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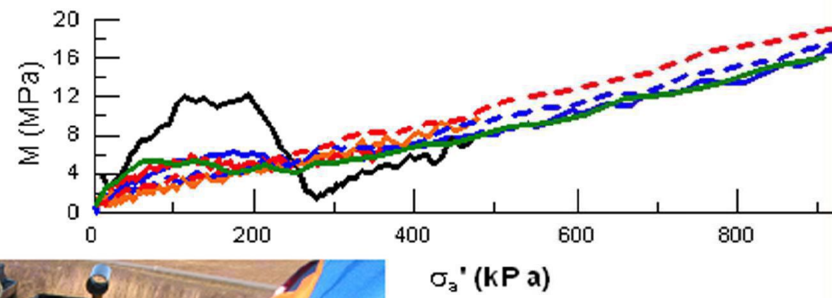
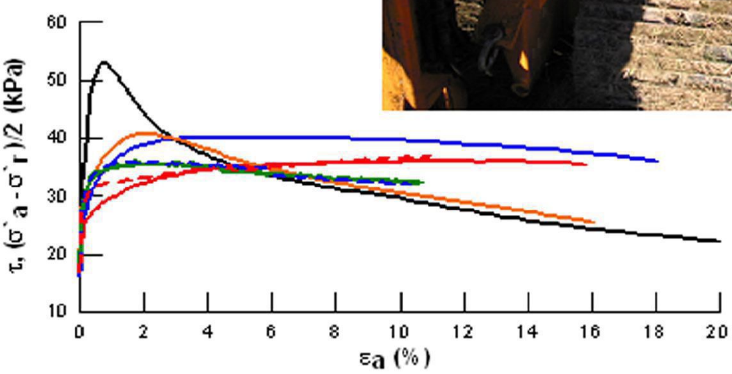
Norwegian Public Roads Administration

R&D-project no. 601369
Quality in site and laboratory investigations

REPORT Technology Department No. 2426





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Statens vegvesen

TECHNOLOGY REPORT 2426

Norwegian Public Roads Administration
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Title

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Quality in site and laboratory investigations

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Summary

Sampling of undisturbed soil samples is an element of major importance in connection with geotechnical design and accumulation of empirical data for preliminary estimations. The NGI 54 mm piston sampler with composite cylinders is the most commonly used sampler today within the geotechnical community in Norway for sampling of undisturbed soil samples. Other types of samplers used in special cases are the NGI 76 mm and 95 mm piston samplers with steel cylinders and in some cases also the 250 mm Sherbrooke block sampler.

For a long period of time there has been a continuous discussion within the geotechnical community regarding the quality of samples retrieved with the NGI 54 mm piston sampler with composite cylinders. In this connection the Soil Mechanics and Tunnel Section within the Technology Department at the Norwegian Directorate of Public Roads has initiated a R&D-project in order to investigate different aspects of soil sampling. In cooperation with the Norwegian Geotechnical Institute (NGI), Multiconsult AS and the Norwegian Public Roads Administration, Region South and Region East parallel sampling and laboratory analyses have been performed on samples from the same location in connection with the road project Rv 2 (national road) Kløfta – Nybakk at Helleren.

This report describes the background for the project, choice of sampling location, applied sampling procedures and handling of the drill rigs and samples as well as handling procedures used in transport to the laboratories and results from laboratory analyses. Observations of the conditions of the drill rigs and sampling equipment as well as applied sampling procedures are documented, compared and reviewed. Laboratory procedures used are also assessed and the laboratory results are compared and related to conditions observed in connection with the retrieval of samples.

The investigation show that reasonable undisturbed samples may be retrieved with the 54 mm NGI piston sampler with composite cylinders also compared with the 250 mm Sherbrooke block sampler provided that prescribed sampling procedures are followed. The results obtained with the 76 mm NGI piston sampler with steel cylinders in this investigation were surprisingly poor. It is clear from this work that small details in the sampling and sample handling process are very important. It is otherwise unfortunate that available time for sampling are reduced due to competitive tendering as the danger of sample disturbance increases with too fast performance of the sampling procedures.

Sammendrag

Key words:

Block sampler, 76mm NGI piston sampler, 54mm NGI piston sampler, oedometer tests, triaxial tests, sample disturbance, sample quality, sensitive clay

Contents

Annex

No 1	Table 1	Water content w (%)
	Table 2	Unit weight γ (kN/m^3)
No 2	Unit weight and moisture content data from small element index tests or whole tube	
No 3	Unit weight and moisture content data from CRS oedometer	
No 4	Unit weight and moisture content data from CAUC triaxial test	
No 5	Table 3	Liquid limit, plasticity index and liquidity index
	Table 4	Clay content
No 6	Liquid limit and plasticity index	
No 7	Liquidity index and plasticity index	
No 8	Clay content	
No 9	Table 5	s_{ut} (kPa), s_u/s'_{vo} and ε (%) from compression test
	Table 6	s_{uk} (kPa) and s_{uk}' from fall cone test
No 10	Unconfined compression test results	
No 11	Fall cone test and vane results	
No 12-22	CRS oedometer tests results	
No 23	p_c' (kPa) and OCR using Janbu approach	
No 24	p_c' (kPa) and OCR using Casagrande approach	
No 25	Constrained modulus and modulus number	
No 26	Coefficient of consolidation	
No 27	Table 7	s_{uA} and s_{uA}/s_{vo}' form triaxial test and corresponding strain
No 28-42	All triaxial test results	
No 43	Triaxial test results	
No 44	Triaxial test results with normalised s_u	
No 45	Comparison of s_u values from various techniques	
No 46	Table 8	pore pressure parameters D and A_f
	Table 9	sample quality for triaxial tests
No 47	Pore water pressure A_f and dilatancy parameter D	
No 48	Quality of the triaxial samples	
No 49	Table 10	Sample quality for oedometer tests
No 50	Sample quality for oedometer tests	
No 51	Short review of the laboratory procedures involved in the project	

1 Introduction

For sampling of undisturbed clay and silt samples the Norwegian Public Roads Administration (NPRA) today uses almost always the NGI 54 mm piston samplers with composite cylinders.

Knowledge of the composition and geotechnical properties of soils in connection with road projects requires that the collected soil samples are delivered to the laboratory for analysis in an undisturbed state. The Soil Mechanics, Geology and Tunnel Section at the Directorate of Public Roads know how expensive and technically difficult it is to obtain undisturbed soil samples. The section therefore has its focus all the time on quality assurance related to sampling equipment and procedures in order to prevent that samples are disturbed.

Lately situations have emerged where new samples have been required since the quality of the first set of samples delivered to the laboratory has been very poor. In this connection a general doubt has emerged regarding the quality of samples taken with the 54 mm piston sampler and composite tubes.

The Soil Mechanics, Geology and Tunnel Section at the Technology Department has proposed and carried out R&D-project 601369 with the aim to look more closely at the quality of field and laboratory work performed in connection with geotechnical site investigations.

At the end of 2004 and beginning of 2005 three different operators performing soil site investigations and laboratory analysis were asked to participate in this project. Two were private firms. Multiconsult and the Norwegian Geotechnical Institute (NGI), and one was from NPRA.

The initial object of this project was to compare the quality of undisturbed soil samples taken with 3 different drill rigs (light, medium and heavy) in order to investigate if the rig type would influence laboratory results. The question was asked if a light rig would perform differently from a heavy rig during penetration and cutting of the sample. In this connection it was assumed that the rig operators would perform the sampling in the same way and in accordance with the procedures described in Report no 11 from the Norwegian Geotechnical Society. During observations in the field it became apparent that the sampling procedures followed were different and dependant on the operator.

This report describes field observations made, the laboratory procedures followed at three different laboratories and compares the results obtained.

In this connection we would like to express our gratitude to the drill rig operators Bjørn Thune, Frank Ekse, Olav Jensen and Anders Snarheim for their patience, cooperation and openness in discussions during the field work. We would also like to thank laboratory technicians Morten Andreas Sjursen, Staale Kildal and Jan Inge Senneset for their contributions to the report. We are also indebted to GeoCon for efficient translation work and useful suggestions and discussions.

2 Selection of test site

The test site Helleren selected for the project ”Quality in site investigations and laboratory analysis” is situated some 35 km north of Oslo and approximately 2 km east of Kløfta along national road Rv. 2.

Figure 1 Location of national road Rv. 2 Kløfta - Nybakk

A short distance between the test site and the participating laboratories was considered a great advantage. The selection of test site was made based on material type, homogeneity and thickness of the deposit. In addition the NPRA, Region east had in connection with the planning of a new alignment for national road 2 Kløfta – Nybakk performed several relevant site investigations in the area like CPTU tests and vane borings. In this connection high quality samples were taken with a ”Sherbrooke”-sampler (block samples Ø = 250 mm) at the same site and also samples using the 76 mm NGI piston sampler with steel cylinders. Laboratory analyses performed on these high quality samples could then be used for comparison.

3 General information related to the Quaternary geology in the area

The following is an abstract from report no. 1, project D-158A based on descriptions of the quaternary maps for Ullensaker and Kongsvinger by the Geological Survey of Norway (NGU).

The soil deposits present in Norway today mainly dates back to the last part of the last ice age, i.e. the deposits in the central parts of the eastern region in southern Norway are seldom older than 9 – 10 000 years. When the ice melted some 9 – 10 000 years ago it left behind large amounts of soil deposits. The melt water transported large amounts of soil particles into the fiords where the coarsest particles (stone, gravel and sand) were deposited as deltas along the ice rim or beaches. The lightest particles like clay and silt were transported further out into the fiords or ocean (bottom sediments). Due to the weight of the enormous glaciers that covered the country during the ice age, the earth crust was pressed down. When the ice melted isostatic uplift occurred and large areas with fine grained marine deposits (silt/clay) were lifted above ocean level.
The highest level the ocean reached in an area after the glaciers melted is called the marine level or ML. In the area where the test site is located the ML is at a level 190 – 200 m above the present sea level, i.e. all areas below this level have been covered by the ocean and may therefore contain clay deposits.

The thickness of the fine grained marine deposits covering more than 70 % of the area national road 2 passes through varies from a few centimetres to more than 60 m.

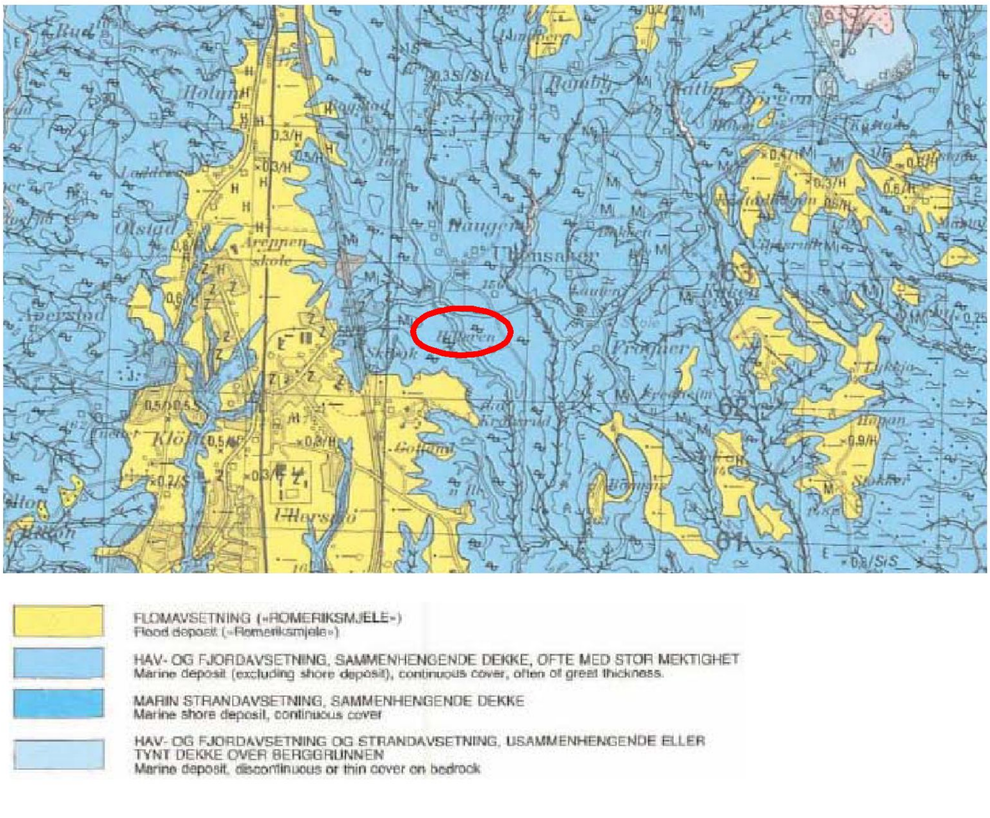

Figure 2 Section from the Quaternary map of Ullensaker

4 Field work

The sampling plan was prepared taking into account the available information from previous site investigations. The plan was to sample 6 borehole series with 6 cylinders in each series. Each borehole was divided into three levels with 2 cylinders for each level. The samples are taken at the same level as the previous block samples and 76 mm samples. The location and identification of the boreholes are as shown on figure 3 between profiles 850-48 m right and 850-52 m right.

Sampling was carried out during the period 15th to 26th of November 2004. Knut Hagberg and El Hadj Nouri, from the Directorate of Public Roads, Technology Department, were present and observed and documented equipment used and procedures and methods employed during the sampling process.

The tasks of the drill operators were to take 6 samples with the NGI 54 mm piston sampler at the same level in 2 boreholes (a total of 12 cylinders). The crews used 2 days each to complete their work.

The levels from which the samples were taken were 5.0-5.8 m; 6.0 – 6.8 m and 10.0 – 10.8 m; 11.0 – 11.8 m and 17.0 – 17.8 m; 18.0 -18.8 m respectively.

The reason for having each crew taking 2 cylinder samples at the same level was to make it possible to have parallel samples analysed both at the drill rig operators own laboratory and at the Central laboratory of the Norwegian Public Roads Administration.

Both samples taken by the crew from the NPRA were analysed at the NPRA Central laboratory. These sample series were taken employing two different methods. The first sample series was taken using the general method of displacing the soil material in front of the sampler when penetrating down to the required level.

The second sample series was taken using an auger to remove soil in the borehole by pre drilling down to the required sampling level. For this purpose a modified 75 mm auger drill was used with a flat sharp edge as shown in the picture on figure 21. In this way no soil was displaced down to the level where the samples were to be taken. At the same time the diameter of the borehole was made somewhat larger than the 54 mm sampler. This was done in order to reduce possible vacuum that may develop below the sampler when it is retrieved.

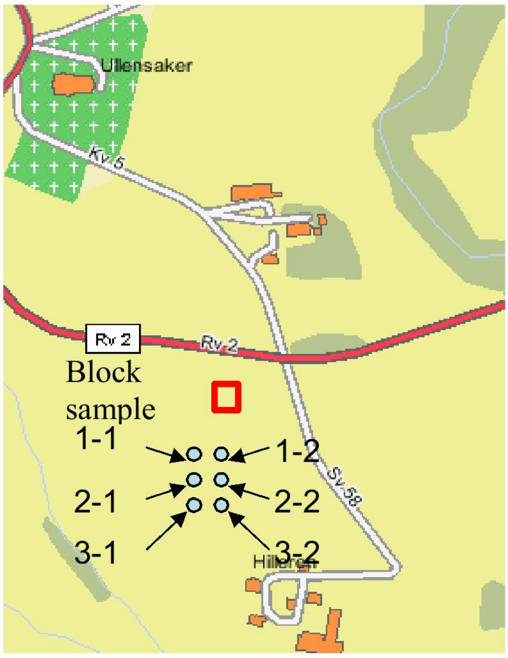

Figure 3 Map showing location of boreholes between profile 850-48 mR. and 52 mR

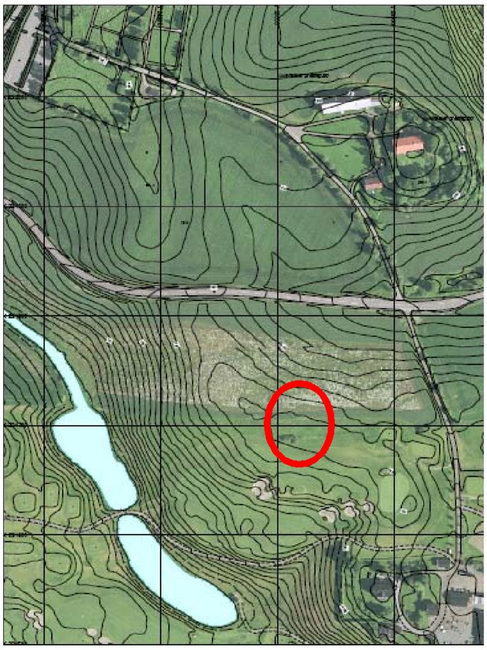

Figure 4 Map with contour lines

5 *Observations made during the field work*

Observations made during the sampling operations may be summarised as follows:

5.1 *Muticonsult AS*

The two first boreholes no. 850-1-1 and no. 850-1-2, were allocated to Multiconsult. Muticonsult used as requested a light drill rig of type Geotech 604 D. with a total weight of approx. 2.5 ton. The drill rig was operated only by one person.

The sample series no. 850-1-1 was delivered to the soil laboratory belonging to Multiconsult. The sample series no. 850-1-2 was delivered to the Central laboratory, NPRA for analysis.

According to visual observation at the drill site the composite cylinders used were of medium quality. The cylinders were clean, but some had damage at the ends. Only slender cutting edges with no damage were used.

The drill rig was equipped with a "”gallows”" for keeping the inner piston rod in a fixed position. The"”gallows”" could only be used after the piston had been released. Upward movements that often occur when the piston is released could not be prevented by this type of"”gallows”", see picture figure 5.

Figure 5 ”gallows” for fixation of piston rod – Multiconsut

Figure 6 The cutting edge was not screwed completely

The cutting edge was not screwed in close contact with edge of the covering tube for the first 4 samples. The gap left was approx. 5 mm; see picture figure 6, i.e. the composite tube inside the covering tube could move freely 5 mm and the sample could expand somewhat in this gap. During the remaining part of the sampling operation the cutting edge was screwed in contact with the covering tube.

When the fourth cylinder was to be taken out of the covering tube a problem occurred. The operator was not able to remove the composite cylinder from the covering tube because remoulded clay had penetrated between the inner part of the covering tube and the composite tube. In order to remove the composite cylinder an empty composite cylinder had to be used in order to push the full composite cylinder out from the covering tube, see picture figure 7.

Due to this incident the sampler was disassembled. It then became apparent that the o-ring on the lower drill head was damaged. This allowed remoulded clay to penetrate in between the covering tube and the composite tube. Apart from this the sampler was found to be well maintained.

In addition a worn lip seal was found in the lower bore head, and the corresponding seal in the upper bore head was missing.

In order to cut the soil sample flush with the cylinder end a screwdriver was used. This caused some change in the cross section of the sample at this end, see picture figure 8.

When the sampler was lifted to a level above the ground surface the operator left the sampler hanging in the drill rig when unscrewing the cutting edge. This apparently caused some tensional strain in the sample, see picture figure 9.

Figure 7 The cylinder was stuck in the covering tube

Figure 8 Use of screwdriver for cutting sample flush with cylinder end

Figure 9 Sampler in rig without cutting edge

Figure 10 Strain in sample more than 2 x diameter

Other observations are summarised in the table A below.

Profile 850	1-1	1-2	1-1	1-2	1-1	1-2	1-1	1-2	1-1	1-2	1-1	1-2
Depth	5.0 – 5.8		6.0 – 6.8		10.0 – 10.8		11.0 – 11.8		17.0 – 17.8		18.0 – 18.8	
Upward movement of ”gallows” (cm)	~ 3	~ 5	> 1	~ 5	< 1	~ 4	0	-	5	2	5	2
Cutting time	Between 40 to 45 sec. was used to cut samples											
Overcoring	Varied between 1 and 2 cm											
Twisting off sample	No samples were twisted off before retraction											
Resting time	Resting time for all samples were 10 min., except for 25 min. at hole 1-2. at 11 m											
Retraction time	5 cm up and 2 min rest before further retraction											
Sample disturbance	10cm*	Ok	**	**	**	Ok	Ok	Ok	Ok	Ok	**	Ok

*: 10 cm of sample lost. Sample fixed in position using a rubber plug.
**: sample was stretched.

Table A Multiconsult - summary of field observations

5.2 NGI

The next 2 boreholes in profile no. 850-2-1 and 850-2-2, were allocated to NGI. NGI used as ordered a medium heavy drill rig of type GM 100 GTT with a total weight of about 4.5 - 5 ton. The drill rig was operated only by one person.

Sample series no. 850-2-1 was delivered to NGI’s laboratory and sample series no. 850-2-2 was delivered to NPRA, Central laboratory for analyses.

According to visual observations at the test site the composite cylinders used were of medium to fair quality. Several of the cylinders were not cleaned properly, see picture figure 11.

Figure 11 Clay residue in cylinder

Figure 12 ”gallows” for fixation of inner rod

The drill rig was equipped with a ”gallows” for fixing the position of the inner piston rod in position. The ”gallows” could only be used after the piston was released. Upward movements that often occur when the piston is released could not be prevented by this type of ”gallows”, see picture figure 12.

Only slender cutting edges were employed. During preparation for taking the next sample the whole sampling assembly with the slender cutting edge sometimes rested on the bottom claps as shown in the picture figure 13. Since the cutting edge unfortunately was not checked before each sampling it is not known if the procedure shown in figure 13 may have caused some damage to the cutting edge.

When releasing the sampling tube from the sampler, the rubber piston may sometimes be drawn out of the cylinder if the bayonet coupling is not fully released. This may cause tensional strain at this end of the sample, see picture figure 14.

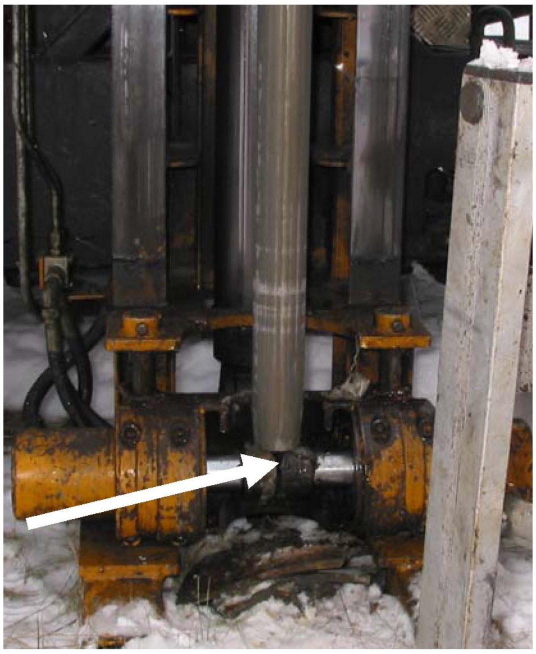

Figure 13 Sampler with slender cutting edge resting on the bottom clamps.

Figure14 Piston drawn out of the cylinder during release from sampler.

Before mounting the rubber sealing cup, one cylinder was put unprotected with one end on the snow covered ground. The snow was not removed before sealing the cylinder.

Some of the sample cylinders were kept in the drill rod storage box with the drill rig engine running while entering data in the borehole log and on labels (potential vibration disturbance), see picture figure 16.

Figure 15 The sample end was put on snow before sealing

Figure 16 Storage of sample cylinders in the drill rod storage box with engine running

NOTE disassembling of the sampler was requested but the drill rig operator refused to comply with this request. It is therefore not possible to comment on the condition and maintenance of the sampler.

Other observations are summarised in the table B below.

Profile 850	2-1	2-2	2-1	2-2	2-1	2-2	2-1	2-2	2-1	2-2	2-1	2-2
Depth	5.0 – 5.8		6.0 – 6.8		10.0 – 10.8		11.0 – 11.8		17.0 – 17.8		18.0 – 18.8	
Upward movement of "gallows" (cm)	~ 2	~ 1	~ 5	~ 2	-	~ 2	~ 5	~ 4	~ 5	~ 2	~ 5	-
Cutting time	Between 15 to 20 sec. was used to cut samples											
Overcoring	Varied between 2 and 8 cm											
Twisting off sample	No samples were twisted off											
Resting time	5	10	10	10	10	10	10	15	15	35	15	***
Retraction time	Slow, continuous retraction											
Sample disturbance	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	**	Ok	Ok	***

** The sample was stretched, picture figure 13

*** Machine problem.

Table B NGI - summary of field observations

5.3 NPRA. Region south

The 2 final boreholes no. 850-3-1 and no. 850-3-2 were allocated NPRA, Region south. As ordered a heavy drill rig of type GONOR GTB 150 with a total weight of about 7.5 ton was used. The drill rig was operated by a crew of two persons.

Both sample series were delivered to the Central laboratory of NRA for analysis.

According to visual evaluation on site the composite cylinders used were of good quality and well cleaned. Rubber sealing cups were in place at both ends protecting the cylinder edges against damage during transportation, picture figure 17.

Figure 17 Cleaned cylinders with sealing cups mounted

Figure 18 ”gallows” for fixation of inner rod

Only slender cutting edges were used and none were damaged.

The drill rig was equipped with a ”gallows” for fixing the position of the inner piston rod in position. The ”gallows” could keep the piston rod in position during release, see picture figure 14. No upward movement that often occur at the moment when the piston is released, was observed, see picture figure 15.

A knife was used for cutting the soil sample flush with the end of the composite cylinder. Even the use of a knife apparently caused changes in the sample cross section some times, but this could also be induced by tensional strain in the sample.

Tensional strain was observed on 3 cylinders even if the sampler was twisted after cutting the sample and before retracting the sample, see picture figure 19 and 20.

Figure 19 Maximum tensional sample strain observed - 2 x diameter

Figure 20 Least tensional sample strain observed

Other observations are summarised in the table C below.

Profile 850	3-1	3-2	3-1	3-2	3-1	3-2	3-1	3-2	3-1	3-2	3-1	3-2
Depth	5.0 – 5.8		6.0 – 6.8		10.0 – 10.8		11.0 – 11.8		17.0 – 17.8		18.0 – 18.8	
Upward movement of ”gallows” (cm)	The design of the ”gallows” prevented upward movements											
Cutting time	Between 40 to 45 sec. was used to cut samples											
Over coring	Hardly any over cutting. less than 1 cm											
Twisting off sample	All samples were twisted off											
Resting time	3	30	20	20	4	20	40	18	10	25	20	10
Retraction time	Slow retraction apart from hole 3-1, depth 5-5.8 and 6-6.8m											
Sample disturbance	**	Ok	**	Ok	Ok	Ok	Ok	**	Ok	Ok	Ok	Ok

** : The sample was stretched, picture figure 16

Table C NPRA - summary of field observations

6 Additional tests in borehole 850-3-2

During sampling of sample series 850-3-2 a new procedure was introduced in order to investigate if this procedure could contribute to less sample disturbance.

The test involved pre drilling with a modified auger, pictures figure 21, and applying two hose clamps to the 54 mm sampler approximately 15 cm above the cutting edge, picture figure 22.

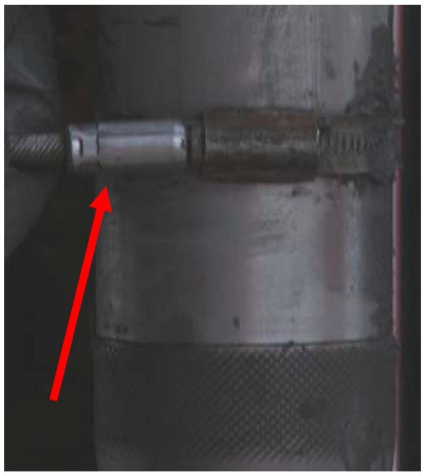

Figure 21 Modified auger with flat and sharp end for predrilling to sampling level

Figure 22 Two hose clamps mounted on sampler approx. 15 cm from cutting edge

The object was to see if:

- there was any advantage in enlarging the borehole diameter (Ø 76 mm)
- remove all soil material above the sampling level in order to prevent displacements
- reduce possible vacuum effects that may occur during retraction.

Before cutting a sample, pre drilling was performed down to the sampling level with the modified auger, see picture figure 3 and 21, which cleaned and levelled the bottom of the sampling hole. The 54 mm sampler could then be lowered down to this level without causing any soil displacement.

The hose clamps that were applied to the outside of the sampler provided furrows in the drill hole during sampling. These furrows were intended to contribute to a more easy passage of water and remoulded soil between the sampler and the borehole wall.

The results from these additional tests will be discussed together with the laboratory results.

7 *Laboratory analyses*

The three laboratories that participated in this project were asked to perform laboratory analyses according to the following plan:

- Visual classification
- Density/unit weight
- Water content
- Undrained shear strength from unconfined compression and fallcone tests
- Consistency limits w_L and w_P
- Grain size distribution
- Oedometer tests CRS
- Triaxial tests CAUC, with K_0' = 0.65, groundwater level 4.0 m below the ground surface and hydrostatic distribution with depth.

In addition has Multiconsult been asked to determine the grain density ρ_s and the Central laboratory NPRA was asked to perform fallcone and unconfined compression tests on samples closest to the cylinder ends where this was possible.

A short review of the laboratory procedures, described by the different laboratories, is listed in annex 51.

A summary of the main differences in laboratory procedures is listed in table D below.

	Multiconsult	**NGI**	**NPRA**
Triaxial tests			
Consolidation time	2 days	2 days	16 – 20 hours
Strain rate	2 % per hour	0.7 % per hour	2 % per hour
Outer filter paper – strips	Yes	Yes	No
Back pressure	~ 300 Kpa	~700 kPa	In situ pore pressure
Oedometer tests			
Strain rate	2 % per hour	0.5 – 0.7 % per hour	2 % per hour
Unloading - reloading	No	Yes	No

Table D Summary of main differences in laboratory procedures

8 Results from the different laboratories

The results from the different laboratories are collected/arranged in tables and plotted on graphs in order to compare the individual 54 mm sample values mutually and against the results from high quality block samples (Ø = 250 mm) and 76 mm samples taken at the same location and levels.

8.1 Index parameters from routine analyses

8.1.1 Unit weight γ and water content w

Unit weights and natural water contents are shown in table 1 and 2 in annex 1. These data are shown together with the values determined for both 76 mm samples and 250 mm block samples taken at the same location. The results are shown graphically in annexs 2. 3. and 4 where water content and unit weights are plotted against depth. The data and corresponding graphs are arranged according to sample and type of analyses used to determine the shown parameters.

The graphs in annexs 2, 3 and 4 show a small data scatter. There is no tendency for an increase in unit weight and reduction in water content with depth which may perhaps be due to some preconsolidation experienced by the soil.

Between 5.0 – 6.8 m the graphs for sample series 850-1-1 show a slight tendency for lower water content. This may possibly explain the lower pore pressure response in the sample during triaxial tests. The unit weight plot show values of the same order as for the block samples.

At depths from 10.0 – 11.8 m there is some scatter of water content values but unit weight values show less variations in conformity with the variations in water content.

For the deepest samples between 17.0 and 19.8 m, apart from sample series 850-1-2 showing a tendency to lower unit weight and higher water content, the remaining results are quite close but with lower unit weight values than the value measured on block sample.

Measured water content is close to the liquid limit, but the clay is not quick before a depth of 17 m.

There are apparently greater variations in the data from sample series 850-1-2 and 850-2-2 than between 850-3-1 and 850-3-2.

8.1.2 Consistency limits

Liquid limits, plasticity and liquidity indices are summarised in table 3, annex 5 and plotted on graphs in annex 6 and 7.

The plasticity index I_P shows a tendency to diminish with depth.

The difference between values is 9 % on the shallowest samples (5.0 - 6.8 m); 2 % at the medium depth (10.0 – 12.1 m) and approx. 10 % on the deepest samples (17.0 – 19.2 m). This difference may be due to differences in operator performance when determining the plastic limit values w_P and how they perceive the condition when the plastic limit is reached. The plasticity index lies between 10 and 20 % and according to Janbu (1970) this corresponds to a medium plastic clay. The water content is close to the liquid limit and with somewhat lean clay (low plasticity index) this may contribute to a greater sensitivity to disturbance. Liquidity index values $I_L > 1$ indicate that the clay has an open structure (Burland 1990).

The clay content is shown in table 4, annex 5 and plotted on graphs, annex 8. The clay content lies in general between 30 to 48 % with less variation in the lower samples. The size of the remaining grains lies within the silt fraction.

8.1.3 Undrained shear strength

s_{ut} values measured by unconfined compression tests and corresponding strains are shown in table 5, annex 9 and plotted in graphs annex 10.

Undisturbed s_{uk} and remoulded s_{uk}' from fallcone tests and calculated sensitivities are summarised in table 6, annex 9 and plotted on graphs annex 11.

Almost all s_{ut} values are lower than 0.3 σ'_{v0} with a corresponding failure strain of more than 5 % indicating that they are disturbed to some extent. When comparing the results from the three different sample series it may be seen that the s_{ut} values from the 850-3 series have a tendency to somewhat less scatter and less failure strain.

Unconfined compression tests performed on samples close to the cylinder ends have shown equal or lower s_{ut} values than values from tests performed on samples further away from the ends. The results from the sample series 850-3-2, with pre boring and hose clamps on sampler, show similar results independent of where within the cylinder the tests have been performed. This indicates that pre boring to some extent may eliminate sample disturbance. The results are shown in table 5, annex 9.

The s_{uk} data also are lower than 0.3 σ'_{v0} and this indicates that the samples are disturbed. The sensitivity, S_t, ratio between undisturbed and remoulded strength, lies between 5 and 33 and in some of the deeper samples between 42 and 58 (135 on block samples). In the deepest samples some variations are observed. According to Janbu (1970) we may see that we have a medium sensitive clay down to a depth of 17 m and below the clay is very sensitive.

	850 1-1	Rank ing	850 1-2	Rank ing	850 2-1	Rank ing	850 2-2	Rank ing	850 3-1	Rank ing	850 3-2	Rank ing
s_u (kPa)	30.3	1	22.8	6	27.5	3	20.9	5	29.3	2	26.2	4
ε (%) < 15 %	7	1	11.5	6	10.33	5	9.2	3	7.38	2	9.78	4
No. of tests width ε ≥ 15 %	0 av 4	2	4 av 8	5	0 av 6	1	7 av 12	6	1 av 9	4	1 av 10	3
Average ranking		1.33		5.67		3.00		4.67		2.67		3.67

Table E Results from unconfined compression tests.

In table E above an evaluation of sample quality has been made with a scale 1 – 6 for s_u-values, strain at failure ε_f and tests where the strain ε_f has been grater than ≥ 15 % (ranking 1 as best and 6 as poorest). The water content in sample series 850-1-1 was very low and the values in table 4 are therefore not representative. Between the remaining results the differences are small, but indicate that sample series 850-3 obtains the best ranking.

8.2 Oedometer test results

8.2.1 General

Results of all CRS oedometer tests are presented on graphs, annex 12 to 22.
The results are given in the form of:

- ε versus σ'_v
- M versus σ'_v
- c_v versus σ'_v
- u_b/σ_a versus σ'_v

where:
σ'_v is the vertical effective stress
ε is the vertical strain
M is the constrained modulus = $\Delta\sigma'_v/\Delta\varepsilon$
u_b/σ_a is the ratio of the pore pressure at the base of the specimen to the applied total stress

Results for all tests at 5.2 m. 6.3 m. 10.3 m. 11.3 m and 18.2 m are given on graphs, annex 15 to 22 respectively. In order to allow examination of results from the individual boring series results from the 850-1. 850-2 and 850-3 series at 5.2 m and 10.3 m depths are given on graphs, annex 12 to 14 and 17 to 19 respectively.

8.2.2 Stress – strain behaviour and stiffness

In general the nature of the stress – strain curves are typical of Norwegian lightly overconsolidated marine clays (Janbu and Senneset 1979, Janbu 1985). On initial loading the behaviour is stiff and then there is a reduction in stiffness, reaching a minimum near the preconsolidation stress (p'_c) before gradually increasing again as the stress increases. This behaviour is most clearly evident in the block samples with very high M values between the in situ overburden stress p'_0 (or σ'_{v0}) and p'_c and a clear kink being evident in the M and c_v versus σ'_v plots.

However inspection of graphs, annex 12 to 14 and 17 to 19 reveals that similar behaviour, albeit less pronounced, can be seen in the 54 mm samples, particularly for the 850-3 series.

The modulus number m (slope of M versus σ'_v plot after p'_c) is clearly defined in all of the tests.

8.2.3 Pore pressure development

The development of pore pressure during the tests is shown by the u_b/σ_a versus σ'_v curves. These data were subsequently used to determine c_v. There is a clear difference in the value of u_b/σ_a for each of the test series and this is directly related to the speed at which the tests were run by the various laboratories. Rates of loading implemented in the tests are summarised on Table F below:

Test Series	Lab	Test speed (% per hr.)
850-1-1	A*	1.5 - 2
850-1-2	C	2
850-2-1	B**	0.4
850-2-2	C***	2
850-3-1	C	2
850-3-2	C	2
Block	B	0.4
76 mm	B	0.4

* Multiconsult ** NGI *** NPRA

Table F Summary of rates of loading in CRS tests

It can be seen clearly from the results that where the loading rate was highest, i.e. Lab A and C tests, the u_b/σ_a values were greater. The loading rate of 2% per hour used by Lab C resulted in u_b/σ_a values of 2% to 10% at stresses above at p'_0. These are considered reasonable. It is felt that the rate used by Lab B was too low. Nevertheless there seems to be no strong influence of this loading rate on the overall tests results although it might be argued that the c_v values determined from the low speed tests might be less reliable.

8.2.4 Preconsolidation pressure p'_c and OCR

Preconsolidation pressure (p'_c) has been determined by 2 techniques namely that of Janbu (1970) and Casagrande (1936) and the results together with the derived overconsolidation ratio (OCR) are presented in annexs 23 and 24 respectively. For the Janbu approach, it has not always been possible to determine p'_c due to lack of a clearly defined minimum M or c_v point. These tests have been denoted by a “zero”plot on the graphs. This seems to have been particularly a problem with the 850-2 series of samples. Some comments on the results are as follows:

- The clearest result from the tests is the significantly higher p'_c and OCR values given by the block sample tests.
- Surprisingly there is no distinctive difference between the results from the 54 mm samples and the 76 mm samples.
- There is no clear pattern between the results from the different 54 mm samples. However these will be analysed in more detail below.
- The Janbu approach yield values on average 20% higher than the Casagrande approach. A similar finding has been reported by others (Long and Lunne, 2000) but often the reported difference is of the order of 10%.
- According to the Janbu approach these p'_c values correspond to an OCR of 2.5 to 3 at about 5.5 m. decreasing to 1.5 to 2 at about 11 m and falling close to 1 at 18 m.

8.2.5 M_0 (i.e. M at σ'_{v0}) and modulus number m

Values of M_0 (i.e. M at σ'_{v0}) and m are plotted on graphs, annex 25.

Again the most striking result is the significantly higher M_0 and higher m yielded by the tests on the block samples.

Several other researchers have reported that sample disturbance due to tube sampling can reduce M_0 values as has been found here.

However the finding that m is also affected by piston sampling is a somewhat unusual result. It seems that sample disturbances have caused a reduction in stiffness in the normally consolidated zone and hence lower m values.

For the 54 mm tube samples M_0 is relatively constant with depth at values from 4 MPa to 6 MPa. Values from the block samples are almost twice as high.

Values for m from 54 mm tube samples fall in the range 15 to 23 and these are typical for clay with water content of about 35 % (Janbu. 1985), see annex 25. The block sample values are in the range 26 to 36 and fall outside Janbu’s typical range, perhaps not surprisingly as the original correlation was based on tube sample results.

There is no clear difference between the results from the various 54 mm samples or the 76 mm samples.

8.2.6 Coefficient of consolidation c_v

A similar pattern emerges for the c_v values. Values at p'_0 and p'_c are summarised in annex 26 and the following conclusion can be made:

The 54 mm and 76 mm results fall in the typical range of 7 m^2/yr. to 16 m^2/yr. suggested by Janbu (1985). At p'_c the block samples generally give the lowest values as can be seen from the detailed c_v versus σ'_v plots. There is no clear pattern evident amongst the 54 mm and 76 mm results but these will be analysed later. Block sample c_v values at p'_0 are almost twice those of the 54 mm or 76 mm samples.

8.2.7 Sample quality assessment

In Norway and elsewhere sample quality in oedometer tests is typically assessed by determining the normalised volume change ($\varepsilon_{v0}=\Delta V/V_0$) during loading back to the in situ stress. p'_0, or alternatively the normalised void ratio change ($\Delta e/e_0$) to the same stress (Andresen and Kolstad, 1979, Lunne et al., 1997). Data for the series of tests under discussion here is presented in annex 27, together with the NGI quality criteria, and the following can be noted:

- There is little difference between the two assessment procedures.
- Sample quality for the block samples is best and falls in the "very good to excellent" or "good to fair" categories.
- Except for the samples around 18 m all of the 54 mm sample tests fall in the "good to fair" and also "very good to excellent" category
- Quality of the 76 mm samples similar to the 54 mm ones.
- There is an overall trend for a decrease in sample quality with depth.

It is maybe worthwhile reviewing the types of material for which NGI intended these quality criteria to be applied. These were (Lunne et al., 1997, NGI, 2002):

Mainly based on tests on marine clays with plasticity index in the range 10-55 %, water content 30-90 %, OCR = 1 - 4 and depth 0 - 25 m below ground level.

It can be seen that the clays from this site fall within the applicable range.

These two assessment criteria are not alone sufficient to examine the differences in quality between the various 54 mm samples. Some further analyses of these data are therefore undertaken as follows

8.2.8 Relative quality of 54 mm specimens

A detailed assessment of the 54 mm samples was undertaken by:

- Choosing the parameters which have been proven to be most susceptible to sampling disturbance (Lunne et al. 1997. NGI. 2002), for oedometer tests these are $\varepsilon_{v0.}$ $\Delta e/e_{0.}$ $M_{0.}$ m. OCR and c_v at p'_0.
- In addition to this consideration was given to whether it was possible to determine p'_c using the Janbu approach.
- The average of each of these parameters for each 850 series was then compared to the results from the block samples.
- For each parameter a rank was assigned to the 850 series, e.g. 850-2-1 has a rank of 1 for ε_{v0} as the average value came closest to that of the block samples.
- An overall rank can then be determined.

The results of this analysis are summarised in table G below.

	850-1-1	Rank	850-1-2	Rank	850-2-1	Rank	850-2-2	Rank	850-3-1	Rank	850-3-2	Rank	Block	76mm
ε_{v0} (%)	4.78	4	4.4	2	3.55	1	5.93	6	4.58	3	5.7	5	2.95	5.23
$\Delta e/e_0$	0.096	3	0.085	2	0.07	1	0.118	5	0.108	4	0.129	6		
M_0 (MPa)	4.7	6	5.15	4	5.44	1	5.08	3	4.9	5	5.16	2	11.6	5.4
m	18.9	4	17.9	6	20.6	2	20.6	2	18.4	5	22.1	1	30.4	21.4
Janbu possible?	3 of 4	4	4 of 4	1	4 of 6	5	2 of 6	6	5 of 5	1	5 of 5	1	3 of 3	1 of 3
OCR (Janbu)	1.99	1	1.99	1	1.95	3	1.6	5	1.83	4	1.59	6	2.09	1.85
OCR (Casa)	1.67	1	1.47	3	1.43	4	1.2	6	1.61	2	1.26	5	1.95	1.26
c_v at σ'_{v0} (m^2/yr)	16.4	1	14.3	3	12.5	5	10.8	6	13.2	4	14.8	2	30.3	11.7
Overall rank		3.00		2.75		2.75		4.88		3.50		3.50		

Table G Detailed assessment of oedometer test results

Test series 850-1-1 and 850-1-2 have comparable rankings. Similarly 850-3-1 and 850-3-2 have the same ranking. The difference in ranking between series 850-2-1 and 850-2-2 is, however, great. It is therefore difficult to draw some clear conclusions when it comes to procedures at the different laboratories, but variations strain rate may be one reason for the differences, see table 4 and 6.

Considering the different drilling techniques it would seem that on average the 850-1 series are the best followed by the 850-3 series and the 850-2 series are the most inferior (when comparing samples tested at the same strain rate).

According to NGI (2002) the potential consequences of sample disturbance are summarised in table H. These are linked to two key design parameters, i.e. the undrained shear strength (s_u) and the constrained modulus (M = change in stress / change in strain in 1D oedometer tests), used for settlement predictions.

Sample quality class	s_u (CAUC) % of perfect sample	M (σ'_{vo} to p'_c range) % of perfect sample
Very good to excellent	> 95	> 90
Good to fair	75 – 95	60 – 90
Poor	< 75	40 – 60
Very poor	< 50	< 40

Table H Consequences of sample disturbance on soil design parameters (NGI. 2002)

In this case the best 54 mm samples have average M_0 of 49 % of that of the block samples. The equivalent values for OCR and m are 95% and 73% respectively.

Comparing the best and worst 54 mm specimens shows that the worst has average M_0, OCR and m of 86 %, 80 % and 81 % of the best respectively.

This indicates that the charts presented earlier, which show little difference between the various 54 mm test results, may be misleading.

8.3 Triaxial test results

8.3.1 General

Results of all CAUC triaxial tests are presented in annexs 28 to 42. The results are given in the form of:

- Shear stress $(\sigma'_a - \sigma'_r) / 2$ versus ε_a
- Pore pressure (u) versus ε_a
- Stress path (MIT or NGI plot) $t' = (\sigma'_a - \sigma'_r) / 2$ versus $s' = (\sigma'_a + \sigma'_r) / 2$

where:
σ'_a is the axial effective stress
σ'_r is the radial effective stress
ε_a is the axial strain

Results for all tests at about 5.3 m. 6.3 m. 10.3 m. 11.3 m. 12.3 m. 17.3 m and 18.3 m are given in annexs 28, 32, 33, 34, 38, 39 and 40 respectively. In order to allow examination of results from the individual 850 boring series results from the 850-1. 850-2 and 850-3 series at 5.3 m. 11.3 m and 18.3 m are given in annexs 29 to 31, 35 to 37 and 41 to 42 respectively.

8.3.2 Stress – strain behaviour

Some comments on the stress – strain behaviour of the various samples can be summarised as follows:

- The block sample specimens show a distinctively different behaviour to that of the 54 mm or 76 mm samples. A clear peak in the $(\sigma'_a - \sigma'_r) / 2$ plot occurs at a low axial strain and post peak there is clear evidence of strain softening.
- For the 54 mm and 76 mm specimens there is a more gradual build up in shear stress and peak $(\sigma'_a - \sigma'_r) / 2$ occurs at a higher strain than for the block samples. Post peak the strain softening behaviour evident in the block samples is not as pronounced.

These findings are as expected and very similar results have been reported by others. Some examples are the classic papers of La Rochelle and Lefebvre (1971) on Canadian Champlain clay, Lacasse et al. (1985) and Lunne et al. (1997) on Norwegian clays, Hight et al. (1992) on Bothkennar clay from the UK and Tanaka et al. (1996) on Japanese clays.

8.3.3 Pore pressure development

As for the stress – strain behaviour there is a clear difference in the development of pore pressure between the block samples and all of the other specimens. After an initial rapid increase, the 54 mm samples show a fairly gradual build up in the pore pressure and beyond axial strain of about 2 %, the increase in pore pressure is very low and in some case there is no further build up. It could be said that these specimens exhibit a “muted” or “suppressed” pore pressure development.

In contrast the block samples show a significant increase in pore pressure throughout the tests.

The behaviour of the 76 mm specimens lie somewhere between that of the 54 mm and the block samples.

8.3.4 Stress paths

According to Lunne et al. (1997) for a “perfect” specimen, pre-peak, in which there is minimum plastic volumetric strain, the initial stress path (plotted in s'. t' space as here) slope will be 1 horizontal to 3 vertical. All of the block sample specimens exhibit this behaviour confirming the samples have retained their structure and are behaving in an “elastic” manner a low strains.

For the 54 mm samples the initial part of the stress path is more curved and leans to the left indicating some disturbance of the material structure. The 76 mm samples show stress paths whose pattern lies between the 54 mm and blocks. This indicates that after initial loading all of the tests show some evidence of contractive behaviour. For the block sample specimens this contractive behaviour continues until critical state conditions are reached and the result is typical of structured lightly consolidated clay.

However for some of the 54 mm specimens, and in particular the 850-2 series, the direction of the stress paths changes and there is a strong tendency for dilatant behaviour. A small number of other researchers have found similar behaviour, i.e. the apparent reversal of the stress path caused by sampling induced disturbance. These are summarised by Long (2005) and were:

- NGI during a study of the very silty Eidsvold clay (Karlsrud, 1995. Lunne et al., 1997).
- NGI (Andersen. 2005) report than similar behaviour can occur with 54 mm diameter (composite) samples of "lean" Drammen clay.
- Seierstad (2000) during a study of another Norwegian marine clay, in this case quick clay from Kvenild near Tiller, just south of Trondheim
- Randolph et al. (1999) proposed a similar hypothesis in order to explain unusual stress paths for soft calcareous sediments.
- Long (2006) for soft laminated clay / silts from central Ireland.

Long (2006) concluded that these effects can occur especially when the clay content is less than about 40 % and the plasticity index is less than 20 %, as is the case for the clays under study here.

The main implication of these findings is that undrained shear strength (s_u) and stiffness can be overestimated from laboratory tests.

8.3.5 Failure envelope

A line representing a Mohr-Coulomb strength of effective friction angle $\phi = 28^o$ and attraction a = 9.5 kPa (effective cohesion c = a tanϕ = 5 kPa) has also been plotted on the various charts. Stress paths for all of the specimens, including those which dilate, ultimately fall on this line. This indicates sampling disturbance has only minimal influence on the effective stress strength parameters.

8.3.6 Undrained shear strength

Undrained shear strength (s_u) values are plotted in annexs 43. Normalised data, i.e. s_u normalised by the in situ vertical effective stress σ'_{v0} are presented in annex 52. For the 54 mm and 76 mm samples s_u increases from about 35 kPa at 6 m to 40 kPa at 11 m and 60 kPa at 18 m. These strengths correspond with normalised values of about $0.4\sigma'_{v0}$, $0.32\sigma'_{v0}$ and $0.3\sigma'_{v0}$ respectively. There is no clear pattern of significantly higher s_u values from the specimens which dilated.

Block sample values are higher in each case, consistent with the shape of the stress – strain and stress paths plots, as discussed above. The 850-3 series 54 mm specimens show s_u values closest to those of the block and the 850-2 series show the lowest values.

Lines representing $s_u/\sigma'_{v0} = 0.3$ and 0.52 have been plotted in annexs 43 and 44. These lines theoretically represent the shear strength of clays with OCR = 1 and 2 (Wood, 1991). The test results generally follow the expected pattern but according to these correlations the material should have OCR somewhat lower than was determined from the oedometer tests, see annexs 23 and 24.

8.3.7 Comparison of undrained shear strength form various tests

A comparison of s_u values determined in different ways is plotted in annex 45. As expected fallcone and unconfined compression tests give similar results. These are the lowest of all measured values and are generally due to lack of confining pressure.

In contrast the CUAC triaxial tests, where in situ pressures are applied, have given the highest s_u values. This is a normal result and is caused by anisotropy in the specimen and different shearing modes and rates.

8.3.8 Strain to failure

Values of the strain to failure, ε_f, are also plotted in annexs 43 and 44. As expected the block samples show the lowest values, being 0.5 % to 0.7%, with the 54 mm and 76 mm samples showing higher values of the order of 1% to 4%. Six of the 54 mm tests show very high values of greater than 8%. These correspond with those tests that dilated on shearing.

8.3.9 Other parameters from triaxial tests

Data for two other parameters, which can be derived from the triaxial test results, namely the dilatancy parameter D and pore pressure coefficient at failure. A_f [$= \Delta u / (\Delta\sigma'_a - \Delta\sigma'_r)$] are shown in annex 46.

As has also been found clearly in this study, Lunne et al. (1997) suggested that the early part of the conventional (σ', τ') stress path plot is dramatically influenced by sample disturbance. They suggested that the pore pressure dilatancy parameter, D, could be used to quantify disturbance. This is defined by the following equation:

$$D = \frac{1}{2}\left[\frac{\Delta\sigma`}{\Delta\tau`} - \frac{1}{3}\right]$$

where:
$\Delta\sigma'$ = change in mean effective stress.
$\Delta\tau'$ = change in shear stress.

They suggested determining D at 2/3 of the peak shear stress less the initial stress and showed that D = 0 (zero dilatancy) corresponds to a line with an inclination of 1 horizontal to 3 vertical. For a perfect specimen (except when close to failure) one would expect a minimum slippage between the soil particles and therefore a D value close to zero.

Values for A_f are lowest for the block samples. Results for the 5 4m and 76 mm samples show significant scatter with those from the 850-2 series being the greatest.

Data for this site are shown in annex 46. Block sample value fall close to the "perfect" specimen value. Some of the other samples show the same tendency as the block samples, but the majority show negative values indicating the onset of contractive behaviour soon after the start of shearing and therefore indicating the samples have been destructured. It would seem that the 850-2 series show the most negative values, with the 850-3 series values being closest to those of the block samples.

8.3.10 Sample quality assessment

As for the oedometer tests sample quality is assessed by determining the parameters $\Delta V/V_0$ or $\Delta e/e_0$ during loading back to the in situ stress (σ'_{v0}. σ'_{h0}). Data for the series of tests under discussion here is presented in annex 47, together with the NGI quality criteria after Kleven et al. (1986) and Lunne et al. (1997). The following can be noted:

- As for the oedometer tests there is little difference between the two assessment procedures.
- Sample quality generally decreases with depth.
- Above 12 m the 54 mm and 76 mm specimens show "good to fair" quality. At 18 m they are generally categorised "poor".
- On balance the quality of the 850-2 series seems worst.
- It is difficult to distinguish between the quality of the 850-1 and 850-3 series using these procedures.
- Quality of the 76 mm samples similar to the 54 mm ones.

8.3.11 Relative quality of 54 mm specimens

As for the oedometer tests a detailed assessment of the 54 mm samples was undertaken by comparing average values of a selected number of parameters and comparing them to the corresponding block sample values. In this case the parameters chosen were again those deemed to be most susceptible to sampling disturbance (Lunne et al. 1997, NGI, 2002). namely:

- $\Delta V/V_0$
- $\Delta e/e_0$
- s_u
- s_u/σ'_{v0}
- ε_f
- A_f
- D
- Whether sample dilates on shearing or not.

The results of this analysis are presented in table I.

	850-1-1	Rank	850-1-2	Rank	850-2-1	Rank	850-2-2	Rank	850-3-1	Rank	850-3-2	Rank	Block	76mm
ε_{v0} (%)	2.15	1	2.49	2	3.88	6	2.75	4	3	5	2.64	3		3.13
$\Delta e/e_0$	0.045	1	0.051	2	0.078	6	0.057	4	0.06	5	0.053	3		0.061
s_u (kPa)	42.4	5	41.3	6	44.6	3	46	1	46	1	44.4	4	59.3	47.7
ε_f (%)	3.55	4	2.13	2	5.2	6	4.63	5	3.3	3	1.7	1	0.63	1.43
$s_u/\sigma`_{v0}$	0.372	1	0.355	2	0.312	5	0.321	6	0.349	3	0.336	4	0.403	0.319
A_f	0.72	2	0.77	4	1.06	6	0.81	5	0.64	1	0.75	3	0.38	0.71
D	-0.29	5	-0.19	3	-0.5	6	-0.22	4	-0.11	2	-0.09	1	-0.09	-0.29
Dilation	1 of 4	3	0 of 4	1	1 of 6	3	3 of 6	6	1 of 5	3	0 of 5	1	0 of 3	0 of 3
Overall rank		2.75		2.75		5.13		4.38		2.88		2.50		

Table I Detailed assessment of triaxial test results

Each pair of test series, e.g. 850-1-1 and 850-1-2 have very similar rank. This indicates that the influence of testing at different laboratories is not important for triaxial tests and that most of the differences may be accounted for in the different drilling techniques.

Considering the different drilling techniques it would seem that, as has been seen during the discussion of the various parameters, the quality of the 850-2 series are worst. There seems to be little to distinguish the 850-1 series and the 850-3.

Average s_u for the best 54 mm specimens is about 78% that measured on the block samples. As was illustrated in table 7 (from NGI, 2002) this is consistent with the 54 mm specimens falling in the "good to fair" or "poor" categories. It is also worth noting that the worst set of 54 mm specimens has s_u on average 70% of that of the block samples confirming that there are significant differences between the various 54 mm data series.

9 Conclusions

The present data set provides an excellent basis for evaluating the effect of observed boring procedures with the NGI 54 mm sampler with composite cylinders.

When samples from the same drilling rig are tested in different laboratories, the results are similar suggesting differences between the various data sets are due to drilling techniques rather than lab testing techniques. Differences in strain rates and consolidation times used in the laboratories may still have given some variations.

Block samples are significantly superior to 54 mm and 76 mm specimens, and show substantially different behaviour and this suggests that enforcement of the current standard sampling techniques for piston samplers are important.

Results from 76 mm samples are disappointing. Since these samples were taken at a time prior to the present investigation, no information is available regarding the sampling procedures followed or the conditions of the steel sample tubes. The reason why NPRA decided to use 54 mm piston samplers with composite tubes some 30 years ago was that the steel cylinders were easily damaged (cutting edge and cylindrical form) and may have already been damage even when sampling for the first time.

Of the 54 mm series 850-2 is clearly the worst.
It is difficult to separate 850-1 and 850-3 series.
It is less difficult to separate 850-3-1 and 850-3-2 series

The results show that it is possible to obtain relatively reasonable samples with the 54 mm sampler with composite cylinders for normal site investigation purposes. This requires that the specified sampling procedures listed in report no. 11 from the Norwegian Geotechnical Society and/or NPRA. Handbook 015 Feltundersøkelser ("Site investigations") are followed. Furthermore the current test indicates that special emphasis should be placed on the following:

- The competence of the drill rig operator is of major importance and he should be provided with information regarding to what use the samples are intended and requirements regarding sample quality in relation to the analyses to be performed in the laboratory.
- It is essential to have a proper arrangement with "gallows" allowing the inner rod to be kept fixed in position when the piston is released.
- The cutting edge should be in an undamaged condition during sampling. This should be checked for each sampling operation.
- Good maintenance and cleaning routines of the sampler must be established and maintained. Faulty parts must be replaced.
- Overcoring must be prevented.
- Only cleaned and undamaged composite cylinders must be used for obtaining undisturbed samples.
- When the sampler is retrieved, the bayonet coupling should be completely loosened in order to prevent tensional strain in the sample.

- The sampler should furthermore be placed in a horizontal position on proper support before unscrewing the cutting edge.
- The composite cylinder with a retrieved sample should at no time be stored in the storage box for drill rods when the drill rig engine is running in order to prevent possible disturbing effects from engine vibrations.
- Cutting the sample flush with the end of the composite cylinder may be performed with a knife, but preferably a wire saw should be used.

Special care should also be taken when transporting, storing and handling samples etc. in the laboratory.

Quality assurance in soil sampling and testing depends on drill rig operators, transporting units and laboratory technicians. Every link in this quality chain must perform as expected, otherwise poor design data will result.

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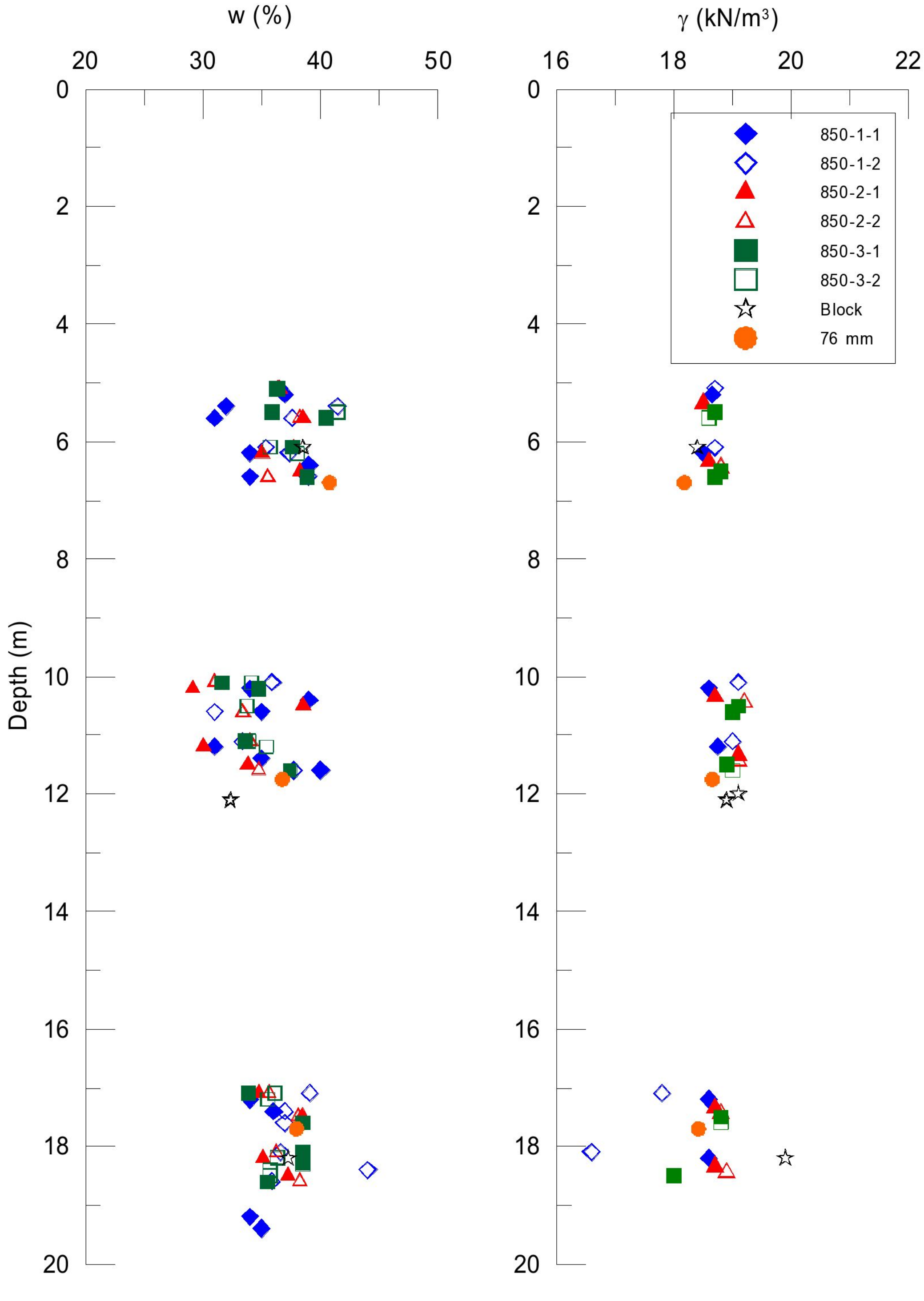
Depth	5.0 – 5.8			6.0 – 6.8			10.0 – 10.8			11.0 – 12.1			17.0 – 17.8			18.0 – 18.8		
Hole	D	Ø	T	D	Ø	T	D	Ø	T	D	Ø	T	D	Ø	T	D	Ø	T
1 – 1	37 32 31	33.4	30.4	34 39 34	34	35.6	34 39 35	33.2	32.8	31 35 40	31.9	34.1	34 36			34 35		
1 – 2	36.5 41.4 37.6	40.7	36.2	35.3 37.3 38.9	40	36.2	35.9 31	43.7	33.9	39.1 36.9 36.9	32.6	38.8	39.1 36.7 36.9			36.6 44 35.8		
2 – 1		38.51	36.5	35 38.2	38.21	36.4	29.1 38.5	41.9 1	39.4	30 33.8	28.96	32.8	34.7 38.4	37.52	33.9	35.1 37.2	35.59	36.3
2 – 2		36.8	36		37.7	38.1		29.2	36.6		39.5	34.2	38.1	36.6	38.5		38.5	35.9
3 – 1	35.8	39.5	38.2		39.8	37.9	34.7	35.1	39.8		32.8	34.3			37.7	18.3		
3 – 2	41.4	38.5	40.4	38	37.6	36.6	33.7	43.1	37.6	35.	343.8	37.6	35.5	39	38.8	36.3		
Block					38.5	38.6					32	32.2					37.2	36.6
76mm					43.6	40.76					34.1	36.74					36.1	37.96

Table 1 Water content w (%) determined on sub sample where unconfined compression test/fallcone test have been performed (D). oedometer tests (Ø) and triaxial tests (T)

Depth	5.0 - 5.8 m			6.0 – 6.8 m			10.0 – 10.8 m			11.0 – 11.8 m			17.0 – 17.8 m			18.0 – 18.8 m		
Hole	H	Ø	T	H	Ø	T	H	Ø	T	H	Ø	T	H	Ø	T	H	Ø	T
1 – 1		18.7	19.15		18.5	18.89		18.6	19.2		18.7	19.15						
1 – 2	18.17	18.7	19.17	18.7	18.7	19.2	19.1	18	19.5	19	19.2	18.9	17.8			16.6		
2 – 1		18.32	18.59		18.36	18.63		18.02	18.19		19.64	19.06		18.54	18.98		18.71	18.49
2 – 2	18.5	19.1	19.4	18.8	18.9	19.06	19.2	19.6	19.2	19.1	18.3	19.5	18.8	19.5	19	18.9	18.5	19.4
3 – 1	18.7		19	18.8		19	19.1		18.8	18.9		19.1	18.8		18.9	18		
3 – 2	18.6		18.7	18.7		19.1	19		19.1	19		19.1	18.8		19	18.8		
Block					18.4	18.2					19.2	18.9					18.7	18.8
76mm						18.37					18.91							18.42

Table 2 Unit weight γ (kN/m^3) determined on the whole cylinder (H), on odometer test samples (Ø) and on triaxial test samples (T)



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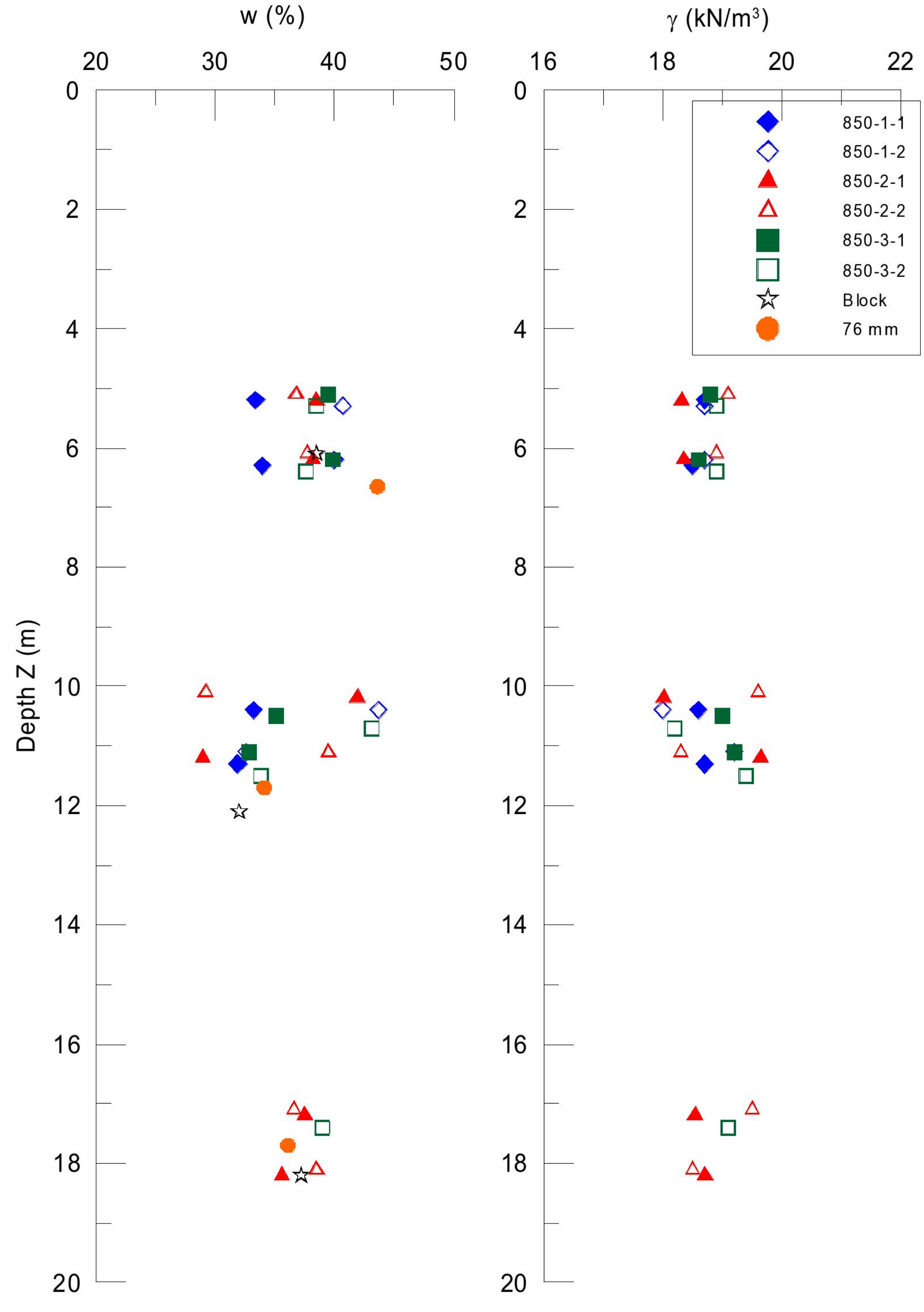
Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Bulk density and moisture content from small element index tests or whole tube

Teknologirapport	2426
Dato	2006-01-04
Figur	2



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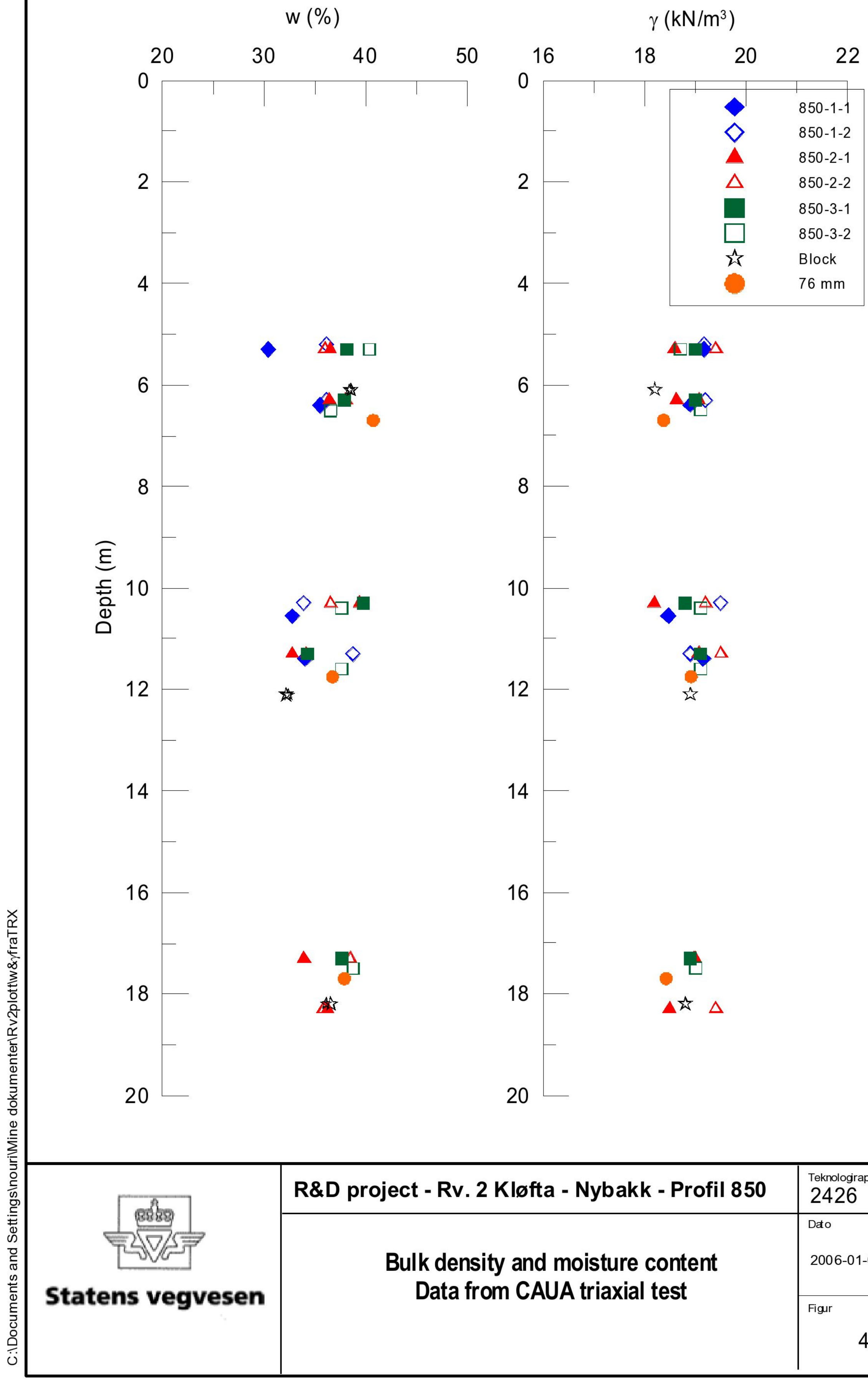
Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Bulk density and moisture content
Data from CRS oedometer

Teknologirapport	2426
Dato	2006-01-04
Figur	3



Statens vegvesen	R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
	Bulk density and moisture content **Data from CAUA triaxial test**	Dato 2006-01-04
		Figur 4

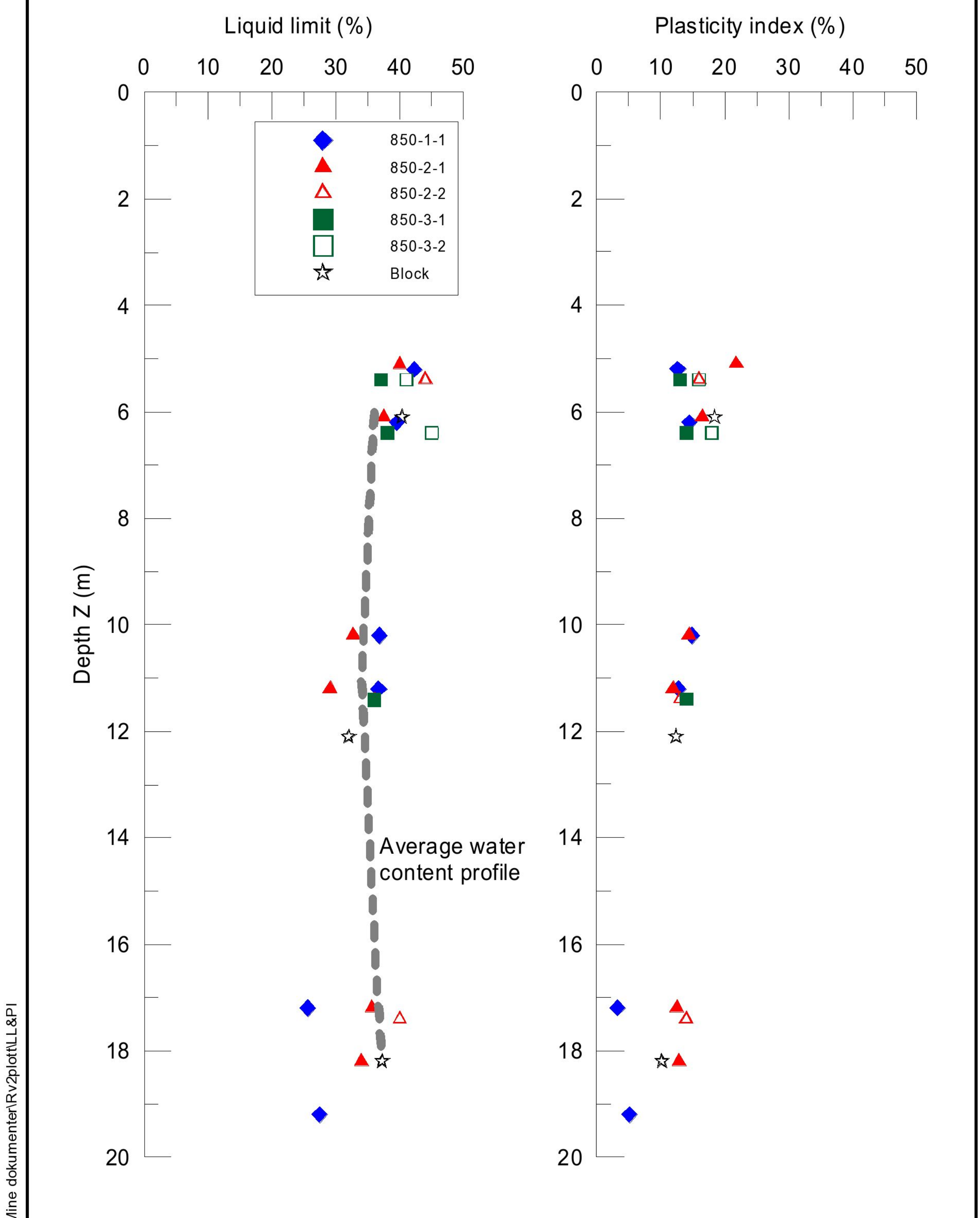
Depth	5.0 - 5.8 m			6.0 – 6.8 m			10.0 – 10.8 m			11.0 – 12.1 m			17.0 – 17.8 m			18.0 – 19.2 m		
Hole	w_L	I_P	I_L	w_L	I_p	I_L	w_L	I_p	I_L	w_L	I_p	I_L	w_L	I_p	I_L	w_L	I_p	I_L
1 – 1	42.2	12.7	0.55	39.6	14.5	0.84	36.8	14.9	0.94	36.7	12.8	0.74	25.6	3.2	2	27.5	5.1	2
2 – 1	40	21.8	0.84	37.5	16.5	0.85	32.8	14.4	0.74	29.1	11.9	1.08	35.7	12.5	0.92	34	12.9	1.09
2 – 2	44	16	0.64	36	13	0.9	40	14	0.86									
3 – 1	37	13	0.91	38	14	1.04	36	14	1.1									
3 – 2	41	16	1.03	45	18	0.61												
Block				40.3	18.4	0.90				32.0	12.4	1.02				27.8	7.9	1.0

Table 3 Results from liquid limit w_L (%). plasticity index I_P (%) and liquidity index I_L (%)

Depth	5.0 - 5.8 m		6.0 – 6.8 m		10.0 – 10.8 m		11.0 – 11.8 m		17.0 – 17.8 m		18.0 – 18.8 m	
Hole	Clay	Silt	Clay	Silt	Clay	Silt	Clay	Silt	Clay	Silt	Clay	Silt
1 – 1 *	46	54	43	57	39	61	37	63	43	57	40	60
1 – 2**	36	64	34	66	30	70	42	58	42	58		
2 – 1*	48	52	40	60	42	58	32	68	43	57	44	66
2 – 2*	38	52			38	52	32	68	45	55		
3 – 1*	41	59	38	42	43	57	30	70	33	67		
3 – 2*	45	55	34	66	39	61	35	65	42	58		
Block**			45.9				33.2				45.7	
76mm**												

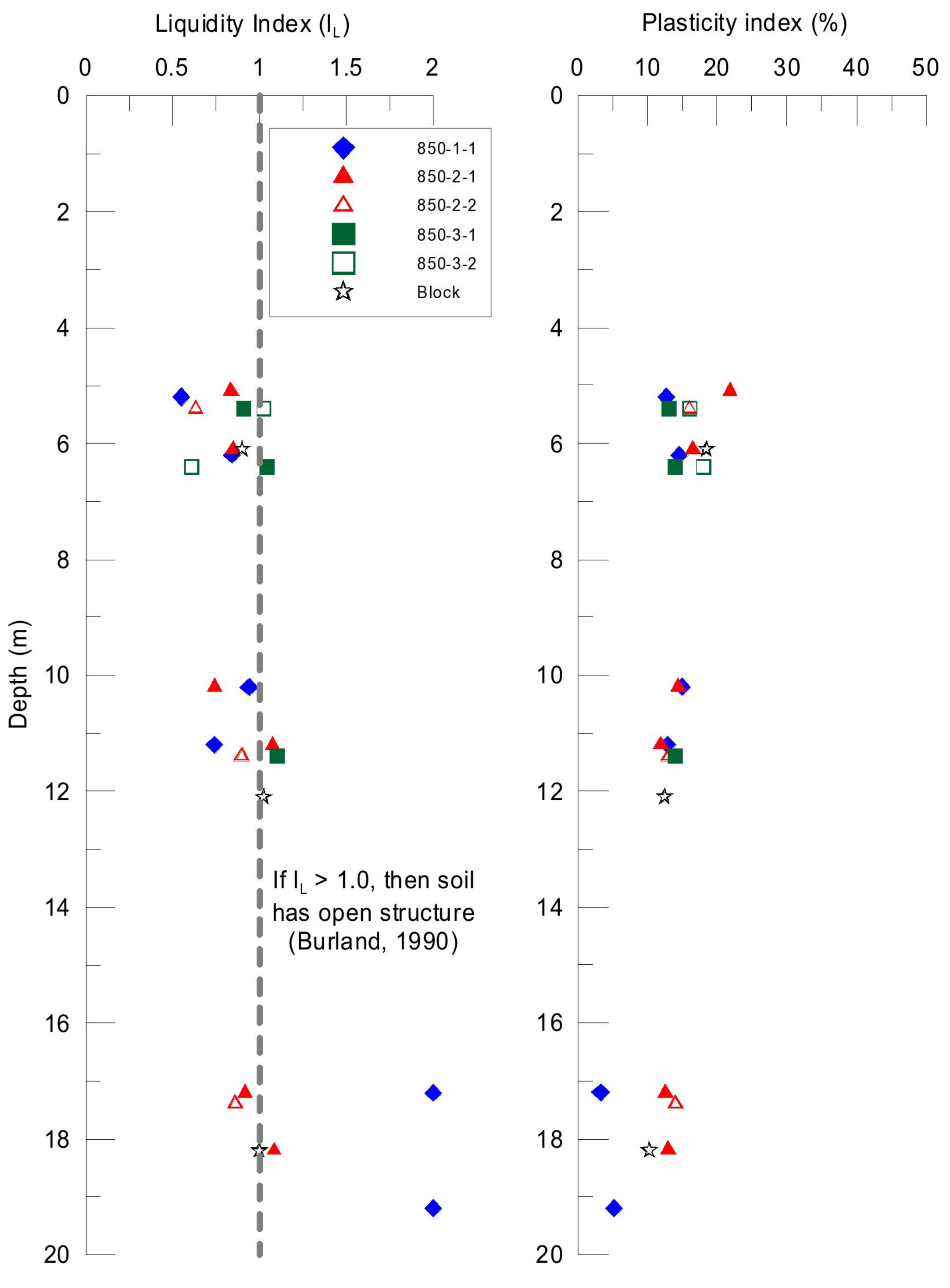
Table 4 Clay content (%).
* : hydrometer analysis.
** : ”falling drop” analysis

Annex 5



Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
	Dato 2006-01-04
Liquid limit and plasticity index	Figur 6



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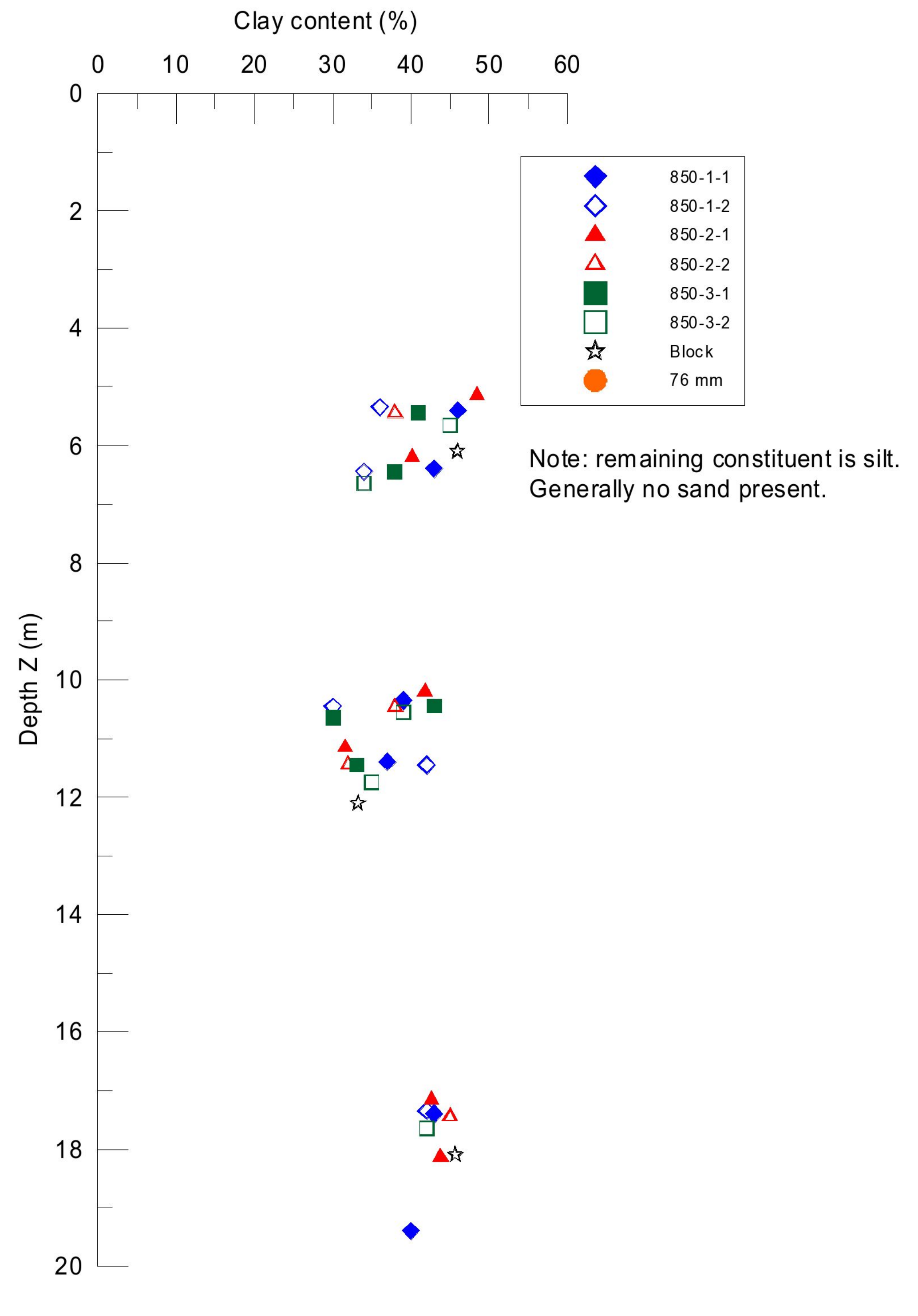
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
	Liquidity index and plasticity index	Dato 2006-01-04
		Figur 7



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R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Clay content

Teknologirapport	2426
Dato	2006-01-04
Figur	8

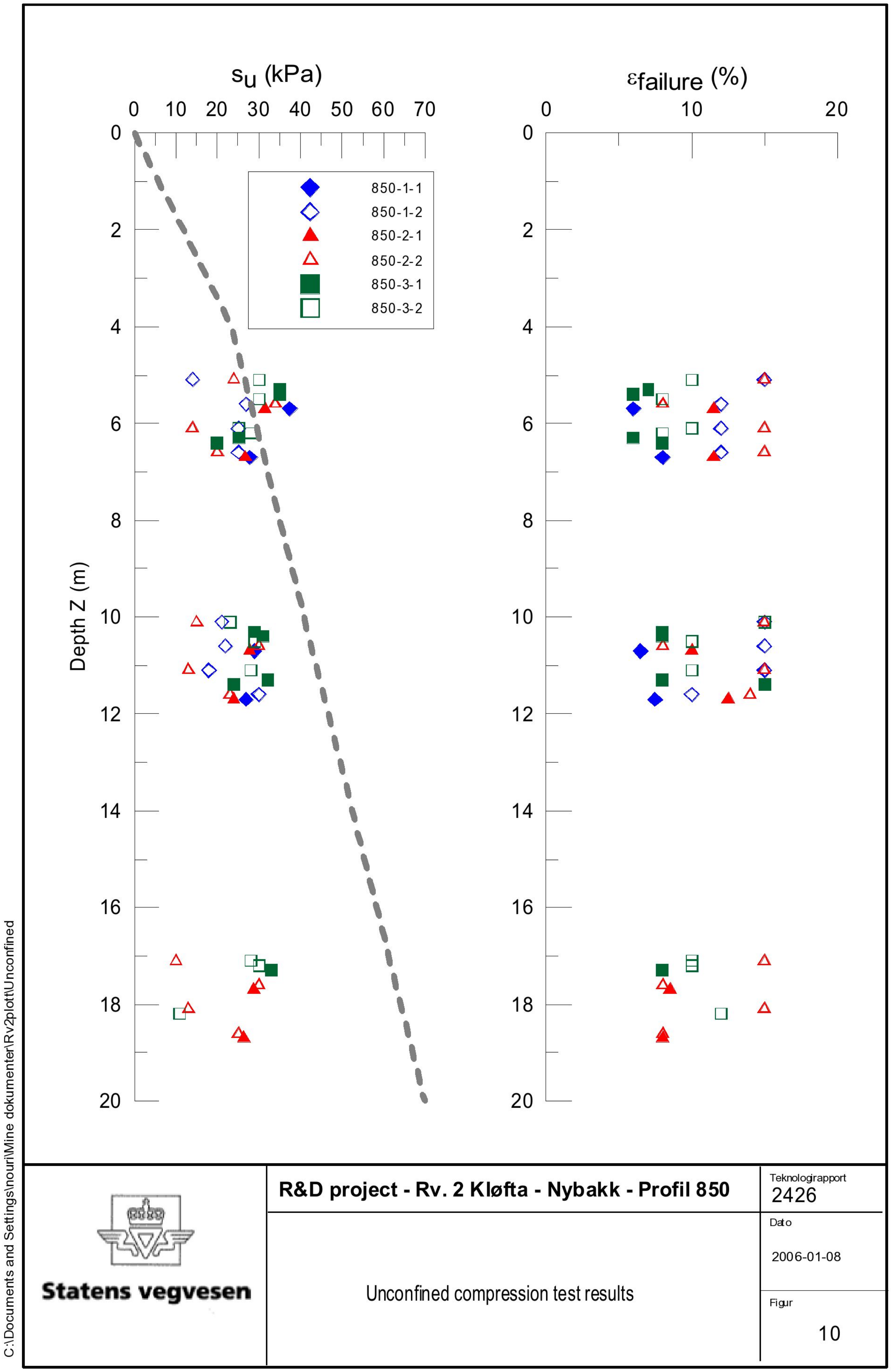
Depth	5.0 - 5.8 m				6.0 – 6.8 m				10.0 – 10.8 m				11.0 – 11.8 m				17.0 – 17.8 m				18.0 – 18.8 m			
Hole	$^{*}s_{ut}$	$^{**}s_{ut}$	$*\varepsilon_t$	$**\varepsilon_t$	$^{*}s_{ut}$	$^{**}s_{ut}$	$*\varepsilon_t$	$**\varepsilon_t$	$^{*}s_{ut}$	$^{**}s_{ut}$	$*\varepsilon_t$	$**\varepsilon_t$	$^{*}s_{ut}$	$^{**}s_{ut}$	$*\varepsilon_t$	$**\varepsilon_t$	$^{*}s_{ut}$	$^{**}s_{ut}$	$*\varepsilon_t$	$**\varepsilon_t$				
1 – 2	14	27	15	12	25	25	12	12	21	22	15	15	18		15									
2 – 2	24	34	15	8	14	23.8	15	3	18	30	15	10	13	23	15	14	10	30	15	8	13	25	15	8
3 – 1	35	35	7	6	25	20	6	8	29	31	8	8	32	24	8 15		33		8					
3 – 2	30	30	10	8	25	28	10	8	23	29	15	10	28	28	10	10		28	30	10	10	11	12	

Table 5 Undrained shear strength s_{ut} (kPa) from unconfined compression tests, the ratio between s_u/σ_{v0}' and the corresponding strain ε_t (%)
* tests performed on samples close to the cylinder ends.
** tests performed on samples further away from cylinder ends.

Depth	5.0 - 5.8 m			6.0 – 6.8 m			10.0 – 10.8 m			11.0 – 12.1 m			17.0 – 17.8 m			18.0 – 19.2 m		
Hole	s_{uk}	s_{uk}'	S_t	s_{uk}	s_{uk}'	S_t	s_{uk}	s_{uk}'	S_t	s_{uk}	s_{uk}'	S_t	s_{uk}	s_{uk}'	S_t	s_{uk}	s_{uk}'	S_t
1 – 1	36.1	7.9		34.2	4.7		30	4.4		28.2	4.1		6.7	0.1		8.6	0.1	
1 - 2	26.3	3.7		23.9	3		28.7	3		35.7	6.7					11.7	0.2	
2 – 1	25	4.8		24	3.8		22	3		24	4.7		25	4.2		20	1.4	
2 – 2	36.5	3.7		19.8	3		28.2	3		34.3	4.2		30.5	3.4		35.7	18.5	
3 – 1	32.4	3.7		25	3					22.5	3.4		18.5	1.3		9.8	3	
3 – 2	12.6	3.7		16.2	3.7		25.5	3		23.9	4.8		17.7	1.1		9.3	0.3	
Block				27.5	6	8				25	6	7				27	0.2	135

Table 6 Undrained shear strength. undisturbed s_{uk} and remoulded s_{uk}' (kPa) from fallcone tests and calculated sensitivity S_t

Annex 9


s_u (kPa)
0 10 20 30 40 50 60 70
$\varepsilon_{failure}$ (%)
0 10 20
Depth Z (m)
0 2 4 6 8 10 12 14 16 18 20
850-1-1
850-1-2
850-2-1
850-2-2
850-3-1
850-3-2
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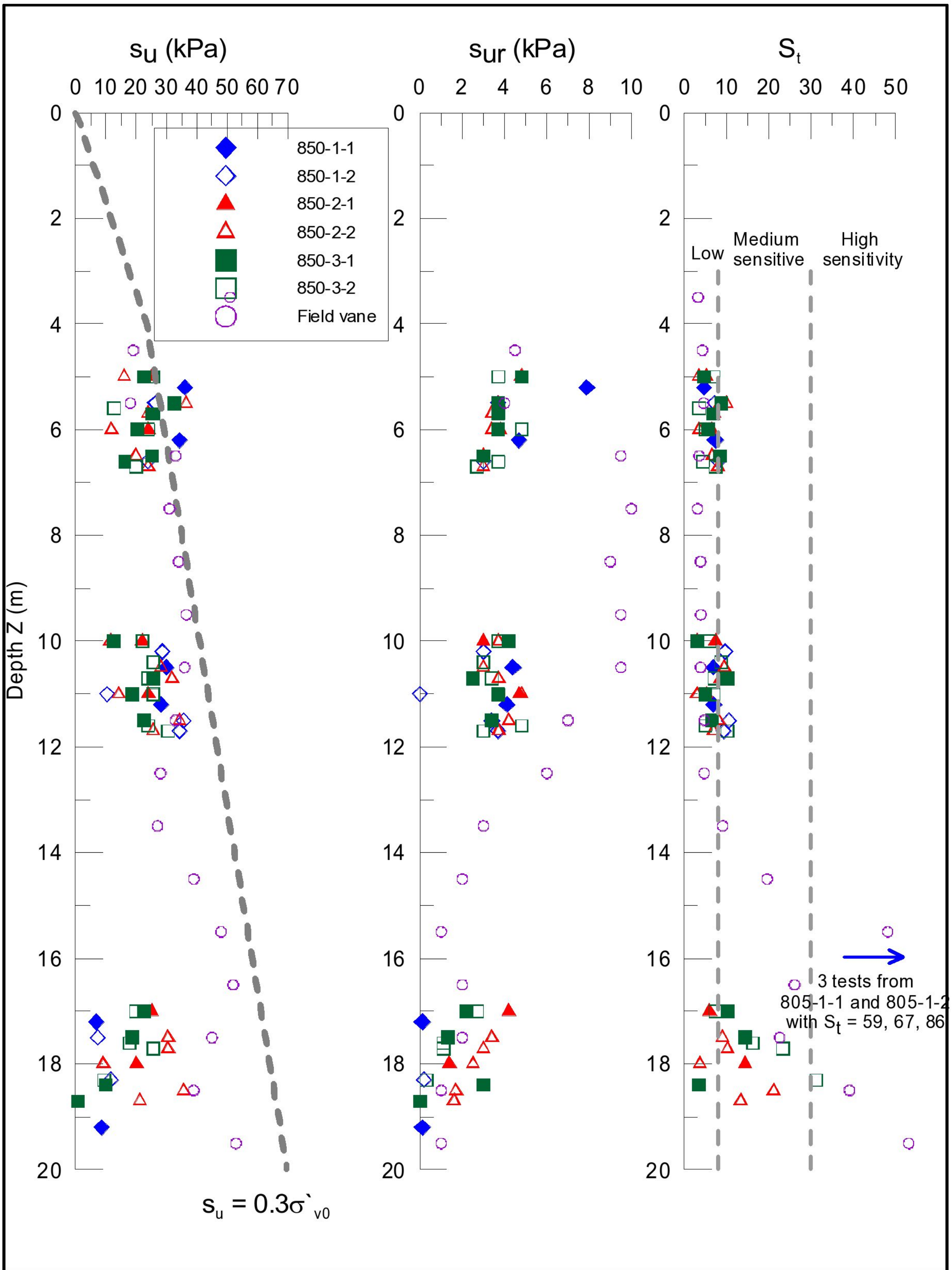
Statens vegvesen
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850
Unconfined compression test results
Teknologirapport
2426
Dato
2006-01-08
Figur
10



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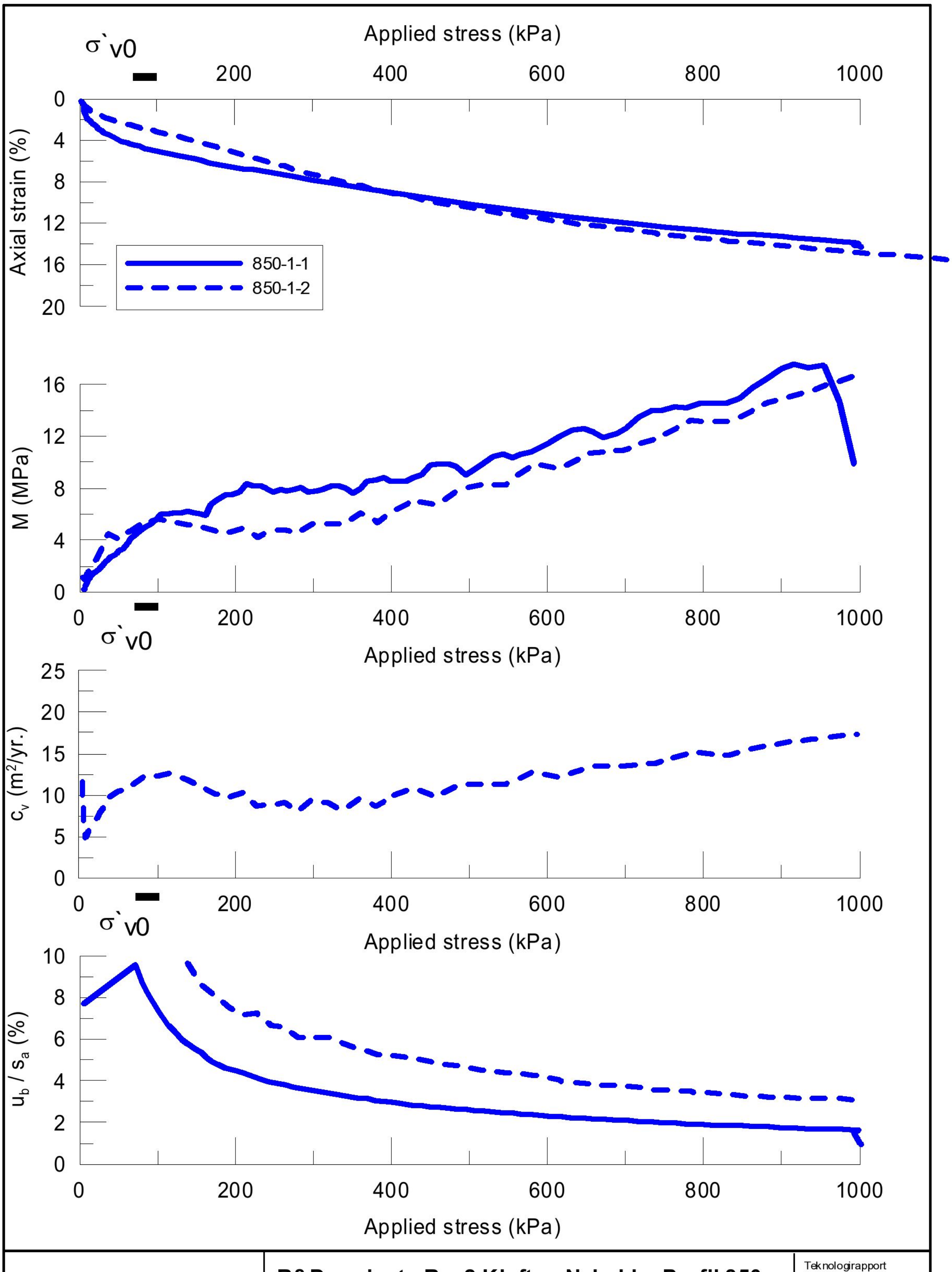
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-04

Fall cone test and field vane results

Figur 11



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Statens vegvesen

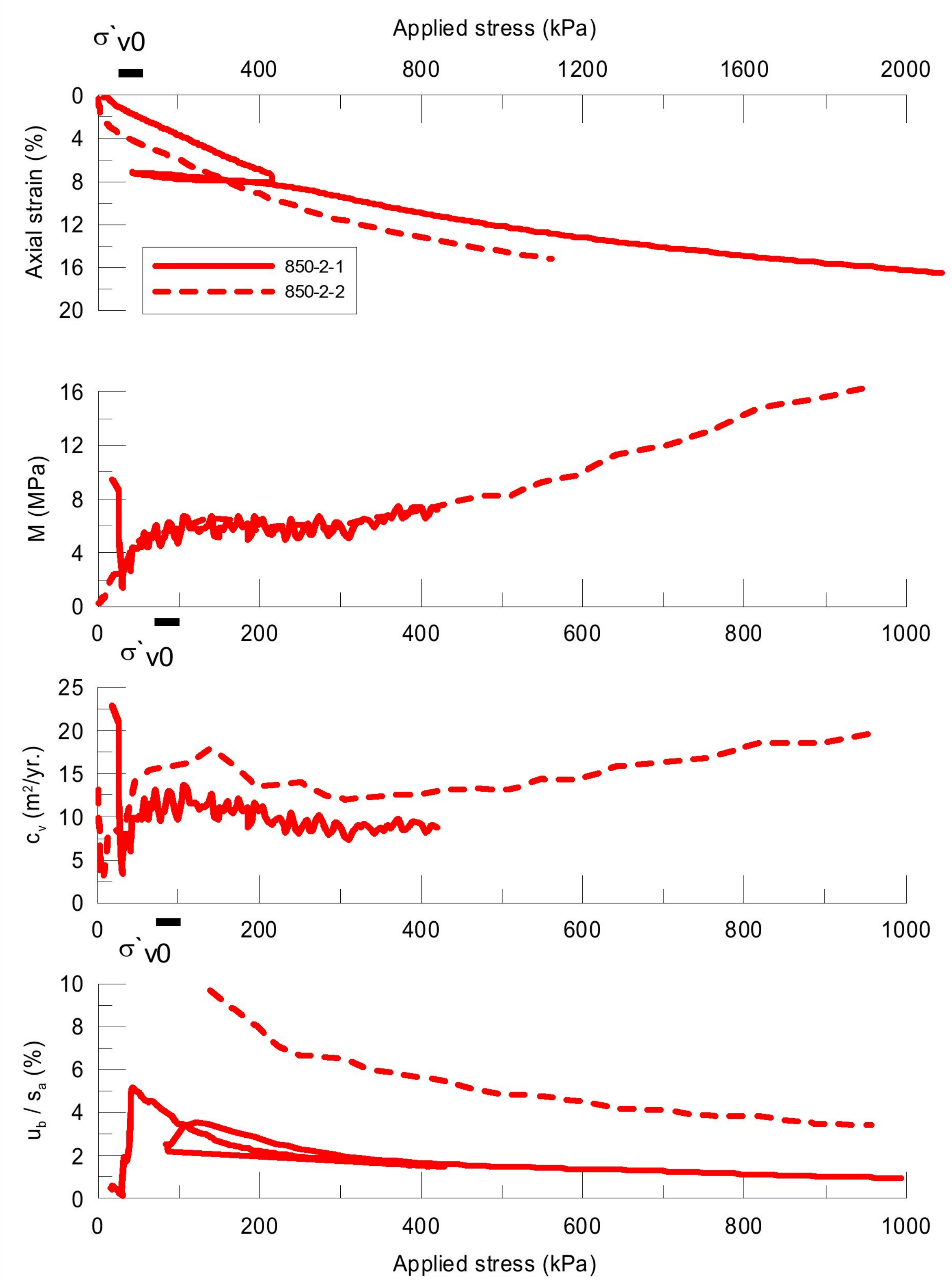
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-08

Comparison of CRS oedometer tests at 5.2 m, σ'_{v0} = 90 kPa, 850-1 Series

Figur 12



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Statens vegvesen

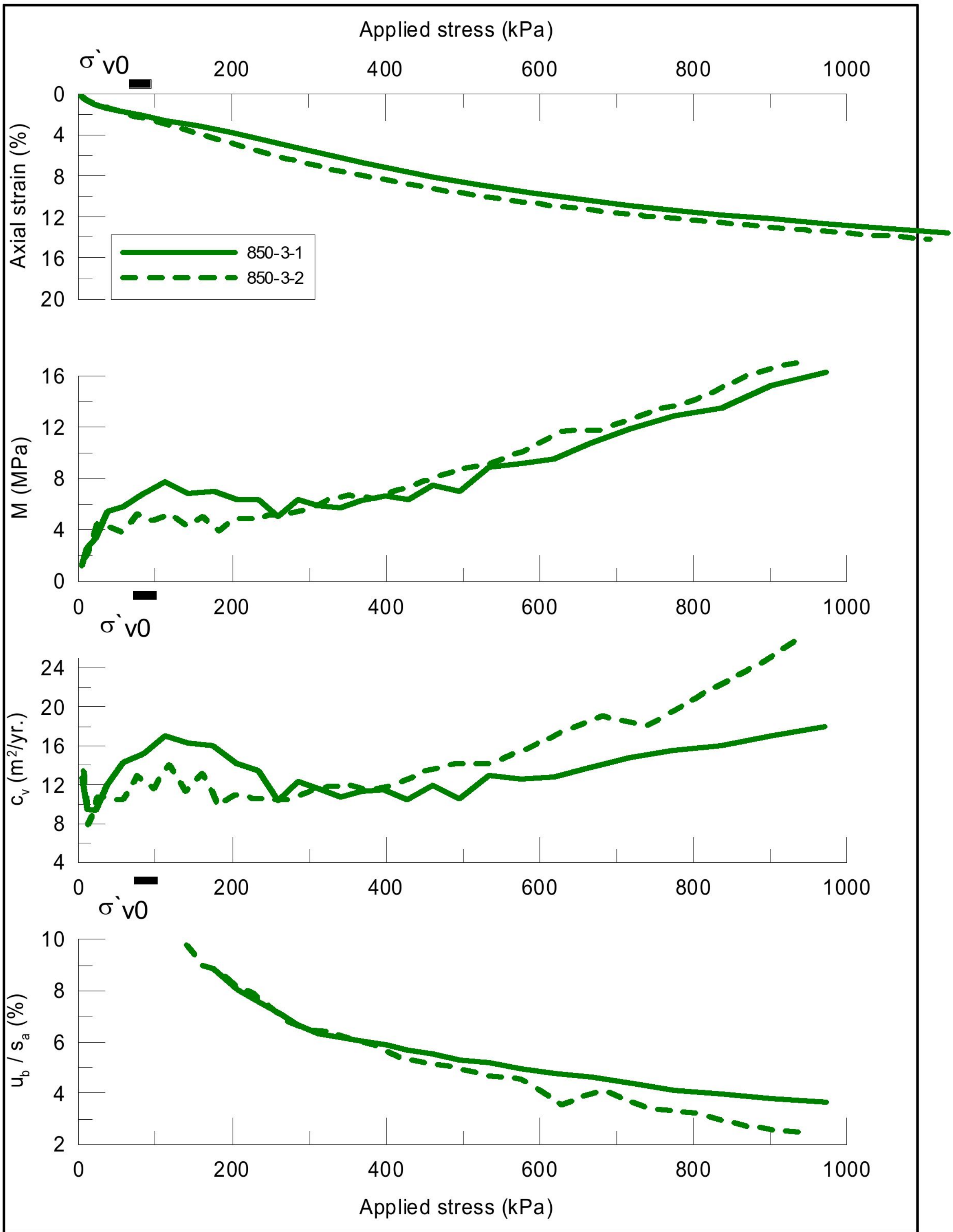
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparison of CRS oedometer tests
at 5.2 m, $\sigma`_{v0}$ = 90 kPa, 850-2 Series

Teknologirapport
2426

Dato
2006-01-08

Figur
13



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Statens vegvesen

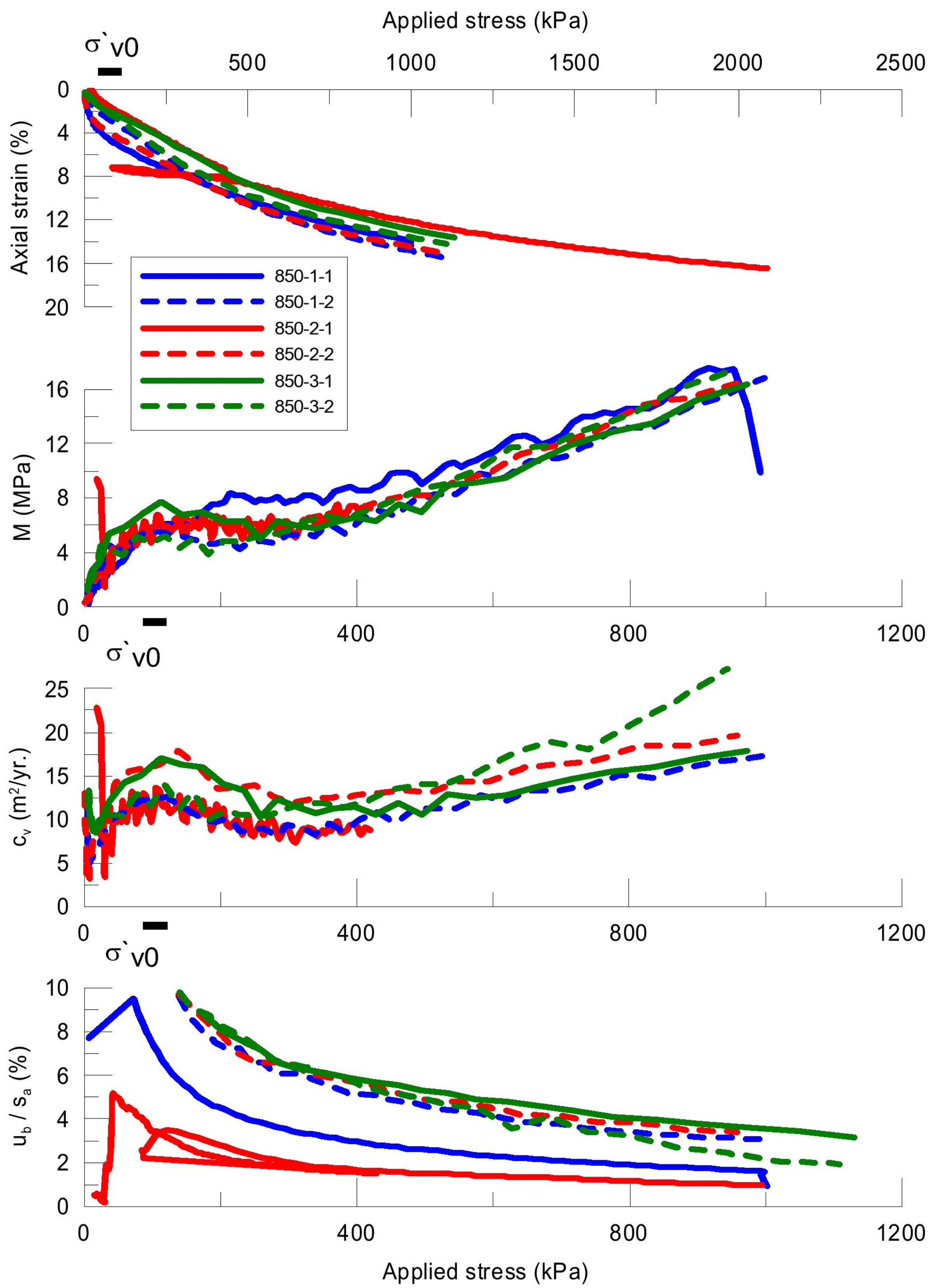
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-08

Comparison of CRS oedometer tests
at 5.2 m, σ'_{v0} = 90 kPa, 850-3 Series

Figur 14



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Statens vegvesen

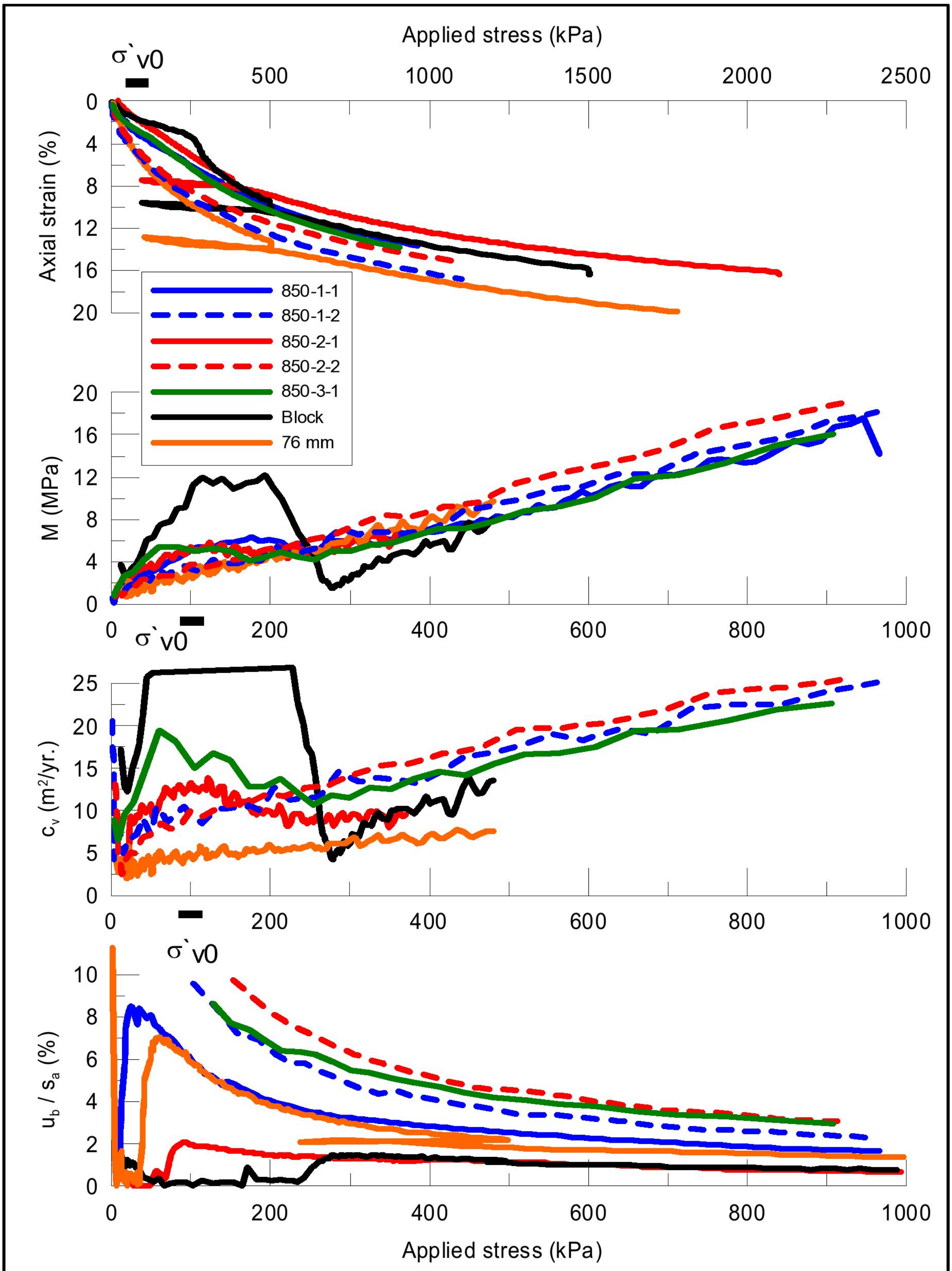
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparison of CRS oedometer tests
at 5.2 m, σ'_{v0} = 90 kPa

Teknologirapport
2426

Dato
2006-01-08

Figur
15



Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport
2426

Dato
2006-01-08

Comparison of CRS oedometer tests
at 6.3 m, $\sigma`_{v0}$ = 100 kPa

Figur
16

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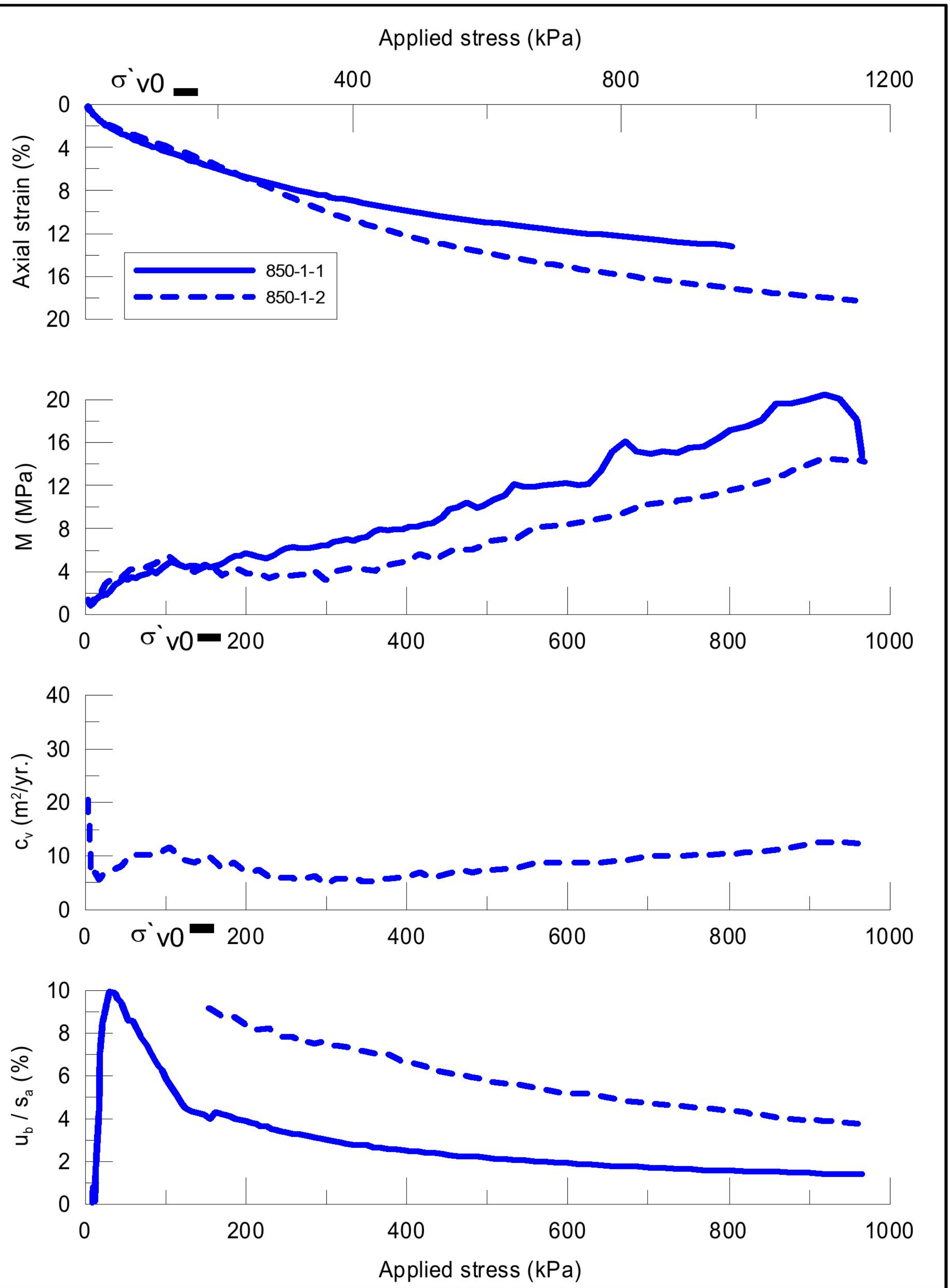

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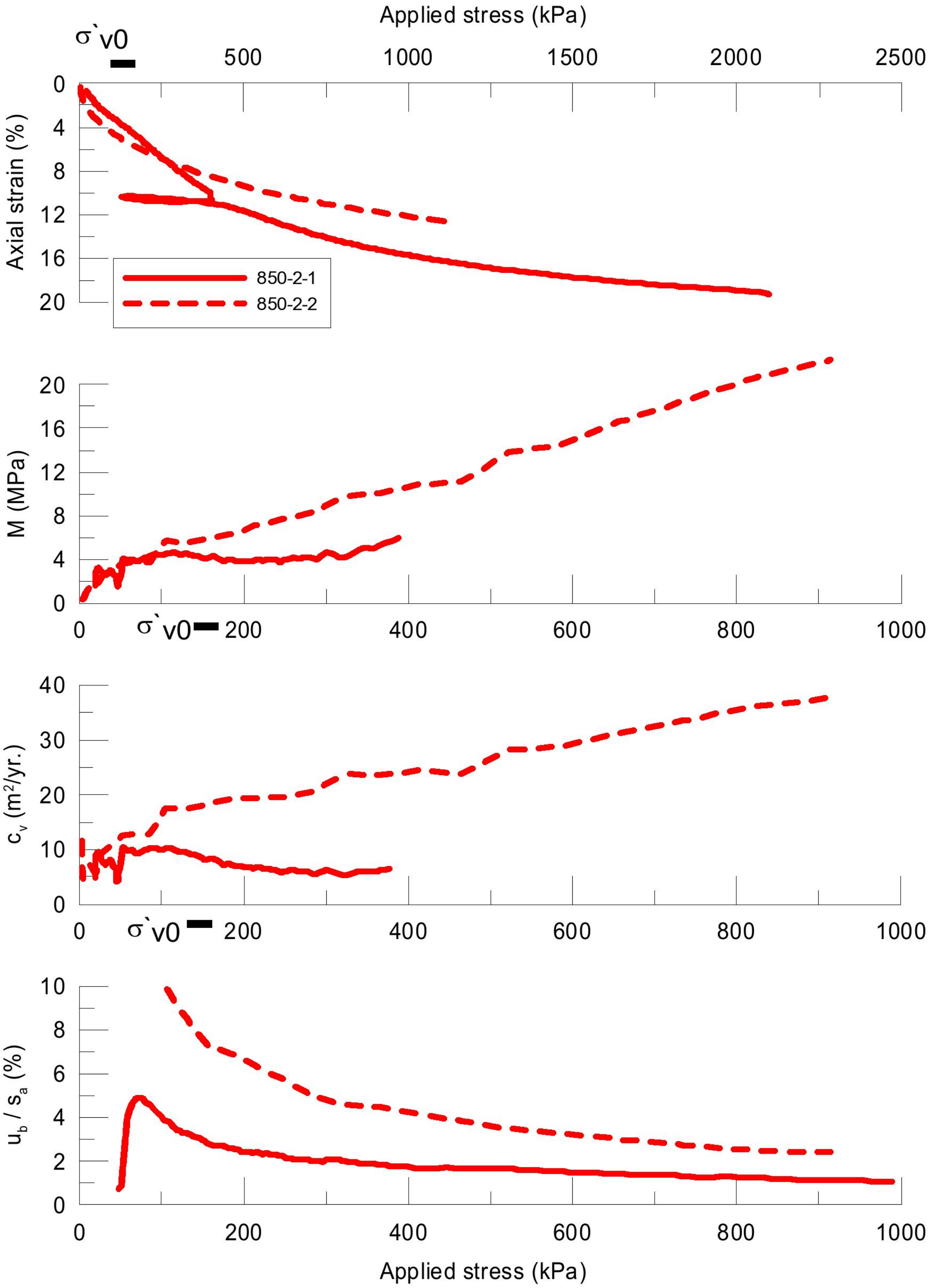
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport
2426

Dato
2006-01-08

Comparison of CRS oedometer tests
at 10.3 m, σ'_{v0} = 140 kPa, 850-1 series

Figur
17



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Statens vegvesen

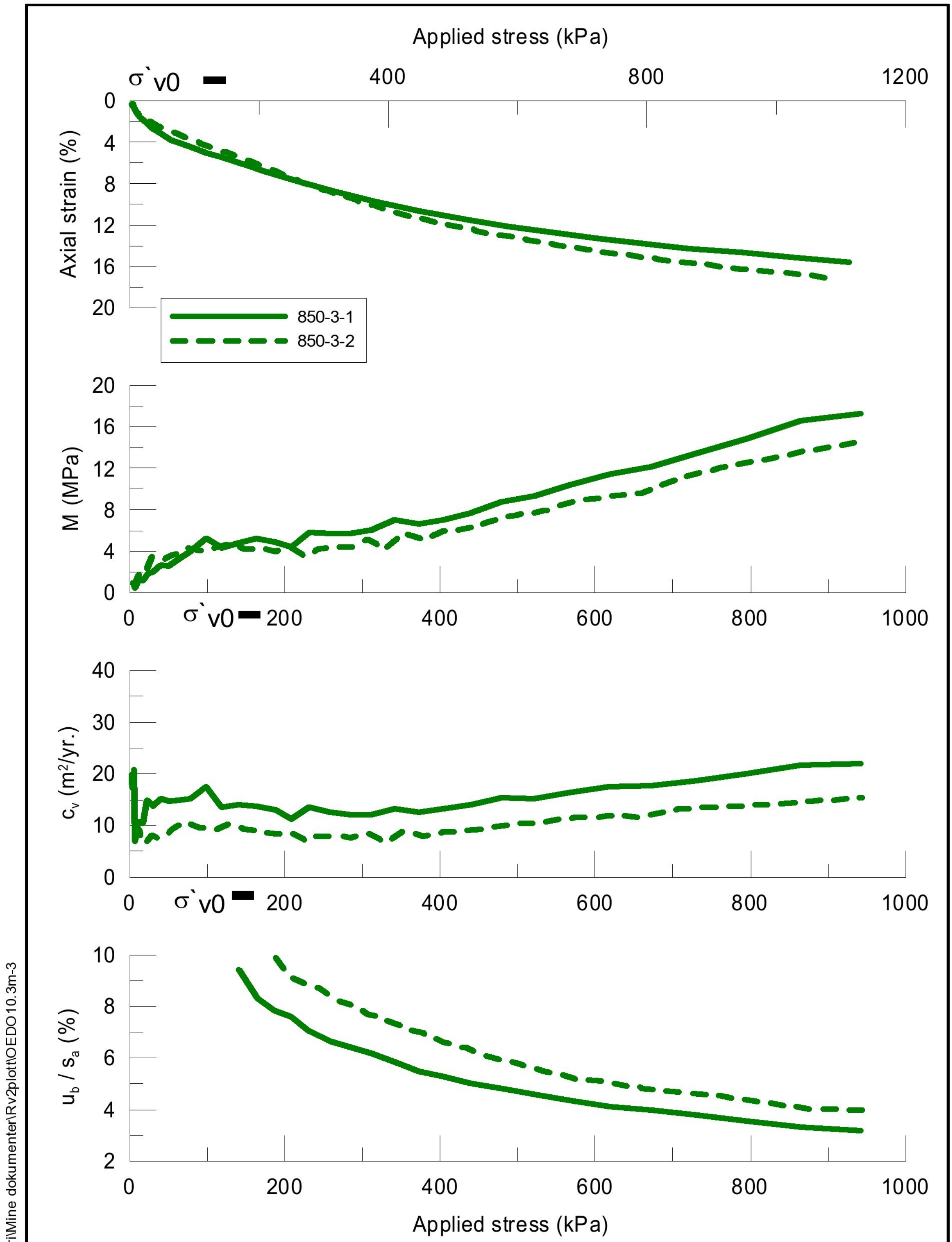
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparison of CRS oedometer tests
at 10.3 m, σ'_{v0} = 140 kPa, 850-2 series

Teknologirapport
2426

Dato
2006-01-08

Figur
18



Statens vegvesen

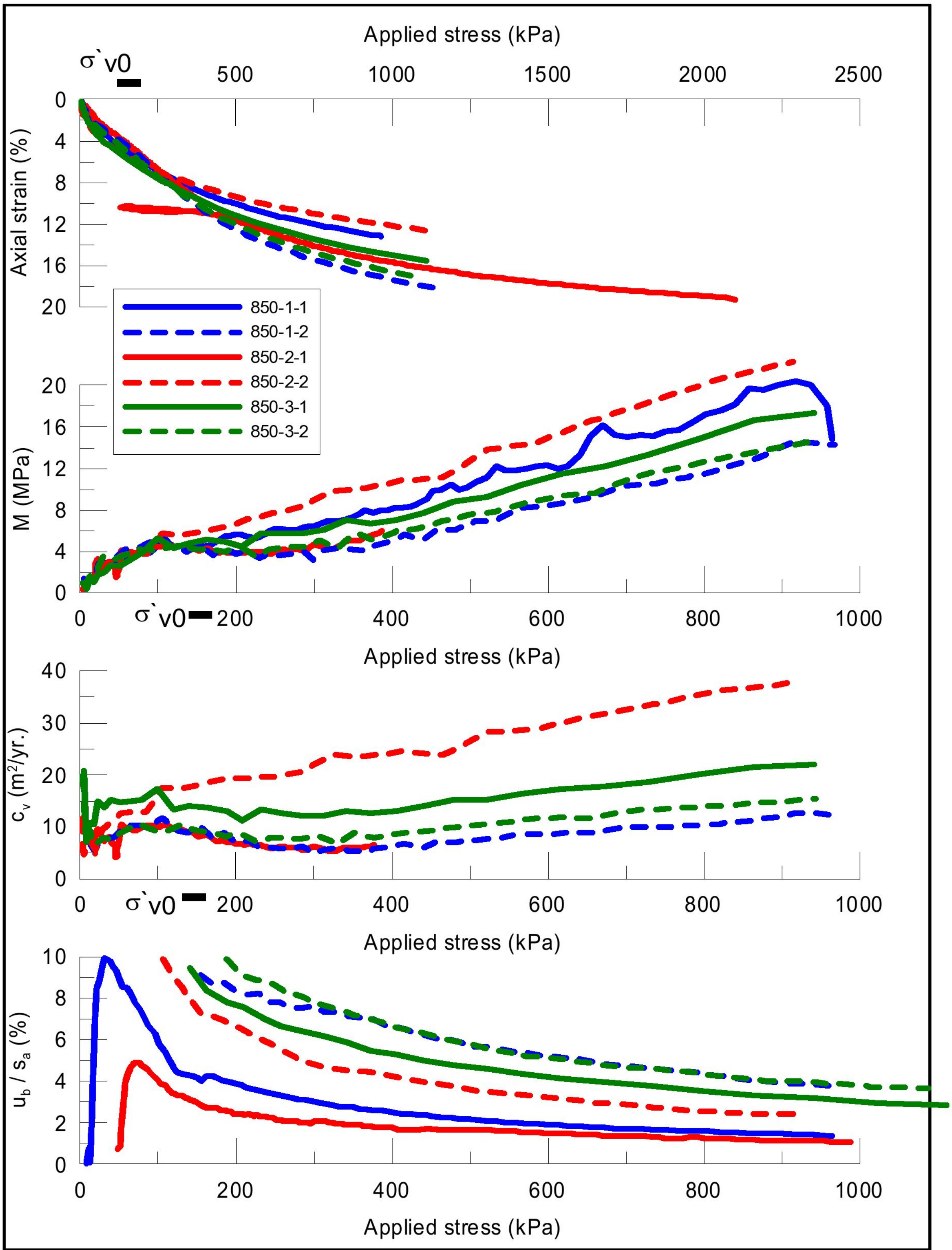
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-08

Comparison of CRS oedometer tests at 10.3 m, $\sigma`_{v0}$ = 140 kPa, 850-3 series

Figur 19



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Statens vegvesen

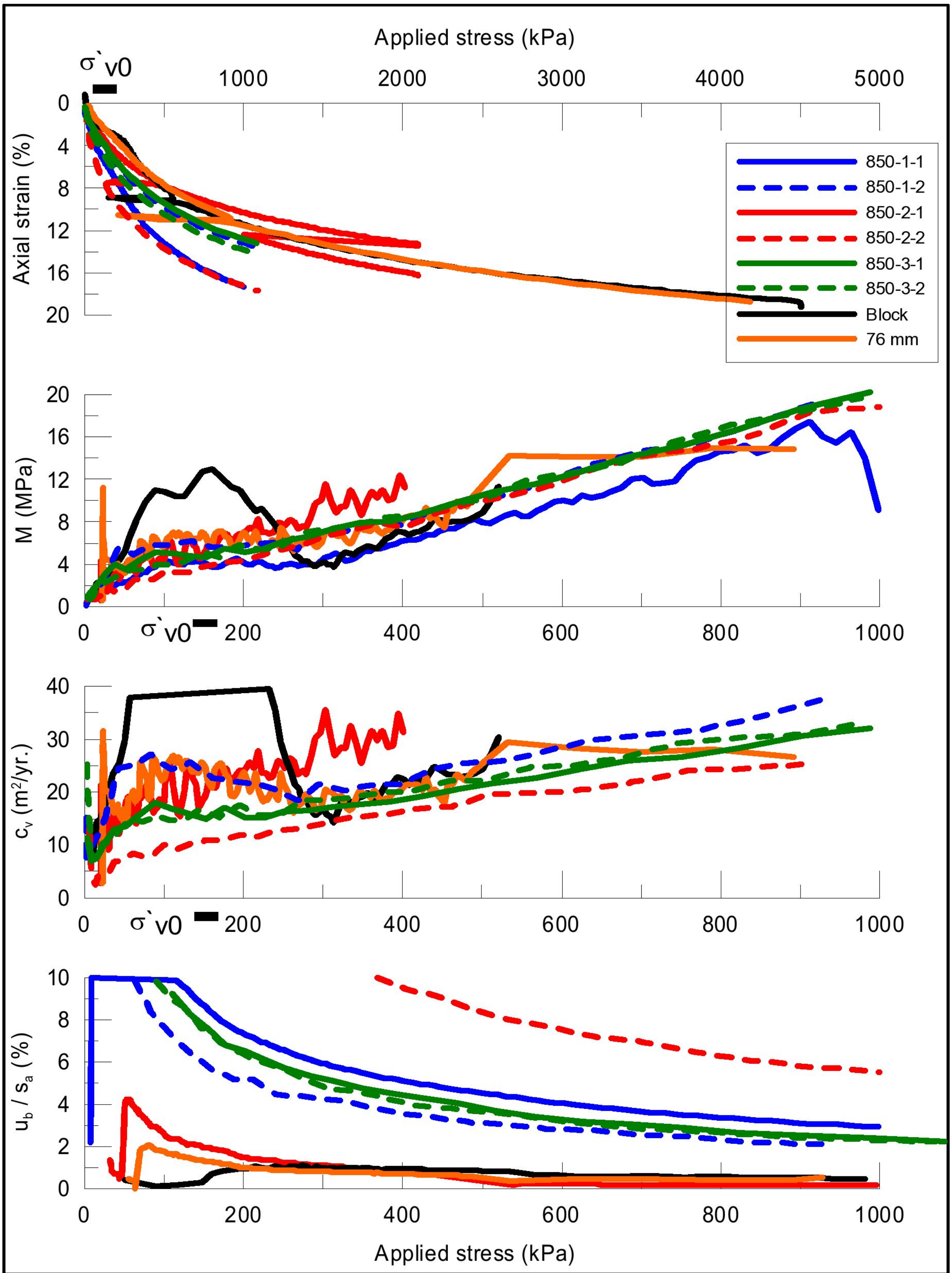
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport
2426

Dato
2006-01-08

Comparison of CRS oedometer tests
at 10.3 m, $\sigma`_{v0}$ = 140 kPa

Figur
20



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Statens vegvesen

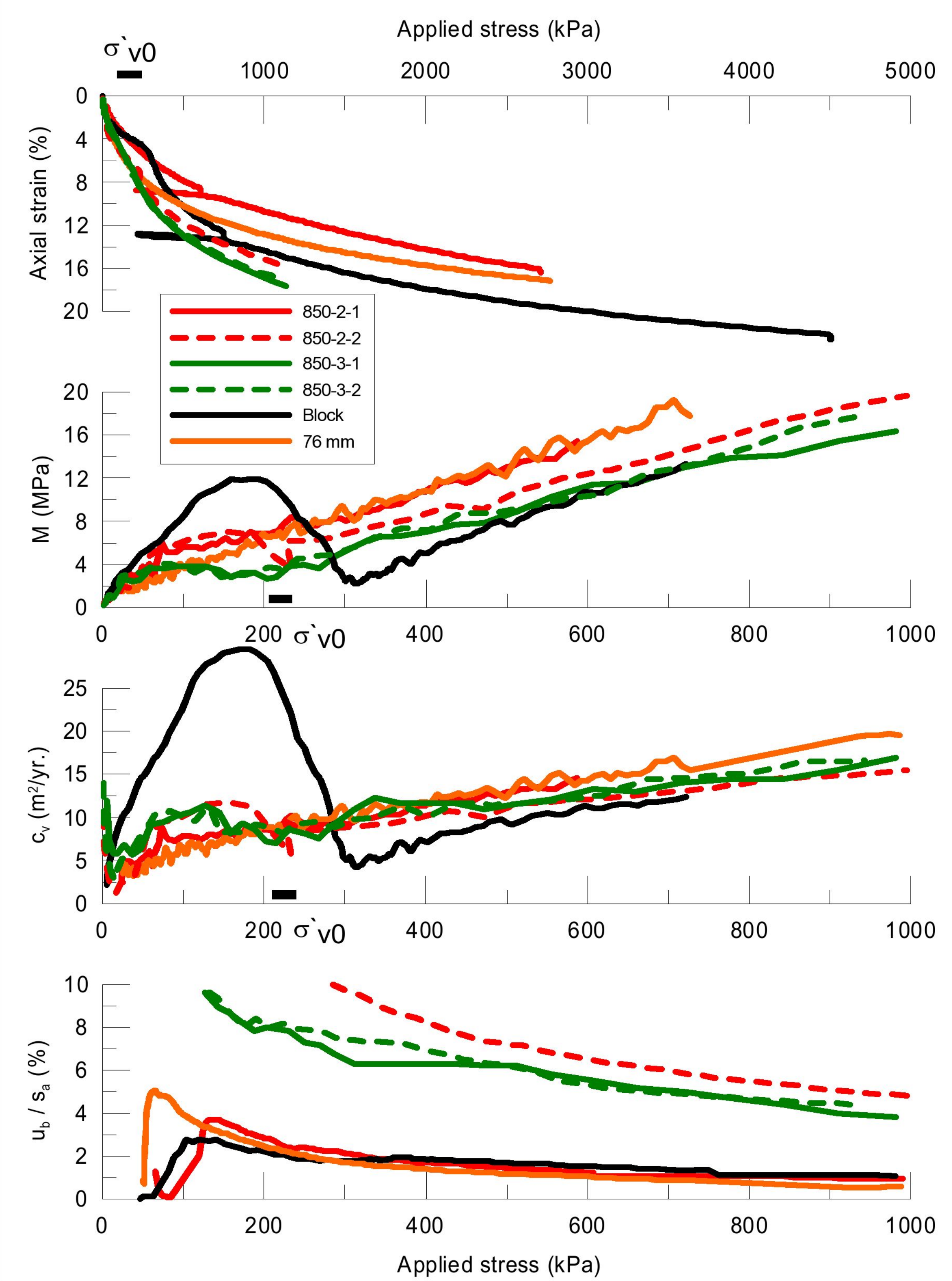
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparison of CRS oedometer tests
at 11.3 m, $\sigma`_{v0}$ = 150 kPa

Teknologirapport
2426

Dato
2006-01-08

Figur
21



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Statens vegvesen

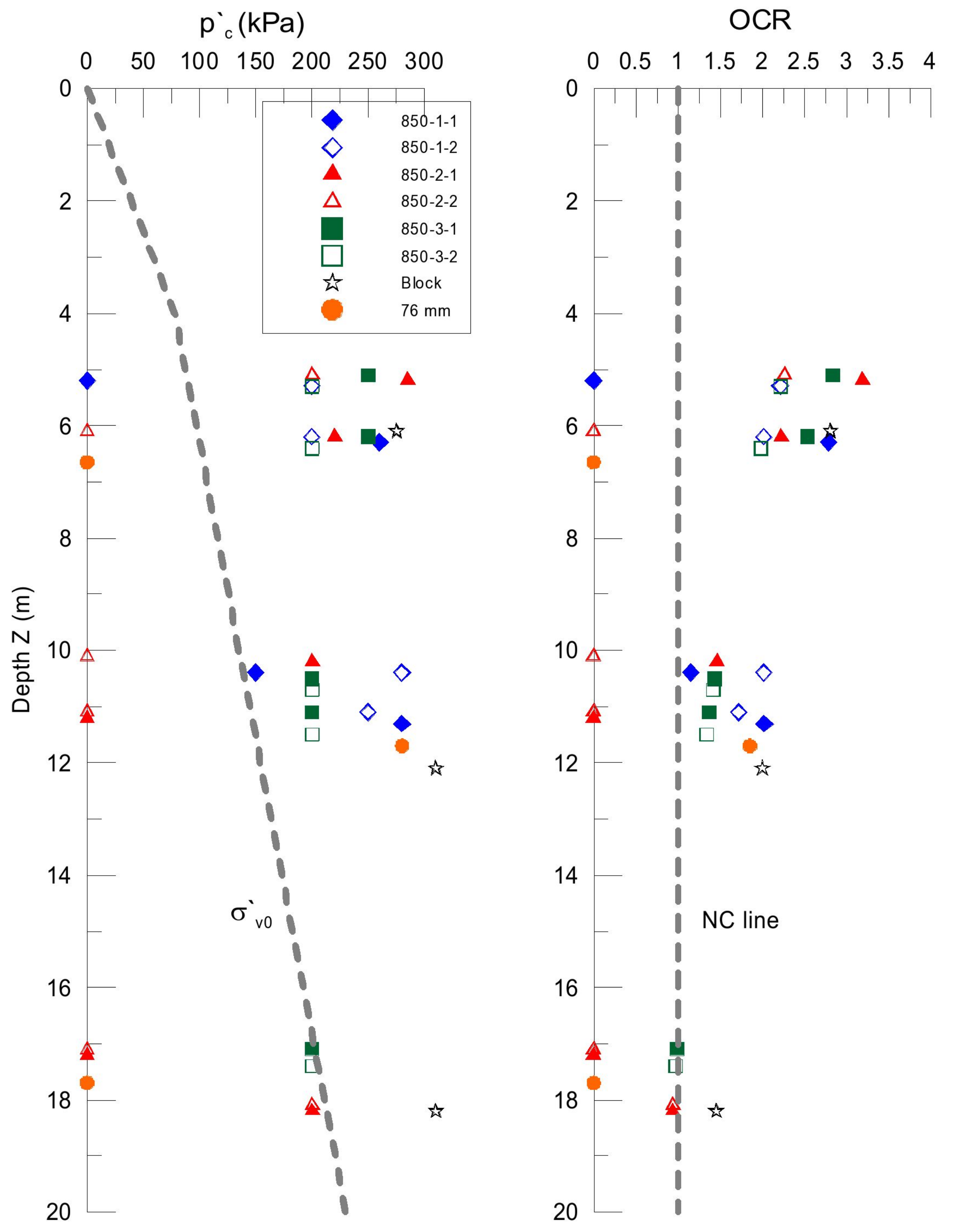
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-08

Comparison of CRS oedometer tests at 18.2 m, σ'_{v0} = 215 kPa

Figur 22



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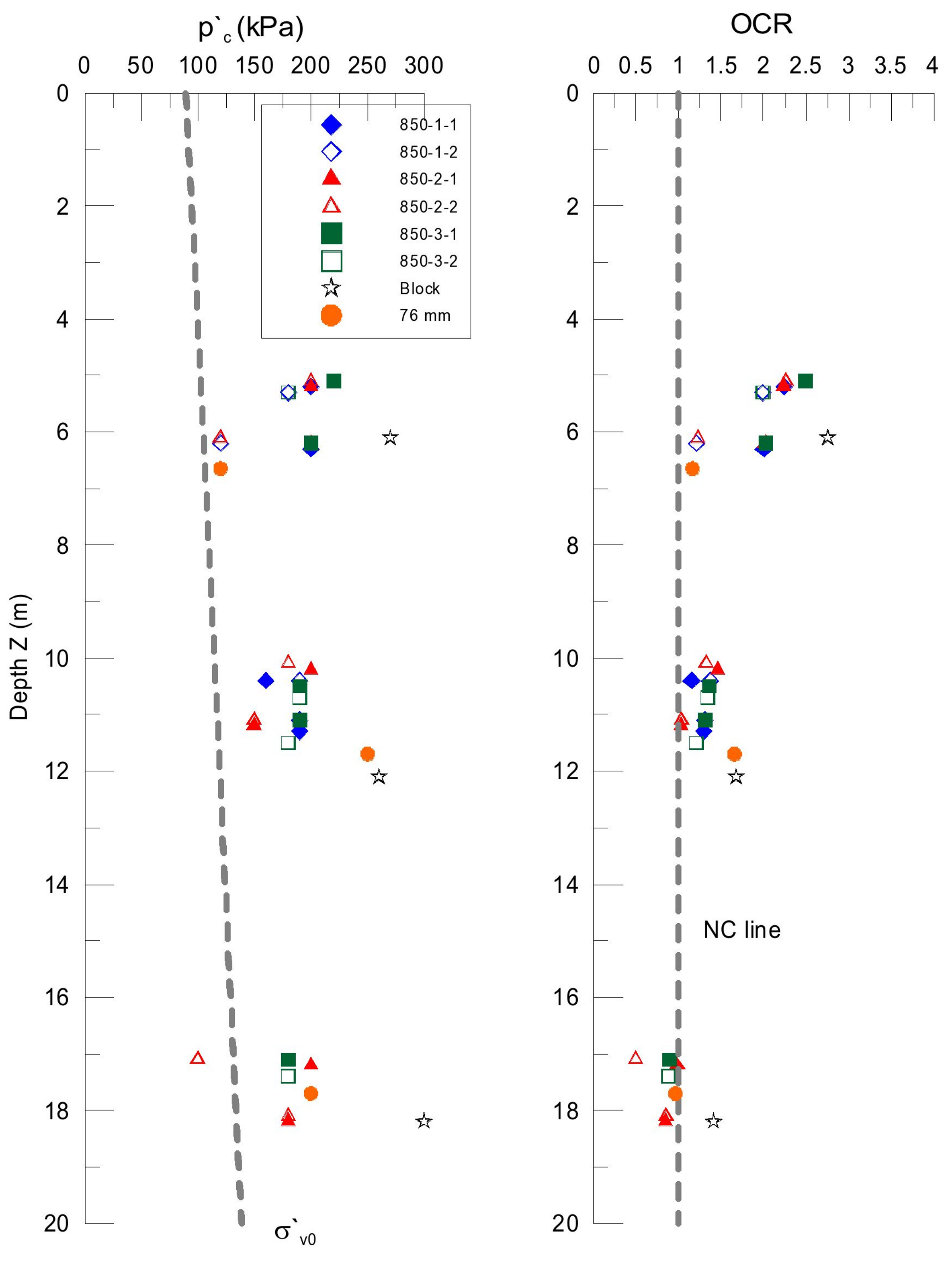
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
	Preconsolidation stress and overconsolidatio ratio using Janbu approach	Dato 2006-01-05
		Figur 23



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Statens vegvesen

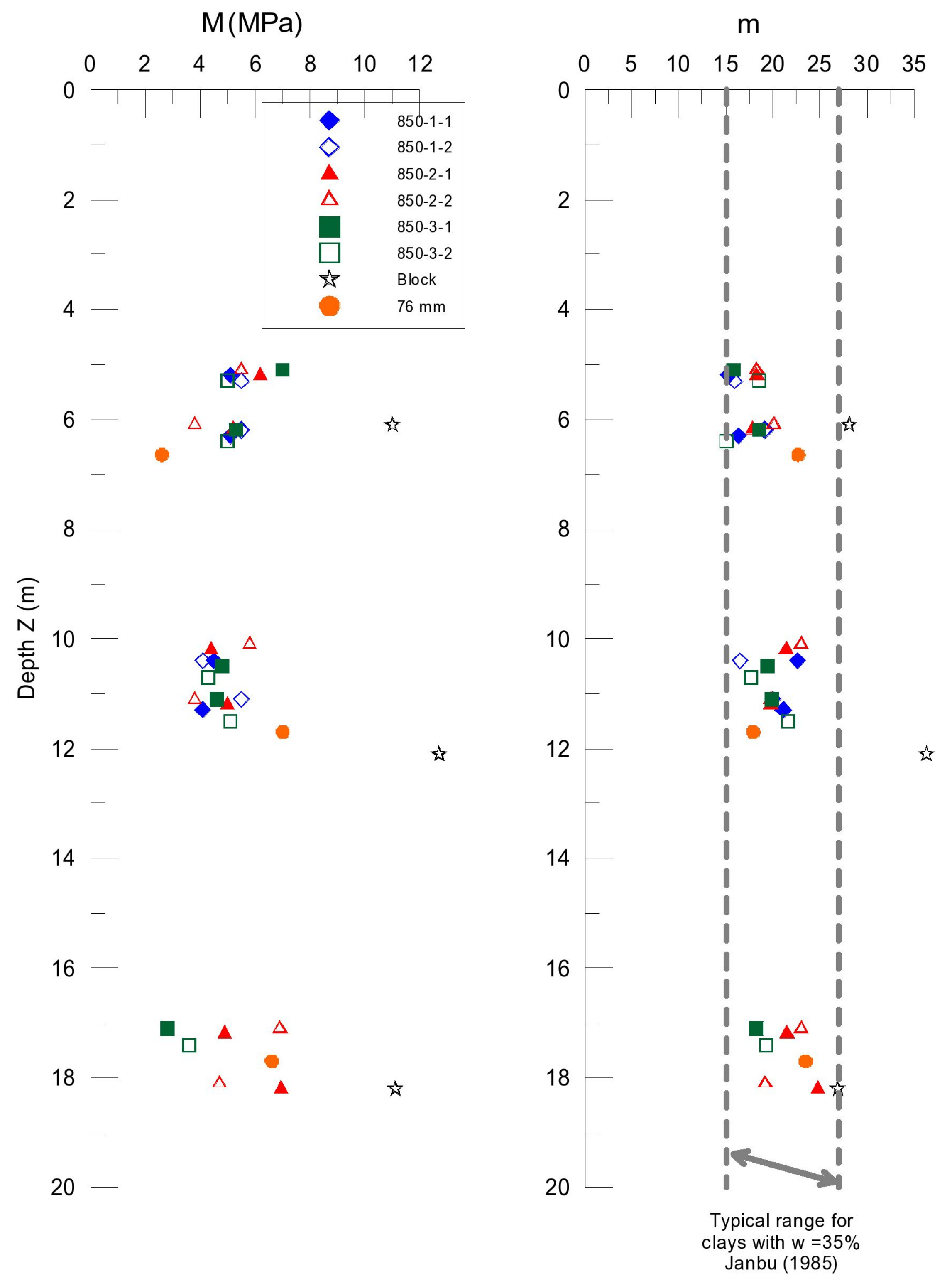
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Preconsolidation stress and overconsolidatio ratio using Casagrande approach

Teknologirapport 2426

Dato 2006-01-05

Figur 24



R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Constrained modulus and modulus number

Statens vegvesen

Teknologirapport 2426

Dato 2006-01-05

Figur 25

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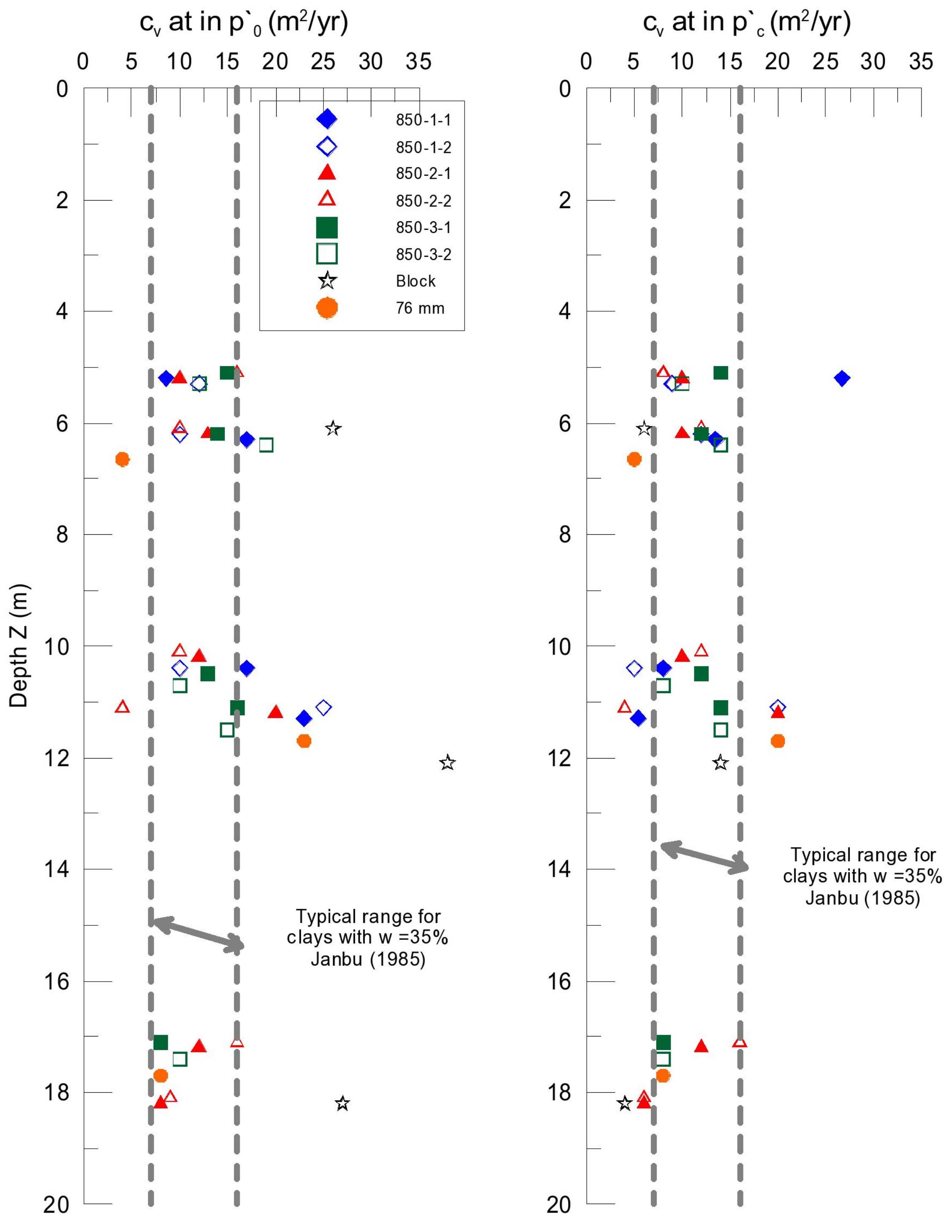

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Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-01-05

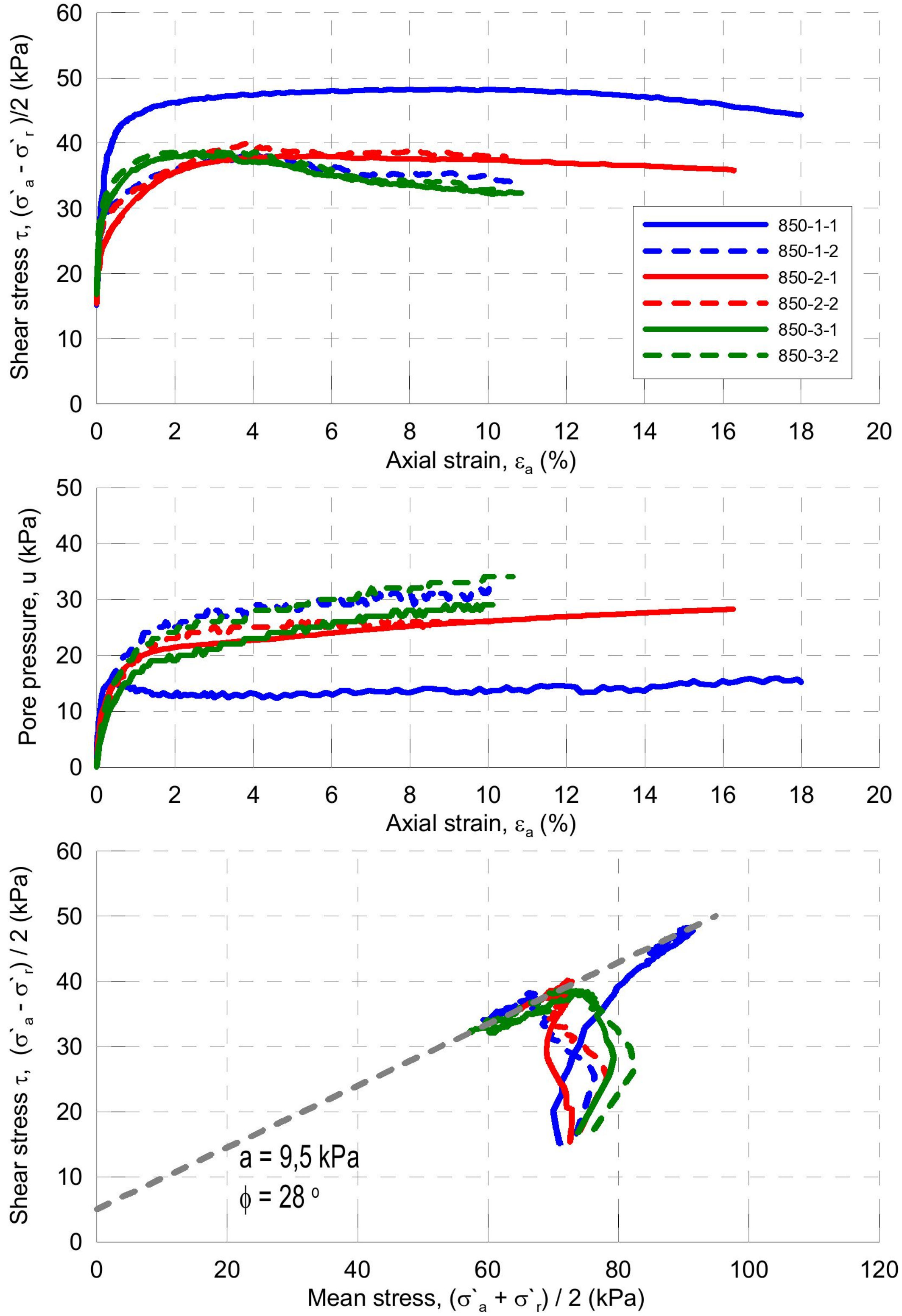
Coefficient of consolidation c_v

Figur 26

Depth	5.0 - 5.8 m			6.0 – 6.8 m			10.0 – 10.8 m			11.0 – 12.1 m			17.0 – 17.8 m			18.0 – 18.8 m		
Hole	s_{uA}	s_A/σ_{v0}’	ε_B	s_{uA}	s_{uA}/σ_{v0}’	ε_B	s_{uA}	s_{uA}/σ_{v0}’	ε_B	s_{uA}	s_{uA}/σ_{v0}’	ε_B	s_{uA}	s_{uA}/σ_{v0}’	ε_B	s_{uA}	s_{uA}/σ_{v0}’	ε_B
1 – 1	46	0.509	8	40	0.396	3	40.5	0.288	1.6	43.2	0.291	1.6						
1 – 2	37	0.413	4	36	0.360	1.5	44	0.319	1.5	48	0.325	1.5						
2 – 1	37	0.409	4	33	0.330	10	40	0.290	2.2	43	0.291	12	55	0.269	2	59.5	02.78	1
2 – 2	38	0.420	4	34	0.340	9.5	42	0.304	2	43	0.291	10.8	58	0.283	0.5	61	0.285	0.5
3 – 1	38	0.420	2	36	0.360	2	44	0.319	1	52	0.352	11	60	0.293	0.5			
3 – 2	38	0.411	3	36	0.353	2	44	0.317	2	46	0.306	1	58	0.306	0.5			
Block				50	0.510	0.7				56	0.361	0.7				72	0.338	0.5
76mm				38	0.366	2				48	0.316	1.5				57	0.273	0.8

Table 7 Maximum undrained shear strength s_{uA} and normalised shear strength s_{uA}/σ_{v0}’ from active triaxial tests and corresponding strain

Annex 27



C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\all\TRX 5.0-5.8m

Statens vegvesen

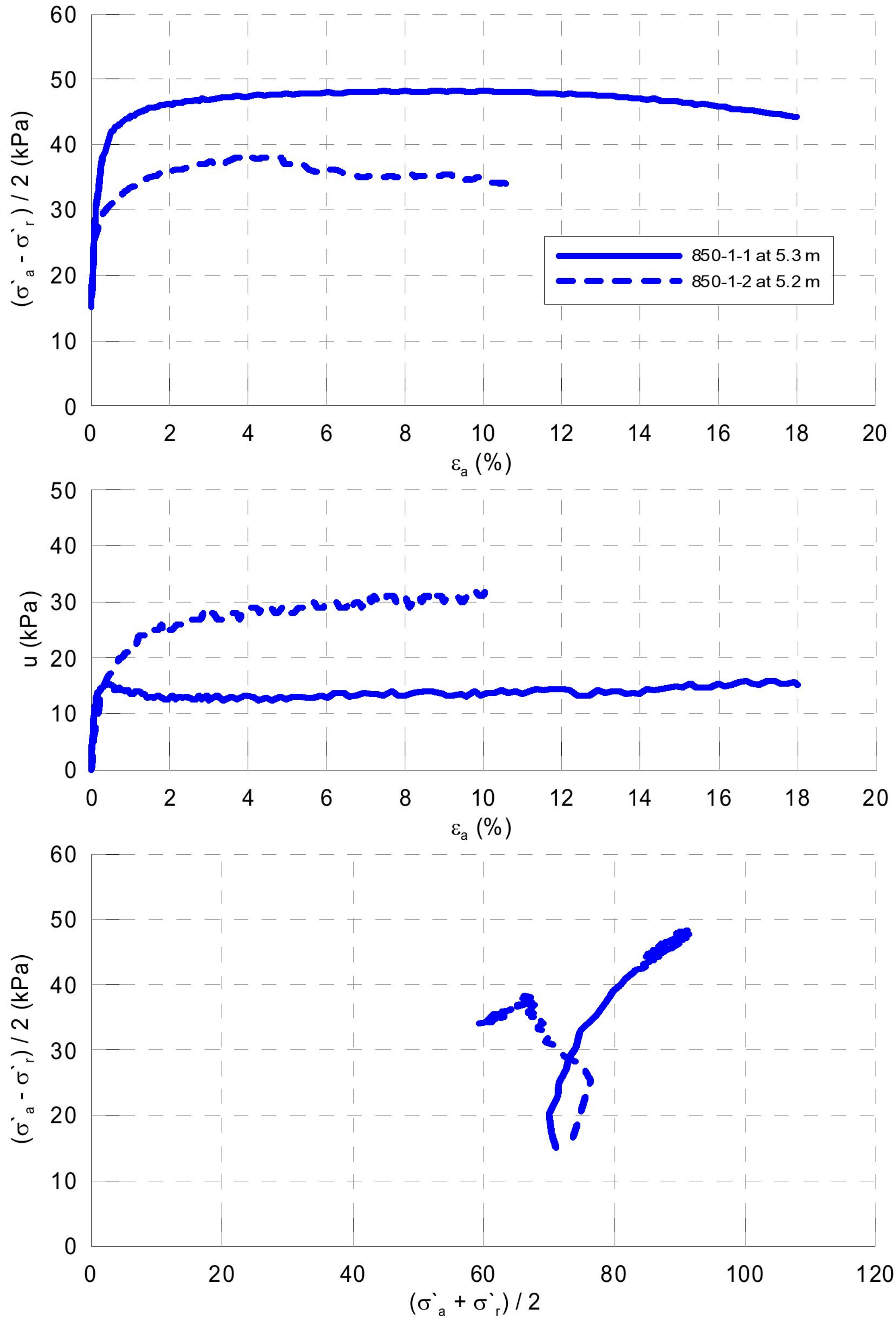
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

All triaxial test from 5.0 to 5.8 m

Teknologirapport 2426

Dato 2006-04-03

Figur 28



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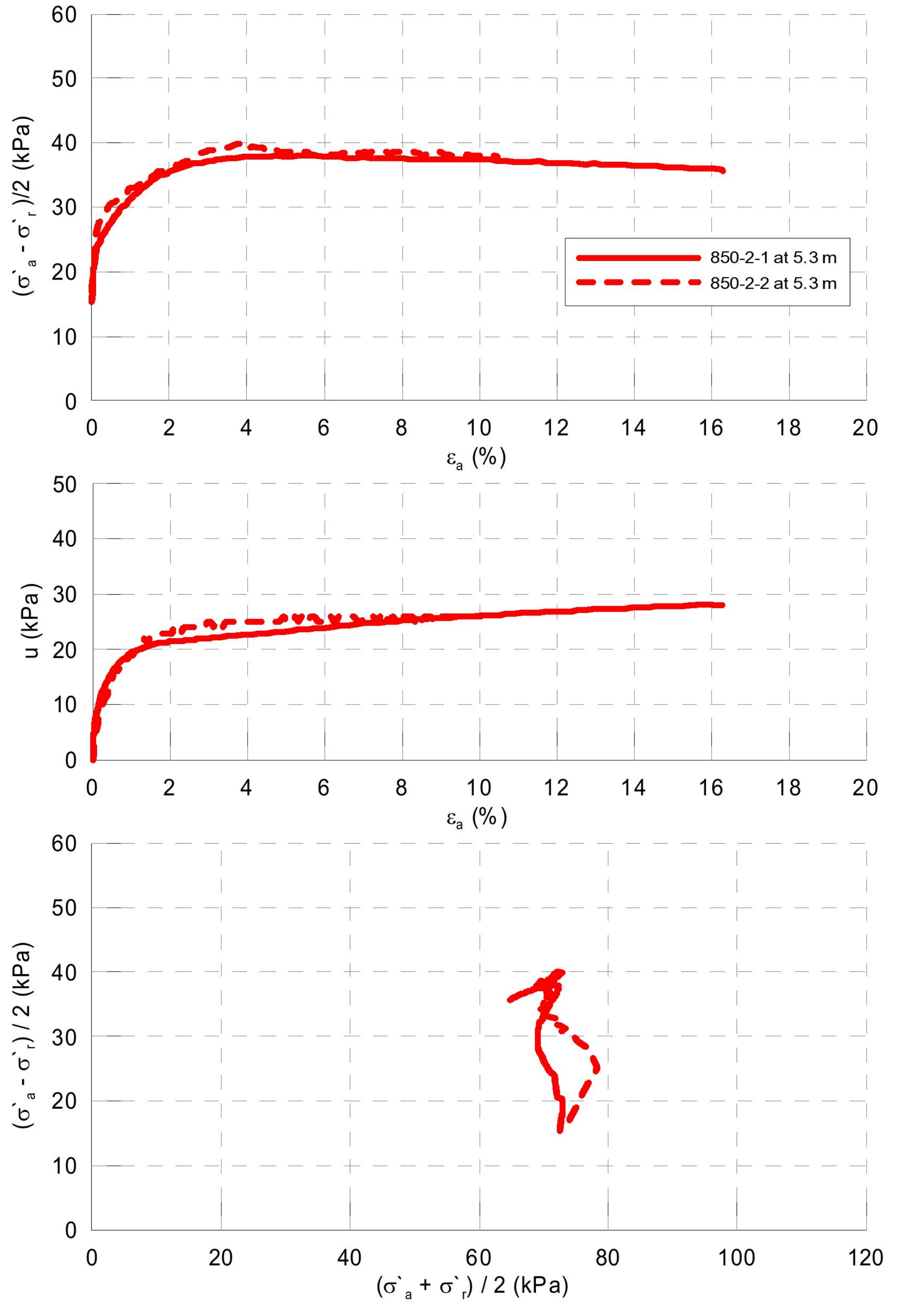
Statens vegvesen	R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
		Dato 2006-01-05
	Comparaison of 850-1 triaxial tests at about 5.3 m	Figur 29



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Statens vegvesen

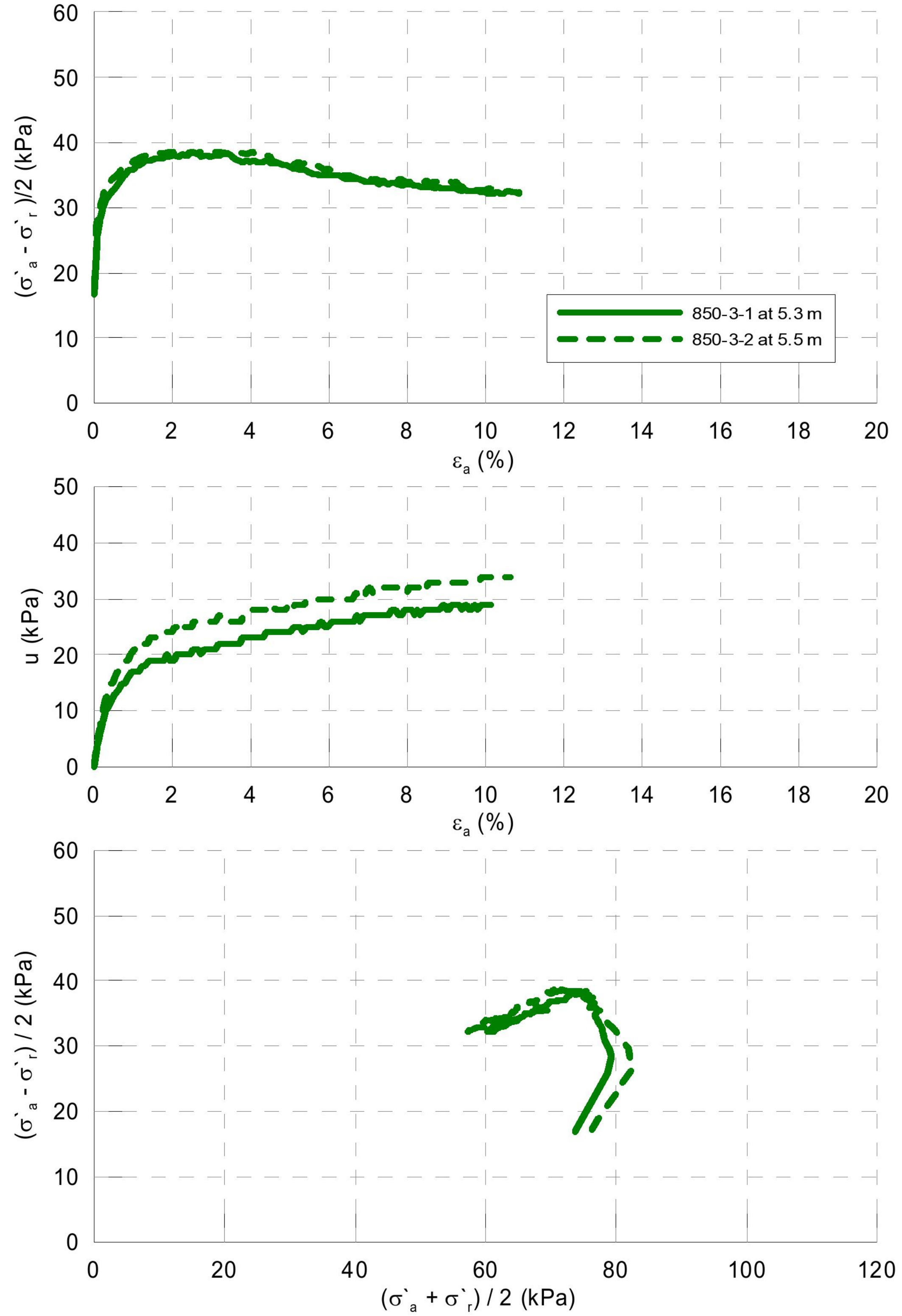
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparaison of 850-2 triaxial tests at about 5.3 m

Teknologirapport
2426

Dato
2006-01-05

Figur
30



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Statens vegvesen

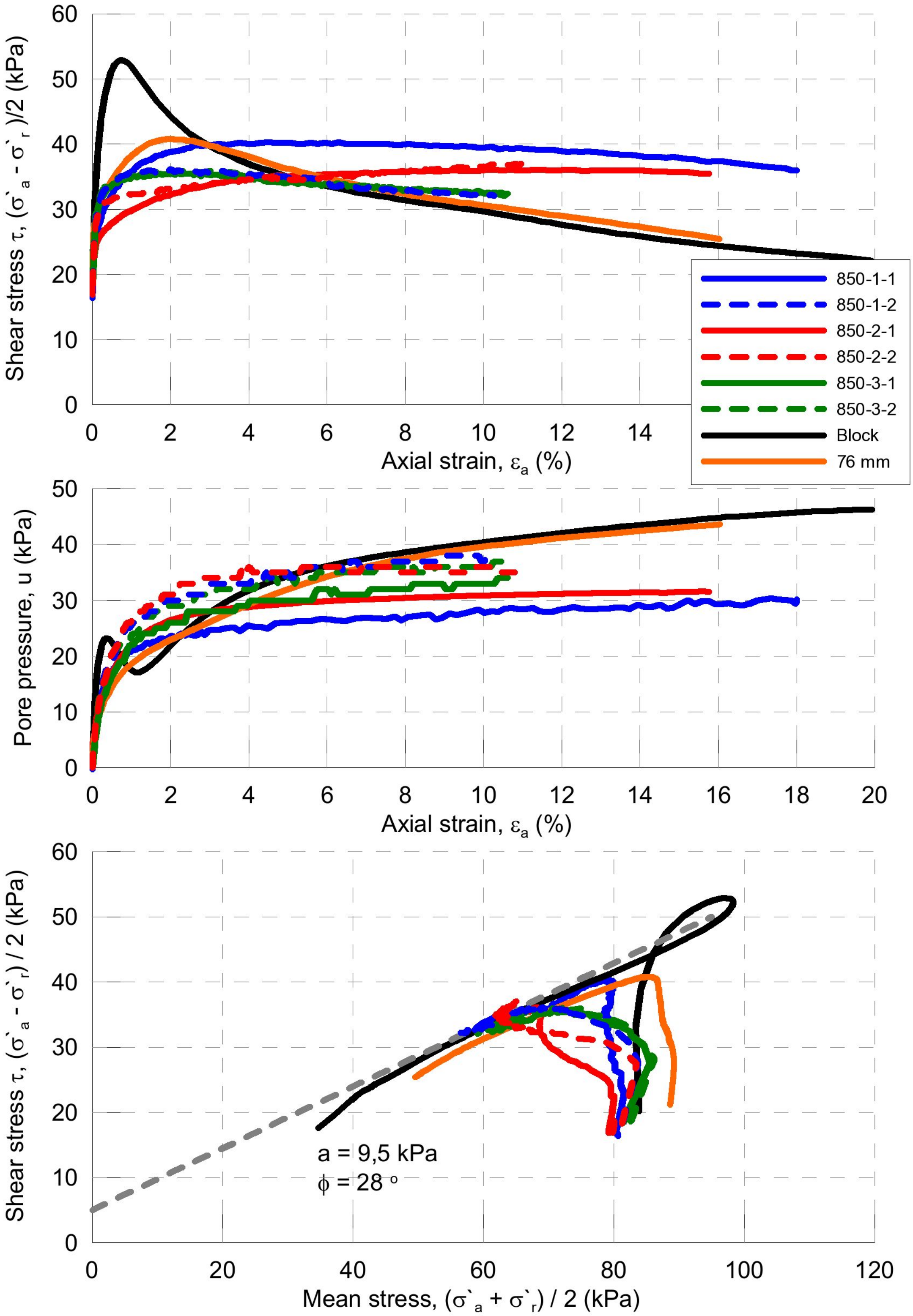
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparaison of 850-3 triaxial tests at about 5.3 m

Teknologirapport
2426

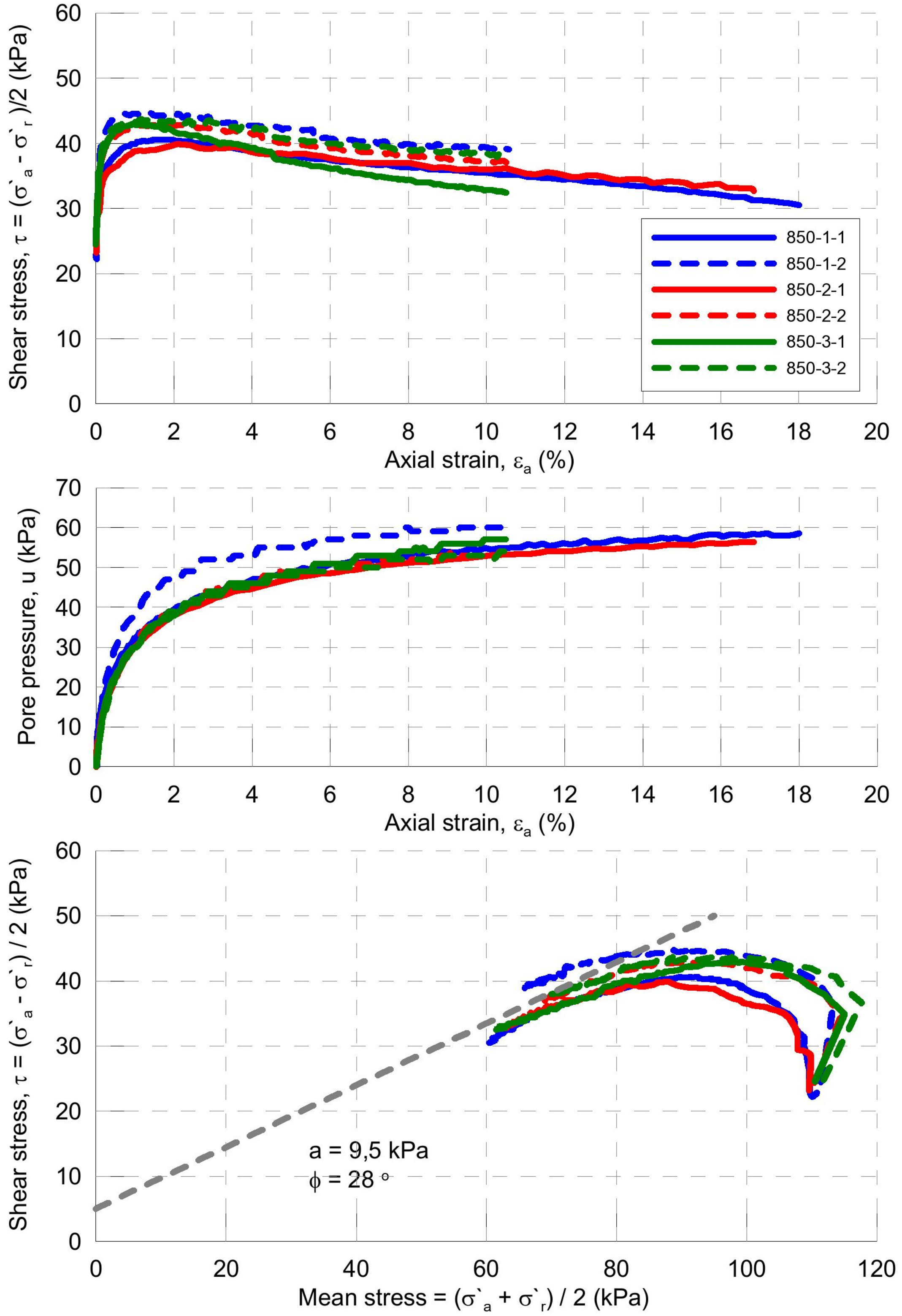
Dato
2006-01-05

Figur
31



C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\allTRX 6.0-6.8m

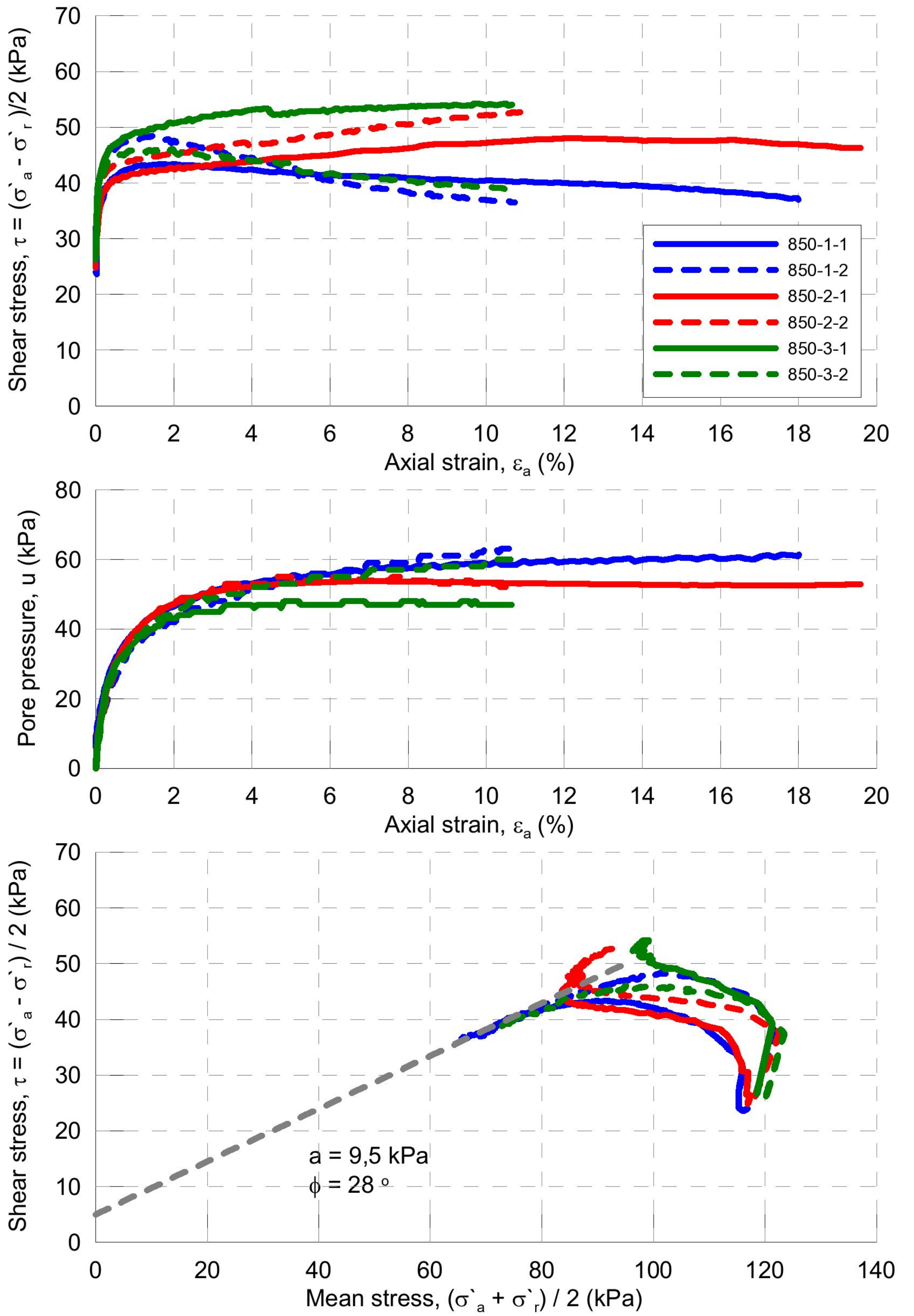
Statens vegvesen	R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknolgirapport 2426
	All triaxial test from 6.0 to 6.8m	Dato 2006-04-03
		Figur 32



R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
All triaxial test from 10.0 to 10.8m	Dato 2006-04-03
	Figur 33

Statens vegvesen

C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\allTRX 10.0-10.8m



C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\allTRX 11.0-11.8m

Statens vegvesen

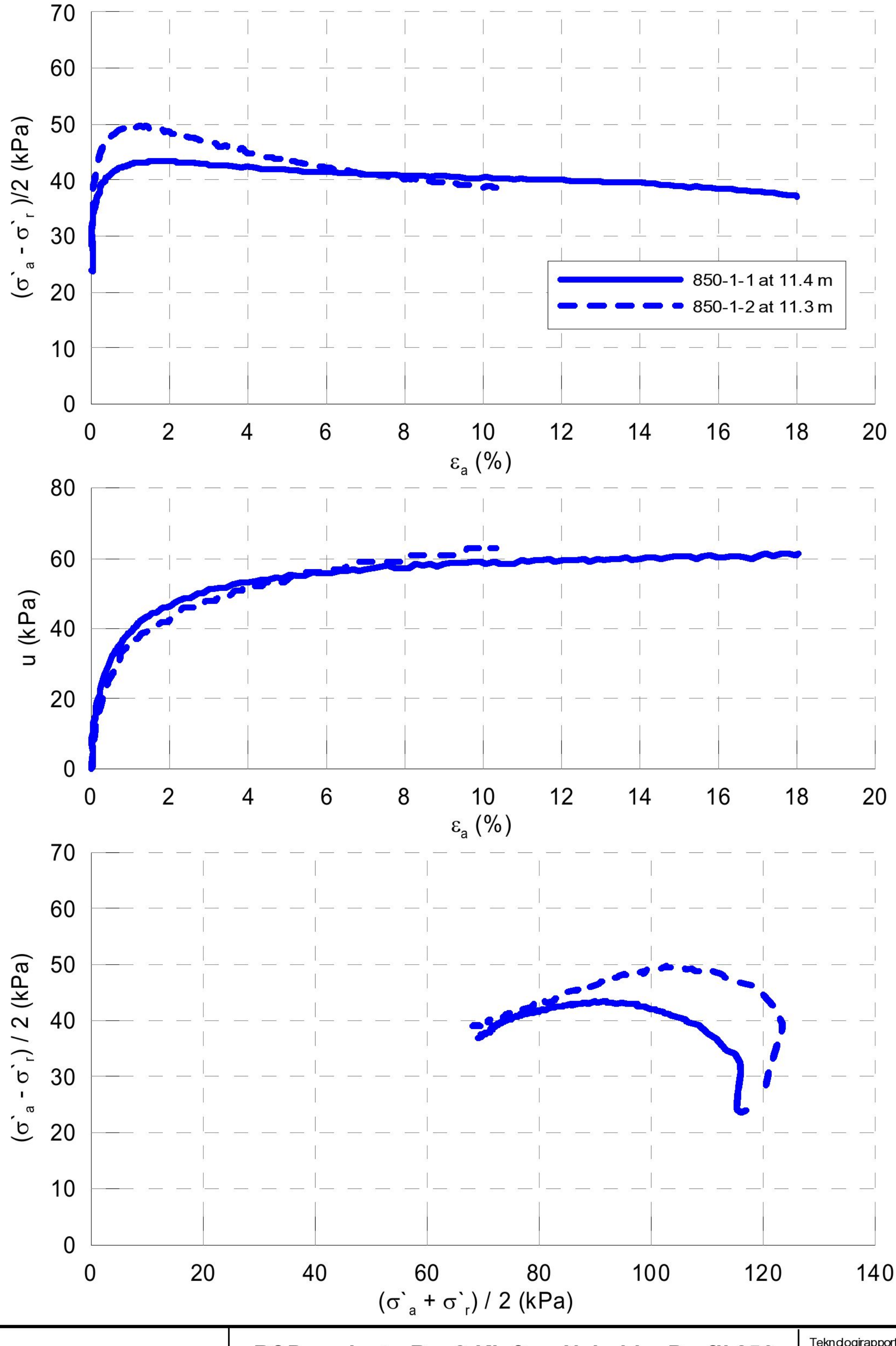
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Teknologirapport 2426

Dato 2006-04-03

All triaxial test from 11.0 to 11.8m

Figur 34



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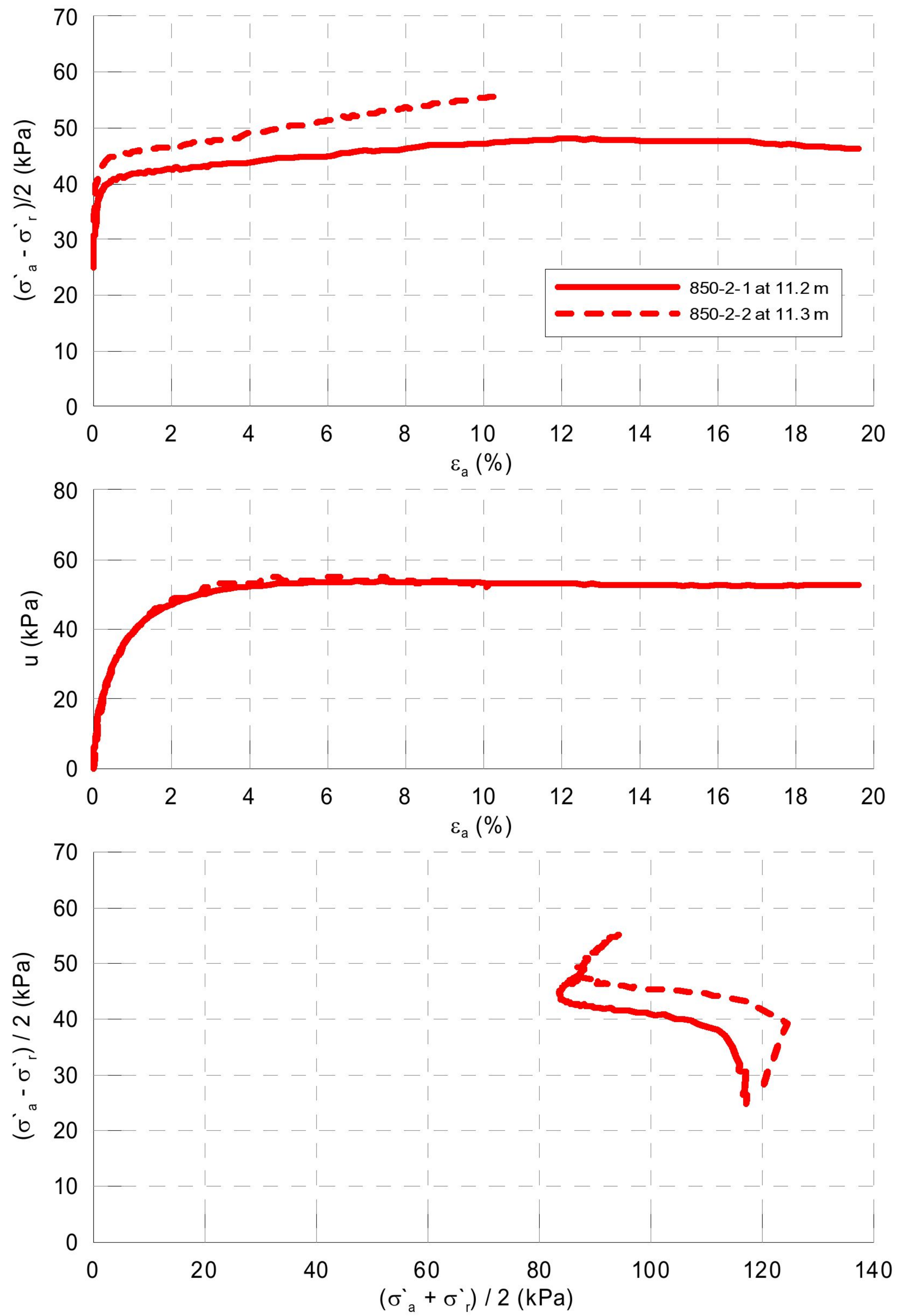
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
		Dato 2006-01-05
	Comparaison of 850-1 triaxial tests at about 11.3 m	Figur 35



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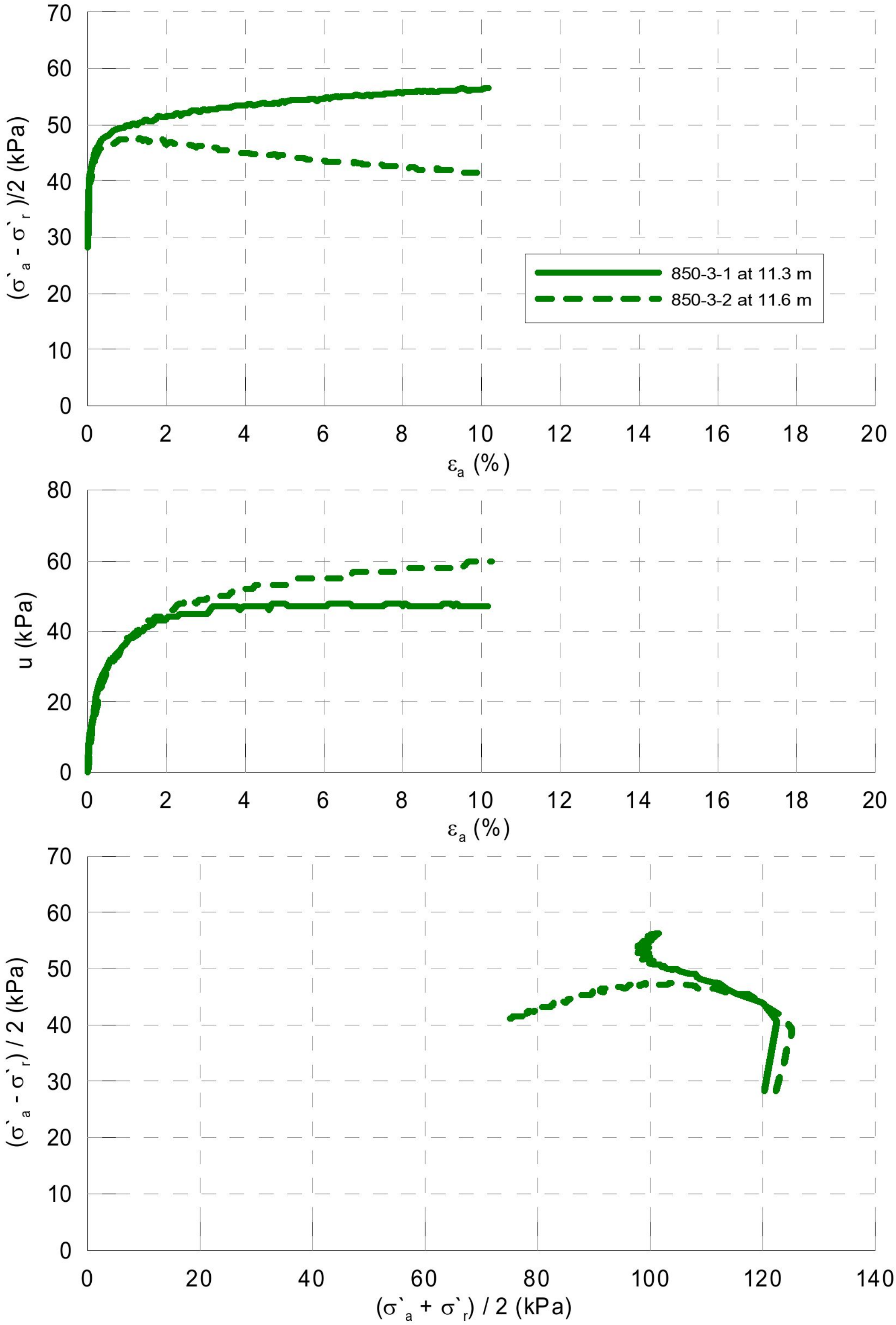
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
	Comparaison of 850-2 triaxial tests at about 11.3 m	Dato 2006-01-05
		Figur 36



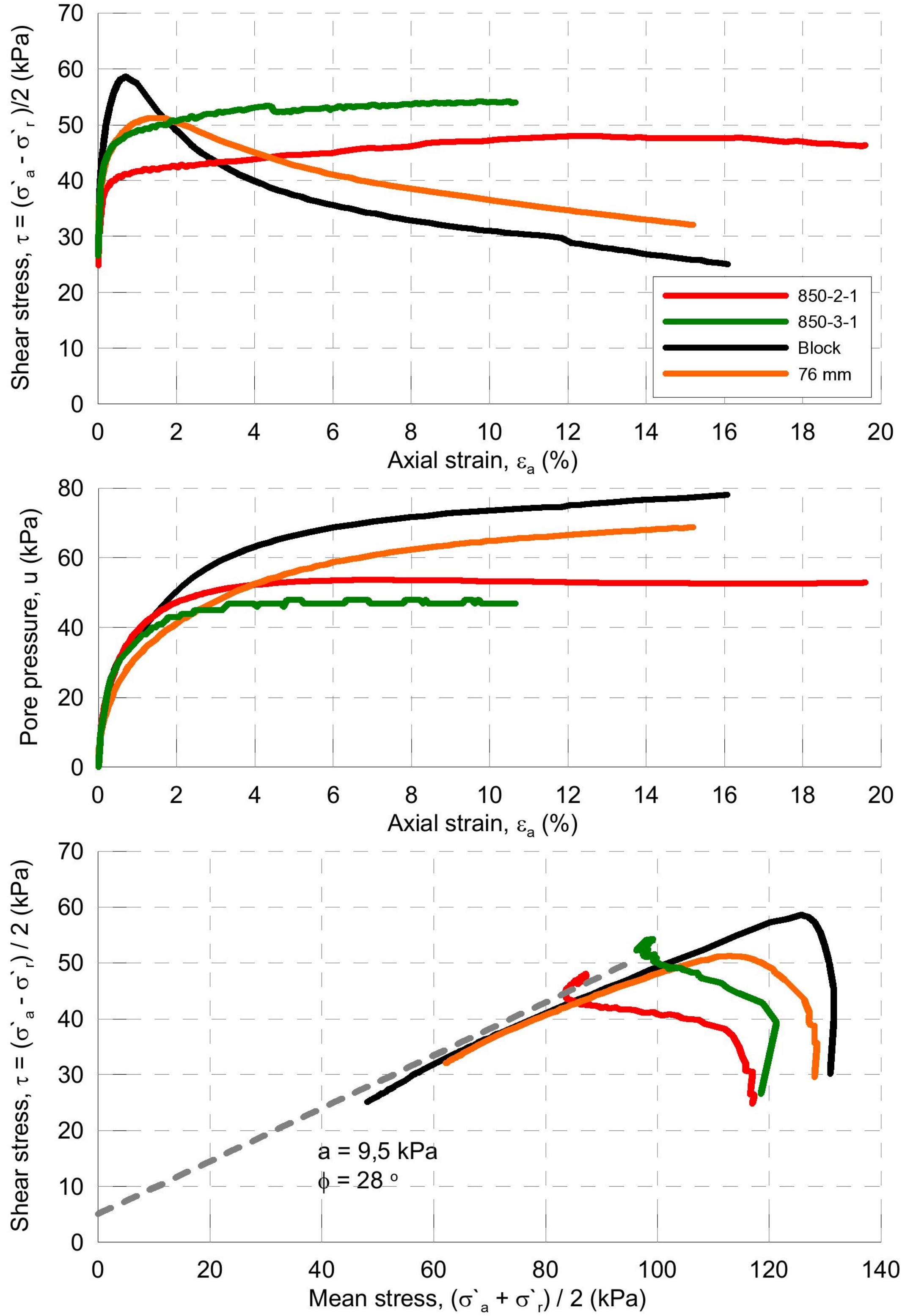
Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparaison of 850-3 triaxial tests at about 11.3 m

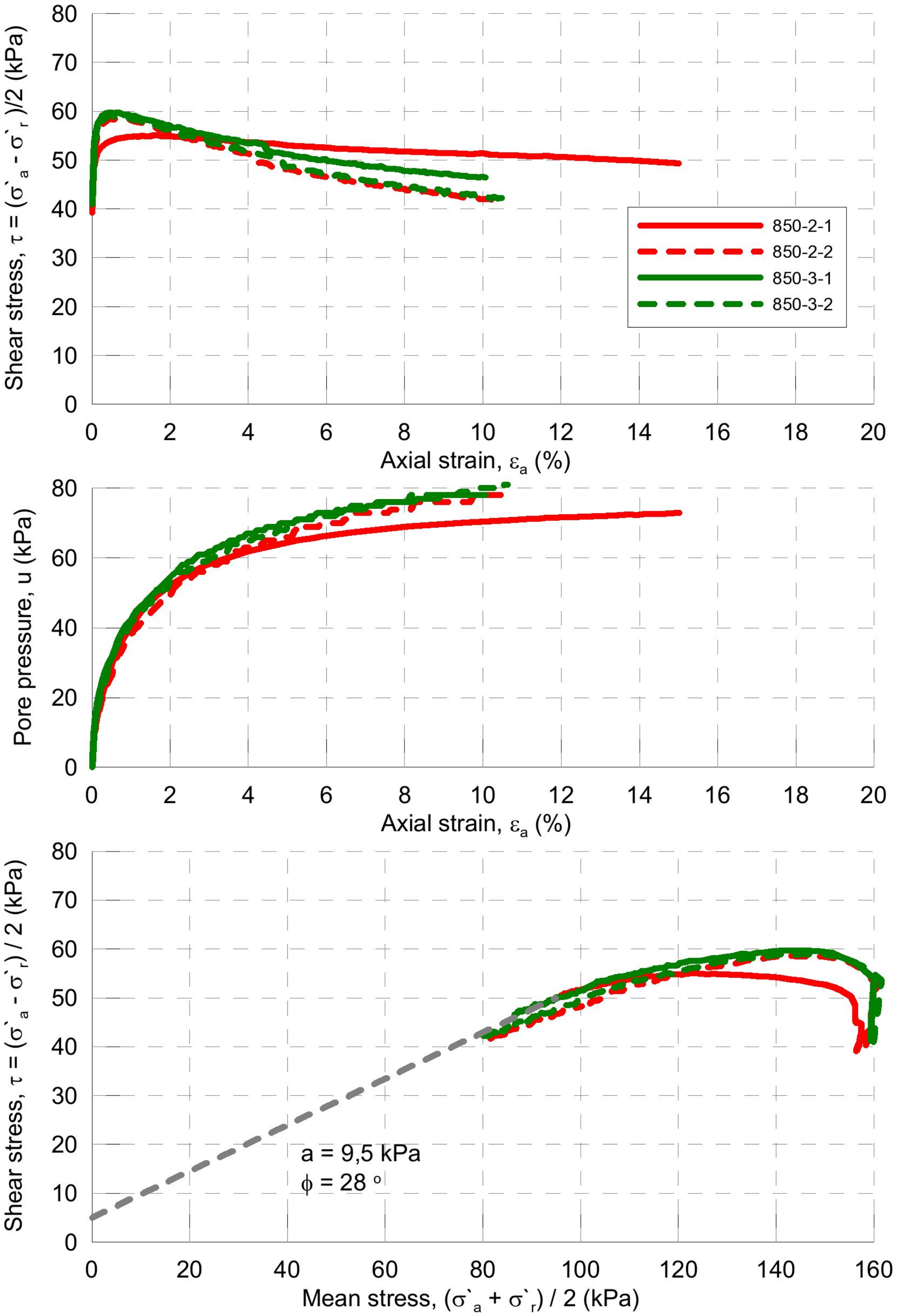
Teknologirapport	2426
Dato	2006-01-05
Figur	37

C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\Triax-3-11,3



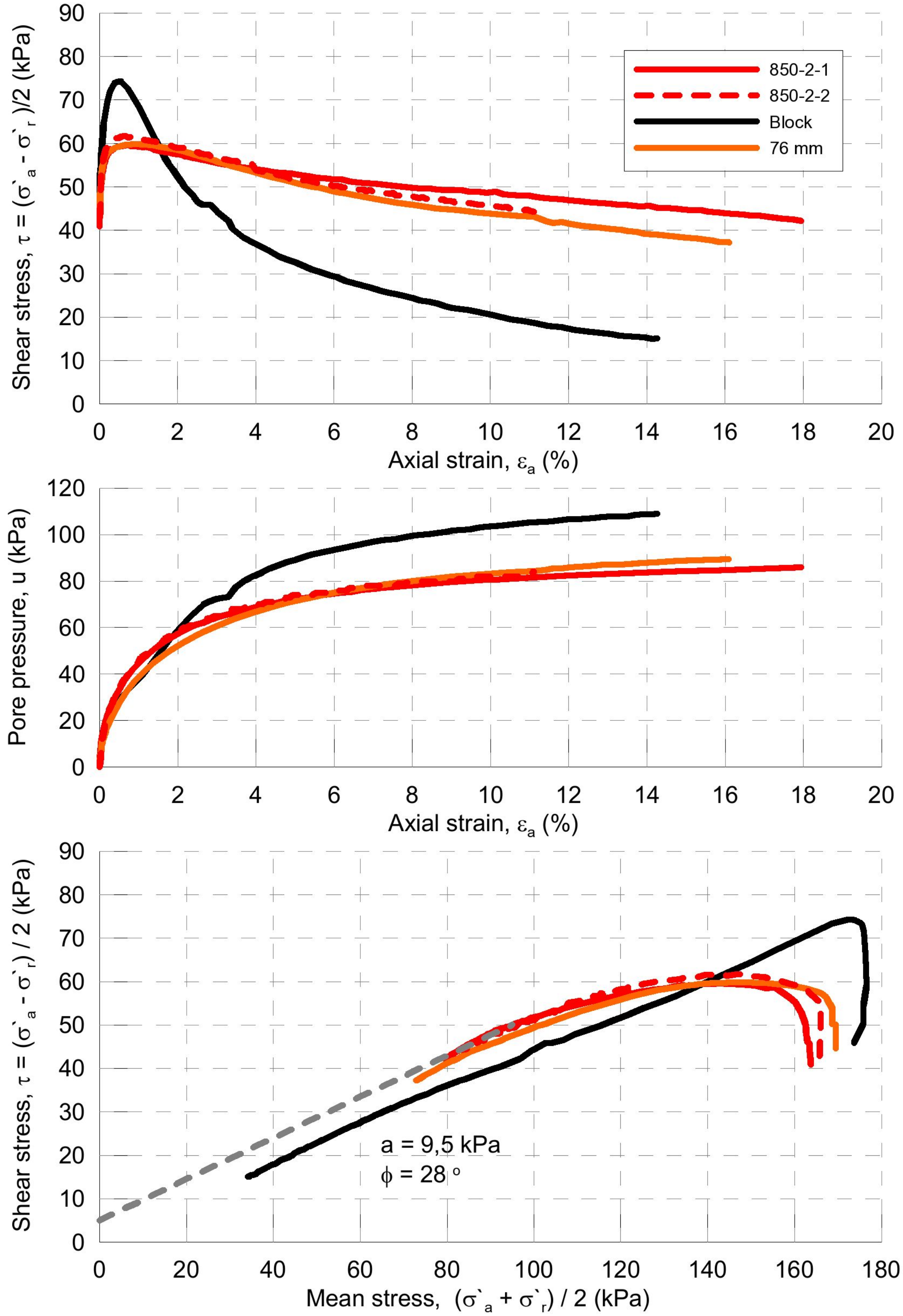
C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\TRX fra 11.3m og 12.3m

Statens vegvesen	R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
	Triaxsial test from 11.3m and 12.3m	Dato 2006-04-03
		Figur 38



Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
		Dato 2006-04-03
	All triaxial test from 17.0 to 17.8m	Figur 39

C:\Documents and Settings\nouri\Mine dokumenter\Rv2plott\all\E39TRX17.0-17.8m



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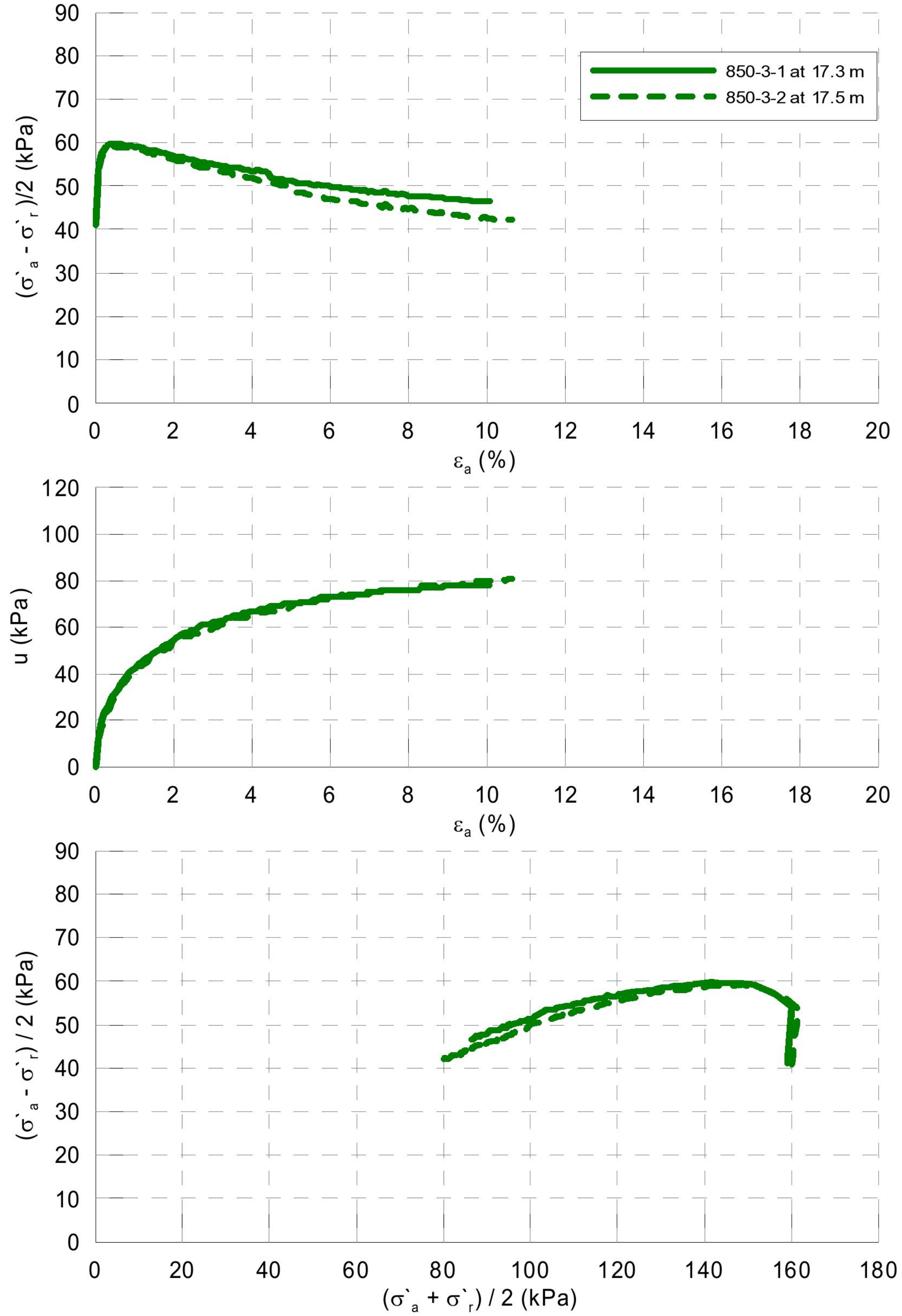
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
	All triaxial test from 18,0 to 18,8m	Dato 2006-04-03
		Figur 40



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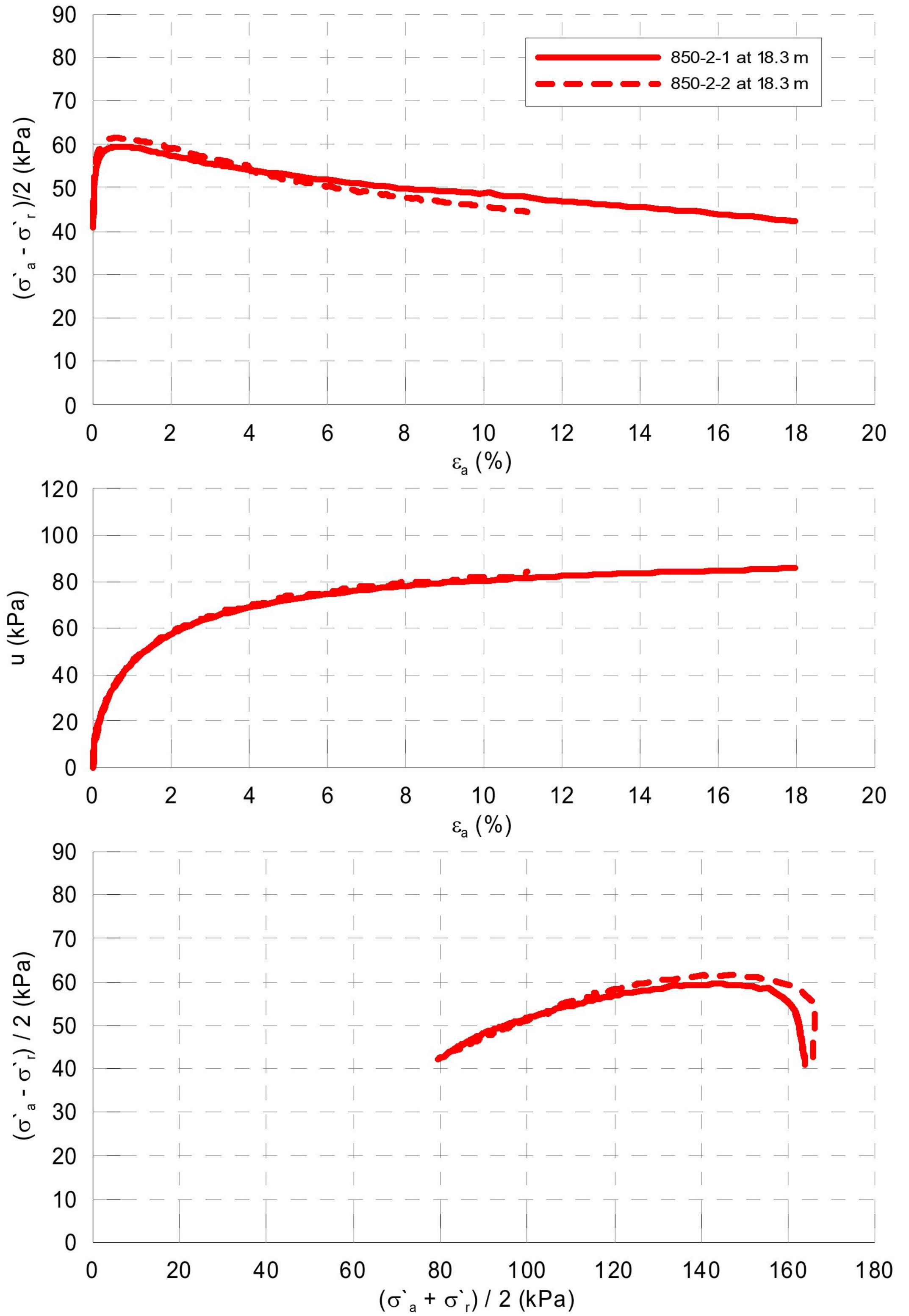
Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
		Dato 2006-01-05
	Comparaison of 850-3 triaxial tests at about 17.4 m	Figur 41



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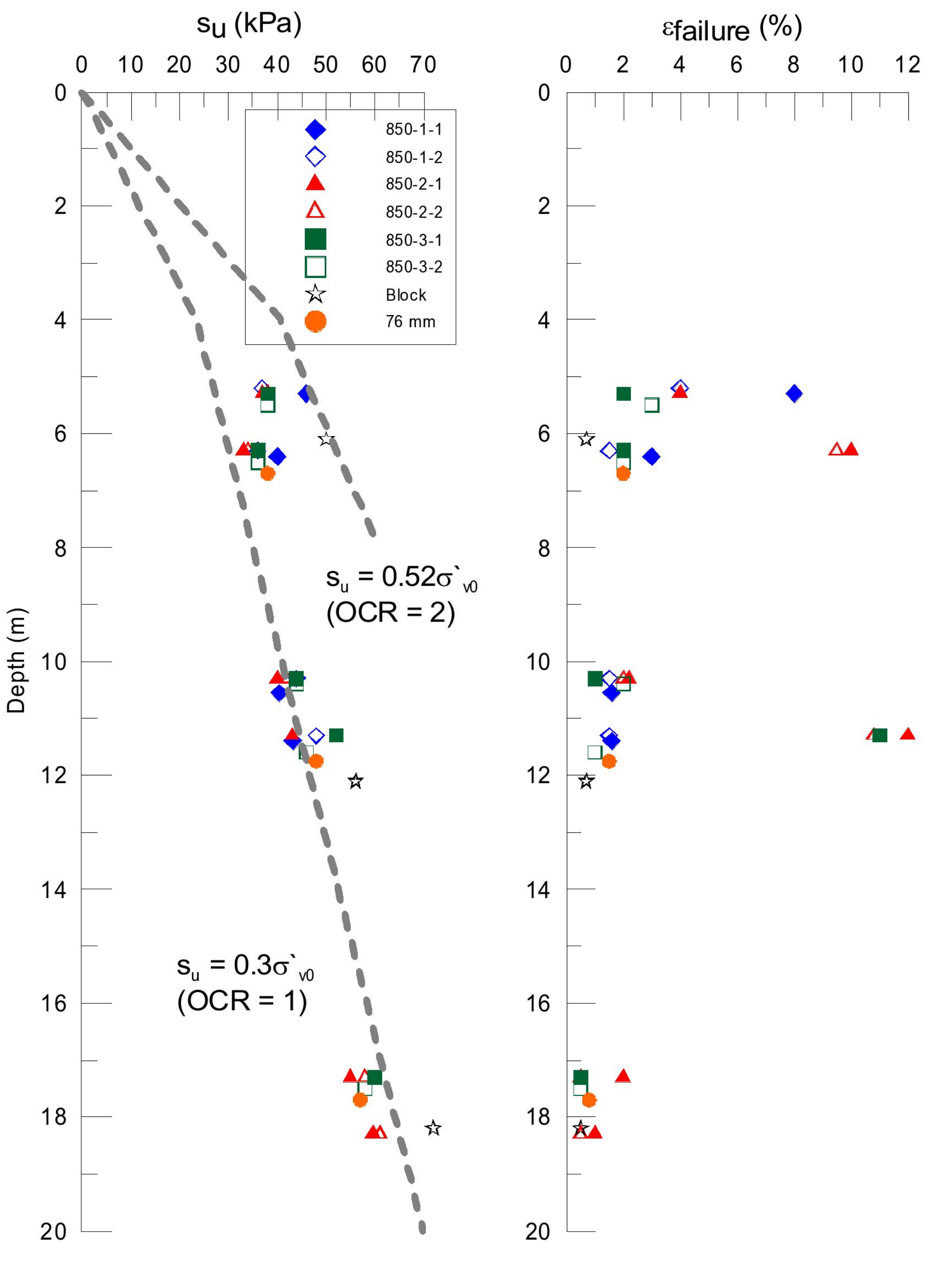
Statens vegvesen	R&D project - Rv. 2 Kløfta - Nybakk - Profil 850	Teknologirapport 2426
	Comparaison of 850-2 triaxial tests at about 18.34 m	Dato 2006-01-05
		Figur 42



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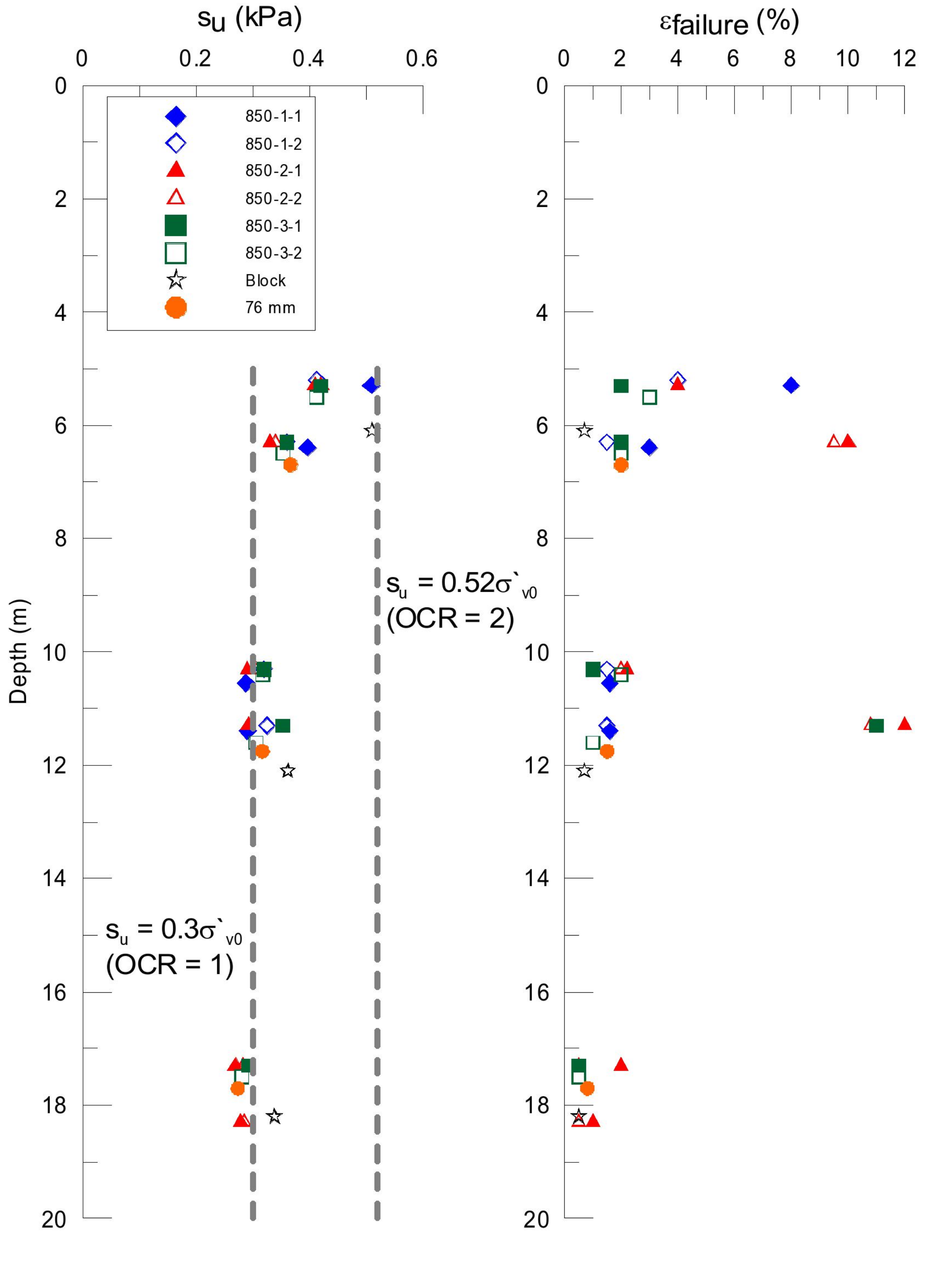
Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Triaxial compression test result

Teknologirapport	2426
Dato	2006-01-05
Figur	43



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Statens vegvesen

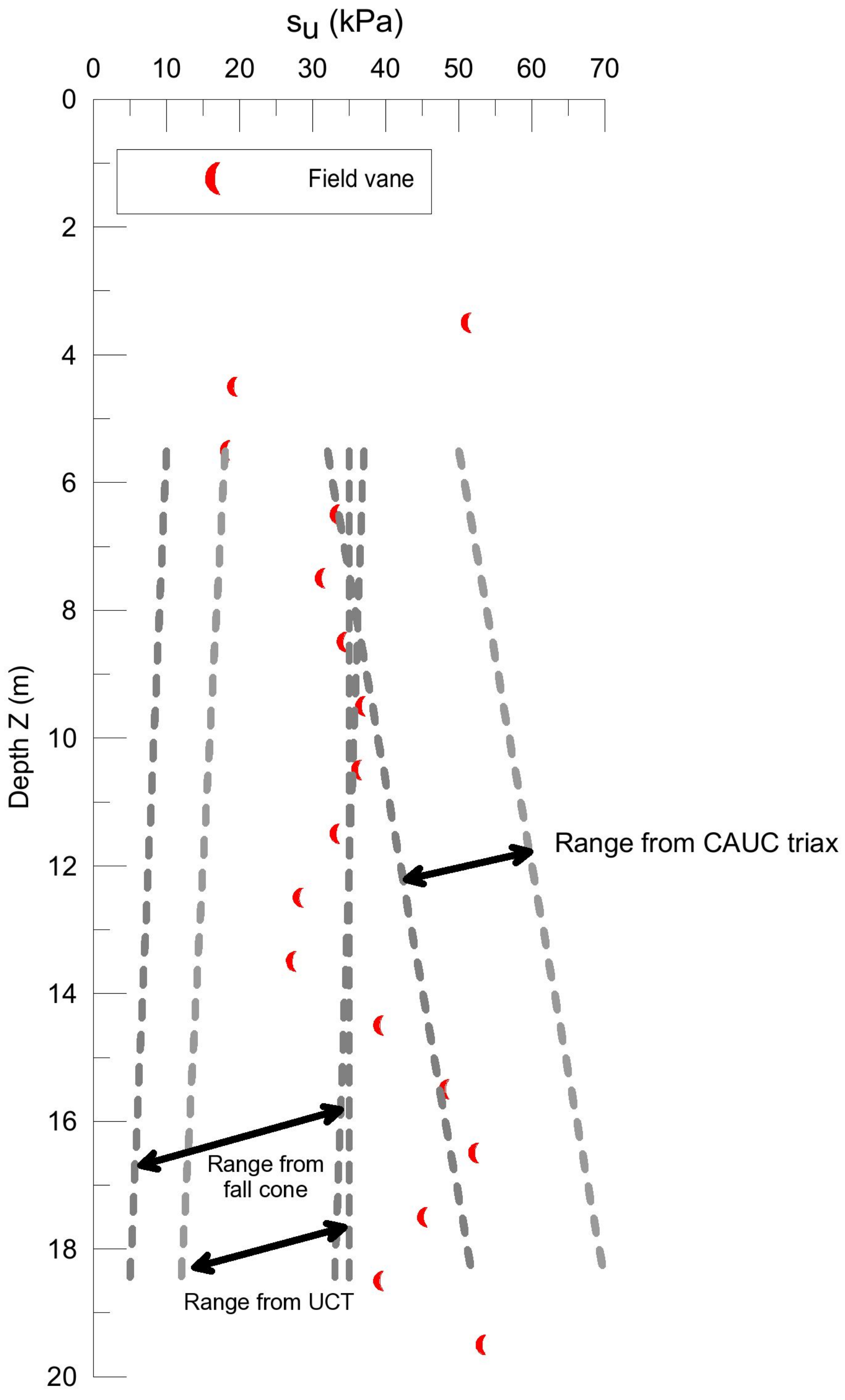
R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Triaxial compression test result with normalised s_u

Teknologirapport 2426

Dato 2006-01-05

Figur 44



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Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Comparison of s_u values from various techniques

Teknologirapport 2426

Dato 2006-04-03

Figur 45

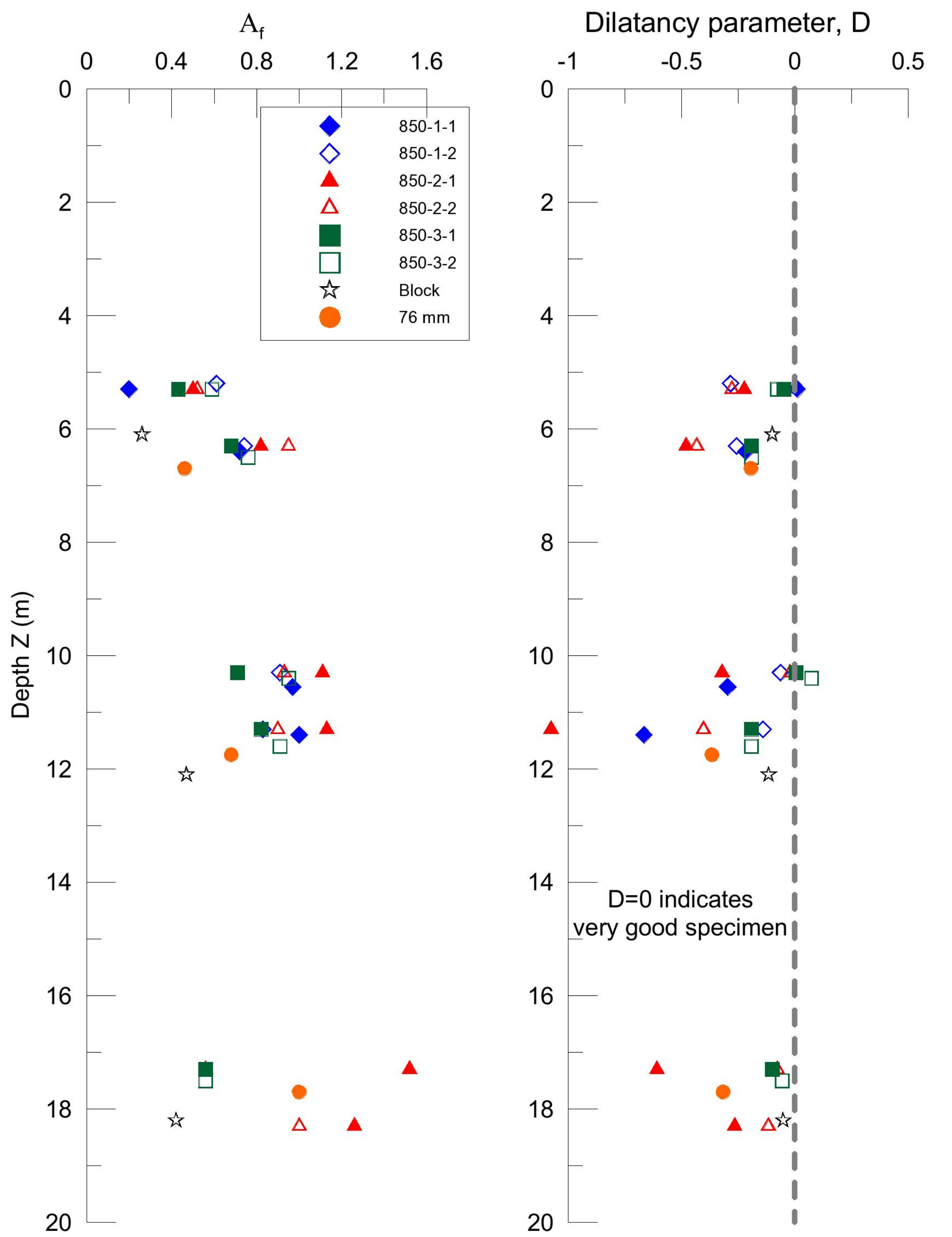
Depth	5.0 - 5.8 m		6.0 – 6.8 m		10.0 – 10.8 m		11.0 – 12.1 m		17.0 – 17.8 m		18.0 – 18.8 m	
Hole	D	A_f	D	A_f	D	A_f	D	A_f	D	A_f	D	A_f
1 – 1	0.010	0.2	-0.17	0.72	-0.297	0.97	-0.667	1				
1 – 2	-0.284	0.61	-0.258	0.74	-0.064	0.91	-0.14	0.83				
2 – 1	-0.224	0.5	-0.479	0.82	-0.321	1.11	-1.076	1.13	-0.609	1.52	-0.67	1.26
2 – 2	-0.278	0.52	-0.43	0.95	-0.023	0.93	-0.404	0.9	-0.078	0.56	-0.117	1
3 – 1	-0.049	0.43	-0.192	0.68	0.005	0.71	-0.193	0.82	-0.1	0.56		
3 – 2	-0.078	0.59	-0.192	0.76	0.073	0.95	-0.193	0.91	-0.056	0.56		
Block			-0.1	0.26			-0.117	0.47			-0.052	0.42
76mm			-0.194	0.46			-0.367	0.68			-0.317	1

Table 8 Pore pressure parameters D and A_f

Depth	5.0 - 5.8 m		6.0 – 6.8 m		10.0 – 10.8 m		11.0 – 12.1 m		17.0 – 17.8 m		18.0 – 18.8 m	
Hole	$\Delta e/e_0$	$\Delta V/V_0$	$\Delta e/e_0$	$\Delta V/V_0$	$\Delta e/e_0$	$\Delta V/V_0$	$\Delta e/e_0$	$\Delta V/V_0$	$\Delta e/e_0$	$\Delta V/V_0$	$\Delta e/e_0$	$\Delta V/V_0$
1 – 1	0.065	3.007	0.049	2.405	0.032	1.566	0.034	1.615				
1 – 2	0.061	2.953	0.032	1.582	0.058	2.721	0.054	2.723				
2 – 1	0.039	1.961	0.06	3.011	0.069	3.611	0.11	5.2229	0.098	4.746	0.093	4.713
2 – 2	0.043	2.045	0.069	3.44	0.014	0.682	0.064	2.997	0.059	2.972	0.091	4.362
3 – 1	0.023	1.218	0.045	2.26	0.035	1.808	0.095	4.567	0.102	5.083		
3 – 2	0.031	1.582	0.051	2.491	0.074	3.646	0.0555	2.726	0.055	2.749		
Block												
76mm			0.043	2.231			0.056	2.762	0.085	4.39		

Table 9 Sample quality for triaxial tests.

Annex 46



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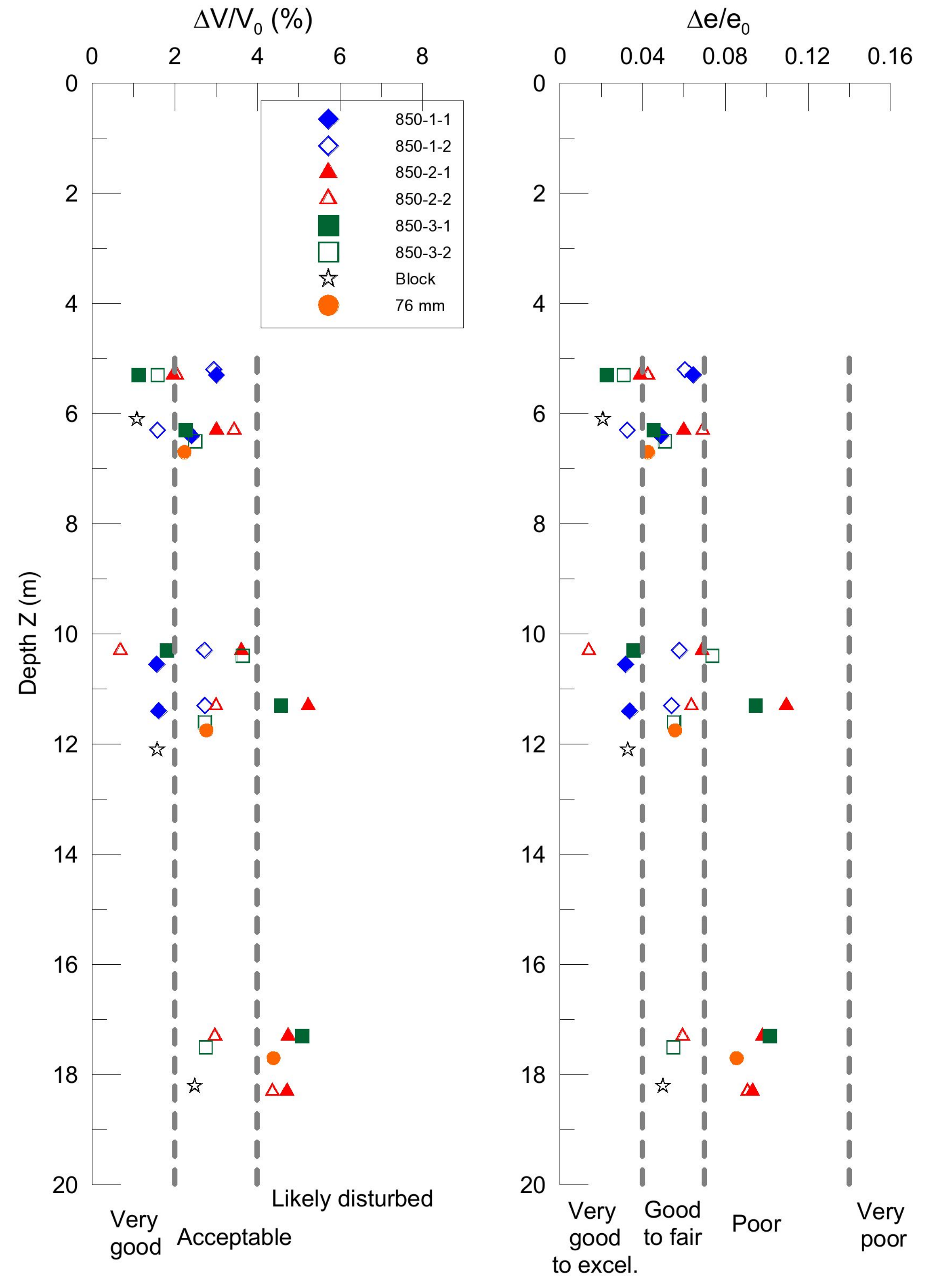
Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Pore water pressure coefficient A_f and dilatancy parameter, D

Teknologirapport	2426
Dato	2006-04-03
Figur	47



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Statens vegvesen

R&D project - Rv. 2 Kløfta - Nybakk - Profil 850

Quality of triaxial samples

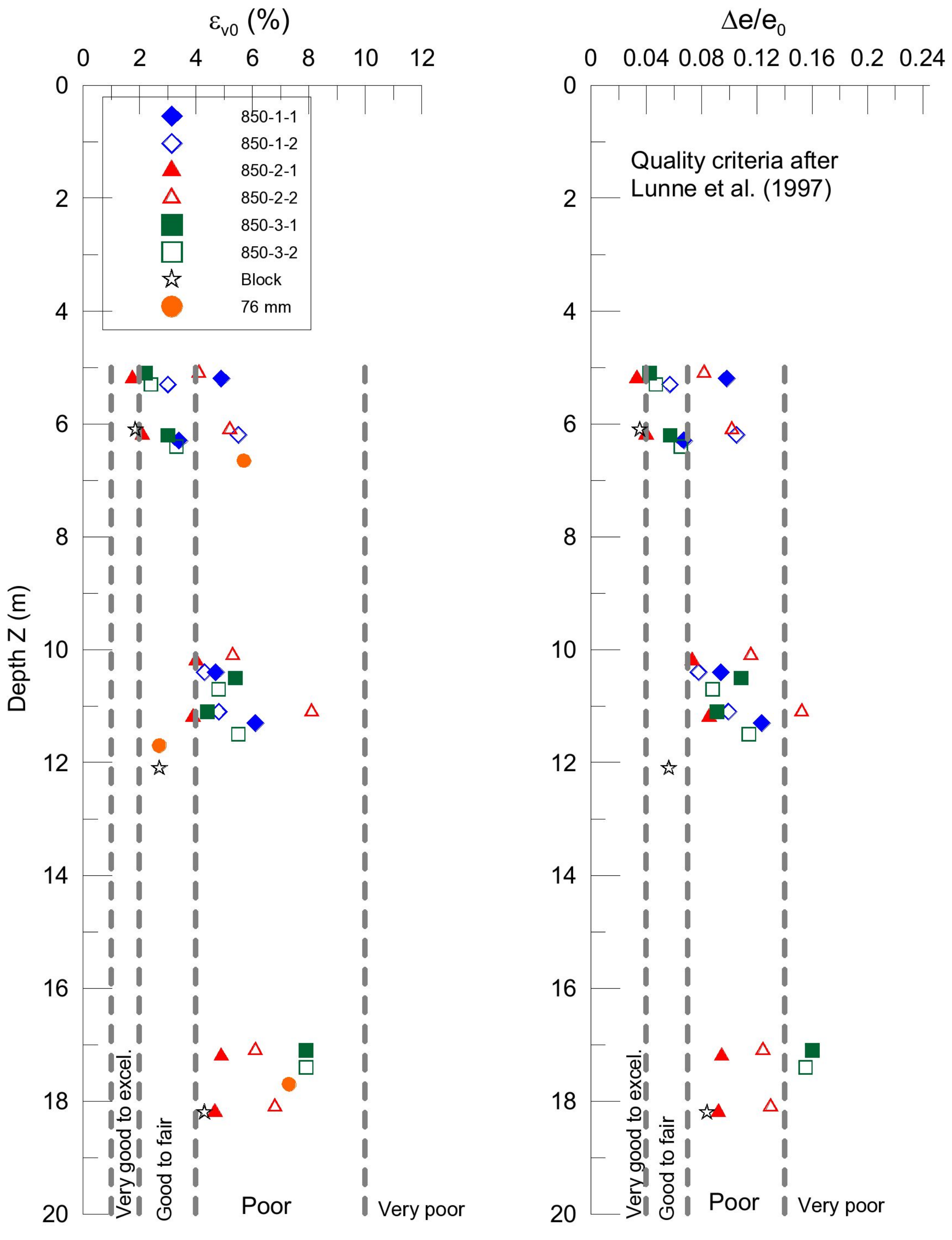
Teknologirapport
2426

Dato
2006-04-03

Figur
48

Depth	5.0 - 5.8 m		6.0 – 6.8 m		10.0 – 10.8 m		11.0 – 12.1 m		17.0 – 17.8 m		18.0 – 18.8 m	
hole	A	A_f	D	A_f	D	A_f	D	A_f	D	A_f	D	A_f
1 – 1	4.9	0.098	3.4	0.067	4.7	0.094	6.1	0.124				
1 – 2	3	0.057	5.5	0.105	4.3	0.078	4.8	0.099				
2 – 1	1.75	0.033	2.1	0.04	4	0.073	3.9	0.086	4.9	0.095	4.67	0.092
2 – 2	4.1	0.082	5.2	0.102	5.3	0.116	8.1	0.152	6.1	0.124	6.8	0.13
3 – 1	2.2	0.042	3	0.57	5.4	0.108	4.4	0.91	7.9	0.243		
3 – 2	2.4	0.047	0	0	4.8	0.088	5.5	0.114	7.9	0.155		

Table 10 Sample quality for oedometer tests.



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Statens vegvesen	**R&D project - Rv. 2 Kløfta - Nybakk - Profil 850**	Teknologirapport 2426
	Sample quality for oedometer tests	Dato 2006-04-03
		Figur 50

Procedures at NGI's laboratory

Annex 51

Sample opening (cylinder):

There are no standard procedures for opening sample cylinders. The type and number of laboratory analyses to be performed will vary from project to project, but material closer than 2 times the sample diameter is not utilized for determination of shear strength.

Triaxial tests:
- Sample height = ca. 110mm
- Sample cross section area = ca 23 cm^2
- Filter paper. 4 in spiral (no correction necessary)
- Drainage at top and bottom of sample
- Stress correction due to membrane (C-value and radial pre stressing)
- Back pressure approx. 700 kPa
- Day 1: mounting of sample and applying isotropic consolidation pressure
- Day 2: back pressure and applying deviator stress
- Day 3: B-value measurement (requirement >95 %) and load increase to failure (approx. 0.7 %/hour)

Oedometer tests:
- Sample height = 20mm
- Sample cross section area =20cm^2
- Loading procedure and ratio U_b/σ_a will be apparent from plot
- Loading rate approx. 0.5-0.7 %/hour

Correction for false deformation in apparatus.

Procedures at Multiconsult's laboratory

Routine tests on 54 mm sample cylinders

If possible the upper and lower 10 cm of the test sample is not utilized. Samples for determining shear strength are taken where the soil is assumed to the least disturbed.

Water content and density

Water content for unconfined compression tests are determined on soil trimmed from the end surfaces.

When CRS or triaxial tests are performed water contents and densities are recorded on the borehole profile from measurements on the soil specimens.

When no CRS or triaxial tests are performed densities and water contents are determined on separate soil specimens.

Oven dried materials are taken directly from the oven and weighed. No exsicator is utilized.

Humus content (Naoh) is determined on dried samples for determination of water content.

Shear strength is determined both by unconfined compression tests and as fallcone tests on a separate sample both for undisturbed and remoulded values.

w_L and w_p are normally determined on samples close to or on the sample used for determining fallcone strength.

Where the remoulded strength lies within cone penetration values of 7 – 15 mm for the 60 g/60° cone the values for water content and remoulded cone penetration values are used for determining w_L.

For softer or firmer soils w_L is determined on separate samples.

Triaxial tests

Tests are performed on samples with 100 mm height. The sample is weighed and measured for calculation of density.

Radial drainage is provided by filter strips + drainage paths at both end surfaces.

For anisotropic consolidation the calculated horizontal pressure σ_{rc} is applied first. The following day the remaining axial load is applied in steps until σ_{ac} is reached. On day 3, if consolidation of the sample is completed, backpressure is applied in steps until a level of approx. 300 kPa is reached and the pore pressure response of the sample is recorded. If a pore pressure response of 0.95 % is not obtained, more backpressure is applied.
Backpressure is applied without altering the effective stress σ_{ac} of the sample.

Loading the sample to failure is performed with a rate of 2 % per hour and the test is terminated when a strain of 18 % is achieved.

Hydrometer analysis

A sample mass of 40 g dry soil material (calculated or weighed) is utilized. For clay wet samples are used and the water content is determined on a parallel and homogenised sample. The dry weight of the sample is calculated. The sample is submerged in water and a dispersing agent until the next day. The sample is then transferred to a mixer and stirred while distilled water is added and then poured into the measuring glass with more distilled water added up to the 1000 ml mark.

For every time interval the reading of the hydrometer and the temperature of the suspension is recorded.
The normal time intervals in minutes are 0.5 – 1 – 2 – 5 – 10 – 20 – 30 – 60 – 120 – 240. The final reading is taken the following day for recording the percentage of clay content.

CRS

The sample is pushed into the oedometer ring having a height of 20 mm and a cross section area of 20 cm^2. The surplus material is weighed and the water content determined.

The oedometer test is performed with a constant rate of strain of approx. 2 % per hour.
The test is terminated when a load of 1000 kPa is reached.

Specific weight

Specific weight is determined using a pycnometer. Pycnometers having a volume of about 700 – 750 cm^3 are utilized. About 100 – 150 g dry material is used for the analysis. Distilled water is added until the sample is fully immerged and the pycnometer is then subjected to a controlled vacuum in order to remove possible air bubbles. The pycnometer is then filled up with more distilled water and left in a temperature controlled water bath until a stable temperature of 20^o C is achieved.

The water level in the pycnometer is adjusted to the calibrated mark if necessary and the pycnometer is then weighed. When the weight of the soil sample is not known, the suspension is transferred to a beaker and left for drying in a drying oven and weighed when all the water is removed.

Procedures at the NPRA Central laboratory

Sample storage in the laboratory

Soil samples delivered to the Central laboratory are stored immediately after being received in a cooling room (approx. 6^o C) until the samples are opened and analysed.

Sample extraction

For extracting soil samples from the sample cylinders a hydraulically operated extraction bench is used where a ”tension rod” is used to move the rubber piston in a parallel movement with the piston of the extraction bench acting on the bottom of the sample. A rubber disk is employed between the bottom of the sample and the piston of the extraction bench in order to prevent shock effects on the sample when moving the piston in contact with the sample. The rubber disk has a somewhat larger diameter than the inner diameter of the sample cylinder in order to prevent that soil material may be squeezed in between the piston and the cylinder thereby making it easier to clean the cylinder. The rubber disk and the piston are first gently moved into contact with the bottom of the sample. The “tension rod” is then connected to the rubber piston in the sample cylinder through a special device on the extraction bench. The sample is then extracted at a constant rate on to an aluminium sheet moving at the same rate as the sample on to a receiving table. The sample is the divided into 10 cm long sub samples. Normally the two sub samples closest to the ends of the cylinder are not used for geotechnical analyses.

In this project both fallcone and unconfined compression tests are performed on the end sub samples in order to investigate if sample disturbance may be detected compared to sub samples from the middle part of the cylinder.

On every cylinder routine analyses were performed – visual classification, unit weight, water content, undrained shear strength measured by unconfined compression tests and fallcone tests, liquid limit, plasticity limit and grain size distribution as well as triaxial tests of type CAUC-1 and oedometer tests of type CRS.

The tests were performed in accordance with specifications given in NPRA's Handbook 14. "Laboratorierundersøkelser" (Laboratory analyses).

Routine analyses

Water content is determined on sub samples where also fallcone or unconfined compression tests have been performed, on oedometer tests and triaxial tests in accordance with process 14.426 in Handbook 014.

Density (unit weight) is measured on the whole cylinder and on oedometer/triaxial test samples in accordance with process 14.427 in Handbook 014.

Consistency limits. fallcone liquid limit and plasticity limit, are determined on all cylinders and in accordance with processes 14.441 and 14.442 in Handbook 014.

Undrained shear strength is determined by fallcone and unconfined compression tests and in accordance with the processes 14.471 and 14.472 in Handbook 014.

Grain size distribution is determined by hydrometer analysis on samples where triaxal tests have been performed and in accordance with process 14.433 in Handbook 014.

Triaxial tests are performed on samples from all the cylinders and in accordance with process 14.481 in Handbook. 014. A short description of the test is as follows:

- Sample height = ca. 100mm
- Sample cross section area = 22.9 cm^2
- Drainage in top and bottom
- Day 1: mounting of sample and application of a total radial stress and pore pressure in turns stepwise in four steps. Just after that additional loads are applied by use of a step motor with a rate of 0. 5 mm/hour. A comparator ensures that the axial stress remains constant during the whole consolidation period.
- Day 2: airing and reading the amount of expelled pore water during consolidation. The shear test is started at a strain rate of 2.0 mm/hour.

Oedometer tests of type CRS are performed on all samples and according to process14.482 in Handbook 014. In a CRS test the axial rate of strain is kept constant.

Test samples are mounted in a 20 cm^2 ring with a height of 20 mm and with a filter stone on top and at the bottom. The test specimen may drain upwards towards the top while the pore pressure is measured at the bottom. The load is applied by a step motor. The loading rate should not result in a pore pressure increase greater than 20 % of the axial load and should normally not be above 10 %. Higher values may be accepted at the start of the test. The test is stopped when the axial load has reached a value of 1200 kPa.

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