USING OFFSHORE SAMPLE QUALITY METHODOLOGY FOR ONSHORE INVESTIGATIONS

Tom Lunne, NGI

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- Background
- Development of sample quality criteria for marine clays
- Application for onshore projects in Norway
- Application for UK clays
- Need for other method(s) in overconsolidated clays
- Summary and conclusions

Background

- Sample quality is as important onshore as offshore
- In connection with deep water oil and gas development offshore Norway, sample quality becam key issue
- This led to comprehensive R&D work on establishing a criteria for evaluating sample quality
- The sample quality criteria has been accepted in the ISO standard for offshore and also in Norwegian adoption of Eurocode for onshore works

Large gravity platform in Norwegian Trench

Water depth: 320 m

Platform hight: 500 m

Skirts: 36 m long

Large forces, including cyclic

Very soft soils in upper layers

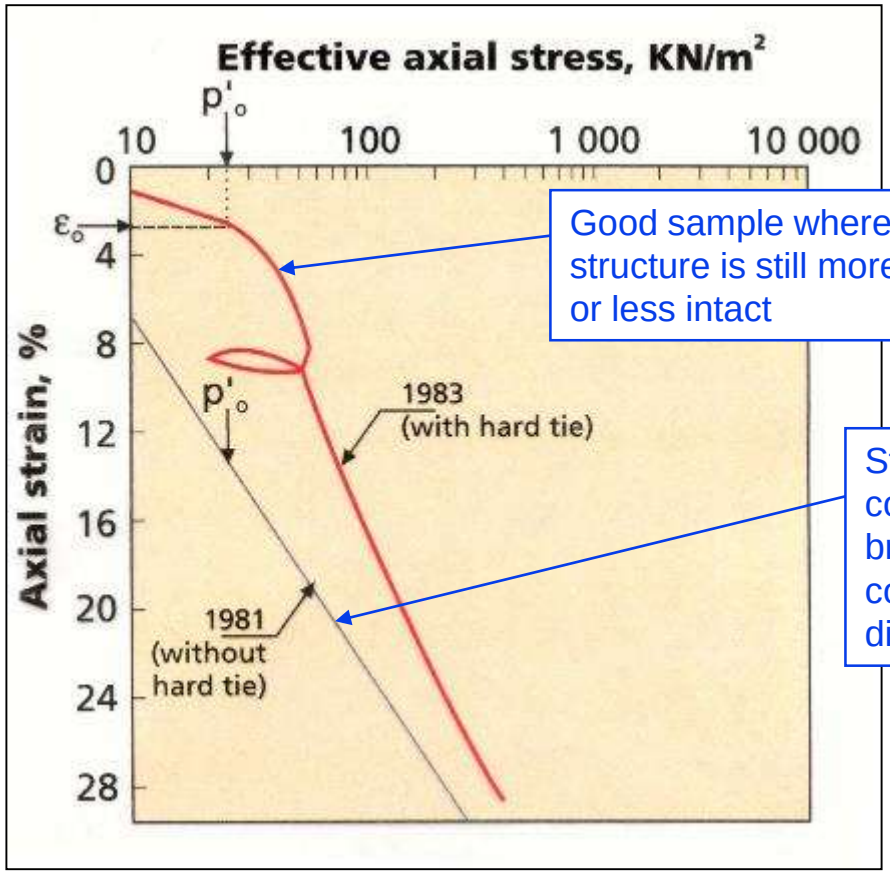
Accurate soil parameters required for installation and long term behaviour

Classical example from Troll field

Soil investigations started in 1981

Primitive method for controlling heave during drilling and sampling – *bad sample quality*

In 1983 a new method for heav compensation was developed – good sample quality



Results of CRSC oedometer test

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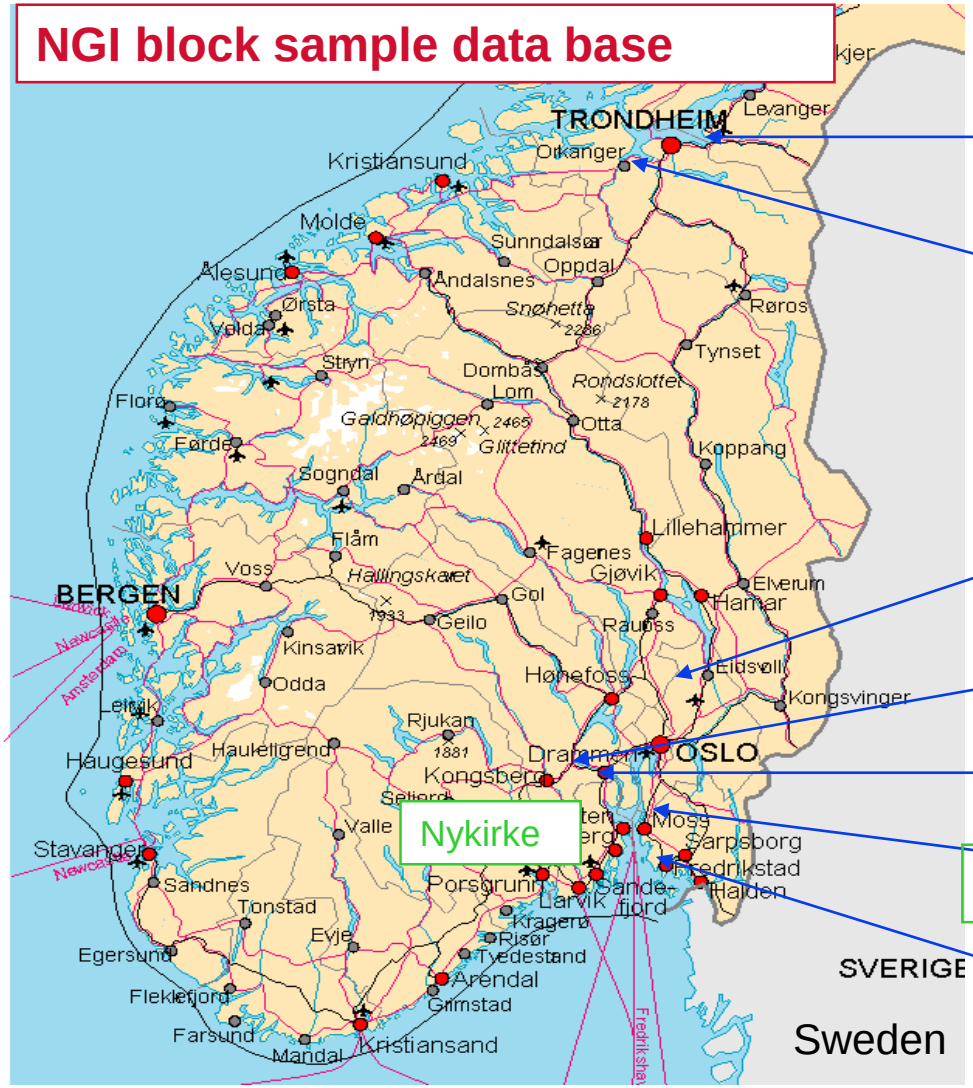
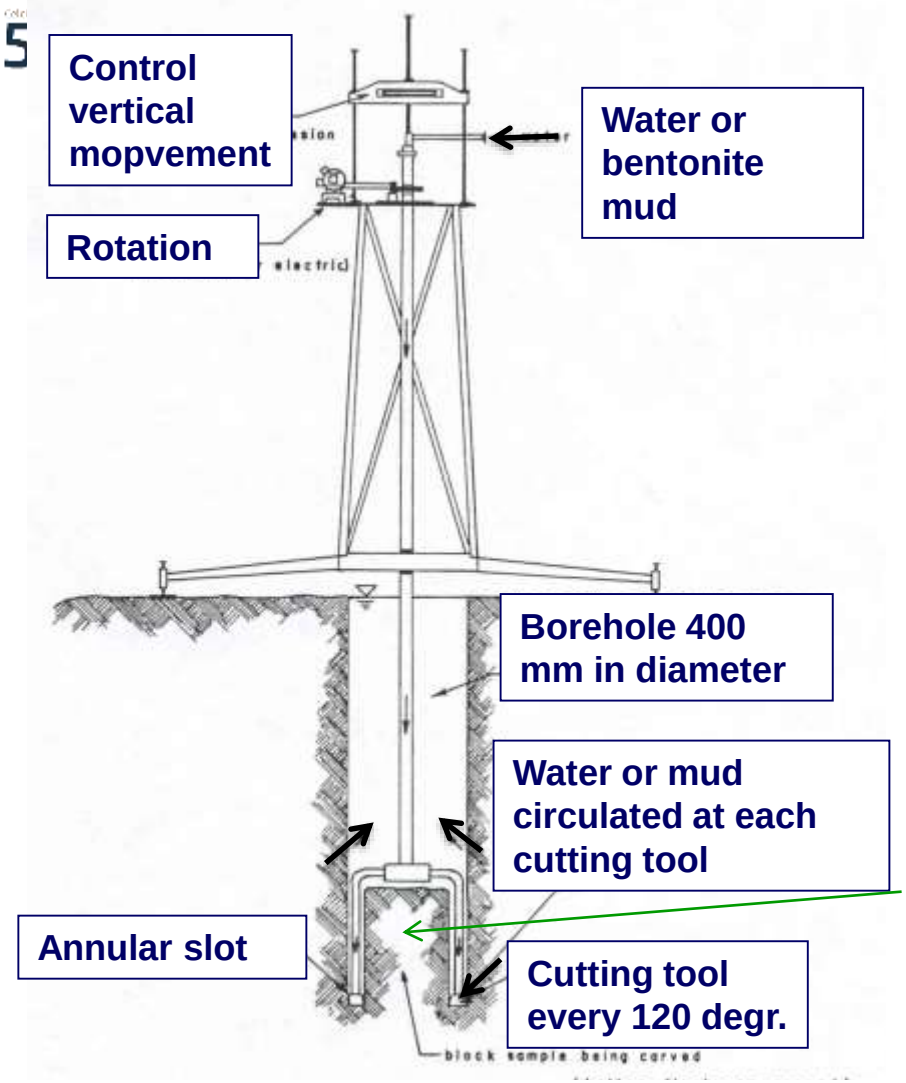
At a number of soft clay sites laboratory tests on high quality and low quality samples were carried out



NGI DATA BASE OF HIGH QUALITY BLOCK SAMPLES, 75 MM AND 54 MM PISTON TUBE SAMPLES

- ***Block sampler*** **: the best possible sample today (only onshore – use as benchmark)**
- ***75 mm thin wall piston sampler*** **: the best possible offshore sample today**
- ***54 mm composite (w/liner) piston tube sampler*** **: bad sample quality**



CANADIAN SHERBROOKE BLOCK SAMPLER

Sample dia= 250 mm
Sample height = 350 mm

Lefebvre and Poulin, 1979

CANADIAN SHERBROOKE BLOCK SAMPLER

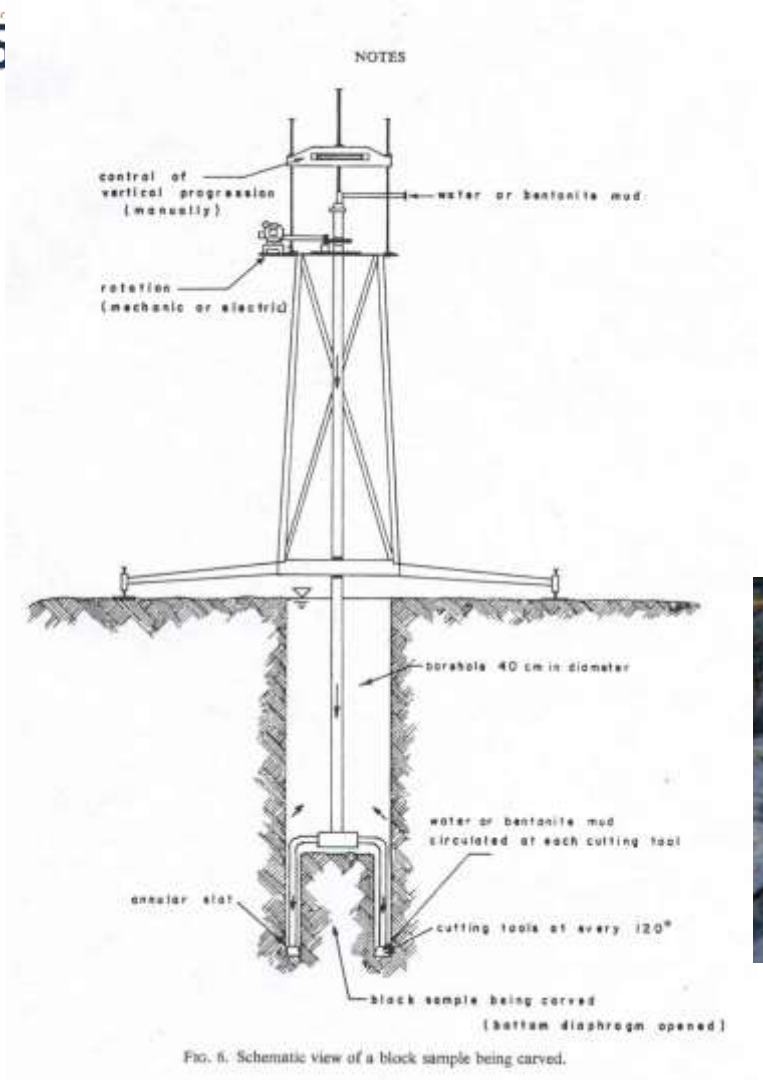


Fig. 6. Schematic view of a block sample being carved.

Sherbrooke block sampler

Cutting edge

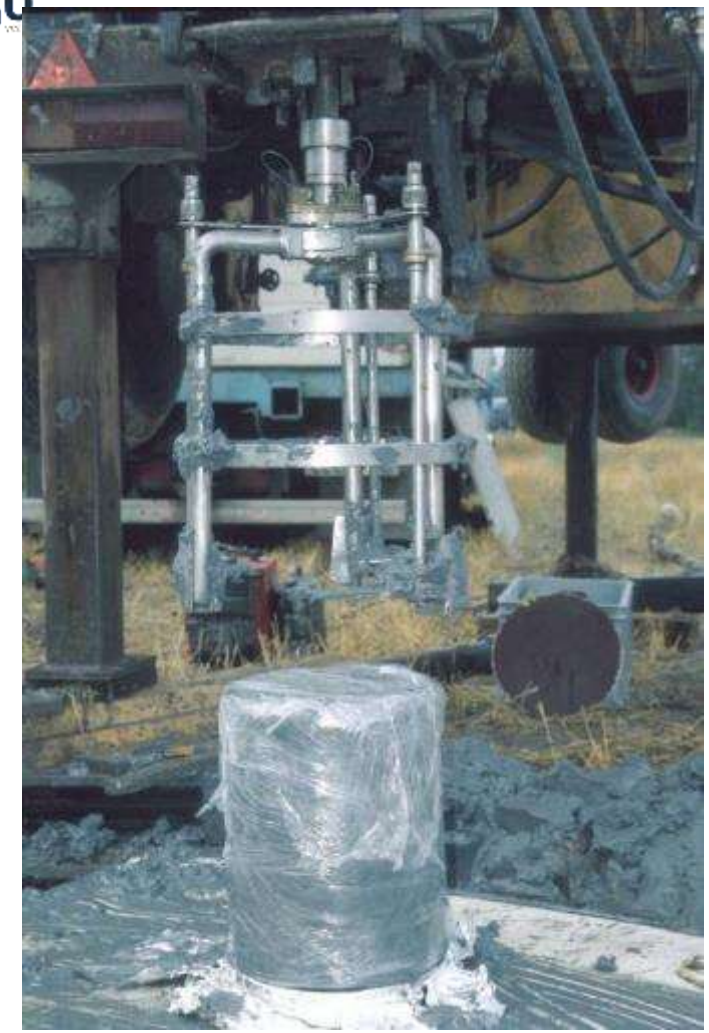
THE DRILL RIG USE TO OPERATE THE SHERBROOKE BLOCK SAMPLER

BLOCK SAMPLING WITH SHERBROOKE SAMPLER

Sampler is lowered into borehole

Sample as recovered

Install casing through upper crust



BLOCK SAMPLING WITH SHERBROOKE SAMPLER

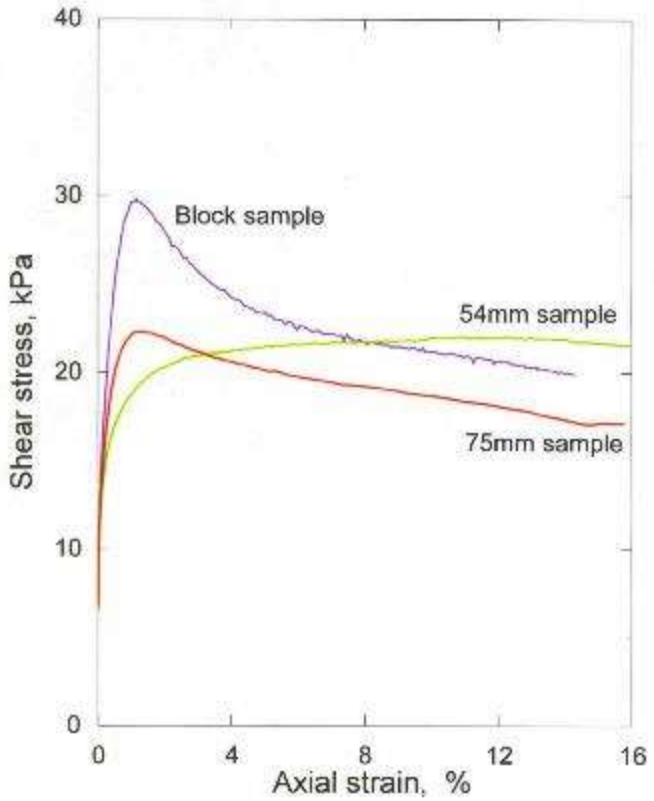
Block sample cleaned and wrapped in plastic cling film and sent to laboratory

BASIC LABORATORY TESTS

CRS CONSOLIDATION TEST : constant rate of strain

CAUC/CAUE TRIAXIAL TESTS : Consolidated anisotropically to best estimate of in situ stresses and sheared in compression or extension

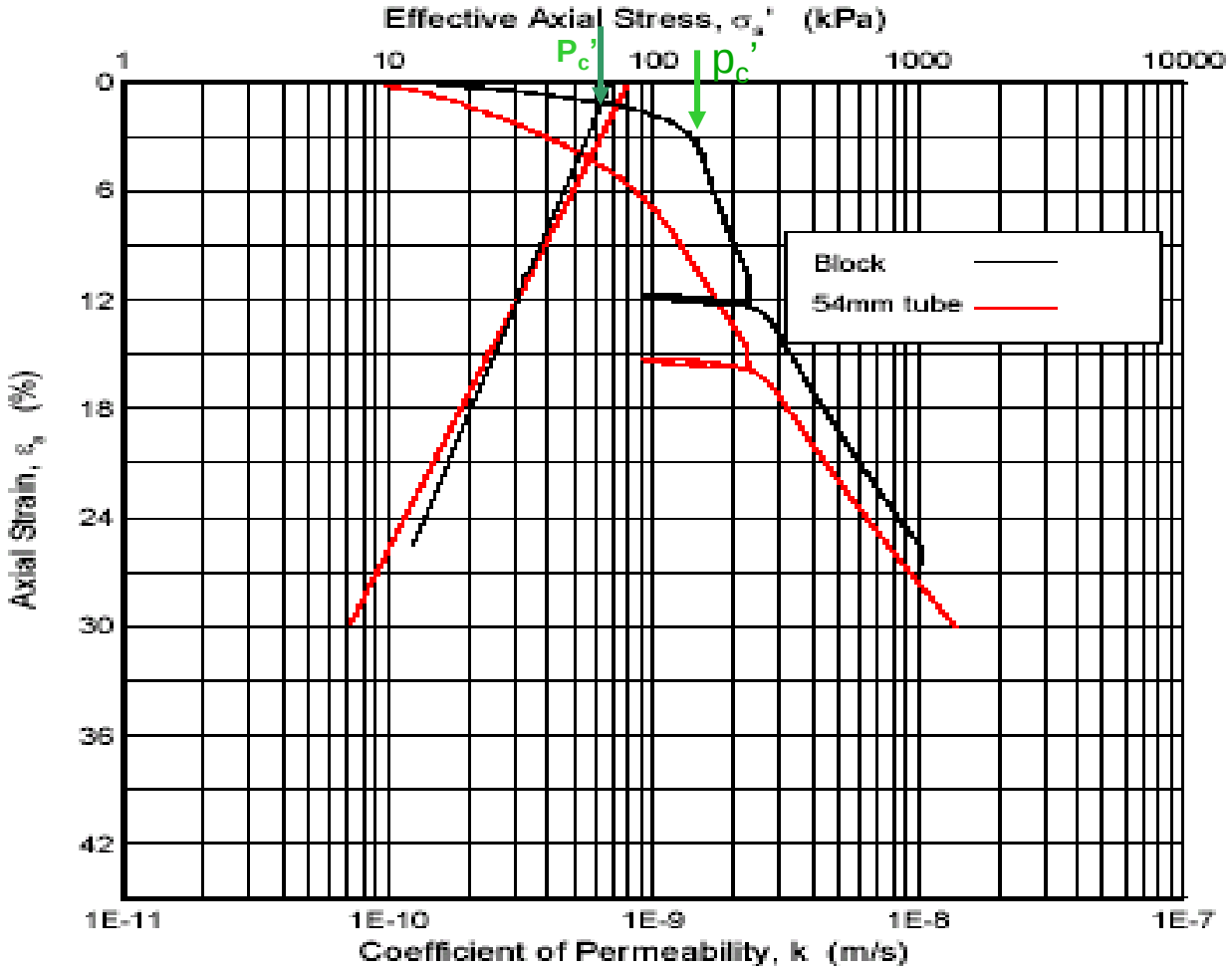
RESULTS FROM SHEARING PHASE OF CAUC TESTS



Shear stress versus axial strain for CAUC tests at 6.1m depth.

Lierstranda clay from 6.1 m depth

Results of CRSC tests on block and 54 mm samples

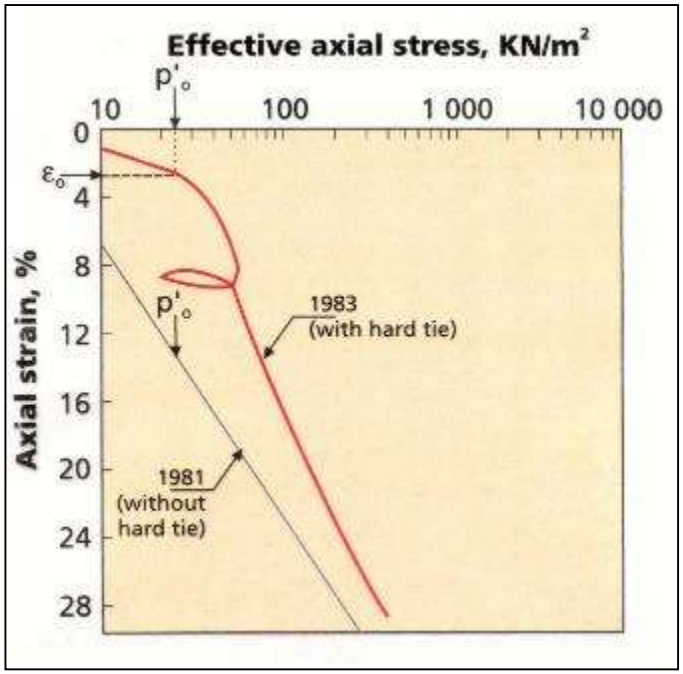


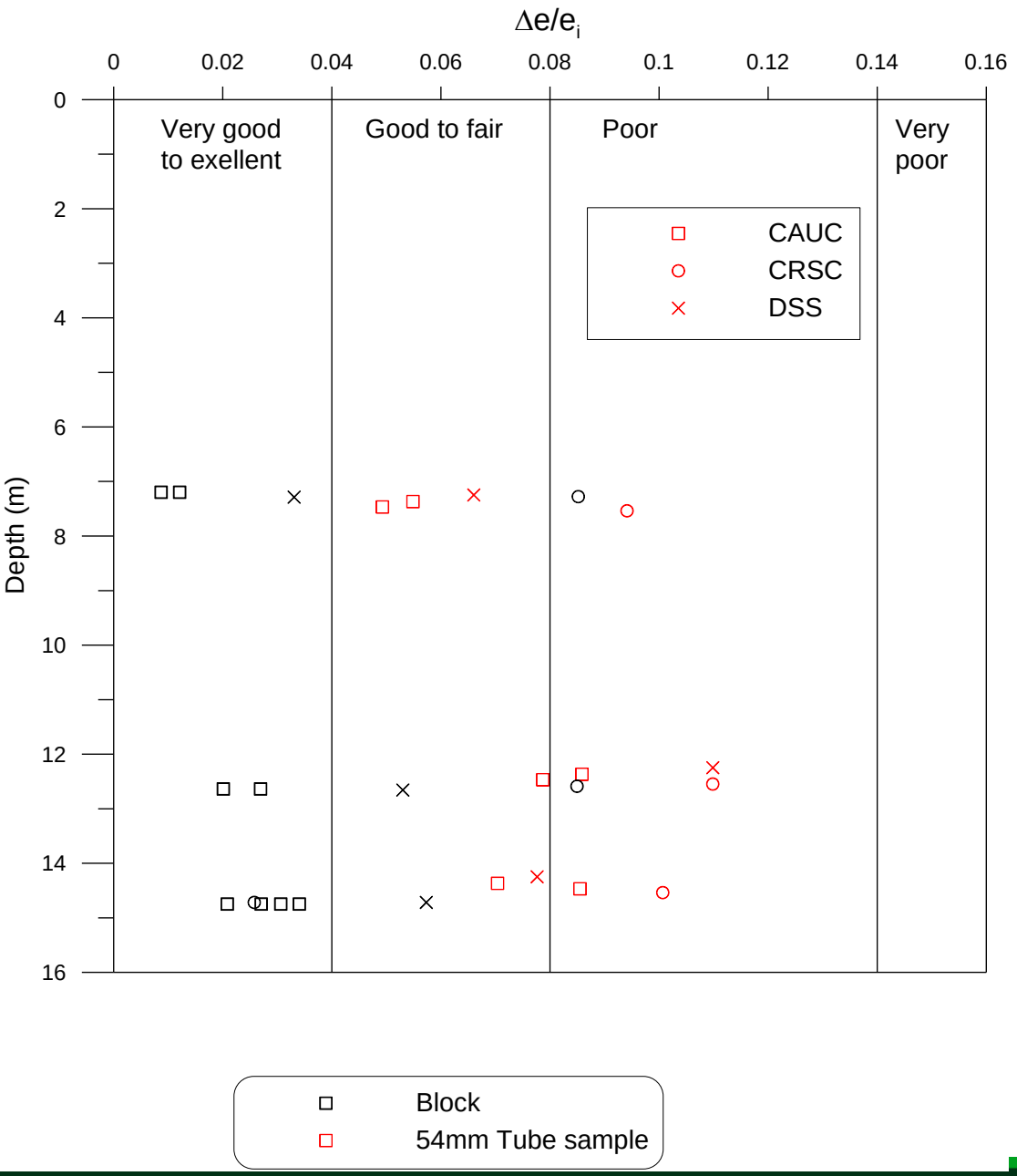
ONSØY CLAY

CRITERIA FOR QUANTIFYING SAMPLE DISTURBANCE

Volume change when consolidating a sample back to in situ stresses expressed as change in void ratio: $\Delta e/e_i$

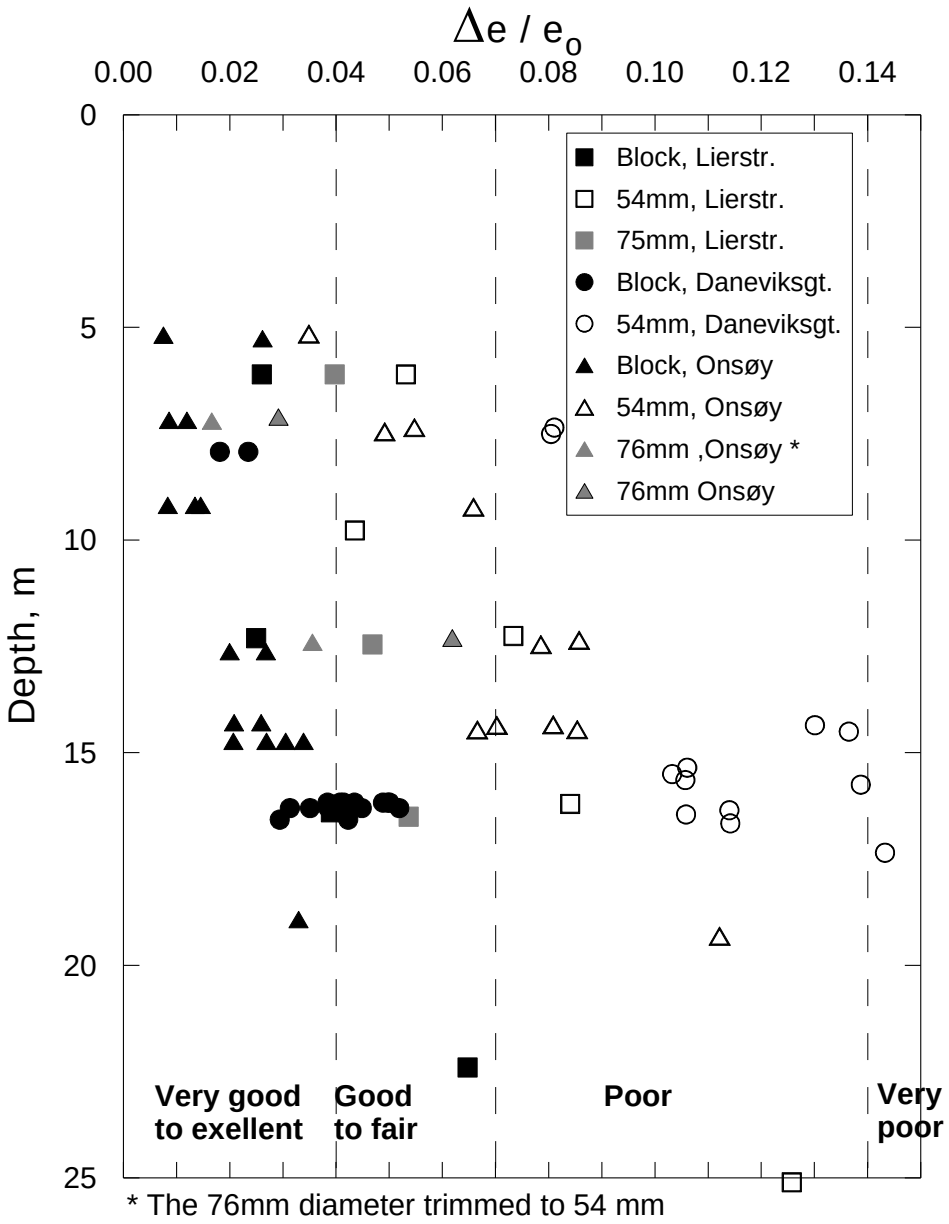
Oedometer test results on good and severely disturbed sample from Troll field illustrating strain (equivalent to $\Delta e/e_i$) as indicator of sample disturbance





Onsøy clay $\Delta e/e_i$ from CRSC and CAU tests

Based on similar results from a number of marine clays in Norway and one clay in Scotland (Bothkennar); NGI has developed a set of criteria for evaluation of SD



NGI's scale for quantifying sample disturbance based on change in void ratio when consolidating sample to best estimate of in situ stresses

Based on NGI's data base with block samples and piston samples

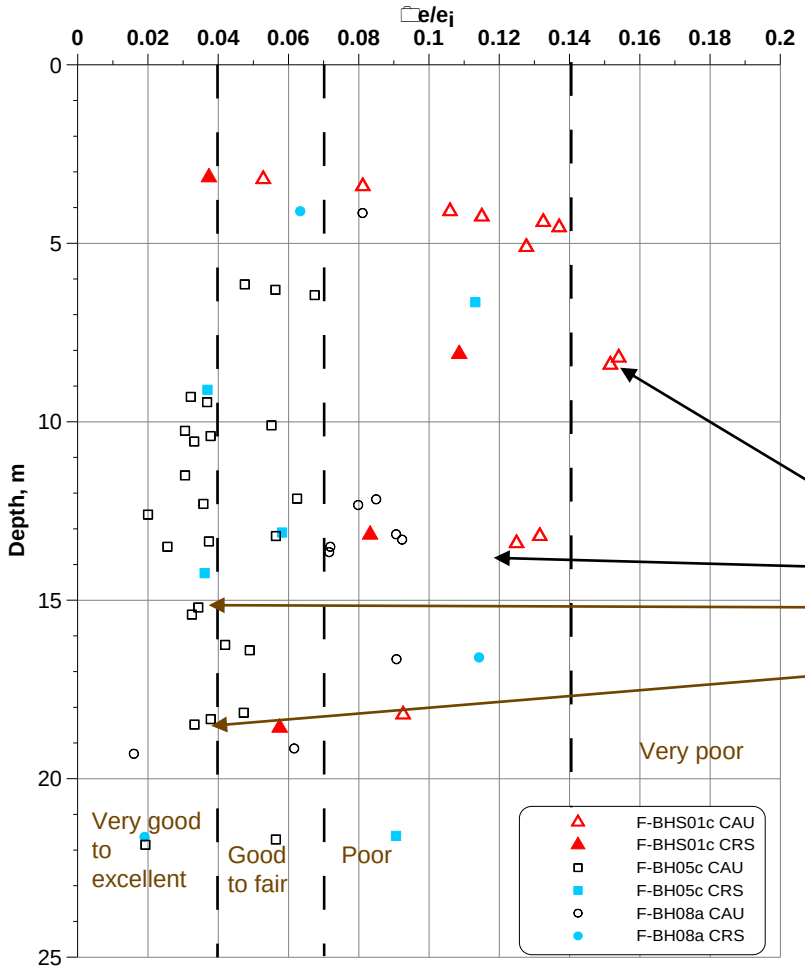
NGI'S CRITERIA FOR SAMPLE DISTURBANCE

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

Based on CAUC and CRSC tests on Sherbrooke block samples and tube samples in Norwegian soft clays

Has been used at NGI since 1996, SQ evaluation included in all lab reports.

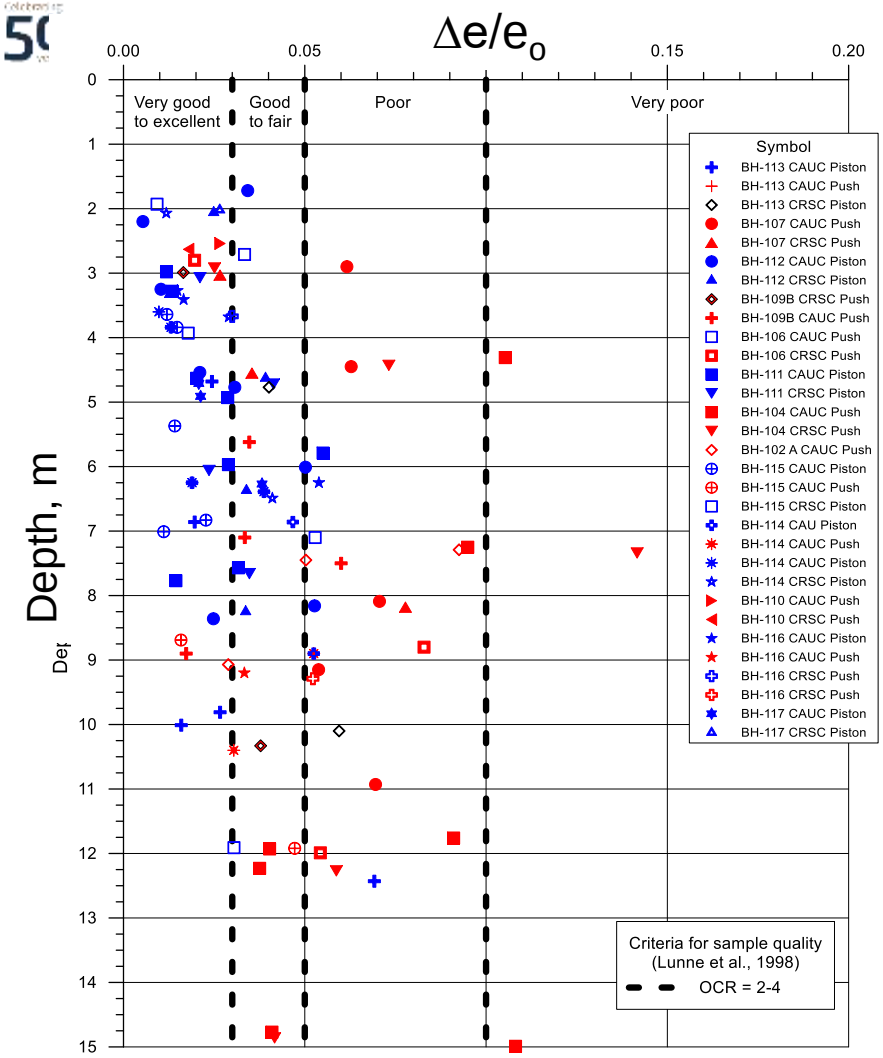
EFFECT OF SAMPLE QUALITY ASSESSMENT OFFSHORE MALAYSIA



Two types of samplers: 1st phase of testing showed thin walled piston samples are of highest quality. Focussed on these in remaining testing programme.

Gravity core samples

Downhole thin walled piston samples

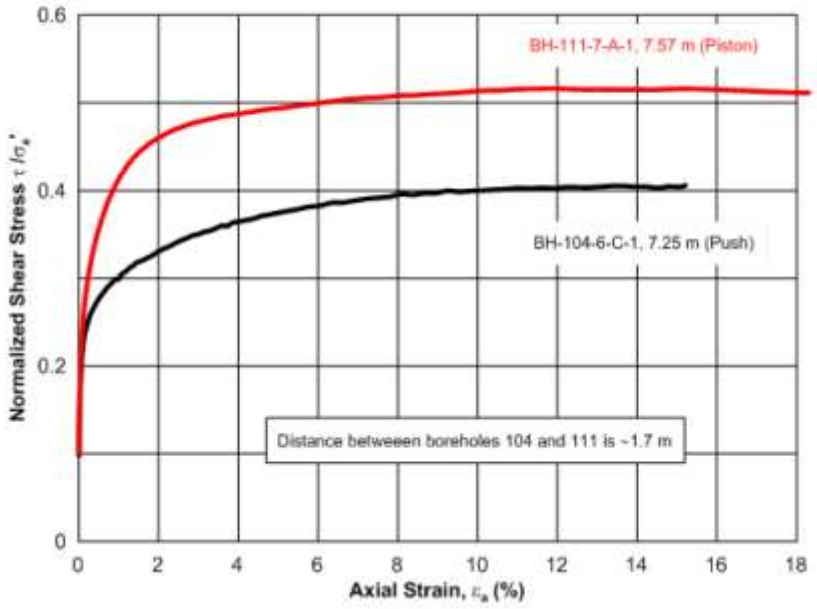


Sample quality evaluation at Barents Sea site

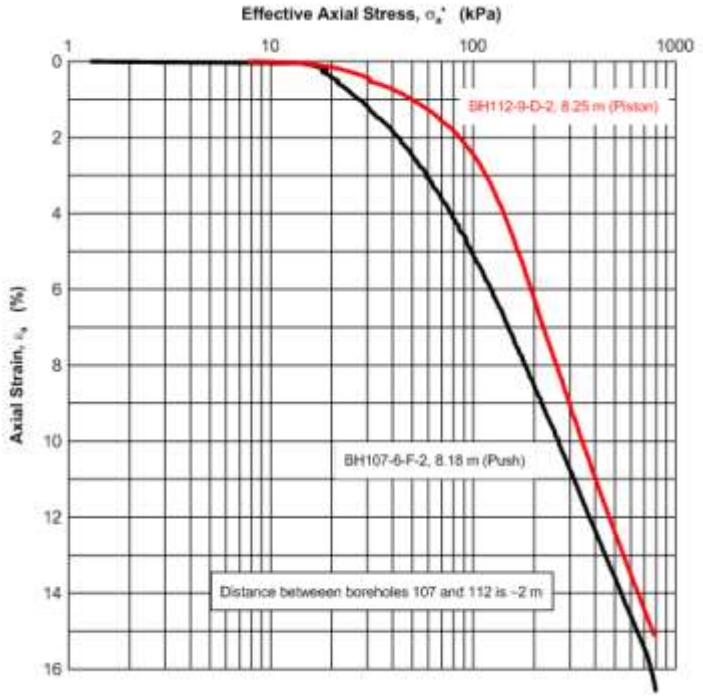
Red is push sampler

Blue is piston sampler

Example downhole sampling in medium stiff clay in Barents sea



Results of CAUC tests



Results of CRSC tests

INTERNATIONAL STANDARD

ISO 19901-8

First edition
2014-12-01

Petroleum and natural gas industries — Specific requirements for offshore structures —

Part 8:
Marine soil investigations

The Sample Quality Criteria is now included in new ISO standard

INTERNATIONAL STANDARD ISO 19901-8

The values of $\Delta e/e_0$ and ε_{vol} should be computed and reported for laboratory consolidation tests conducted on intact clay soils (e.g. incremental load oedometer, constant rate of strain and anisotropic consolidation phase of strength tests such as triaxial and direct simple shear), provided the best estimate *in situ* effective stresses are given. The sample quality is determined using Table 6 for the method of Lunne et al.(2006). An alternative method is given by Terzaghi et al. (1996).

Table 6 — Evaluation of intact sample quality for low to medium OCR clays

OCR	$\Delta e/e_0$ at σ'_{v0}			
1 to 2	< 0,04	0,04 to 0,07	0,07 to 0,14	> 0,14
2 to 4	< 0,03	0,03 to 0,05	0,05 to 0,10	> 0,10
Sample quality	1 (very good to excel-lent)	2 (fair to good)	3 (poor)	4 (very poor)

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Application for onshore projects in Norway

The last version of the ***Norwegian Geotechnicial Society Guideline*** (2013) for sampling requires that sample quality shall be documented in soil investigation reports.

Tabell 6. Veiledende kriterier for evaluering av prøvekvalitet basert på endring i poretall.

OCR	$\Delta e/e_0$[4]			
	Veldig god til utmerket	God til brukbar	Dårlig	Veldig dårlig
1–2	<0,04	0,04-0,07	0,07-0,14	>0,14
2–4	<0,03	0,03-0,05	0,05-0,10	>0,10

Application for onshore projects in Norway

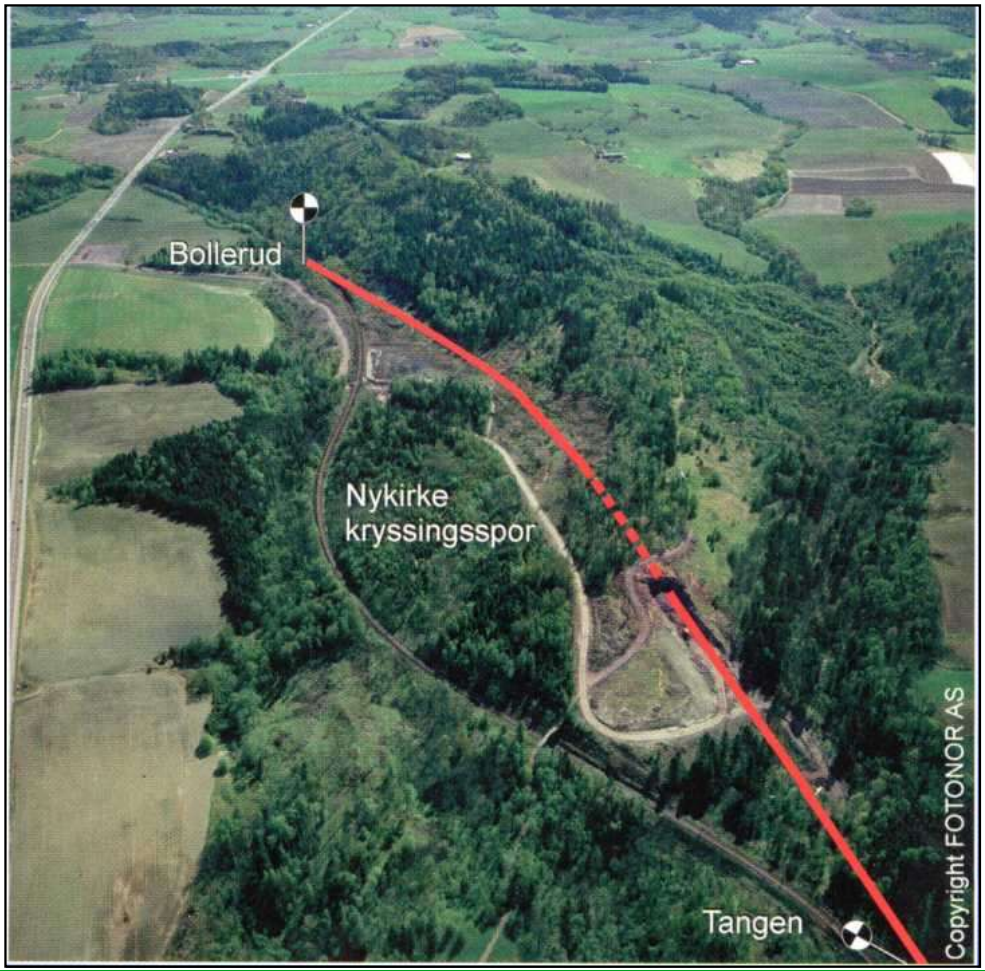
Some project examples on importance of sample quality

- Fill on soft clay in connection with new railway track south of Oslo
- Very low plasiticity clays

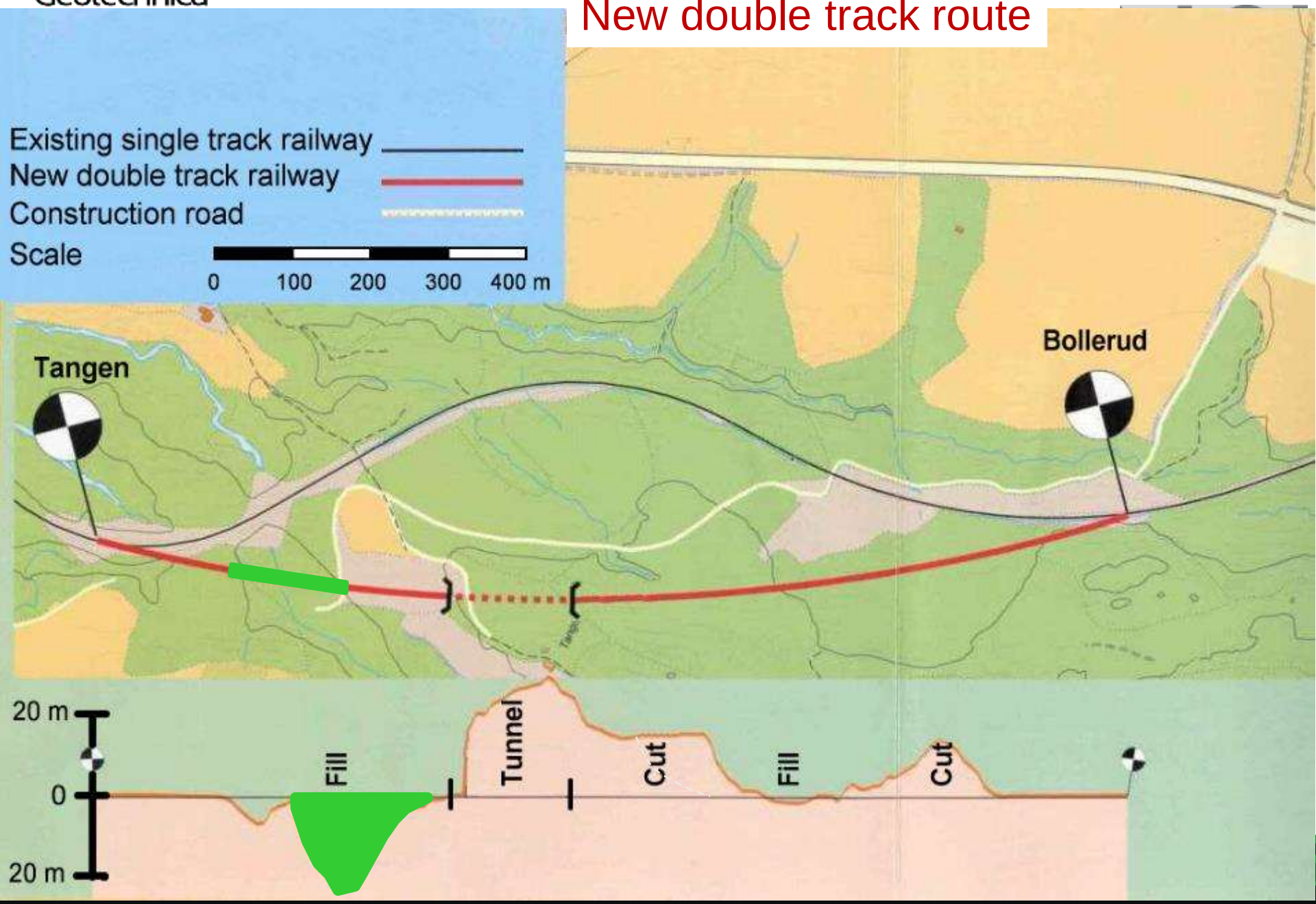
Example in connection with upgrading of railway system south of Oslo

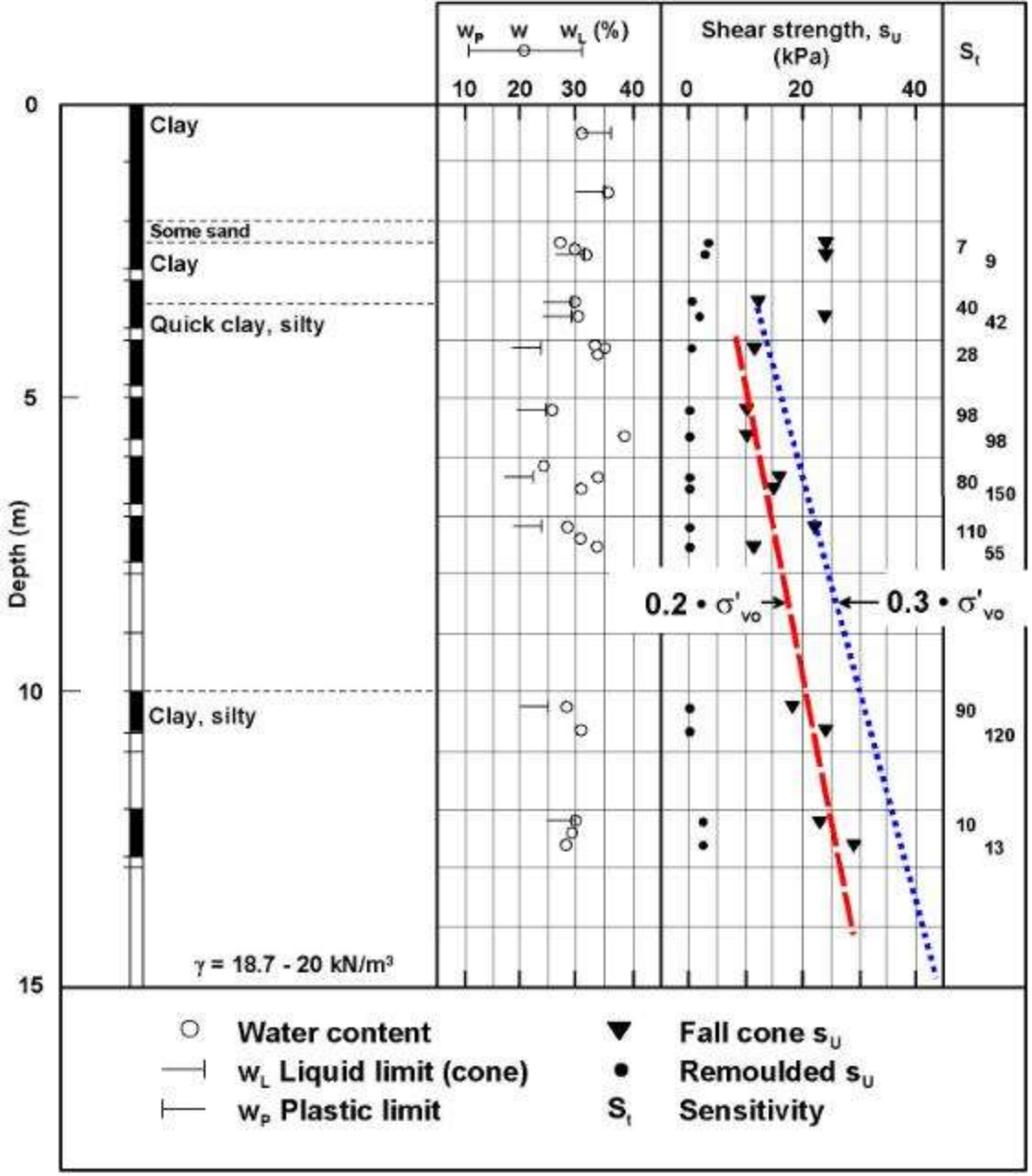
Ref. paper by Hermann and Jensen (2000)

NEW RAILWAY TRACK NYKIRKE, NORWAY



New double track route

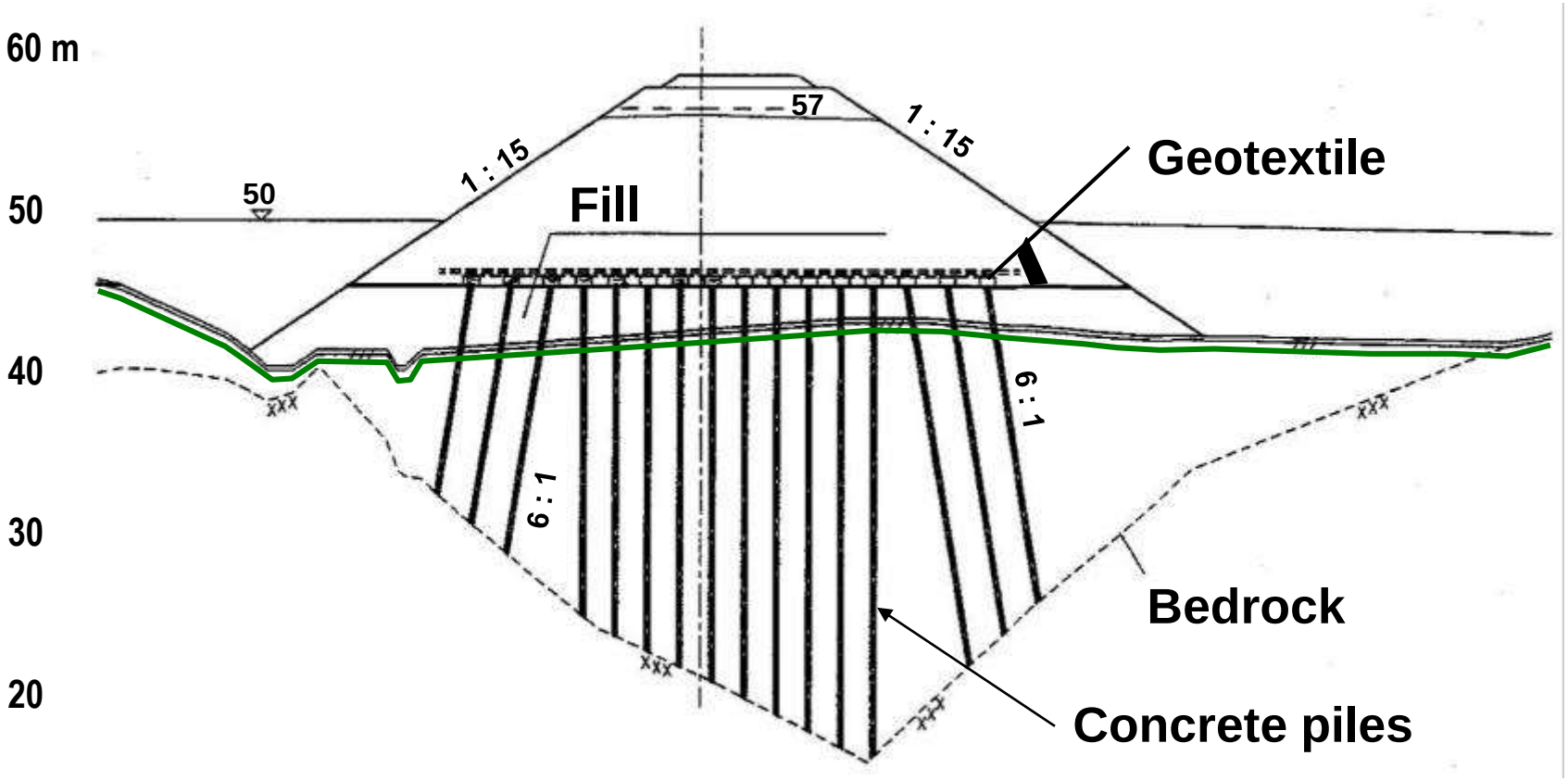




Results of standard soil boring with 54 mm composite piston sample

Given in tender documents

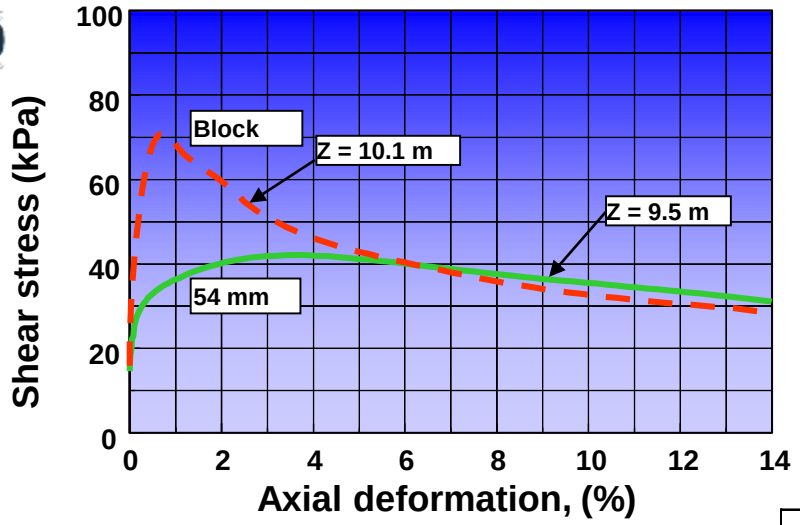
Initial solution in tender documents



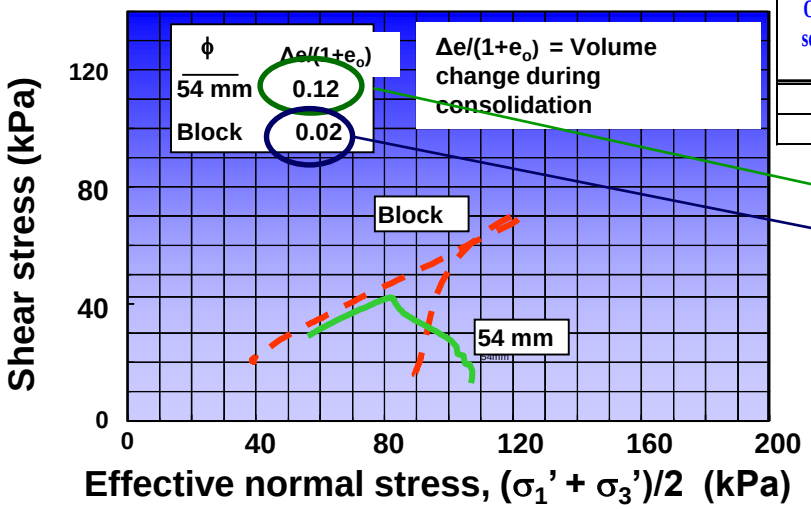
Very expensive solution

Example in connection with upgrading of railway system south of Oslo

NGI as subcontractor to main contractor evaluated the soil data given by client to be of bad quality and recommended CPTU and high quality block samples be obtained



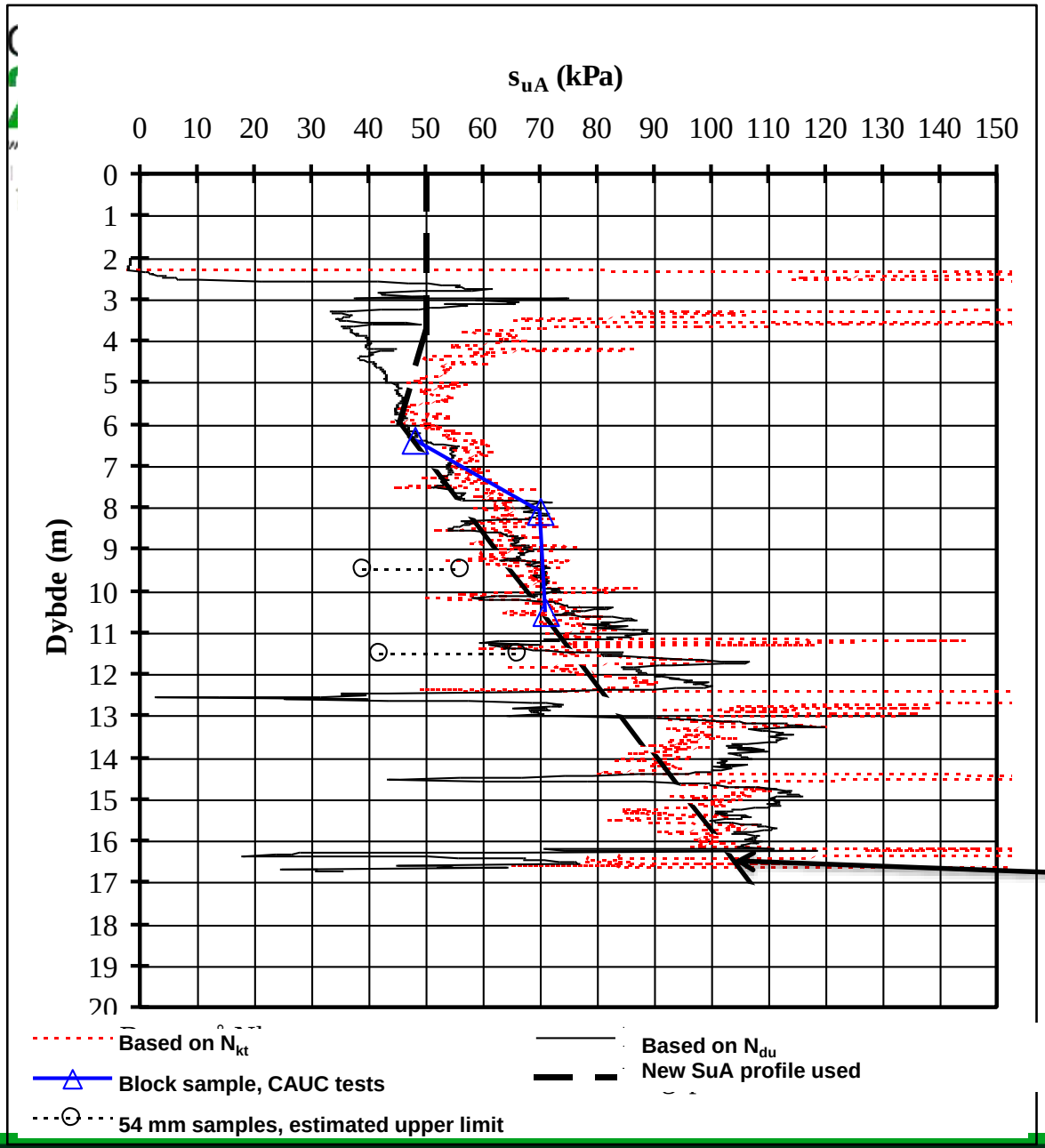
Results of CAUC triaxial tests on new block sampels compared with old 54 mm piston samples



NGI scale sample quality

Overcon-solidation ratio	Δe/e$_o$ Very good to excellent	Good to fair	Poor	Very poor
1 - 2	<0.04	0.04-0.07	0.07-0.14	>0.14
2 - 4	<0.03	0.03-0.05	0.05-0.10	>0.10

Both $\Delta e/1+e_o$ values and shape of stress paths confirm much higher quality of block sample



Example in connection with upgrading of railway system south of Oslo

NEW CAUC TESTS CONFIRMED INTERPRETED S_U VALUES FROM CPTUS

Design shear strength for final design

CASE HISTORY NYKIRKE RAILWAY TRACK

Upgraded shear strength profile resulted

in possible change in technical solution:

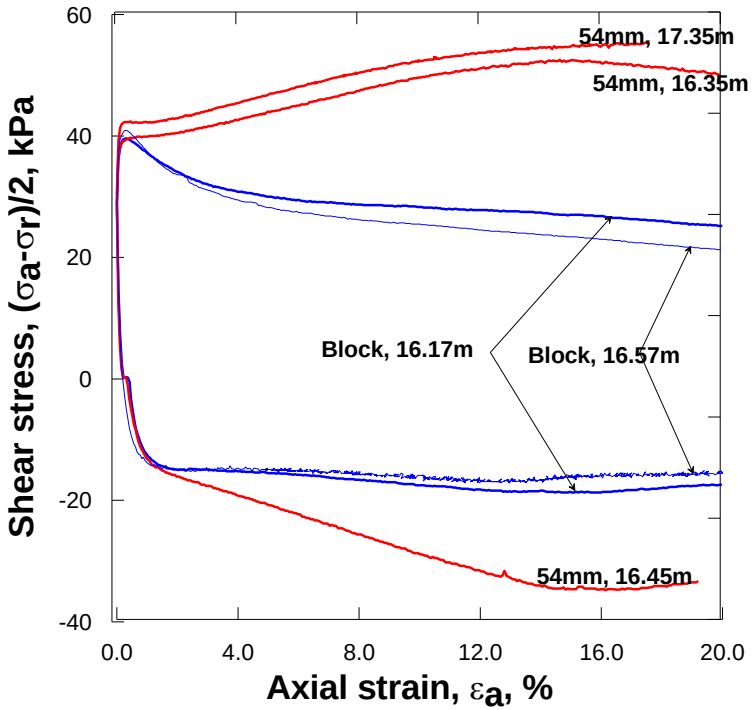
From stability viewpoint not neccessary with piles to rock

Settlements could be taken care of by vertical drainage combined with preloading

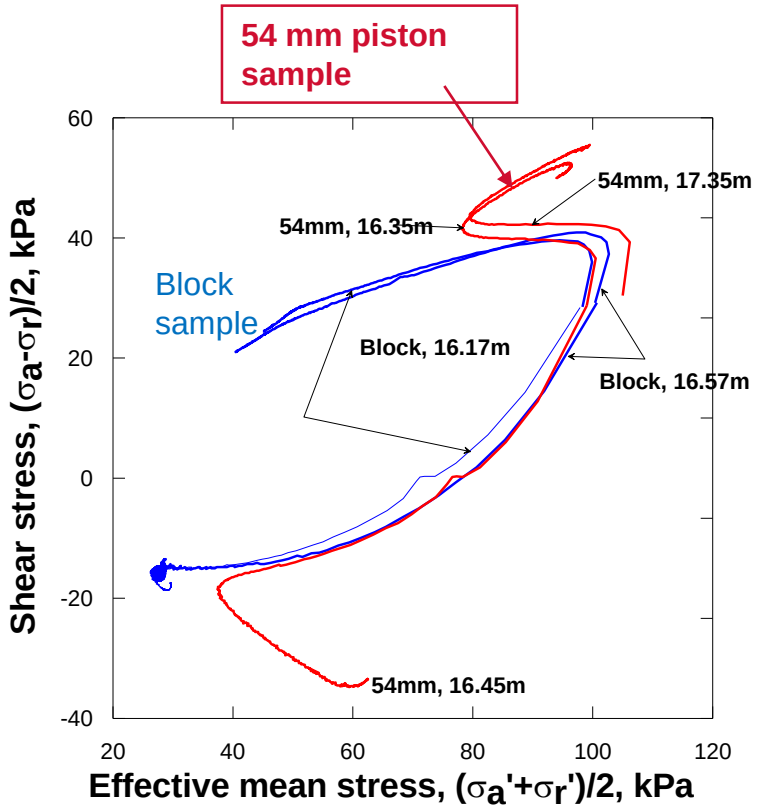
Total cost savings of about USD 1.2 mill or 25 % of total contract cost

Low plasticity Norwegian clays (I_p < 15 %) are more susceptible to sample disturbance compared to high plasticity clays

DRAMMEN LOW PLASTICITY CLAY

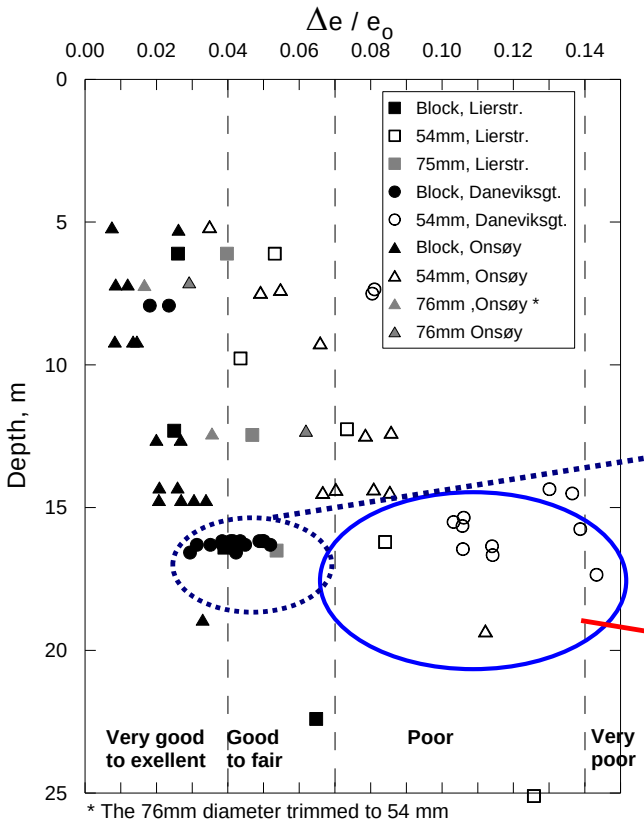


Stress – strain curve



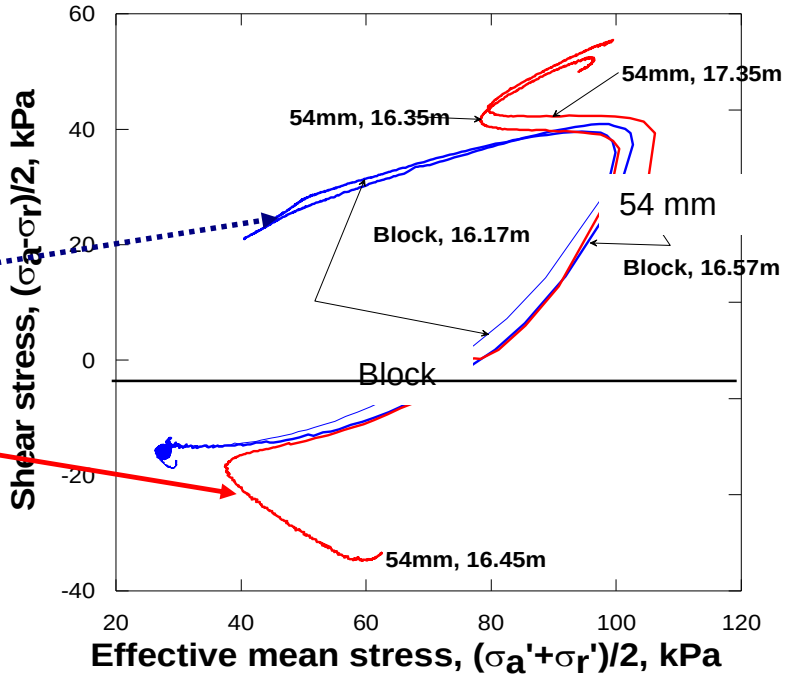
Stress path curve

Effect of sample disturbance is to change material behaviour from contractant to dilatant

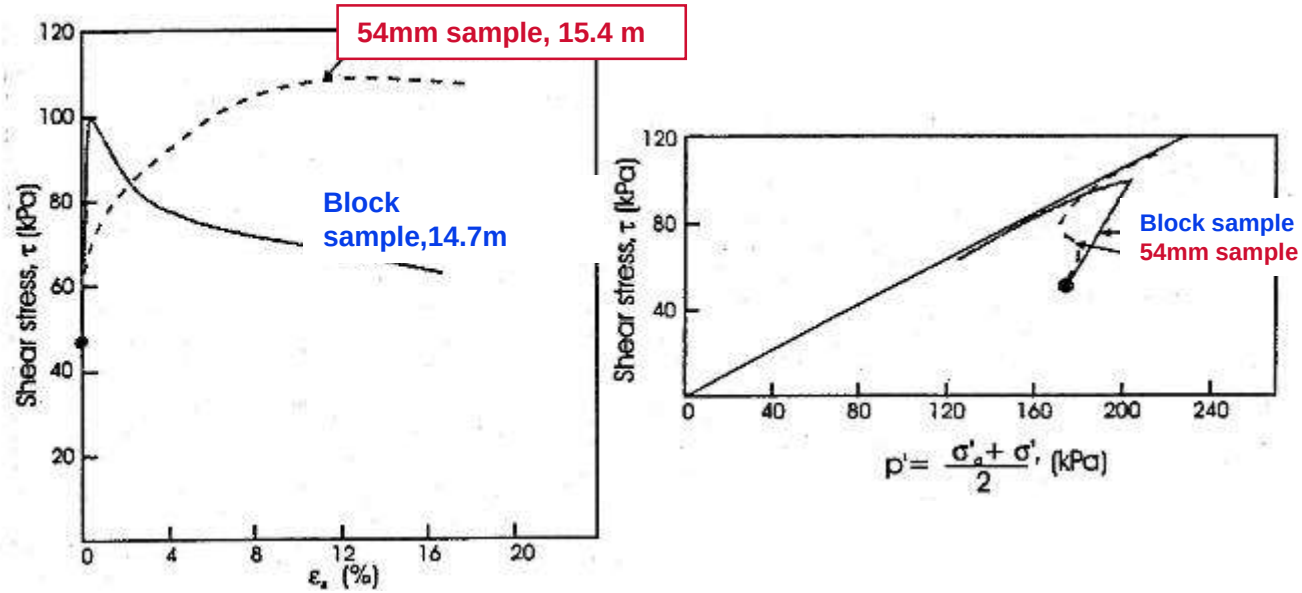


Low plasticity Drammen clay

Can be explained by large void ratio change $\Delta e/e_o$ when consolidating CAU specimen back to in situ stresses



EIDSVOLD CLAY - CAU TESTS



For some low plasticity clays volume change during reconsolidation is so large that behaviour change from contractant to dilatant – selecting s_u at high strains will be non- conservative

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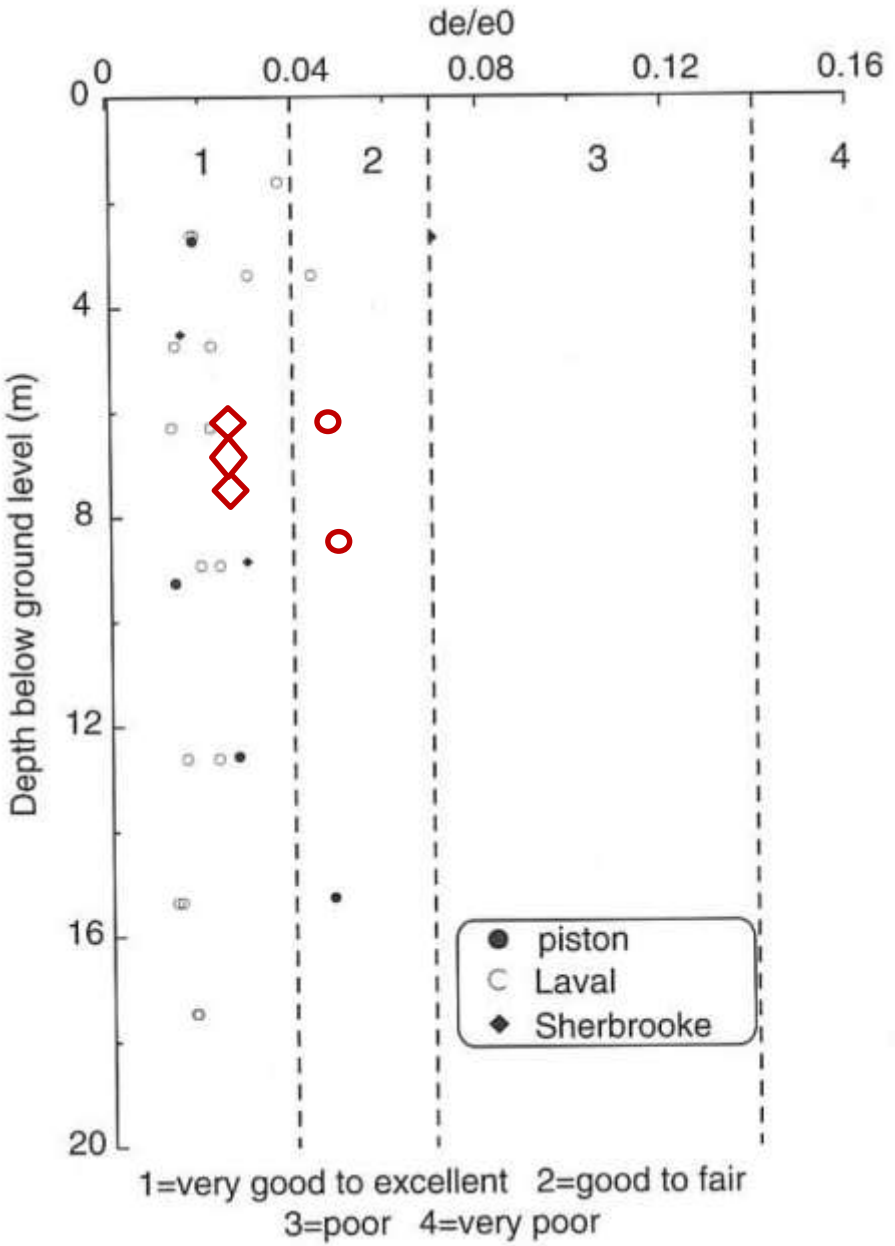

Bothkennar, Scotland, estuarine clay

Clay has some organic content and higher I_p, less susceptible to sample disturbance. In general SQ criteria work well

Data from Hight et al. (2003) and some tests from NGI (red)

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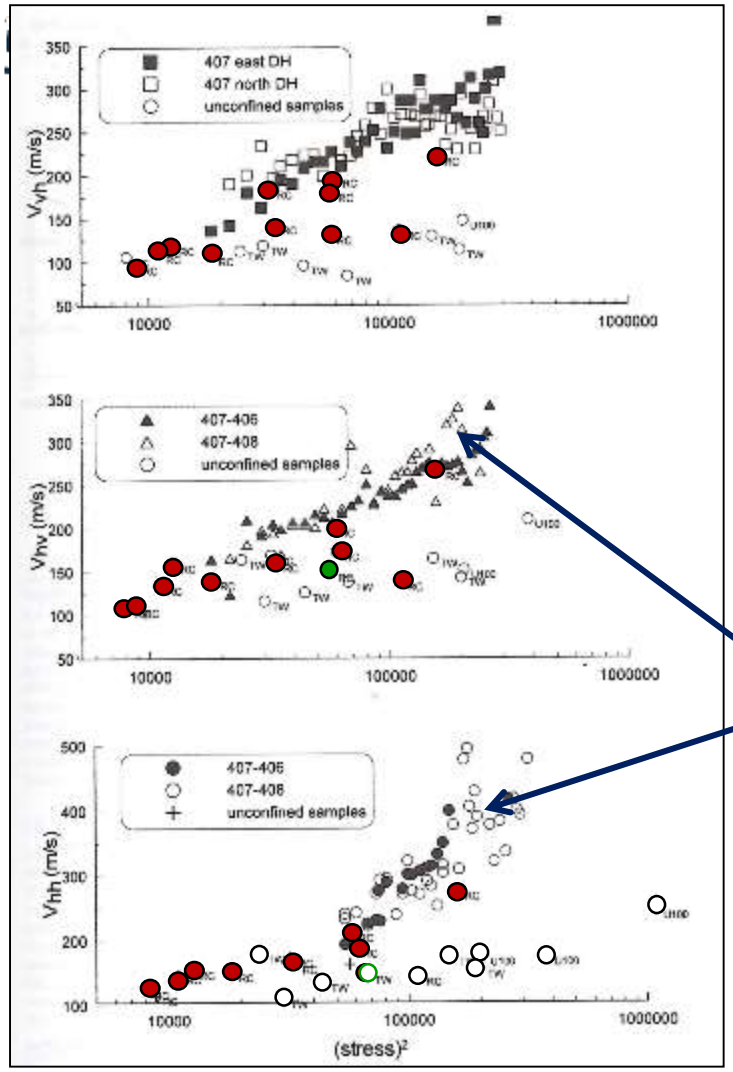
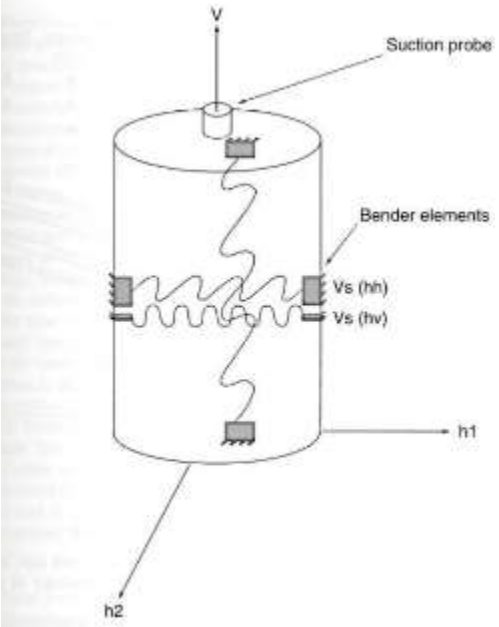
Need for other method(s) in overconsolidated clays

- Hight et al. (2003) have shown that in heavily OC clay tube sampling can induce negative pore pressure
- Can have tendency for swelling during consolidation
- In general it is recommended not to use NGI criteria for other than soft marine clay with OCR < 4

RESULTS OF SUCTION AND V_S MEASUREMENTS OC CLAY TERMINAL 5, HEATHROW



In situ measu-rements



Measurements on unconfined sample

- Tube sample
- Rotary core

SUMMARY AND CONCLUSION

- Based on requirements in offshore industry a sample quality (SQ) criteria has been developed for soft marine clays
- This has now been incorporated into new ISO standard for marine soil investigations and Norwegian adoption of Eurocode
- The criteria is now used in practise both offshore and onshore Norway
- The SQ criteria also works well for Bothkennar (UK) estuarine soft clay
- For heaviliy overconsolidated clays another approach is needed – measurements of shear wave velocity and suction as advocated by Prof. D. Hight is very promising