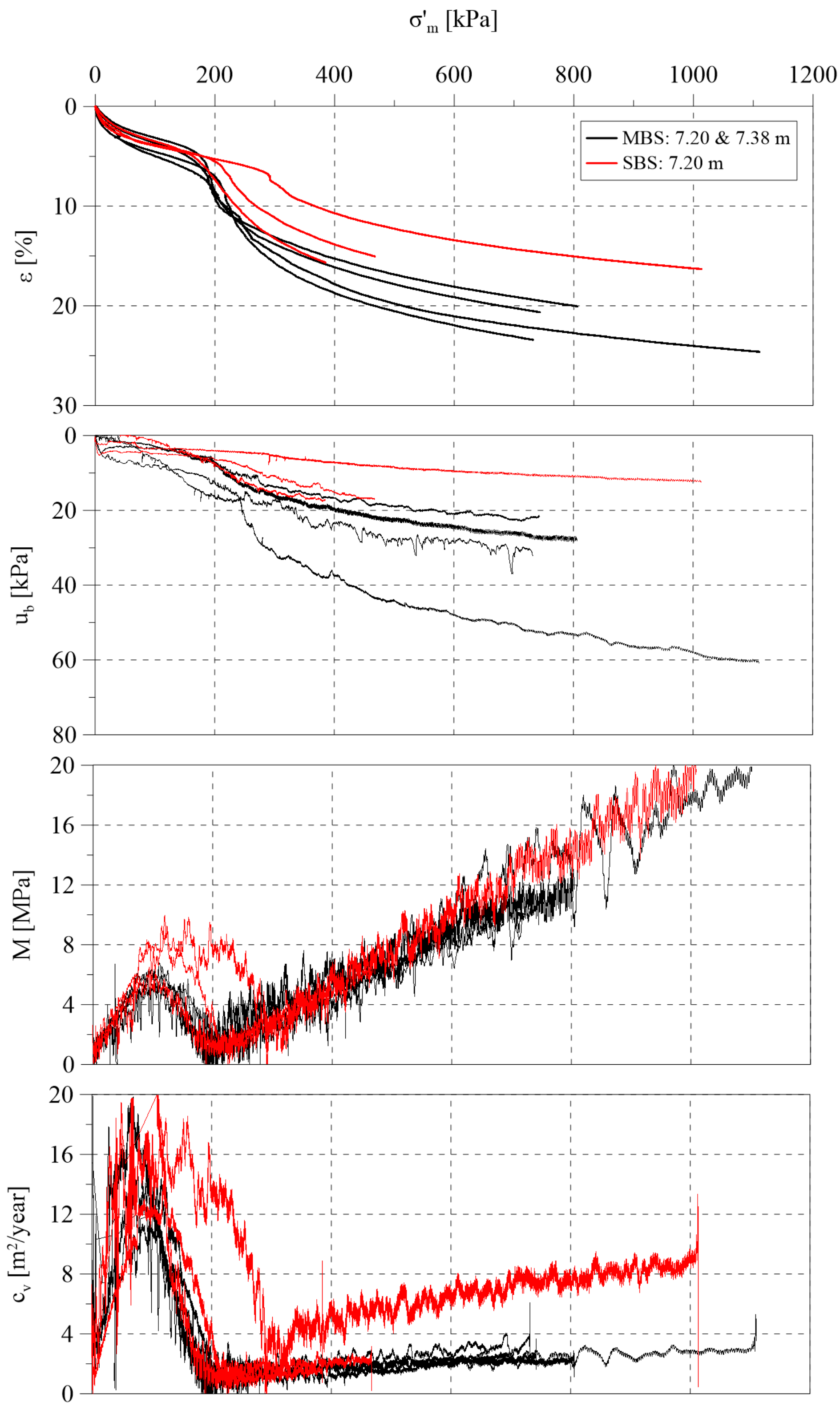


Figure B.33: CRS results from oedometer tests from depths of 7.20 m

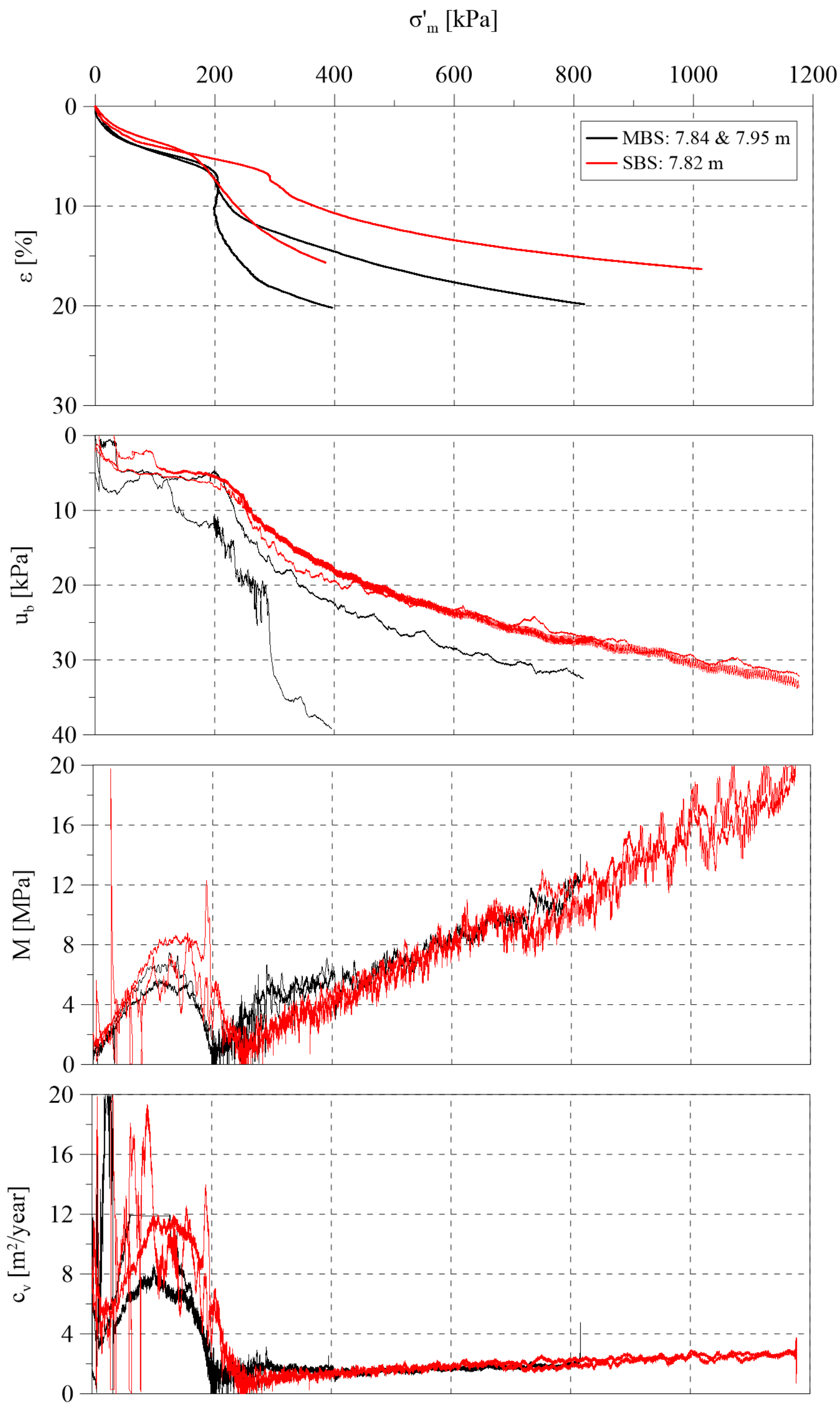


Figure B.34: CRS results from oedometer tests from depths of approximately 7.8 m

Appendix C

Triaxial Testing

Time t, deformation δ, vertical load F, differential pressure, cell pressure σ_{cell}, back pressure and expelled pore water (measured with a burette) were logged with a 10 second sampling interval. Processing of these data were done in Microsoft Excel and plots where made in Grapher. The equations used in the processing will be presented here.

In the consolidation phase, ΔV was measured by the burette in ml, which has a 1:1 ratio with cm^3. The adjusted area of the sample after consolidation A_a was calculated after Eq. C.1

$$A_a = A_0\left(1 - \frac{\Delta V}{V_0}\right) \Big/ \left(1 - \frac{\Delta V}{3V_0}\right) \tag{C.1}$$

where A_0 is the initial area of the sample = 22.9 cm^2, ΔV is the expelled pore water at the end of consolidation and V_0 is the initial volume of the sample = 229 cm^3.

The sample area corrected for the shear phase A_s was calculated after Eq. C.2

$$A_s = \frac{A_a}{1-\varepsilon} \tag{C.2}$$

where ε is the axial strain calculated after Eq. C.3

$$\varepsilon = \frac{\delta}{h_0} \tag{C.3}$$

where δ is the recorded deformation and h_0 is the initial height of the soil sample, which for all tests where 100 mm.

σ'_1 was calculated after Eq. C.4

$$\sigma'_1 = \sigma_{cell} + 10 \cdot \frac{F}{A_s} - u \tag{C.4}$$

where σ_{cell} is the cell pressure calculated as the recorded cell pressure minus back pressure, F is the recorded vertical load and u is the pore pressure calculated as the recorded cell pressure minus the differential pressure and back pressure.

σ'_3 was calculated after Eq. C.5

$$\sigma'_3 = \sigma_{cell} - u \tag{C.5}$$

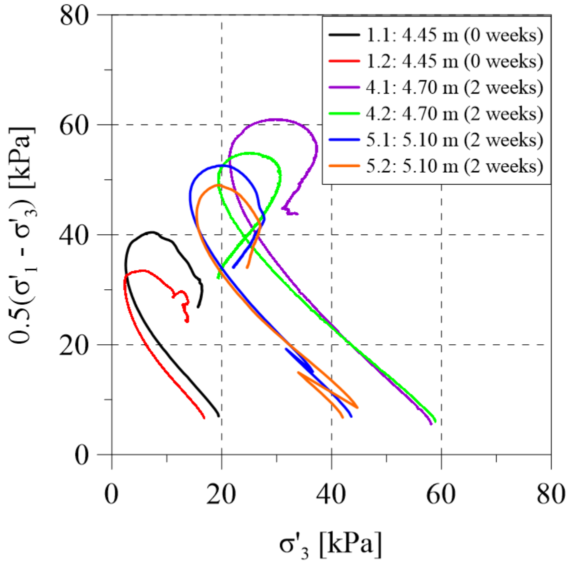
p', q and τ is calculated after Eq. C.6, Eq. C.7 and Eq. C.8, respectively

$$p' = \frac{\sigma'_1 + 2\sigma'_3}{3} \tag{C.6}$$

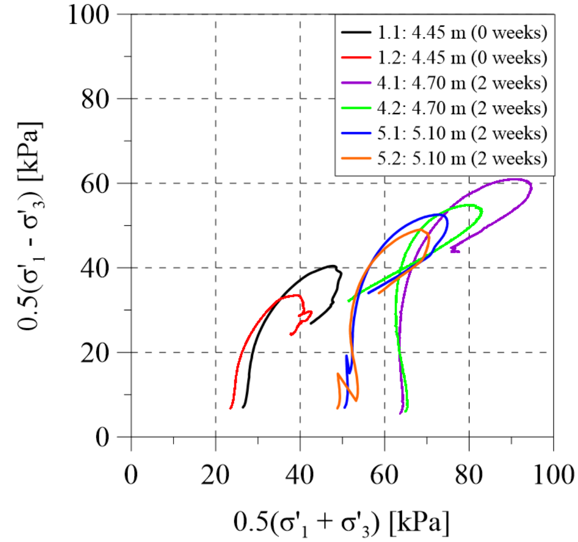
$$q = \sigma'_1 - \sigma'_3 \tag{C.7}$$

$$\tau = \frac{\sigma_1' - \sigma_3'}{2} = q/2 \tag{C.8}$$

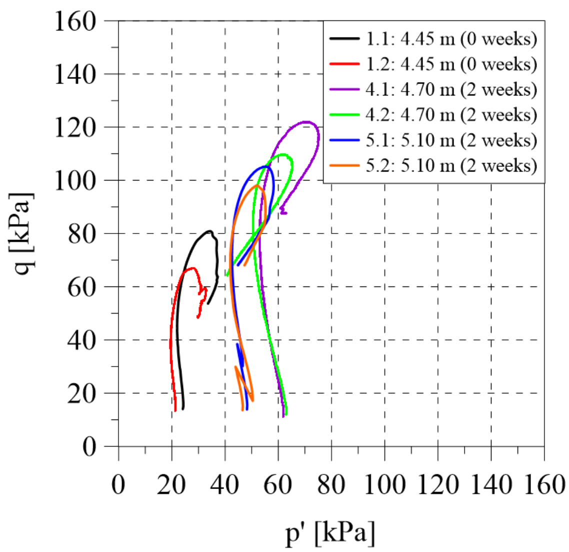
C.1 Triaxial Results from Mini Block Samples



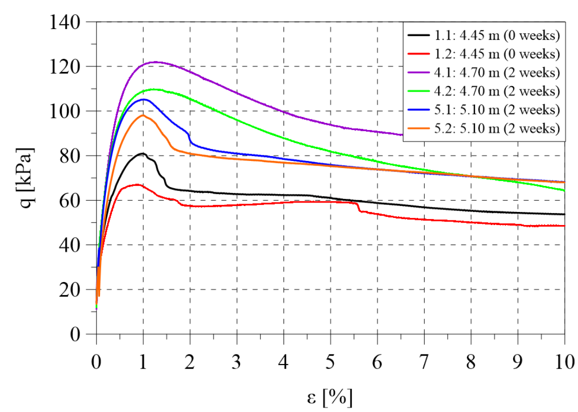
(a) NTNU plot



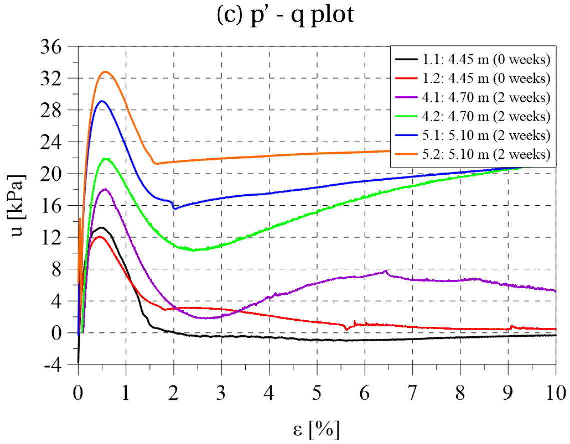
(b) NGI plot



(c) p' - q plot

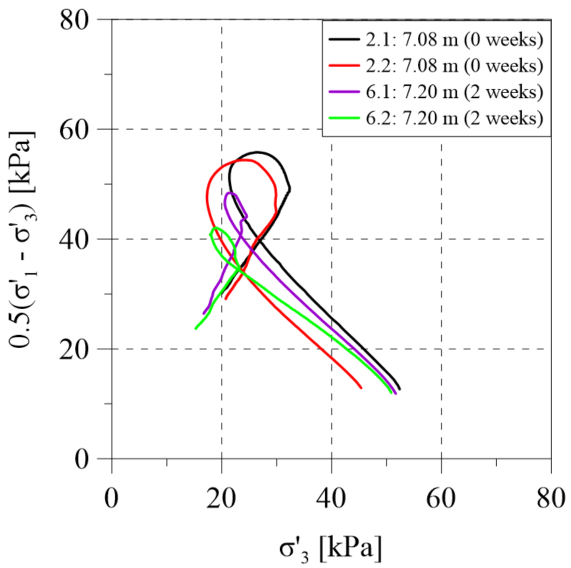


(d) ε - q plot

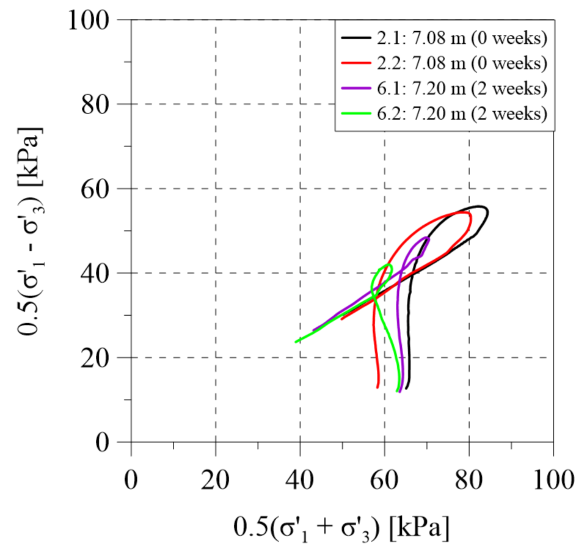


(e) ε - u plot

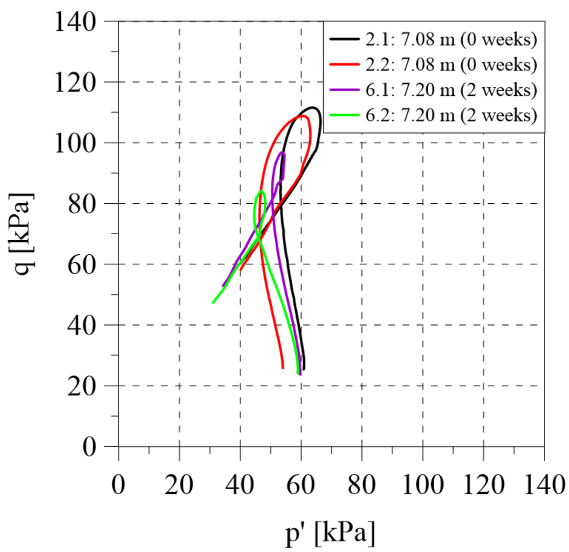
Figure C.1: CAUc results from triaxial test from depths 4.45 to 5.10 m, mini block sample



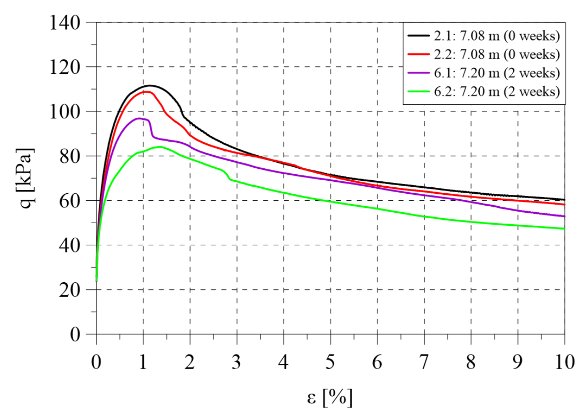
(a) NTNU plot



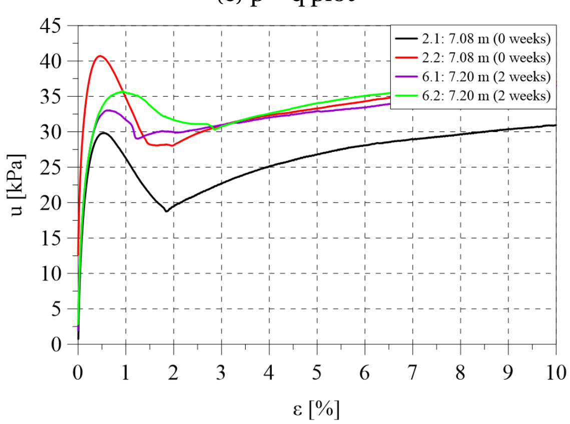
(b) NGI plot



(c) p' - q plot

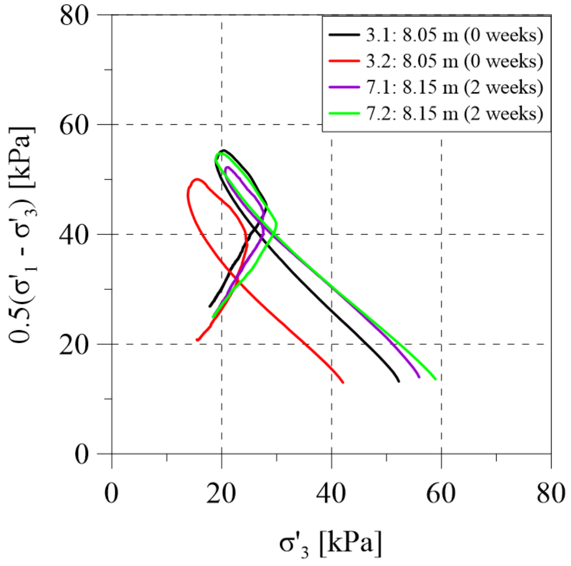


(d) ε - q plot

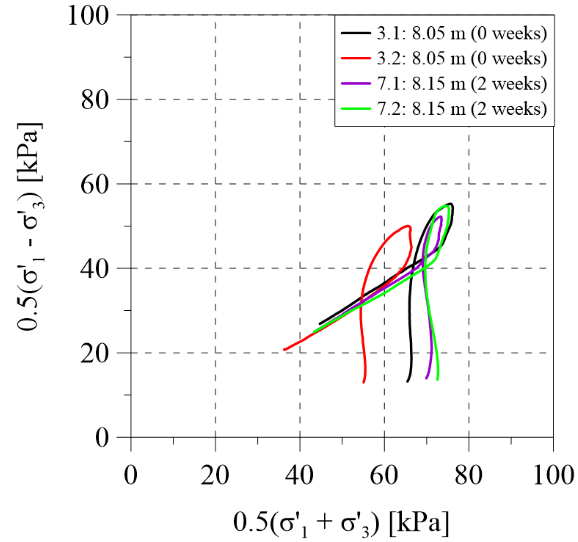


(e) ε - u plot

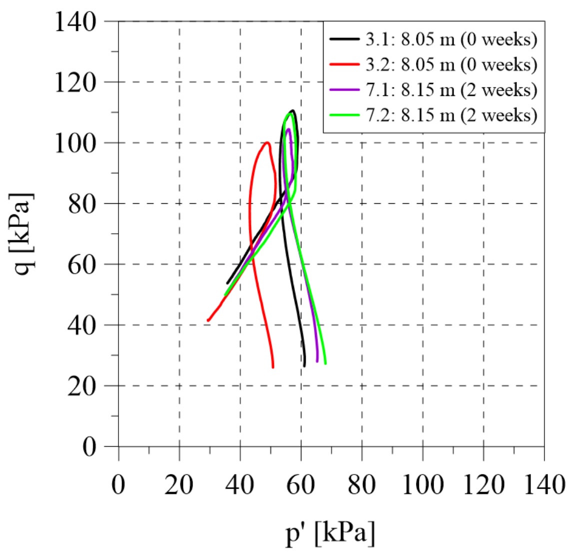
Figure C.2: CAUc results from triaxial test from depths 7.08 to 7.20 m, mini block sample



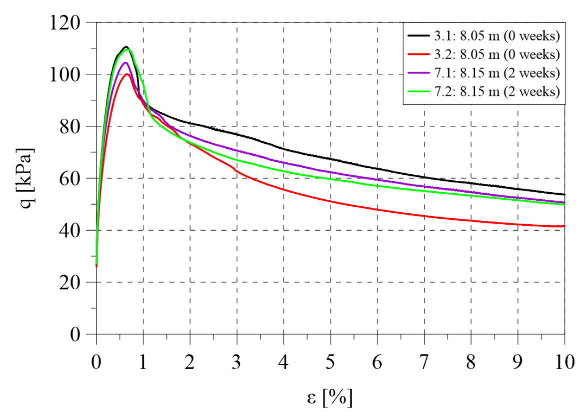
(a) NTNU plot



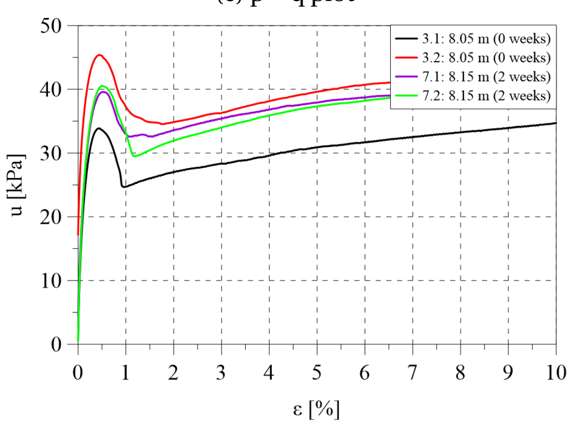
(b) NGI plot



(c) p' - q plot



(d) ε - q plot



(e) ε - u plot

Figure C.3: CAUc results from triaxial test from depths 7.08 to 7.20 m, mini block sample

CAUc-1.1 Mini Block Sample Flotten, Trondheim			**0 weeks after sampling**
Depth	4.45 m	σ'_{v0}	33.8 kPa
Sampling date	20.09.17	w	54.9 %
Opening date	21.09.17	γ	17.6 kN/m^3
Testing date	21.09.17	ΔV	3.40 cm^3
Vertical strain rate	1.5 % /hr	ε_v	1.44 %

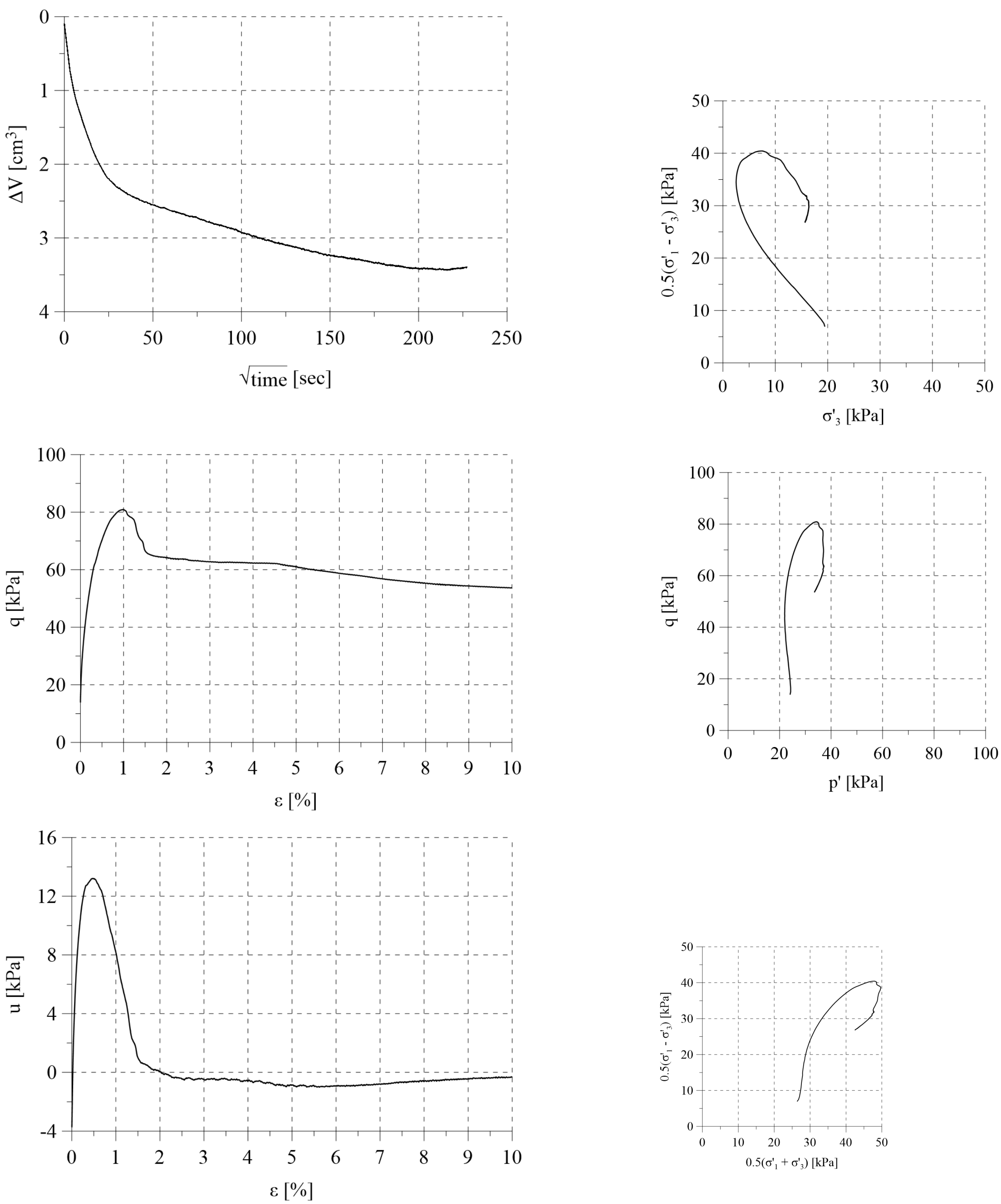


Figure C.4: CAUc results from triaxial test no. 1 at depth 4.45 m, mini block sample.

CAUc-1.2 Mini Block Sample Flotten, Trondheim			**0 weeks after sampling**
Depth	4.45 m	σ'_{v0}	32.2 kPa
Sampling date	20.09.17	w	54.9 %
Opening date	21.09.17	γ	17.2 kN/m^3
Testing date	23.09.17	ΔV	3.18 cm^3
Vertical strain rate	1.5 % /hr	ε_v	1.21 %

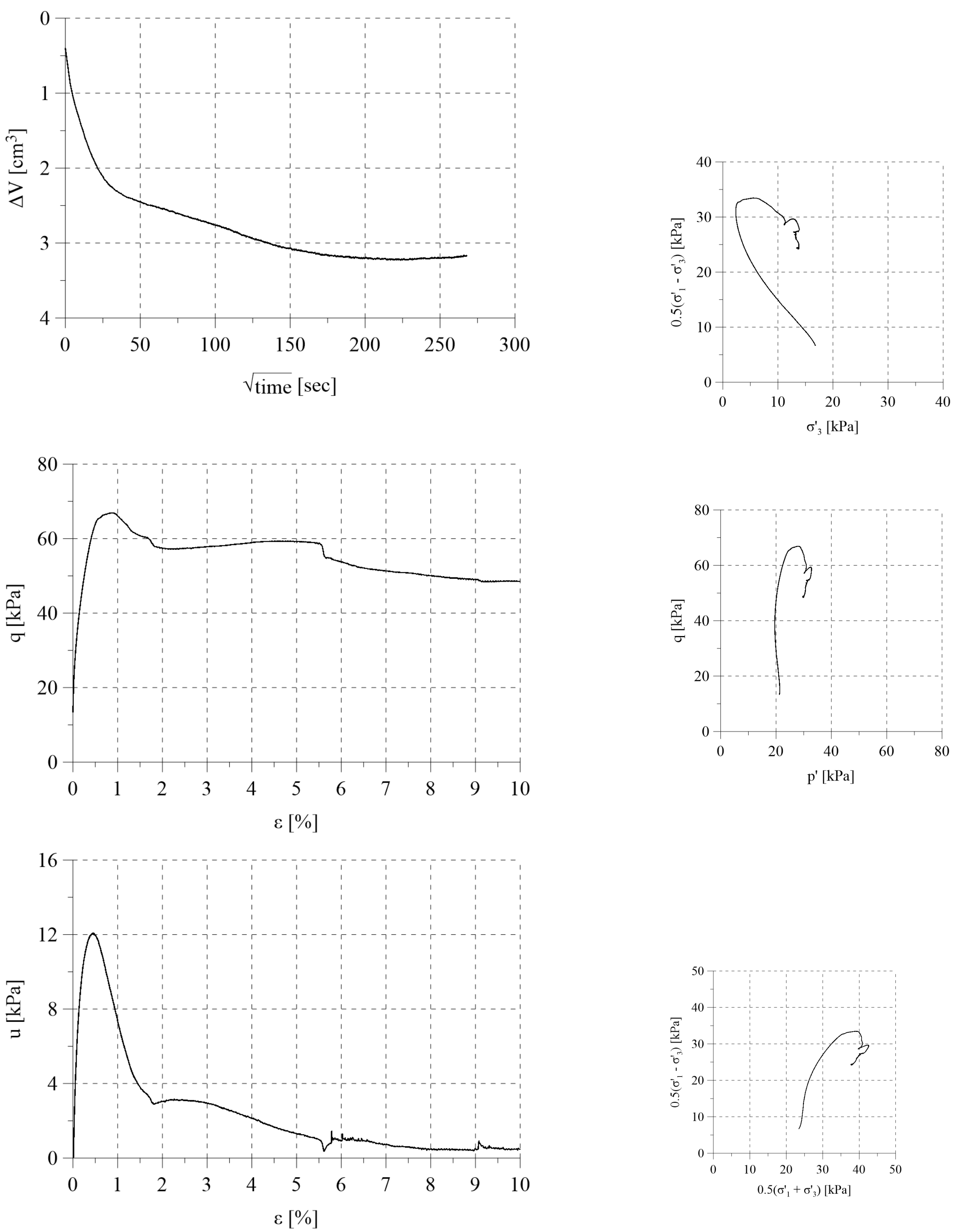


Figure C.5: CAUc results from triaxial test no. 2 at depth 4.45 m, mini block sample.

CAUc-2.1			**0 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	7.08 m	σ'_{v0}	80.5 kPa
Sampling date	20.10.17	w	44.1 %
Opening date	20.10.17	γ	18.5 kN/m^3
Testing date	20.10.17	ΔV	6.92 cm^3
Vertical strain rate	1.5 % /hr	ε_v	3.01 %

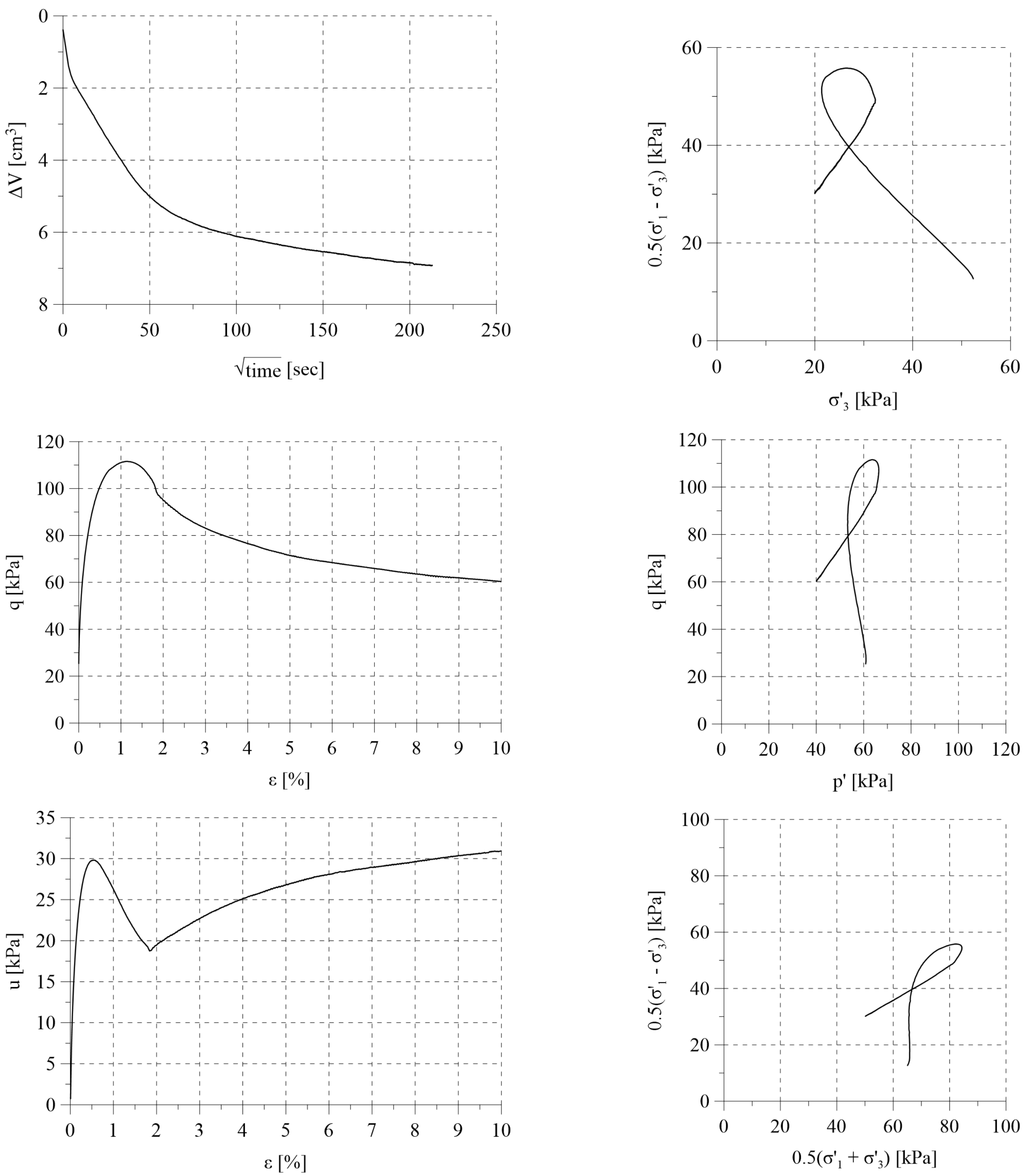


Figure C.6: CAUc results from triaxial test no. 1 at depth 7.08 m, mini block sample.

CAUc-2.2			**0 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	7.08 m	σ'_{v0}	80.7 kPa
Sampling date	20.10.17	w	44.1 %
Opening date	20.10.17	γ	18.6 kN/m^3
Testing date	20.10.17	ΔV	4.82 cm^3
Vertical strain rate	1.5 % /hr	ε_v	1.93 %

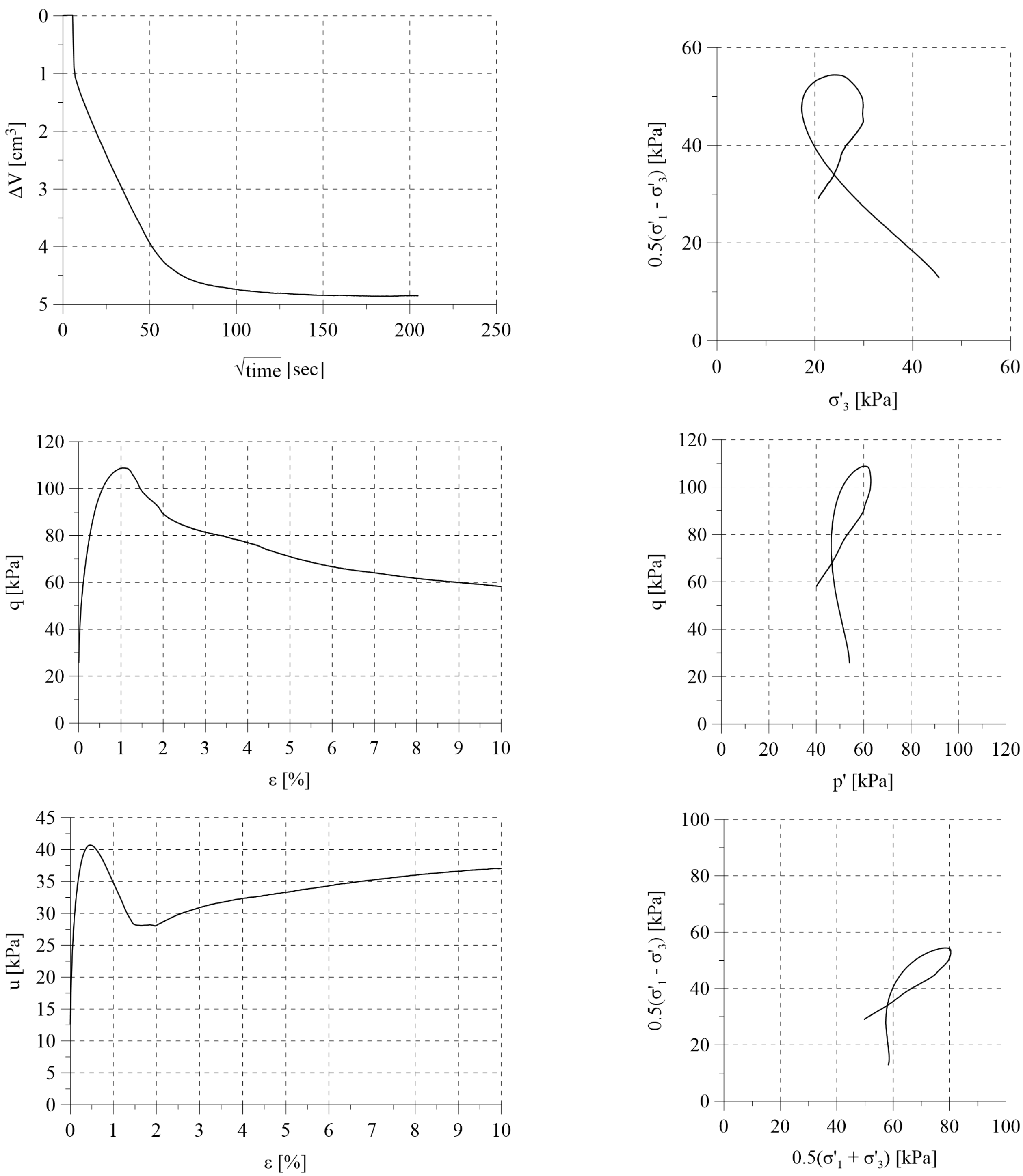


Figure C.7: CAUc results from triaxial test no. 2 at depth 7.08 m, mini block sample.

CAUc-3.1			**0 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	8.05 m	σ'_{v0}	82.2 kPa
Sampling date	23.10.17	w	42.7 %
Opening date	23.10.17	γ	17.7 kN/m^3
Testing date	23.10.17	ΔV	4.95 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.09 %

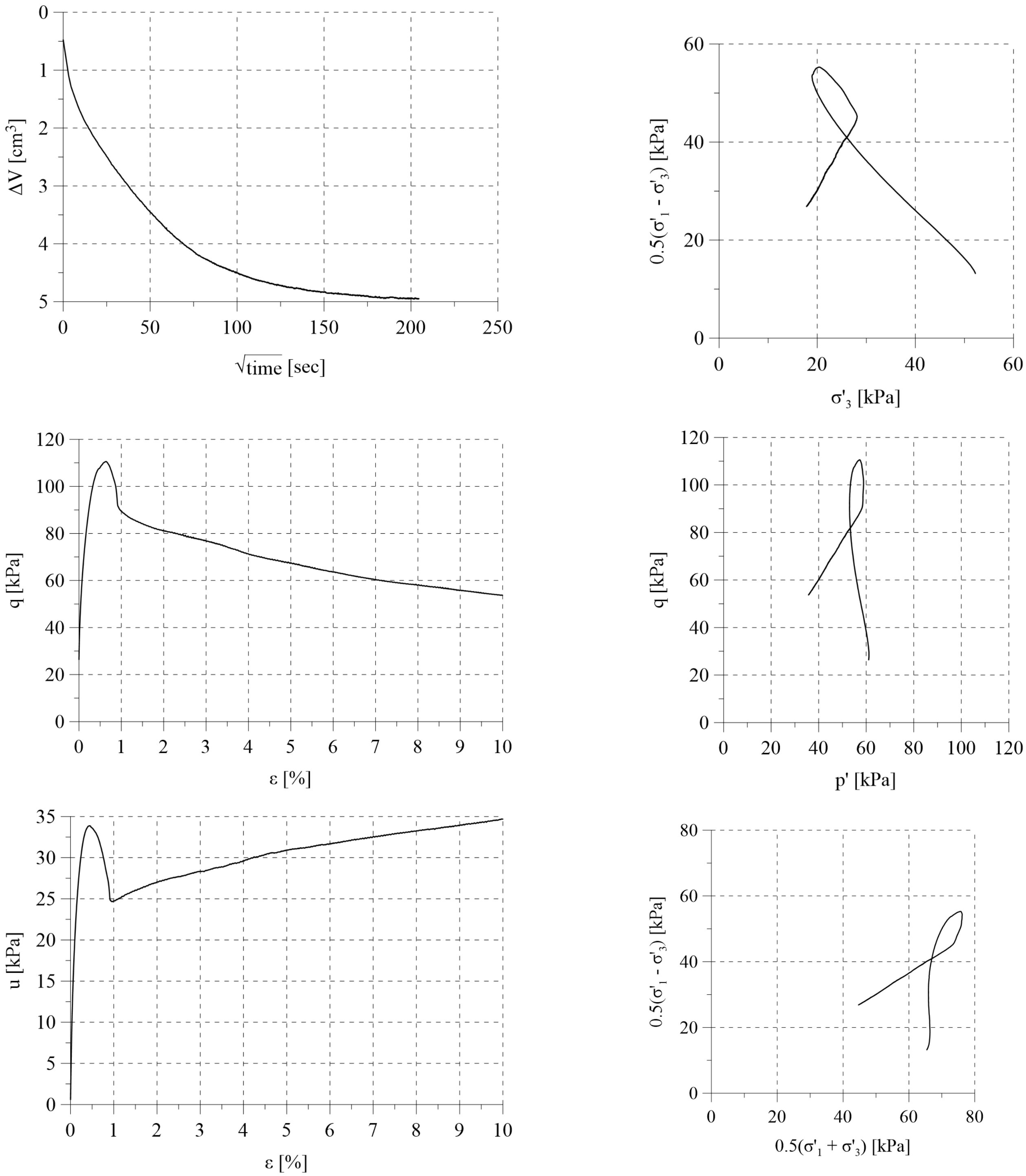


Figure C.8: CAUc results from triaxial test no. 1 at depth 8.05 m, mini block sample.

CAUc-3.2 **Mini Block Sample** **Flotten, Trondheim**			**0 weeks after sampling**
Depth	8.05 m	σ'_{v0}	82.9 kPa
Sampling date	23.10.17	w	42.7 %
Opening date	23.10.17	γ	17.8 kN/m^3
Testing date	23.10.17	ΔV	4.22 cm^3
Vertical strain rate	1.5 % /hr	ε_v	1.63 %

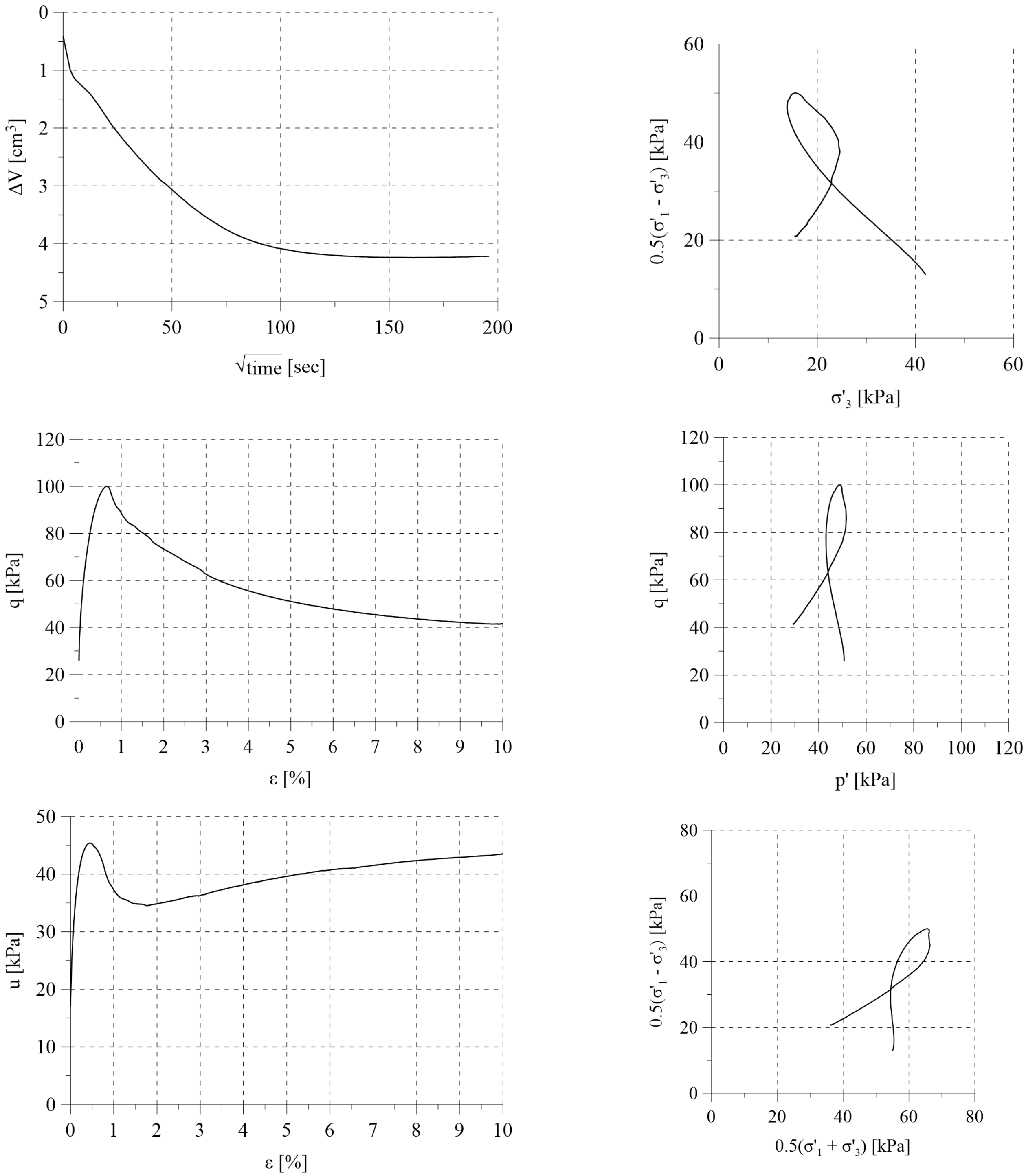


Figure C.9: CAUc results from triaxial test no. 2 at depth 8.05 m, mini block sample.

CAUc-4.1 **Mini Block Sample** **Flotten, Trondheim**			**2 weeks after sampling**
Depth	4.70 m	σ'_{v0}	57.6 kPa
Sampling date	21.09.17	w	48.5 %
Opening date	02.10.17	γ	18.0 kN/m^3
Testing date	02.10.17	ΔV	16.74 cm^3
Vertical strain rate	1.5 % /hr	ε_v	7.18 %

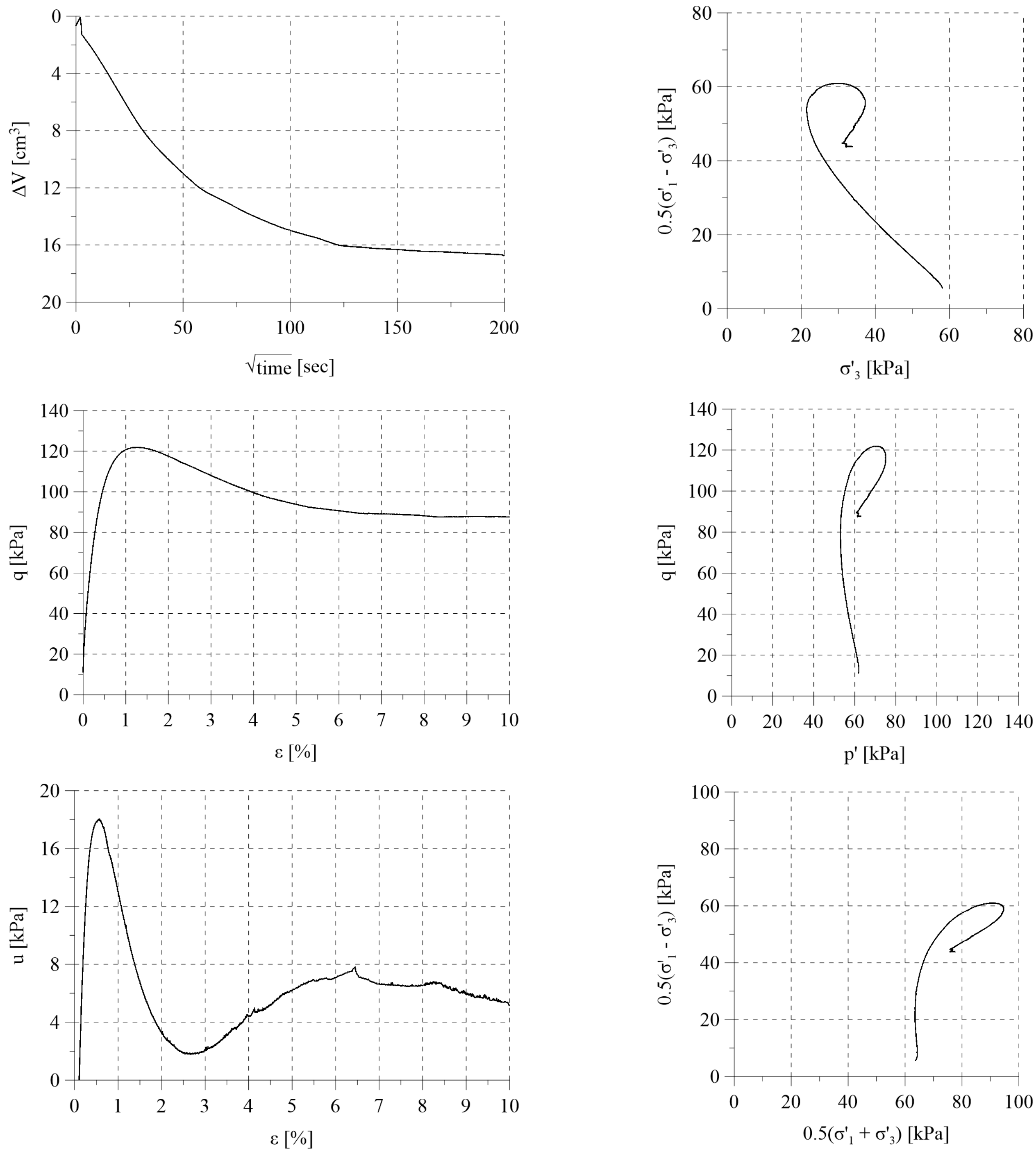


Figure C.10: CAUc results from triaxial test no. 1 at depth 4.70 m after 2 weeks of storage, mini block sample.

CAUc-4.2			**2 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	4.70 m	σ'_{v0}	57.1 kPa
Sampling date	21.09.17	w	48.5 %
Opening date	02.10.17	γ	17.9 kN/m^3
Testing date	03.10.17	ΔV	6.03 cm^3
Vertical strain rate	1.5 % /hr	ε_v	1.88 %

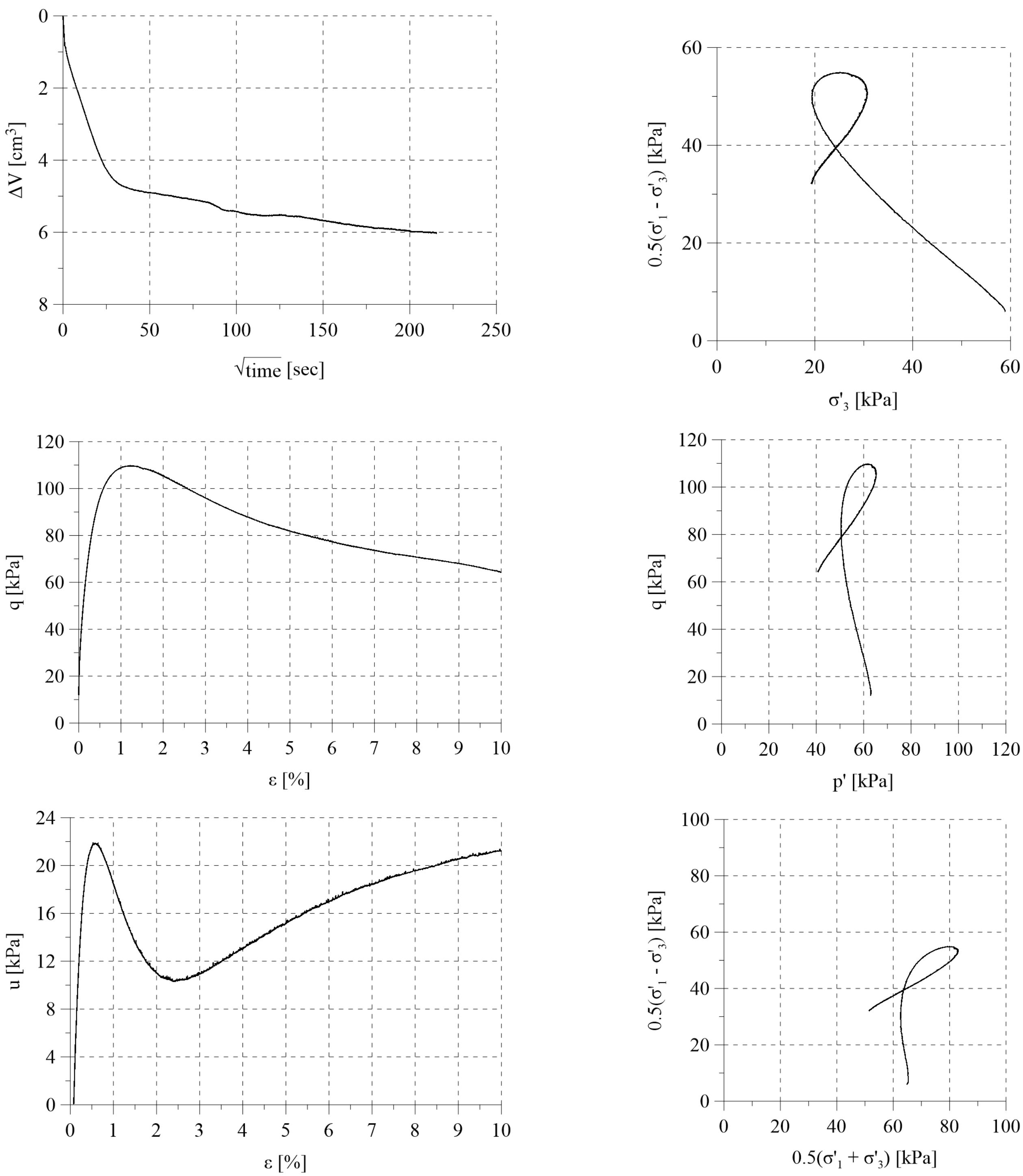


Figure C.11: CAUc results from triaxial test no. 2 at depth 4.70 m after 2 weeks of storage, mini block sample.

CAUc-5.1 **Mini Block Sample** **Flotten, Trondheim**			**2 weeks after sampling**
Depth	5.10 m	σ'_{v0}	58.7 kPa
Sampling date	21.09.17	w	57.6 %
Opening date	06.10.17	γ	17.6 kN/m^3
Testing date	06.10.17	ΔV	13.34 cm^3
Vertical strain rate	1.5 % /hr	ε_v	5.78 %

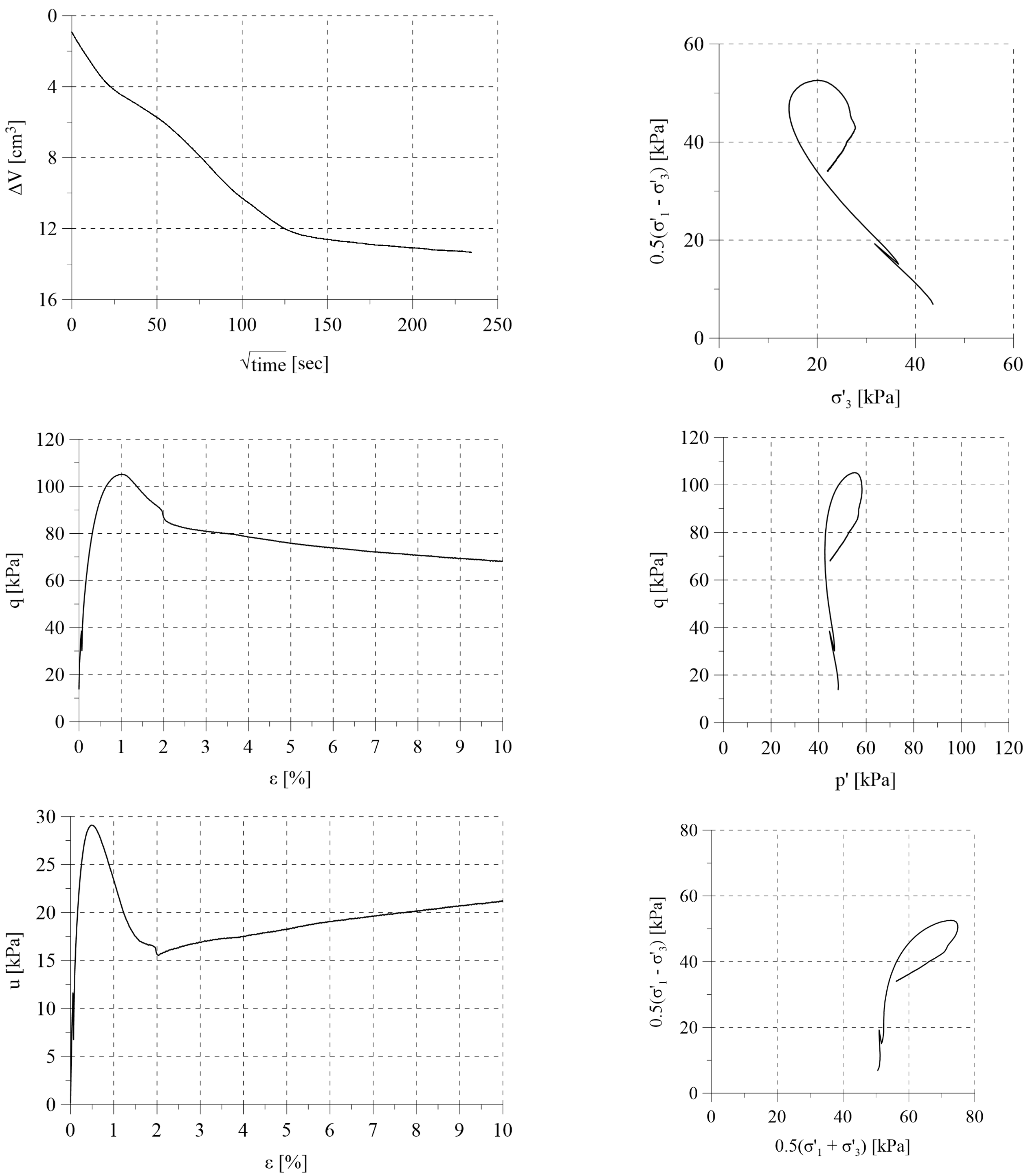


Figure C.12: CAUc results from triaxial test no. 1 at depth 5.10 m after 2 weeks of storage, mini block sample.

CAUc-5.2 Mini Block Sample Flotten, Trondheim			**2 weeks after sampling**
Depth	5.10 m	σ'_{v0}	58.7 kPa
Sampling date	21.09.17	w	57.6 %
Opening date	06.10.17	γ	17.6 kN/m^3
Testing date	06.10.17	ΔV	5.40 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.30 %

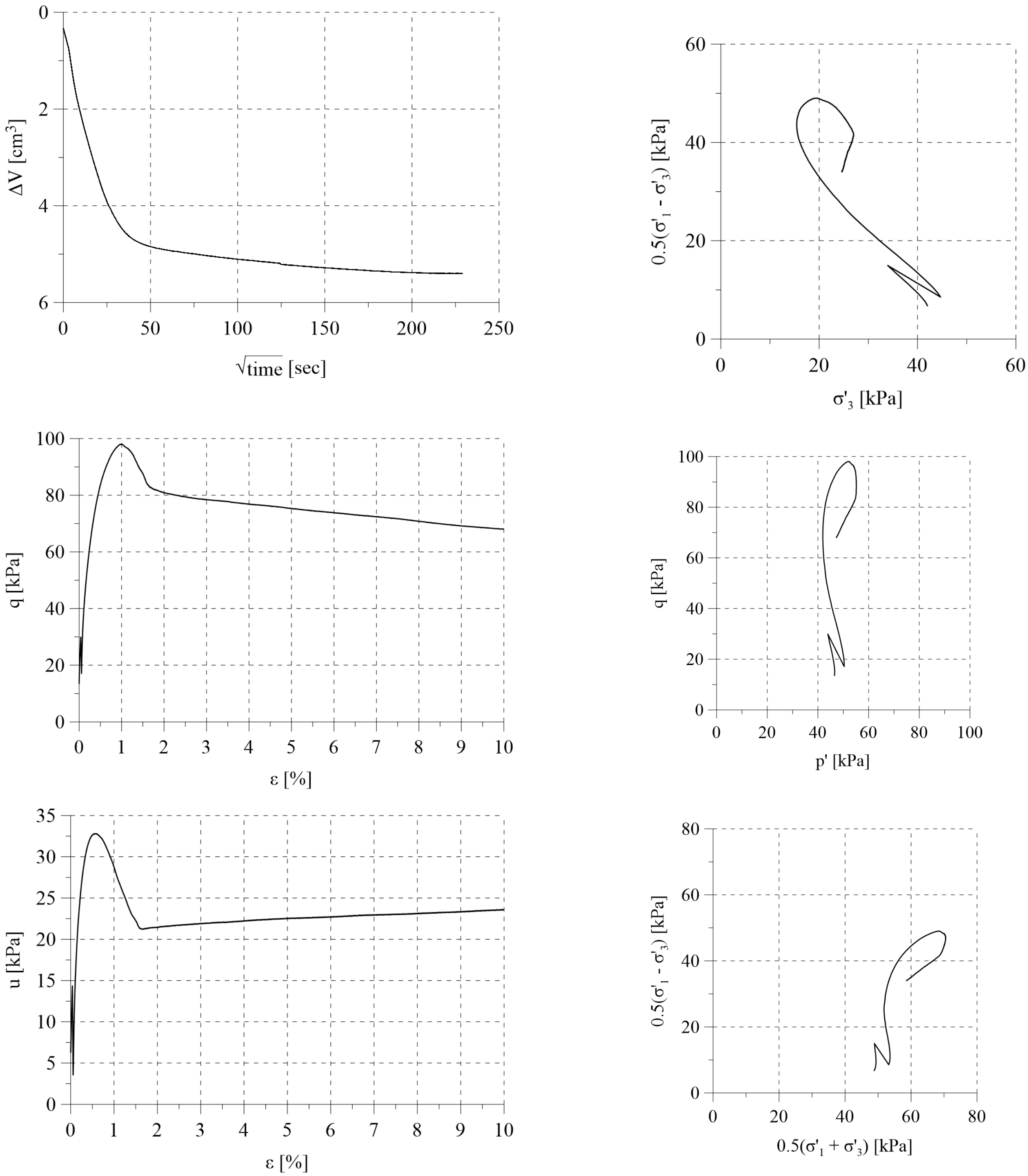


Figure C.13: CAUc results from triaxial test no. 2 at depth 5.10 m after 2 weeks of storage, mini block sample.

CAUc-6.1			**2 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	7.20 m	σ'_{v0}	76.8 kPa
Sampling date	20.10.17	w	39.3 %
Opening date	20.10.17	γ	17.9 kN/m^3
Testing date	02.11.17	ΔV	6.52 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.82 %

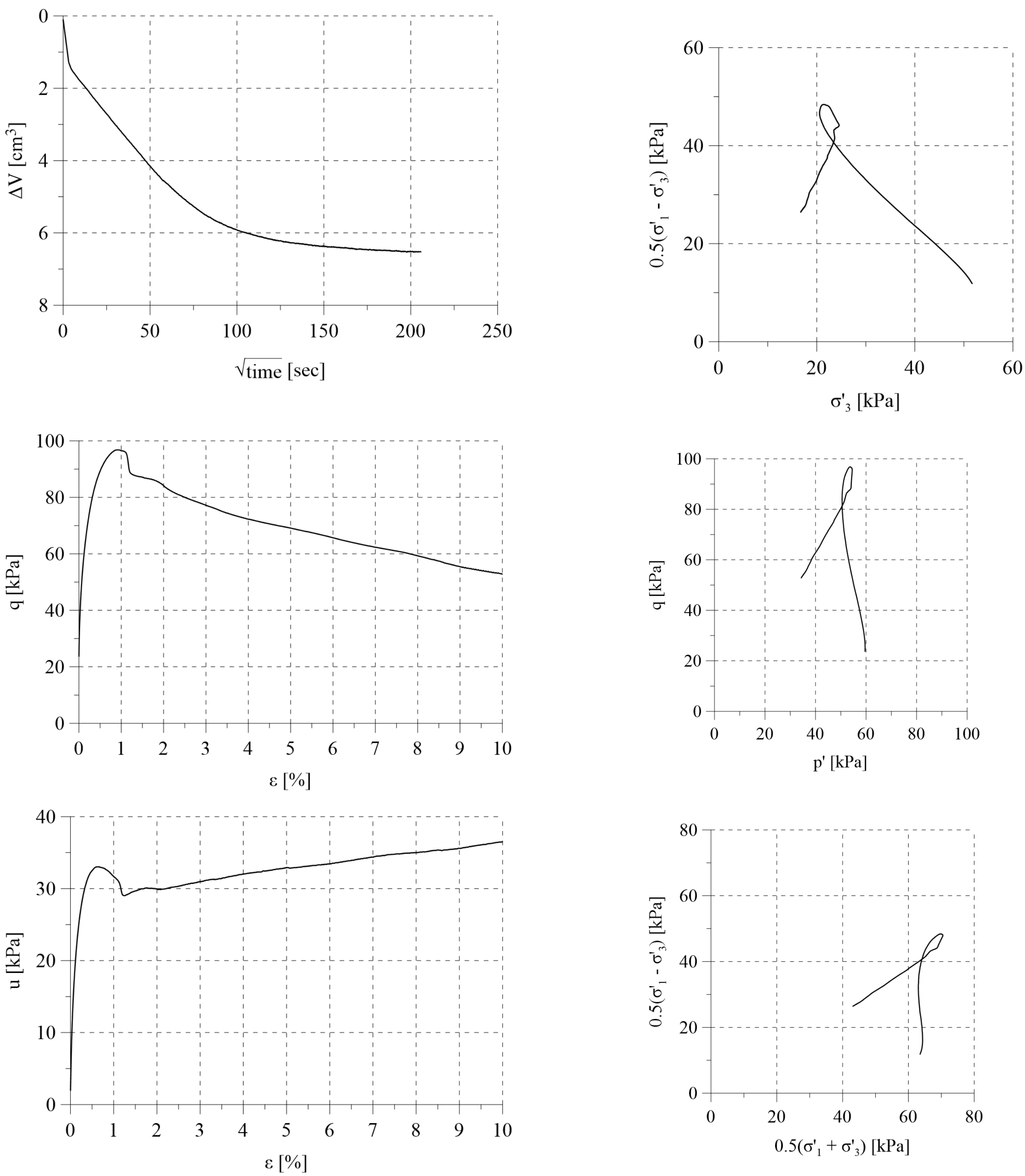


Figure C.14: CAUc results from triaxial test no. 1 at depth 7.20 m after 2 weeks of storage, mini block sample.

CAUc-6.2			**2 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	7.20 m	σ'_{v0}	76.8 kPa
Sampling date	20.10.17	w	39.3 %
Opening date	20.10.17	γ	17.9 kN/m^3
Testing date	02.11.17	ΔV	6.75 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.65 %

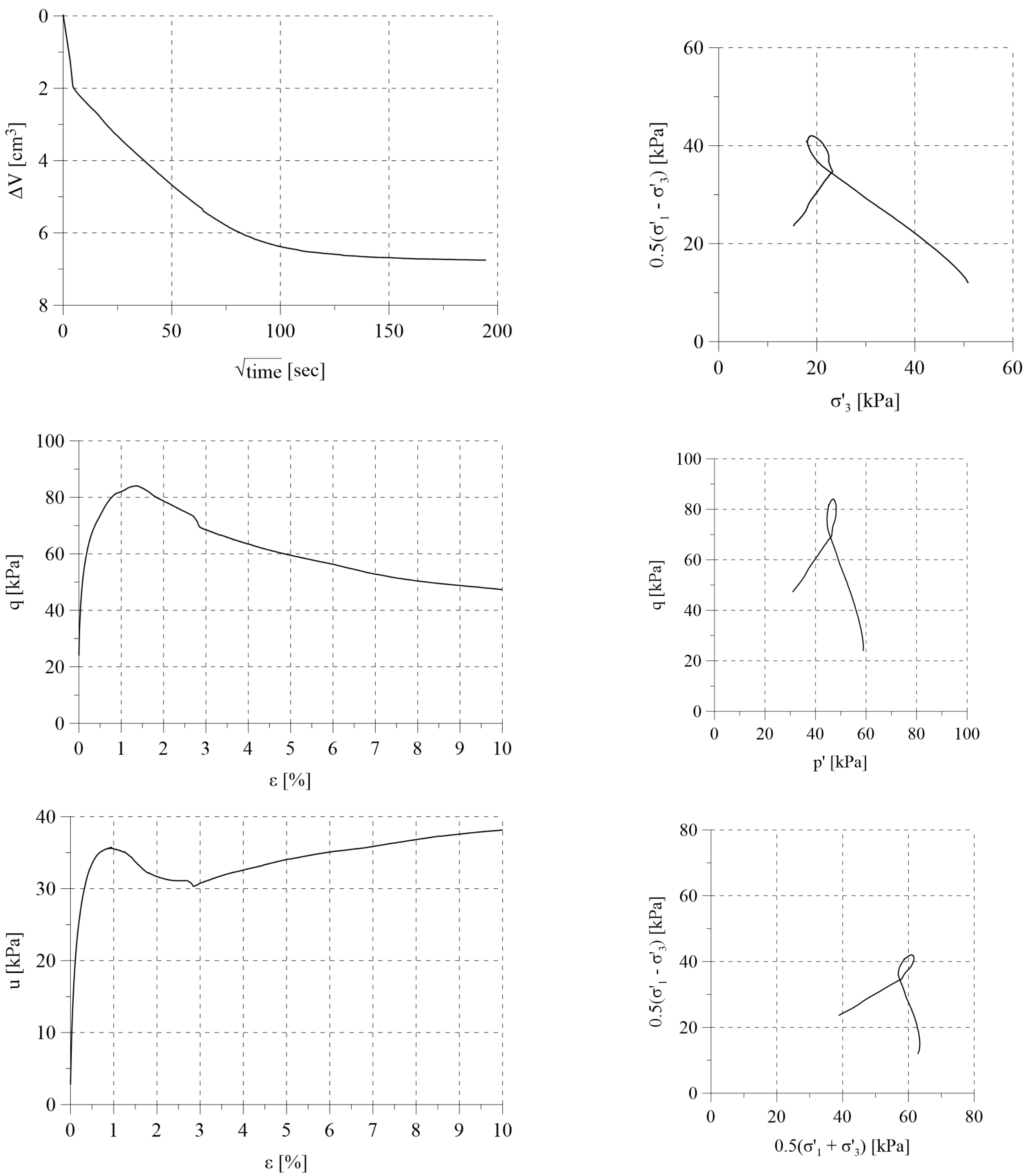


Figure C.15: CAUc results from triaxial test no. 2 at depth 7.20 m after 2 weeks of storage, mini block sample.

CAUc-7.1			**2 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	8.15 m	σ'_{v0}	86.1 kPa
Sampling date	23.10.17	w	47.7 %
Opening date	23.10.17	γ	18.1 kN/m^3
Testing date	03.11.17	ΔV	13.07 cm^3
Vertical strain rate	1.5 % /hr	ε_v	5.66 %

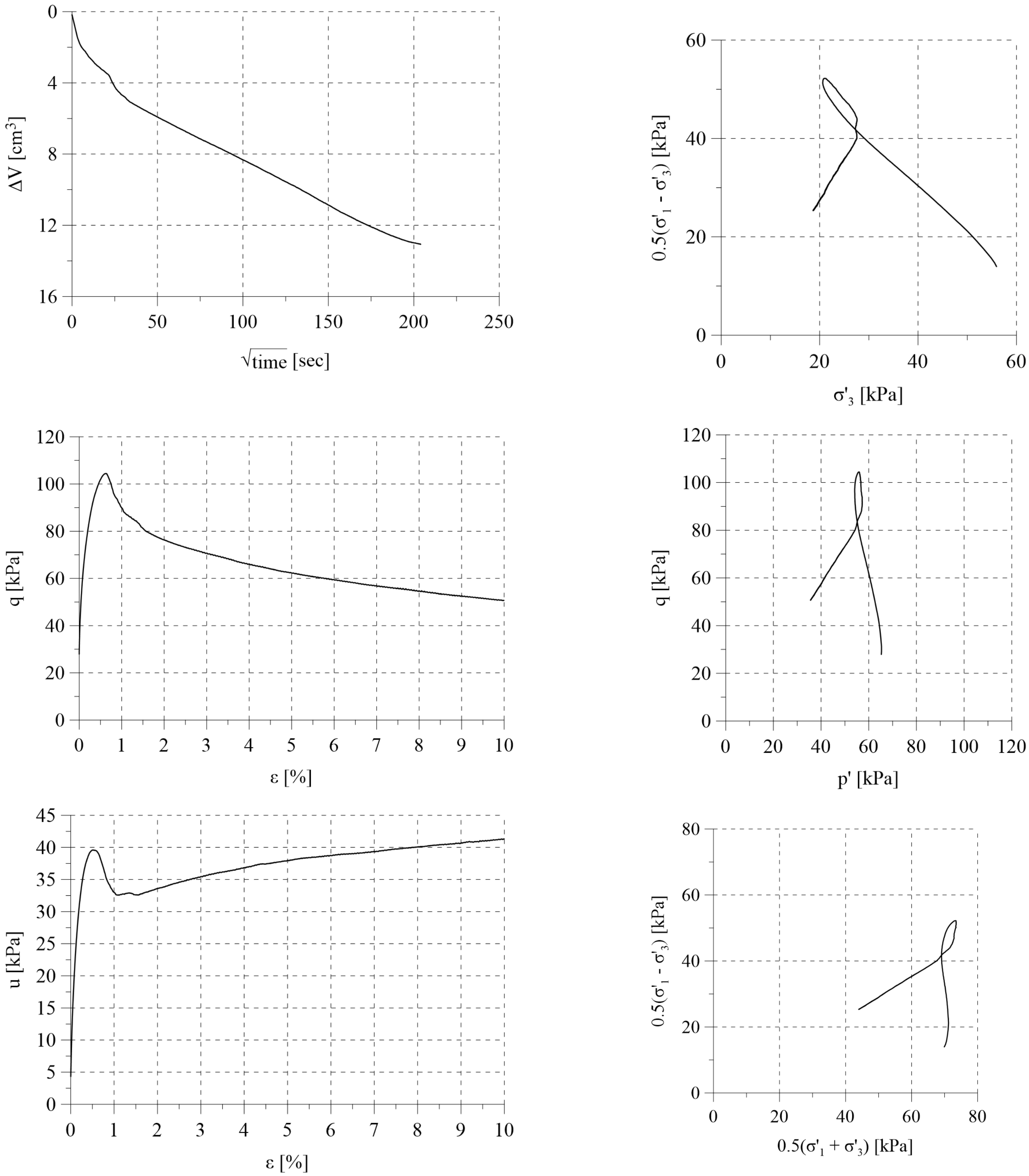


Figure C.16: CAUc results from triaxial test no. 1 at depth 8.15 m after 2 weeks of storage, mini block sample.

CAUc-7.2			**2 weeks after sampling**
Mini Block Sample			
Flotten, Trondheim			
Depth	8.15 m	σ'_{v0}	84.9 kPa
Sampling date	23.10.17	w	47.7 %
Opening date	23.10.17	γ	18.0 kN/m^3
Testing date	03.11.17	ΔV	5.93 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.21 %

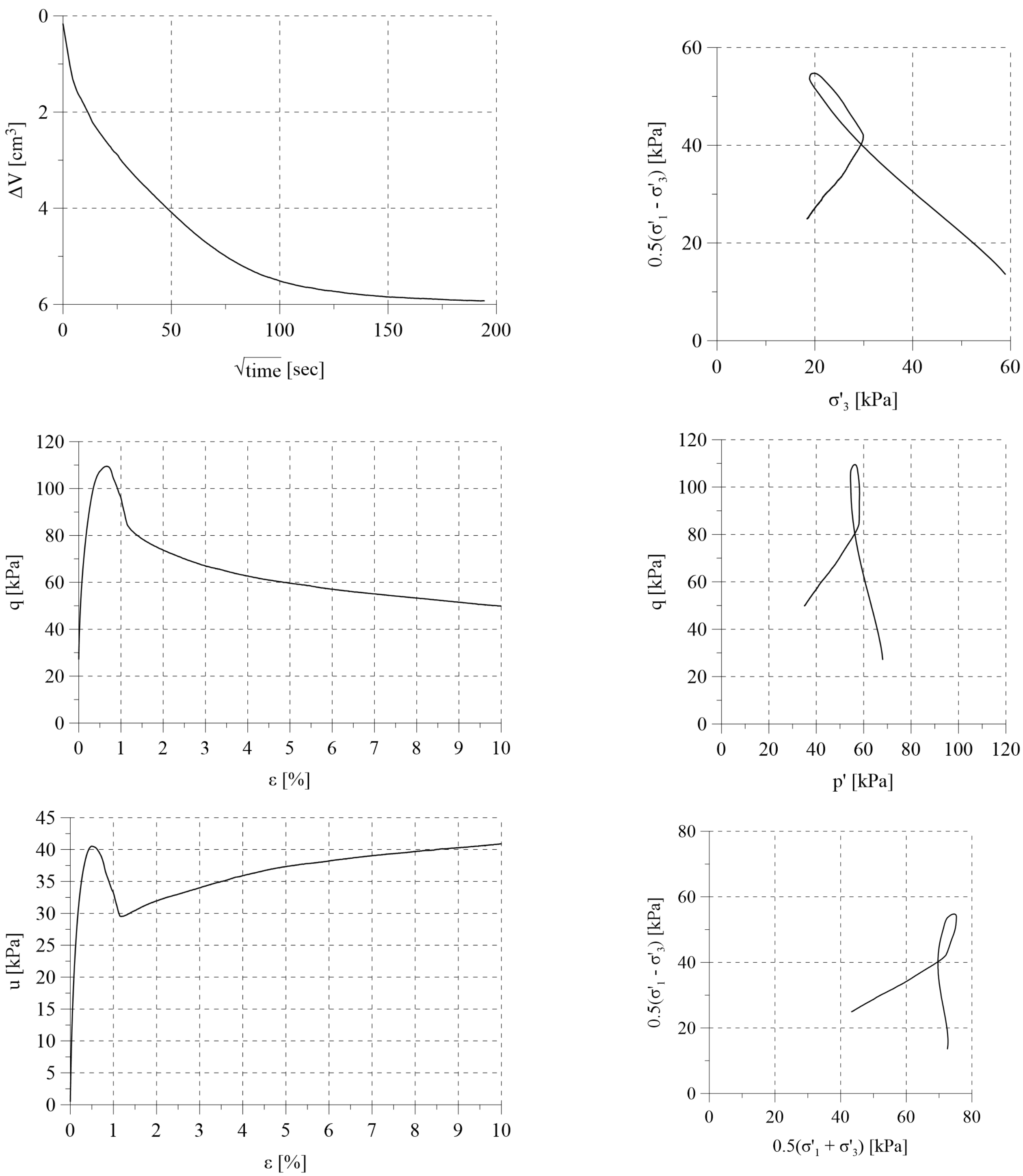
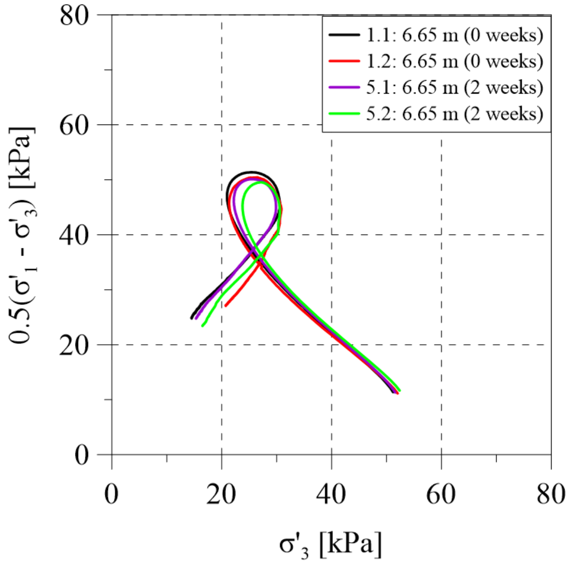
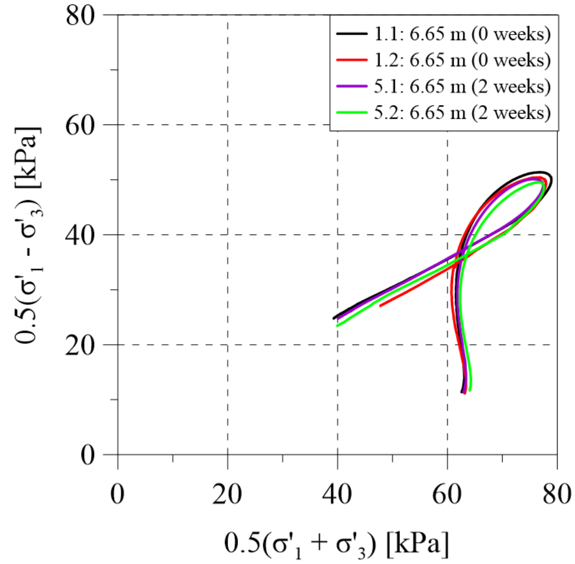


Figure C.17: CAUc results from triaxial test no. 2 at depth 8.15 m after 2 weeks of storage, mini block sample.

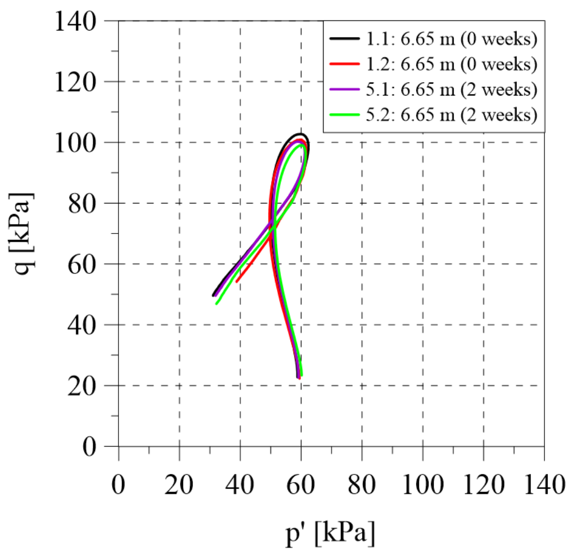
C.2 Triaxial Results from Sherbrooke Block Samples



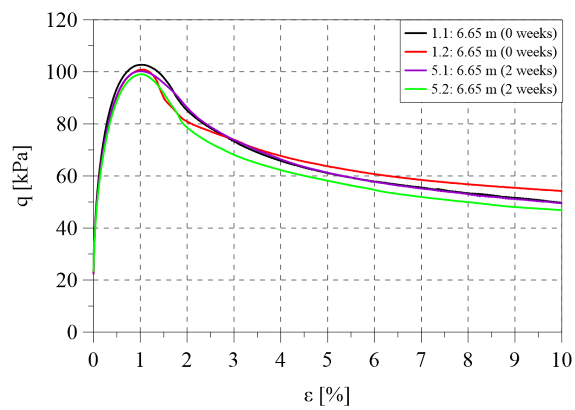
(a) NTNU plot



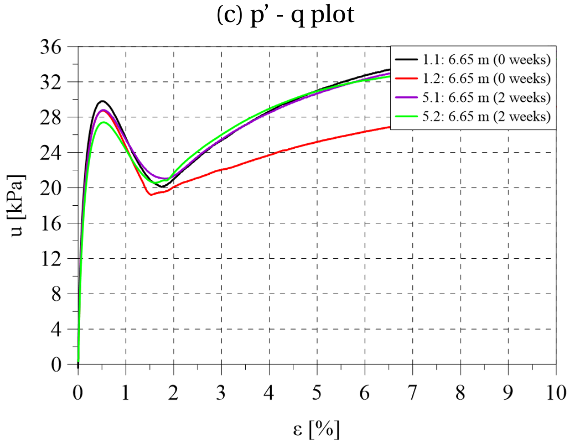
(b) NGI plot



(c) p' - q plot

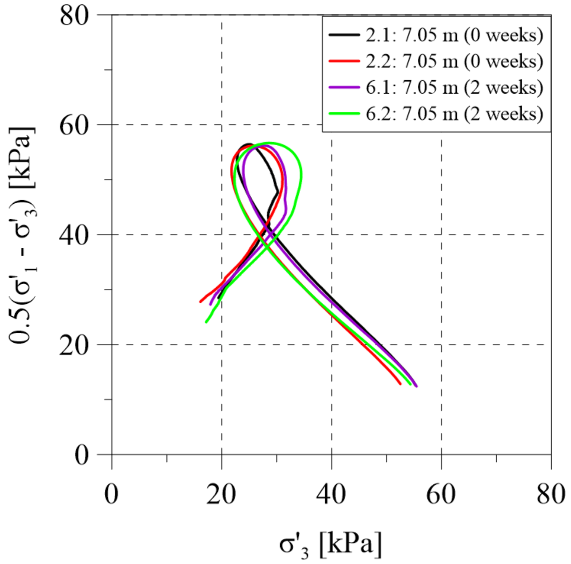


(d) ε - q plot

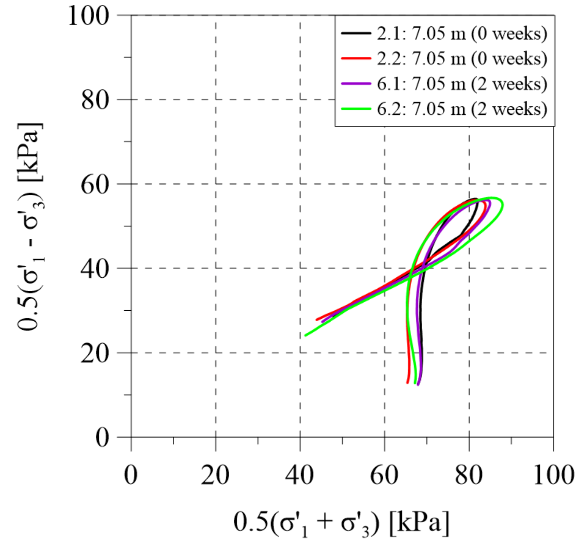


(e) ε - u plot

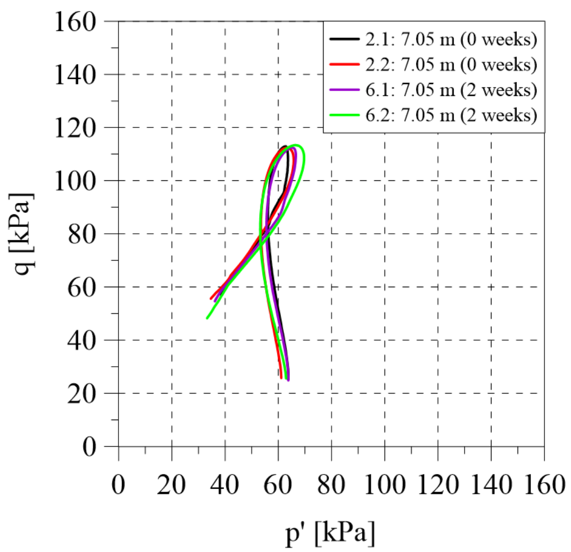
Figure C.18: CAUc results from triaxial tests from depths 6.65 m, Sherbrooke block sample



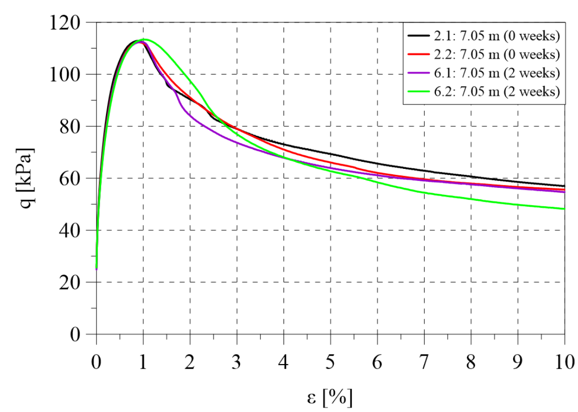
(a) NTNU plot



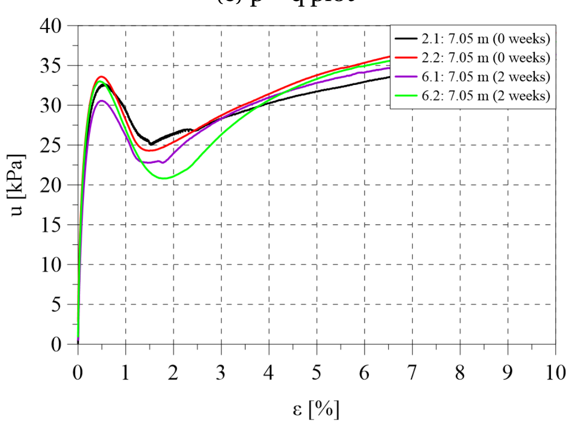
(b) NGI plot



(c) p' - q plot

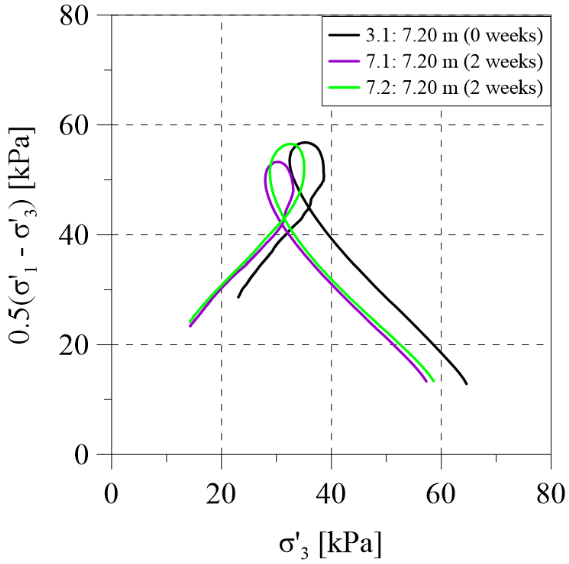


(d) ε - q plot

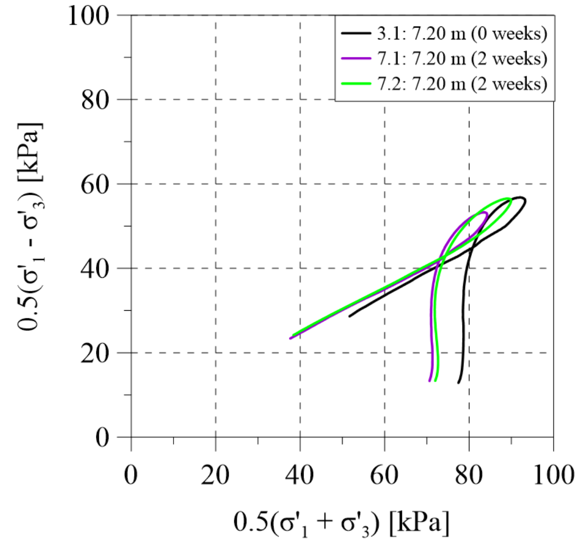


(e) ε - u plot

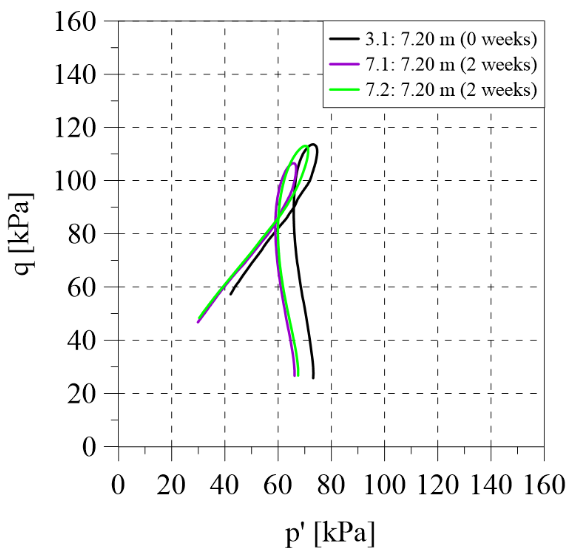
Figure C.19: CAUc results from triaxial tests from depths 7.05 m, Sherbrooke block sample



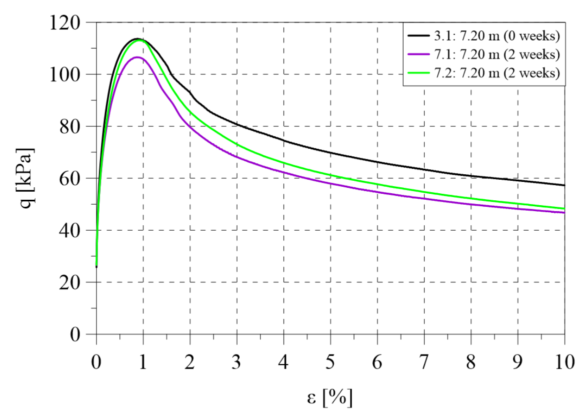
(a) NTNU plot



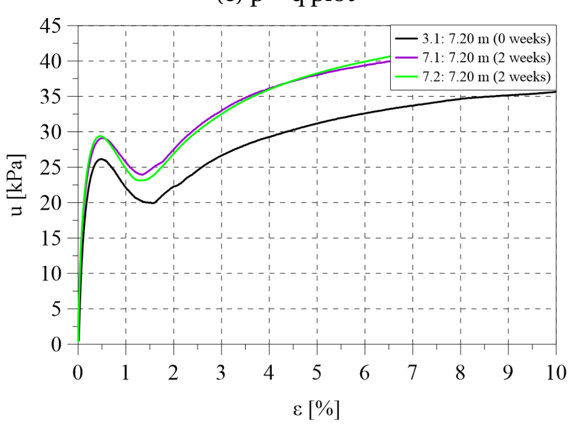
(b) NGI plot



(c) p' - q plot

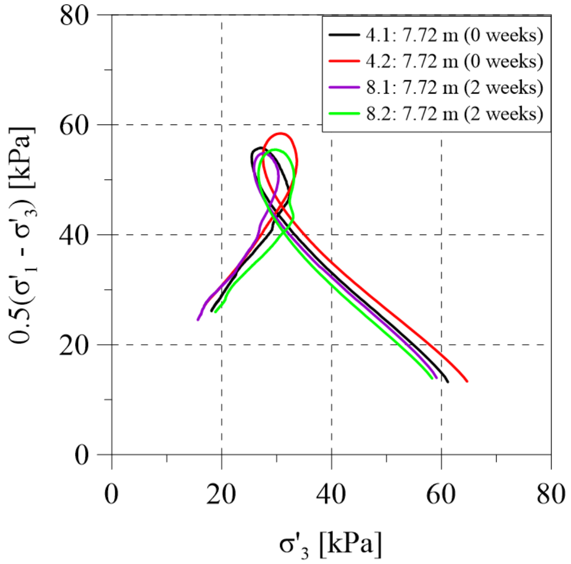


(d) ε - q plot

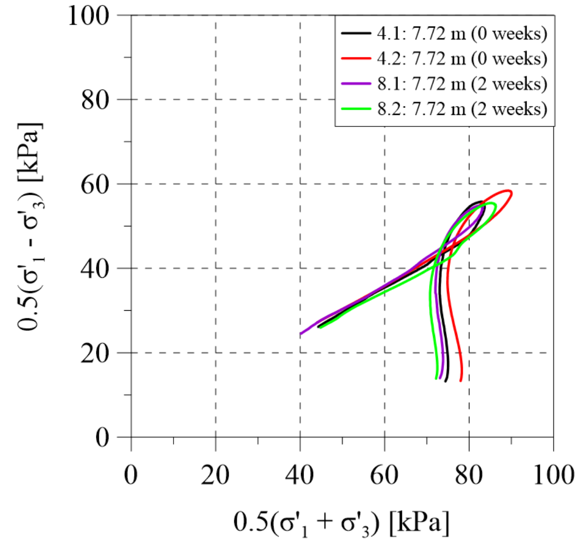


(e) ε - u plot

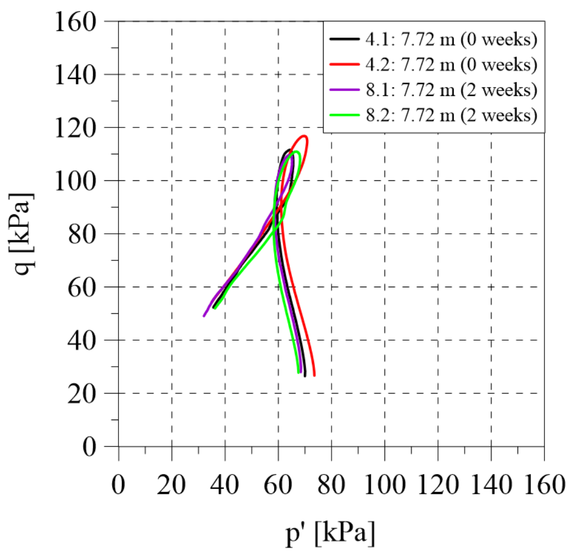
Figure C.20: CAUc results from triaxial tests from depths 7.20 m, Sherbrooke block sample



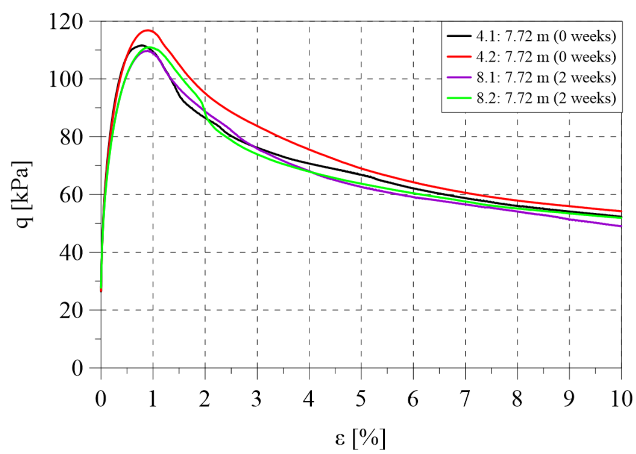
(a) NTNU plot



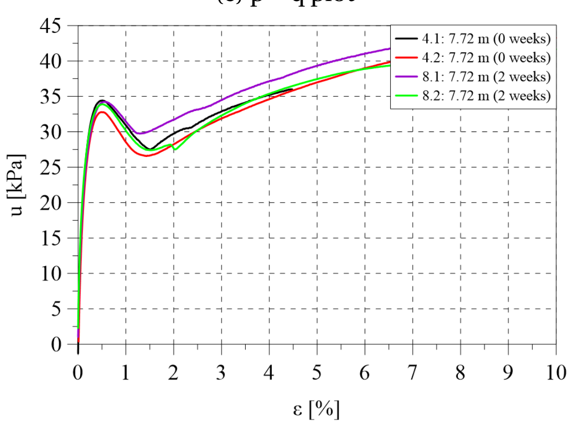
(b) NGI plot



(c) p' - q plot



(d) ε - q plot



(e) ε - u plot

Figure C.21: CAUc results from triaxial tests from depths 7.72 m, Sherbrooke block sample

CAUc-S1.1 **Sherbrooke Block Sample** **Flotten, Trondheim**			**0 weeks after sampling**
Depth	6.65 m	σ'_{v0}	72.7 kPa
Sampling date	23.11.17	w	50.1 %
Opening date	26.11.17	γ	17.9 kN/m^3
Testing date	26.11.17	ΔV	6.54 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.25 %

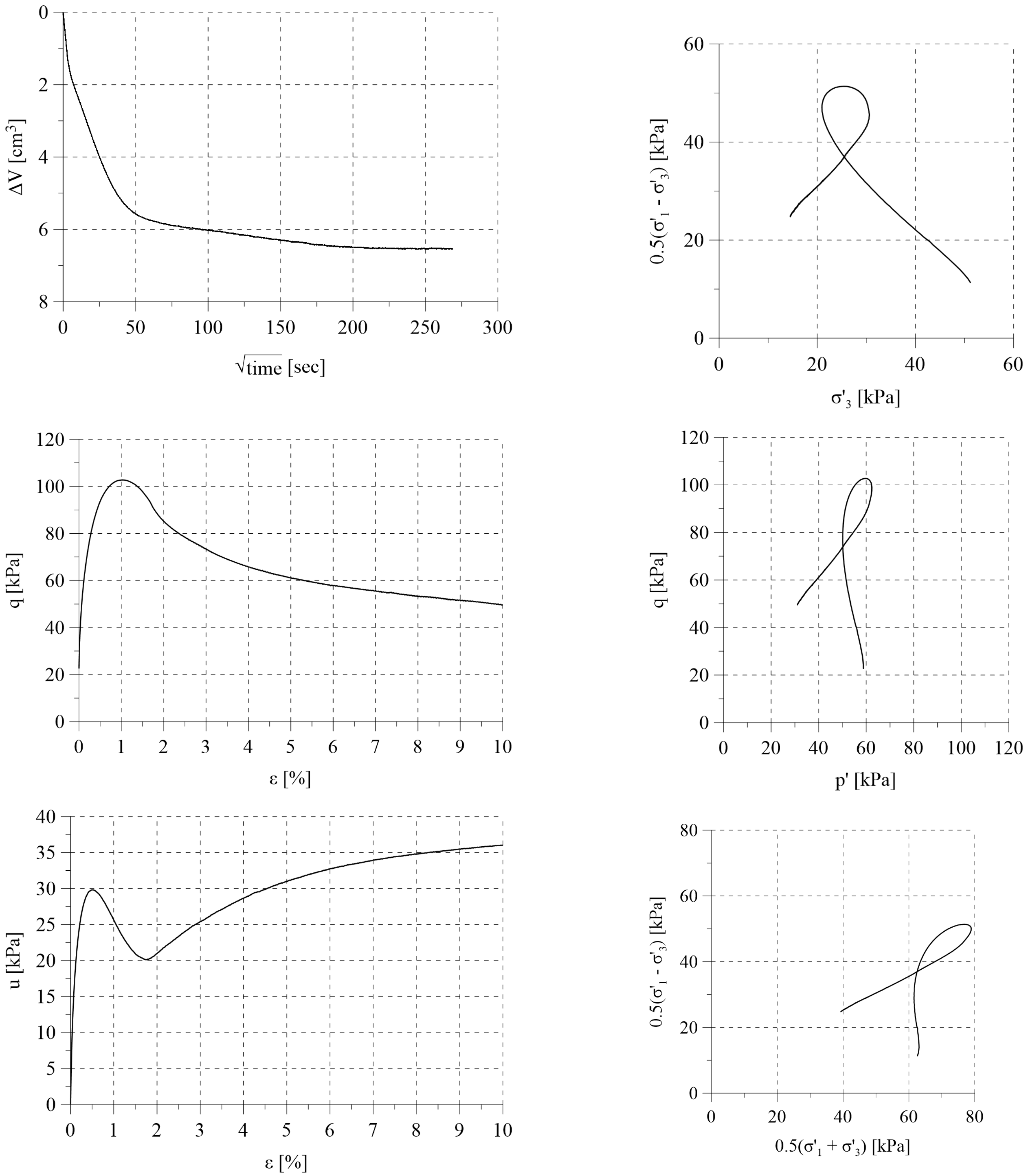


Figure C.22: CAUc results from triaxial test no. 1 at depth 6.65 m, Sherbrooke block sample.

CAUc-S1.2			**0 weeks after sampling**
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	6.65 m	σ'_{v0}	71.6 kPa
Sampling date	23.11.17	w	50.1 %
Opening date	26.11.17	γ	17.8 kN/m^3
Testing date	26.11.17	ΔV	7.36 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.67 %

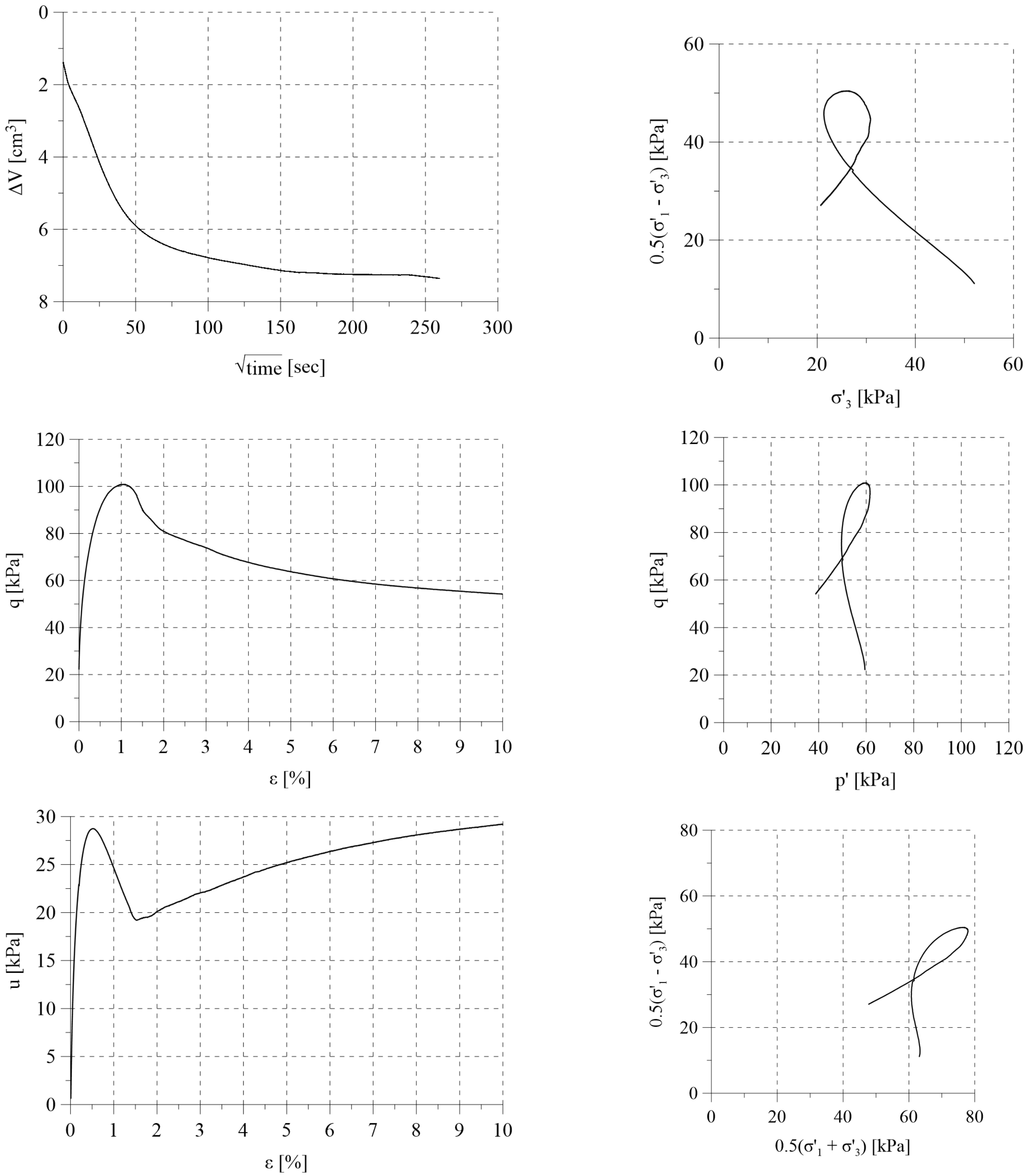


Figure C.23: CAUc results from triaxial test no. 2 at depth 6.65 m, Sherbrooke block sample.

CAUc-S2.1 Sherbrooke Block Sample Flotten, Trondheim		**0 weeks after sampling**	
Depth	7.05 m	σ'_{v0}	79.7 kPa
Sampling date	23.11.17	w	44.4 %
Opening date	23.11.17	γ	18.5 kN/m^3
Testing date	23.11.17	ΔV	5.54 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.23 %

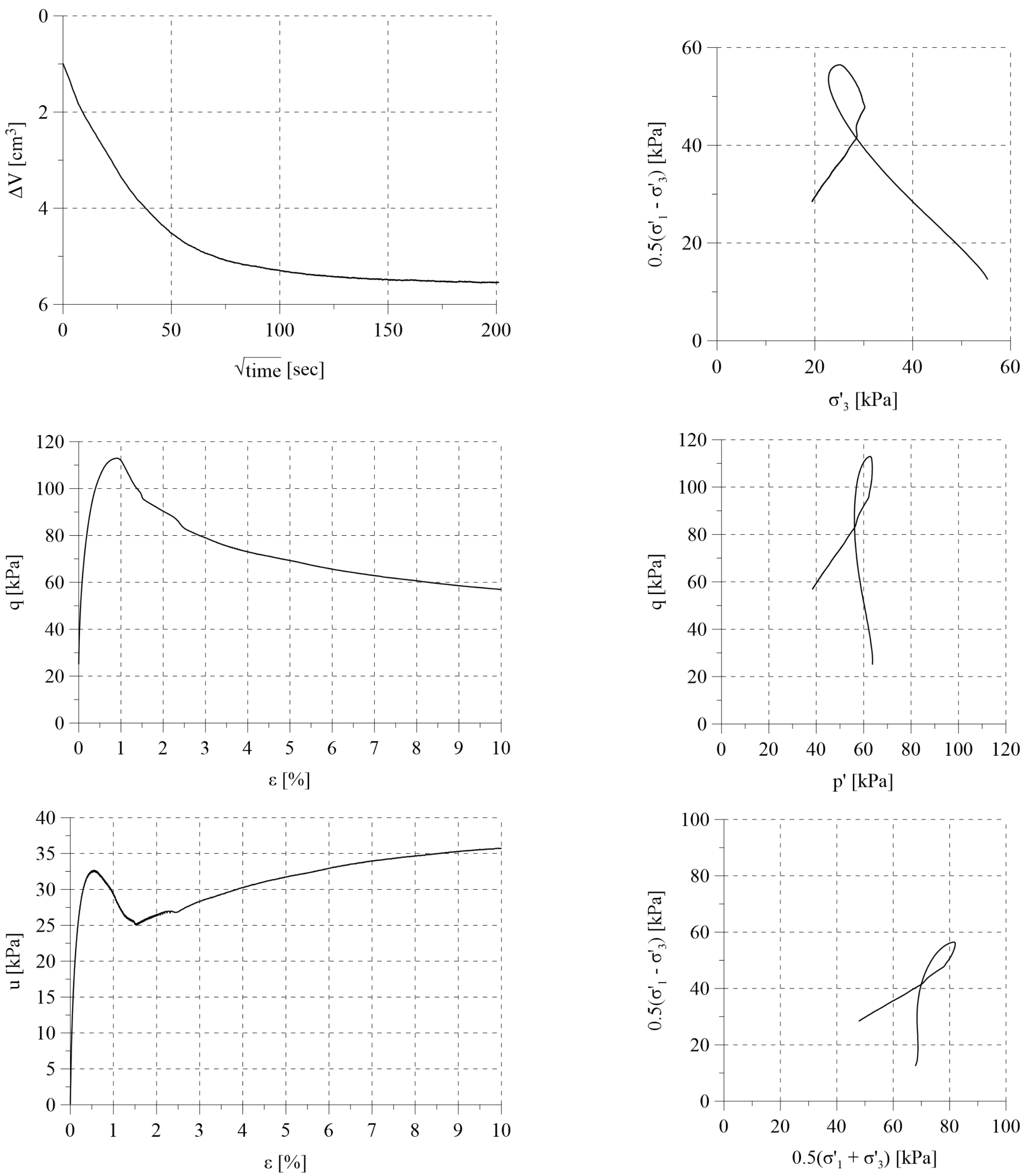


Figure C.24: CAUc results from triaxial test no. 1 at depth 7.05 m, Sherbrooke block sample.

CAUc-S2.2		**0 weeks after sampling**	
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	7.05 m	σ'_{v0}	78.9 kPa
Sampling date	23.11.17	w	44.4 %
Opening date	23.11.17	γ	18.4 kN/m^3
Testing date	23.11.17	ΔV	6.01 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.34 %

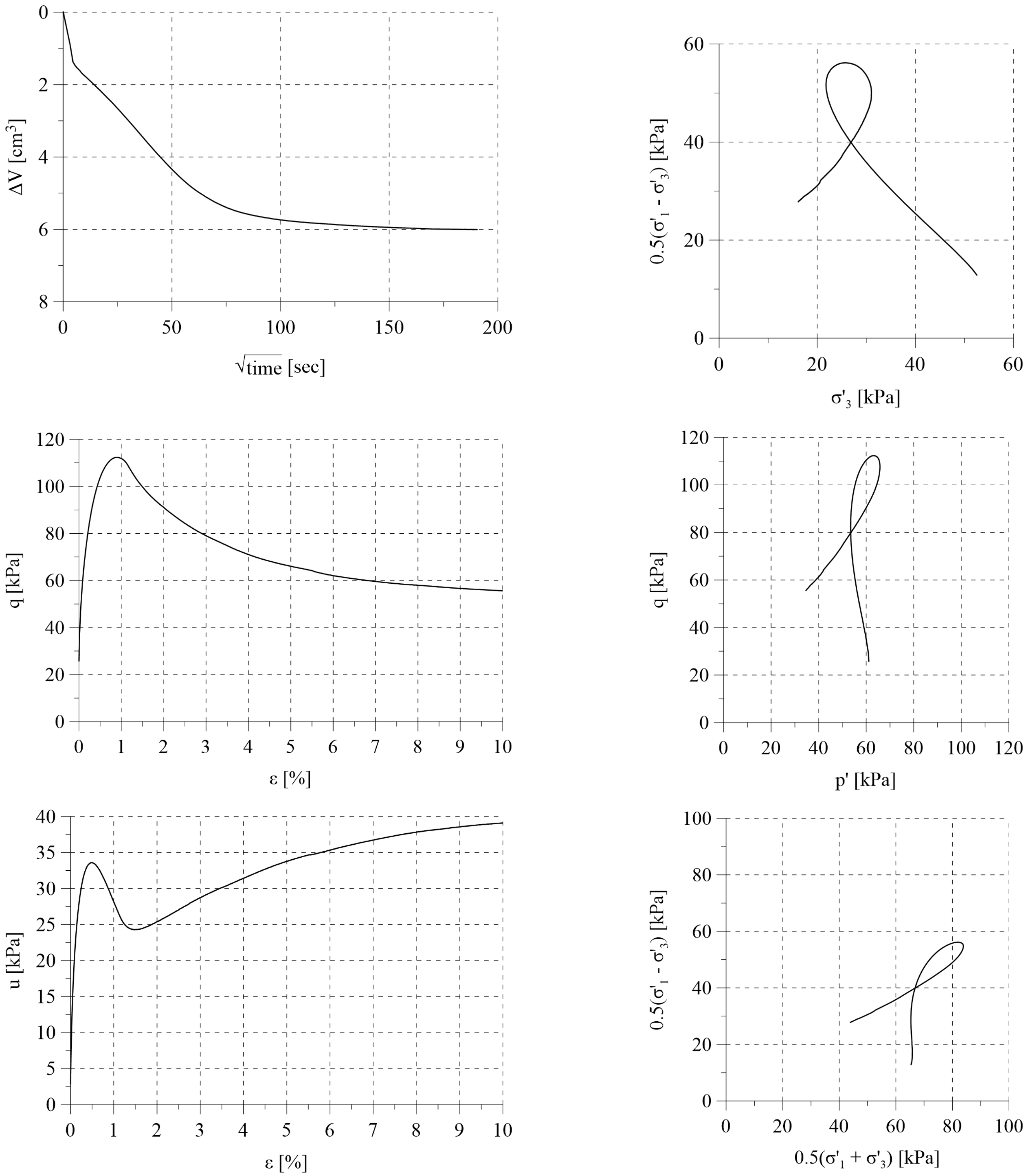


Figure C.25: CAUc results from triaxial test no. 2 at depth 7.05 m, Sherbrooke block sample.

CAUc-S3.1			**0 weeks after sampling**
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	7.20 m	σ'_{v0}	84.0 kPa
Sampling date	23.11.17	w	40.8 %
Opening date	23.11.17	γ	18.9 kN/m^3
Testing date	24.11.17	ΔV	5.29 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.15 %

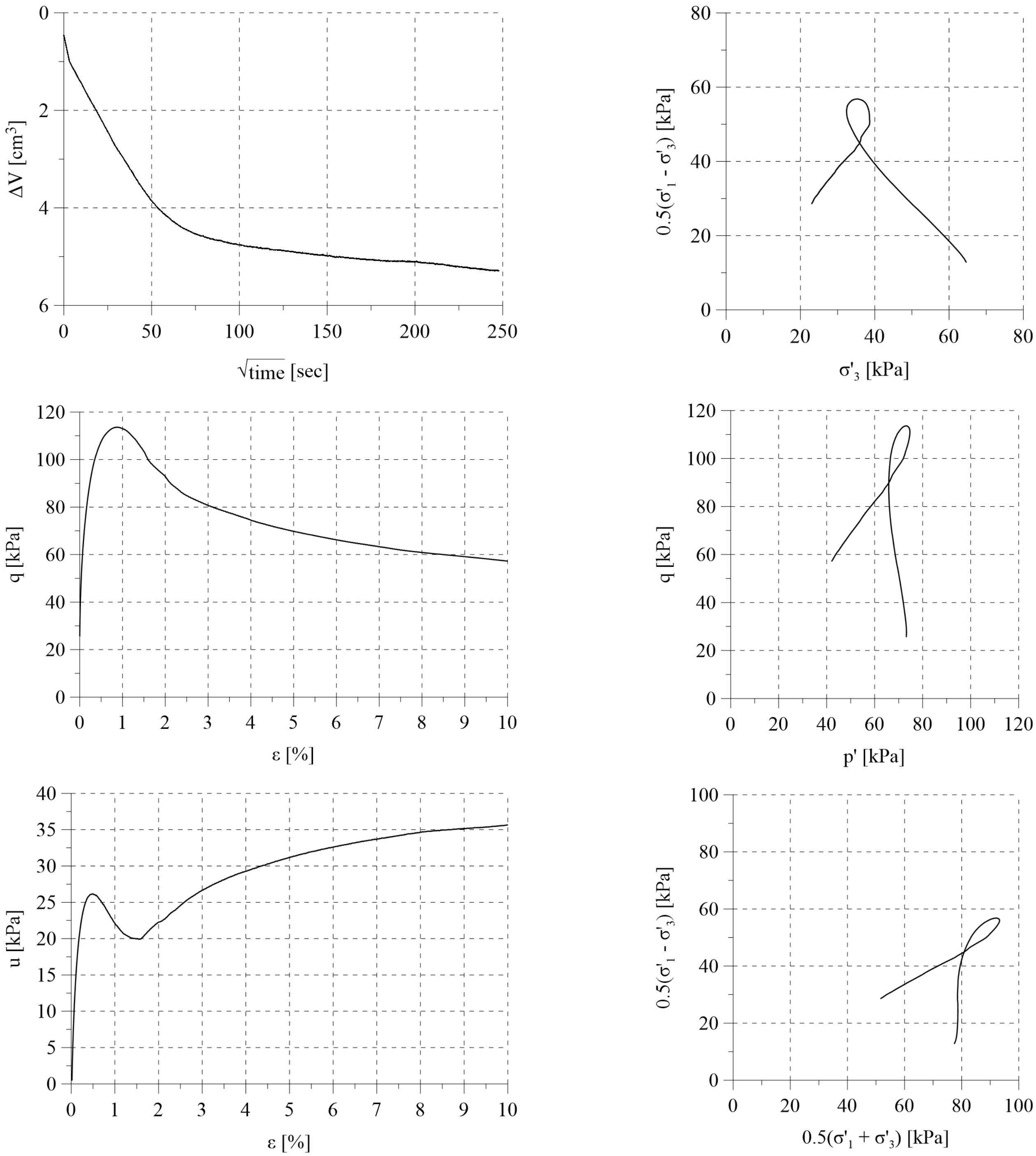


Figure C.26: CAUc results from triaxial test no. 1 at depth 7.20 m, Sherbrooke block sample.

CAUc-S3.2 **Sherbrooke Block Sample** **Flotten, Trondheim**		**0 weeks after sampling**	
Depth	7.20 m	σ'_{v0}	85.0 kPa
Sampling date	23.11.17	w	40.8 %
Opening date	23.11.17	γ	19.0 kN/m^3
Testing date	24.11.17	ΔV	8.54 cm^3
Vertical strain rate	1.5 % /hr	ε_v	3.63 %

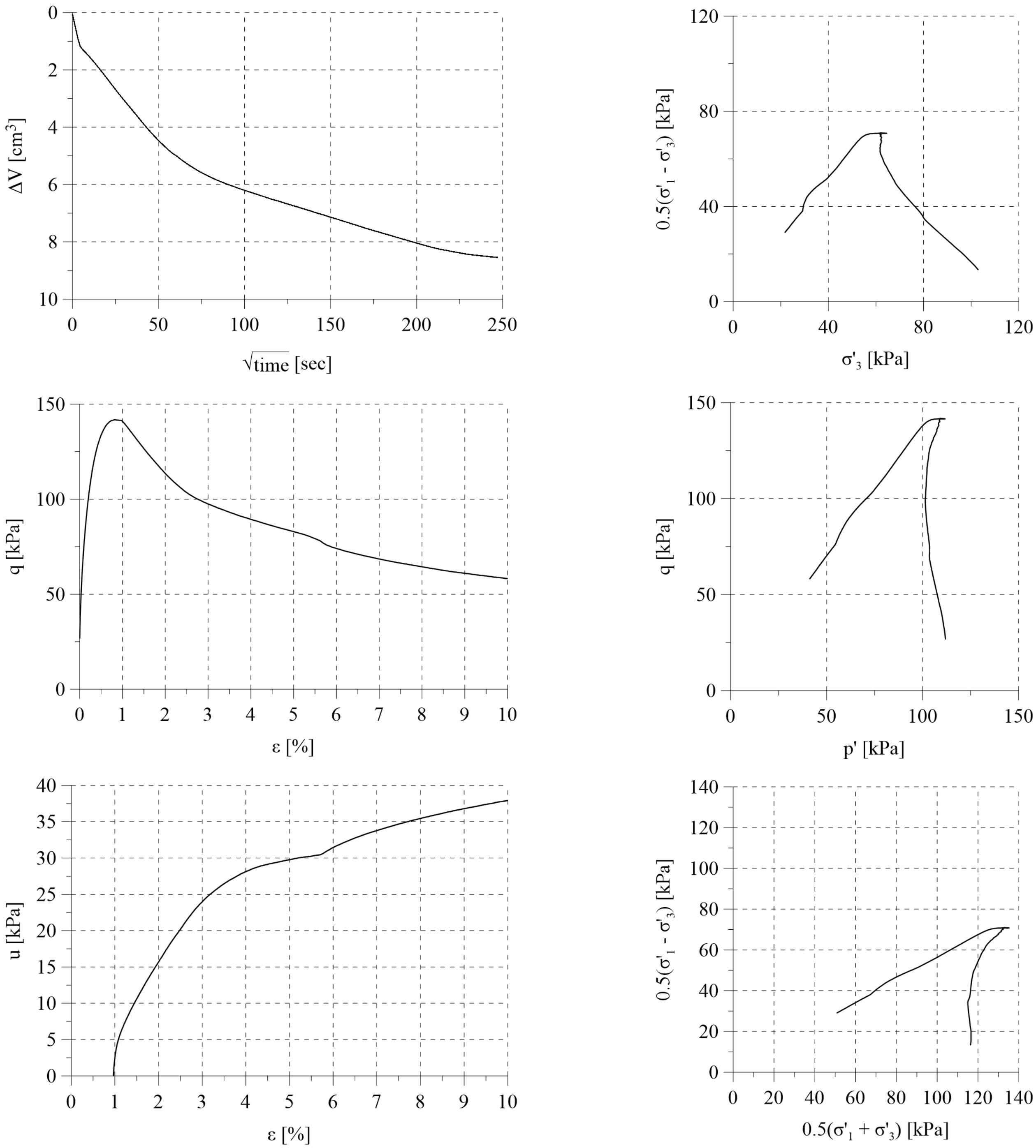


Figure C.27: CAUc results from triaxial test no. 2 at depth 7.20 m, Sherbrooke block sample.

CAUc-S4.1			**0 weeks after sampling**
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	7.72 m	σ'_{v0}	85.6 kPa
Sampling date	27.11.17	w	43.5 %
Opening date	27.11.17	γ	18.5 kN/m^3
Testing date	27.11.17	ΔV	7.17 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.88 %

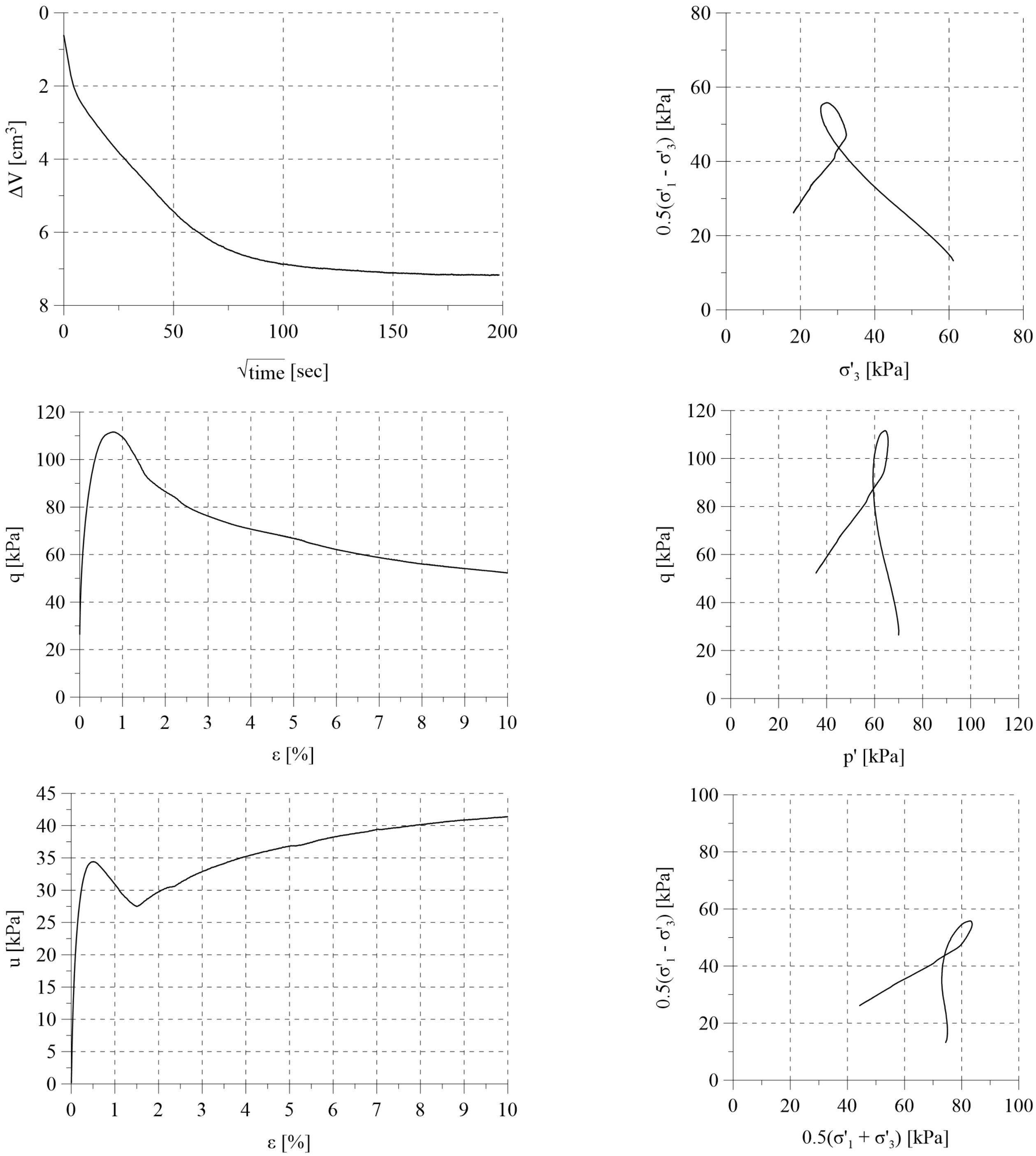


Figure C.28: CAUc results from triaxial test no. 1 at depth 7.72 m, Sherbrooke block sample.

CAUc-S4.2 **Sherbrooke Block Sample** **Flotten, Trondheim**		**0 weeks after sampling**	
Depth	7.72 m	σ'_{v0}	86.1 kPa
Sampling date	27.11.17	w	43.5 %
Opening date	27.11.17	γ	18.6 kN/m^3
Testing date	27.11.17	ΔV	6.32 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.46 %

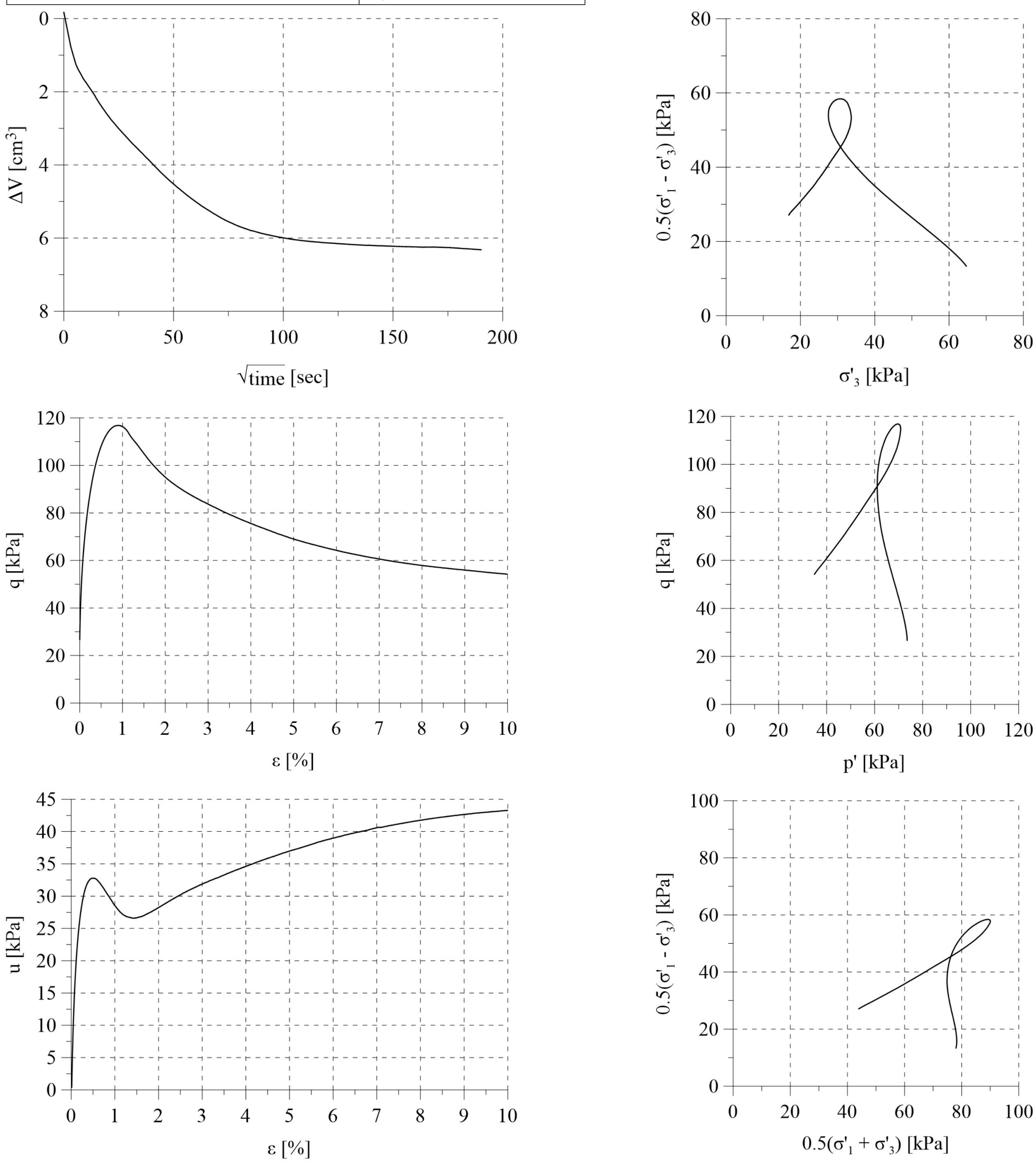


Figure C.29: CAUc results from triaxial test no. 2 at depth 7.72 m, Sherbrooke block sample.

CAUc-S5.1 **Sherbrooke Block Sample** **Flotten, Trondheim**		**2 weeks after sampling**	
Depth	6.65 m	σ'_{v0}	73.2 kPa
Sampling date	23.11.17	w	49.5 %
Opening date	26.11.17	γ	18.0 kN/m^3
Testing date	09.12.17	ΔV	7.16 cm^3
Vertical strain rate	1.5 % /hr	ε_v	3.05 %

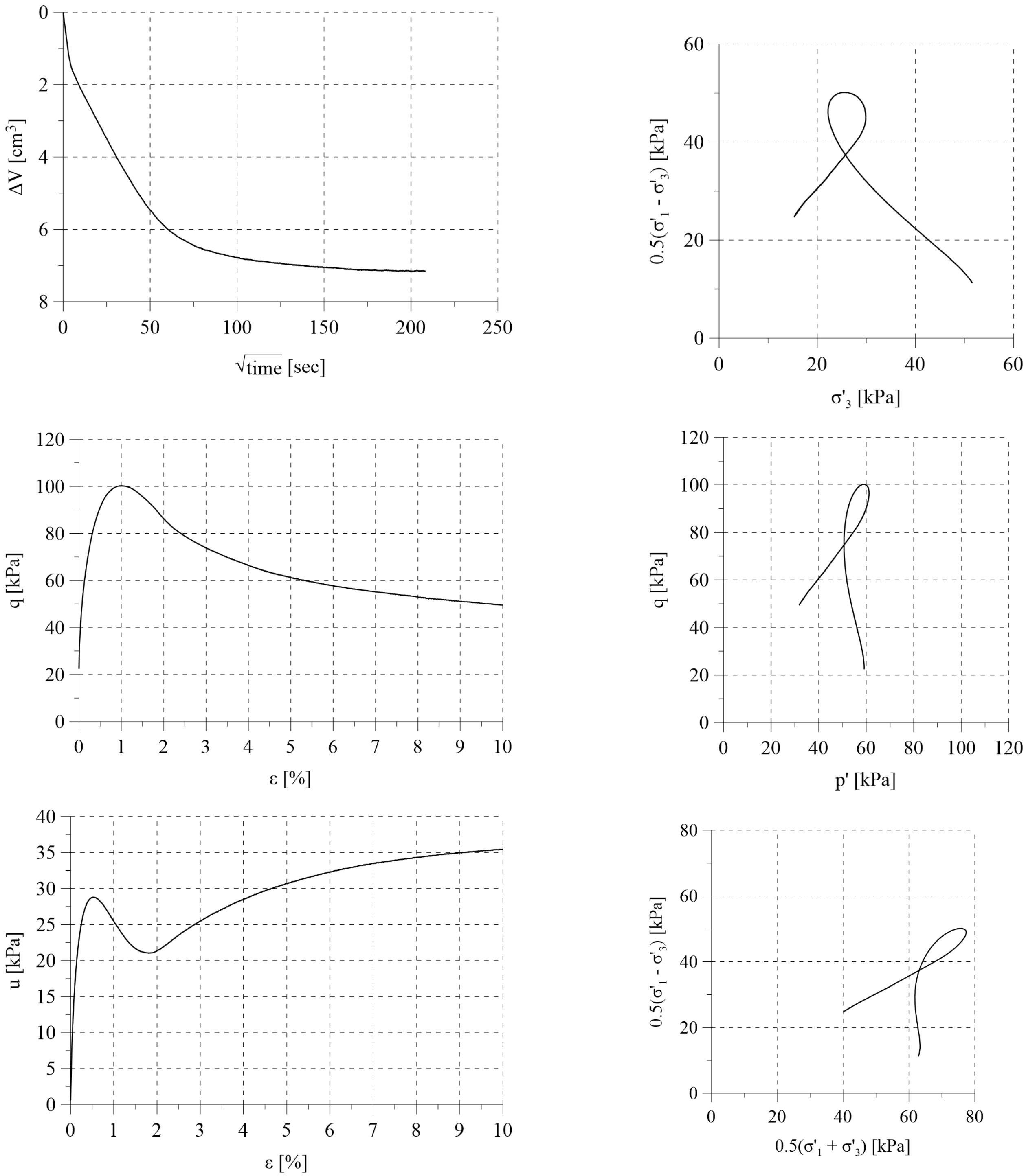


Figure C.30: CAUc results from triaxial test no. 1 at depth 6.65 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S5.2 **Sherbrooke Block Sample** **Flotten, Trondheim**			**2 weeks after sampling**
Depth	6.65 m	σ'_{v0}	73.3 kPa
Sampling date	23.11.17	w	49.5 %
Opening date	26.11.17	γ	18.0 kN/m^3
Testing date	09.12.17	ΔV	6.60 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.30 %

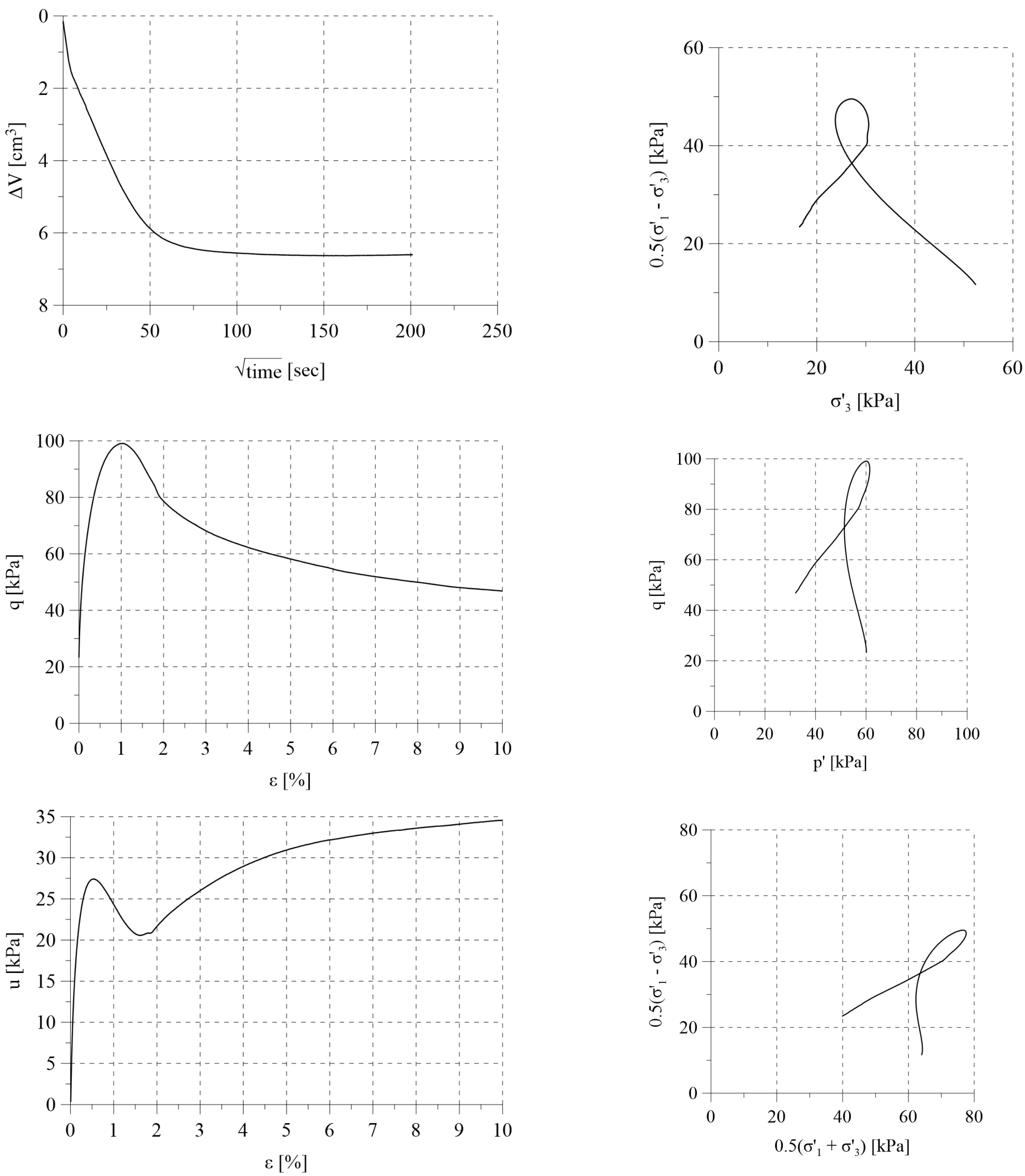


Figure C.31: CAUc results from triaxial test no. 2 at depth 6.65 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S6.1 **Sherbrooke Block Sample** **Flotten, Trondheim**		**2 weeks after sampling**	
Depth	7.05 m	σ'_{v0}	78.1 kPa
Sampling date	23.11.17	w	38.8 %
Opening date	23.11.17	γ	18.2 kN/m^3
Testing date	07.12.17	ΔV	6.01 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.45 %

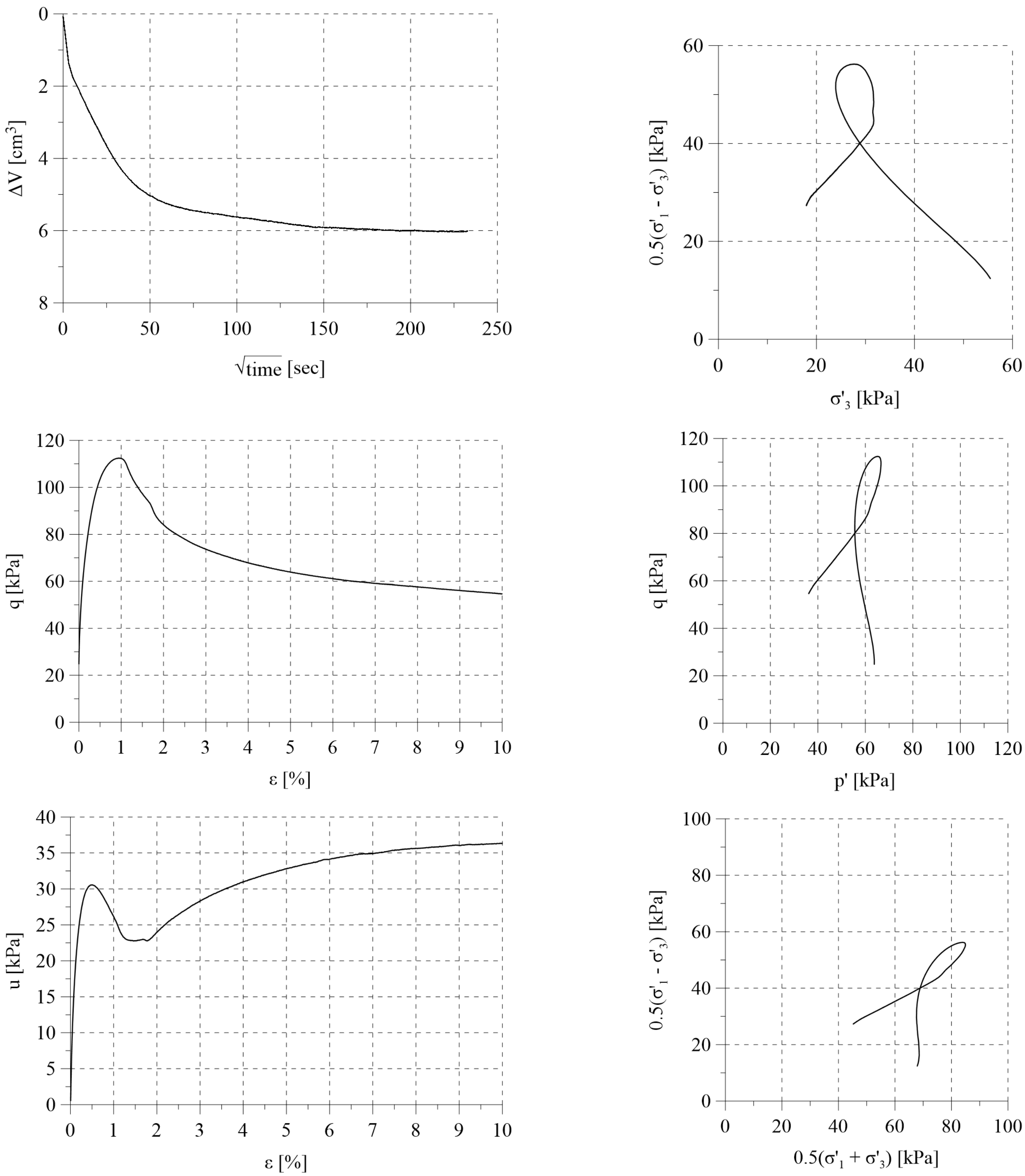


Figure C.32: CAUc results from triaxial test no. 1 at depth 7.05 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S6.2 **Sherbrooke Block Sample** **Flotten, Trondheim**		**2 weeks after sampling**	
Depth	7.05 m	σ'_{v0}	79.1 kPa
Sampling date	23.11.17	w	38.8 %
Opening date	23.11.17	γ	18.4 kN/m^3
Testing date	07.12.17	ΔV	5.85 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.14 %

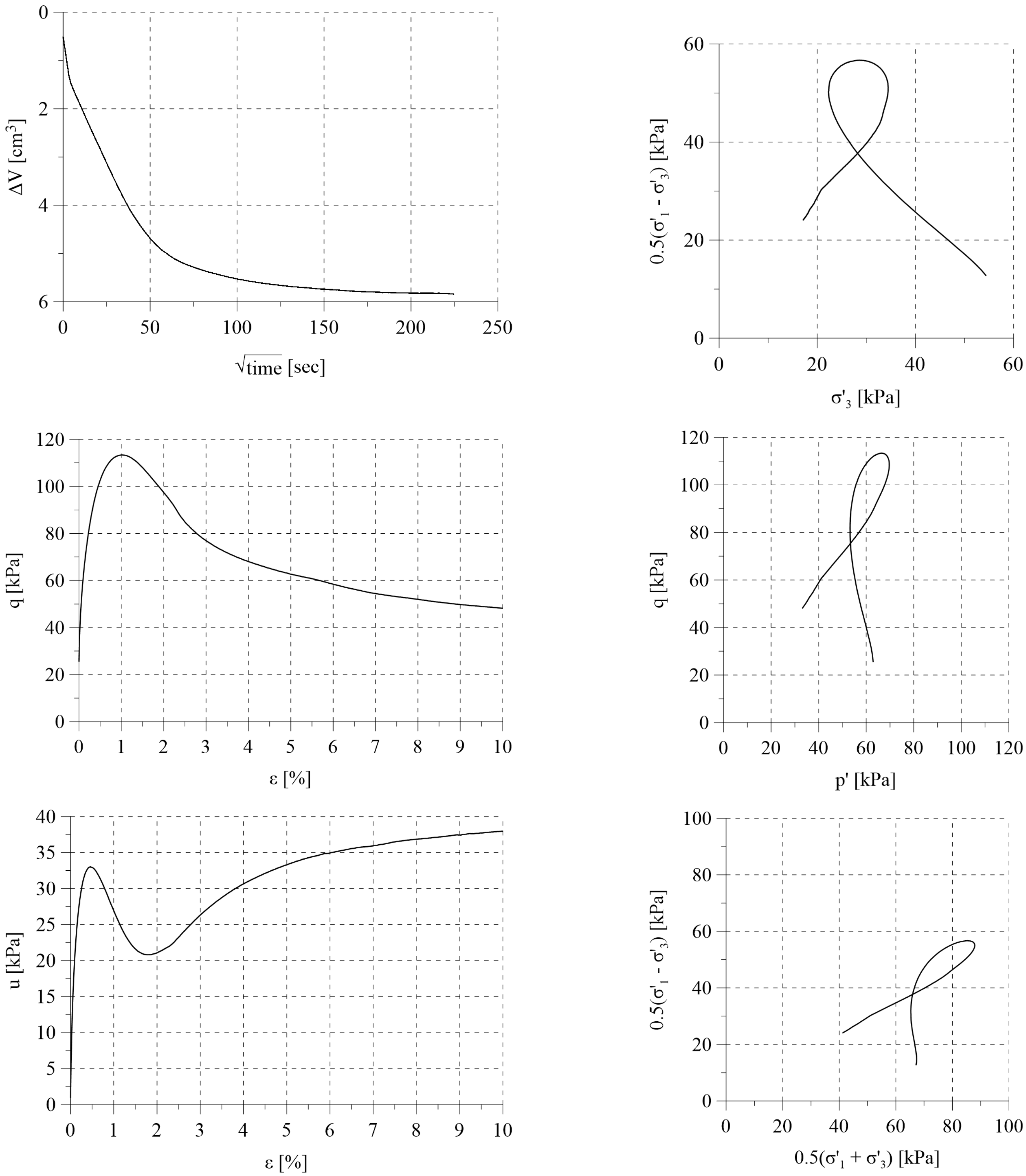


Figure C.33: CAUc results from triaxial test no. 2 at depth 7.05 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S7.1			**2 weeks after sampling**
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	7.20 m	σ'_{v0}	82.3 kPa
Sampling date	23.11.17	w	42.1 %
Opening date	23.11.17	γ	18.7 kN/m^3
Testing date	08.12.17	ΔV	7.05 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.81 %

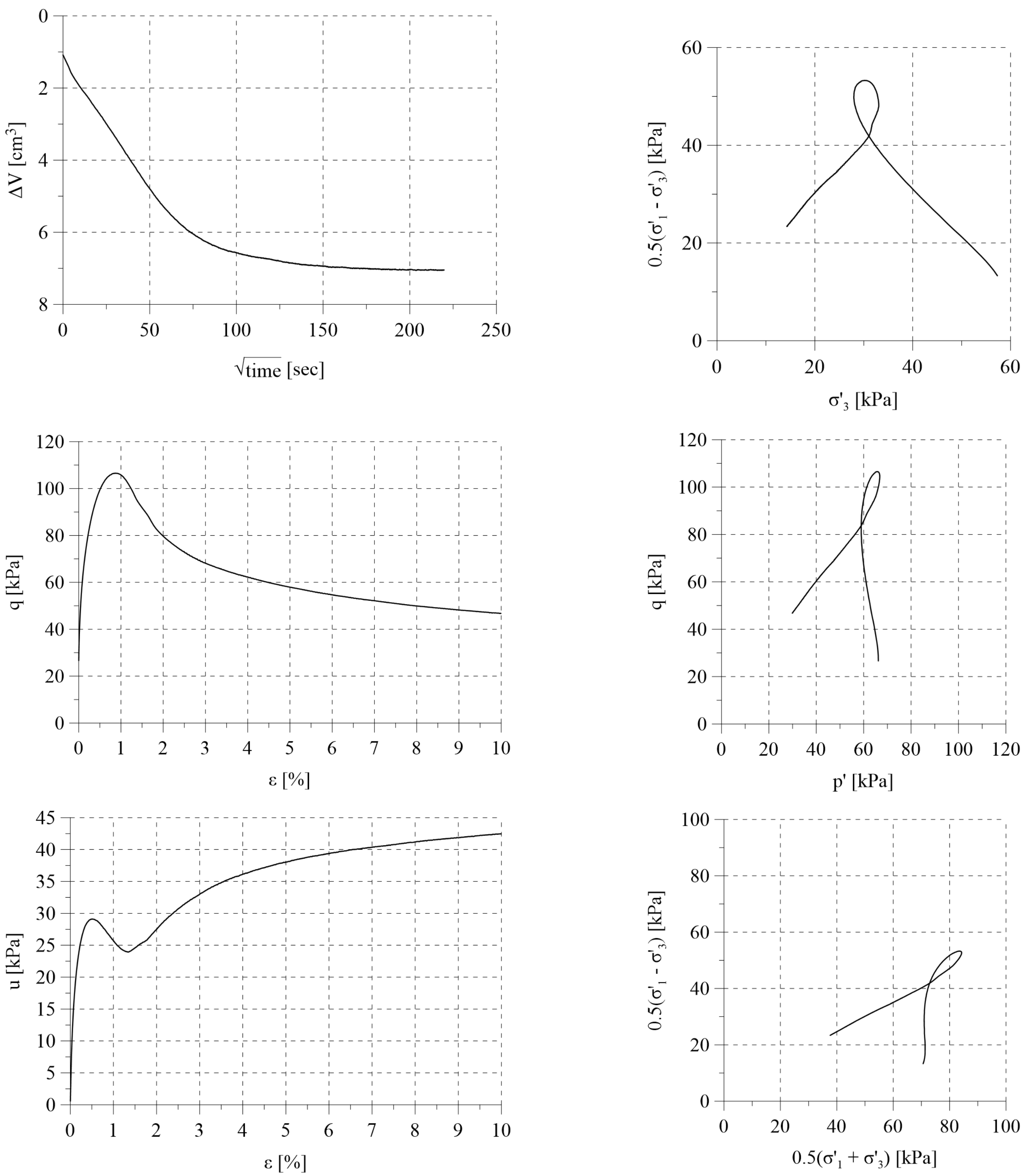


Figure C.34: CAUc results from triaxial test no. 1 at depth 7.20 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S7.2 **Sherbrooke Block Sample** **Flotten, Trondheim**		**2 weeks after sampling**	
Depth	7.20 m	σ'_{v0}	83.3 kPa
Sampling date	23.11.17	w	42.1 %
Opening date	23.11.17	γ	18.8 kN/m^3
Testing date	08.12.17	ΔV	6.04 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.02 %

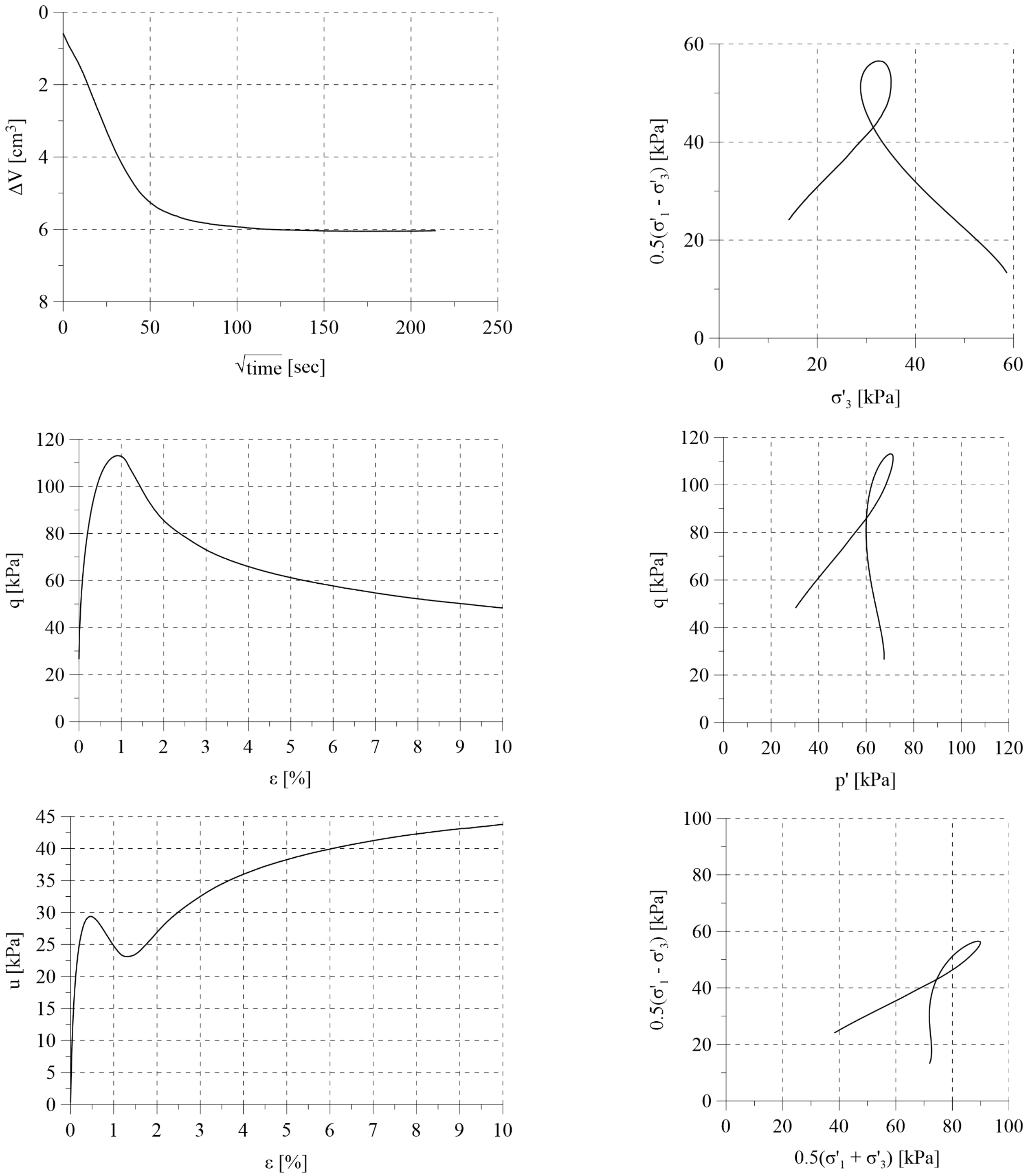


Figure C.35: CAUc results from triaxial test no. 2 at depth 7.20 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S8.1 Sherbrooke Block Sample Flotten, Trondheim			**2 weeks after sampling**
Depth	7.72 m	σ'_{v0}	86.4 kPa
Sampling date	27.11.17	w	43.3 %
Opening date	27.11.17	γ	18.6 kN/m^3
Testing date	10.12.17	ΔV	13.46 cm^3
Vertical strain rate	1.5 % /hr	ε_v	5.68 %

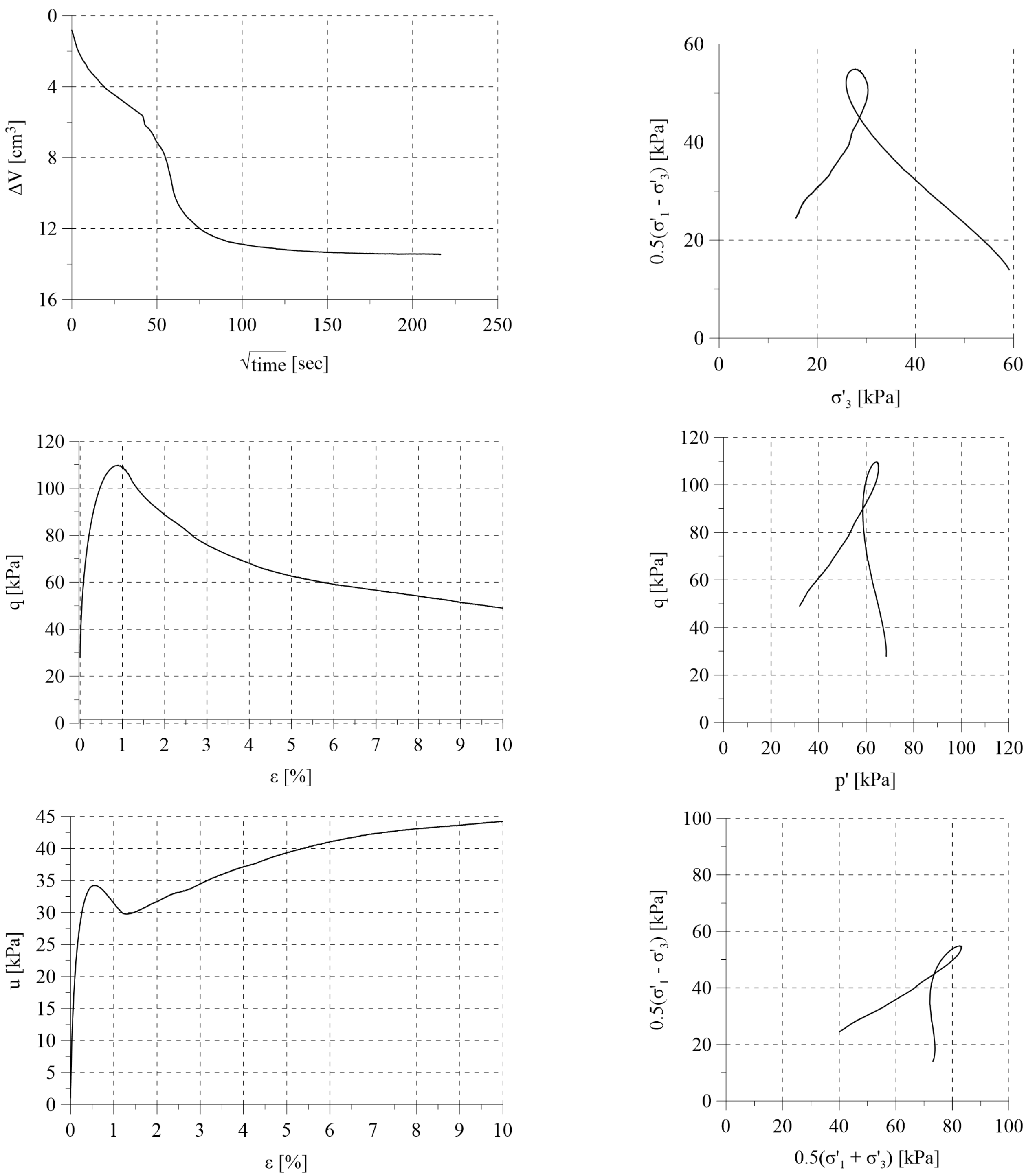


Figure C.36: CAUc results from triaxial test no. 1 at depth 7.72 m after 2 weeks of storage, Sherbrooke block sample.

CAUc-S8.2			**2 weeks after sampling**
Sherbrooke Block Sample			
Flotten, Trondheim			
Depth	7.72 m	σ'_{v0}	86.7 kPa
Sampling date	27.11.17	w	43.3 %
Opening date	27.11.17	γ	18.6 kN/m^3
Testing date	10.12.17	ΔV	6.70 cm^3
Vertical strain rate	1.5 % /hr	ε_v	2.70 %

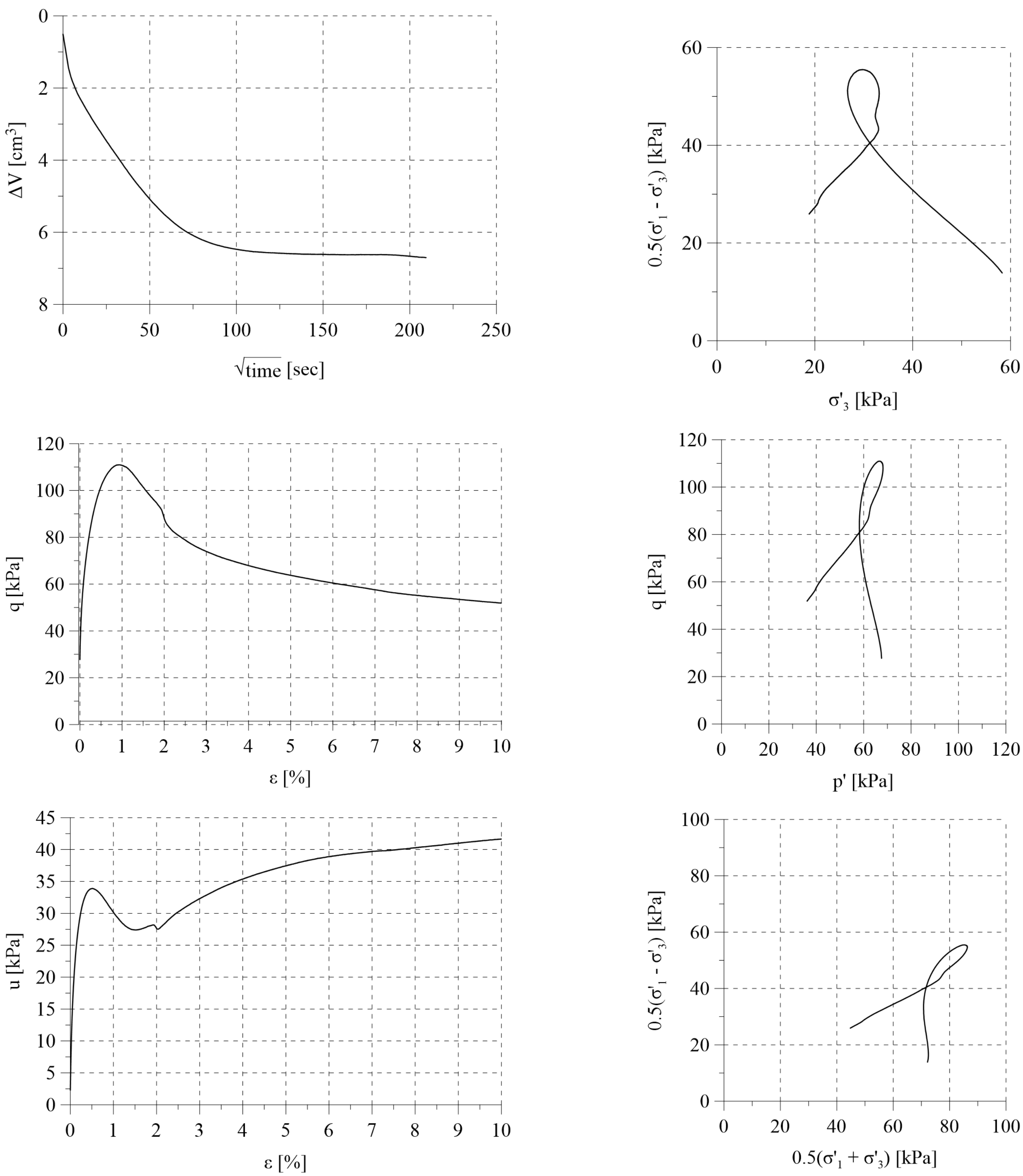
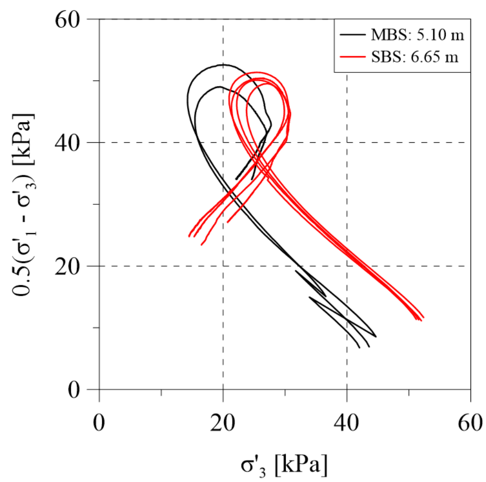
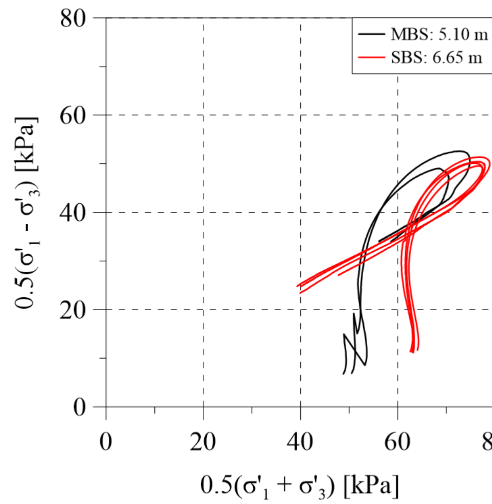


Figure C.37: CAUc results from triaxial test no. 2 at depth 7.72 m after 2 weeks of storage, Sherbrooke block sample.

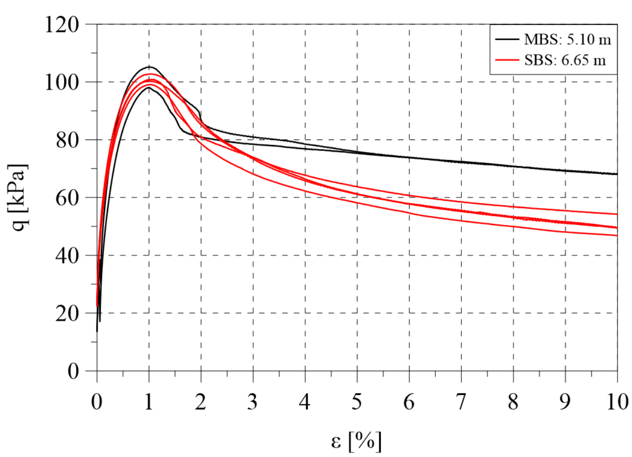
C.3 Triaxial Results from both Mini Block and Sherbrooke Block Samples



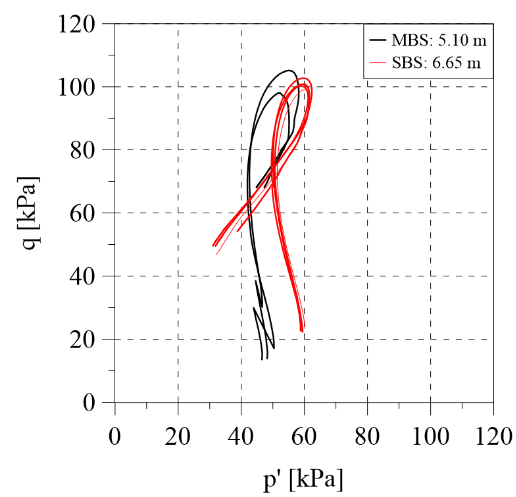
(a) NTNU plot



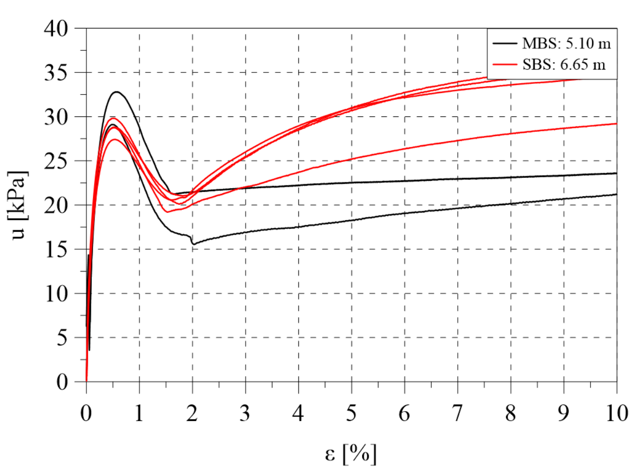
(b) NGI plot



(c) ε - q plot

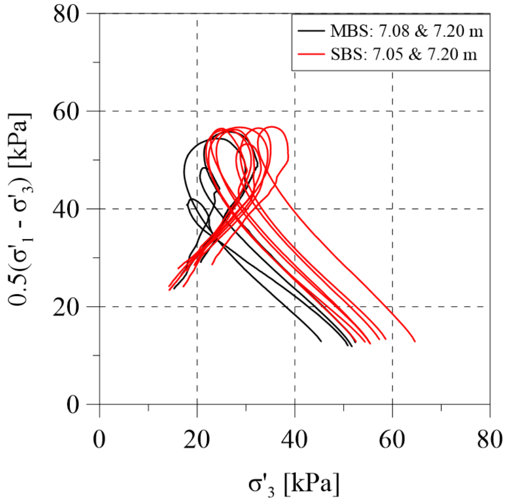


(d) p' - q plot

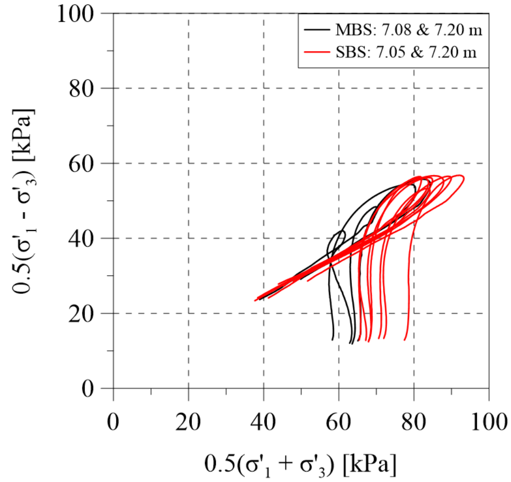


(e) ε - u plot

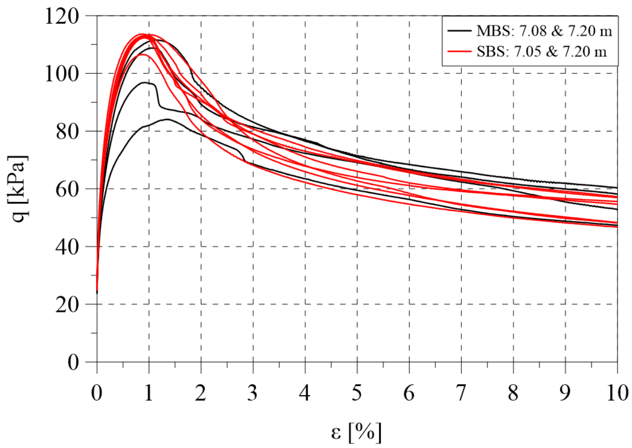
Figure C.38: CAUc results from triaxial tests from depths of 5.10 to 6.65 m



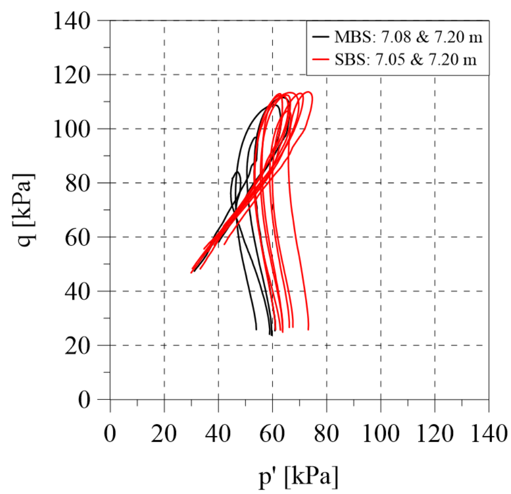
(a) NTNU plot



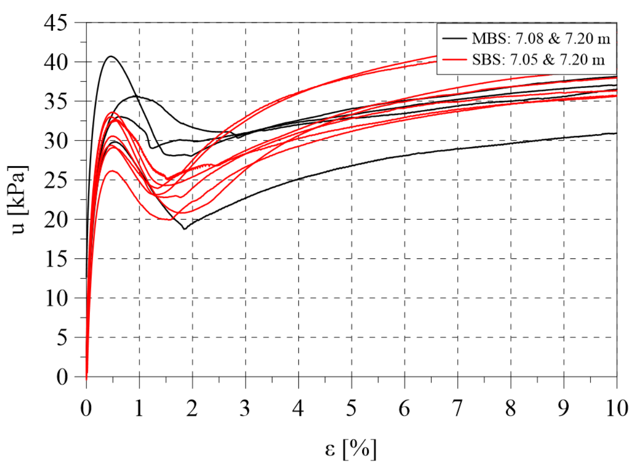
(b) NGI plot



(c) ε - q plot

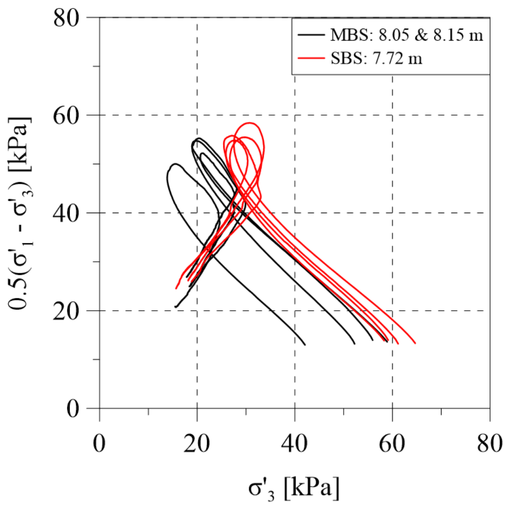


(d) p' - q plot

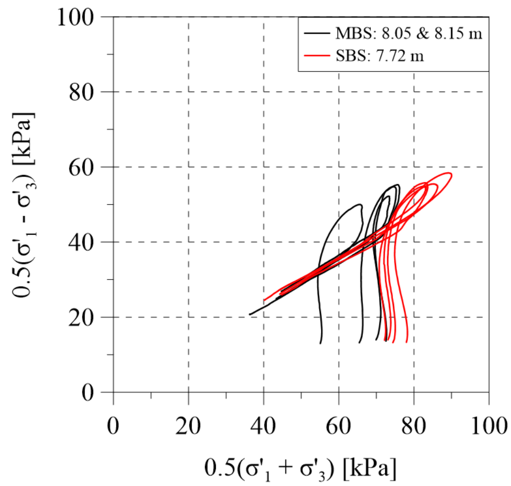


(e) ε - u plot

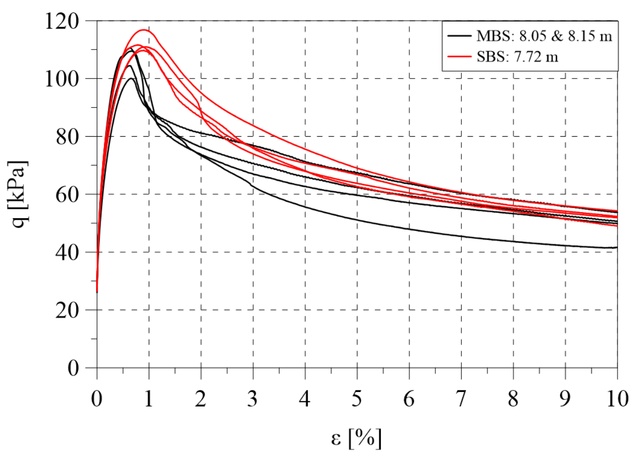
Figure C.39: CAUc results from triaxial tests from depths of 7.05 to 7.20 m



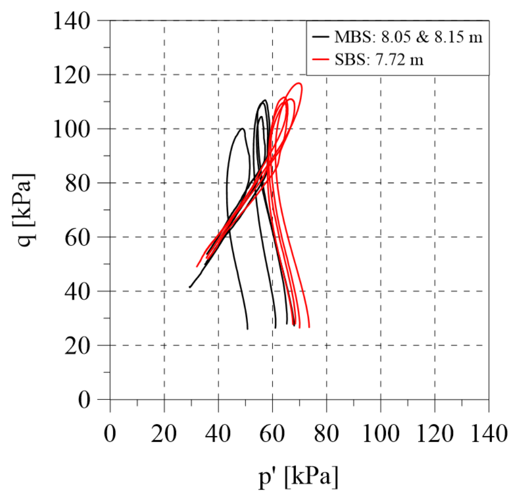
(a) NTNU plot



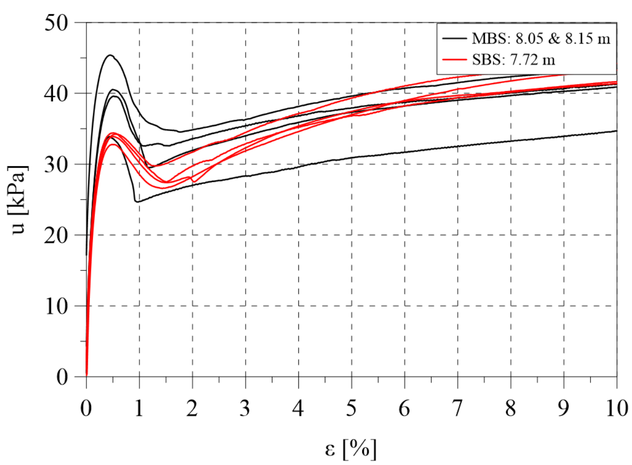
(b) NGI plot



(c) ε - q plot



(d) p' - q plot



(e) ε - u plot

Figure C.40: CAUc results from triaxial tests from depths of 7.72 to 8.15 m