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SMOCS (Sustainable Management of Contaminated Sediments in Baltic Sea Region)
Field test in Port of Kokkola, Finland

Project acronym:	SMOCS
Title of project:	Sustainable Management of Contaminated Sediments
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Summary

SMOCS is a project in the Baltic Sea Region Programme of EU aiming at introducing innovative, economical, sustainable and environmentally safe solutions to the management of contaminated sediments in ports of the Baltic Sea Region.

The leading partner of the SMOCS project is Swedish Geotechnical Institute (Sweden) and other partners are Luleå University of Technology (Sweden), Port of Gävle (Sweden), Lappeenranta University of Technology (Finland), Port of Kokkola (Finland), Maritime Institute in Gdansk (Poland), Port of Gdynia Authority (Poland), Coastal Research and Planning Institute of Klaipeda University (Lithuania), Port of Klaipeda (Lithuania) and Hamburg University of Technology (Germany). There are many other associated and supporting organizations in the project as well.

The Baltic Sea has many “hot-spots” with highly contaminated sediments in coastal areas, estuaries, ports, etc. Human activities often take place in coastal areas and are affected by these “hot-spots”. Examples are land reclamation for new residential areas and development, maintenance and dredging in ports and fairways due to more deep-draught ships and all these activities will imply management of contaminated sediments. The project will produce a guideline for the management of contaminated sediments with a common approach being a prerequisite of the development of coastal areas and harbours.

Mass stabilization technology has been developed for treatment of soft soil and sediment materials. With this technology the technical properties of dredged sediment can be improved by mixing binder materials with sediment and the mixture can be utilized in harbor field fillings. Stabilization also affects the mobility of contaminants by physical and/or chemical binding and thus decreases the environmental impacts of dredged sediment.

During SMOCS project a pilot test of dredging and stabilization was performed in Port of Kokkola in Finland between July and October 2011. Before piloting, technical and environmental properties of stabilised, contaminated sediment were studied in laboratory to determine optimum binder recipe for stabilization. During pilot test about 12 000 m^3 of sediment was dredged and dumped to the deposit basin, which is a basin isolated from sea with embankment structure. Stabilisation was carried out in deposit basin by using mass stabilization technology. Quality control tests for stabilization and environmental monitoring was carried out during pilot test. The results give valuable information about technical and environmental acceptability of stabilization technology.

Notations and Symbols

A	area of the embankment, where untreated sediment has contact
k	permeability
DI	dihydrate gypsum
dw	dry weight
H	pressure head of water
i	hydraulic gradient
ICP-MS	inductively coupled plasma mass spectroscopy
K	permeability
K400	slag, commercial
KJ	slag
L	distance in the direction of the flow
LOI	loss on ignition
L/S	liquid – solid ratio
LT	fly ash
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
Pika	fast cement
PKT	oil shale ash
Q	flux
Rapid	rapid cement
S/S	solidification stabilization
TBT	tributyltin
TPhT	triphenyltin
V	flow velocity
w	water content
WP	Work package
XRF	X-ray fluorescence
Yse	Portland cement
ρ	density

1. Introduction

The project is led by Swedish Geotechnical Institute with several partners from many countries around the Baltic Sea, will address the issues. A communicative approach will be used to provide the following outcomes: 1) Guideline for management of contaminated sediments incl. i)handling alternatives for sediments, ii)disposal alternatives and iii)beneficial use of treated contaminated sediments; 2) Tool-box of: i)treatment technologies, ii)tools for assessment of sustainability and iii)decision support tool to be used in planning and application processes; 3) Field tests to validate, demonstrate and communicate emerging treatment methods under various conditions: type of sediments, type SMOCS March 30, 2009 2(2) of contamination, climatic condition, availability of technology, costs etc 4) Established durable network for management of contaminated sediments, based upon existing national and trans-national networks, e.g. SedNet and HELCOM. Table 1.1 shows the work packages.

This report is a part of WP6 which considers field tests as a tool for verification of current methods namely in Port of Kokkola case.

Table 1.1 Work packages of SMOCS project.

Number	Name	Description
WP0	PREPARATION ACTIVITIES	Preparation of the project proposal
WP1	PROJECT MANAGEMENT AND ADMINISTRATION	Management and co-ordination of the project by LP and with help of Management Team
WP2	COMMUNICATION AND INFORMATION	Information to the project stakeholders of BSR about the project results and outcome in order to implement and commercialise the results.
WP3	SUSTAINABILITY ASSESSMENT OF HANDLING ALTERNATIVES	Production of the methodology and examples to assess the sustainability of different alternatives for the management of contaminated sediments.
WP4	INVESTIGATION OF CONTAMINATED SEDIMENTS – SITUATION AND METHODS	A comprehensive evaluation of the current contamination of the coastal areas, especially in the ports of BSR, testing of different mapping methods, and compiling of a review about the international, regional and national policies and legislation concerning contaminated sediments.
WP5	NEW EMERGING TECHNOLOGIES – SOA AND NEW POTENTIAL	State-of –the-Art review of the methods for handling contaminated sediments, and evaluation of the applicability and potential of different handling methods including new alternatives. The Focus is on the S/S (stabilisation/solidification) technology. Thus, the WP includes gathering information about the binder potential, commercial and recycled components, within BSR
WP6	VERIFICATION & DEMONSTRATION OF TECHNOLOGIES AND SOLUTIONS	The most important and innovative technologies and solutions for the management of contaminated sediments will be verified and demonstrated using laboratory and field tests. The focus is on the dredging, S/S and binder – contaminant efficiency. The field tests are carried out in Ports of Gävle, Kokkola and Gdynia, each port testing a different technology.
WP7	GUIDELINES AND RECOMMENDATIONS	The project results are compiled and integrated into comprehensive guidelines and recommendations for the management of contaminated sediments. The guideline shall contain the expert knowledge of the project while being user-friendly.

2. Background – Plan for the port

Port of Kokkola is one of the largest northern ports in the Baltic Sea. The history extends to year 1824 while the port is still expanding and developing due to increasing traffic. The most important metal and chemical industry in the Nordic countries is concentrated in Kokkola. The sea area in Kokkola is polluted by emissions from both industry and city. The sediments have harmful substances at levels which locally cause substantial toxicity harm to benthic community. Both point source and diffuse pollution are detrimental. The principal noxious substances are As, Cd, Cu, Pb, Hg, Ni, Zn and TBT.

Building of new quays and deepening of fairways both require dredging of sediment. The dredged sediment is not acceptable for sea dumping, and thus it was desided that the sediment will be stabilized in a banked stabilization pool.

In case Port of Kokkola, the dredging of 12 550 m^3 of contaminated sediments was done in Silverstone (Hopeakivi) Port area, where new quay will be built in the future. The dredging was carried out during July 2011 and August 2011 with environmental dredging method. The level of contamination inhibited dumping of dredged sediments into sea.

The dredged sediments were transported by barges to deposit basin, where they were dumped to the basin by excavator. The stabilization was performed in the basin by mass stabilisation technology. Before stabilisation work, the binder recipes used for stabilisation were determined. During and after stabilisation quality control and quality assurance were conducted.

Dredging and stabilization of contaminated sediment in Port of Kokkola Silverstone (Hopeakivi) area occurred during the project phase of SMOCS. With funding from SMOCS, quality and contamination of the sediment in port and fairway was investigated. Binder material selection was based on testing in laboratory. Testing included geotechnical properties of stabilized material, strength, development of strength along time, water permeability and environmental suitability. Based on the preliminary results of the laboratory study it was decided to perform a field test at Port of Kokkola.

Turbidity was monitored during dredging and during the stabilization work a substantial amount of samples was collected to ensure the quality of stabilization.

The results of the field test will be a base to the design and execution of the s/s-method for the expansion of the port area. The results will be used in future handling of the sediments from dredging of fairways. Stabilized masses well fulfill the requirements for land construction of harbor areas. The port is expanding to sea and the building of harbor areas demands filling of millions of cubic meters. With dredged sediments, the requirements for filling can be reached quite fast. Transporting of corresponding masses from land would be slow and expensive.

Figure 2.1: Port of Kokkola in summer 2010.

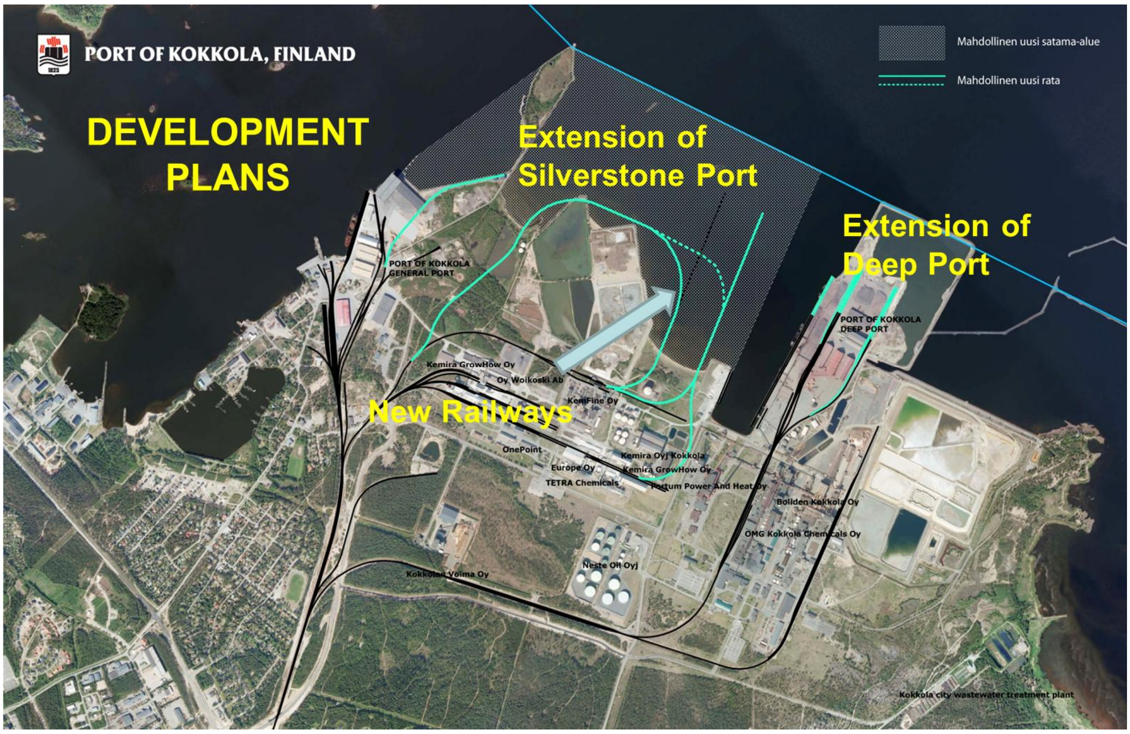


Figure 2.2. Extensions in Port of Kokkola; Silverstone (Hopeakivi) and Deep Port.

3. Objectives of the field test

Sustainable management of contaminated sediments includes choosing the right technique for each phase of dredging and sediment handling project:

- Dredging, Transportation and Dumping
- Dredging area and its location
- Dredging method
- Dredged material and level of contamination
- Dumping site and its location
- All influencing variables shall be taken into consideration while choosing the methods, e.g.

Goal in evaluating different techniques is to choose the most advantageous technique taking into account sustainability. As a result sediment handling and handled sediment will have minor impacts to the environment.

High concentrations of metals in the area are due to local industrial and municipal actions. Present load from these sources is relative minor, but the sediment contains the history from ice age to present day.

As presented in previous Chapter, dredging site was the Port of Hopeakivi in Kokkola. Deposit and stabilization site was located in Deep Port (Syväsatama) basin.

Turbidity measurements were carried out during dredging and stabilization to show the extent and intensity of contaminant spreading in a small approx. 12 000 m^3 dredging with a so called environmental crap. Turbidity effect caused by the dredging was compared to other causes; wind, vessel traffic and normal background level.

With testing of stabilization and quality control samples, the importance of receipting and recognizing future variables was demonstrated.

Based on these results of the field test the expansion of the port area will be designed with the s/s-method (stabilization/solidification).

4. Prestudy

4.1 Sediment to be dredged and stabilised

The dredged sediments must be classified by their geotechnical properties (classification, water content, organic content etc.) as well as for their level of contamination. The testing was done using standardized methods, Appendix 11.1.The quality of the dredged mass has been followed for both geotechnical properties and contaminants. The quality of dredged mass changed from what was expected based on prior sampling due to pooling of the mass.

4.1.1 Geotechnical classification

Preliminary studies for sediment from Port of Kokkola were based on sampling by a diver. Geotechnical properties are shown in Table 4.1.

Table 4.1. Index properties of the sediment samples. Sampling with a diver.

Sample	*Water Content w [%]*	*Density ρ [kg/m3]*	*Loss On Ignition LOI [%] (500 oC)*	*pH*	*Soil type*
KS201	*52.4*	*1690-1710*	*1.5*		*Silt*
KS60	*56.5*	*1680*	*1.3*	*7.6*	*silt-sand*
KS120	*82.0*	*1530*	*1.6*	*7.3*	*silt*
KS180	*68.6*	*1600*	*1.3*	*7.2*	*silt*

Sediment samples KS60, KS120, and KS180 were sampled April 16, 2011 for stabilization and contaminant testing. Sediment sample KS201 was sampled January 2010. This sample was so called mine sample taken by a diver. Samples were collected also after dredging August 19, 2011 from already pooled mass in the stabilization pool. The results for these samples are shown in Table 4.2. and 4.3. Samples differ on all the studied parameters. For instance, the water content of the samples was noticeably lower in the latter samples. Organic content was measured higher in the pool. On the other hand, pH was lower and the samples were more granular in the stabilization pool.

Table 4.2. Index properties of the sediment samples. Samples from the stabilization pool.

Sample (+depth)	*Water content w [%]*	*Density ρ [kg/m3]*	*Loss On Ignition LOI [%] (500 oC)*	*pH*	*Granule size*
P1 d. 0.5 m	*24.4*	*2000*	*0.9*	*7.2*	*silt-sand*
P1 d. 1.5 m	*19.8*	*2070*	*0.6*	*6.3*	*sand*
P2 d. 1.5 m	*19.1*	*2050*	*0.6*	*6.6*	*(sand)sand-silt*
P2 d. 2.5 m	*19.5*	*2070*	*0.7*	*6.4*	*silt-sand*
P3 d. 0.5 m	*18.8*	*2050*	*0.6*	*6.8*	*silt-sand*
P3 d. 1.5 m	*23.6*	*1960*	*0.8*	*6.4*	*(sand)silt-sand*
P4 d. 1.5 m	*24.7*	*2000*	*0.7*	*7.3*	*(sand)sand-silt*
P4 d. 2.5 m	*23.8*	*1990*	*0.6*	*7.1*	*(sand)silt-sand*
P5 d. 1.5 m	*19.1*	*2080*	*0.6*	*6.2*	*(sand)silt-sand*
P5 s. 2.5 m	*13.2*	*1860*	*0.4*	*6.0*	*sand*
P6 d. 0.5 m	*16.2*	*2000*	*0.5*	*6.3*	*sand*
P6 d. 1.5 m	*18.5*	*2130*	*0.7*	*6.9*	*(sand)sand-silt*
P6 d. 2.5 m	*20.5*	*2040*	*0.8*	*6.7*	*sand-silt*

4.1.2 Total concentrations

The contamination in sediment of both harbour area and fairway has been investigated in several stages. The sediment is contaminated especially by zinc and other metals. However, concentrations of TBT, PAH and PCB are low.

Concentrations of main contaminants were analyzed from all the samples. Analyses were done in the laboratory with inductively coupled plasma mass spectrometry (ICP-MS) and *in-situ* with a Niton-XRF-analyser. Niton results are shown in Appendix 11.2. Results from chemical analyses are shown in Tables 4.3 and 4.4 and compared to Finnish “Government Decree on the Assessment of Soil Contamination and the Remediation Needs (214/2007)” (PIMA) and with hazardous waste limit values applied in Finland (Valtioneuvoston asetus maaperän pilaantuneisuuden ja puhdistustarpeen arvioinnista 214/2007). All samples are highly contaminated especially with zinc. Contamination exists in all layers throughout the sampling depth. Sample sites KS 60-201 are shown in Figure 4.1.

Table 4.3. Concentrations of contaminants in the samples compared to PIMA guideline values [mg/kg]. Samples are taken from the dredging area.

	Reference values	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V
	threshold value	5	0,5	1	20	100	100	60	50	200	100
	lower limit	50	2	10	100	200	150	200	100	250	150
	upper limit	100	5	20	250	300	200	750	150	400	250
	hazardous waste	1 000	1 000	100	1 000	1 000	2 500	2 500	1 000	2 500	10 000
sample	dry content m-%	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
KS201	72	59	2.4	16	61	28	160	110	43	3 300	29
KS60	65	34	1.7	20	32	17	230	150	34	6 200	22
KS120	54	29	2	17	26	20	110	150	22	5 000	26
KS180	59	31	2	20	35	21	150	170	26	5 900	30
KS120 0-20	56	25	1.7	16	25	18	87	130	20	4 800	24
KS120 40-60	60	39	2	28	44	21	170	250	28	8 500	28
KS120 80-100	59	21	3	12	22	8	110	110	17	3 700	10

Table 4.4. Concentrations of contaminants in the samples compared to PIMA guideline values [mg/kg]. Samples from the stabilization pool.

Reference value	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V	TBT-TPT
Natural background [1]	1	0,005	0,03	8	31	22	5	17	31	38	sum
threshold	5	0,5	1	20	100	100	60	50	200	100	0
lower limit	50	2	10	100	200	150	200	100	250	150	1
upper limit	100	5	20	250	300	200	750	150	400	250	2
hazardous waste limit	1 000	1 000	100	1 000	1 000	2 500	2 500	1 000	2 500	10 000	
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Sample 1	6.1	0.38	2.6	8.5	16	26	24	10	750	21	0.0085
Sample 2	6.9	0.74	2.5	8.7	18	23	24	11	730	25	0.0085

Aggregate samples were combined from samples taken from different depths:

- Sample 1 (P1 0.5m; P1 1.5m; P2 2.5m; P3 0.5m; P5 2.5m; P6 0.5m) ja
- Sample 2 (P2 1.5m; P3 1.5m; P4 1.5m; P4 2.5m; P5 1.5m; P6 1.5m; P6 2.5m).

Before combining samples, subsamples P1-P6 were analyzed with Niton-XRF-analyser. Results from these are shown in Annex 11.2.

The concentrations of contaminants are clearly lower in the samples taken from the pool than in the ones taken by the diver. In the loose surface sediment samples concentrations were high but during the dredging the clean and contaminated layers were mixed and the average concentrations were affected. Samples were taken during stabilization and these results are given in Chapter 8.

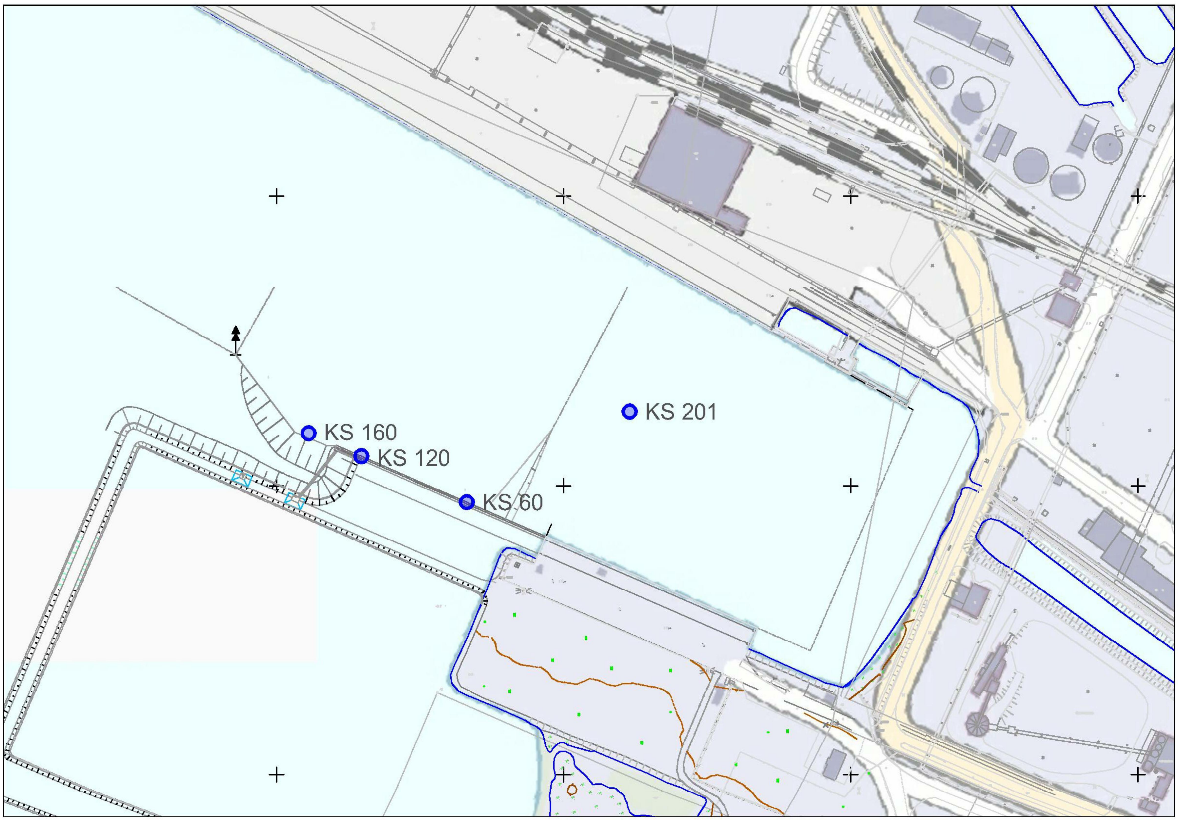


Figure 4.1. Locations of sample sites.

4.1.3 Leaching test

Solubilities of contaminants were studied using a single-stage batch test both from the original sediment and from stabilized test pieces. The results are shown in Table 4.5

In a single stage batch test the crushed sample is being shaken for 24 hours with water / dry matter ratio L/S 10 and from the filtered leachate the concentrations of soluble contaminants are measured, Appendix 11.1.2. The elements were analyzed by inductively coupled plasma mass spectrometry (ICP-MS).

Based on leaching concentrations waste materials are classified into three categories; inert waste, common waste, and hazardous waste materials (Valtioneuvoston asetus 202/2006).

Both in original sediment sample and in stabilized pieces the solubilities of contaminants exceed the lower limit value for common waste material. The solubilities of copper and nickel is less than the limit for inert waste material, Table 4.5.

Toxicity was measured from an untreated sediment sample and from a single stabilized sample using Daphnia magna water flea test. Neither of the samples were found toxic.

Table 4.5. Results from 1-stage batch test and the limit values for land fill waste.

Sample	*KS60*	*Limit values for land fill VNa 202/2006*		
Contaminants		*Inert waste material solubility [mg/kg dw.]*	*Non-hazardous waste solubility [mg/kg dw.]*	*Hazardous waste solubility [mg/kg dw.]*
As	*0.15*	*0.5*	*2*	*25*
Hg	*<0.003*	*0.01*	*0.2*	*2*
Cd	*<0.020*	*0.04*	*1*	*5*
Cr	*<0.020*	*0.5*	*10*	*70*
Cu	*<0.020*	*2*	*50*	*100*
Pb	*<0.020*	*0.5*	*10*	*50*
Ni	*0.054*	*0.4*	*10*	*40*
Zn	*<0.020*	*4*	*50*	*200*
V	*<0.020*			
Co	*0.065*			
Toxicity	*not toxic*			

KS60: untreated sediment sample

4.2 Handling alternatives for dredged sediments

Dredging equipment for removal of contaminated sediments shall be chosen to have the least negative impact for the environment. These negative effects include the turbidity, spread of contaminants due to turbidity and the disturbance of the sea bottom sediments. Turbidity can be minimised by using right methods. Environmentally sound dredging can be conducted by using different methods and techniques for example backhoe dredger with environmental grab.

For sediment transportation there are different possibilities, by car, by vessels and by barges. Environmental impacts vary from technique to another. Each dredging project differs from each other, thus the means of transportation shall be considered case by case to achieve the most advantageous solution environmentally and economically. Solution where the dredged sediments are not moved on-land and can be moved to dumping area directly from barge is often economically the most favourable alternative. However dumping to the sea is often harmful to the environment and restricted contaminated sediments are in the question. One of the dumping solutions, used also in this case, where the dumping area is located near to the shore which makes it possible to dump on-land or to the basin directly from barge. This kind of solution is also advantageous at the areas where the sediment material can be utilized to create new area for different purposes.

Choosing the dumping site location shall be done carefully. Consideration on whether the sediment will be dumped onshore or offshore is the first step. Achieving environmentally and economically the best solution when dumping contaminated sediments attention shall be paid to the design of the dumping site in a way that the chosen solution will prevent the spread of contaminants and minimise the impacts to the environment. There are restrictions where the contaminated sediments are allowed to be dumped; basically the dumping locations are onshore.

Dumping site for contaminated sediments shall be constructed in a way that all the design issues are taken into account. For example stabilisation is often accomplished in the same location where dumping takes place and therefore the design of the dumping basin has been carried out in a way that all the requirements for stabilisation basin are also filled.

There were not a lot options for dredging method in the project. Due to small amount of sediment to dredge, only approx. 12 000 m^3, options were suction dredging and bucket dredging. Excessive water amount that would result in suction dredgin was considered problematic and enclosed dredge bucket was selected as the equipment. Additionally, the environmental permit contained the mention of an enclosed dredge bucket which excluded the use of dipper dredges.

Since the sediment was heavily contaminated with zinc, sea dumping was out of question. Dumping in an isolated dumping pool would also have been impossible without treatment.

Deposition on the land is unfeasible in Port of Kokkola due to lack of space. Based on this the sediment was decided to be stabilized which also enables the depositing in an embankment pool. Stabilization also enabled beneficial use of the sediment in a part of port structures through adequate strength.

Handling alternatives for dredged contaminated sediments were mostly decided prior to SMOCS project when the Port of Kokkola applied for an environmental permit for dumping of contaminated sediment in an isolated stabilization pool. In Kokkola case, sediments being contaminated with zinc up to level of hazardous waste, an alternative to stabilization would have been dumping in landfill.

Due to increasing demand of filler material in port, stabilization was considered as the best option. Geotubes were not considered feasible as the amounts were relatively large and after drying it would still have been necessary to handle the sediment. Coarse sized silt sediment was assumed to dry in a pool efficiently enough. The stabilized sediment layer was deposited below local frost limit, which in Kokkola is about 2 m.

Stabilized area is planned to be a part of dark bulk harbor where, e.g., iron pellets are stored. The load capacity of the field has to be set high enough. Options for superstructures are numerous and it was desired to utilize local industrial by-products (fly ash, bottom ash, crushed concerete and bricks) or crushed rock, Figure 4.2.

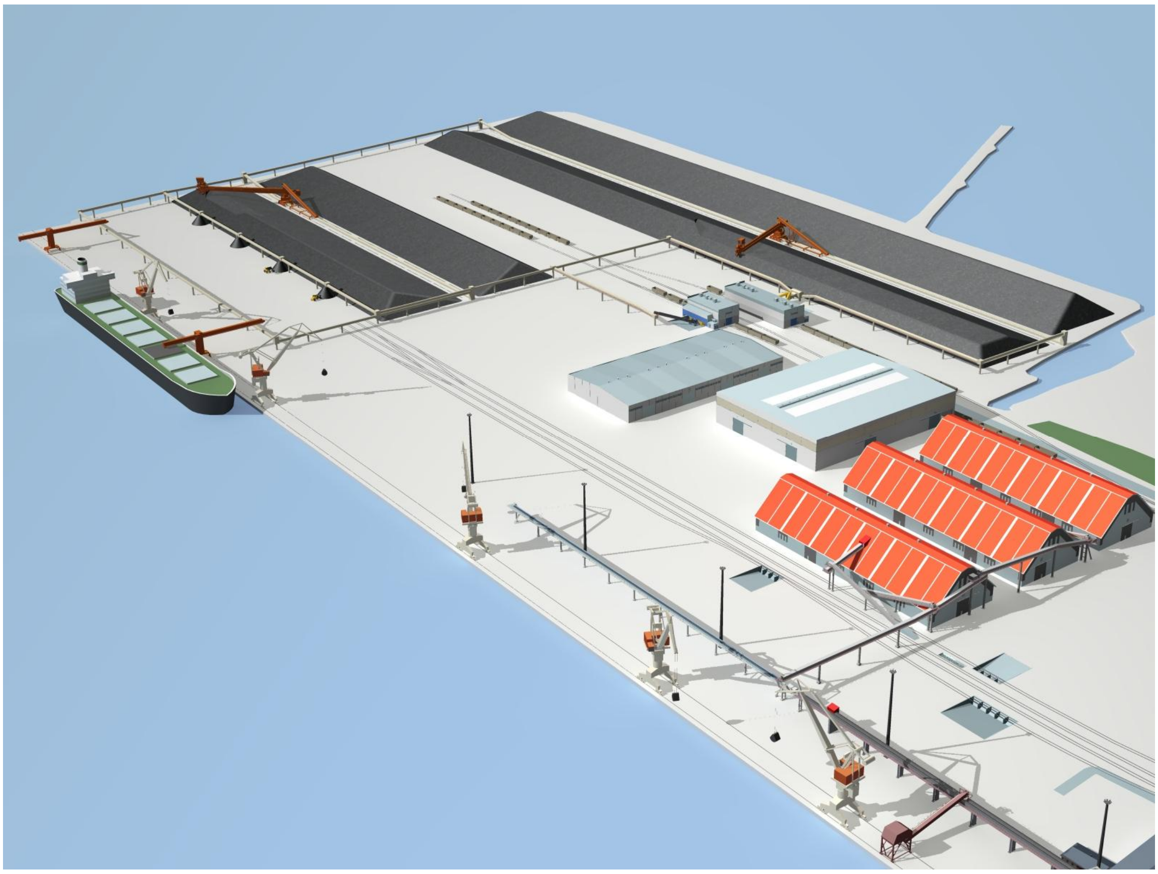


Figure 4.2. Vision of the future use of the deep port by Port of Kokkola.

The final target load bearing capacity for stabilized mass as a compressive strength after one year was set at 150 kPa in laboratory and 100 kPa in field conditions. The target value for shearing strength is set at about 50 kPa in the field. Target strengths were not set by authorities, but rather from the requirements of the future intended use. However, a target value was set for water permeability ($5 \cdot 10^{-8}$ m/s) for the stabilized mass by the authorities.

4.3 Initial study on appropriate binders

Stabilization of contaminated sediments in Port of Kokkola has been widely investigated. The results that have led to execution of the pilot are given in the following Chapters.

4.3.1 Geotechnical tests

Stabilization tests were done in several steps. In a so called matrix study the behavior of common binders was investigated in selected sediment sample KS201. Descriptions of investigated binders are shown in the next chapter.

For the stabilization in year 2011, the most suitable mixture of a commercial binder and fly ash was selected based on the matrix study. The variations of commercial binders and fly ash are shown in Figures 4.3-4.5. Tables of the compressive strength testing are given in Appendix 11.3. The main sediment matrix sample KS201 and samples in dredging area KS60 and KS120 were used in the studies.

4.3.1.1 Investigated binder materials

In the experiments, the following binder materials have been investigated: cement, oil shale ash, fly ash, gypsum and slag.

Cement (Yse) is a common commercial binder that represents regular quality. A similar product is available in all countries around the Baltic Sea. In this case the manufacturer is Finnsementti (http://www.finnsementti.fi).

Oil shale ash (PKT) is fly ash originating from burning of oil shale in Eesti Energia power plant in Narva, Estonia. The ashes vary a lot based on power plant and the technique of burning.

Fly ash (LT) originates from Alholmens Kraft mixed burning facility (wood, peat, coal and recycled fuels) in Pietarsaari, Finland. Fly ash can have a lot of different qualities based on, e.g., technique of combustion and raw material. The current ash has been previously found highly reactive and suitable for binder in sediment stabilization. Testing of that ash will provide a good estimate of the performance in stabilization work.

Gypsum (DI) originates from Yara Finland manufacturing plant in Siilinjärvi, Finland. Gypsum exists in several different forms, but in this case as a binder, dihydrate gypsum is investigated. Gypsum has been stored outdoors in a pile. In previous studies, it has been found to have a positive effect on the strength of the stabilized material.

Slag (KJ, K400) is a commercial binder that has been previously under the status of a by-product. Slag is being manufactured by granulating and grinding slag from production of raw iron.

4.3.1.2 Results from compression strength testing

Results show that significant solidification occurs in time with all considered binders and sediment samples. Matrix KS201 was found the most reactive, i.e. the strength is considerably high already after 7 days and keeps increasing at least until 90 days.

Based on the results, samples from the dredging area (KS60 and KS120) have lower compressive strengths after stabilization (up to 90 days) than the main matrix sample (KS201). This can be seen most clearly in Fig. 4.5. where sample KS201 has a higher compressive strength even with lower amounts of binder materials. A single most important variable causing the difference in hardening is water content. Differences between samples are not evened during time, but the initial level differences remain.

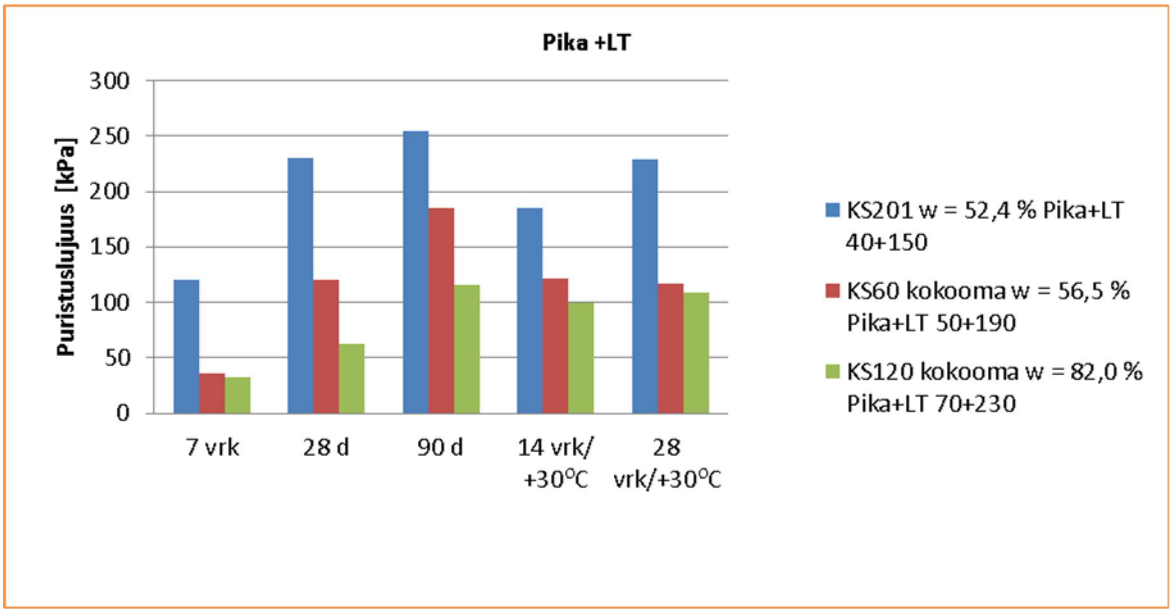


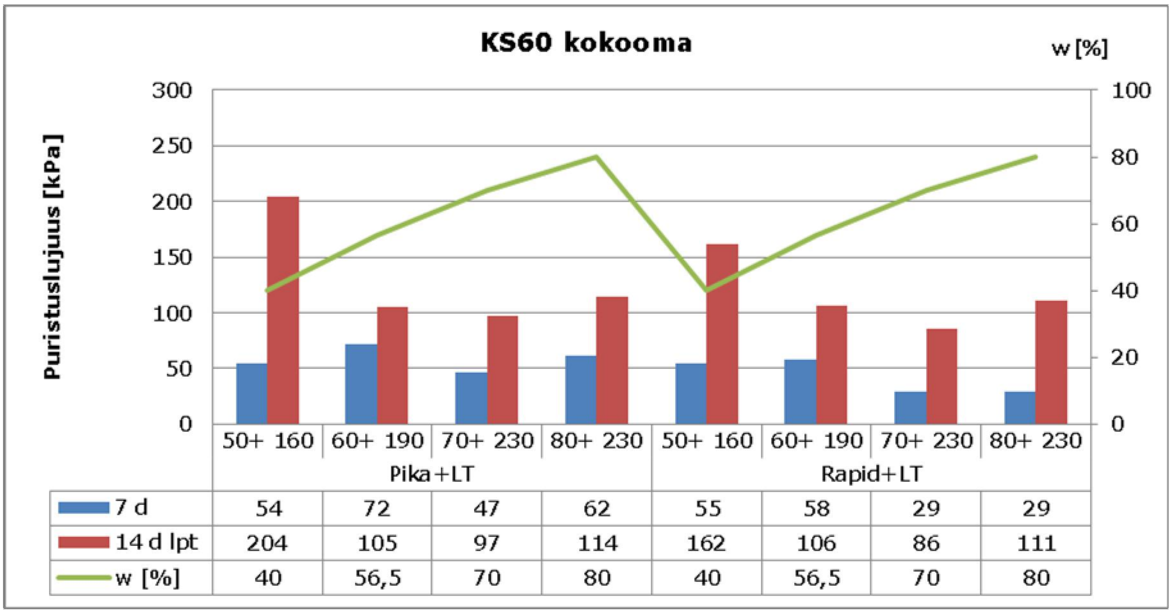
Figure 4.3 Compressive strengths of three different binder matrices. Binder materials are Pika-sementti (fast cement) and fly ash. The amounts of binders vary according to water content.

Binder amounts were adjusted according to water content. Additional results of studies are shown in Figures 4.4. and4.5. Both figures show the effect of water content, commercial binders (Pika = fast cement and Rapid= rapid cement) and fly ash by varying binder amounts.

These results confirm the above shown result, where matrix KS60 obtains less compressive strength than matrix KS120 with the same binder amounts. The binder amounts for the field test were thus calculated based on KS60.

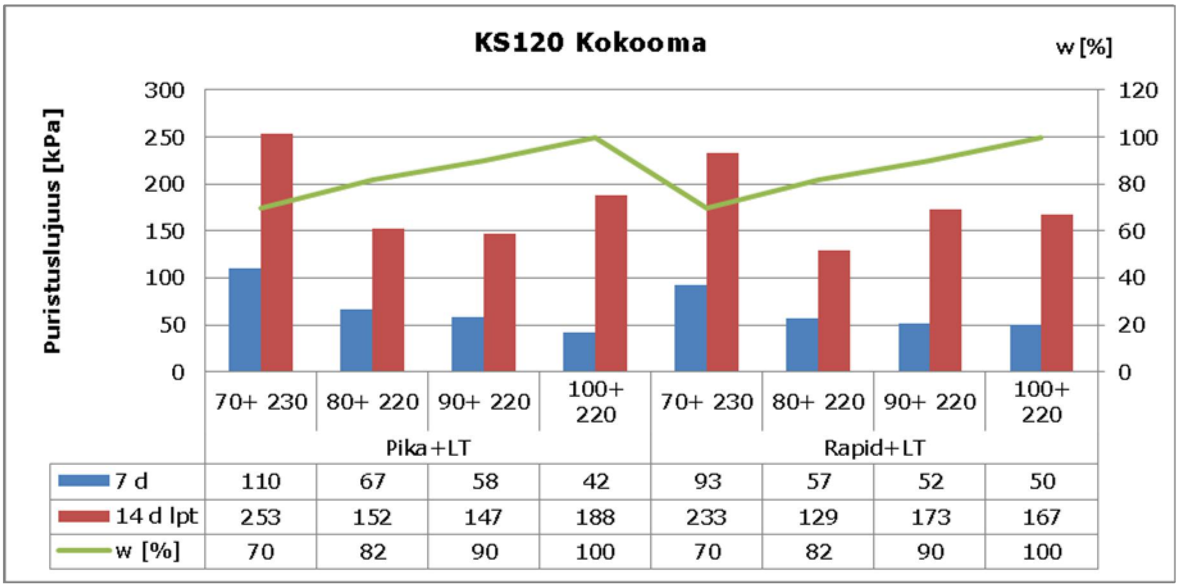
As the water content increases, it takes more binder material to obtain equal strength. With material that is easy to stabilize, the increase in binder amount is about 10 % when the water content increases 10 %. However, with more complex sediments the increase can be significantly higher, in this case about 20 % was found appropriate. This must be taken into account during the field test where the the maximum capacity of mass stabilization mixer is about 300 $kg_{binder}/m^3_{sediment}$, which can vary according to matrix.

In general, it is assumed that strengths after 14 d heat treatment can be used as approximations of the strength after 90 d normal treatment. After 90 days the strength may continue to develop about 30 %, which has to be taken into account.



	Pika+LT				Rapid+LT			
	50+ 160	60+ 190	70+ 230	80+ 230	50+ 160	60+ 190	70+ 230	80+ 230
🟦 7 d	54	72	47	62	55	58	29	29
🟥 14 d lpt	204	105	97	114	162	106	86	111
— w [%]	40	56,5	70	80	40	56,5	70	80

Figure 4.4. Results with KS60 aggregate sample after 7 and 14 days temperature treatment (lpt). Strengths are measured from heat treated samples. The water content is shown.



	Pika+LT				Rapid+LT			
	70+ 230	80+ 220	90+ 220	100+ 220	70+ 230	80+ 220	90+ 220	100+ 220
🟦 7 d	110	67	58	42	93	57	52	50
🟥 14 d lpt	253	152	147	188	233	129	173	167
— w [%]	70	82	90	100	70	82	90	100

Figure 4.5. Results with KS120 aggregate sample after 7 and 14 days temperature treatment (lpt). Strengths are measured from heat treated samples. The water content is shown.

4.3.1.3 Binder receipting

The selection of non-commercial binder material was based on availability of local fly ash. The technical and environmental suitability of fly ash from Alholmens Kraft in Pietarsaari was tested and the material was chosen. In addition to fly ash, cement was considered (Pika- or Rapid-cement grades).The amount of binders depends on the water content of samples according to Table 4.6. Stabilized material must reach 50 kPa compressive strength (25-30 kPa shearing strength) during 7 d because a mixing equipment has to be able to operate on the surface of stabilized layer. Stabilized material is covered with a filter cloth and about 30 cm layer of crush or bottom ash as a working layer. Geotextiles can also be utilized in order to obtain a sufficient load capacity.

Table 4.6. Experimental design for optimization of receipt; utilized binder amounts and water content of sample

Water content of untreated sediment	Binder receipt [kg/m^3]	
	PIKA+LT	RAPID+LT
<40 %	50+200	50+200
40-60 %	60+200	60+200
61-80 %	80+200	80+200
81-100 %	100+200	100+200

4.3.1.4 Water permeability results

Permeability has been tested with three different matrices and binder materials. Permeability was tested on samples shown in Table 4.7.

Table 4.7. Permeability of water on three different samples. Abbreviation Pika stands for Pikasementti and LT fly ash.

Matrix	Sample coding	Binder selection	Amount of binder [kg/m^3]	Grain	Permeability k [m/s]
KS201	HS-23A	Pika+LT	40+150	Silt	$2.3 \cdot 10^{-8}$
KS60	SSV-3G	Pika+LT	50+190	Silt-sand	$8.7 \cdot 10^{-8}$
KS120	SSV-4G	Pika+LT	70+230	Silt	$1.6 \cdot 10^{-7}$
					Mean = $9.0 \cdot 10^{-8}$

As the grain size is rather coarse in the matrices, permeability value $k = 5 \cdot 10^{-8}$ m/s, stated in the environmental permit, will not be achieved. However, since the solubilities of contaminants are low, water permeability around $9 \cdot 10^{-8}$ m/s in stabilized material will not significantly increase the leaching of contaminants.

4.3.2 Environmental tests

Environmental acceptability of stabilized samples was determined by analyzing total concentrations, solubilities with a single-stage batch test and with a modified diffusion testing. The results are given in following chapters.

4.3.2.1 Total concentrations

Total concentrations were analysed from stabilized samples, Table 4.8. Total concentrations follow moderately the concentrations from dredged material in Chapter 5.1. Sample SS-3A is from matrix KS60 and SS-4A from matrix KS120.

Table 4.8. Total concentrations from stabilized samples. SS-3A: matrix KS60, binder recipe rapid cement + fly ash 50+190 kg/m^3 ,SS-4A: matrix KS120, binder recipe rapid cement + fly ash 70+230 kg/m^3

Sample	Dry matter m-%	Reference values	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V
		Threshold value	*5*	*0,5*	*1*	*20*	*100*	*100*	*60*	*50*	*200*	*100*
		Lower guideline value	50	2	10	100	200	150	200	100	250	150
		Upper guideline value	**100**	**5**	**20**	**250**	**300**	**200**	**750**	**150**	**400**	**250**
		Hazardous waste limit										
		Limit value	***1 000***	***1 000***	***100***	***1 000***	***1 000***	***2 500***	***2 500***	***1 000***	***2 500***	***10 000***
			($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)	($^{mg}/_{kg}$)
SS-3A	73		*34*	*1.5*	16	*44*	46	**240**	*180*	30	***5 200***	39
SS-4A	66		*32*	*1.7*	13	*53*	57	**240**	*170*	36	***4 200***	43

4.3.2.2 Solubility testing

4.3.2.2.1 Batch testing and test for toxicity

Solubilities of contaminants were analyzed with a single-stage batch test both from untreated samples and stabilized samples.

In a single-stage batch test, a crushed sample is shaken for 24 h with a liquid-solid ratio L/S 10, and concentrations of contaminants are measured from the filtered solution.

Solubilities from both untreated and stabilized samples were below limit values for non-hazardous waste. Solubilities of copper and nickel exceeded limit value for inert waste in stabilized samples.

From untreated sediment sample and one of the stabilized samples, toxicity was tested with water fleas (*Daphnia Magna*). Neither sample was found toxic.

Table 4.9. Results from 1-stage batch test and the limit values for land fill waste. A= KS60: untreated sediment sample, B= HS-22B-HS-24C: matrix KS201, binder recipe rapid cement+ fly ash 40+150 kg/m^3, C= SS-3A: matrix KS60, binder recipe rapid cement + fly ash 50+190 kg/m^3, D= SS-4A: matrix KS120, binder recipe rapid cement + fly ash 70+230 kg/m^3, E= VV-10C: matrix KS120, binder recipe Rapid 70+230 kg/m^3

Sample	A	B	C	D	E	Limit values for land fill VNa 202/2006		
Con-taminants	L/S=10 [mg/kg dw.]					Inert waste material solubility [mg/kg dw.]	Non-hazardous waste solubility [mg/kg dw.]	Hazardous waste solubility [mg/kg dw.]
As	0.15	0.33	0.047	0.049	0.044	0.5	2	25
Hg	<0.003	<0.003	<0.003	<0.003	<0.003	0.01	0.2	2
Cd	<0.020	<0.020	<0.020	<0.020	<0.020	0.04	1	5
Cr	<0.020	0.15	<0.020	0.024	0.17	0.5	10	70
Cu	<0.020	3.3	7.4	7.7	5.7	2	50	100
Pb	<0.020	<0.020	<0.020	<0.020	0.023	0.5	10	50
Ni	0.054	0.84	0.77	0.83	1.0	0.4	10	40
Zn	<0.020	<0.020	<0.020	<0.020	0.066	4	50	200
V	<0.020	0.28	0.054	0.12	0.039			
Co	0.065	0.15	0.22	0.46	0.29			
Toxicity	not toxic	not toxic						

4.3.2.2.2 Modified diffusion testing

Solubilities of contaminants have been tested with the modified diffusion test (NVN 7347), which is a Dutch pre-standard from 1999. As a result, diffused cumulative concentrations from the surface of material (mg/m^2) is given. The results show releasing concentrations due to diffusion and surface solubility from a monolithic sample. In batch testing the sample is crushed, and it is considered to overestimate solubilities since the reactive surface is higher than in a real situation where stabilized sediment is as a monolith.

Resuls from the modified diffusion testing are given in Tables 4.10 and 4.11. Test has been done to three different matrices and binder amounts. Where solubility has been lower than detection limit, detection limit has been utilized as solubility value.

Table 4.10. Results from modified diffusion testing. Cumulative solubility againts surface area.

Sample	Time /d	Cumulative solubility per surface area [mg/m^2]										
		Contaminant	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V
		Limit value [mg/m^2/64 d]*	140	1.4	3.8	95	480	170	400	170	670	760
HS-24A: PIKA+LT 40+150 kg/m^3, Aggregate KS201 (w = 52,4 %)												
HS-24A/4d	4		1.0	0.2	0.2	1.0	1.0	10.0	1.0	4.0	5.0	1.0
HS-24A/18d	18		4.1	0.4	0.4	2.0	2.0	24.5	2.0	21.7	11.2	2.0
HS-24A/67d	67		15.1	0.6	0.6	4.0	3.0	66.3	3.0	72.5	31.1	5.0
SS-3C: PIKA+LT 50+190 kg/m^3, Aggregate KS60 (w=56,5%)												
SS-3C/4d	4		0.6	0.1	0.1	0.6	0.6	5.8	0.6	1.2	2.9	0.6
SS-3C/18d	18		1.1	0.2	0.2	1.1	1.1	28.7	1.1	7.2	5.6	1.1
SS-3C/64d	64		1.7	0.3	0.3	1.7	1.7	65.2	1.7	19.5	8.4	1.7
SS-4C: PIKA+LT 70+230 kg/m^3, Aggregate KS120 (w= 82,0 %)												
SS-4C/4d	4		0.6	0.1	0.1	0.6	0.6	5.6	0.6	1.1	2.8	0.6
SS-4C/18d	18		1.1	0.2	0.2	1.1	1.1	24.0	1.1	8.7	5.5	1.1
SS-4C/64d	64		1.7	0.3	0.3	2.3	1.7	65.0	1.7	26.3	8.4	1.7

*Dutch 64 d diffusion testing limit values for stabilized material (Sorvari, J. Suomen ympäristö 421/2000)

Yellow results: concentration is lower than detection limit in this case

Table 4.11 Results from modified diffusion testing. Cumulative solubility againts surface area and time.

Sample	Time /d	Cumulative solubility per surface area and time[mg/m^2 d]									
		As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V
HS-24A: PIKA+LT 40+150 kg/m^3, KS201 (w = 52,4 %)											
HS-24A/4d	4	0.25	0.05	0.05	0.25	0.25	2.49	0.25	1.00	1.25	0.25
HS-24A/18d	18	0.23	0.02	0.02	0.11	0.11	1.36	0.11	1.20	0.62	0.11
HS-24A/67d	67	0.22	0.01	0.01	0.06	0.05	0.99	0.05	1.08	0.46	0.07
SS-3C: PIKA+LT 50+190 kg/m^3, KS60 (w=56,5%)											
SS-3C/4d	4	0.14	0.03	0.03	0.14	0.14	1.44	0.14	0.29	0.72	0.14
SS-3C/18d	18	0.06	0.01	0.01	0.06	0.06	1.60	0.06	0.40	0.31	0.06
SS-3C/64d	64	0.03	0.01	0.01	0.03	0.03	1.02	0.03	0.30	0.13	0.03
SS-4C: PIKA+LT 70+230 kg/m^3, KS120 (w= 82,0 %)											
SS-4C/4d	4	0.14	0.03	0.03	0.14	0.14	1.40	0.14	0.28	0.70	0.14
SS-4C/18d	18	0.06	0.01	0.01	0.06	0.06	1.34	0.06	0.48	0.31	0.06
SS-4C/64d	64	0.03	0.01	0.01	0.04	0.03	1.02	0.03	0.41	0.13	0.03

Yellow results: solubility is lower than detection limit

The main results of tests are:

- Metals 64/67 d solubilities clearly are below the Dutch solubility limit values with all samples.

- Diffusion testing give similar results to batch testing concerning arsenic. In batch test it was seen also that matrix KS201 has higher solubility of arsen than samples from matrix KS60 or KS120.
- Mercury, chromium and lead had in all samples solubilities below Dutch limit values.
- Cobalt, cadmium, copper, zinc, nickel and vanadium have solubilities clearly below Dutch limit value.
- Mainly metals had the highest solubilities in the beginning of the test and decreased during testing. As an exception, arsenic and nickel remained their initial solubility during testing of sample from matrix KS201. Solubility of nickel remained constant in samples from matrices from KS60 and KS120.

4.4 Preliminary monitoring and control programme

Monitoring programs were set up for monitoring water areas and stabilization work, which were approved by authority with minor changes. Programs are shown in more detail in Chapter 6.3.

4.5 Selection of technology

Selection of technology was rather simple in Kokkola case, since there were only few options. Stabilization was found the most economical due to high concentrations of contaminants (zinc) and the deep mixing equipment for mass stabilization was the only realistic option considering the size of the project.

Commercial binder and Alholmens Kraft fly ash were selected as binder materials. Alholmens Kraft is a local enterprise located in about 40 km distance from Port of Kokkola.

Oil shale ash from Eesti Energia was found highly reactive and applicable during testing. However, due to time consuming environmental permit procedure, this was decided not to be used in this case.

5. Permit application

An environmental permit application is needed in Finland. The procedure is quite slow and it may take up to several months to gain a permission for dredging and stabilization. Demands vary usually case by case.

5.1 Situation in Finland

Stabilization of dredged masses is already a quite well established method in Finland. The first environmental permit for stabilization is from 2004 (Länsi-Suomen ympäristölupaviraston päätös 10.3.2005 nro 26/2005/3). The permit was about utilization of contaminated sediment in port structures. Since then the knowledge about, e.g., organic tin compounds has increased significantly.

The case in Port of Kokkola is the 6th stabilization project for contaminated sediments, which has gained environmental permission from Finnish environmental authorities, since 2005. Due to the large number of the stabilized cases the environmental authorities have sufficient knowledge about the stabilization process itself.

In novel stabilization permits, requirements have been set only for water permeability of stabilized material. It has been nearly always $5 \cdot 10^{-8}$ m/s. Requirements have been defined also for geotextiles located inside embankments to ensure sufficiently low permeability and spread of contaminants bound in fine particles. Permits also state that authorities have to accept water quality monitoring and stabilization quality monitoring programs before the work starts. Monitoring programs are compiled taking into account special features of each case. An example is given in Chapter 6.3.

A recent (December 2011) decision of the supreme administrative court of Finland stated that all the sediments exceeding limits for sea dumping (level 2) have to be stabilized.

5.2 Kokkola Case

For Kokkola field test the following permission and official documents were required:

- Water permission concerning dredging of sediments: Nro 224/2010/4, Dnro ESAVI/14/04.09/2010
- Environmental permission for banking:Nro 20/2011/2 Dnro ESAVI/290/04.08/2010
- Water monitoring plan of construction of port of Silverstone:
    - SouthOstrobothnia Centre for Economic Development, Transport and the Environment accepted the monitoring plan on 18.3.2011 and 16.5.2011 (Dnro EPOELY/ 160/07.00/2010).
    - SouthOstrobothnia Centre for Economic Development, Transport and the Environment accepted the plan on 20.5.2011 (Dnro POHELY/433/5723/2011).
- Monitorig plan for water quality of deep-water harbour:
    - SouthOstrobothnia Centre for Economic Development, Transport and the Environment (Etelä-Pohjanmaan ELY –keskus) accepted the plan on 10.8.2011 (Dnro EPOELY/284/07.00/2010)
- Stabilization plan

  - SouthOstrobothnia Centre for Economic Development, Transport and the Environment (Etelä-Pohjanmaan ELY –keskus) accepted the plan on 19.9.2011 (Dnro EPOELY/322/07.00/2010)
- Decision on the acceptance of reports from an authorized body on 23.5.2012

Following reports concerning the monitoring of dredging and stabilization or quality control were send to authorities:

- Monitoring report on water quality during dredging and banking of Silverstone harbour (Hopeakiven sataman ruoppauksen ja läjityksen aikainen vesistötarkkailuraportti), 8.9.2011
- Interim evaluation report on quality monitoring of stabilization, 10.10.2011
- Memo of visit of supervisory authority at the construction site (Valvovan viranomaisen muistio valvontakäynnistä stabilointityömaalla) 10.10.2011.
- Quality monitoring report on stabilization 21.11.2011
- Risk assessment for stabilization 22.11.2011
- Memo of visit of supervisory authority at the construction site (Valvovan viranomaisen muistio valvontakäynnistä stabilointityömaalla) 27.3.2012.
- Quality monitoring report on stabilization, complement the results of quality monitoring 19.4.2012

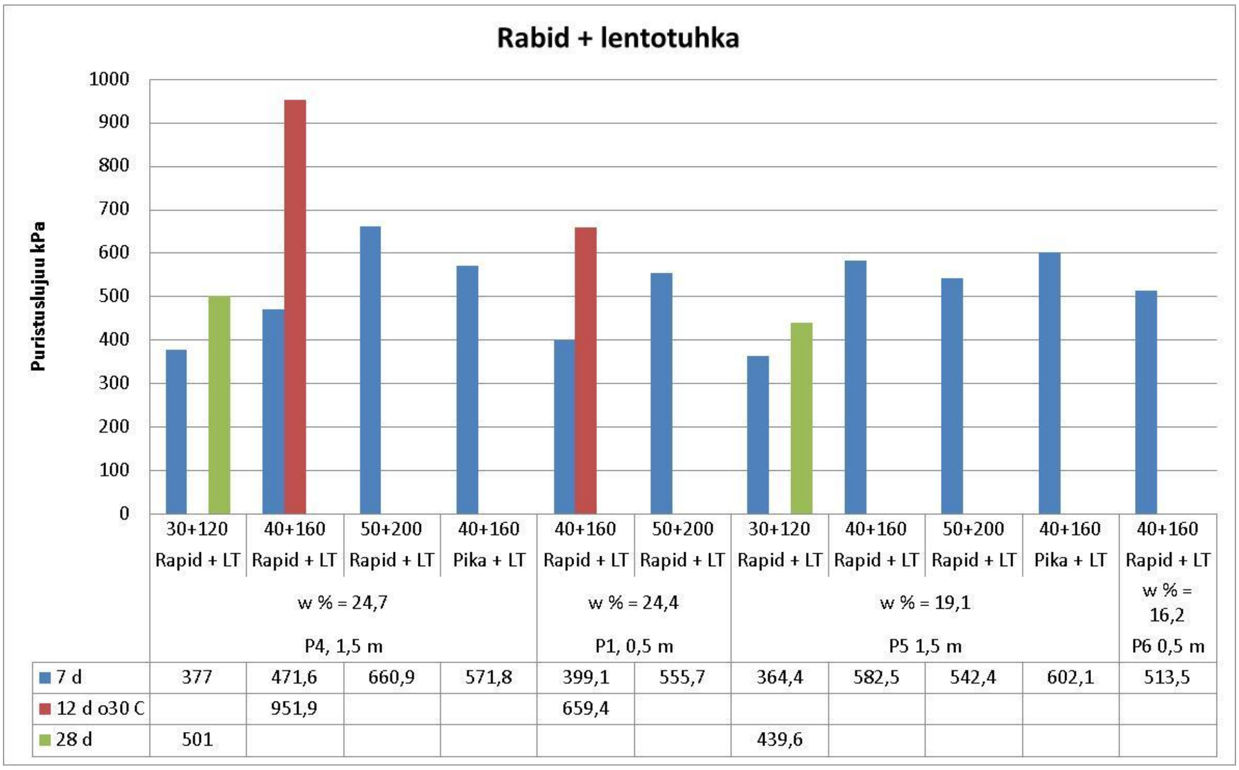
6. Detailed design

6.1 Binder recipe

The preliminary studies are shown in Chapter 4.4. The stabilization investigations for sediment in the dumping pool show that the stabilization can be carried out using only fly ash. Any commercial was not needed.

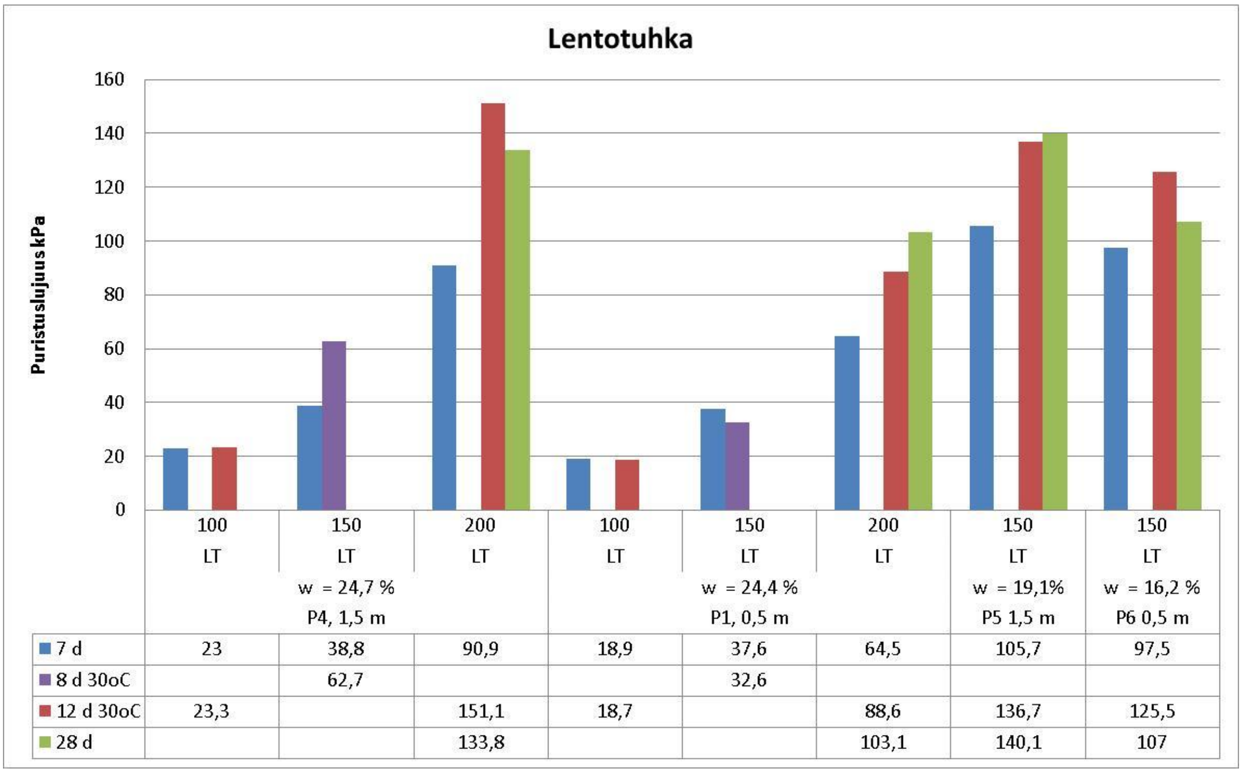
The test started with mixtures containing commercial binder material (Rapid) and fly ash (from Alholmens Kraft power plant). The mixtures were found to generate extremely high strengths already after 7 days of reaction as shown in Figure 6.1.

Due to the high strengths revealed the experimental optimization of recipe were continued without the commercial binder component (Rapid). Figure 6.2 shows the compression strengths of formulas applying only the fly ash as binder. The experiments have been carried out to banked sediment samples (dredged material at stabilization basin).



	30+120 Rapid + LT	40+160 Rapid + LT	50+200 Rapid + LT	40+160 Pika + LT	40+160 Rapid + LT	50+200 Rapid + LT	30+120 Rapid + LT	40+160 Rapid + LT	50+200 Rapid + LT	40+160 Pika + LT	40+160 Rapid + LT
■ 7 d	377	471,6	660,9	571,8	399,1	555,7	364,4	582,5	542,4	602,1	513,5
■ 12 d o30 C		951,9			659,4						
■ 28 d	501						439,6				

Figure 6.1 *Results of compression strength of mixtures involving Rapid-cement and fly ash of Almonds Kraft Power Plan (LT) as binder materials. Samples are taken from aggregate of banking area.*



	100 LT	150 LT	200 LT	100 LT	150 LT	200 LT	150 LT	150 LT
		w = 24,7 % P4, 1,5 m			w = 24,4 % P1, 0,5 m		w = 19,1% P5 1,5 m	w = 16,2 % P6 0,5 m
🟦 7 d	23	38,8	90,9	18,9	37,6	64,5	105,7	97,5
🟪 8 d 30oC		62,7			32,6			
🟥 12 d 30oC	23,3		151,1	18,7		88,6	136,7	125,5
🟩 28 d			133,8			103,1	140,1	107

Figure 6.2 Results of compression strength of mixtures involving fly ash of Almonds Kraft Power Plan (LT) as binder materials. Samples are taken from aggregate of banking area.

6.2 Construction

In the final structure, the stabilized dredged material is covered with bottom ash, fly ash, crush and dense asphalt on top. Most likely structure of the future field on top of stabilized material is shown in Figure 6.3.

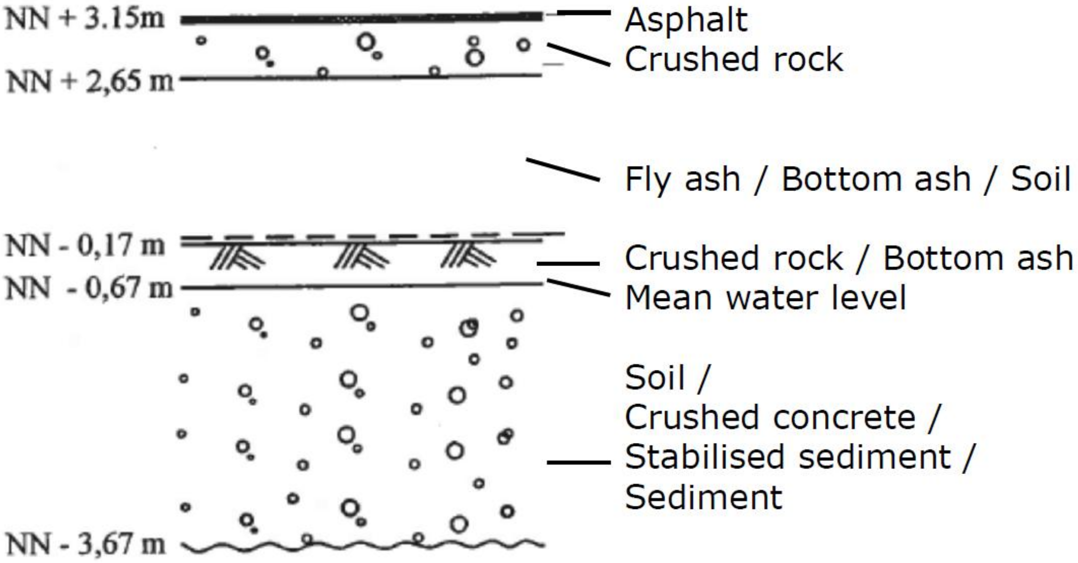


Figure 6.3. Superstructures on top of stabilized material.

Drilling information below stabilized mass in shown in Figure 6.4. Below stabilized mass there is about 5 m clay and 15 m of silt layer with more dense, probably sandy, middle layers. Moraine is detected in about 27 m depth. Drillings have been terminated to either rock or stones.

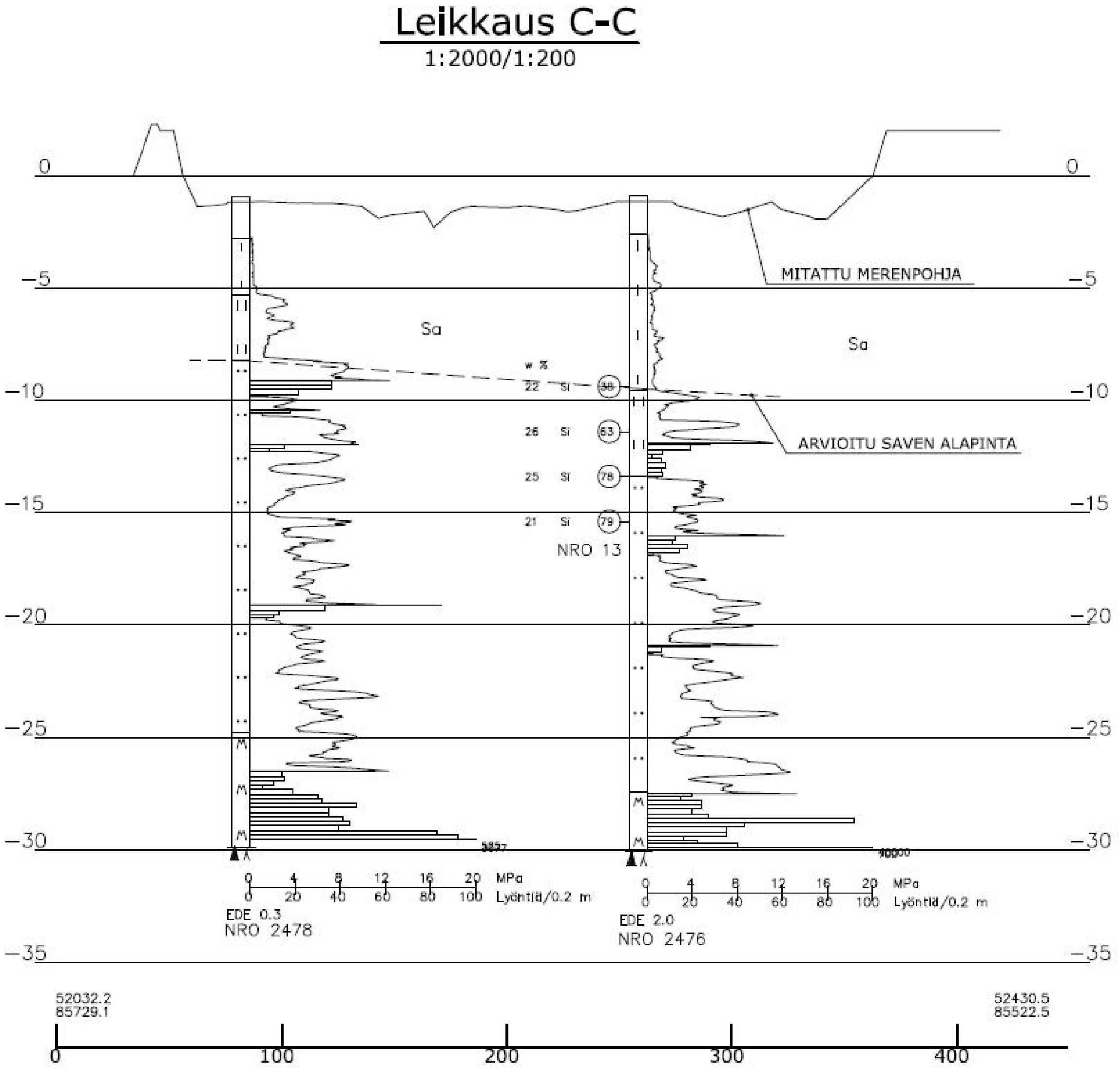


Figure 6.4 Ground layers below stabilized material.

Mass stabilization has been selected for technical execution of stabilization in September 2011. Environmental permit for the pool in Deep Port allows to select mass stabilization based on technical reasons.

6.3 Monitoring and control programme

Monitoring and quality assurance of dredging and stabilization was done according to monitoring programs approved by authorities. The required reports are listed in Chapter 5.1. Summary of the monitoring programs is given in this chapter.

6.3.1 Quality control of stabilization

In the beginning quality controlling is more frequent, but when quality has been found to evened and selected binder materials are of correct quality controlling is more sparse. Table 6.1. shows the minimum amounts of samples in quality control studies.

Table 6.1. Quality control sampling plan

Sample	***Frequency of sampling***		***Amount samples (pcs.)/ project***
	In the beginning	***Later***	
Dredged mass			
Water content	*1 pc/1000 m^3*	*As needed*	*1 pc/1000 m^3*
Contaminant concentration with a field analyzer	*1 pc/2000 m^3*		*1 pc/2000 m^3*
Ca-content with a field analyzer	*1 pc/2000 m^3*		*1 pc/2000 m^3*
Dredged mass-binder mixture			
Ca-content *field analyzer (quality of mixing and binder amounts)*	*Continuous following* *For at least 1 week*	*1 pc/d*	*1 pc/2000 m^3*
Binder amounts (titration)			*20 pcs/project*
Compressive strength	*4 pcs/d* *For the first week*	*1 pc/d*	*1 pc/2000 m^3*
Water permeability	*1 pc/ week*	*1 pc/2 week*	*1 pc/5000 m^3*
Solubility testing: *Diffusion testing*			*1 pc/10000 m^3*

More detailed procedures of the quality control are given in Chapters 6.3.1.1.-6.3.1.9. All the results are collected in table shown in Annex 11.5.

6.3.1.1 Quality control of the dredged mass

Prior to beginning of stabilization, 10-15 samples are taken from the dredged mass (approx. 12 000 m^3) in stabilization pool. Samples are taken from different depths and so that they represent different parts of the pool.

From the samples at least following are analyzed: water content, density, pH, granulation, loss on ignition, contaminants with a field analyzer. Additionally Ca- and S- content. Results are shown in Table 4.2 in Chapter 4.1.

6.3.1.2 Quality control of mixing

Quality of mixing and actual binder amounts were followed with Ca-concentrations based on Niton-XRF-analyzer. Ca content of the sample is compared to Ca content of a calibration sample and so the binder amount of a sample can be estimated. Binder content is analyzed also in a laboratory with titration for some of the samples.

6.3.1.3 Quality control of compressive strength

Samples for compressive strength are taken in the beginning 4 times a day and later once a week. Samples are stored in a dark and cool place before testing. Testing is done for parallel samples either 7, 28 or 90 days after sampling, depending on the need for technical follow-up. Some of the parallel samples are stored for testing in 180 d.

6.3.1.4 Quality control of water permeability

Permeability samples are taken in the beginning once a week and after that once in two week. Permeability samples are stored in dark and cool place before testing. More than 1 sample per 5000 m^3 are analysed if large variations are detected in matrix. Permeability has a strong correlation to matrix, whereas binder material quality and amounts have not a large significance.

6.3.1.5 Quality Control of solubilities

From representative samples leaching testings are done with the modified diffusion testing. If needed for comparison, single-stage batch testing can be done.

6.3.1.6 Quality control from finished structure

In about year after the end of stabilization, the strength of stabilized structure is determined with drilling from 3-6 measuring points. The aim is to determine the situation of technical target strength.

6.3.1.7 Documentation

A record is kept of quality assurance sampling, that will include at least: sample coding, sampling date, analysis to be made from sample, sampling operator. Stabilization constructor will keep a register of stabilization work including at least: identification of stabilization area, used binder materials and amounts in every screen, duration and date of stabilization, daily accomplishments, operator of machinery, conditions (weather, temperature, wind direction and strength), any deviations, failures and causes.

A final report will be composed to environmental authorities explaining

- Identification of location
- Responsible persons
- A summary of site register
- Used binders and amounts
- A description of work: stabilization method, dates and any deviations from the plan
- Origin of stabilized masses
- Maps indicating actual locations of stabilization
- Quality assurance and analytical methods
- Results of environmental controlling
- Contaminants of stabilized masses and solubilities of the material

6.3.2 Work safety

Binder material ashes are very fine powders and correspond to soil texture classification silt (fly ash) and finer (commercial binders). The binders are basic and dusting and will irritate eyes while in the air. If there is dusting in the work ground, eye protection is required.

All binder materials and stabilized mass are basic and skin contact may cause symptoms. In working ground necessary protective devices must be used and handling of materials with bare hands or without adequate protection must be avoided.

Dedged material contains mainly metallic contaminants and the solubility is found to be low. Even though, handling of the mass without protective clothing and gloves must be avoided. General rules about protective devices are to be followed in the worksite.

6.3.3 Environmental controlling

Environmental monitoring has to be performed according to monitoring plans accepted by authorities. Main content of these plans is described here.

6.3.3.1 Fisheries monitoring

Fry density of European white fish is to be followed in 2011, once a year during construction work and three years after completion of work with three seine fishings in June in the vicinity of harbor area. Seining sites will primarily be the same as in previous measurements (3 different places in shoreline). If there is found abnormally high concentrations of contaminants, these contaminants must be measured also from perch and pike from the area.

6.3.3.2 Turbidity

Turbidity effect caused by dredging is followed daily. Intensity and spreading of turbidity is followed visually and visual broadness of turbidity is recorded on a proper map. Turbidity observations are recorded each day while work is on-going in order to find out the largest daily turbidity zone.

In addition to visual observations, the spreading of turbidity is followed by a field analyzer every other day. Background measurements are made with a field analyzer a week before the beginning of dredging. Stationary measurement point locations are selected based on these results. Stationary measurement points are located 50 m, 100 m, 250 m and 500 m distance from the dredging site and at 1-5 points in each distance. If turbidity varies in some control sample at 500 m distance, must there also be 750 m distance sample points.

From each point, measurements are made near bottom (+1,0 m from bottom), near surface (-1,0 m below surface) and middle layers. In addition to field analyzer, a depth of visibility is used. Field analyzer gives the following parameters from each point:

- temperature
- turbidity
- solids
- conductivity

Visual result will be obtained for:

- depth of visibility
- color /turbidity

6.3.3.3 Quality of water and contaminants

Water quality is analyzed once a week during dredging and once after the dredging has ended. Preliminary and control samples will be the results obtained from sea area in front of Kokkola. Joint sampling point D and E are suitable for observing Silverstone port. Point E is a point for expanded sampling

The locations for sampling points are selected based on turbidity measurements. Samples are taken from three distances from the dredging site in direction of turbidity spreading. Surface sampling (-1,0 m below surface) is taken 250 from dredging site and after that every 250 m distances if escalated turbidities are detected. Bottom sampling (+1,0 m from bottom) is taken 50, 100, 250 m from dredging site and and after that every 250 m distances if escalated turbidities are detected.

Following parameters are measured from each sample:

- Total phosphorus, total nitrogen, chlorophyll and solid content

From surface sampling points and points closest to dredging site (100 m and 250 m) the following parameters are measured:

- Phosphates, ammonium-, nitrate- ja nitrite nitrogen, TBT- and TPhT- concentrations and As, Hg, Cd, Cr, Cu, Pb, Ni and Zn.

From the bottom sampling points closest to dredging site (50 m and 100 m) will be measured for:

- TBT- ja TPhT- concentrations and As, Hg, Cd, Cr, Cu, Pb, Ni ja Zn.

If exceeding amounts of tin compounds (>0,2 µg/l) are detected in water, TBT and TPhT will be measured from the next distance in surface (500 m) or bottom (250 m) sampling point during next sampling.

Water quality controling during dredging, depositing and stabilization. Results are shown in Chapter 8.2 (Turbidity).

6.3.3.4 Water quality monitoring during the emptying of barges

Emptying of the barges is related to the utilized dredging technique. Sediment, dredged with an environmental grab or equivalent, is loaded into barges in dredging site and emptied in a stabilization pool with controlled lifting of an excavator from the edge of the pool. Effects on water quality are being followed from one sampling point in about 30 m distance from the docking site of barges in direction of sea currents. Water samples are taken from surface (-1,0 m below surface) and bottom (+1,0 m from the bottom). Water samples are taken once a week during the first two week of action and after that once a month. Additional samples are taken after a week from ending of actions.

Water samples are analyzed for total phosphorus, total nitrogen, chlorophyll, solid content, phosphate phosphorus, ammonium, nitrate and nitrite nitrogen, TBT, TPhT and As, Hg, Cd, Co, Cr, Cu, Pb, Ni and Zn.

6.3.3.5 Water monitoring on dumping site in Deep Port

Filtration water samples from Deep Port dumping site are taken from the pool and two points outside the pool during extended sampling (3 times a year). From these samples, the following are analyzed as stated by the environmental permit: Al, Na, K, Ca, Fe, As, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sb, Se, Sn, V, Zn and SO_4. This program is followed for three years (2009 – 2011), after which the need for continuance is evaluated. Measurements are done either from filtrated samples (0.45 µm) or from unfiltrated samples. This is agreed case separately.

Table 6.2. Summary of monitoring during dredging actions.

Monitoring	*Task*	*Frequency and disances*
Log	*Location of dredging site* *Quality of dredged material* *Amount of dredged material* *Dumping site* *Weather conditions* *Wind direction and speed* *Dredging equipment* *Working hours* *Other procedures at site* *Sampling times* *Vessel traffic*	*Each day*
Visual monitoring of turbidity	*Intensity and spreading of turbidity is followed visually and extent of turbidity is noted on a map.*	*Each day*
Field analyzer	*Intensity and spreading of turbidity is followed with a field analyzer every other day.* *Solid sampling points (minimum 1-3 and maximum 5 points in each distance) are located in 50 m, 100 m, 250 m and 500 m distance from the dredging site.* *Measurements are done from surface, bottom and middle layers.*	*Every other day*
Monitoring of water quality	*In a laboratory samples are analyzed for total phosphorus, total nitrogen, chlorophyll and solids.* *Surface samples (100 m and 250 m) are analyzed for phosphate phosphorus, ammonium, nitrate and nitrite nitrogen, TBT, TPhT, As, Hg, Cd, Cr, Cu, Pb, Ni ja Zn.* *Bottom samples (50 m and 100 m) are analyzed for TBT- and TPhT-concentrations and As, Hg, Cd, Cr, Cu, Pb, Ni and Zn.* *If tin compounds are found more than 0.2 µg/l, are TBT and TPhT analyzed from next distance also during following sampling.* *Locations of monitoring points are determined based on field analyzer measurements, as above mentioned* *Surface samples (-1.0 m below surface) are taken 100 m and 250 m distance from dredging site and following samples every 250 m, if needed.* *Bottom samples (+1.0 m from bottom) are taken 50m, 100 m and 250 m distance from dredging site and following samples every 250 m, if needed.*	*Once a week*

Table 6.3. . Summary of monitoring during dumping actions.

	Monitored action	*Monitoring of water quality*
DUMPING	*Emptying of barge*	*One sample point from surface and bottom. Water samples once a week during the first two weeks of action and after that once a month. Samples are also taken two weeks after the end of work.* *Samples are analyzed for total phosphorus, total nitrogen, chlorophyll, solid matter content, phosphate phosphorus, ammonium, nitrate and nitrite nitrogen, TBT, TPhT, As, Hg, Cd, Co, Cr, Cu, Pb, Ni and Zn.*
OTHER	*Water monitoring in the pool*	*Three water samples taken from south and north side of the embankment of the deposit pool are being analyzed for (Al, Na, Ca, Cl, Fe, As, Cd, Co, Cr, Cu, Mg, Mo, Ni, Pb, Sb, Se, Sn, Ti, V, Zn, Hg). During work samples are taken three times a year: spring, summer and fall in the middle depth of water.*

Water was not directed into sea from the stabilization pool, but the water was filtered into sea through embankments. Due to this, leaching water quality could not be analyzed directly.

6.3.3.6 Documentation

A record of quality assurance is kept during sampling that will include at least: sample coding, sampling date, analysis to be made from sample, sampling operator. Stabilization con-structor will keep a register of stabilization work including at least: identification of stabilization area, used binder materials and amounts in every screen, duration and date of stabilization, daily accomplishments, operator of machinery, conditions (weather, temperature, wind direction and strength), any deviations, failures and causes.

A record is kept during dredging that will include at least:

- Location of dredging site
- Quality of dredged material
- Amounts dredged
- Dumping site
- Weather conditions
- Wind speed and direction
- Dredging equipment
- Working hours
- Other procedures at site
- Sampling times
- Vessel traffic

7. Implementation

7.1 Dredging and dumping

Dredging at Silverstone port was carried out during14.7.-6.8.2011. Contractor for the dredging works was YIT and the works were carried out 6 days per week, 10 hours per day.

Dredging works were carried out to remove contaminated sediments underneath the quay to be constructed at the Silverstone port. Dredged material was mainly contaminated silty sediment. Total amount of dredged material was 12 550 m^3. Dredged masses were dumped to dumping basin located at the Kokkola deep port where it will later be stabilised to form a base for new field at the port area.

Overall picture of the port where dredging and dumping areas are marked is shown below (Figure 7.1).

Figure 7.1 Overall view of port of Kokkola where the dredging and dumping areas have been marked

Dredging was conducted by using backhoe dredger with environmental bucket with the closing mechanism. The equipment is presented in Figure 7.2.

Figure 7.2. Dredging equipment used in dredging of Silverstone port.

During the project very important part was the quality control of dredged sediments and also the water content of the sediment during dredging. The water content was kept minimum by using backhoe dredger, it results lower water content in the dredging material than for example suction dredging. Low water content in the dredged material in this case gave an advantage for further actions because sediment drying before stabilisation took place did not take very much time. The closing system of the bucket decreases the turbidity and spread of contaminants due to that since the sediment was proven contaminated by sampling prior to dredging works.

7.1.1 Dumping of dredged material to stabilisation/dumping basin

Dumping basin where the dredged material was dumped from the barge was constructed to the deep port of Kokkola. The basin was dimensioned based on mass amount calculations, where also the binder material amounts to be fed during the stabilisation process was taken into account. The first step was to construct an embankment to isolate sufficient sized basin from the large basin which outer embankments did already exist.

Possible water overflow from the basin was taken into account during the construction of dumping basin thus overflow ditch leading to the overflow basin was constructed. Figure 7.3. shows the work stages during the construction of the dumping basin.

Figure 7.3 On the left is construction of the dumping pool, on the right is the constructed overflow ditch leading to overflow basin.

Dumping of the dredged material was conducted from a barge over an embankment directly to the basin by excavators. The process of dumping and filling phase by phase is shown in Figure 7.4.

Figure 7.4 Process of dumping and filling of the dumping basin at the deep port of Kokkola

The chosen dumping method was working well and at the end it resulted a basin filled by sediment which surface was above the mean sea water level (MW2011) as it was a requirement set for the contractor. During the dredging and dumping works there were made some modifications for the basin, since while works were on-going it was found that the basin volume was slightly too big to achieve the required level of filling.

Figure 7.5 shows the dumping basin before the dredging and dumping was started and after all the sediment was dumped to the basin and the basin is filled with the dredged material.

The process of drying of the sediment in the basin was efficient and stabilisation took place after the filling works as scheduled.

Figure 7.5. Dumping basin before and after the dredging and dumping works.

7.2 Turbidity study

One of the most significant matter causing negative impacts for the water environment during dredging and dumping is turbidity. During the dredging and dumping at the port of Kokkola was conducted a turbidity study to achieve information about dredging and dumping induced turbidity and the spread of it during the actions. Dredging of contaminated sediments causes turbidity and spread of contaminants, but there are ways to minimize the impacts to the environment. Choosing the most applicable methods for the target and taking into account the impacts and minimising those leads to the best solution.

Turbidity monitoring was carried out visually every day and by using in-situ measuring equipment (in NTU unit) every second day. Results of investications are shown in Chpter 8.2.

7.3 Stabilisation/solidification method

Stabilization was started September 12, 2011 with testing of mass stabilization equipment and finding right adjustments. The stabilization was done grid-wise (grid size approx. 5x5 m, depth approx. 2.5 m). The first grids were successfully stabilized in the beginning day and stabilization was completed October 14, 2011. A total of 157 grids were stabilized covering total of 10 032.5 m³ of dredged sediment. Coarse material accumulated in northern corner of the pool proved to be too difficult to be processed with the stabilization equipment, so differing from the original plan about 800 m² (approx. 2 000 m³) was left unstabilized.

7.3.1 Stabilisation method

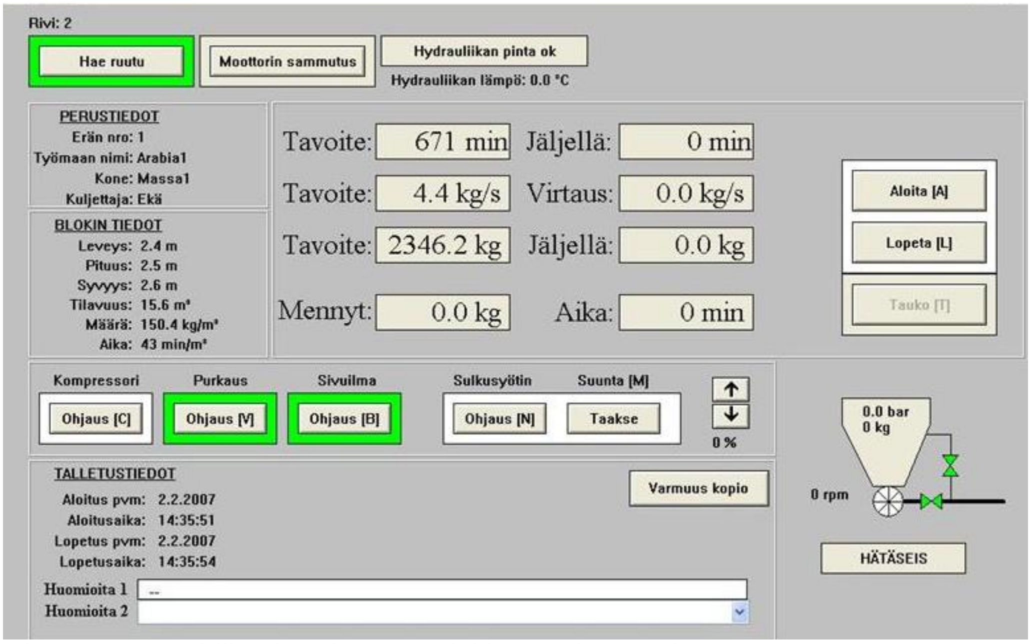
Stabilisation System is developed for mass stabilisation of soft soils, but it can also be used in the treatment of contaminated soils, by encapsulating contaminants within the soil and preventing them to leach to the surrounding areas. Stabilisation is successful only when using equipment and techniques that can homogenise the soil mass effectively and accurately. Additionally, the feeding accuracy is essential, along with quality control and reporting.

Biomaa stabilisation system consists of four elements (see Figures 7.6 and 7.7):

- Excavator, adjusted for stabilisation
- Mixing head
- Pressure Feeder
- Data acquisition and control system

Figure 7.6. Mass stabilization machinery in Vuosaari (Helsinki) harbor contaminated sediment treatment project. Similar set up was used in Kokkola stabilisation project

Stabilisation System uses dry binder and dried compressed air to transport the binder from the container into the soil. The binder is fed through the hose directly into the middle of the mixing drums of the mixing head. With the data acquisition and control system the operator can control all the functions of the pressure feeder and can also accurately set the amount of the binder to be fed into the soil. With these elements, the mass stabilisation can be completed successfully.



Rivi: 2

Hydrauliikan lämpö: 0.0 °C

PERUSTIEDOT
Erän nro: 1
Työmaan nimi: Arabia1
Kone: Massa1
Kuljettaja: Ekä

BLOKIN TIEDOT
Leveys: 2.4 m
Pituus: 2.5 m
Syvyys: 2.6 m
Tilavuus: 15.6 m^3
Määrä: 150.4 kg/m^3
Aika: 43 min/m^3

Tavoite: 671 min Jäljellä: 0 min
Tavoite: 4.4 kg/s Virtaus: 0.0 kg/s
Tavoite: 2346.2 kg Jäljellä: 0.0 kg
Mennyt: 0.0 kg Aika: 0 min

0 %

0.0 bar
0 kg
0 rpm

TALLETUSTIEDOT
Aloitus pvm: 2.2.2007
Aloitusaika: 14:35:51
Lopetus pvm: 2.2.2007
Lopetusaika: 14:35:54
Huomioita 1 --
Huomioita 2

Figure 7.7. Stabilisation data acquisition and control system

7.3.2 Binders and storage of binders

The following binder materials were used in the stabilization:

- Rapid = Rapid cement (CEM II/A-LL 42,5 R),
- LT = Alholmens Kraft, Pietarsaari, fly ash

Cement and fly ash were brought to work site dry. Dry binders were transported with tank trucks, where they were pneumatically transferred into own separate storage tanks. Binders were fed dry to stabilization equipment.

Cement was transported to work site from Finnsement Pietarsaari plant and fly ash from Alholmens Kraft Pietarsaari powerplant. The binders and used amounts are shown in Table 7.1.

Table 7.1. The binder materials and amounts used in stabilization work.

Binder	*Amount of used binder (kg)*
Rapid-cement	*43 050*
Fly ash	*1 225 900*

7.3.3 Stabilisation work

The dredged mass in stabilization pool was mass stabilized. The binders were fed from storage tanks pneumatically via hosepipes to mixing tip of an excavator which was used in stabilization. Just before the stabilization the dredged mass was homogenized and loosened with another excavator for easier stabilization, Figure 7.8. A filter cloth and a layer (approx. 0.3 m) of bottom ash was placed on top of stabilized material, Figure 7.9.

Figure 7.8. Mass stabilization equipment: binder storages and the feeding unit in left, the excavator with mixing tip and the outlet for binder materials in right.

Figure 7.9. Stabilization progresses in the pool October 6, 2011.

7.3.4 Planned field-tests for quality control

The quality control and sampling frequency were emphasized to the beginning of stabilization so that the actual stabilization could be followed in real time and, e.g., binder feed could be checked instantly and adjusted to match the instructions if needed. Follow-up and sampling for quality control samples was done on weekly basis. A table with results for quality control and sampling is shown in Appendix 6. Progress of stabilization can be seen in gridded map where the numbering of grids indicate the order of stabilization, Appendix 3.

During the quality control, so called 0-samples were taken from the original dredged mass which were analyzed for, e.g., water content and Ca-content with Niton XRF-analyzer.

Success of stabilization was followed from, e.g., calcium concentration and strength development. Ca content was used for evaluating the fulfillment of correct binder receipt and homogeneity of mixing work. The fulfillment of receipt was followed on-site using calibration values obtained from field laboratory mixings. The homogeneity of mixing was detected from parallel samples. The closer the samples are to each other, the more homogenic the material is.

Test samples for compression strength testing were done in the field. Test samples were/will be tested in laboratory after 7, 28, 90 and 180 days. Additionally samples were prepared for testing of water permeability and solubility testing. Samples were also collected for further testing of, eg., binder materials.

An indicative strength value was measured for 0-mass and stabilized mass using light, hand-held vane drill.

Figure 7.10. Original 0-mass, stabilized mass and samples taken from the mass in left, vane drill measurement in right.

7.4 Execution procedure

There was no significant deviations from planned procedure that should be mentioned.

8. Monitoring

8.1 Dredging and transport

Monitoring during the dredging and transport was done as part of turbidity monitoring.

Also water sampling with laboratory analyses were carried out near dredging and dumping sites once a week during the dredging period.

8.2 Turbidity

In-situ turbidity monitoring was carried out in 15 locations at the sea area and in 3 locations in the overflow basin. All the monitoring points are presented in Figure 8.1 and point coordinates with investigation depths in the Table 8.1.

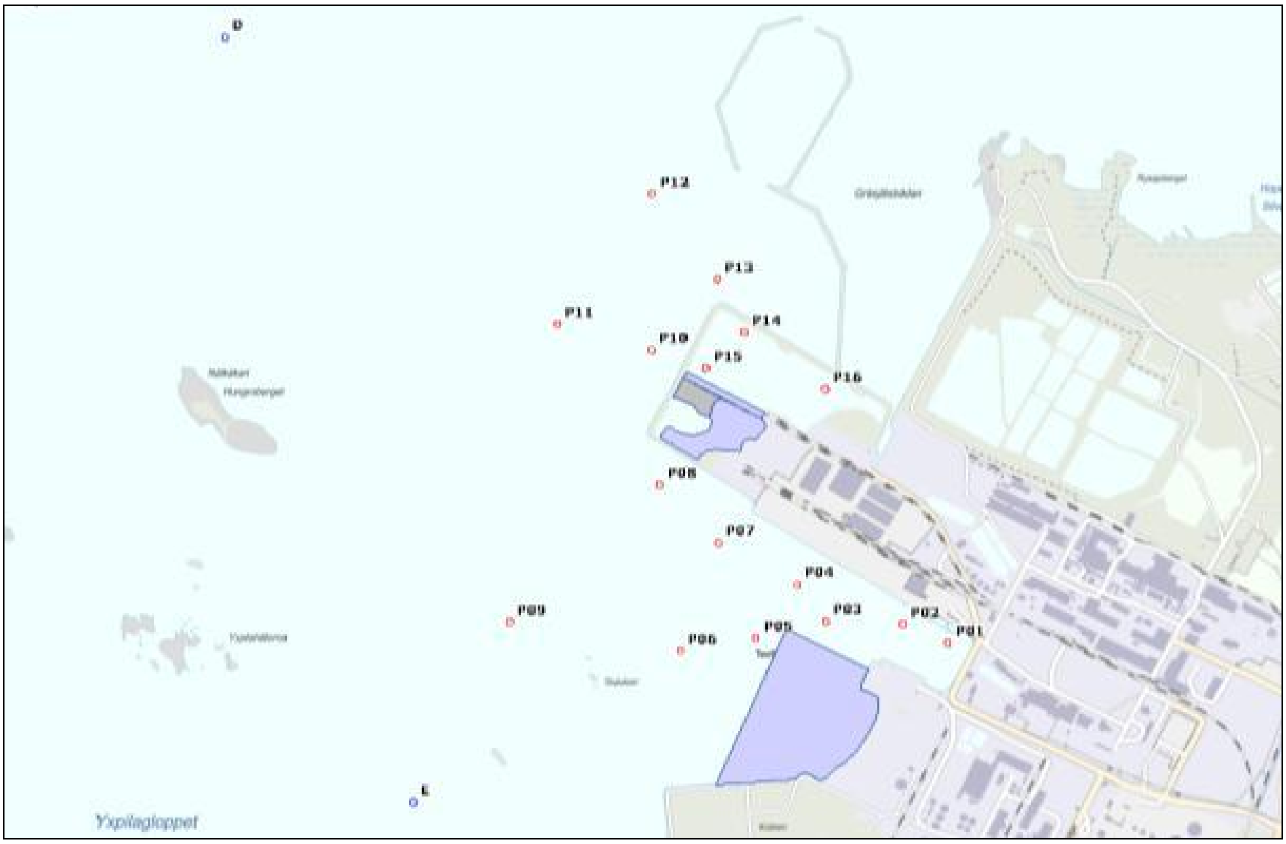


Figure 8.1. Turbidity monitoring points during dredging works at Silverstone harbor (at Port of Kokkola)

Table 8.1. *Turbidity monitoring point coordinates with water depths and monitoring depths*

Monitoring point	*Point coordinates*		*Water depth*	*Depths of monitoring points*
	x	*y*		
P01	*7084831*	*2453003*	*10.5 m*	*1 m; 5 m; 9.5 m*
P02	*7084889*	*2452849*	*12 m*	*1 m; 5 m; 9.5 m*
P03	*7084886*	*2452594*	*12 m*	*1 m; 5.5 m; 11 m*
P04	*7085008*	*2452493*	*14.5 m*	*1 m; 6.5 m; 13.5 m*
P05	*7084818*	*2452363*	*5 m*	*1.5 m; 4 m*
P06	*7084763*	*2452115*	*9 m*	*1 m; 4 m; 8 m*
P07	*7085139*	*2452223*	*14.5 m*	*1 m; 6.5 m;13.5 m*
P08	*7085330*	*2452018*	*14.5 m*	*1 m; 7 m; 13.5 m*
P09	*7084835*	*2451543*	*11 m*	*1 m; 5 m; 10 m*
P10	*7085791*	*2451971*	*11 m*	*1 m; 5.5 m; 10 m*
P11	*7085866*	*2451652*	*13 m*	*1 m; 6 m; 12 m*
P12	*7086330*	*2451946*	*13 m*	*1 m; 6 m; 12 m*
P13	*7086045*	*2452178*	*10 m*	*1 m; 4.5 m; 9 m*
P14	*7085867*	*2452275*	*< 1 m*	*0.7 m*
P15	*7085738*	*2452154*	*< 1 m*	*0.7 m*
P16	*7085684*	*2452554*	*<1 m*	*0.7 m*
D	*7086800*	*2450500*	*16 m*	*1 m; 7.5 m; 15 m*
E	*7084200*	*2451250*	*10 m*	*1 m; 4.5 m; 9 m*

Water quality and turbidity monitoring programme is presented in Table 8.2. In the table it is seen that the turbidity monitoring took place every day by visual observation and every second day by *in-situ* measuring equipment. Water sampling with laboratory analyses took place in the same points as turbidity monitoring following the direction of observed turbidity at the area near the dredging (sampling points P01, P02 and P03) near the dumping basin (sampling point P10) and from the overflow basin (sampling point P15).

Table 8.2. Water quality monitoring program for dredging works at Silverstone port.

Dredging of contaminated sediments	Monitoring of turbidity	How strong is the turbidity, how far has turbidity expanded.	whole area		Every day
	Visual				
	Measuring equipment	The spreading and intensity of turbidity is monitored every second day. Fixated monitoring points are determined 50m, 100m, 250m and 500 m away from the dredging location, at least 1-3 points and max 5 points. Monitoring is made from surface, middle and bottom water layer.	all points	surface layer - 1,0 m middle layer bottom layer +1,0 m	Every second day
	Water quality monitoring in laboratory	From all the samples in the lab area measured general P, general N, Clorofyla a and solid matter	at least. 5 max 10	surf. - 1,0 m bottom +1,0 m	Once a week
		From the surface layers (100 m and 250 m away) phosphate phosphorus, ammonium-, nitratate- and nitrit types, the levels of TBT and TPhT and levels of As, Cd, Hg, Cd, Cr, Cu, Pb, Ni and Zn. Monitoring points are the same as everyday field monitoring.			
		From bottom layers (50 m and100 m) TBT- ja TPhT-levels and As, Hg, Cd, Cr, Cu, Pb, Ni ja Zn. From surface layers (-1,0 m above surface) 100 m and 250 m away from the dredger and if necessary 250 m away			
		If the level of TBT and TPhT are over 0,2 mg / l unit, then during the next sampling these are measured from the surface and botttom layers. From the bottom layer (+1,0 m from bottom) 50, 100 and 250 m away from the dreger and further away if necessary after 250 m			

Visual observation included the magnitude, spread and direction of turbidity from the location where dredging took place at the present moment. *In-situ* measurements were carried out in a wider extent covering all the port area. Also in each point the turbidity was measured in three depths including 1 m down from the water surface, 1 m up from the seabed and at the middle. Also visibility was recorded every second day during turbidity monitoring.

8.2.1 Turbidity measurement methods

Turbidity was measured every second day in 18 sampling points by in-situ equipment presented in Figure 8.2. Besides turbidity in each sampling location and depth was recorded electric conductivity and water temperature. Results are shown in Annex 11.4 where are also shown the results of the laboratory analyses for water samples.

Turbidity study was conducted by Liis Tikerpuu and Maria Kangaskolkka from Ramboll and water sampling to laboratory analyses by Jutta Piispanen and Pekka Grims.

Figure 8.2. In-situ water quality measuring equipment for turbidity monitoring during dredging.

Water samples from different depths for laboratory analyses and also for feed of turbidity monitoring equipment were taken by Ruttner sampler which is presented in Figure 8.3. Turbidity was measured on-site and the results were recorded right after the monitoring.

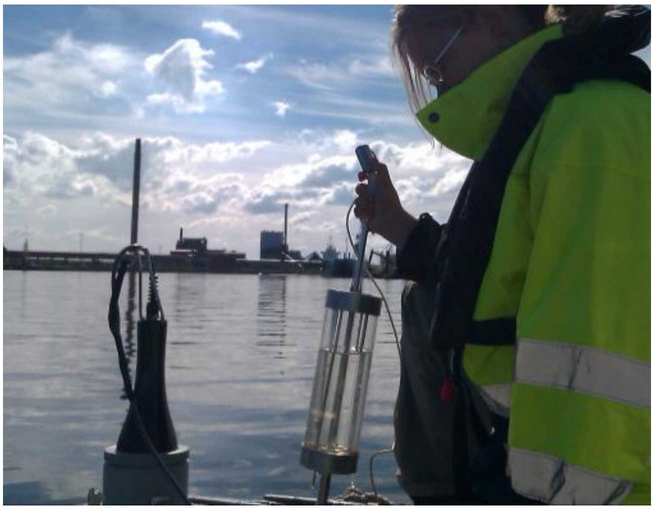


Figure 8.3. Ruttner water sampler with the turbidity monitoring equipment

8.2.2 Results

The results of the turbidity study showed that turbidity in this case did not spread far from the dredging equipment, it was local and detected just until 100 m distance from the location where dredging took place in the present moment, in that distance the measured turbidity value was already minorVisually observed turbidity during shipping and during dredging is presented in Figure 8.4.

Figure 8.4. Visual turbidity from normal vessel traffic in the port, before dredging had started and visual turbidity during dredging next to dredger

The turbidity during dredging period in the 5 nearest monitoring locations are shown in Figure 8.5. As seen from the figures in the location P5, which is the furthest of these from the location where dredging took place. In that point the turbidity is already very minor and further from that point there was observed no turbidity by the measuring equipment. Also the measured turbidity at the sampling points in overflow basin are presented in the figure below.

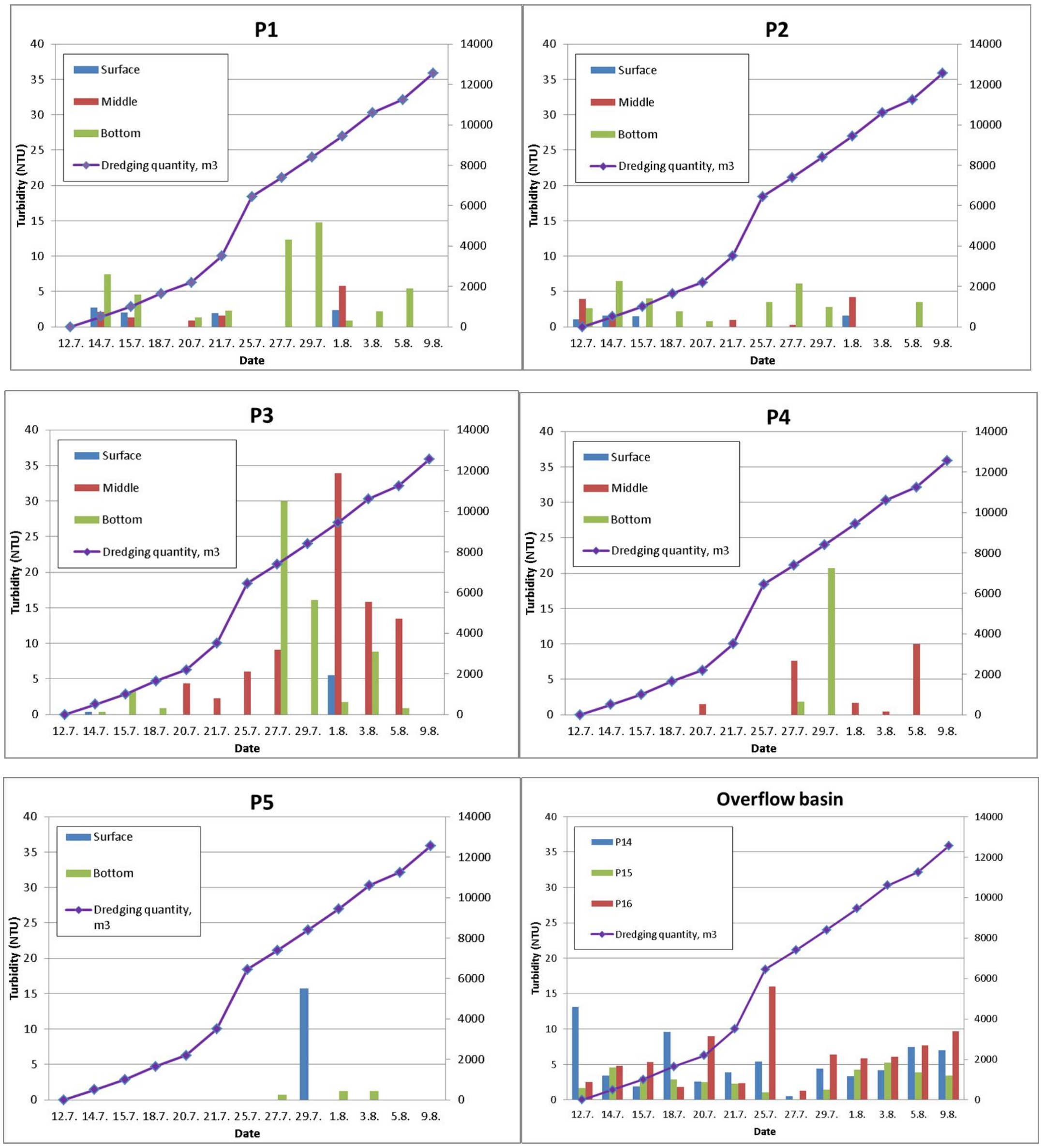


Figure 8.5. Turbidity monitoring results during dredging period.

In the figures above it can be seen that the turbidity values were highest during the second and third week of dredging. However even in the monitoring point P3, which was the closest to the location where dredging took place turbidity value did not exceed magnitude of 40 NTU which was exceeded during normal shipping operations at the port area (see Figure 8.4).

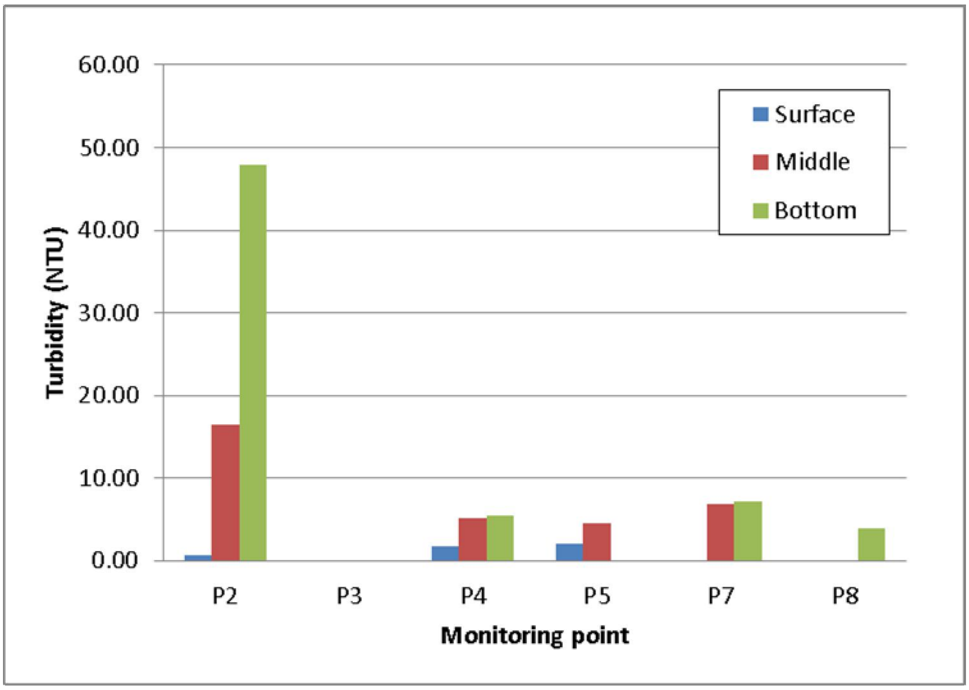


Figure 8.6. Turbidity monitoring results during shipping before dredging took place

Source of turbidity in the overflow basin could not be detected. There were measured turbidity values during dredging, but the values were at similar level also before the dredging works were started (see Figure 8.6). It is deemed that the turbidity in the overflow basin in this case does not depend on dredging.

8.3 Properties of s/s-treated dredged material

The quality controlling was carried out as described in Chapter 6.3 accoring to monitoring programme. The results are shown here.

8.3.1 Geotechnical properties

Strength development, water permeability and actual binder amount was tested in laboratory from test pieces made on stabilization site. Ca content of binder material was measured by titration. Quality control and sampling grid with results is shown in Appendix 2.

Strength level and mixing of binders in stabilization field is planned to be verified after a year from completion of work with quality control drillings. Strength of the stabilized structure is evaluated with appropriate drillings.

8.3.1.1 Use of binders

A mixture of Rapid-cement and fly ash from Alholmens Kraft was used in the beginning of stabilization with a recipe of 30 kg/m^3 cement and 100 kg/m^3 fly ash. Results from stabilization testing in laboratory showed that the achieved strength with that recipe was, in fact, too high and the receipting was continued. At the end of receipting it was decided that mere fly ash was enough with target feed 150-200 kg/m³ depending on the workability of the dredged mass.

Stabilization with only fly ash was started from grid 30. Actual feeds grid by grid are shown in a report from the contractor shown in Table 8.3. According to report, target feed could not be achieved in all grids due to properties of dredged mass. Map of the stabilization pool, Figure 8.7., is numbered according to order of stabilization.

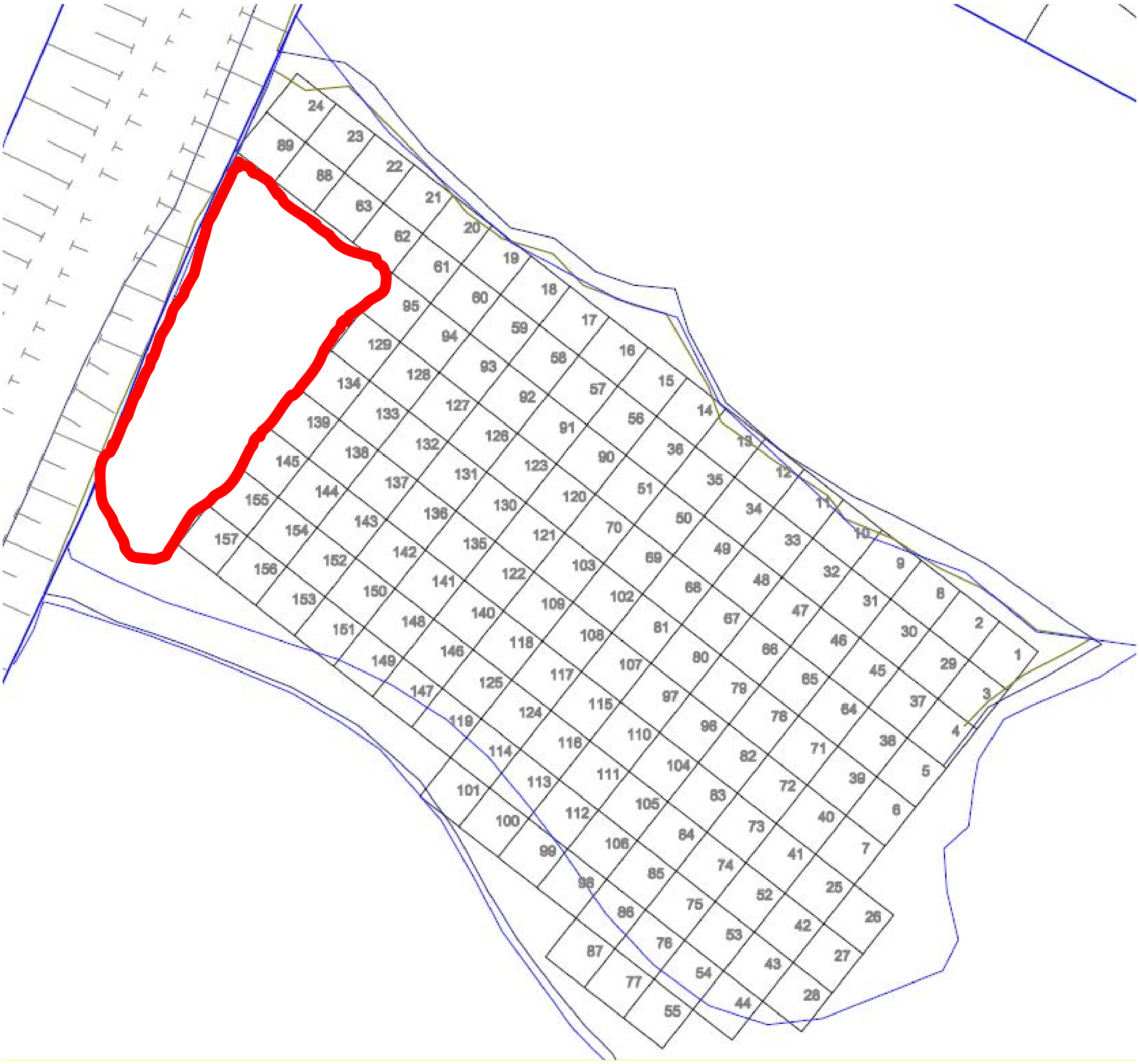


Figure 8.7. Map of stabilization pool with numbered grid accoring to order of stabilization. Lined unidentified area shows, where stabilization could not be done. Figure is not at accurate scale.

8.3.1.2 Mixing work

Mixing during stabilization was followed with Niton XRF-analyzer. Parallel Ca-measurements show homogenity of mixing and average values show the actual binder amount in sample. Binder amounts were investigated additionally in laboratory from a total of 16 stabilized samples (6 Rapid cement/fly ash samples and 10 fly ash samples), three unstabilized samples and binder materials.

From the results from titration or Niton-XRF analyzer, binder material mixture ratios cannot be evaluated. Total amount of binder materials in the sample can be estimated assuming that binder ratios are close to planned.

Figure 8.8 shows the dependence of binder material amounts measured by titration or Niton XRF-analyzer. Rapid cement + fly ash mixture points are circled with dashed line.

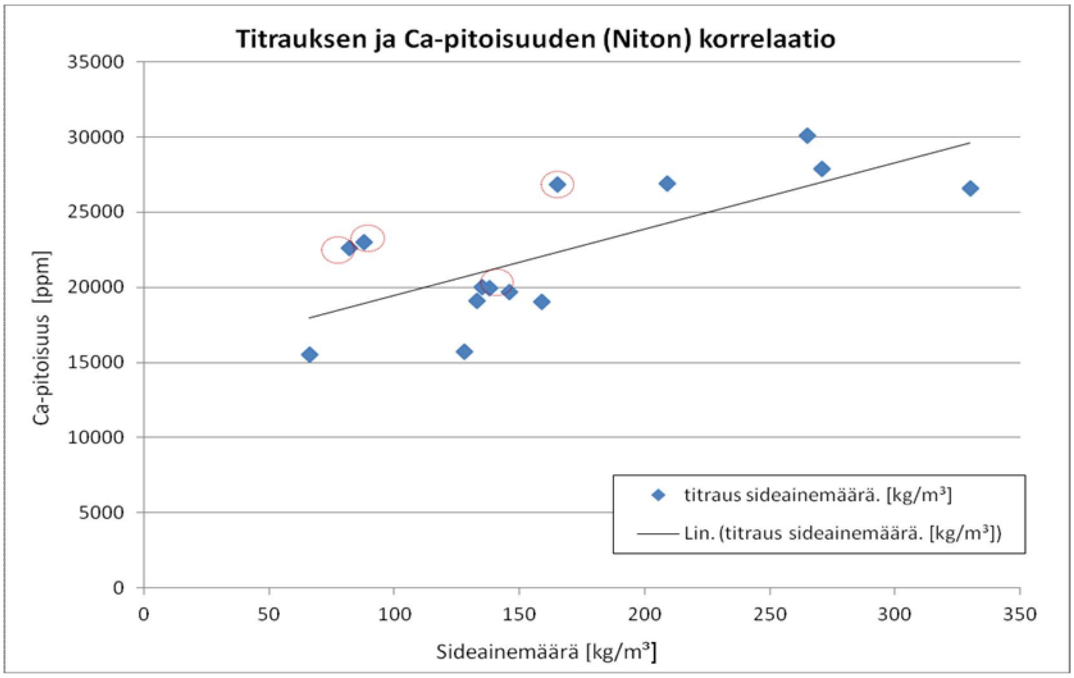


Figure 8.8. Dependence of Ca concentration measured by titration or Niton XRF-analyzer and binder material amount.

Table 8.3 gives the results from titration. Considering the results, it should be noted that the volume of mass increases during stabilization. The addition of binder materials increases the volume approximately 7-9 % depending on the binder selection. Thus, when utilizing Rapid cement-fly ash recipe, target binder amount 130 kg/m^3 will result in “corrected” target of about 121 kg/m^3 in finished structure. Correspondingly, when utilizing fly ash 150 kg/m^3, the corrected target level is about 138 kg/m^3. Based on this, the titration results are classified in Table 8.3 with background colors (green=good, yellow=adequate, red=bad).

Variance in titration results is large. This shows that stabilization has remained heterogenic due to difficult matrix material. Mostly the results are, however, good according to binder amounts in final structure and will lead to target strength level.

Table 8.3. Binder concentrations by titration.

Grid	Depth [m]	Target Rapid+LT [kg/m^3]	Titration Binder amount [kg/m^3]	Binder feed reported by contractor [kg/m^3]
2	0.0-1.0	30+100	165	30+90
10	0.0-0.5	30+100	105	30+100
10	1.0-2.0	30+100	58	30+100
14	0.0-0.5	30+100	116	30+100
14	2.0	30+100	59	30+100
18	2.0	30+100	137	30+100
35	2.0-3.0	0+150	66	0+100
37	1.0-2.0	0+150	209	0+100
38	1.0	0+150	146	0+100
40	0.0-1.0	0+150	133	0+100
47	3.0	0+150	159	0+150
49	2.0	0+150	271	0+150
63	1.0	0+150	128	0+80
72-74	0.0-1.0	0+150	136	0+150
91	0.5	0+150	330	0+120
104	0.0-1.0	0+150	265	0+100

Figure 8.9 shows the dependence of Ca content (Niton XRF) and compression strength (28d) in laboratory. Rapid cement + fly ash mixtures are shown with dashed line.

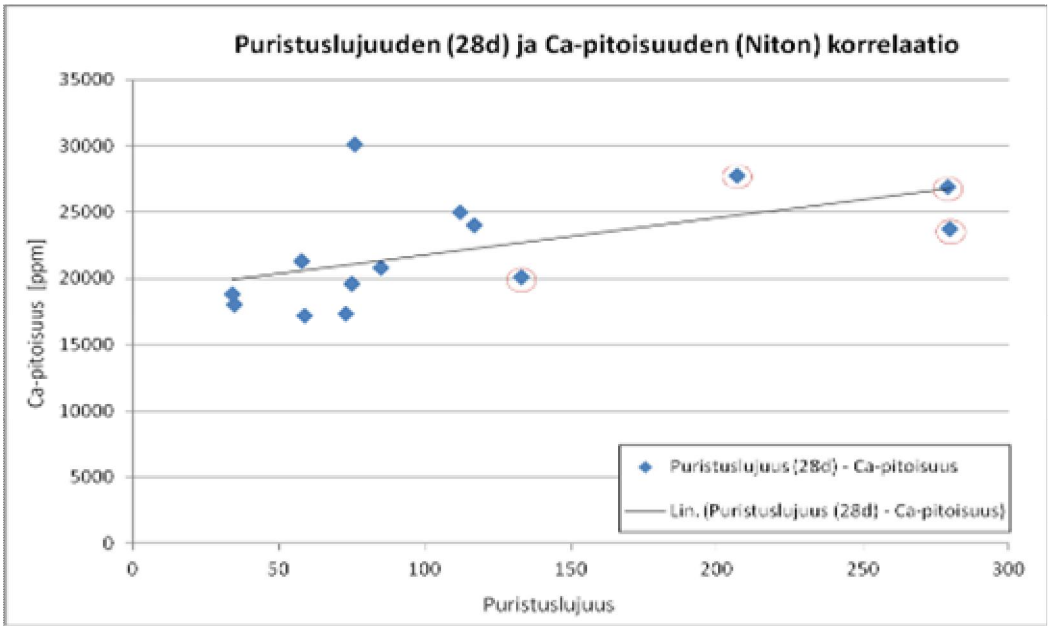


Figure 8.9. Correlaio between strength of stabilized test pieces (28d) and Ca content based on Niton XRF –analyzer.

8.3.1.3 Compressive strength

There are more factors affecting the strengthening of stabilized mass in the field than in a laboratory where the conditions are constant. A single most important factor for strength development is temperature. In the laboratory the test pieces are heat treated in room temperature for about 2 days before they are transferred to +8°C conditions. In Kokkola case the temperature of the stabilized mass depended solely on the local weather conditions. During stabilization work (September-October) monthly average temperatures vary between +12 - +6 °C. Stabilization test pieces from field were transferred to laboratory after 1-2 days to +8°C constant conditions. This way the test pieces made in field conditions have not achieved similar initial hardening than the samples prepared in laboratory due to difference in temperature. Development of strength is slower in the field than in the laboratory. Direct comparison between laboratory and field test samples is not possible.

1-axial compression strength was measured from test pieces from quality control samples in 7 and 28 days. Furthermore, 90 days samples will be measured and for some samples also 180 day samples. Target strength for the stabilized mass in the pool is 100 kPa and 150 kPa in the laboratory. Target shearing strength in the field is about 50 kPa.

Figure 11 shows the compressive strength results from quality control samples and other measurements/results of the corresponding masses.

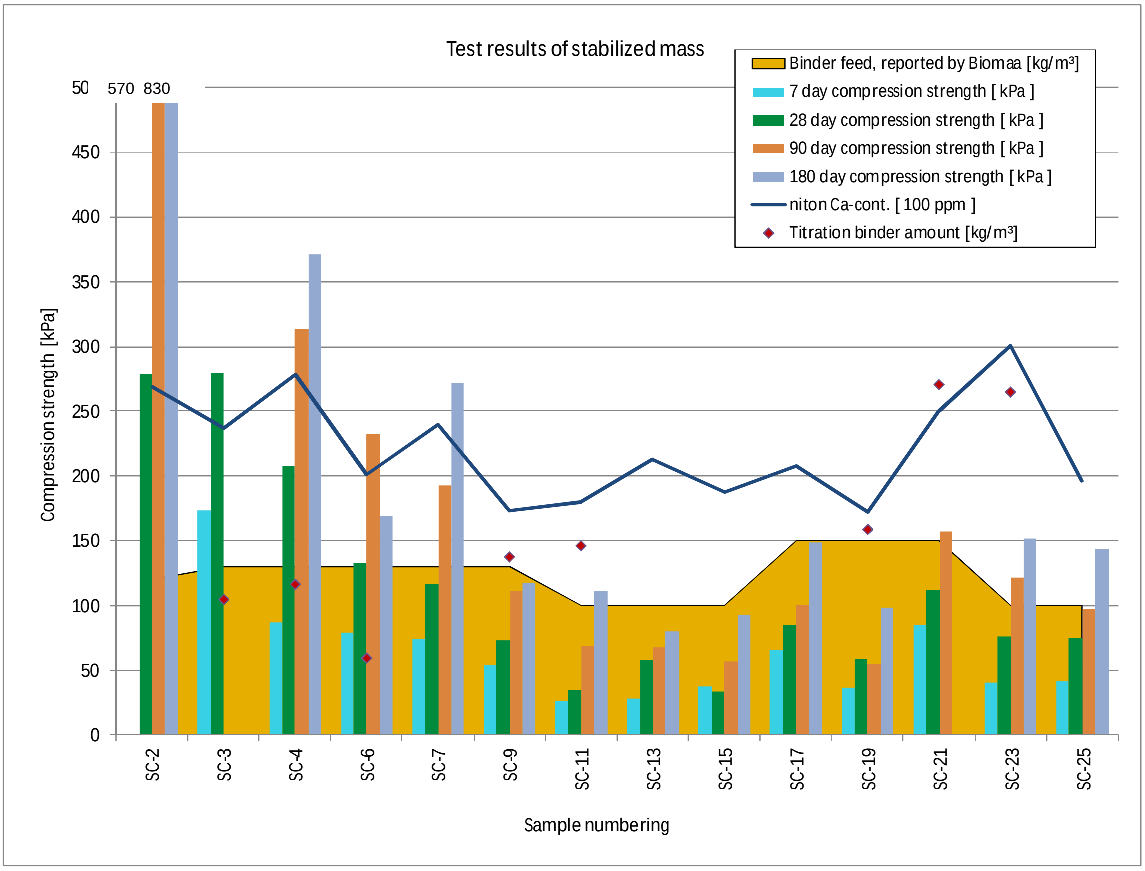


Figure 8.10. Compressive strengths of stabilized mass after 7 and 28 days. Also shown titration results from the masses, Ca concentrations with Niton XRF-analyzer, and the amounts of binders fed reported by the contractor.

Test pieces made from quality control samples (mixture Rapid-cement and fly ash) are coded from SC-2 through SC-6. Based on receipting experiments in the laboratory it was noted that the obtained strength is too high. During stabilization new receipting experiments were completed and it was decided that only fly ash is used in the stabilization. In work site this started from grid 30 and in the coding of test pieces from SC-7.

The level and development of strength are good, especially considering the temperature conditions in the pool. Essential averages quality control samples during stabilization are shown in Table 8.4.

Table 8.4. Ca-content, binder amounts and compression strength averages from quality control samples

Binder		*Rapid+Fly ash*	*Fly ash*
Ca-content, average in all quality control samples [ppm]		*25120*	*21475*
Binder amount in titrated samples, average [kg/m3]		*107*	*184*
Binder amount per box reported by contractor, average [kg/m3]		*125*	*125*
Compression strength, average in different ages	*7 d*	*113*	*49*
	28 d	*225*	*72*
	90 d	*372*	*103*
	180 d	*457*	*122*

So called long-term strength development has occurred both with Rapid-cement and just fly ash. The average strength after 180 days of test pieces stabilized with only fly ash clearly exceed the target value of 100 kPa set for field. Since the samples are prepared as quality control samples, the mixing level in field conditions is fulfilled. However, the storage temperature is more constant in refridgerator than on the field. Actual strength level on the field will not be determined until quality control drillings in Fall 2012.

8.3.1.4 Shearing strength

An indicative shearing strength was determined for 0-mass and stabilized mass in the field using a light, handheld vane drill suitable for quick testing. Individual results from vane drillings and sample locations are shown a quality control table in Appendix 6.

In the vicinity of south border of the field, looser material was found than from other parts of the pool and the shearing strength level varied from 0 to 20 kPa throughout the depth. The shearing strengths in the main part of the pool varied from 15 to 50 kPa with a rather constant variation through the depth. Coarse material, that was left unstabilized, in the northern corner of the pool had 0-sample shearing strength 50-90 kPa throughout the depth. Clearly the dredged material segregated during depositing.

Measured strength from stabilized mass are obtained 0-2 days after the stabilization. Given strengths are lower than what was expected, because the material was too hard (>90 kPa) for a light vane drill. Rough estimates from strengths levels based on vane drillings are given in Table 8.5.

Table 8.5. Rough estimates from average shearing strength levels based on vane drillings after 0-2 days from stabilization.

	Shearing strength [kPa]	
Depth [m]	*0-mass*	*Stab.mass (age 0-2 days)*
0-1	*20 (15-25)*	*50*
1-2	*30 (25-45)*	*45*
2-3	*40 (30-50)*	*30*

8.3.1.5 Water permeability

Water permeability from samples collected from the field are determined with a soft wall, back pressured water permeability test. Water permeability of stabilized masses varied from $3.5 \cdot 10^{-8}$ m/s to $1.9 \cdot 10^{-8}$ m/s, which fulfills the demand set in permit ($<5 \cdot 10^{-8}$ m/s). Water permeability printings are given in Appendix 11.6 and results are shown in Table 8.6.

Table 8.6. Water permeability results from quality control samples.

Sample	*Age of curving*	*Water permeability (K) [m/s]*
SCV-5	*1 month*	$3.2 \cdot 10^{-8}$
SCV-12	*1 month*	$2.3 \cdot 10^{-8}$
SCV-14	*1 month*	$3.5 \cdot 10^{-8}$
SCV-22	*1 month*	$2.9 \cdot 10^{-8}$
SCV-24	*1 month*	$1.9 \cdot 10^{-8}$
SCV-27	*0-mass*	$1.1 \cdot 10^{-7}$
SCV-28	*0-mass*	$1.6 \cdot 10^{-8}$

8.3.2 Environmental properties of dredged material and stabilised material

8.3.2.1 Total concentrations of the unstabilized dredged mass

Samples were taken from the dredged mass for determination of contaminants, in addition to samling in Chapter 5.2, after the stabilization. Samples were taken from the area that was left unstabilized. It seems that the results from contaminant determinations match to those prior to stabilization in the pool and that results do not correlate with granulation.

Table 8.7. Concentrations of contaminants in the samples compared to PIMA-guideline values. Stabilization samples from the pool are taken prior tp stabilization. Aggregate 3A 0-1.0 m, unstabilized sample from unstabilized area; aggregate 3B 2-2.5 m, unstabilized sample from unstabilized area; SC-26, unstabilized sample from unstabilized area

Reference values	*As*	*Hg*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*	*V*
Natural background	*1*	*0 .005*	*0 .03*	*8*	*31*	*22*	*5*	*17*	*31*	*38*
Threshold value	*5*	*0.5*	*1*	*20*	*100*	*100*	*60*	*50*	*200*	*100*
Lower guideline value	*50*	*2*	*10*	*100*	*200*	*150*	*200*	*100*	*250*	*150*
Upper guideline value	*100*	*5*	*20*	*250*	*300*	*200*	*750*	*150*	*400*	*250*
Hazardous waste limit	*1 000*	*1 000*	*100*	*1 000*	*1 000*	*2 500*	*2 500*	*1 000*	*2 500*	*10 000*
	(mg/kg)	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*
Aggregate 3A 0-1.0 m	*5.7*	*0.38*	*2.3*	*11*	*12*	*27*	*21*	*11*	*700*	*15*
Aggregate 3B 2-2.5 m	*5.4*	*0.27*	*1.8*	*7.0*	*15*	*26*	*16*	*10*	*550*	*21*
SC-26	*7.4*	*0.56*	*2.8*	*10*	*14*	*34*	*<0.020*	*14*	*870*	*18*

8.3.2.2 Total concentrations from stabilized mass

Contaminants were analyzed from stabilized mass from three different stabilization grid. Based on the results it can be seen that binder material fly ash added materials As, Cr, Cu, Ni and V concentrations. The changes in concentrations are not, however, significant unless concerning copper in sample SC-21 which exceeded the lower guideline value. Niton XRF-analyzer results are shown in Appendix 11.2.

Table 8.8. Concentrations of contaminants in samples from stabilized sediment. Reference values from guidelines. Samples have been taken from stabilization pool during stabilization. SC-4, stabilized sample from grid box 14. Binder material Rapid 30 + LT 100 kg/m^3;SC-11, stabilized sample from grid box 38. Binder material LT 150-200 kg/m^3;SC-21, stabilized sample from grid box 49. Binder material LT 150-200 kg/m^3.

Reference value	*As*	*Hg*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*	*V*
Background level	*1*	*0.005*	*0.03*	*8*	*31*	*22*	*5*	*17*	*31*	*38*
Threshold value	*5*	*0.5*	*1*	*20*	*100*	*100*	*60*	*50*	*200*	*100*
Lower guideline value	*50*	*2*	*10*	*100*	*200*	*150*	*200*	*100*	*250*	*150*
Upper guideline value	*100*	*5*	*20*	*250*	*300*	*200*	*750*	*150*	*400*	*250*
Hazardous waste limit	*1 000*	*1 000*	*100*	*1 000*	*1 000*	*2 500*	*2 500*	*1 000*	*2 500*	*10 000*
	(mg/kg)	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*
SC-4	*10*	*0.38*	*2.4*	*8.9*	*35*	*68*	*<0.020*	*15*	*730*	*26*
SC-11	*12*	*0.36*	*2.4*	*9.4*	*34*	*83*	*<0.020*	*19*	*710*	*34*
SC-21	*21*	*0.63*	*3.5*	*12*	*45*	*190*	*<0.020*	*26*	*890*	*35*

8.3.2.3 Solubilities of contaminants from stabilized mass during batch test

From stabilized mass and one unstabilized sample, batch testing was done with 1-stage batch testing. For two stabilized test samples, additionally modified diffusion testing was done.

Table 8.9. Results from batch testing and toxicity testing. A= KS60: unstabilized sediment sample, sampling by diver 16.4.2011;B= SC-4, stabilized sample from grid box 14. Binder Rapid 30 + LT 100 kg/m^3;C= SC-11, stabilized sample from grid box 38. Binder LT 150-200 kg/m^3; D= SC-21, stabilized sample from grid box 49. Binder LT 150-200 kg/m^3; E= SC-26, unstabilized sediment sample from area that was left unstabilized. Sample does not contain binders.

	A	*B*	*C*	*D*	*E*	*Landfill limit values VNa 202/2006*		
	L/S=10 [mg/kg dw]					*Inert waste solubility [mg/kg dw]*	*Common waste solubility [mg/kg dw]*	*Hazardous waste solubility [mg/kg dw]*
As	*0.15*	*0.042*	*0.16*	*0.093*	*<0.02*	*0.5*	*2*	*25*
Hg	*<0.003*				*<0.003*	*0.01*	*0.2*	*2*
Cd	*<0.020*	*<0.02*	*<0.02*	*<0.02*	*0.07*	*0.04*	*1*	*2*
Cr	*<0.020*	*0.073*	*0.078*	*0.083*	*<0.02*	*0.5*	*10*	*70*
Cu	*<0.020*	*1.3*	*0.18*	*0.43*	*0.086*	*2*	*50*	*100*
Pb	*<0.020*	*<0.02*	*<0.02*	*<0.02*	*<0.020*	*0.5*	*10*	*50*
Ni	*0.054*	*0.13*	*0.041*	*0.027*	*1.0*	*0.4*	*10*	*40*
Zn	*<0.020*	*0.088*	*0.061*	*0.037*	*36*	*4*	*50*	*200*
V	*<0.020*	*0.28*	*0.52*	*0.41*	*<0.020*			
Co	*0.065*	*0.046*	*<0.02*	*<0.02*	*1.51*			
Toxicity	*Sample not toxic to water fleas*			*Sample not toxic to water fleas*	*Sample not toxic to water fleas*			

Based on the results, stabilized dredged masses have solubilities clearly below the limit value for inert waste. In the unstabilized sample, solubilities of Ca, Ni, Zn exceed the limit value of inert waste.

8.3.2.4 Solubilities of contaminants from stabilized mass with modified diffusion test

Solubilities from stabilized test samples have been investigated with the modified diffusion test (NVN 7347), which is described in more detail in Chapter 4.3.2.2.2.

Geotechnical properties from test samples are shown in Table 8.10.

Diffusion test results during quality control are shown in Tables 8.11 and 8.12. Test has been done with two different matrices, where in both only fly ash has been used.

Table 8.10. Geotechnical properties of tested samples

			Compressive strength [kPa]				
Sample	*Binders [kg/m³]*	*Ca-average*	*7days*	*28days*	*90days*	*180days*	*Water permeability k [m/s]*
SC-11	*LT 150-200*	*18033*	*26*	*35*	*68*	*111*	$2.3\cdot10^{-8}$
SC-21	*LT 150-200*	*25033*	*85*	*112*	*157*		$2.9\cdot10^{-8}$

Table 8.11. Modified diffusion test, cumulative solubility of sample fractions per leaching area. Highlighted values below detection limit

Sample	*Time /d*	*Cumulative solubility per area [mg/m²]*										
		Contaminant	*As*	*Hg*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*	*V*
		*Limit value [mg/m²/64 d]**	*140*	*1.4*	*3.8*	*95*	*480*	*170*	*400*	*170*	*670*	*760*
SC-11E, LT 150-200 kg/m3												
SC-11E/4d	*4*		*0.6*	*0.1*	*0.1*	*0.3*	*0.6*	*2.5*	*0.3*	*0.6*	*5.1*	*0.6*
SC-11E/17d	*17*		*1.3*	*0.1*	*0.1*	*0.6*	*1.3*	*5.0*	*0.6*	*1.3*	*15.0*	*1.9*
SC-11E/63d	*63*		*3.8*	*0.2*	*0.2*	*0.9*	*1.9*	*8.2*	*0.9*	*1.9*	*24.0*	*5.1*
SC-21D,LT 150-200 kg/m3												
SC-21D/4d	*4*		*0.6*	*0.1*	*0.1*	*0.3*	*0.6*	*3.8*	*0.3*	*0.6*	*3.8*	*1.3*
SC-21D/17d	*17*		*1.3*	*0.1*	*0.1*	*0.7*	*1.3*	*9.9*	*0.7*	*2.0*	*14.6*	*4.0*
SC-21D/63d	*63*		*2.0*	*0.2*	*0.2*	*1.0*	*2.0*	*22.5*	*1.0*	*4.1*	*35.6*	*9.6*
**Dutch 64 d diffuusion test maximum solubility guideline values for solidified material (Sorvari, J. Suomen ympäristö 421/2000)*												

Table 8.12. Modified diffusion test, cumulative solubility of sample fractions per leaching area and time. Highlighted values below detection limit

Sample	*Time /d*	*Cumulative solubility per area and time [mg/m² d]*									
		As	*Hg*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*	*V*
SC-11E, LT 150-200 kg/m3											
SC-11E/4d	*4*	*0.16*	*0.02*	*0.02*	*0.08*	*0.16*	*0.63*	*0.08*	*0.16*	*1.27*	*0.16*
SC-11E/17d	*17*	*0.07*	*0.01*	*0.01*	*0.04*	*0.07*	*0.30*	*0.04*	*0.07*	*0.88*	*0.11*
SC-11E/63d	*63*	*0.06*	*0.00*	*0.00*	*0.02*	*0.03*	*0.13*	*0.02*	*0.03*	*0.38*	*0.08*
SC-21D,LT 150-200 kg/m³											
SC-21D/4d	*4*	*0.16*	*0.02*	*0.02*	*0.08*	*0.16*	*0.95*	*0.08*	*0.16*	*0.95*	*0.32*
SC-21D/17d	*17*	*0.08*	*0.01*	*0.01*	*0.04*	*0.08*	*0.58*	*0.04*	*0.12*	*0.86*	*0.23*
SC-21D/63d	*63*	*0.03*	*0.00*	*0.00*	*0.02*	*0.03*	*0.36*	*0.02*	*0.06*	*0.56*	*0.15*

The most important findings are:

- 64/67 days metal solubilities are below Dutch solubility limits in all samples.
- Solubilities of Hg, Co, Cr and Pb are below detection limit or Dutch solubility limit in all samples.
- Solubilities of Cd were mainly below detection limit and clearly below Dutch solubility limit.
- Solubilities of other metals were quite equal and clearly below Dutch solubility limit. The minor differences between test samples are most likely due to amount of binder (fly ash). Based on Ca concentration measurements it can be noted that in sample SC-21D more ash has been used than in sample SC-11E. Strength development of parallel samples confirm this.
- Solubilities of metals are highest in the beginning of testing and diminish during testing.

8.4 Influence on the surroundings

In the beginning of stabilization, a mixture of cement and fly ash was used with a recipe 30 kg/m^3 cement and 100 kg/m^3 fly ash. As the results from stabilization testing in laboratory showed that the obtained strengths are, in fact, too high receipting was continued. As a result from the receipting, it was found that fly ash alone is sufficient as a binder if the target feed is 150-200 kg/m^3 depending on workability of dredged mass.

During the work it became apparent that the stabilization will be rather successful for about 10 000 m^3 of sediment. The last 2000 m^3 were so dense and segregated that the stabilization equipment could not mix the mass. The optimum mixing is obtained when the density of matrix is between 1500 and 1600 kg/m^3. In this case, the density of matrix material was 1860-2130 kg/m^3. Throughout the stabilization, also with the material that was more easily stabilized, an excavator was used to loosen the material. This was done just prior to addition of binder to prevent any segregation of the material. However, despite the loosening in some areas the target feed could not be reached. In the northern corner of the pool where coarser grained material was segregated, the loosening did not help and so the area (2000 m^3) was left unstabilized.

This was reported before the end of stabilization to the responsible authority. In a negotiation, it was decided that Port of Kokkola can present a risk assessment of unstabilized dredged mass, where environmental effects of the situation are considered. The risk assessment is shown in Chapter 9.1. In a follow-up meeting it was noted that water permeability condition was fulfilled and changes to the environmental permit are not required.

8.5 Risk assessment.

The risk assessment was done for the unstabilized dredged mass. The risk assessment concentrates on the evaluation and determination of risks for health and environment caused by not stabilizing the mass. The evaluation considers properties, migration paths and target groups for different contaminants. The report in whole is given in Finnish, but the results are shown here.

The stabilized mass inside the pool has been left out of the risk assessment since it fulfilled the condition of water permeability set in the environmental permit.

8.5.1 Measured concentration and solubilities

Quality control samples were taken from dredged mass before and after stabilization.

Total concentrations of metals and semi metals from dredged mass samples taken from unstabilized are shown in Table 8.7. The results are compared to reference values for contaminated soil (VNa 214/2007).

The sample from unstabilized area (SC-26) was analyzed for metal and semi metals with 1-stage batch test and the toxicity of the leachate was analyzed with water flea test (Daphtoxkit FTM magna -test). A sample with the highest contaminant concentrations was selected for testing. The results are shown in Table 8.7. The water leacheate was not acutely toxic to water fleas.

8.5.2 Migration of contaminants and evaluation of exposure

Deposited dredged mass can pose a threat or inconvenience to surrounding environment or to health if the following boundaries are met:

1. Material contains contaminants significant concentrations
2. The contaminant migrates in the environment
3. An exposure path exists though which an object (animal or human) will expose to the substance

If all three boundaries are met, the significance of the risk is evaluated. In Figure 8.11 possible migration paths of deposited dredged mass and possible exposurees, are shown in a conceptual model.

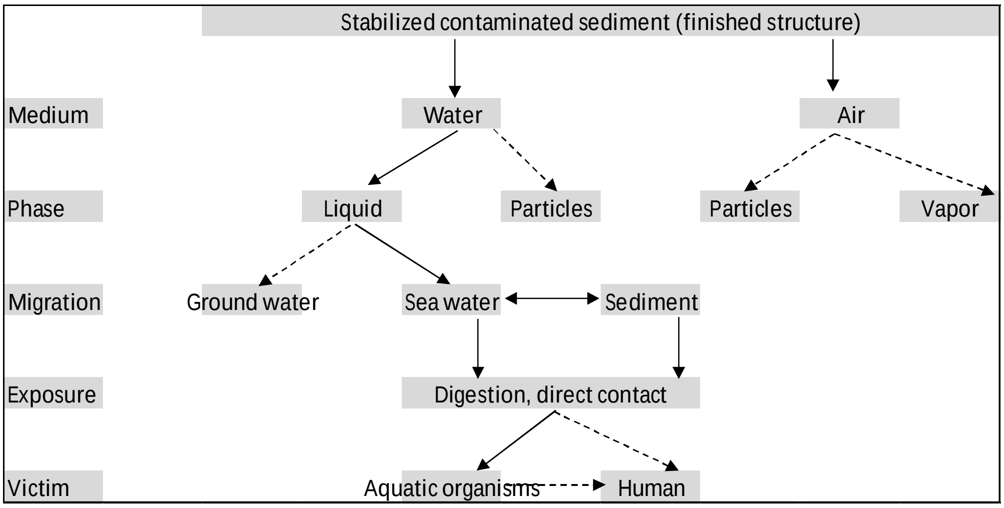


Figure 8.11. Migration paths and exposurees of contaminants. Unlikely paths are shown with a dashed line.

8.5.3 Focused risk assessment

The possible migration and exposure path of contaminants from the dredged mass in the pool was found migrating to sea in a soluble form where aquatic organisms may be exposed. Thus in the focused risk assessment migration path to sea and following ecological risk to aquatic organisms is investigated.

8.5.3.1 Critical contaminants

Those contaminants that can dissolve from dredged mass and solubilities exceed NOECaq reference values (concentrations, which have not been found to cause effects on aquatic organisms being tested) are considered as critical contaminants.

Based on the risk assessment, the critical contaminants are selected as Cd, Co, Cu, Ni and Zn.

8.5.3.2 Effect of critical contaminants on aquatic organisms

Water amount filtrating through the embankment of the stabilization pool and the theoretical concentrations outside the pool was evaluated in the focused risk assessment. The concentrations in sea water are compared to ecological reference values and background concentrations in the location.

The parameter values are selected based on site specific knowledge or have been conservatively estimated by overestimating the migration path. Flux *Q*, i.e filtrated water through the embankment in time, has been estimated using Equation (1). (Rantamäki, M. et al. Geotekniikka, 2004):

$$Q = A \cdot k \cdot \frac{H}{L} \quad (1)$$

(1)

Q flux [m^3/s]
A area of the embankment, where untreated sediment has contact [m^2]
k water permeability of the soil in the embankment [m/s]
H pressure head of water [m]
L distance in the direction of the flow [m]
H/L hydraulic gradient [-]

The value 1·10-6 m/s was used for water permeability of the embankment in the calculations, which overestimates the true permeability. The embankment consists of sand, gravel, moraine and blasted stone for which at least moraine has most probably water permeability lower than estimated.

For the calculation of the pressure head of water, three scenarios were considered where the water flows in the direction of pool to sea. In scenario 1, height difference between dredged mass and average theoretical water level was used. In scenario 2, height difference between dredged mass and minimum water level in the past year was used. In scenario 3, height difference between dredged mass and minimum water level in the past 90 years was used. The site specific values have been used for cross-sectional area of the embankment and as a distance in the direction of the flow.

The dilution of contaminants on sea water has been calculated in 10 m distance from the pool where water depth was about 14.8 m. As the flow of water, 2 cm/s was estimated. This way the flux of water in front of the pool is estimated as 10 m · 14.8 m · 0.02 m/s = 3.0 m^3/s.

Dilution factor for contaminants in sea water is estimated by dividing the flow of sea water outside the pool with the flow of water through the embankment. Different dilution factors are obtained from scenarios 1, 2 and 3. Concentrations of contaminants are solubilities from batch testing in L/S 10 ratio and the diluted concentrations are estimated by dividing those solubilities with the dilution factor.

The concentrations do not exceed NOECaq- reference values, i.e. values that are not affecting test organisms. The estimated concentrations in sea water do not exceed concentrations in sea detected in control sampling in Summer 2011 and so unstabilized, deposited dredged sediment will not add pollution load to sea water. Based on the risk assessment, the dredged mass will not pose a threat to aquatic organisms even in the close vicinity of the pool.

8.5.4 Uncertainty estimations

Conservative assumptions and parameter values were used in the risk assessment of migration evaluation. In the evaluation of water filtrating through the embankment, flux through the embankment has been used where dredged mass has been deposited against the embankment. It was assumed that the flow of water is laminar and follows Darcy’s law ($v = k \cdot i$). However, in the actual embankment water permeability varies locally. A conservative value (10^{-6} m/s) for water permeability was selected since the water permeability of moraine in the embankment is smaller than that.

When evaluating the water flux throuh the embankment three different estimates (scenarios 1-3) have been given to water pressure head based on sea water height level (theoretical average, minimum height of a short time interval, minimum height of a long time interval) and height level of deposited dredged mass. In reality, sea water height and pressure head vary which causes the flux and direction of water flow to vary. The direction of water flow may also be towards the stabilization pool. Based on all three scenarios, however, the flow will be minor and so will be the amount of contaminants migrating to sea.

The deposited dredged mass has water permeability $1.1*10^{-7}$ m/s based on laboratory measurements (Table X). This is smaller than the value estimated for the embankment and the leaching amounts will be very small. In the finished field structure plumbing and superstructures practically prevent any filtration of water to dredged mass through superstructures.

In the evaluation of the dilution factor the value for the flow rate of sea water was 2 cm/s. Contaminant concentrations in leacheate have been estimated based on batch testing. The batch testing has been with L/S ratio 10. The flux is an estimate and is not based on site specific knowledge. In reality the flux has also vertical variation and weather conditions have an effect (wind, ice, etc.). However, concentrations leaching to sea are mixing to huge water amounts in reality. In addition, the leaching of contaminants decreases along time. It increases uncertainty that the estimate is based on leaching test results of a single sample.

Reference values (NOECaq) in the estimation of ecological risk are based mainly on toxicity tests done outside Finland, so the reference values are not directly comparable to conditions in Finland. For instance, the reference species can be different than Finnish water animal species. In determination of reference values, usually easily soluble and bioavailable metal salts are used. In the sediment in location the metals exist in different compounds and oxidation states and the bioavailability and vastly differ from the reference materials.

8.5.5 Results and conclusions of risk assessment

Unstabilized mass in the stabilization pool was evaluated for possible risks to environment and health in the risk assessment. Possible path of exposure and migration was found to be drifting of soluble contaminants from dredged mass to sea where sea organisms can be exposed to contaminants.

The contaminants were not found to cause health risk to humans. Cd, Co, Cu, Ni and Zn were found as the critical contaminants. The theoretical concentrations of these contaminants outside the stabilization pool at sea were calculated and these concentrations were compared to the ecological reference values.

Based on the risk assessment, the concentrations of contaminants diluted in the sea do not pose an ecological threat to marine organisms. The concentrations do not exceed the NOECaq values, i.e. values that do not have an effect on aquatic organisms. The concentrations are also lower than concentrations measured from sea water before the dredging. This led to conclusion that unstabilized mass in the stabilization pool does not increase the load on water quality. The volume of leaching water through the embankment was estimated so low that the migration of contaminants is insignificant to water organisms.

8.6 Long-term monitoring

There are no demands from the authoring bodies. Water quality is controlled at site as a routine procedure.

9. Conclusions and recommendations

Solidification stabilization has been found as a highly applicable tool for managing contaminated sediments. It has environmental, economical and technical benefits, thus making it a truly sustainable method. After the successful field test in Port of Kokkola, another dredging and stabilization project is planned to be carried out during 2013.

Modern knowledge on the technique and availability of local binder materials is well established in Finland, thus enabling highly efficient and robust utilization of the method in large scale. In addition, the supreme court has stated that all contaminated sediments should be stabilized, if they are handled. The utilization of by-products and renewable materials is of interest in government level. As similar project continue to be executed, knowledge is also increased amongst local environmental authorities enabling more flexible permitting procedure.

SMOCS project and the network on supporting the sustainable management of contaminated sediments in Baltic Sea region has been most beneficial on gathering information throughout Europe. This information will be used both in national and international level in equalizing the procedures and policies.

10. List of analytical standards

	Standard
LEACHING TESTS	
Two-step batch test	SS-EN 12457-3
Static Diffusion test	NEN 7345
Static Diffusion test	NVN 7347
Dynamic Diffusion test	Draft standard WI 00292056 CEN/TC 292/WG 6 N486
Static pH Leaching Test	
CHEMICAL ANALYSIS	
pH	ISO 10390:2007
Electric conductivity	ISO 11265
TOC (Total organic content)	SFS-EN 13137
Inorganic content	
16PAH, 7PCB	CEN 15308:2005
Metals (As, Ba, Cd, Co, Cr, Cu, Mo, Ni, Pb, Zn)	EN-ISO 11885 ISO 8288
Ions (bromide, chloride, fluoride, nitrate, nitrite, phosphate, sulfate)	EN-ISO 10304-1 EN-ISO 10304-2 SFS-EN 12506
Determination of total residue and total fixed residue in water, sludge and sediment	SFS 3008
GEOTECHNICAL	
Density	CEN ISO 17892-2
Water content	CEN ISO 17892-1
Liquid limit	CEN ISO 17892-12
Organic content (LOI)	EN 15169:2007
Strength (undrained shear strength): Fall-cone test	CEN ISO 17892-6
Strength (undrained shear strength): Unconfined compression	CEN ISO/TS 17892-7:2005

11. Appendices

11.1 Description of test methods

11.1.1 Technical tests

The **water content** (SFS 179-2 – CEN ISO/TS 17892-1:fi) of a material is the ratio of the quantity of water removed from the wet material (mm) in the course of drying in an oven up to a constant mass value and the dry material mass (md). The general drying temperature is 105 °C for most of the samples; the calculation is according to formula

$$w = \frac{m_m - m_d}{m_d} * 100\%$$

The **Dry Matter Content** can be expressed as $Drymatter = \frac{m_d}{m_m} * 100\% = \frac{1}{w+1} * 100\%$

Loss of Ignition (LoI) (SFS-EN 1997-2 5.6) describes the content of the organic matter of the material. This is characterised by the weight loss a dried material sample (m_d) in the course of heating where the organic matter is combusted at a very high temperature (550 / 800 °C for at least 1 hour). The residual mass is m_i. This weight loss is expressed in dry weight percentage, and called Loss of Ignition (LoI):

$$LoI = \frac{m_d - m_i}{m_d} * 100\%$$

Active lime test is done chemically according to the standard SFS 5188. 0,5 g of ash is mixed with 10 ml of water and the mixture is heated on a stove to hydrate the lime. After the lime hydration 20 g of sugar is mixed to the cooled solution. After 15 minutes of reaction time the indicator phenolphthalein is added to the solution. The solution is titrated with hydrochloric acid. The amount of active lime in the ash is calculated from the amount of the hydrochloric acid used and from the mole masses of the used chemicals and lime.

pH is determined by mixing 10 g of dry sample with 50 g of water and letting it settle for 2-4 hours. After settling the solution is mixed again and the pH is measured with the pH instrument.

Niton is x-ray fluorescence analyser which can be used in analysing the total amount of elements in material. It can be used in analysing for example the calcium content of the material or the contents of harmful metals in the material.

Particle Size Distribution (SFS 179-2 – CEN ISO/TS 17892-4:fi) is determined by sieving and/or by a sedimentation tests. In the (dry or wet) sieving procedure a dried sample is poured through sieves of different grades (e.g. 2, 0,063 mm …). The particle size distribution can be calculated from the amount of the particles staying on the grades divided with the total mass (percentages). In a sedimentation test (Areometer test) the grain size is determined on the basis of the settling rate of the particles in a liquid (according to Stokes' Law). The settling rate is measured by a specific gravity hydrometer, which is placed on a prefabricated solution on certain intervals. The maximum grain size in sedimentation test is 2 mm and for some materials sieving with 2 mm sieve is needed. If the sample contains more than 2 % of organic matter, it should be treated with hydrogen peroxide to eliminate organic matter.

Preparation of the aggregate specimens for unconfined compressive strength test, frost susceptibility test and freeze-thaw durability test. The preparation of the specimens begins with calculation of the amounts of binders mixed with the aggregate. Usually several different binder amount is tested especially in unconfined compression strength test to determine the most suitable binder mixture for the construction. The aggregate and the binders are mixed in laboratory mixer for 2 minutes. After mixing the mixture is compacted in to a cylinders having uniform diameter (42…50 mm) and the cylinders are put in to plastic bags to prevent the drying of the specimens. For the first two days the specimens are kept in room temperature after which the specimens are put in refrigerator (+8 °C) to stabilise. The specimens can also be put on thermal treatment in which the specimens are stored in thermally insulated in +30^{o}C temperature. Usually the stabilisation time is 7…90 days for normally treated specimens and 3…28 days for thermally treated specimens. The target of thermal treatment is to find out the potential maximum unconfined compressive strength of the material, but usually it is not recommended to use the values in designing the actual structures. Before testing the unconfined compressive strength the specimen is cut so that the height of the specimen is twice the diameter of the specimen.

Figure 11.1. Specimens ready to unconfined compression test.

Unconfined Compressive Strength, UCS, (adjusted SFS 179-2 – CEN ISO/TS 17892-7:fi) is a standard test where a cylindrical test piece is subjected to a steadily increasing axial load until failure occurs. The axial load is the only force or stress applied. The rate of the load is 1 - 2 mm/min. If any noticeable failure does not occur, the maximum value of the compression strength is taken when the deformation (change of height) is 15 %. Usually, the test will be made on test pieces after at least 28-30 days stabilisation. Figure 1 below shows the test in progress.

or

Figure 11.2. Unconfined compression test in progress. Ramboll Finland Oy.

In **Soft wall permeability test** with constant pressure (SFS 179-2 – CEN ISO/TS 17892-11:fi) a test piece inside a rubber membrane will be subject to a 3-dimensional pressure in a test cell. Water will be conducted through the test piece from a front container to a back container, and the water level differences of the containers will be measured. Water flows upward inside the test piece when there is higher pressure in the front water container than in the back container. The simple formula to calculate the water permeability factor is as follows:

$$k = \frac{Q * L}{A * t * H},$$

where k = water permeability [m/s]; Q = quantity of water seeping through a test piece [m3]; L = height of the test piece [m]; A = area of the cross-section of the test piece [m2]; t = time [s]; H = hydraulic differential pressure [m]

Figure 11.3. Permeability test in progress. Ramboll Finland Oy.

11.1.2 Analytical methods

The sediment samples were analysed by Ramboll Analytics Oy laboratory in Lahti, except for grain size and organic matter analyses, which were carried out by the Luopioinen laboratory of Ramboll Finland.

The chemical elements (As, Hg, Cd, Co, Cr, Cu, Pb, Ni, Zn and V) were analysed in a total number of 31 samples. The samples were treated with microwave-assisted digestion (*aqua regia* dissolution) and analysed with the ICP-MS technique. The reporting limit is 0.1 to 1 mg / kg, and the measurement uncertainty of 16-35%, depending on the element. The method is based on the following standards: ISO 17294-1, BS EN ISO 17294-2, BS EN ISO 15587-1 and EPA 6020.

The PCBs (polychlorinated biphenyls) were analysed in three samples. The samples are extracted with toluene in a vortexer and purified with florisil. The solvent was changed into hexane and the clean-up was done with sulphuric acid. The purified extract was analysed with the GC/MS technique. The reporting limit of the method 0.001 mg / kg, and the measurement uncertainty of 15-40%. The laboratory's internal research method.

PCDD/F compounds (dioxins and furans) were analysed for one sample. The PCDD/F compounds were analysed using isotope dilution method and HRMS. Samples were extracted using toluene and cleanup was performed with silica gel and activated carbon chromatography. Analytes were separated by the GC and detected by a high resolution mass spectrometer (EPA 1613, EPA 8280A, EN 1948-2).

Tributyltin (TBT) and triphenyltin (TPT) were determined in 31 samples with the GC/MS technique in the laboratory. The method's reporting is limit of 0.001 mg / kg, and the measurement uncertainty is 25-40%. The laboratory's internal research method.

Toxicity was studied in three samples using the Vibrio Fischeri (SFS-EN ISO 11348-3) test. Solid material and water were mixed in a ration 1/10 (v/v) for 24h. Liquid was filtrated through 0.45 through 0.45 µm membrane, pH-value was adjusted and strongly turbid samples were filtrated. The inhibition of light emission by cultures of *Vibrio fischeri* was determined by the means of a batch test.

C10-C40 was determined for three samples. Samples were extracted with acetone/hexane. Polar compounds were removed by adsorption on florisil. The purified extract was analysed by GC/FID. The laboratory's internal method – RA4020 - based on the ISO 16703 standard.

The PAH compounds were determined for three samples. The testing was based on the laboratory's internal method RA4055, gas chromatography (GC/FID and GC/MS).

11.2 Total contents from Niton-XRF -analyser

Table 11.1. Measurements from Niton-XRF-analyser. <LOD = below level of detection. (ppm = mg/kg). Samples from the sea bottom taken by diver.

Sample	*As*	*Hg*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*	*V*	*Br*	*Ca*	*Sb*	*S*	*Ba*	*Fe*
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
KS 60 0-20 cm	*16*	*< LOD*	*< LOD*	*< LOD*	*47*	*101*	*93*	*< LOD*	*4 273*	*446*	*< LOD*	*5080*	*< LOD*	*5704*	*381*	*27411*
KS 60 20-40 cm	*19*	*< LOD*	*15*	*< LOD*	*< LOD*	*108*	*102*	*< LOD*	*3 461*	*556*	*13*	*4706*	*< LOD*	*7001*	*285*	*24121*
KS 60 40-60 cm	*20*	*< LOD*	*14*	*179*	*84*	*92*	*77*	*56*	*2 700*	*542*	*12*	*4343*	*< LOD*	*3670*	*203*	*14939*
KS 60 total sample	*28*	*< LOD*	*< LOD*	*< LOD*	*101*	*96*	*79*	*49*	*4 092*	*34*	*14*	*9652*	*< LOD*	*1540*	*214*	*19697*
KS 120 0-20 cm	*16*	*< LOD*	*< LOD*	*127*	*92*	*40*	*44*	*< LOD*	*1 966*	*< LOD*	*14*	*5758*	*< LOD*	*1714*	*139*	*10817*
KS 120 20-40 cm	*15*	*< LOD*	*< LOD*	*75*	*42*	*50*	*39*	*36*	*2 126*	*20*	*11*	*13373*	*< LOD*	*1125*	*190*	*12380*
KS 120 40-60 cm	*26*	*< LOD*	*< LOD*	*227*	*90*	*69*	*91*	*< LOD*	*3 635*	*< LOD*	*20*	*7193*	*< LOD*	*2681*	*115*	*17117*
KS 120 60-80 cm	*31*	*< LOD*	*< LOD*	*146*	*66*	*104*	*111*	*< LOD*	*3 788*	*< LOD*	*18*	*9857*	*< LOD*	*1611*	*179*	*17808*
KS 120 80-100 cm	*26*	*< LOD*	*< LOD*	*112*	*58*	*82*	*73*	*< LOD*	*2 705*	*< LOD*	*17*	*10176*	*< LOD*	*1661*	*106*	*15297*
KS 120 total sample	*22*	*< LOD*	*< LOD*	*< LOD*	*75*	*43*	*45*	*< LOD*	*2 388*	*39*	*14*	*10021*	*< LOD*	*1285*	*150*	*13963*
KS 180 0-25 cm	*21*	*< LOD*	*< LOD*	*124*	*91*	*72*	*86*	*< LOD*	*3 189*	*36*	*11*	*6064*	*< LOD*	*1233*	*217*	*15837*
KS 180 25-50 cm	*22*	*< LOD*	*< LOD*	*< LOD*	*103*	*87*	*57*	*< LOD*	*1 963*	*< LOD*	*10*	*4653*	*< LOD*	*2370*	*198*	*12901*
KS 180 total sample	*29*	*< LOD*	*< LOD*	*< LOD*	*66*	*83*	*77*	*60*	*2 946*	*33*	*14*	*8395*	*< LOD*	*1101*	*231*	*15817*

Table 11.2. Measurements from Niton-XRF-analyser. < LOD = below level of detection. (ppm = mg/kg).Samples from the stabilization pool.

Reference value	Sb	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V
Natural background 1	0,02	1	0,005	0,03	8	31	22	5	17	31	38
threshold	2	5	0,5	1	20	100	100	60	50	200	100
lower limit	10	50	2	10	100	200	150	200	100	250	150
upper limit	50	100	5	20	250	300	200	750	150	400	250
hazardous waste limit	2 500	1 000	1 000	100	1 000	1 000	2 500	2 500	1 000	2 500	10 000
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
P1 d. 0,5 m	<LOD	15,7	<LOD	<LOD	<LOD	39,64	37,4	21,5	57,8	980,8	<LOD
P1 d. 1,5 m	<LOD	10,6	<LOD	<LOD	<LOD	<LOD	16,8	<LOD	44,8	373,5	<LOD
P2 d. 1,5 m	<LOD	10,0	<LOD	<LOD	<LOD	<LOD	17,2	<LOD	67,1	278,7	<LOD
P2 d. 2,5 m	<LOD	10,6	<LOD	<LOD	<LOD	<LOD	19,1	<LOD	58,9	354,5	<LOD
P3 d. 0,5 m	<LOD	9,5	<LOD	<LOD	<LOD	<LOD	12,0	<LOD	55,9	303,3	<LOD
P3 d. 1,5 m	<LOD	16,0	<LOD	<LOD	<LOD	45,5	28,9	23,0	<LOD	1060,1	<LOD
P4 d. 1,5 m	<LOD	11,9	<LOD	<LOD	<LOD	<LOD	19,8	<LOD	55,7	297,4	<LOD
P4 d. 2,5 m	<LOD	13,3	<LOD	<LOD	<LOD	<LOD	25,3	12,3	39,4	834,7	<LOD
P5 d. 1,5 m	<LOD	9,2	<LOD	<LOD	<LOD	<LOD	15,1	<LOD	43,1	219,0	<LOD
P5 d. 2,5 m	<LOD	8,3	<LOD	<LOD	<LOD	<LOD	11,5	<LOD	27,0	334,4	<LOD
P6 d. 0,5 m	<LOD	7,9	<LOD	<LOD	<LOD	<LOD	16,1	5,2	34,3	409,6	<LOD

Table 11.3. Niton-XRF-analysaattorilla tehdyt mittaukset. Merkintä <LOD merkitsee laitteen määritysrajaa alhaisempaa pitoisuutta. (ppm = mg/kg).Stabiloidut ruutukohtaiset näytteet.

Näyte	As	Hg	Cd	Co	Cr	Cu	Pb	Ni	Zn	V	Br	Ca	Sb	S	Ba	Fe
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ruutu 3	11	< LOD	< LOD	< LOD	87	33	< LOD	37	324	47	8	10383	< LOD	360	430	13449
Ruutu 18	11	< LOD	< LOD	< LOD	84	22	< LOD	36	427	30	6	10268	< LOD	881	394	9230
Ruutu 47	9	< LOD	< LOD	< LOD	85	24	< LOD	35	323	43	9	10078	< LOD	430	435	10625
Ruutu 50	11	< LOD	< LOD	< LOD	99	31	< LOD	39	407	42	8	10980	< LOD	430	401	11323
Ruutu 100	10	< LOD	< LOD	< LOD	67	24	6	41	643	33	7	9380	< LOD	540	457	10774
Ruutu 104	13	< LOD	< LOD	< LOD	91	23	< LOD	39	269	52	7	10761	< LOD	239	453	15299
Ruutu 106	14	< LOD	< LOD	< LOD	93	27	32	43	815	45	7	10347	< LOD	524	411	12360
Karkea alue	9	< LOD	< LOD	< LOD	86	23	7	35	464	37	4	8181	< LOD	598	431	8729

11.3 1-Axial unconfined compression strength

Table 11.3.1 SMOCS, studies of stabilized materials matrix, stabilized material is "Ko-kooma KS201 – KS 202"

Binder components	Amount of binders				Normal treatment		
	Binder 1	Binder 2	Binder 3	Binder 4	Compression strength		
	[kg/m3]	[kg/m3]	[kg/m3]		28 days	90 days	180 days
Yse	30				18		
	70				78	89	
	100				153	264	
PKT	100				14		
	200				30	82	
LT1	100				<10		
	200				15		
Yse+LT1	30	100			48	70	
	30	200			126	162	
Yse+KJ+LT	15	30	100		26		
	15	30	200		84	147	
Yse+KJ+LT+DI	15	30	50	50	16		
	15	30	100	100	27	45	
Yse+PKT	30	100			89	140	
	30	200			179		
Yse+PKT+DI	30	50	50		45	187	
	30	100	100		84	270	
(CaO+Yse 3:7) +DI	30	100			24		
	30	200			34	80	
Yse+KJ+PKT	15	30	100		53	61	
	15	30	200		74	385	
Yse+KJ+PKT+DI	15	30	50	50	20	224	
	15	30	100	100	32	121	
PKT+DI	50	50			12		
	100	100			14		
KJ+PKT	60	100			19	20	
	60	200			35	190	
KJ+PKT+DI	60	50	50		16	113	
	60	100	100		17	34	
Yse+DI	30	100			28		
	30	200			27		

Table 11.3.2 Stabilization studies Kokkola, Stabilized material is "KS201"

	Amounts of binders			Compression strength [kPa]		
	Binder 1	Binder 2	Binder 3	30 °C	30 °C	90 days
	[kg/m3]	[kg/m3]	[kg/m3]	7 days	30 days	Normal + 8 °C
Commercial binders	100			43	128	129
	200			372	937	766
	100			32	104	88
	200			86	352	351
	100			52	159	133
	150			211	637	518
	200			539	1441	1230
	50	50		20	21	22
	100	100		60	665	593
Yse+LT1	70	150		231	354	358
	50	150		172	273	274
	50	200		239	411	347
	30	150		69	128	114
	30	200		106	185	116
Yse+PKT	70	150		50	351	463
	50	150		46	295	395
	30	150		34	182	278
GTC+PKT	70	150		27	177	131
	50	150		29	138	92
Yse+LT1+Gypsum	70	75	75	74	429	392
	50	100	100	60	198	222
	30	100	100	34	74	81
Yse+PKT+Gypsum	70	75	75	35	584	321
	50	100	100	26	107	247
	30	100	100	23	79	208
PeSe+LT1+ gypsum	70	75	75	89	441	437
(Yse+K400)+LT1+ gypsum	70	75	75	52	225	254
(Yse+K400)+PKT+gypsum	70	75	75	31	141	424
(Yse+K400)+PKT	70	150		43	203	336

Table 11.3.3 SMOCS stabilization studies for Kokkola Sediments; stabilized material is "KS 201"

	Amounts of binders			Compression strength [kPa]		
	Binder 1	Binder 2	Binder 3	30 °C	30 °C	90 days
	[kg/m3]	[kg/m3]	[kg/m3]	7 days	30 days	Normal + 8 °C
Commercial binders	100			43	128	129
	200			372	937	766
	100			32	104	88
	200			86	352	351
	100			52	159	133
	150			211	637	518
	200			539	1441	1230
	50	50		20	21	22
	100	100		60	665	593
Yse+LT1	70	150		231	354	358
	50	150		172	273	274
	50	200		239	411	347
	30	150		69	128	114
	30	200		106	185	116
Yse+PKT	70	150		50	351	463
	50	150		46	295	395
	30	150		34	182	278
GTC+PKT	70	150		27	177	131
	50	150		29	138	92
Yse+LT1+Gypsum	70	75	75	74	429	392
	50	100	100	60	198	222
	30	100	100	34	74	81
Yse+PKT+Gypsum	70	75	75	35	584	321
	50	100	100	26	107	247
	30	100	100	23	79	208
PeSe+LT1+ gypsum	70	75	75	89	441	437
(Yse+K400)+LT1+ gypsum	70	75	75	52	225	254
(Yse+K400)+PKT+gypsum	70	75	75	31	141	424
(Yse+K400)+PKT	70	150		43	203	336

Table 11.3.4 SMOCS Kokkola sediments long term stabilization studies, "stabilized material is KS 201"

Binder components				Amounts of binders			Compression strength [kPa]				
	Binder 1	Binder 2	Binder 3	Binder 1	Binder 2	Binder 3	Heat Treatment + 30°C	Normal treatment			
				[kg/m3]	[kg/m3]	[kg/m3]	28 days	28 days	90 days	180 days	365 days
Yse 30	yse			30			8	3	12		
Yse 50	yse			50			11	4	22	27	23
Yse 70	yse			70			20	28	51		
PKT 150	PKT			150			124	32	101		
PKT 200	PKT			200			165	37	150	360	532
PKT 300	PKT			300			1067	95	738		
LT 150	LT1			150			8	<4	8		
LT 200	LT1			200			15	11	18	26	24
LT 300	LT1			300			62	36	195		
Yse+kipsi 50+100	Yse	kipsi		50	100		144	60	157		
Yse+kipsi 50+200	Yse	kipsi		50	200		169	55	152	160	143
Yse+PKT 40+150	Yse	PKT		40	150		182	126	288	422	512
Yse+PKT 30+150	Yse	PKT		30	150		251	67	249		
PeSe+PKT 30+150	PeSe	PKT		30	150		237	80	284		
Pika+PKT 30+150	Pika	PKT		30	150		290	220	318		
Yse+PKT 20+150	Yse	PKT		20	150		187	44	171		
PeSe+PKT 20+150	PeSe	PKT		20	150		200	49	188		
Pika+PKT 20+150	Pika	PKT		20	150		238	100	235		
Yse+PKT 20+200	Yse	PKT		20	200		351	73	335		
Yse+PKT 10+150	Yse	PKT		10	150		155	45	119		
Yse+PKT 10+200	Yse	PKT		10	200		292	96	224		
Yse+LT1 50+150	Yse	LT1		50	150		187	136	267		
Yse+LT1 40+150	Yse	LT1		40	150		136	114	220	308	346
PeSe+LT1 40+150	PeSe	LT1		40	150		117	105	214		
Pika+LT1 40+150	Pika	LT1		40	150		220	171	288		
Yse+LT1 40+200	Yse	LT1		40	200		241	139	328		
Yse+LT1 30+150	Yse	LT1		30	150		99	43	136		
Yse+LT1 30+200	Yse	LT1		30	200		205	100	217		
Yse+LT1 30+300	Yse	LT1		30	300		369	283	366		
Yse+LT1+kipsi 50+100+100	Yse	LT1	kipsi	50	100	100	296	104	311		
Yse+LT1+kipsi 40+100+100	Yse	LT1	kipsi	40	100	100	181	87	203	250	233
PeSe+LT1+kipsi 40+100+100	PeSe	LT1	kipsi	40	100	100	131	78	164		
Pika+LT1+kipsi 40+100+100	Pika	LT1	kipsi	40	100	100	212	107	252		
Yse+LT1+kipsi 40+150+100	Yse	LT1	kipsi	40	150	100	256	121	288		
Yse+LT1+kipsi 40+150+150	Yse	LT1	kipsi	40	150	150	271	144	290		
Yse+LT1+kipsi 30+150+100	Yse	LT1	kipsi	30	150	100	155	105	180		
Yse+LT1+kipsi 30+100+150	Yse	LT1	kipsi	30	100	150	98	61	124		
Yse+LT1+kipsi 30+150+150	Yse	LT1	kipsi	30	150	150	164	91	168		
Yse+PKT+kipsi 50+100+100	Yse	PKT	kipsi	50	100	100	279	100	282	348	334
PeSe+PKT+kipsi 50+100+100	PeSe	PKT	kipsi	50	100	100	639	106	528		
Pika+PKT+kipsi 50+100+100	Pika	PKT	kipsi	50	100	100	774	163	499		
Yse+PKT+kipsi 50+150+100	Yse	PKT	kipsi	50	150	100	1142	138	577		
Yse+PKT+kipsi 50+100+150	Yse	PKT	kipsi	50	100	150	759	149	486		
Yse+PKT+kipsi 40+150+100	Yse	PKT	kipsi	40	150	100	950	111	458		
Yse+PKT+kipsi 40+200+100	Yse	PKT	kipsi	40	200	100	1310	137	554		
Yse+PKT+kipsi 40+100+150	Yse	PKT	kipsi	40	100	150	512	94	397		
Yse+PKT+kipsi 40+100+200	Yse	PKT	kipsi	40	100	200	607	88	391		
Yse+PKT+kipsi 40+150+150	Yse	PKT	kipsi	40	150	150	947	115	488		
Yse+PKT+kipsi 30+150+150	Yse	PKT	kipsi	30	150	150	668	103	390		

Table 11.3.5 Testing different binder properties of gypsum for Kokkola dredged sediments

Stabilized material	Binder		Compression strength [kPa]			remarks
	Quality	amount [kg/m^3]	28 days	90 days	treatment, +30°C [1]	
Dredged material from Kokkola	YSe	100	< 10	<10		Comparision materials
		200	12	29		
	YSe+KJ400	200	12	32		
	YSe+LT	75+150	81	74		
	(YSe+KJ400)+LT	100+150	73	81		
	YSe+kipsi	75+150	28	88	56	DI-Gypsum straigth from process
	YSe+LT+kipsi	75+75+75	41	189	171	
		100+75+75	53	188	353	
	(YSe+KJ400)+kipsi	100+150	19	154	95	
	(YSe+KJ400)+LT+kipsi	75+75+75	34	127	109	
		100+75+75	37	291	216	
	PeSe+CaO+kipsi	66+66+66	12	47	24	
	YSe+kipsi	75+150	30	107	68	DI-Gypsum from heap
	YSe+LT+kipsi	75+75+75	45	170	161	
		100+75+75	59	217	311	
	(YSe+KJ400)+kipsi	100+150	23	226	133	
	(YSe+KJ400)+LT+kipsi	75+75+75	31	137	104	
		100+75+75	38	331	249	
	PeSe+CaO+kipsi	66+66+66	11	47	30	
	YSe+kipsi	75+150	56	151	111	Dried Gypsum
	YSe+LT+kipsi	75+75+75	43	178	171	
		100+75+75	74	175	327	
	(YSe+KJ400)+kipsi	100+150	35	291	199	
	(YSe+KJ400)+LT+kipsi	75+75+75	36	135	128	
		100+75+75	40	299	236	
	PeSe+CaO+kipsi	66+66+66	17	42	28	
	YSe+kipsi	75+150	50	158	141	Hemi Gypsum
	YSe+LT+kipsi	75+75+75	55	144	231	
		100+75+75	67	304	382	
	(YSe+KJ400)+kipsi	100+150	77	304	281	
	(YSe+KJ400)+LT+kipsi	75+75+75	76	239	156	
		100+75+75	140	485	378	
	PeSe+CaO+kipsi	66+66+66	10	96	17	

1) Heat treated test samples are used to assess the long term strength development potential. The mixtures are store for 28 days in +30 °C.

Annex 11.3

Yse	Portland cement
PeSe	Straight cement
LT	Alholmens Kraft fly ash
PKT	Oil shale ash
kipsi	Yara di-gypsum
Pika	Rapid cement

a	7 d normal treatment
b	7 d thermal treatment
c	14 d thermal treatment
d	28 d normal treatment
e	28 d thermal treatment
f	90 d normal treatment
g	180 d normal treatment

Sensing 7.1.2010				Compression strength [kPa]							Numbering						
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c	d	e	f	g	a	b	c	d	e	f	g
KS201	w_0 = 52,4	Yse	100		43			128	129			KO-1A			KO-1B	KO-1C	
		Yse	200		372			937	766			KO-2A			KO-2B	KO-2C	
		GTC	100		32			104	88			KO-3A			KO-3B	KO-3C	
		GTC	200		86			352	351			KO-4A			KO-4B	KO-4C	
		PeSe	100		52			159	133			KO-5A			KO-5B	KO-5C	
		PeSe	200		539			1441	1230			KO-6A			KO-6B	KO-6C	
		Yse+K400	50+50		20			21	22			KO-7A			KO-7B	KO-7C	
		Yse+K400	100+100		60			665	593			KO-8A			KO-8B	KO-8C	
		Yse+LT	70+150		231			354	358			KO-9A			KO-9B	KO-9C	
		Yse+LT	50+150		172			273	274			KO-10A			KO-10B	KO-10C	
		Yse+LT	50+200		239			411	347			KO-11A			KO-11B	KO-11C	
		Yse+LT	30+150		69			128	114			KO-12A			KO-12B	KO-12C	
		Yse+LT	30+200		106			185	116			KO-13A			KO-13B	KO-13C	
		Yse+PKT	70+150		50			351	463			KO-14A			KO-14B	KO-14C	
		Yse+PKT	50+150		46			295	395			KO-15A			KO-15B	KO-15C	
		Yse+PKT	30+150		34			182	278			KO-16A			KO-16B	KO-16C	
		PeSe+LT	70+150		236			331	327			KO-17A			KO-17B	KO-17C	
		GTC+PKT	70+150		27			177	131			KO-18A			KO-18B	KO-18C	
		GTC+PKT	50+150		29			138	92			KO-19A			KO-19B	KO-19C	
		Yse+LT+kipsi	70+75+75		74			429	392			KO-20A			KO-20B	KO-20C	
		Yse+LT+kipsi	50+100+100		60			198	222			KO-21A			KO-21B	KO-21C	
		Yse+LT+kipsi	30+100+100		34			74	81			KO-22A			KO-22B	KO-22C	
		Yse+LT+kipsi	70+75+75		35			584	321			KO-23A			KO-23B	KO-23C	
		Yse+LT+kipsi	50+100+100		26			107	247			KO-24A			KO-24B	KO-24C	
		Yse+LT+kipsi	30+100+100		23			79	208			KO-25A			KO-25B	KO-25C	
		PeSe+LT+kipsi	70+75+75		89			441	437			KO-26A			KO-26B	KO-26C	
		(Yse+K400)+LT+kipsi	70+75+75		52			225	254			KO-27A			KO-27B	KO-27C	
		(Yse+K400)+PKT+kipsi	70+75+75		31			141	424			KO-28A			KO-28B	KO-28C	
		(Yse+K400)+PKT	70+150		43			203	336			KO-29A			KO-29B	KO-29C	
		PeSe	150		223			637	518			KO-30A			KO-30B	KO-30C	

Hopeakiven satama 11.2.2011																	
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c	d	e	f	g	a	b	c	d	e	f	g
KS201	50	Yse + LT	40+150	48,9		127			203		HS-1A		HS-1B			HS-1C	
KS201	75	Yse + LT	40+150	8,8		48,6			23,1		HS-2A		HS-2B			HS-2C	
KS201	100	Yse + LT	40+150	<5		21,3			12,1		HS-3A		HS-3B			HS-3C	
KS201	150	Yse + LT	40+150	<5		15			<15		HS-4A		HS-4B			HS-4C	
KS201	50	Pika + LT	40+150	103		181			303		HS-5A		HS-5B			HS-5C	
KS201	75	Yse + LT	50+190	18,1		94,5			115		HS-6A		HS-6B			HS-6C	
KS201	75	Yse + LT	40+250	16,2		106			98,2		HS-7A		HS-7B			HS-7C	
KS201	100	Yse + LT	50+190	<10		47			30,5		HS-8A		HS-8B			HS-8C	
KS201	100	Yse + LT	40+250	4,7		50,7			27,5		HS-9A		HS-9B			HS-9C	
kokooma 104-105	50	Yse + LT	40+150	98,1					51,5		HS-10A					HS-10B	
kokooma 104-105	75	Yse + LT	40+150	19,7					19,7		HS-11A					HS-11B	
kokooma 104-105	75	Yse + LT	40+250	64,9					26,3		HS-12A					HS-12B	

Hopeakiven satama 15.3.2011																	
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c	d	e	f	g	a	b	c	d	e	f	g
kokooma 104-105	50	Pika + LT	40+150	56,9		170			82,5		HS-13A		HS-13B			HS-13C	
kokooma 104-105	75	Pika + LT	40+250	41,1		134,7			45		HS-14A		HS-14B			HS-14C	
kokooma 104-105	100	Pika + LT	40+250	17		67,4			26,9		HS-15A		HS-15B			HS-15C	
kokooma 104-105	150	Pika + LT	40+250	5,6		11,4			3,8		HS-16A		HS-16B			HS-16C	
kokooma 104-105	100	Pika + LT	50+150	16,3		29,3			14,6		HS-17A		HS-17B			HS-17C	
kokooma 104-105	150	Pika + LT	50+250	5		12,8			8,4		HS-18A		HS-18B			HS-18C	
kokooma 104-105	150	Pika + LT	60+150	13,8		12,2			15,5		HS-19A		HS-19B			HS-19C	
kokooma 104-105	150	Pika + LT	60+250	21,8		29,8			21,8		HS-20A		HS-20B			HS-20C	
KS201	150	Pika + LT	40+250	8,9		30,5			11,1		HS-21A		HS-21B			HS-21C	
KS201	50	Pika + LT	40+150	138		190	230		206		HS-22A		HS-22B	HS-22C		HS-22E	

Effect of water content II 10.6.2011																	
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c	d	e	f	g	a	b	c	d	e	f	g
KS60 kokooma	40*	Pika+LT	50+160	54		204					VV-1A		VV-1B				
	40*	Rapid+LT	50+160	55		162					VV-2A		VV-2B				
	56,5	Pika+LT	60+190	72		105					VV-3A		VV-3B				
	56,5	Rapid+LT	60+190	58		106					VV-4A		VV-4B				
	70,0	Pika+LT	70+230	47		97					VV-5A		VV-5B				
	70,0	Rapid+LT	70+230	29		86					VV-6A		VV-6B				
	80,0	Pika+LT	80+230	62		114					VV-7A		VV-7B				
	80	Rapid+LT	80+230	29		111					VV-8A		VV-8B				
KS 120 kokooma	70*	Pika+LT	70+230	110		253					VV-9A		VV-9B				
	70*	Rapid+LT	70+230	93		233					VV-10A		VV-10B				
	82,0	Pika+LT	80+220	67		152					VV-11A		VV-11B				
	82,0	Rapid+LT	80+220	57		129					VV-12A		VV-12B				
	90,0	Pika+LT	90+220	58		147					VV-13A		VV-13B				
	90	Rapid+LT	90+220	52		173					VV-14A		VV-14B				
	100	Pika+LT	100+220	42		188					VV-15A		VV-15B				
	100	Rapid+LT	100+220	50		167					VV-16A		VV-16B				

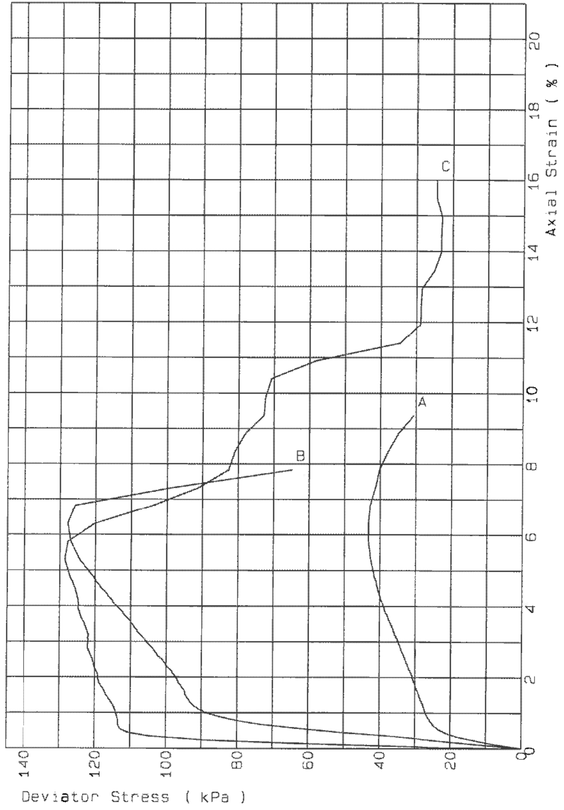
Adjustments 23.8.2011																	
P4, 1,5 m	24,7	Rapid + LT	30+120	377			501				SVT-1A			SVT-1B			
		Rapid + LT	40+160	472		952					SVT-2A		SVT-2B				
		Rapid + LT	50+200	661							SVT-3A			SVT-3B			
		Pika + LT	40+160	572							SVT-4A			SVT-4B			
P1, 0,5 m	24,4	Rapid + LT	40+160	399		659					SVT-5A		SVT-5B				
		Rapid + LT	50+200	556							SVT-6A			SVT-6B			
P5, 1,5 m	19,1	Rapid + LT	30+120	364			440				SVT-7A			SVT-7B			
		Rapid + LT	40+160	583							SVT-8A		SVT-8B				
		Rapid + LT	50+200	542							SVT-9A			SVT-9B			
		Pika + LT	40+160	602							SVT-10A			SVT-10B			
P6, 0,5 m	16,2	Rapid + LT	40+160	514							SVT-11A			SVT-11B			

1.9.2011																	
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c (12 d)	d	e	f	g	a	b	c	d	e	f	g
P4, 1,5 m		LT	100	23		23,3			26,3		SVT-12A		SVT-12B			SVT-12C	
		LT	150	38,8		62,7			126,2		SVT-13A		SVT-13B			SVT-13C	
		LT	200	90,9		151	134				SVT-14A		SVT-14B	SVT-14C			
P1, 0,5 m		LT	100	18,9		18,7					SVT-15A		SVT-15B			*SVT-15C*	
		LT	150	37,6		32,6			72,2		SVT-16A		SVT-16B			SVT-16C	
		LT	200	64,5		88,6	103,1				SVT-17A		SVT-17B	SVT-17C			
P5, 1,5 m		LT	150	106		137	140				SVT-18A		SVT-18B	SVT-18C			
P6, 0,5 m		LT	150	97,5		125,5	107				SVT-19A		SVT-19B	SVT-19C			

On-site specimens 14.9.2011																	
Aggregate	w %	Binder	Amount [kg/m^3]	a	b	c	d	e	f	g	a	b	c	d	e	f	g
Box 1		Rapid + LT	30+100				279		570	830				SC-2A		SC-2B	SC-2C
Box 10		Rapid + LT	30+100				174		280					SC-3A		SC-3B	
Bok 14		Rapid + LT	30+100	87			207		314	372	SC-4A			SC-4B		SC-4C	SC-4D
Bok 14		Rapid + LT	30+100	79			133		233	169	SC-6A			SC-6B		SC-6C	SC-6D
Box 18		LT	200	74			117		193	272	SC-7A			SC-7B		SC-7C	SC-7D
Box 18		LT	200	54			73		111	118	SC-9A			SC-9B		SC-9C	SC-9D
Box 38		LT	150-200	26			35		68	111	SC-11A			SC-11B		SC-11C	SC-11D
Box 38		LT	150-200	28			58		67	80	SC-13A			SC-13B		SC-13C	SC-13D
Box 44		LT	150-200	38			34		57	93	SC-15A			SC-15B		SC-15C	SC-15D
Box 47		LT	150-200	66			85		100	149	SC-17A			SC-17B		SC-17C	SC-17D
Box 47		LT	150-200	37			59		55	98	SC-19A			SC-19B		SC-19C	SC-19D
Box 49		LT	150-200	85			112		157		SC-20A			SC-21B		SC-21C	
Box 104		LT	150-200	40			76		122	151	SC-23A			SC-23B		SC-23C	SC-23D
Box 106		LT	150-200	41			75		97	144	SC-25A			SC-25B		SC-25C	SC-25D

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-1

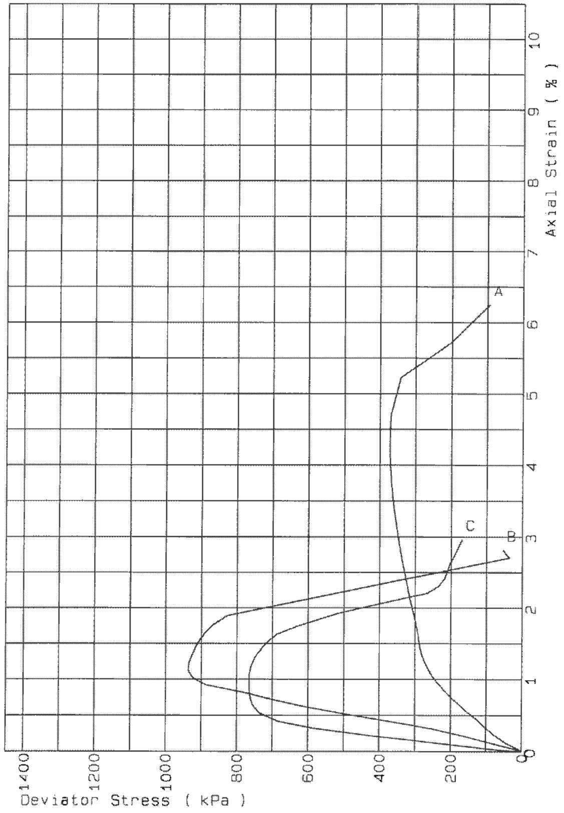
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-2

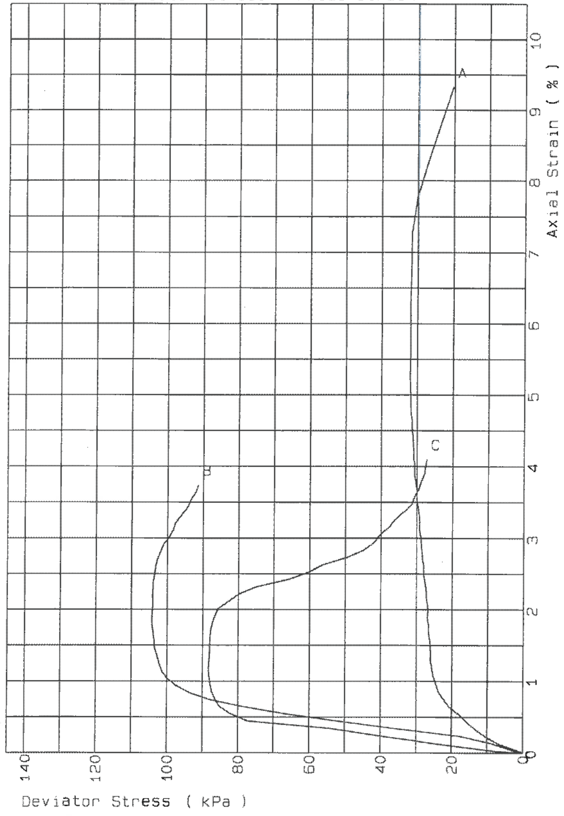
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-3

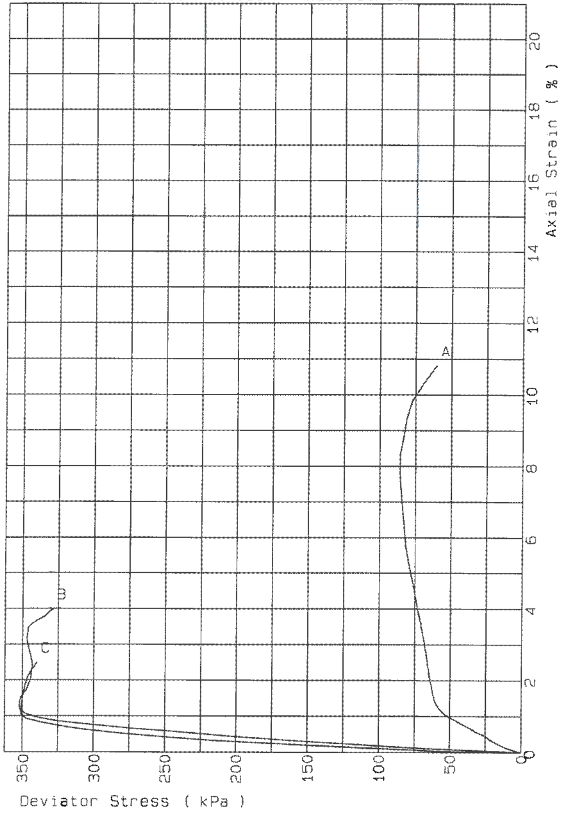
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-4

Deviator Stress v Axial Strain



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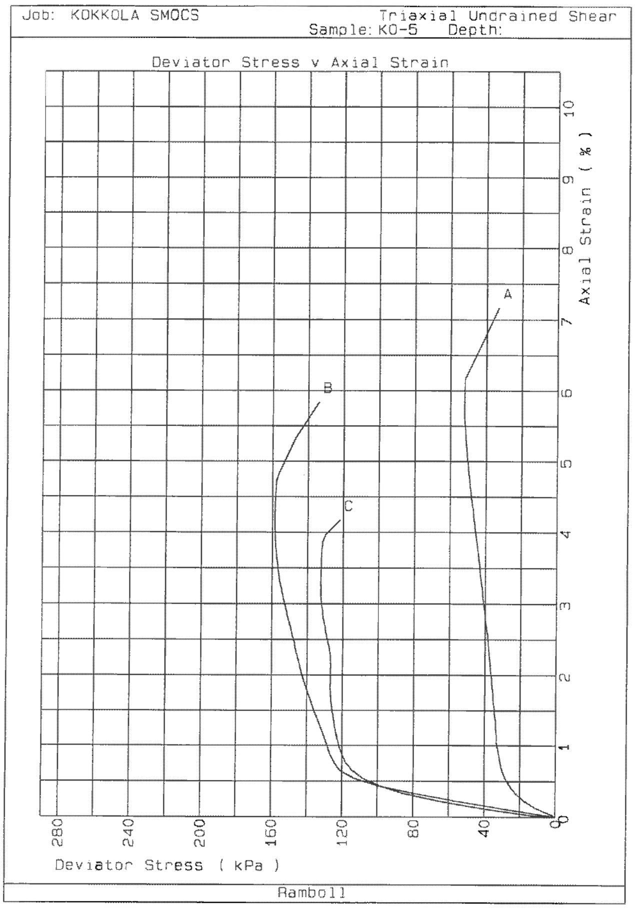
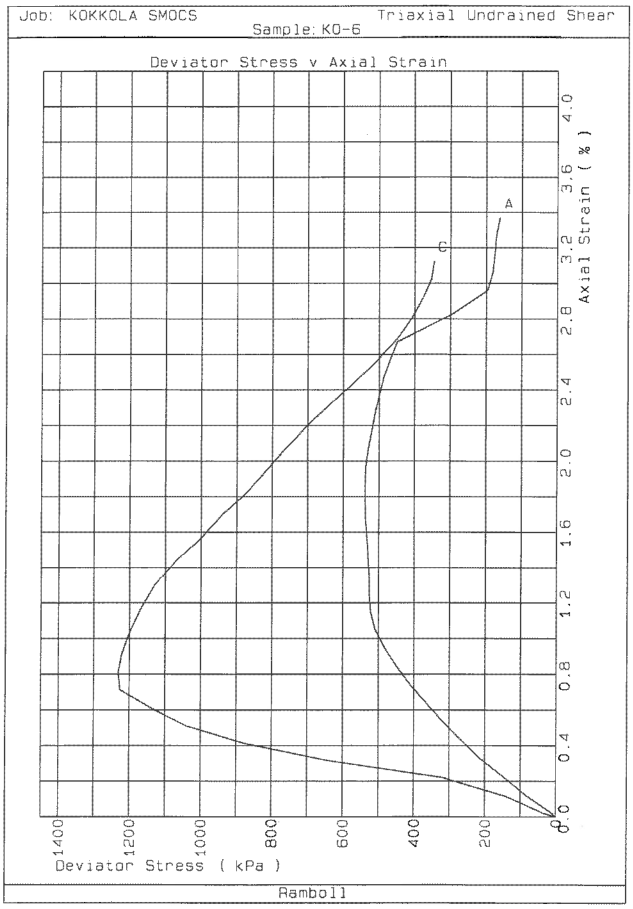
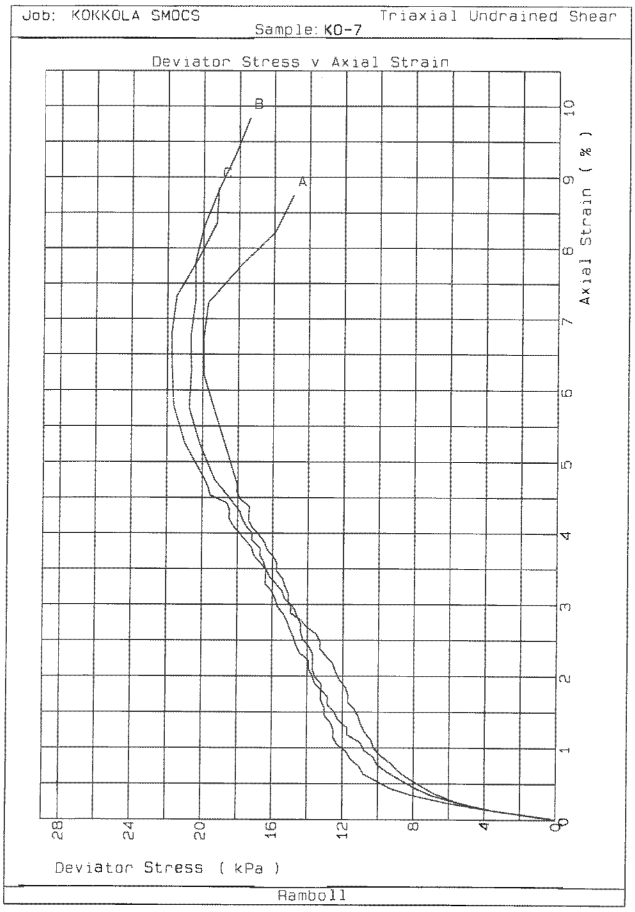
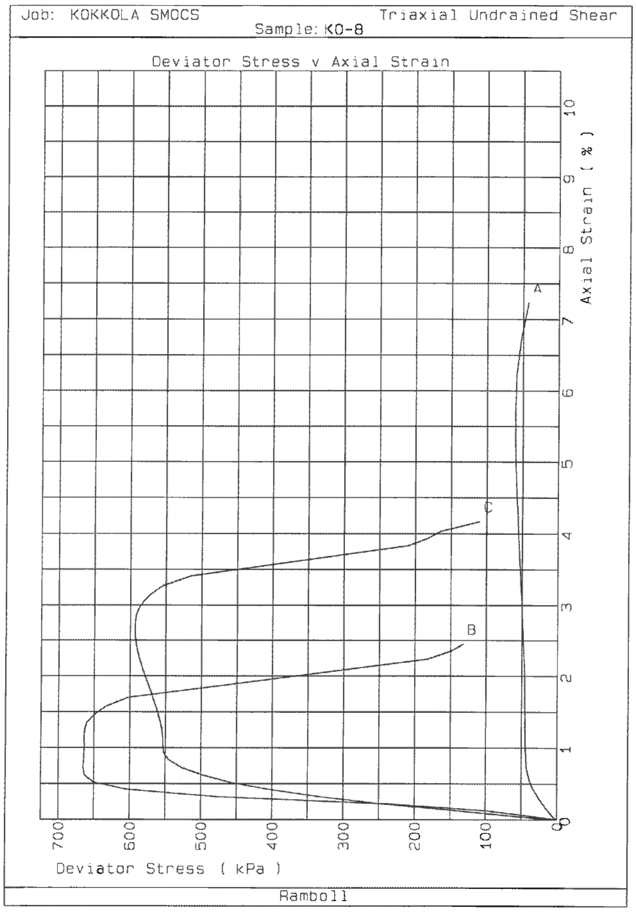

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-5 Depth:
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
40
80
120
160
200
240
280
A
B
C
Ramboll

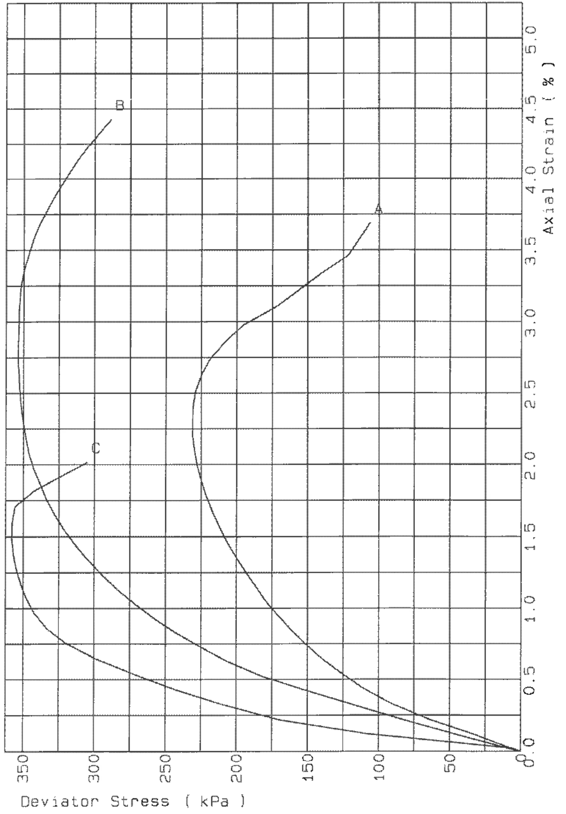

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-6
Deviator Stress v Axial Strain
Axial Strain (%)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Deviator Stress (kPa)
0
200
400
600
800
1000
1200
1400
A
C
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-7
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
4
8
12
16
20
24
28
A
B
C
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-8
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
100
200
300
400
500
600
700
A
B
C
Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-9

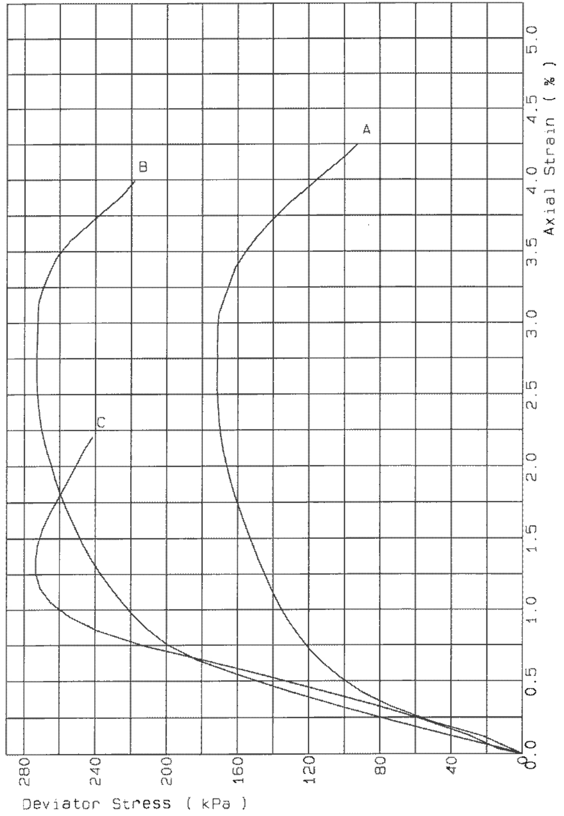
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-10

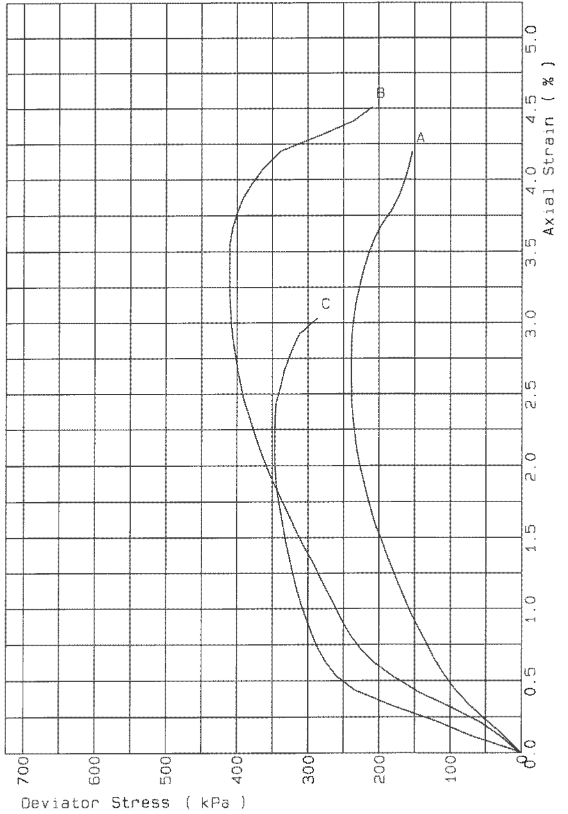
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-11

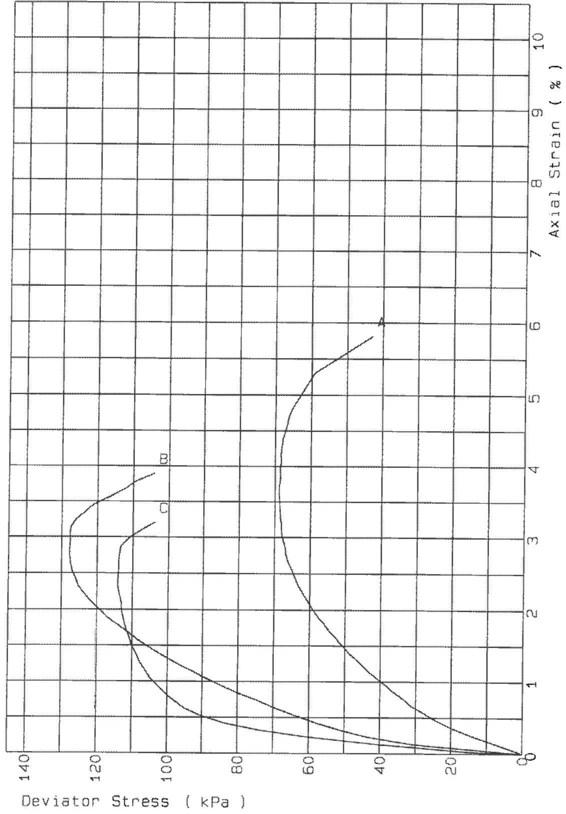
Deviator Stress v Axial Strain



Ramboll

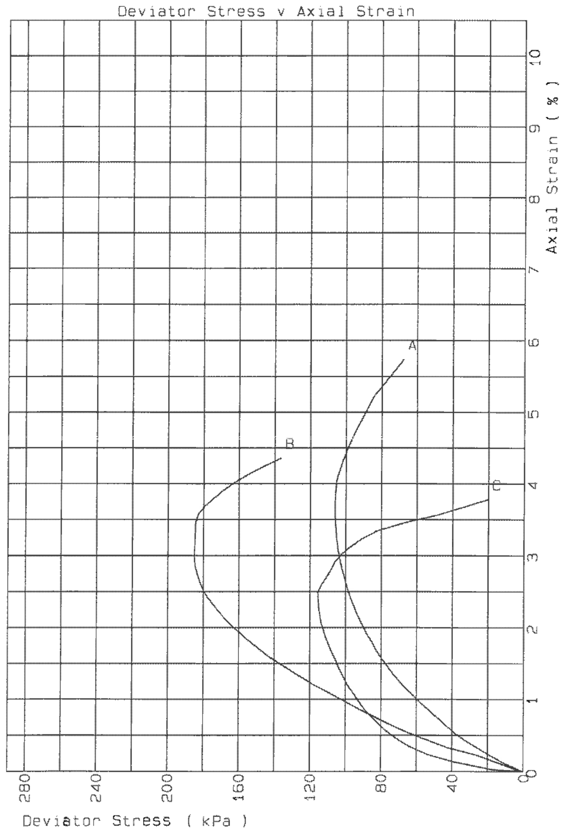
Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-12

Deviator Stress v Axial Strain



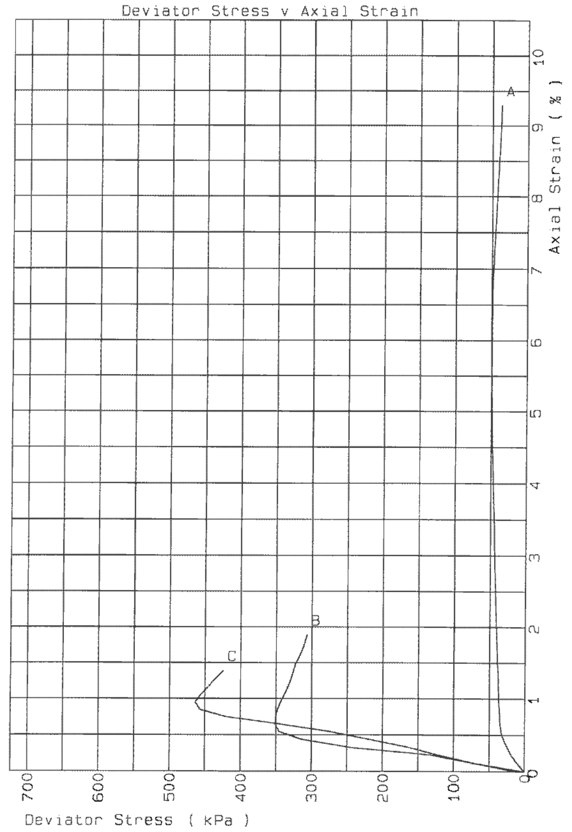
Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-13



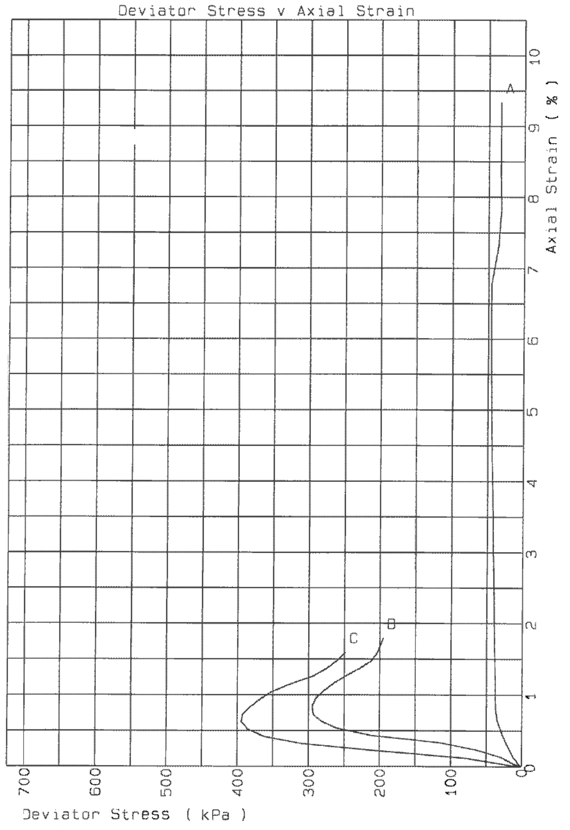
Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-14



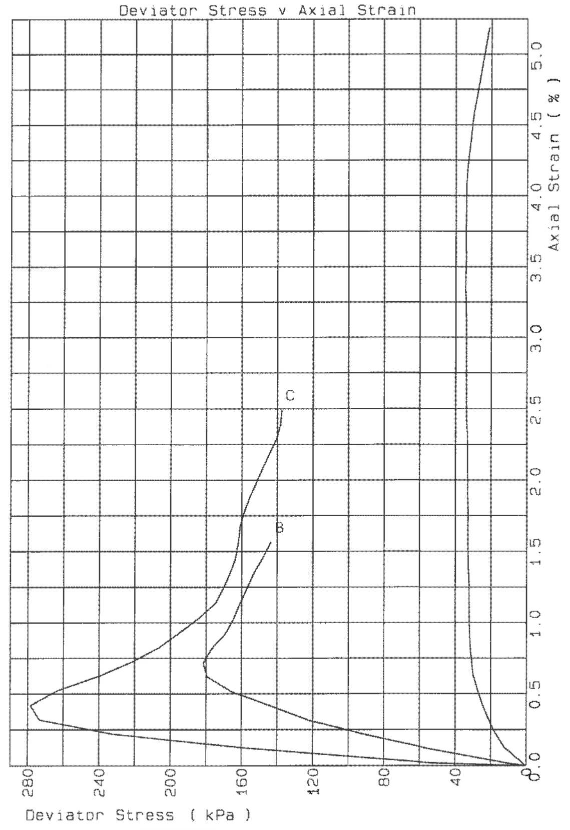
Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-15



Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-16



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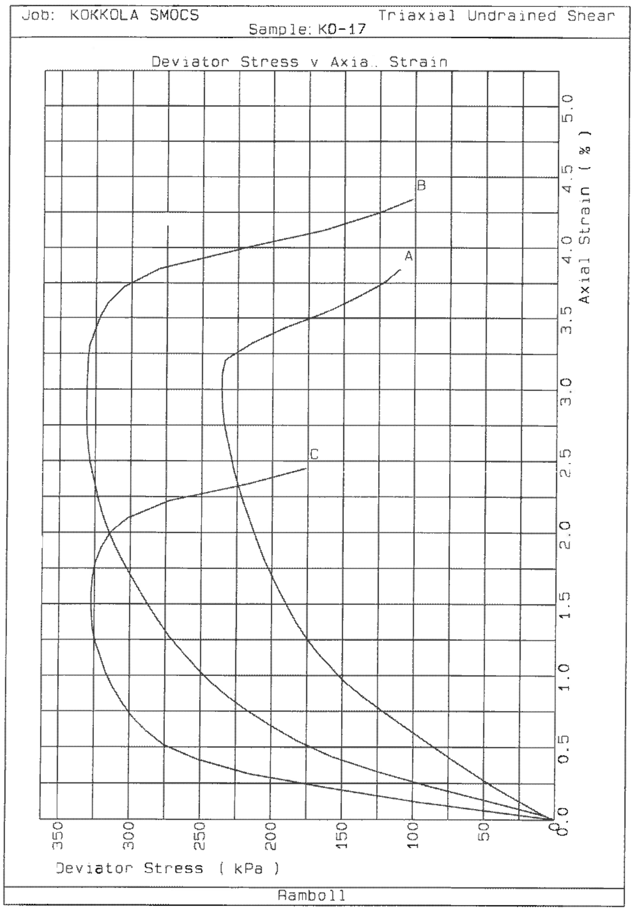
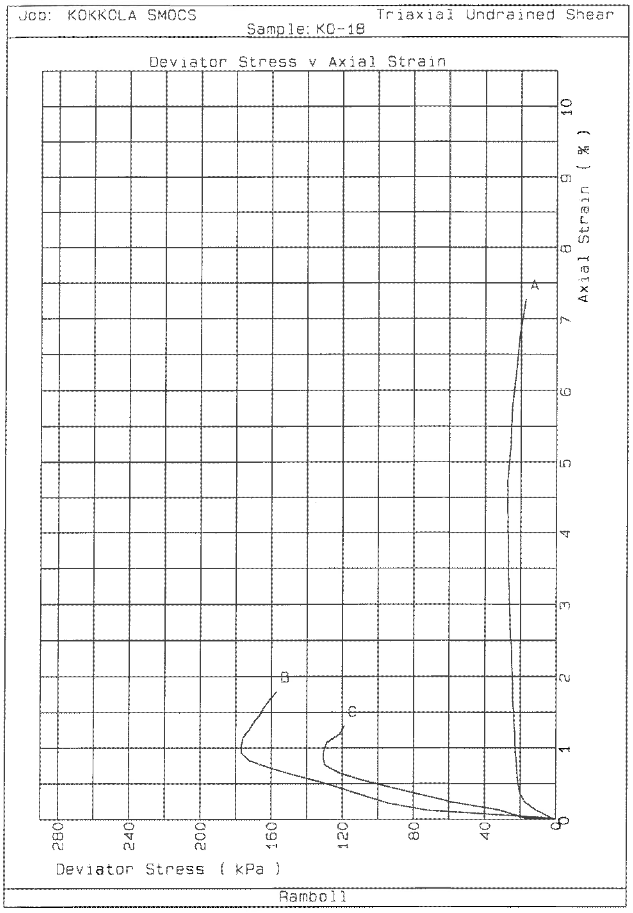
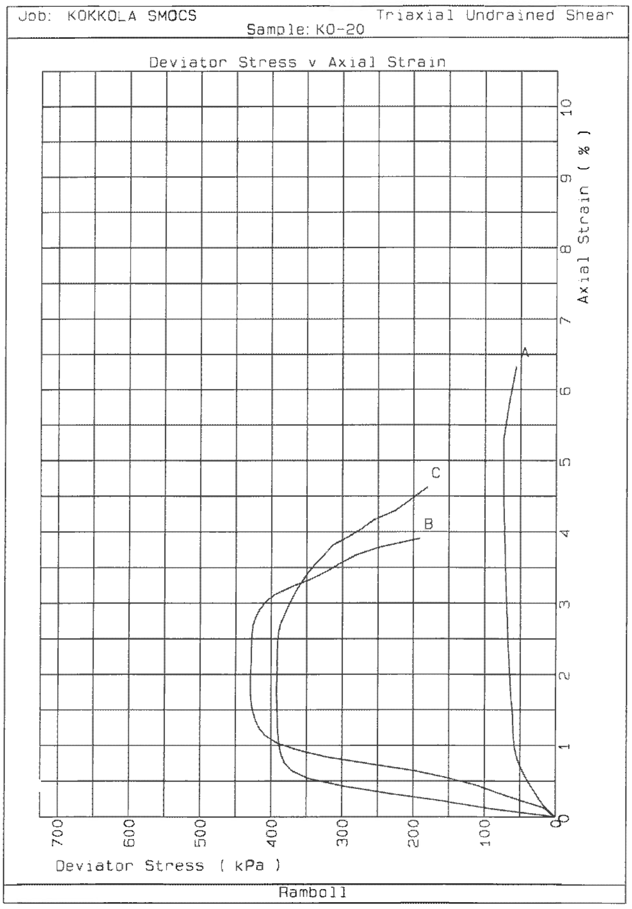
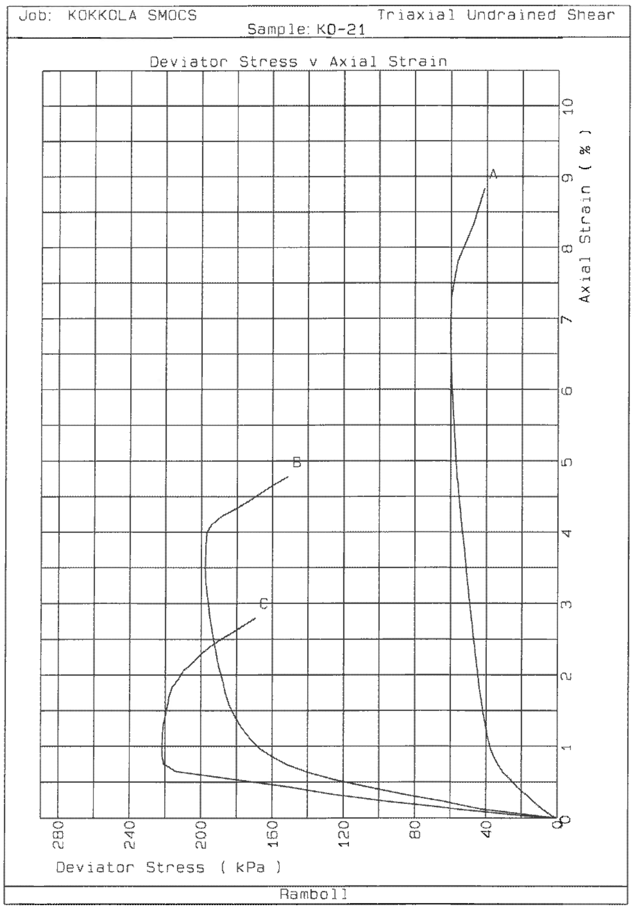

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-17
Deviator Stress v Axia. Strain
Axial Strain (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
A
B
C
350
300
250
200
150
100
50
0
Deviator Stress (kPa)
Ramboll

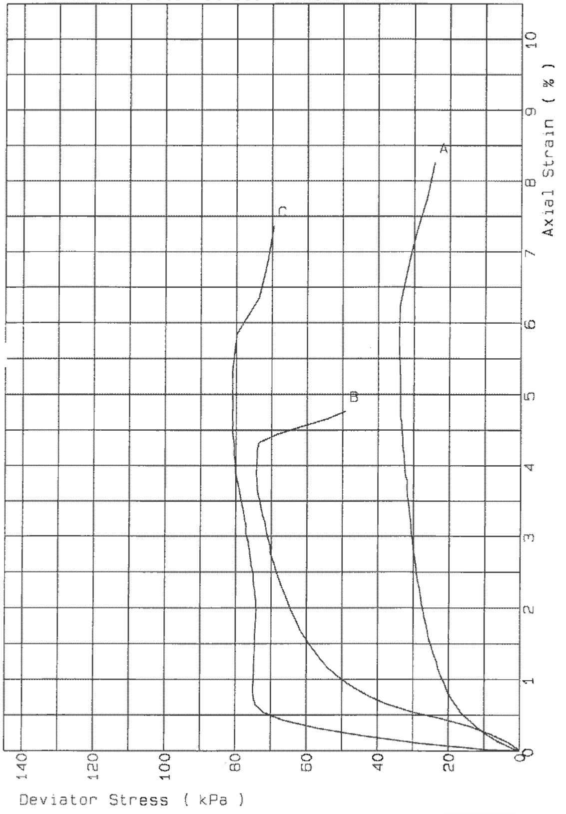

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-18
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
280
240
200
160
120
80
40
0
Deviator Stress (kPa)
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-20
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
700
600
500
400
300
200
100
0
Deviator Stress (kPa)
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-21
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
280
240
200
160
120
80
40
0
Deviator Stress (kPa)
Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-22

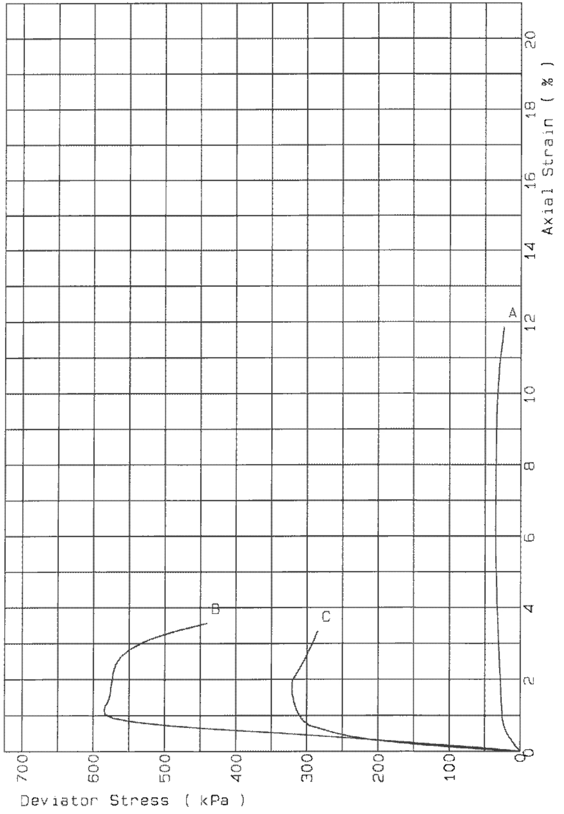
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-23

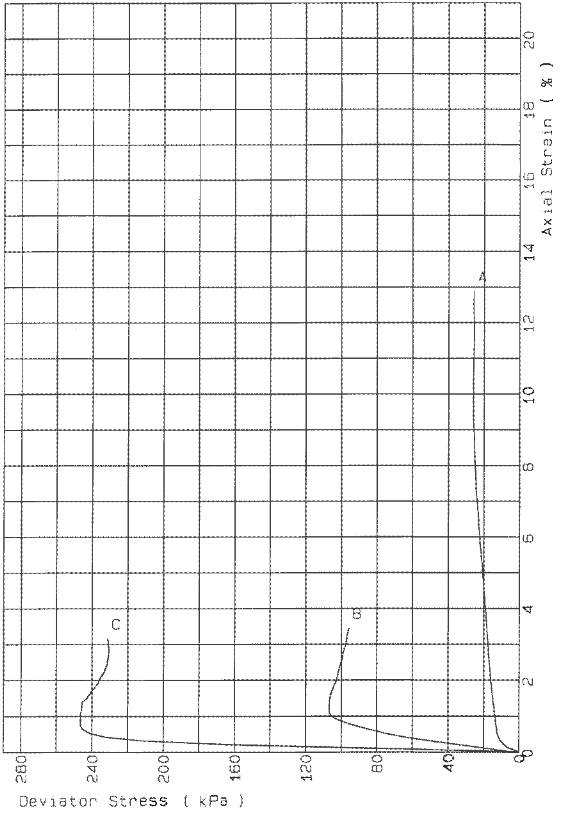
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-24

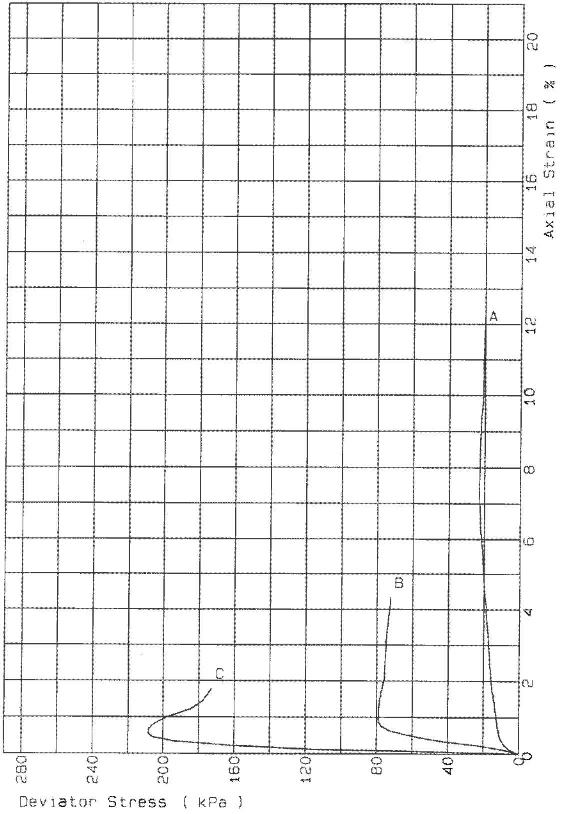
Deviator Stress v Axial Strain



Ramboll

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-25

Deviator Stress v Axial Strain



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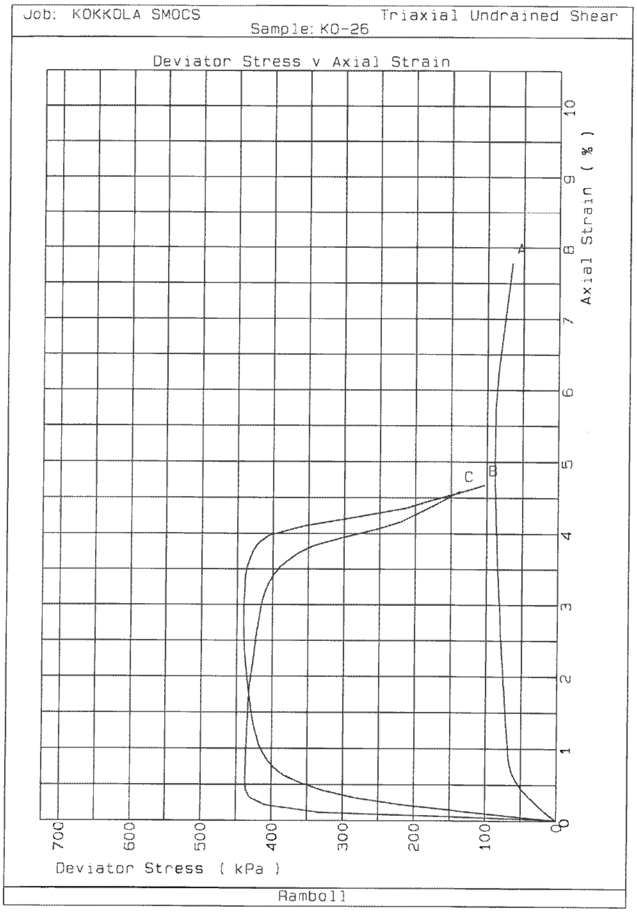
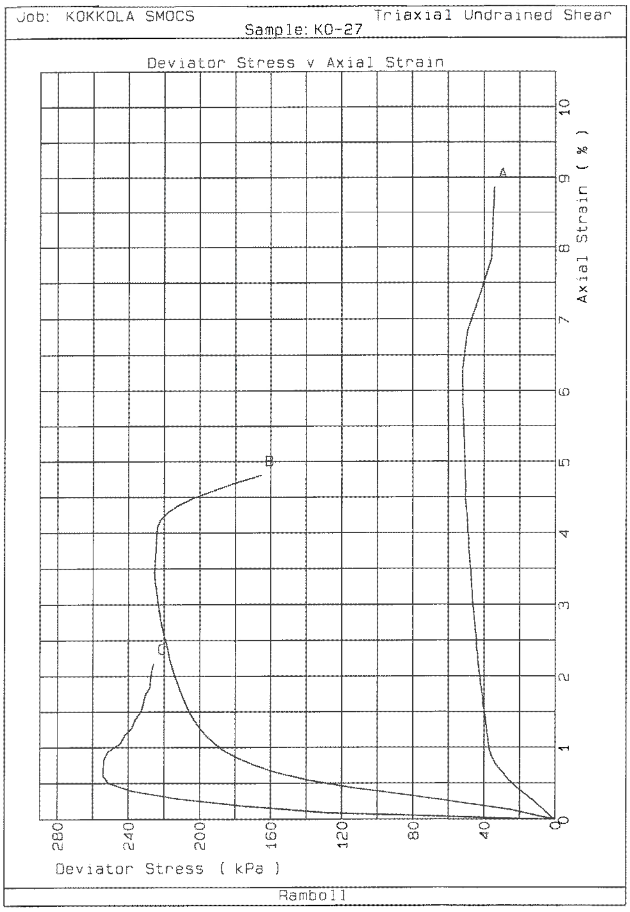
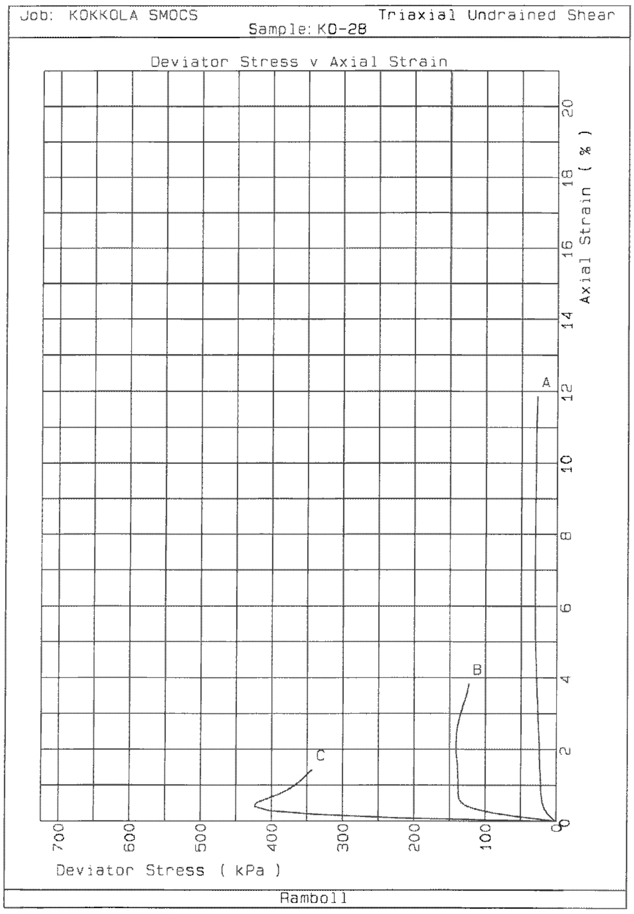
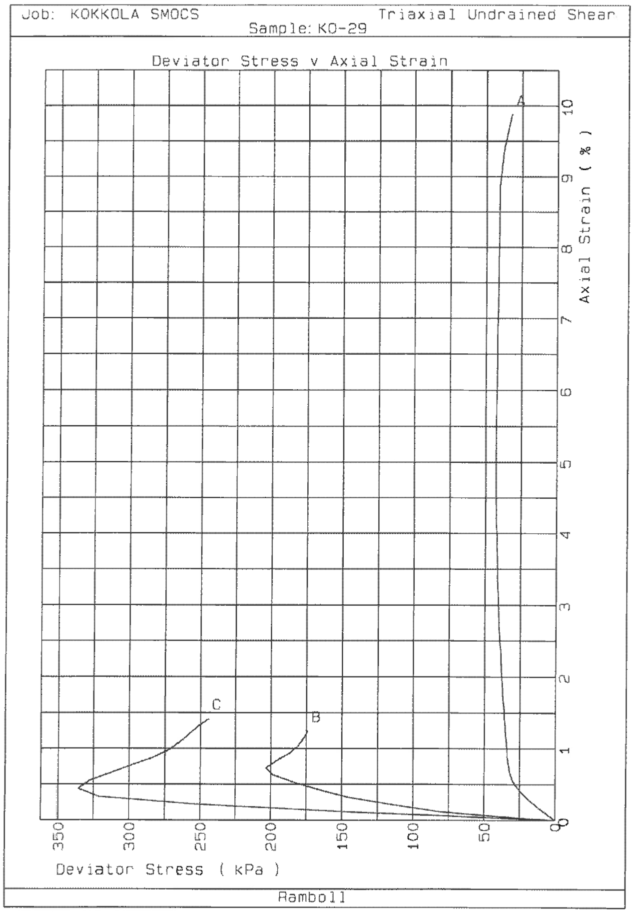

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-26
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
Deviator Stress (kPa)
700
600
500
400
300
200
100
0
Ramboll

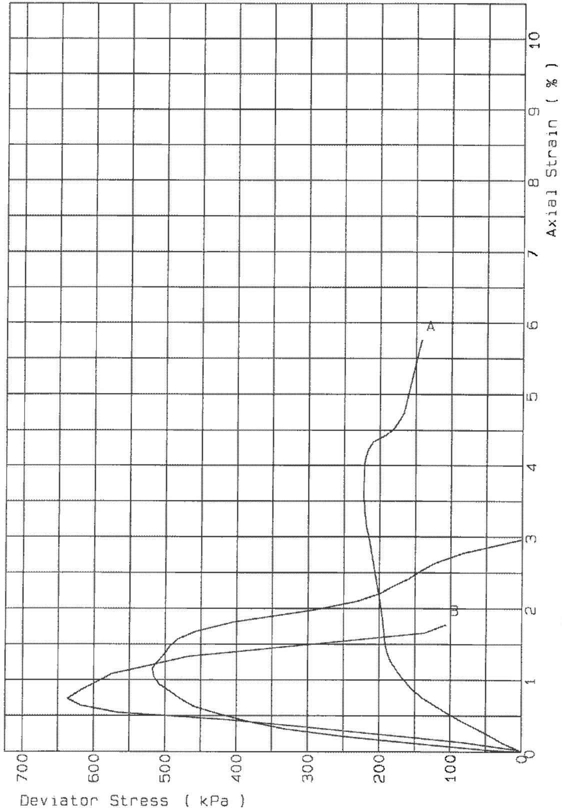

Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-27
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
Deviator Stress (kPa)
280
240
200
160
120
80
40
0
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-28
Deviator Stress v Axial Strain
Axial Strain (%)
0
2
4
6
8
10
12
14
16
18
20
A
B
C
Deviator Stress (kPa)
700
600
500
400
300
200
100
0
Ramboll


Job: KOKKOLA SMOCS
Triaxial Undrained Shear
Sample: KO-29
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
A
B
C
Deviator Stress (kPa)
350
300
250
200
150
100
50
0
Ramboll

Job: KOKKOLA SMOCS Triaxial Undrained Shear
Sample: KO-30

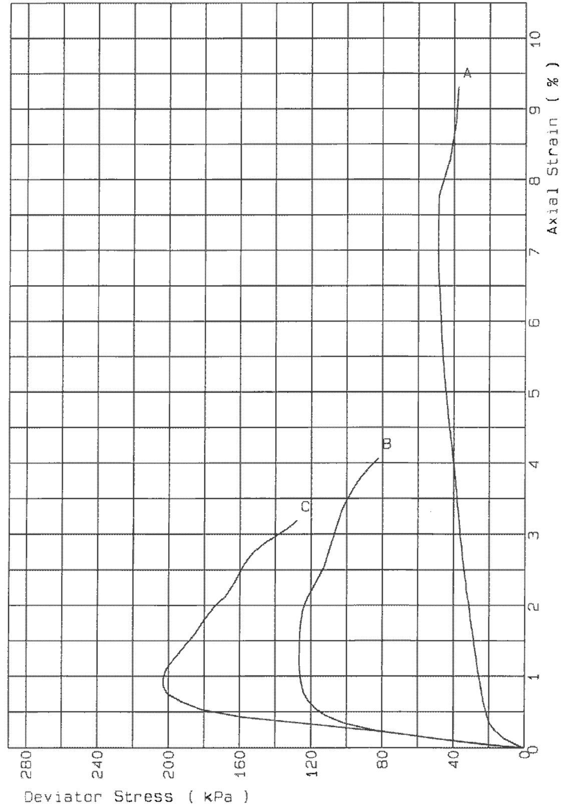
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-1

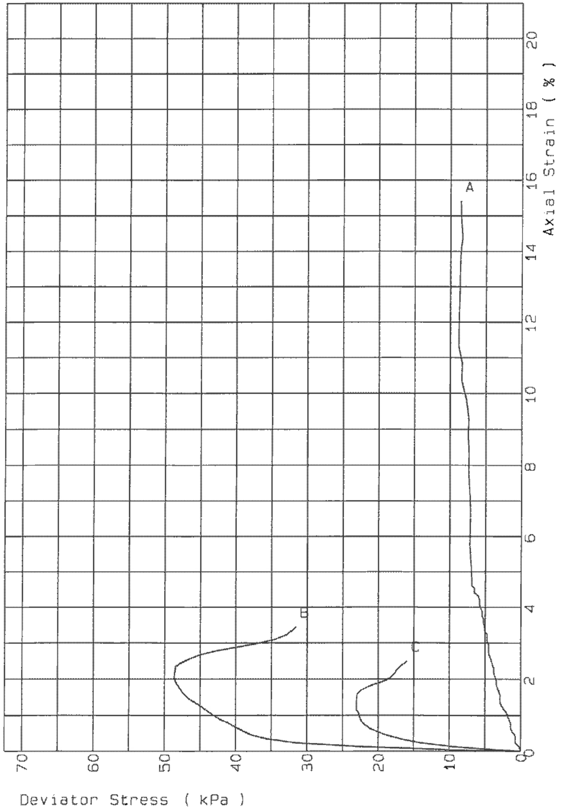
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-2

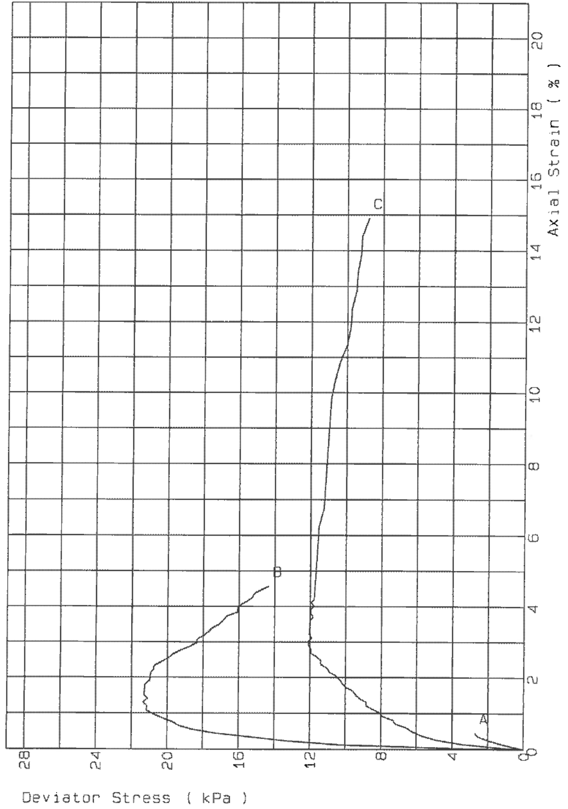
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-3

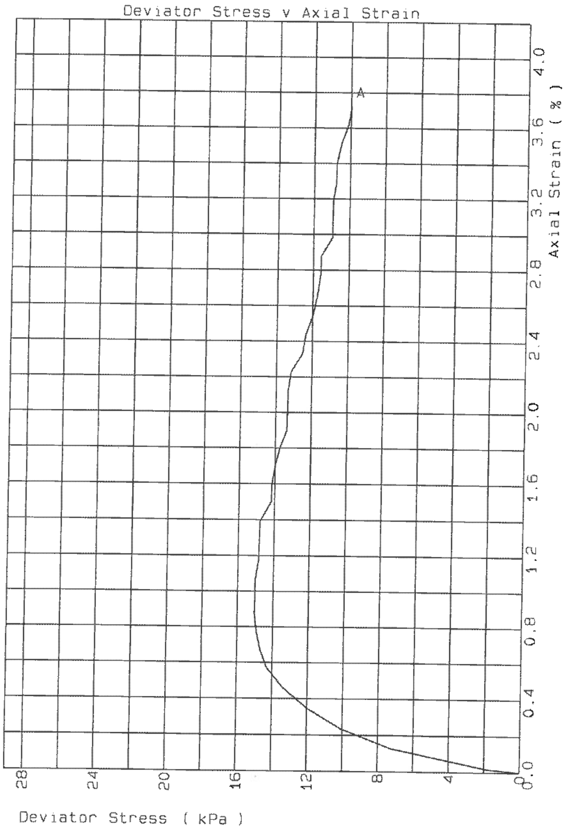
Deviator Stress v Axial Strain



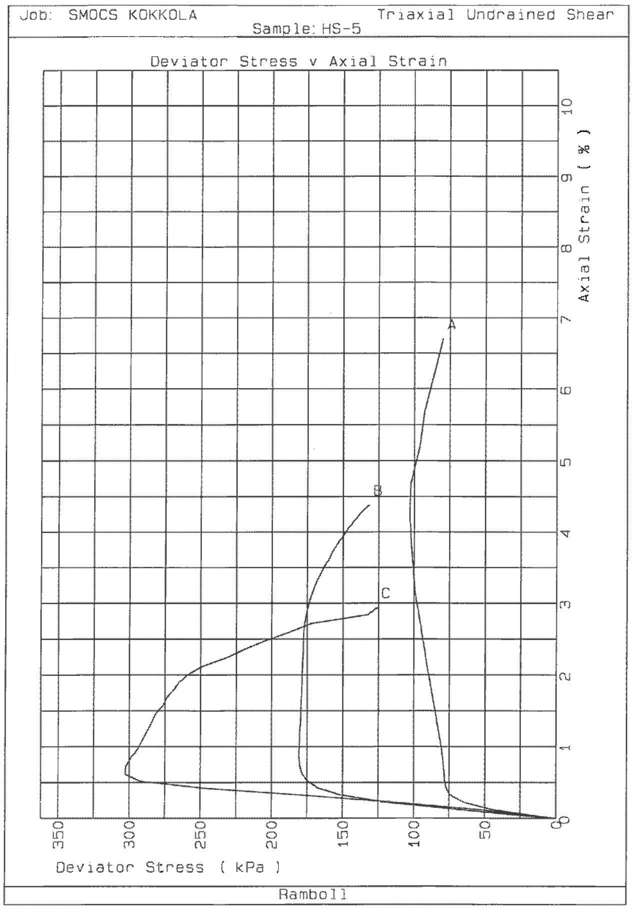
Ramboll

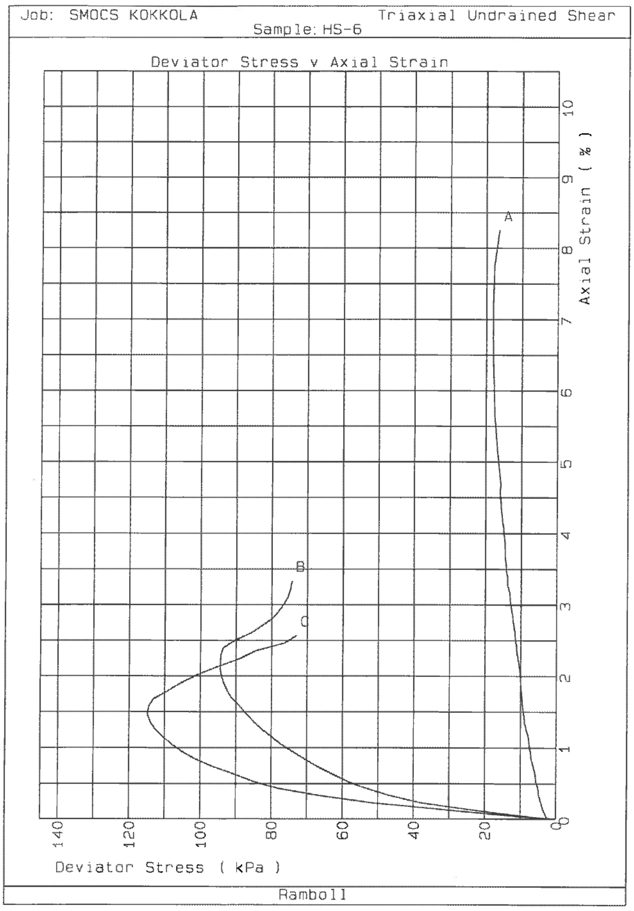
Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-4

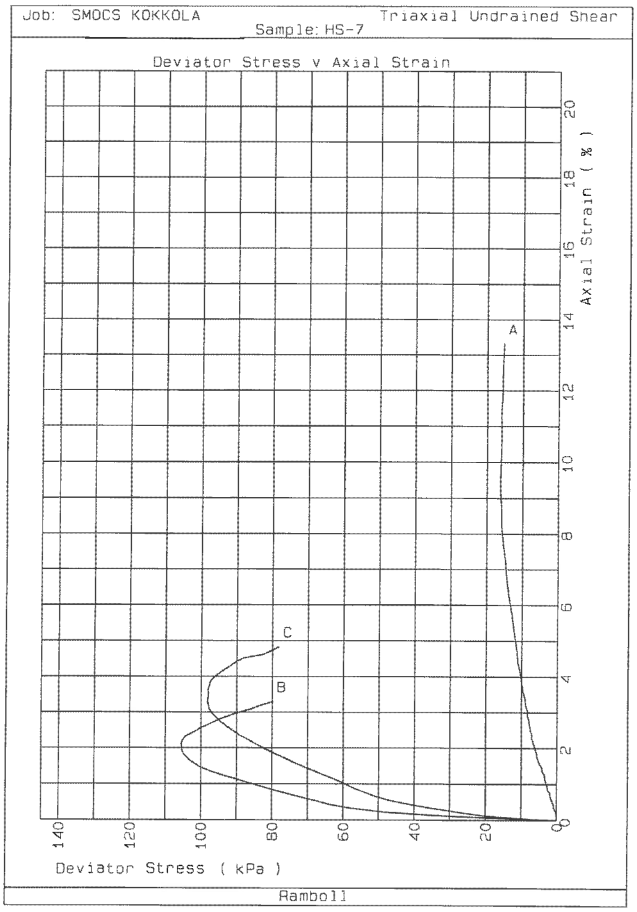
Deviator Stress v Axial Strain

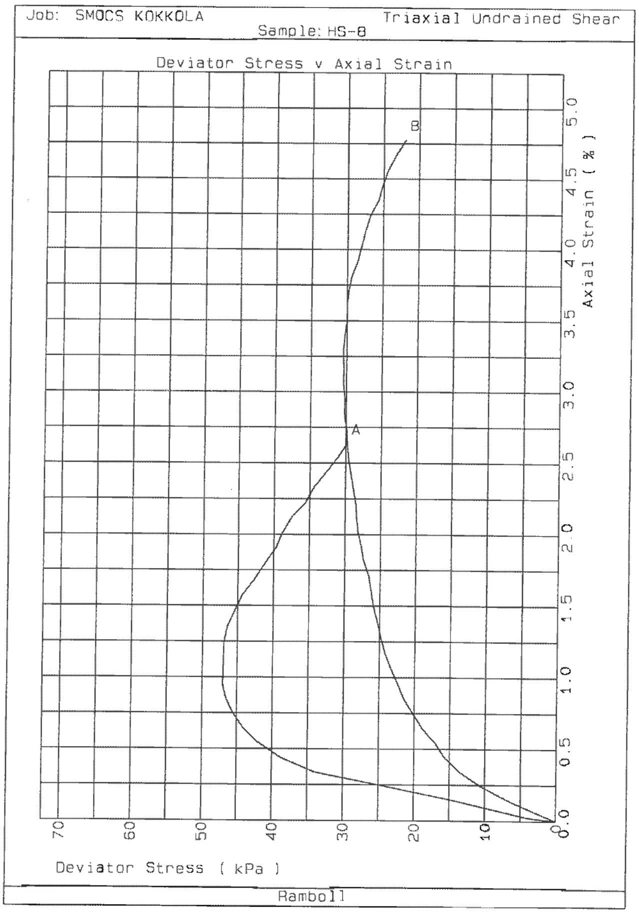


Ramboll


Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-5
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
350
300
250
200
150
100
50
0
A
B
C
Ramboll

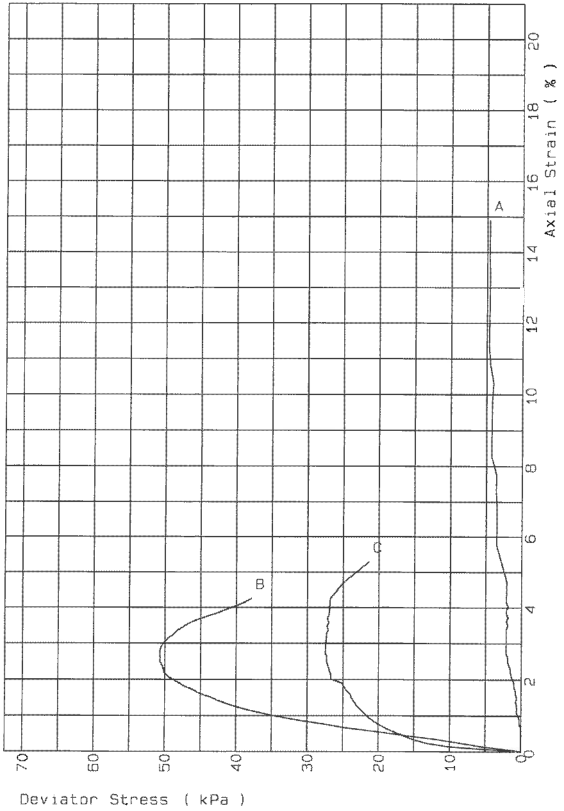

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-6
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
140
120
100
80
60
40
20
0
A
B
C
Ramboll


Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-7
Deviator Stress v Axial Strain
Axial Strain (%)
0
2
4
6
8
10
12
14
16
18
20
Deviator Stress (kPa)
140
120
100
80
60
40
20
0
A
B
C
Ramboll


Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: HS-8
Deviator Stress v Axial Strain
Axial Strain (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Deviator Stress (kPa)
70
60
50
40
30
20
10
0
A
B
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: HS-9

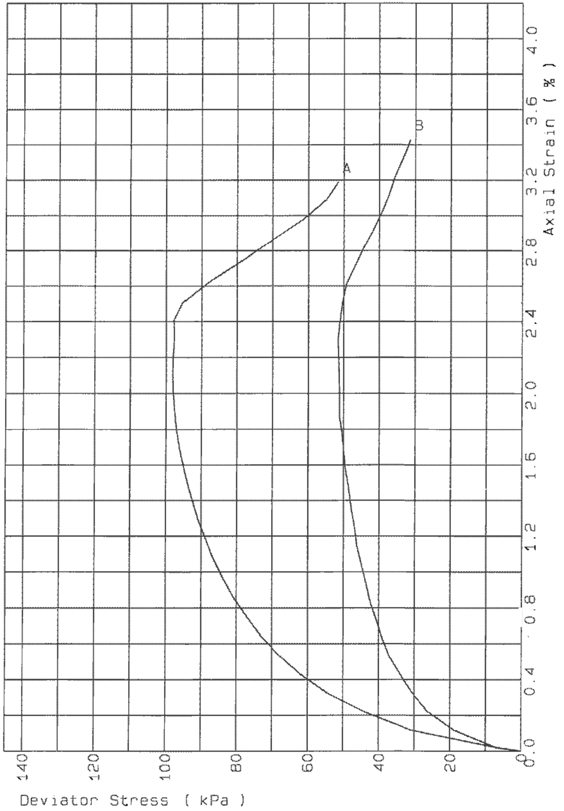
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: HS-10

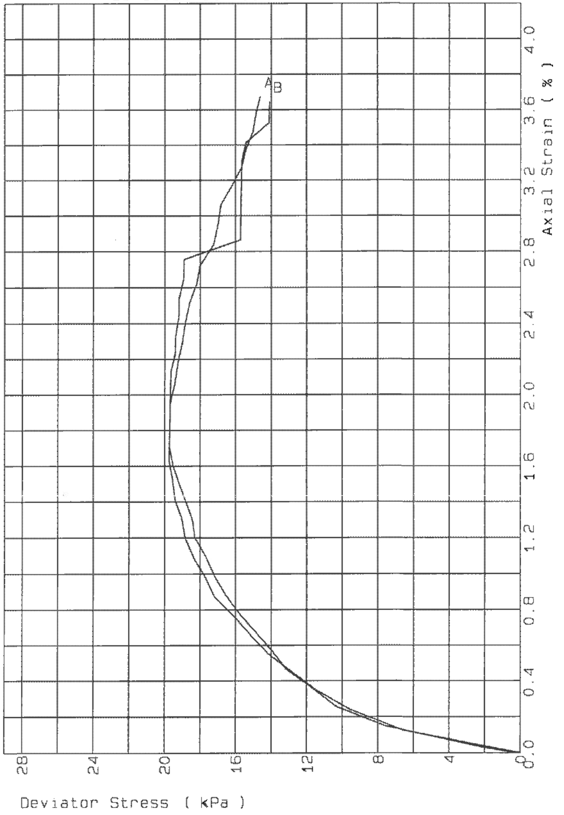
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: HS-11

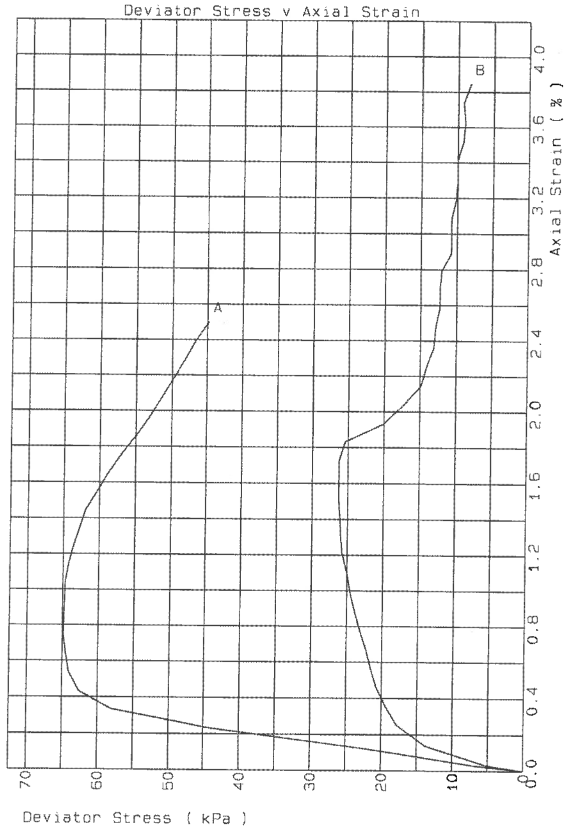
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: HS-12

Deviator Stress v Axial Strain

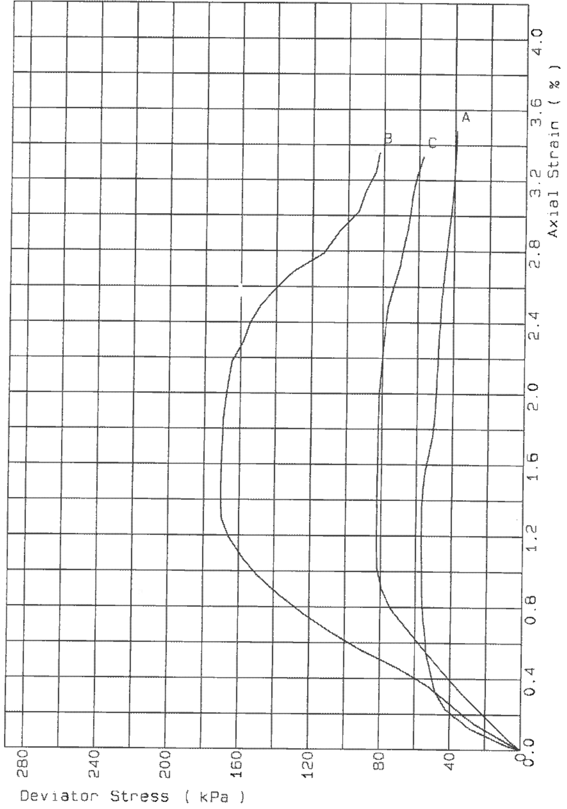


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: HS-13

Deviator Stress v Axial Strain

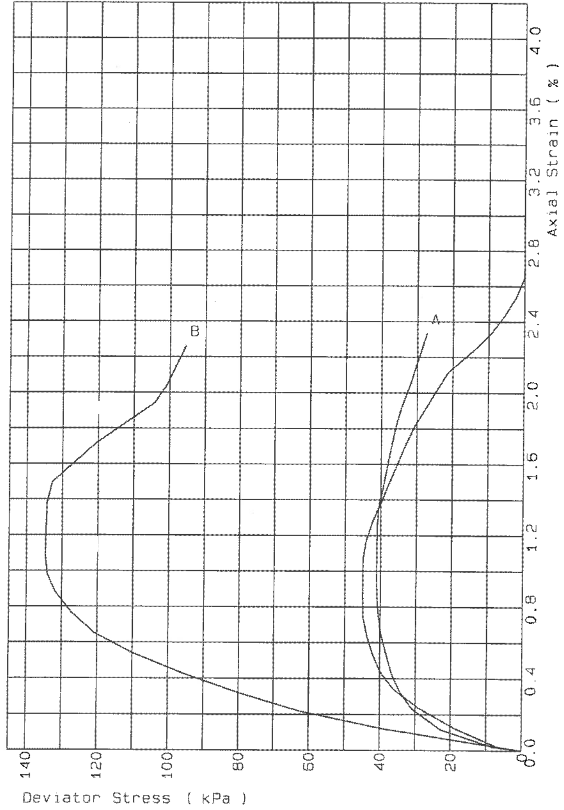


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: HS-14

Deviator Stress v Axial Strain

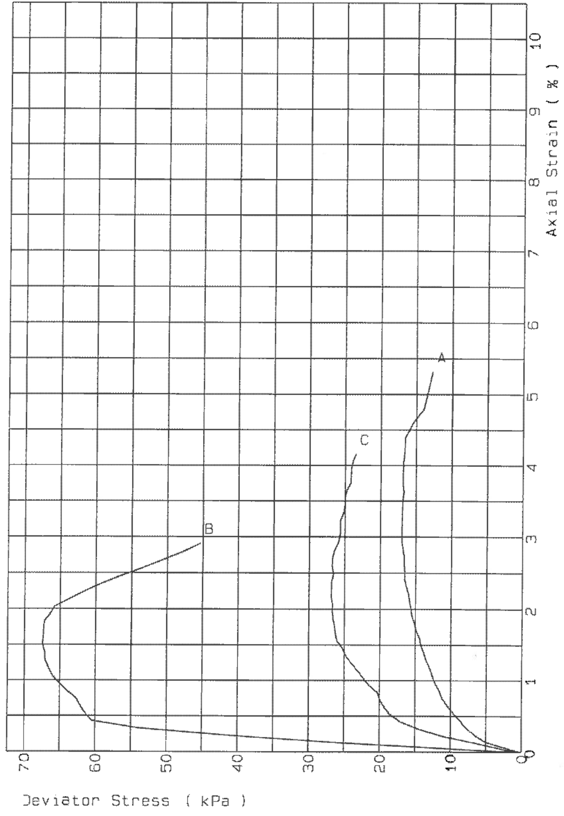


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: HS-15

Deviator Stress v Axial Strain

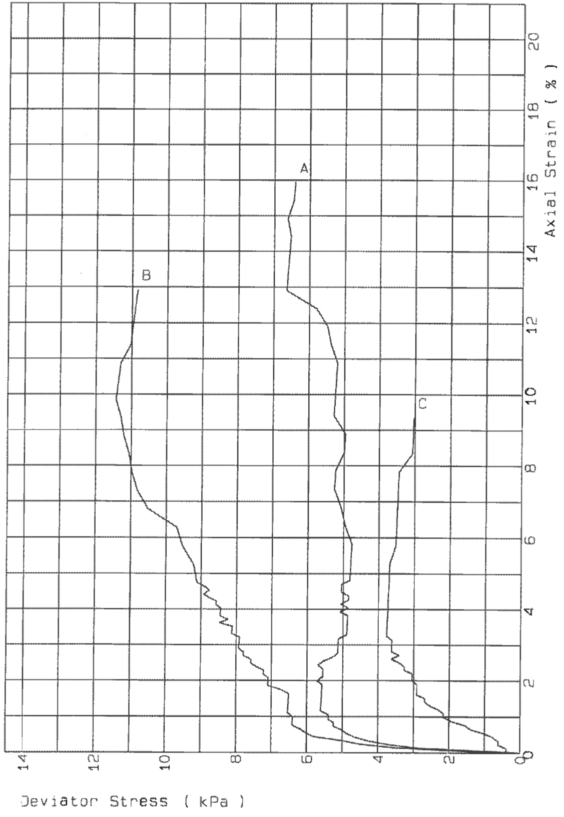


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: HS-16

Deviator Stress v Axial Strain



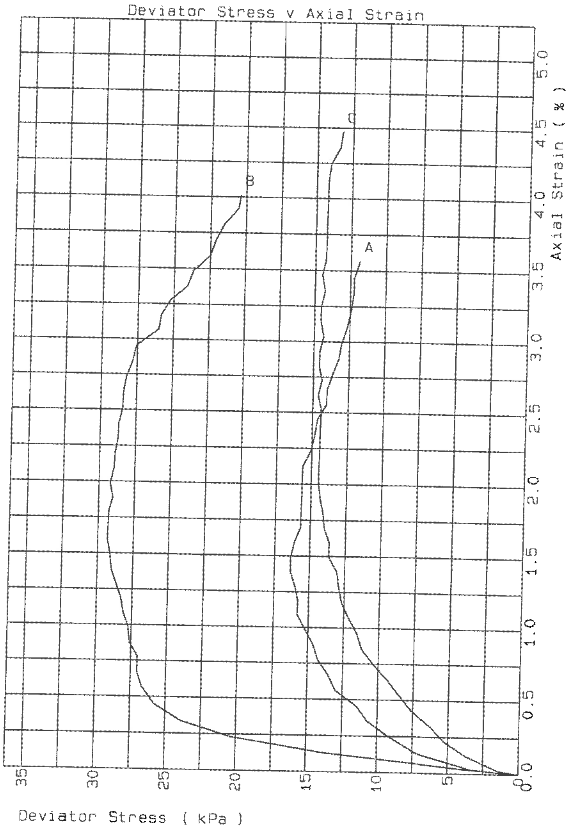
Ramboll

Job: SMOCS KOKKOLA

Sample: HS-17

Triaxial Undrained Shear

Deviator Stress v Axial Strain



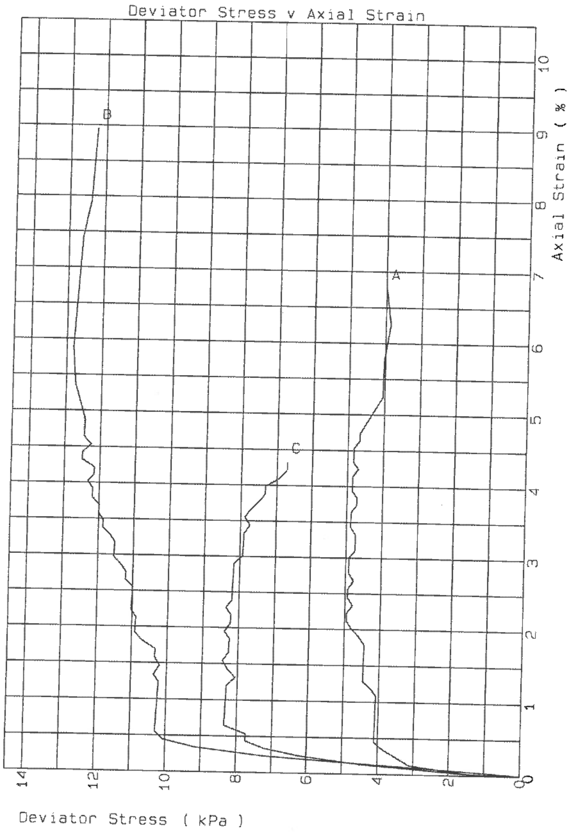
Ramboll

Job: SMOCS KOKKOLA

Sample: HS-18

Triaxial Undrained Shear

Deviator Stress v Axial Strain



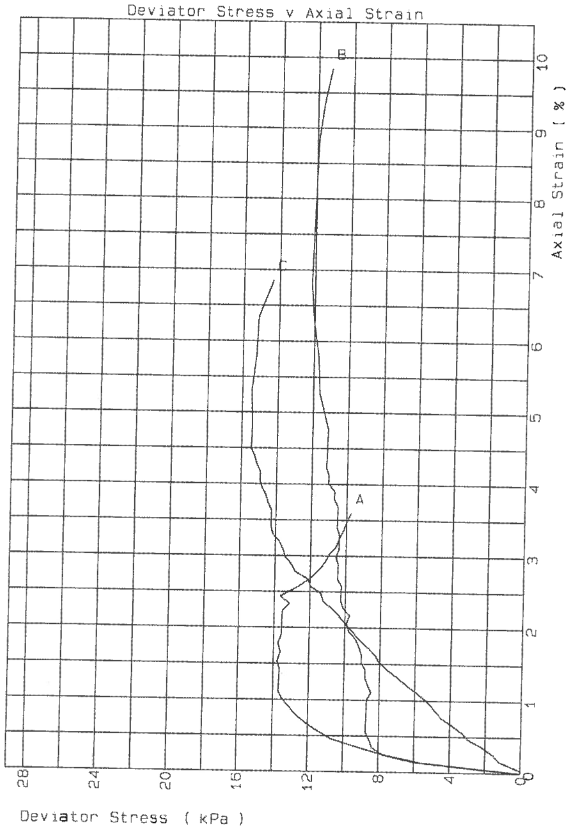
Ramboll

Job: SMOCS KOKKOLA

Sample: HS-19

Triaxial Undrained Shear

Deviator Stress v Axial Strain



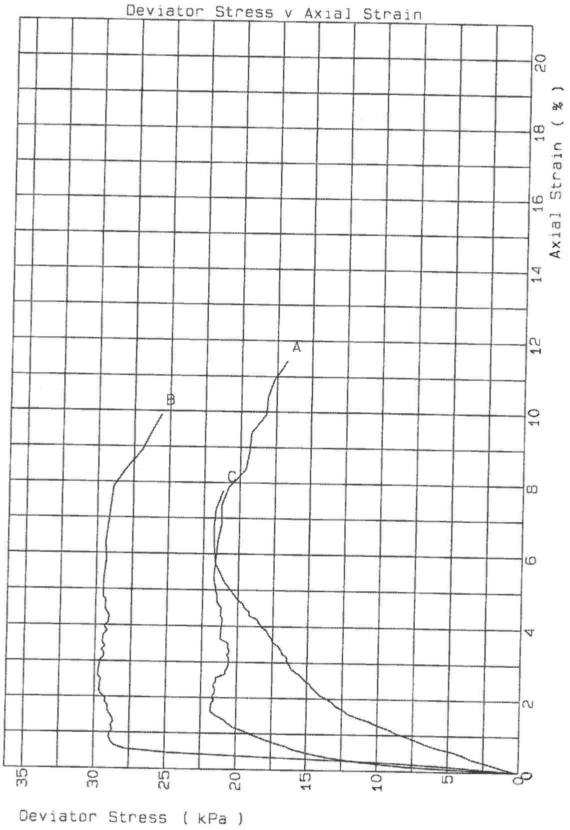
Ramboll

Job: SMOCS KOKKOLA

Sample: HS-20

Triaxial Undrained Shear

Deviator Stress v Axial Strain

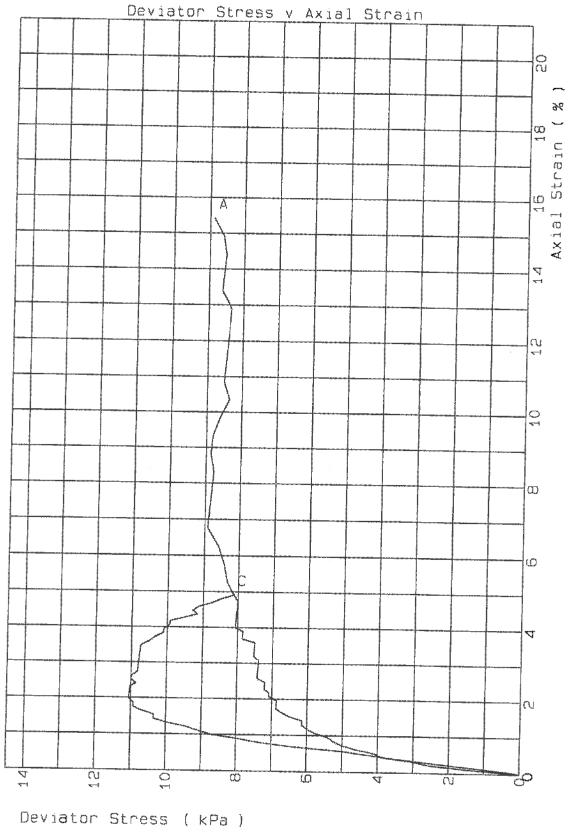


Ramboll

Job: SMOCS KOKKOLA

Triaxial Undrained Shear

Sample: HS-21

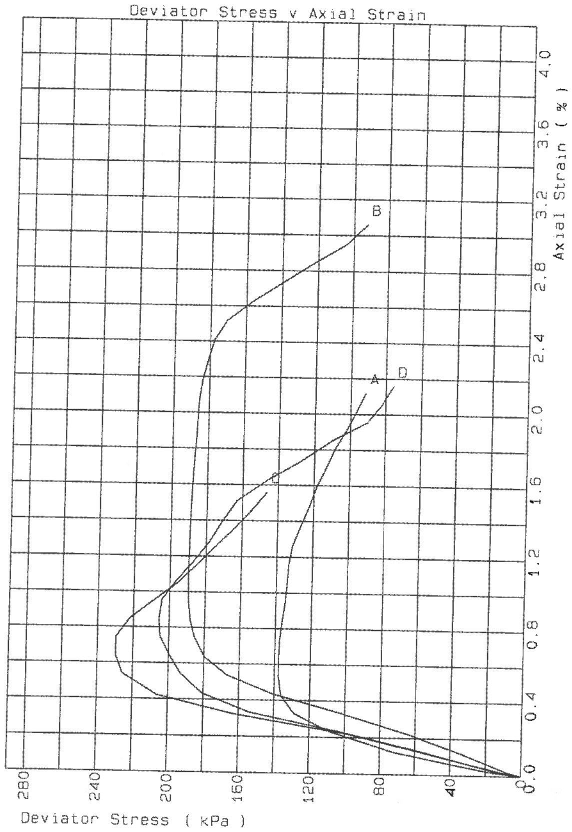


Ramboll

Job: SMOCS KOKKOLA

Triaxial Undrained Shear

Sample: HS-22

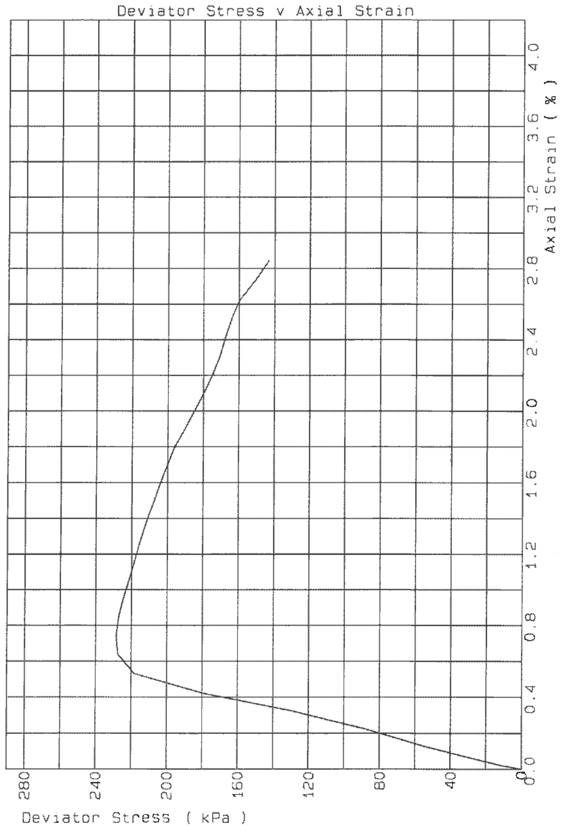


Ramboll

Job: SMOCS KOKKOLA

Triaxial Undrained Shear Inc.No. 1

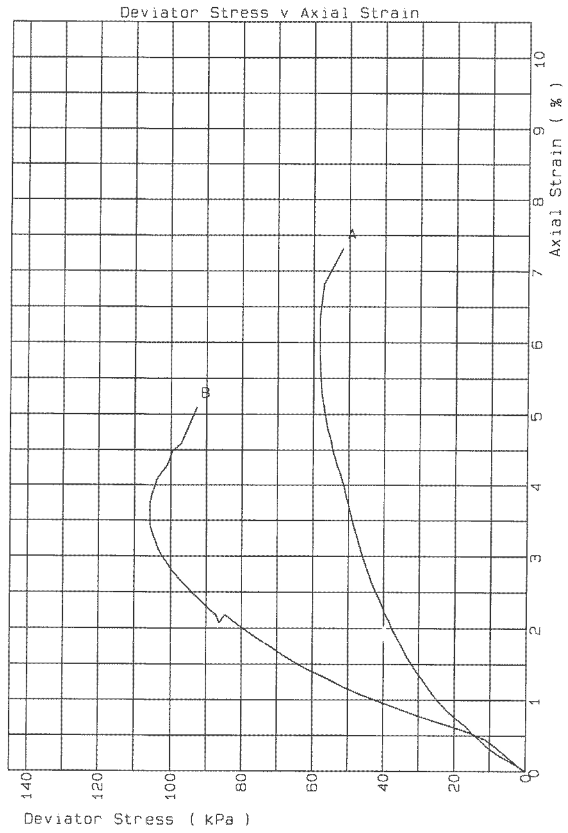
Sample: HS-24B/A



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

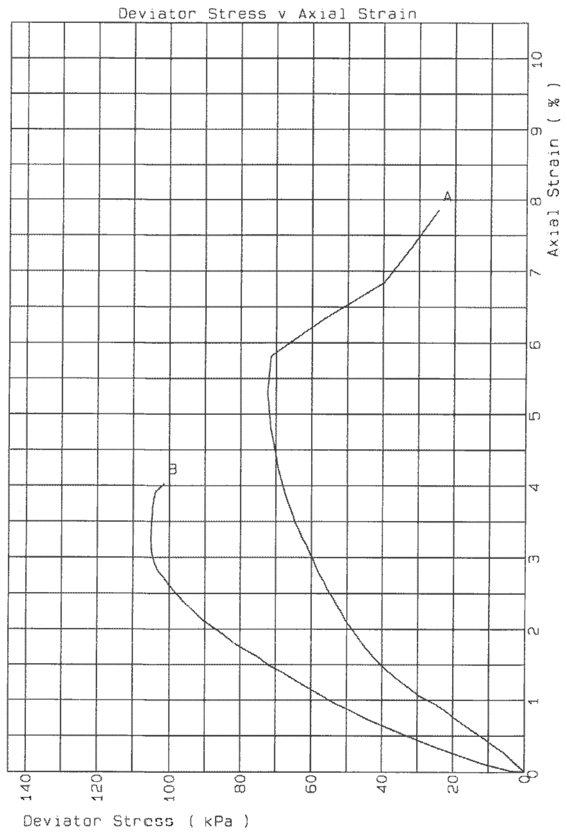
Sample: VV-4



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

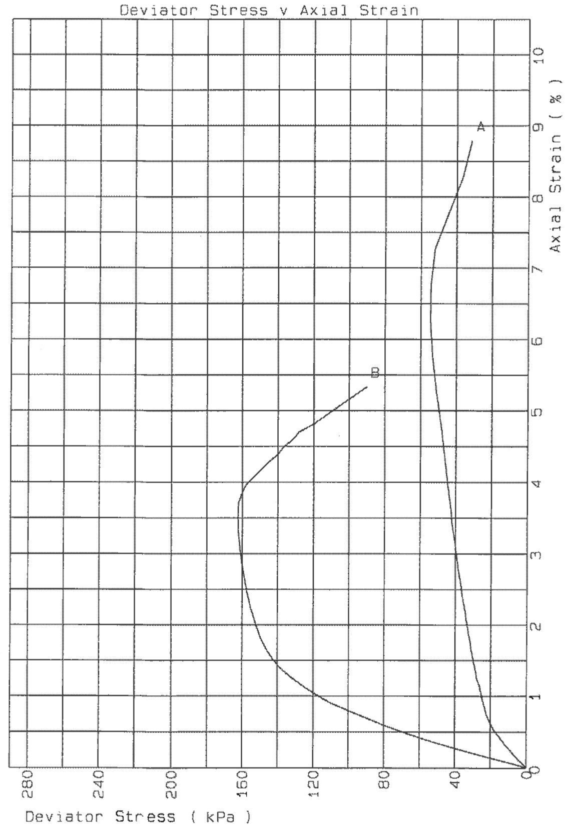
Sample: VV-3



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

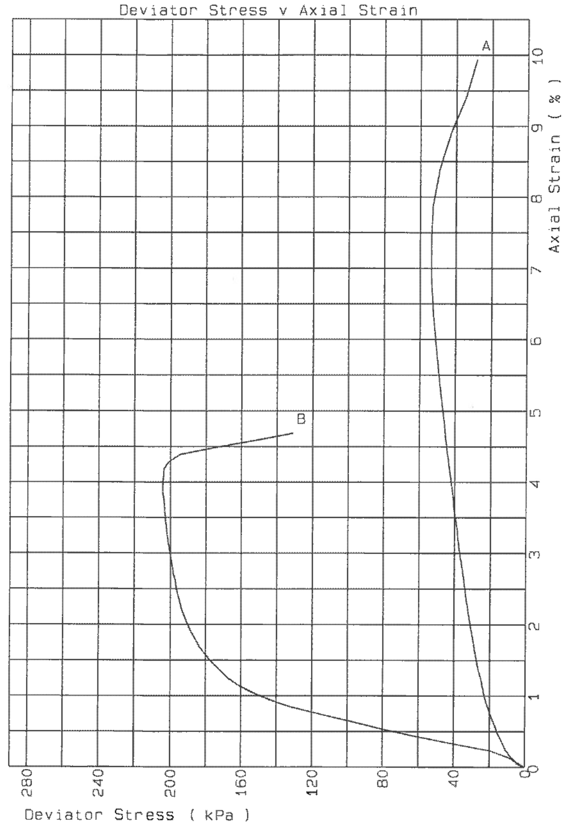
Sample: VV-2



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

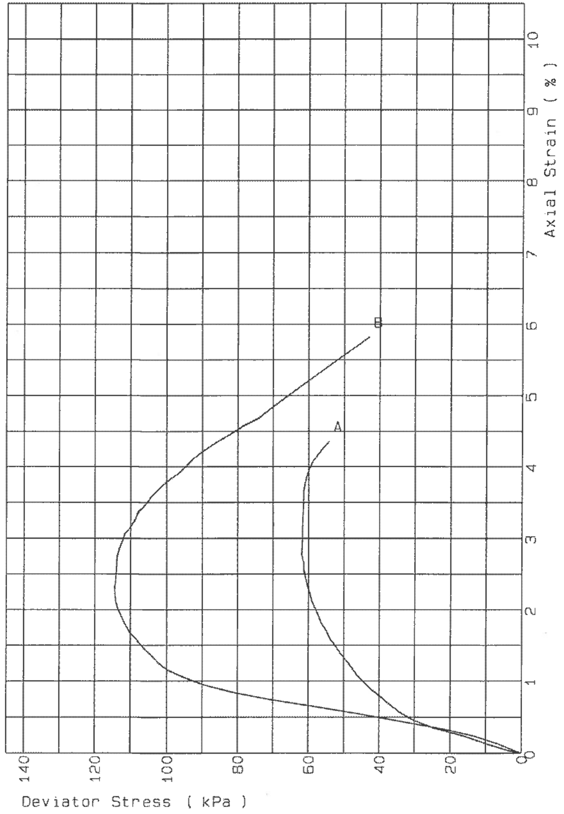
Sample: VV-1



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-7

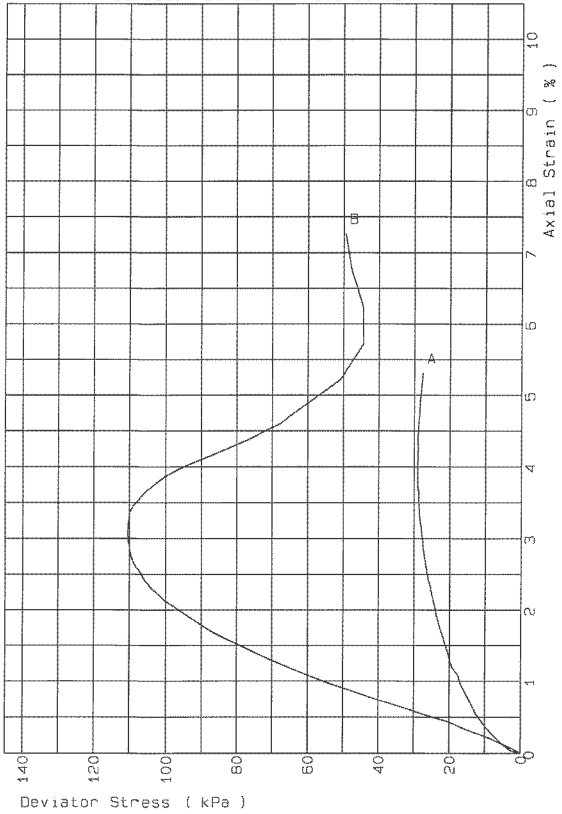
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-8

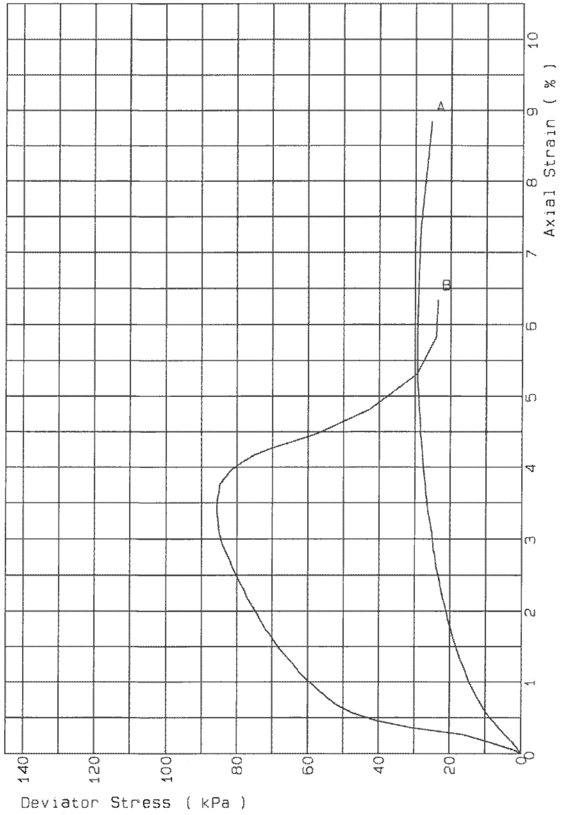
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-6

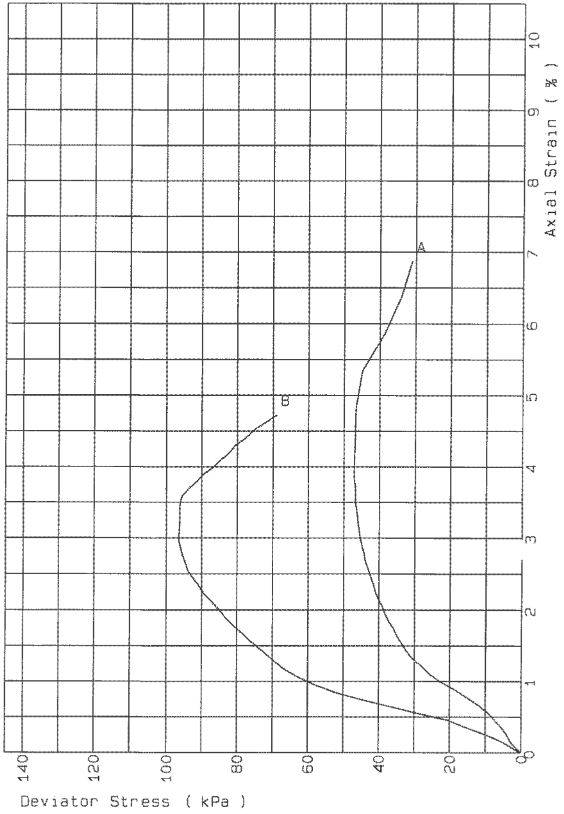
Deviator Stress v Axial Strain



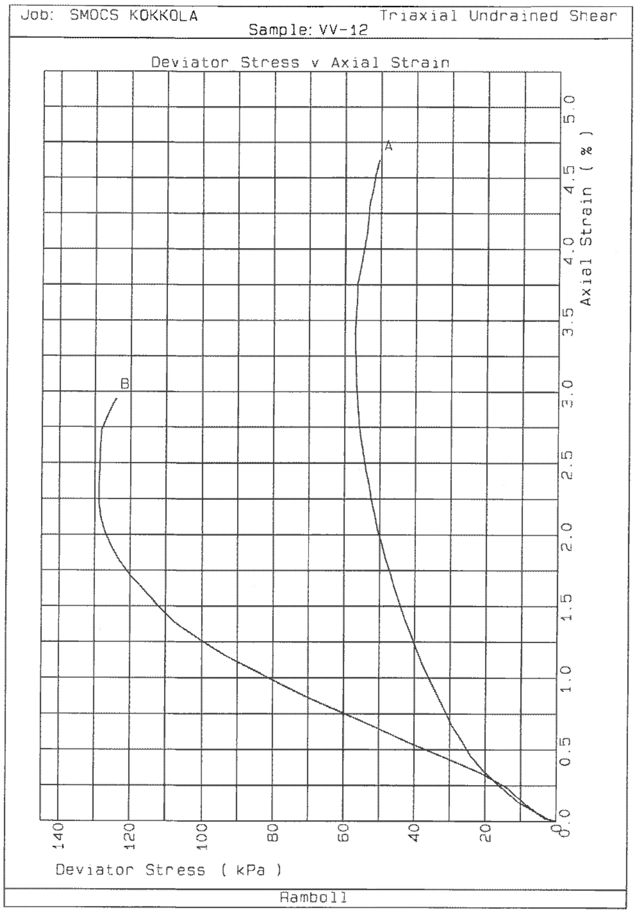
Ramboll

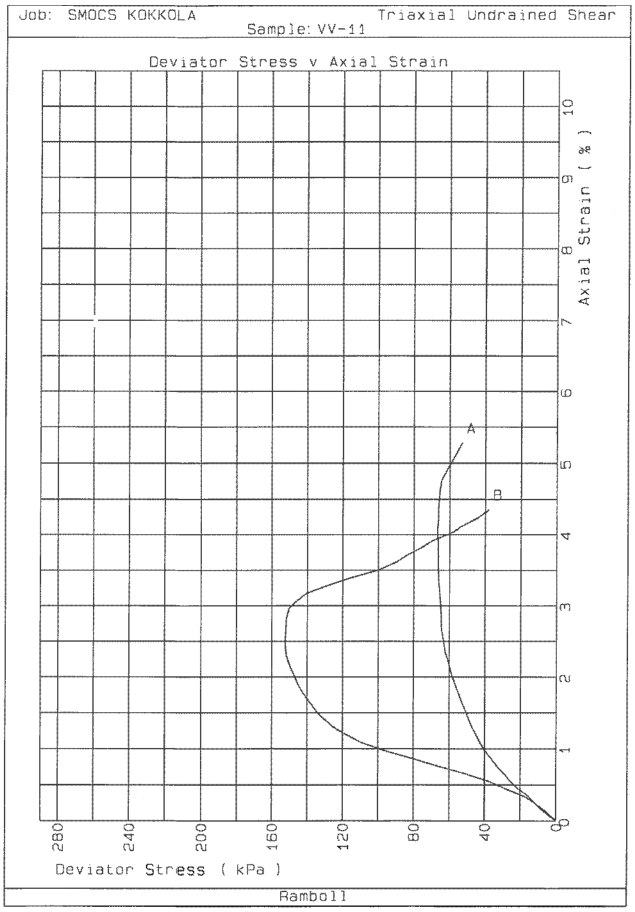
Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-5

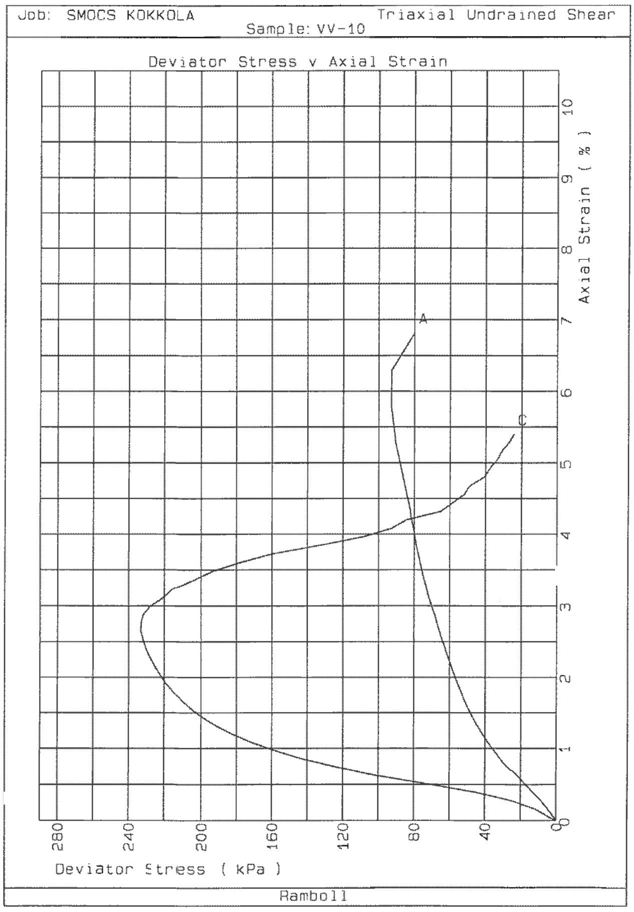
Deviator Stress v Axial Strain

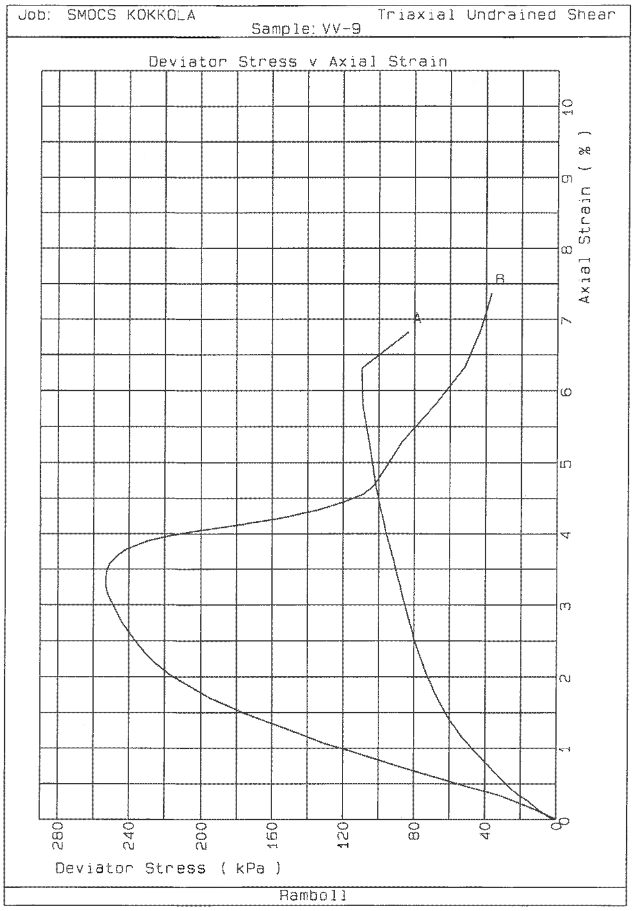


Ramboll

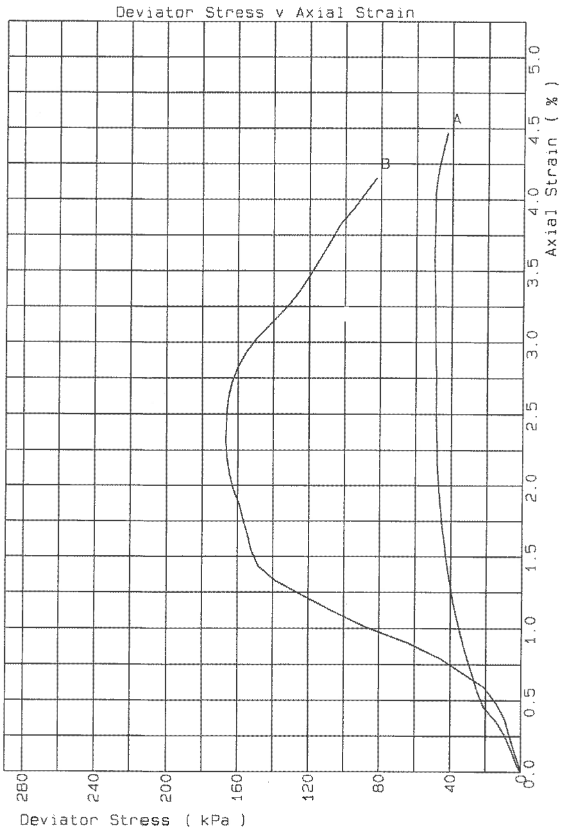

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: VV-12
Deviator Stress v Axial Strain
Axial Strain (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Deviator Stress (kPa)
0
20
40
60
80
100
120
140
A
B
Ramboll


Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: VV-11
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
40
80
120
160
200
240
280
A
B
Ramboll


Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: VV-10
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
40
80
120
160
200
240
280
A
C
Ramboll

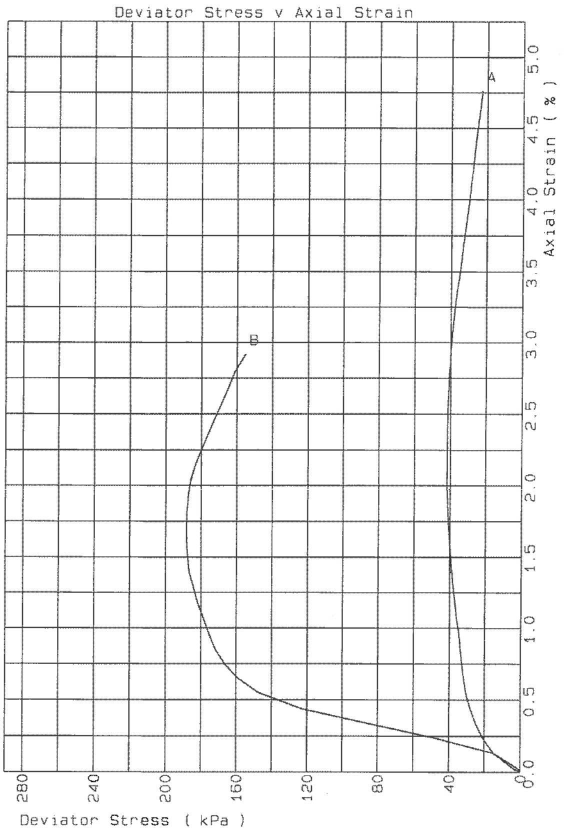

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: VV-9
Deviator Stress v Axial Strain
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10
Deviator Stress (kPa)
0
40
80
120
160
200
240
280
A
B
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-16



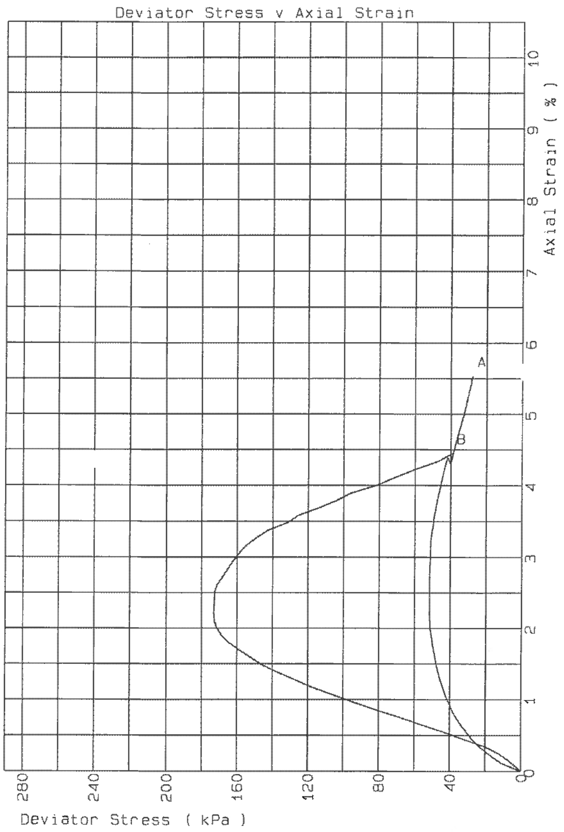
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-15



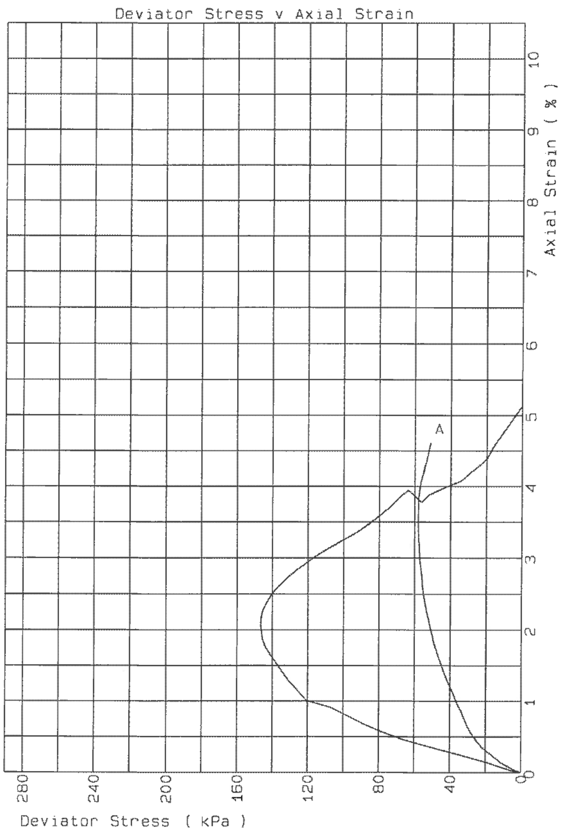
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-14



Ramboll

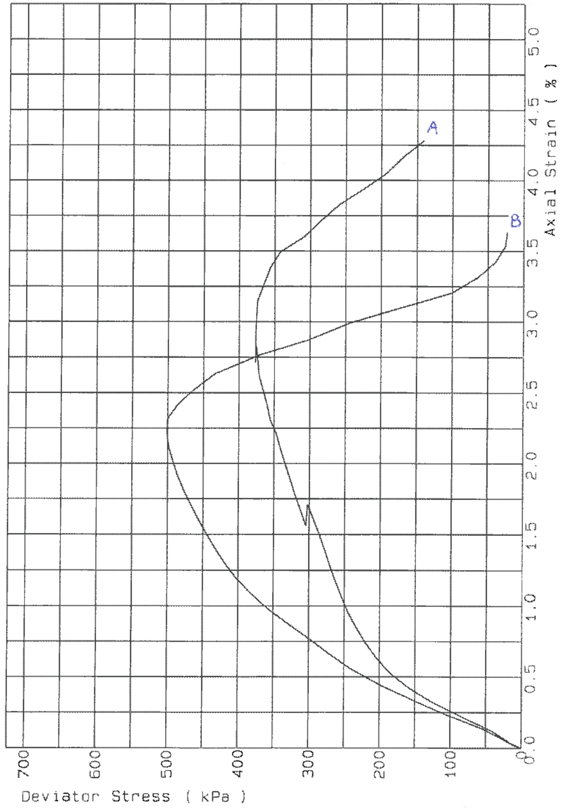
Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: VV-13



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-1

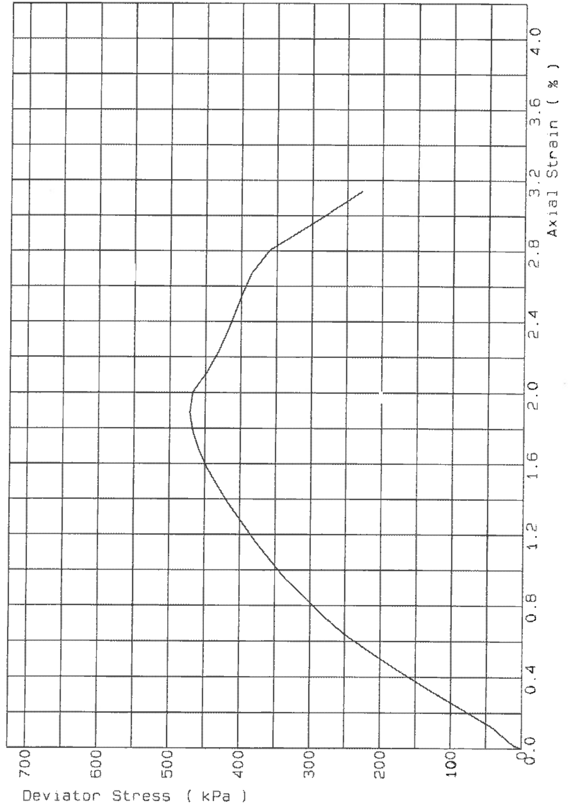
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-2/A

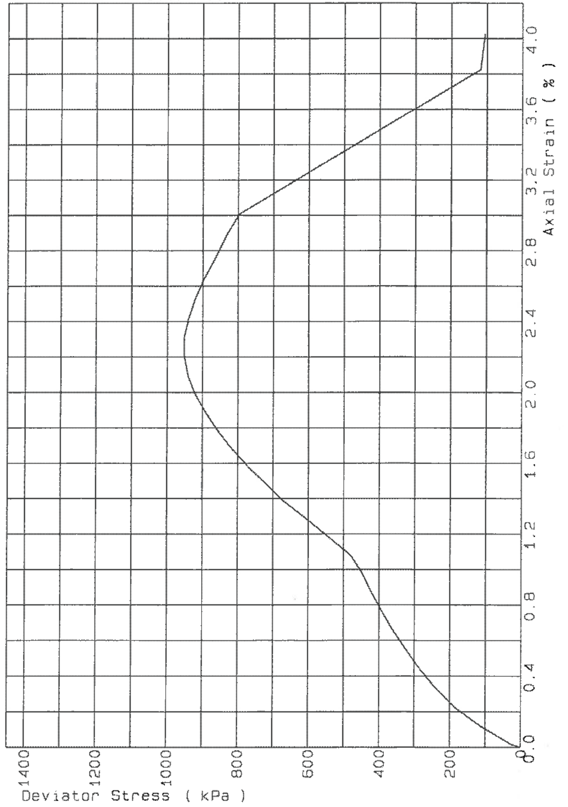
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-2/B

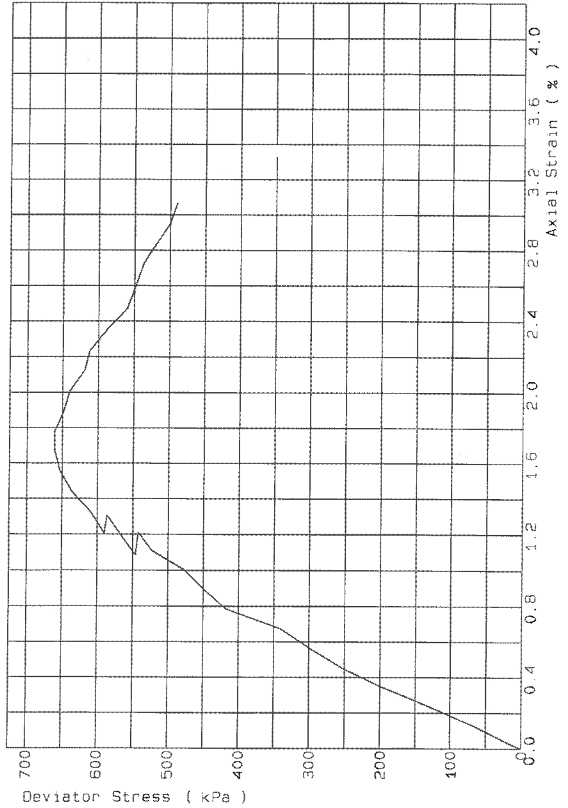
Deviator Stress v Axial Strain



Ramboll

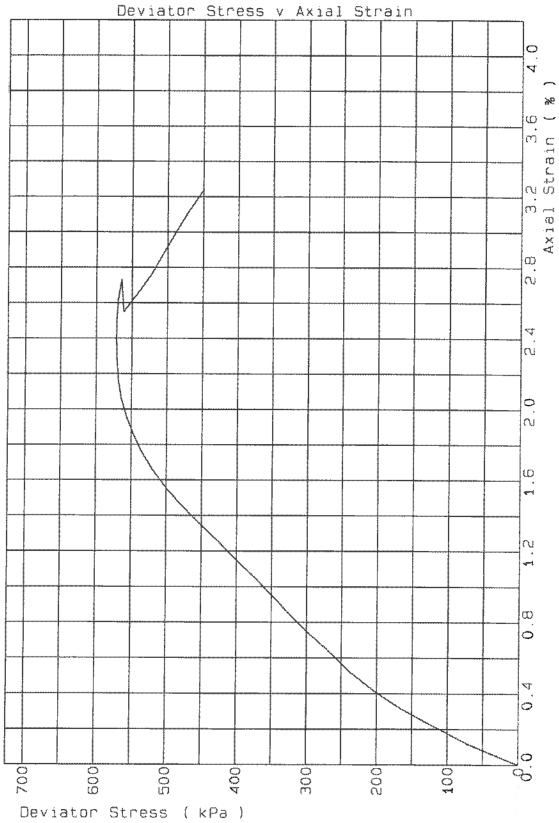
Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-3/A

Deviator Stress v Axial Strain



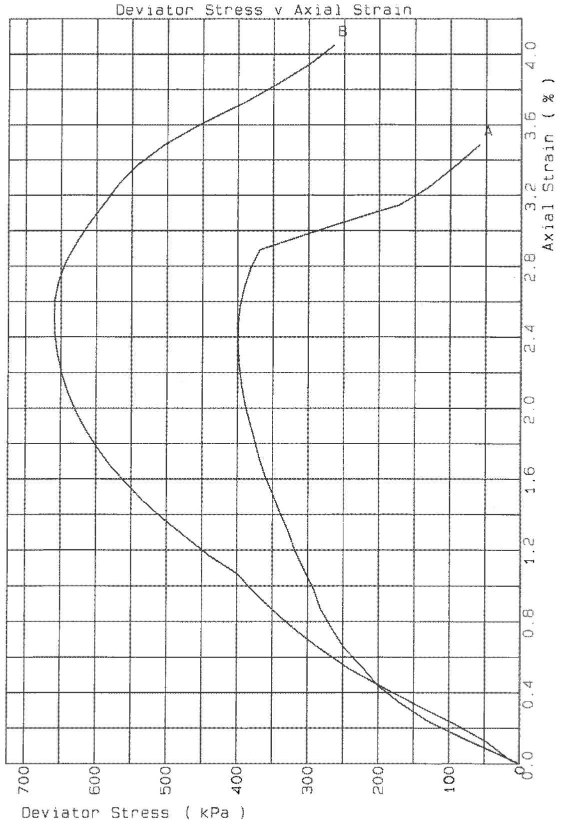
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-4/A



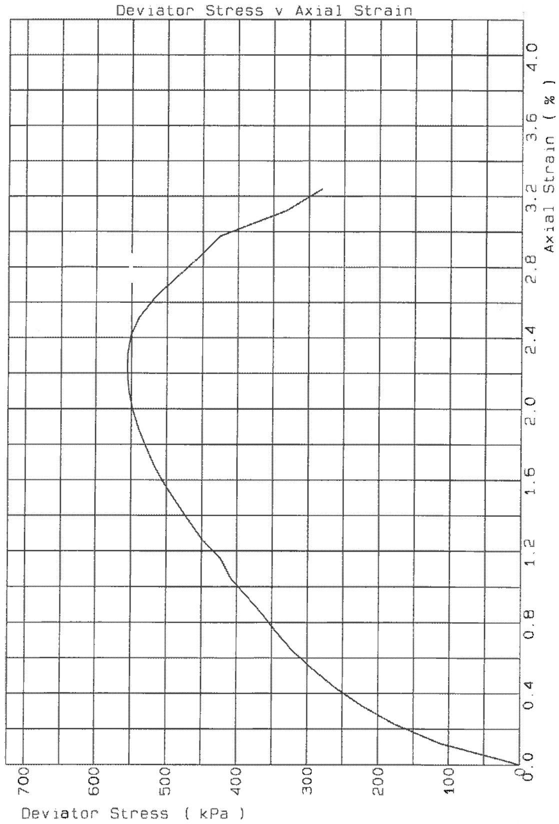
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-5



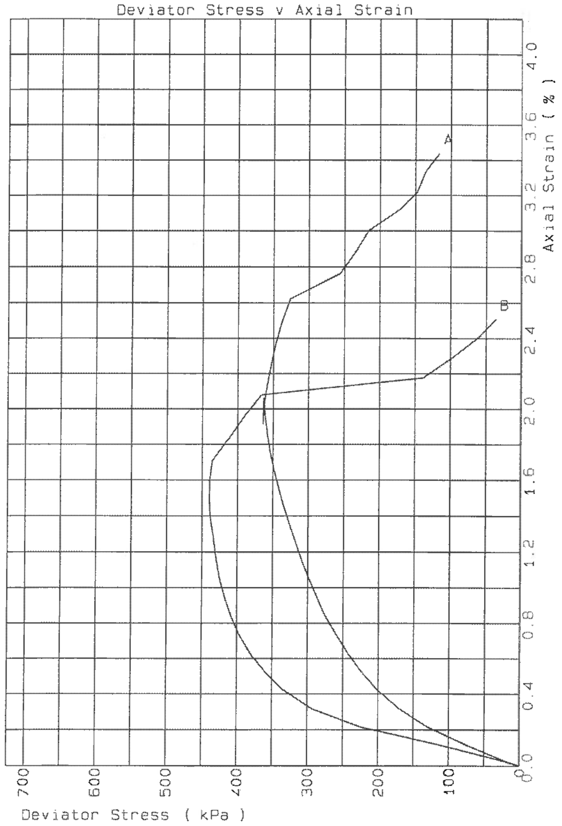
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-6/A



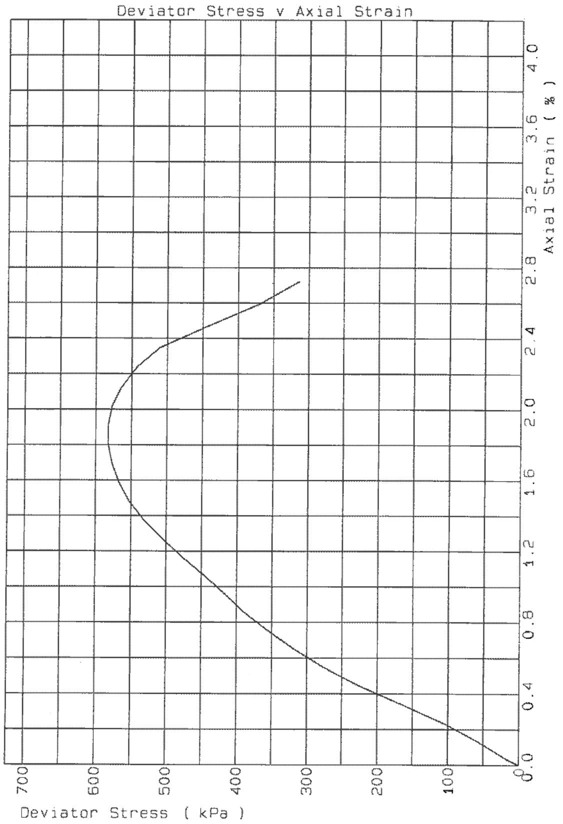
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-7



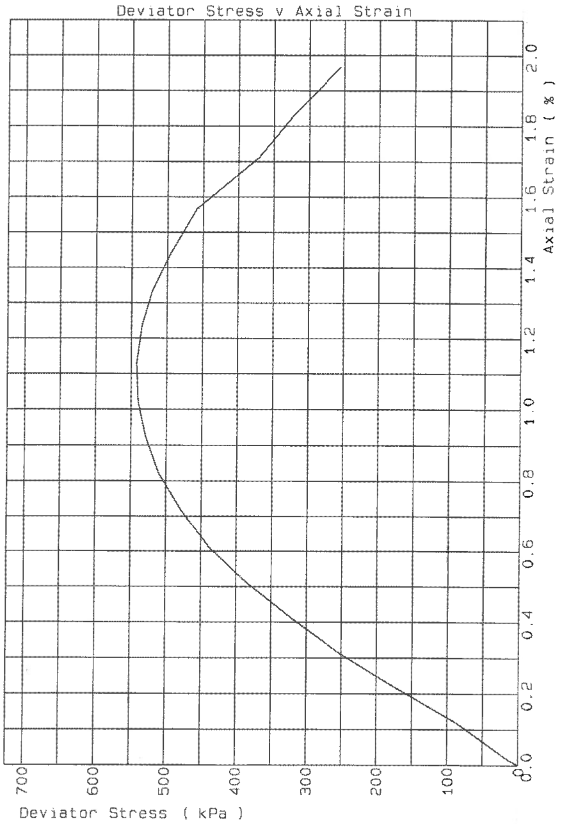
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-8/A



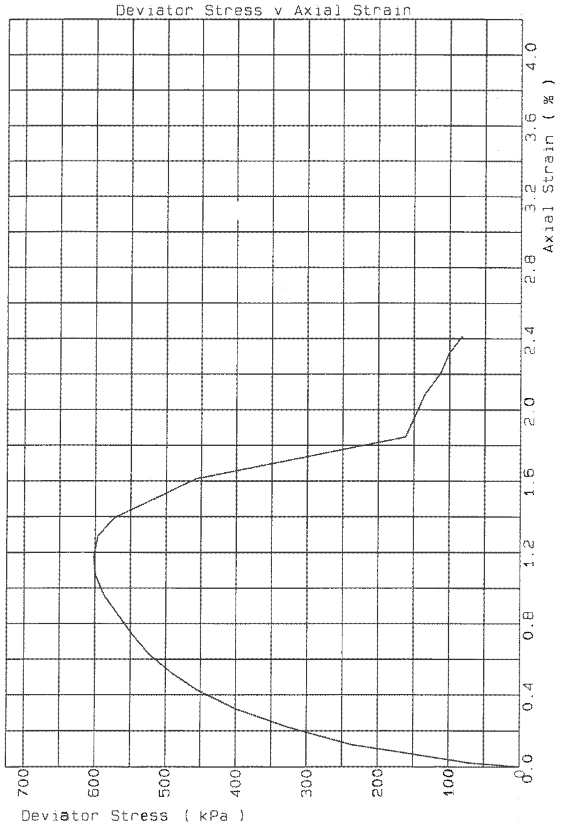
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-9/A



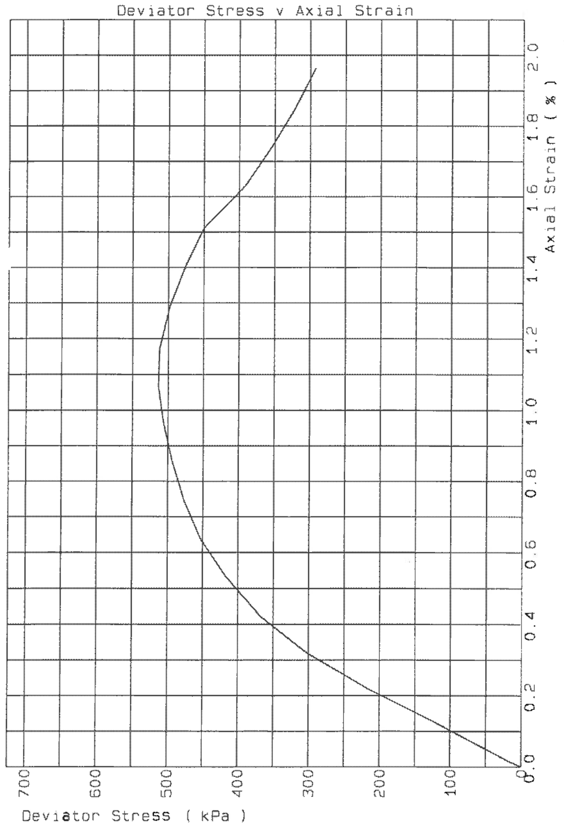
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-10/A



Ramboll

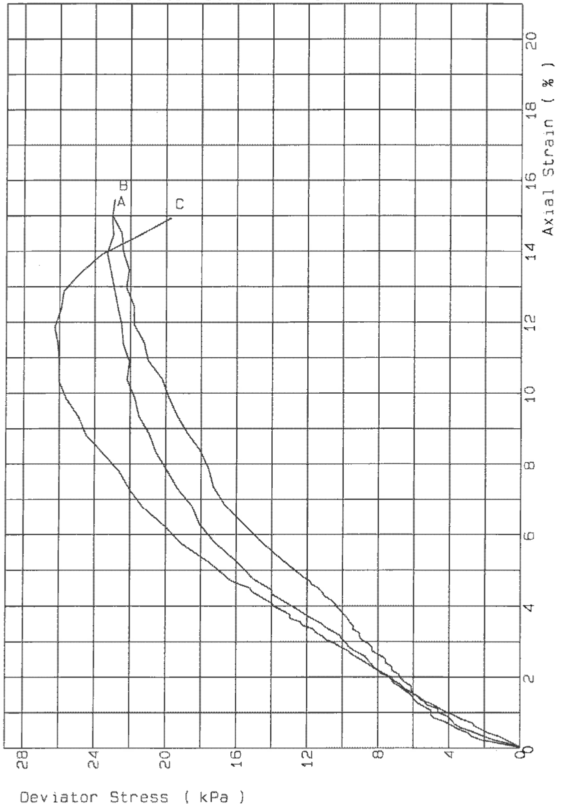
Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SVT-11/A



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SVT-12

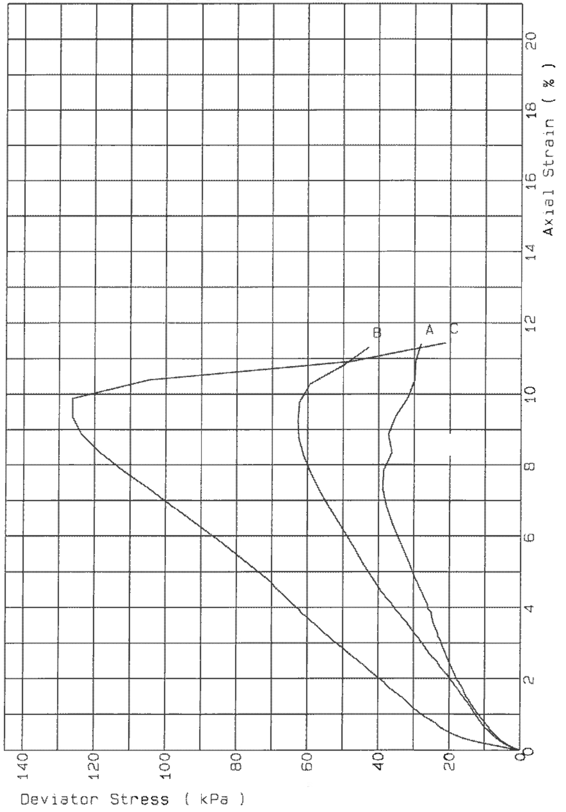
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SVT-13

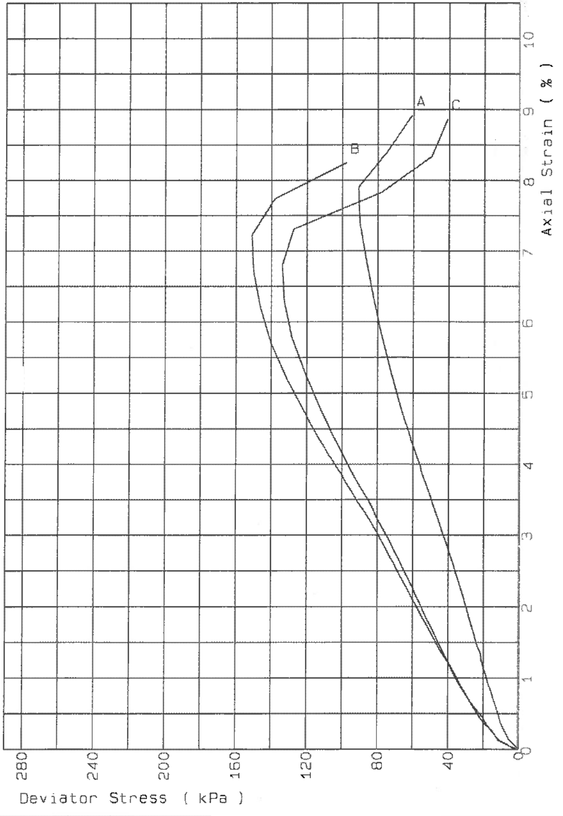
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SVT-14

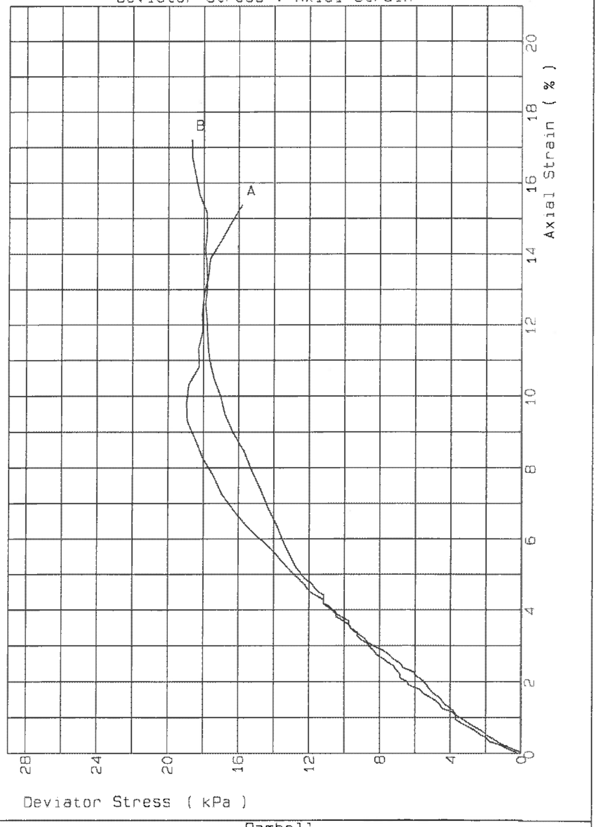
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Drained Shear
Sample: SVT-15

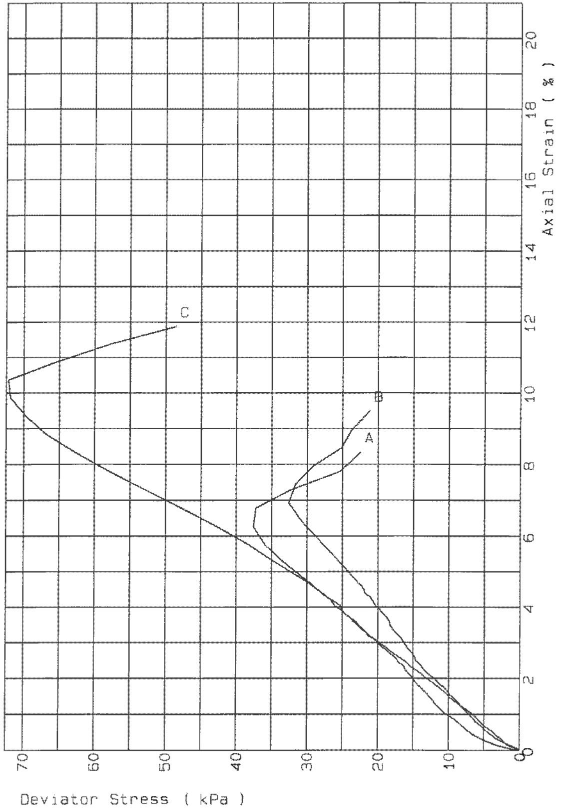
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-16

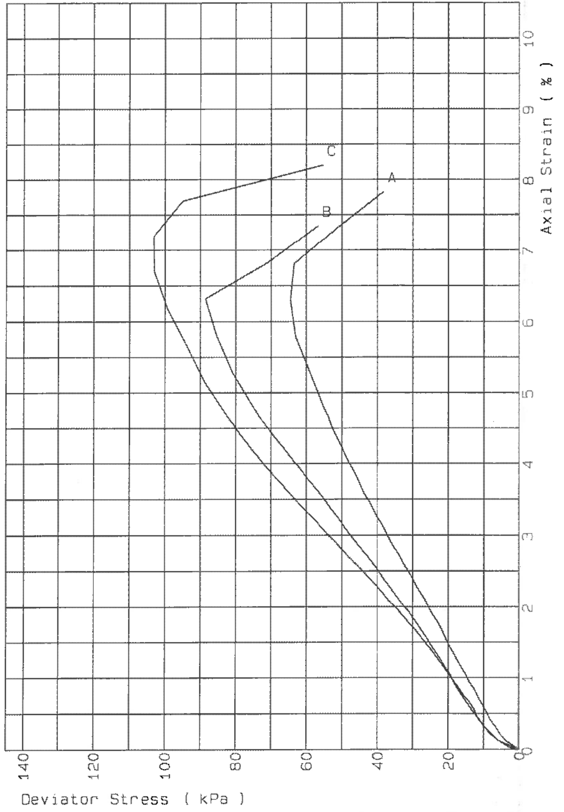
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-17

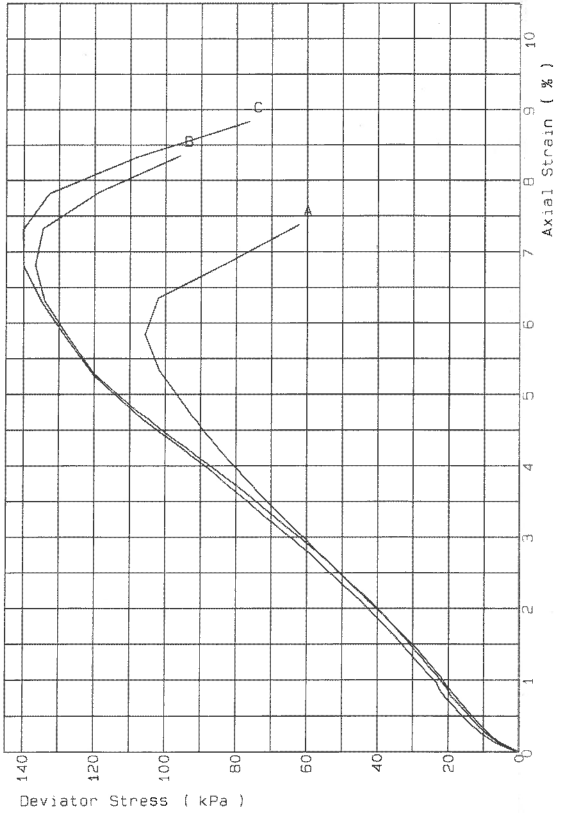
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-18

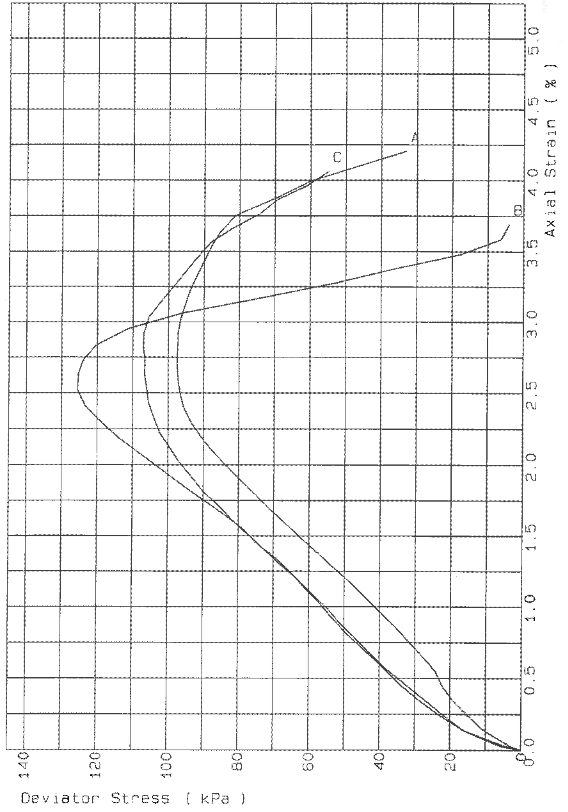
Deviator Stress v Axial Strain



Ramboll

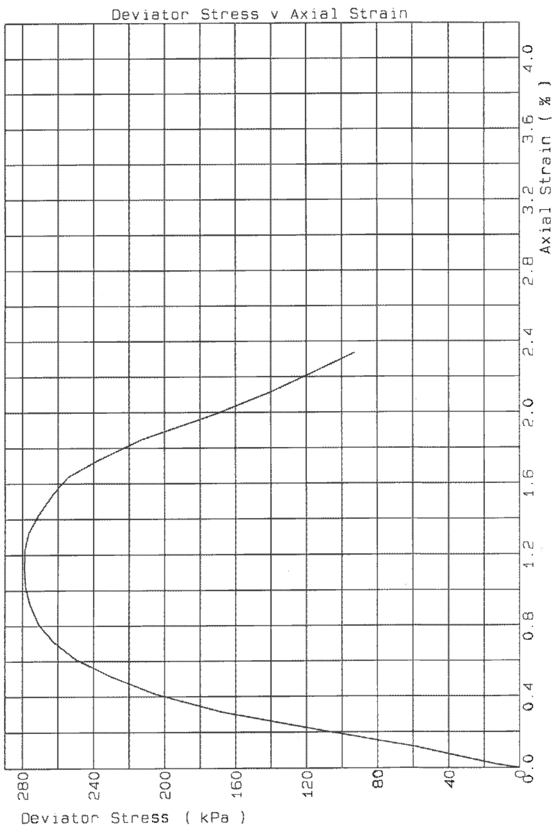
Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SVT-19

Deviator Stress v Axial Strain



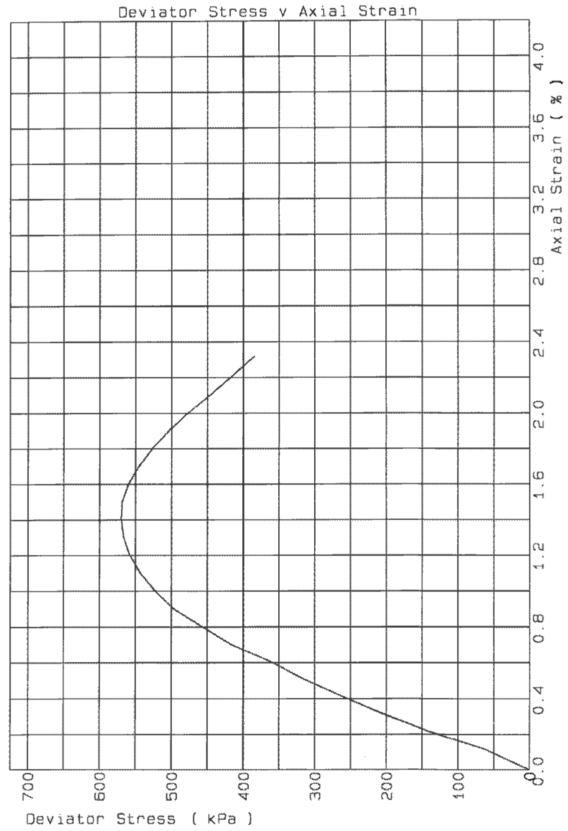
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SC-2/A



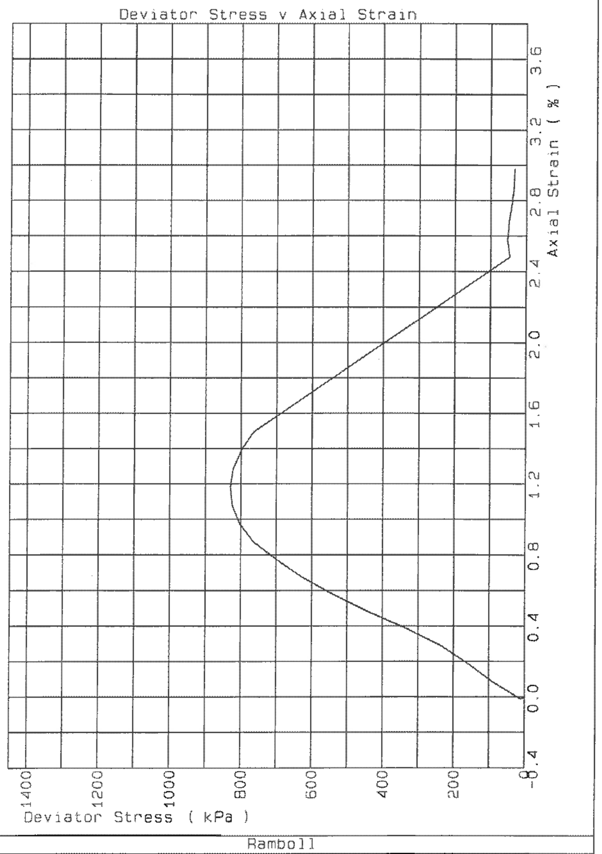
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SC-2/B



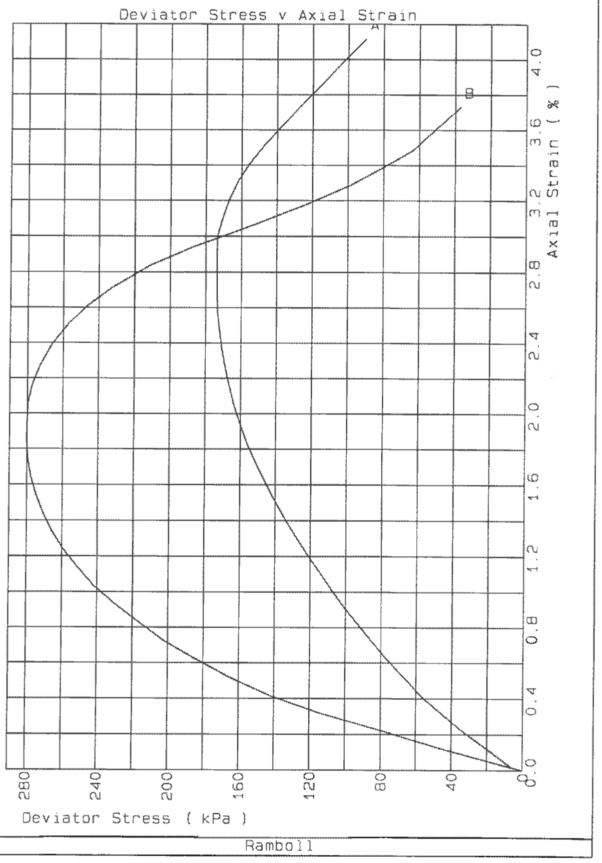
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear Inc.No. 1
Sample: SC-2c



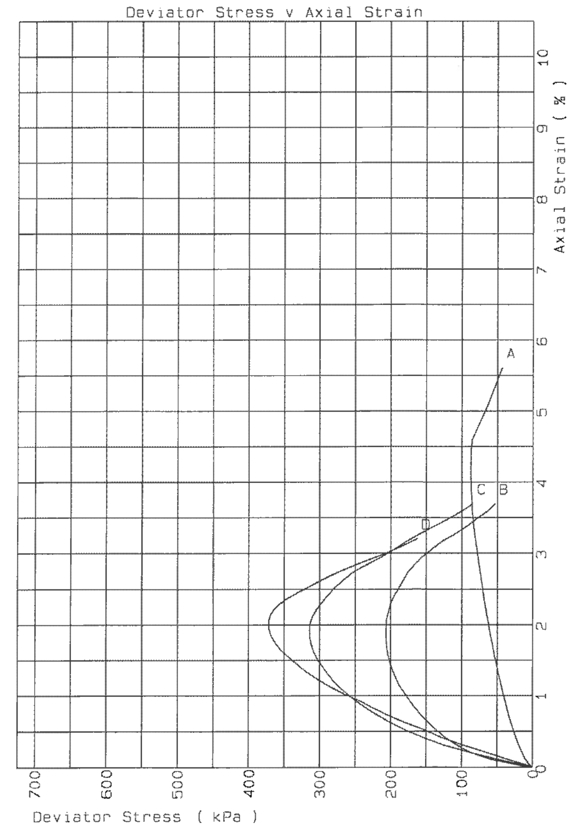
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SC-3



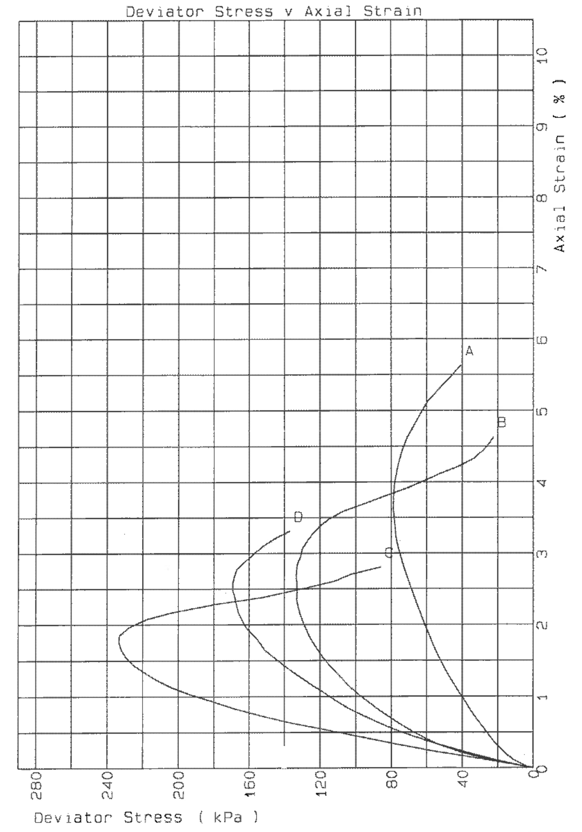
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SC-4



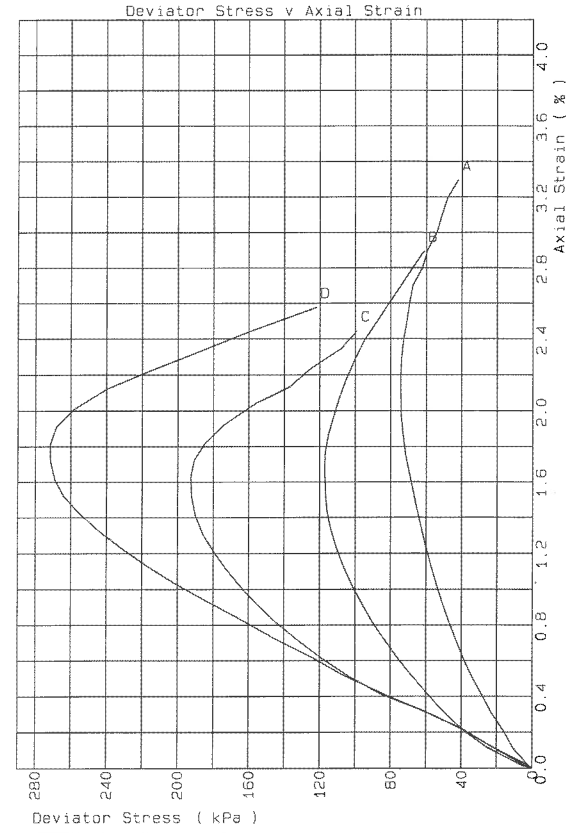
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SC-6



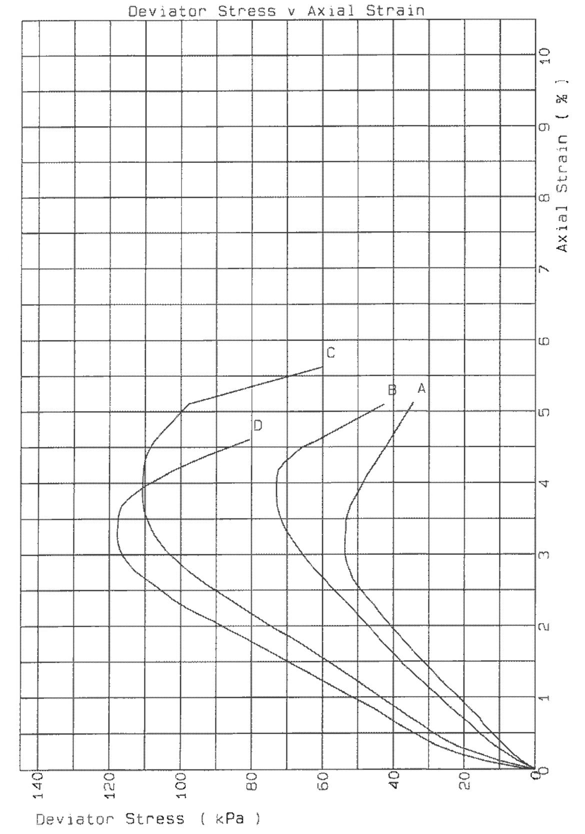
Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SC-7



Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear
Sample: SC-9

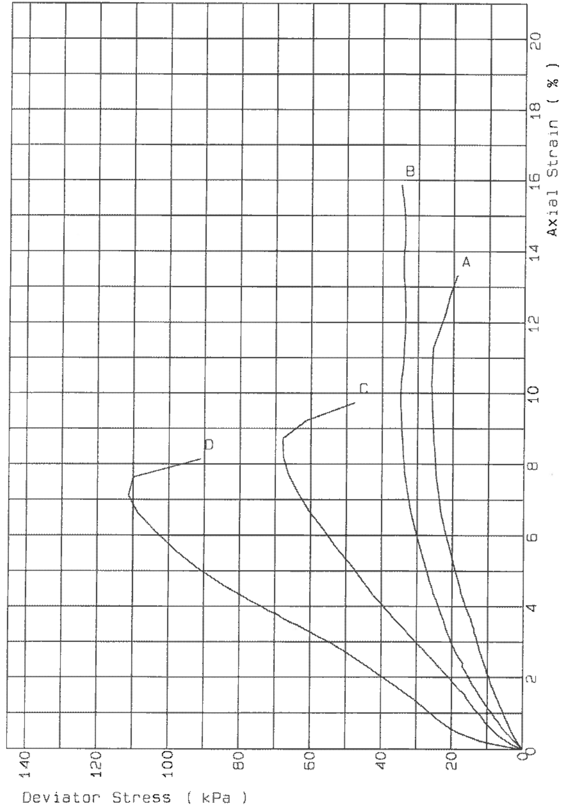


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: SC-11

Deviator Stress v Axial Strain

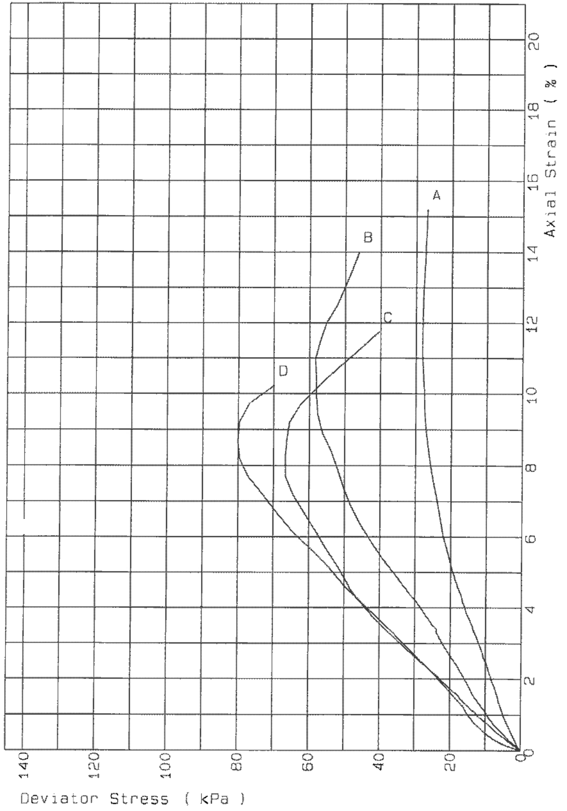


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: SC-13

Deviator Stress v Axial Strain

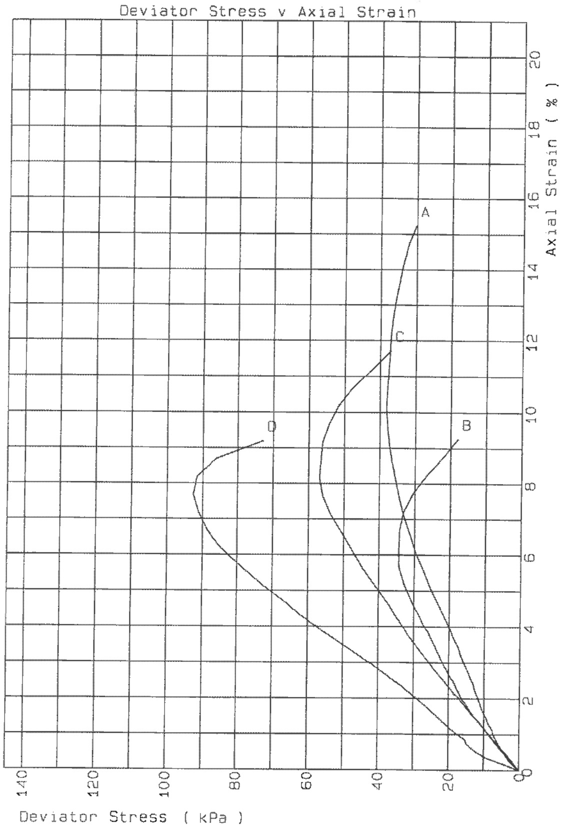


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: SC-15

Deviator Stress v Axial Strain

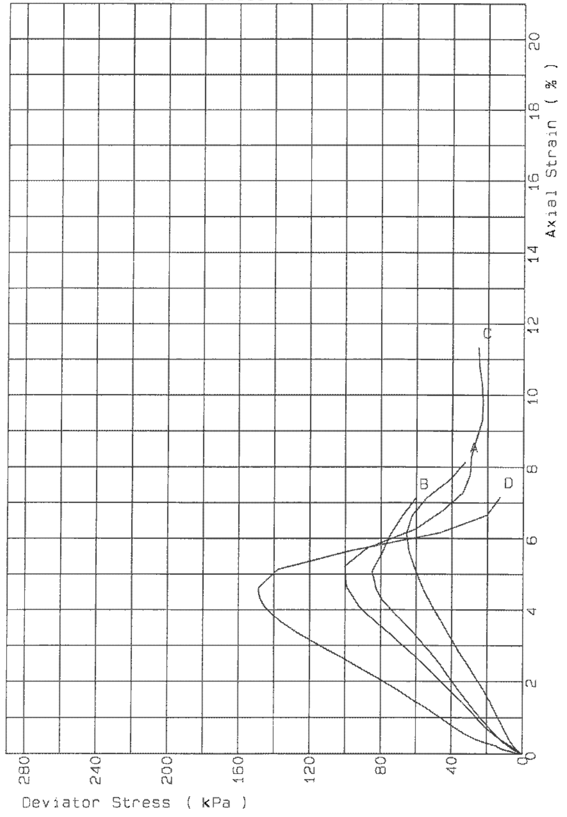


Ramboll

Job: SMOCS KOKKOLA Triaxial Undrained Shear

Sample: SC-17

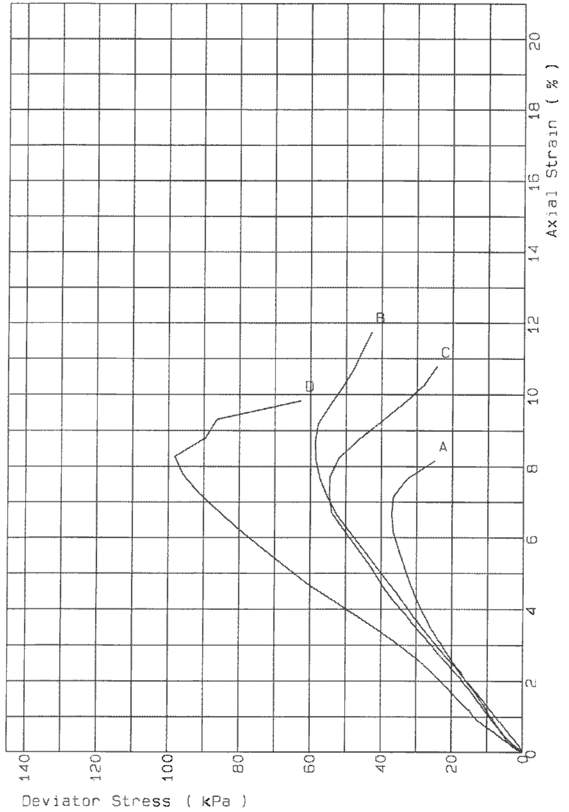
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SC-19

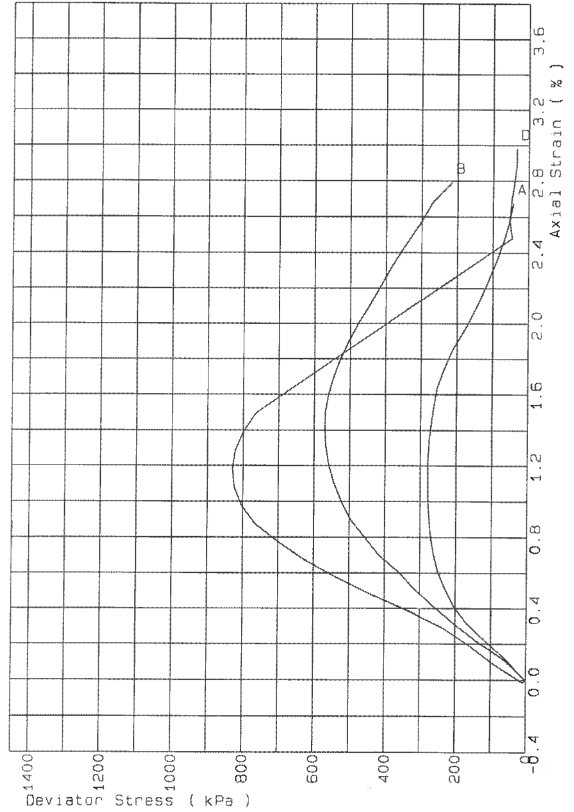
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SC-21

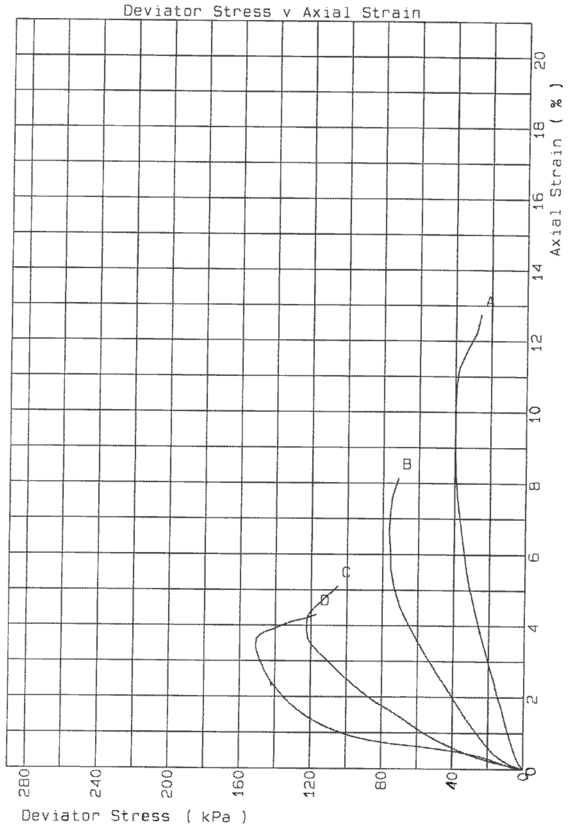
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SC-23

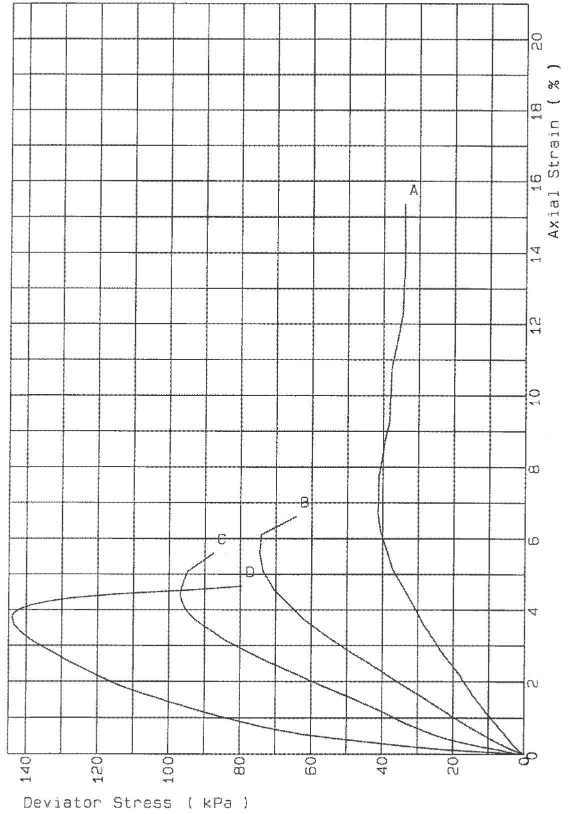
Deviator Stress v Axial Strain



Ramboll

Job: SMOCS KOKKOLA
Triaxial Undrained Shear
Sample: SC-25

Deviator Stress v Axial Strain



Ramboll

11.4 Turbidity monitoring results

Sampling point	Sampling depth (m)	28.6.2011			29.6.2011			12.7.2011			14.7.2011		
		Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)
P1	1,0										17,0	2,71	5,99
	5,0										17,2	2,07	5,10
	9,5										16,0	7,39	6,48
P2	1,0	16,0	0,00	4,13	16,0	0,74	6,47	16,0	1,08	7,16	17,2	1,60	6,15
	5,0	14,0	0,00	6,77	13,0	16,40	6,34	10,0	3,96	5,80	17,2	1,55	6,47
	9,5	10,0	0,00	6,58	11,0	47,90	5,31	14,7	2,61	6,75	11,0	6,51	5,13
P3	1,0	15,0	0,00	0,04	16,5	0,00	6,03	17,5	0,00	7,48	17,0	0,31	5,52
	5,5	14,0	0,00	7,01	12,0	0,00	6,86	9,5	0,00	6,95	17,0	0,00	6,87
	11,0	9,0	0,00	6,64	10,6	0,00	6,06	8,0	0,00	5,82	10,0	0,39	5,50
P4	1,0	15,0	0,00	0,05	14,0	1,75	5,99	17,6	0,00	6,95	17,2	0,00	6,68
	6,5	14,0	0,00	7,08	13,0	5,20	6,55	9,1	0,00	6,29	17,0	0,00	6,98
	13,0	9,2	0,00	6,35	13,0	5,41	5,93	7,2	0,00	5,87	9,5	0,00	6,19
P5	1,5	15,0	0,00	5,97	12,0	2,14	6,38	17,5	0,00	6,70	17,0	0,00	6,24
	4,0	16,2	0,00	6,13	10,0	4,55	6,24	11,0	0,00	6,90	17,0	0,00	6,28
P6	1,0	14,0	0,00	3,37				17,5	0,00	7,33	17,2	0,00	6,52
	4,0	14,0	0,00	6,36				13,0	0,00	5,94	17,5	0,00	6,77
	8,0	10,0	0,00	5,87				10,0	0,00	6,42	16,8	0,00	6,89
P7	1,0	16,0	0,00	0,04	15,0	0,00	6,81	17,5	0,00	7,36	17,0	0,00	6,92
	6,5	13,0	0,00	5,82	12,0	6,92	5,62	9,0	0,00	6,76	17,0	0,00	7,00
	13,5	8,0	0,00	5,45	10,0	7,15	5,01	7,2	0,00	5,90	17,0	0,00	6,14
P8	1,0	16,5	0,00	6,63	15,5	0,00	6,07	17,4	0,00	6,78	17,0	0,00	6,09
	7,0	13,0	0,00	6,50	11,0	0,00	5,61	8,5	0,00	6,57	16,2	0,00	6,98
	13,5	9,5	0,00	6,52	9,5	3,91	5,82	7,5	0,00	5,79	9,0	0,00	5,97
P9	1,0	15,5	0,00	6,10				16,0	0,00	6,42			
	5,0	14,0	0,00	5,80				10,0	0,00	6,06			
	10,0	9,0	0,00	5,39				7,5	0,00	5,97			
P10	1,0	16,0	0,00	5,66				17,4	0,00	6,45	17,0	0,00	6,50
	5,5	13,4	0,00	6,94				10,2	0,00	6,45	17,0	0,00	6,55
	10,0	9,5	0,00	6,36				7,8	0,00	5,61	16,5	0,00	6,46
P11	1,0	15,0	0,00	6,97				17,0	0,00	7,30			
	6,0	12,5	0,00	6,52				9,0	0,00	6,50			
	12,0	8,5	0,00	5,75				15,0	0,00	6,82			
P12	1,0	16,0	0,00	5,69				18,0	0,00	7,38	17,0	0,00	2,13
	6,0	12,0	0,00	5,77				10,0	0,00	6,93	16,5	0,00	6,48
	12,0	9,0	0,00	6,23				6,6	8,17	5,91	14,0	0,00	6,76
P13	1,0	16,5	0,00	0,04				18,0	0,00	7,14	17,0	0,00	5,95
	4,5	14,0	0,00	6,92				12,0	0,00	6,73	17,0	0,00	6,00
	9,0	10,0	0,00	5,13				8,0	0,00	6,06	16,0	0,00	5,45
P14	0,7		2,57	6,23					13,10	6,77		3,39	6,62
P15	0,7		2,39	6,30					1,68	5,16		4,55	6,61
P16	0,7		4,41	5,51					2,48	3,69		4,78	6,53
E	1,0							17,0	0,00	6,54			
	7,5							10,0	0,00	6,93			
	15,0							9,0	0,00	6,90			
D	1,0							17,0	0,00	7,02	16,6	0,00	7,19
	4,5							7,0	0,00	1,52	16,0	0,00	6,40
	9,0							7,0	0,00	5,29	9,0	0,00	5,93

Sampling point	Sampling depth (m)	15.7.2011			18.7.2011			20.7.2011			21.7.2011		
		Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)
P1	1,0	16,9	2,02	6,74	17,6	0,00	12,66	18,5	0,00	6,61	17,0	1,95	6,23
	5,0	16,5	1,28	4,28	17,5	0,00	12,55	17,0	0,91	4,49	16,3	1,58	6,16
	9,5	16,0	4,57	4,84	17,5	0,00	12,49	13,0	1,31	4,00	13,6	2,28	4,50
P2	1,0	17,0	1,53	5,64	18,0	0,00	12,60	18,5	0,00	5,90	17,7	0,00	6,54
	5,0	16,5	0,00	6,81	17,5	0,00	13,18	18,2	0,00	5,69	16,7	1,00	6,97
	9,5	11,0	4,06	4,55	16,5	2,22	12,58	12,7	0,83	5,64	13,6	0,00	5,66
P3	1,0	17,0	0,00	5,20	18,2	0,00	12,63	18,1	0,00	5,19	18,0	0,00	5,95
	5,5	16,5	0,00	6,82	17,5	0,00	13,44	16,5	4,40	5,02	16,4	2,24	4,88
	11,0	12,0	3,26	6,11	9,8	0,85	13,45	12,4	0,00	6,78	13,3	0,00	4,66
P4	1,0	17,0	0,00	5,09	18,0	0,00	12,56	18,0	0,00	6,08	18,0	0,00	5,39
	6,5	16,7	0,00	5,14	16,7	0,00	13,01	14,0	1,49	5,35	15,1	0,00	4,89
	13,0	9,2	0,00	6,20	9,7	0,00	12,63	11,8	0,00	5,19	12,8	0,00	6,81
P5	1,5	17,0	0,00	6,24	18,0	0,00	12,44	18,0	0,00	6,90	17,7	0,00	5,75
	4,0	16,5	0,00	5,79	17,7	0,00	12,28	17,5	0,00	6,90	16,5	0,00	5,17
P6	1,0	17,0	0,00	6,08	18,2	0,00	12,49	17,6	0,00	6,22	18,3	0,00	5,76
	4,0	16,6	0,00	6,96	18,0	0,00	12,79	17,0	0,00	6,04	16,7	0,00	5,84
	8,0	16,5	0,00	5,58	14,2	0,00	12,31	13,7	0,00	5,22	14,3	0,00	6,04
P7	1,0	16,8	0,00	4,45	18,0	0,00	12,61	17,7	0,00	4,68	18,2	0,00	6,27
	6,5	16,5	0,00	5,18	16,0	0,00	13,06	14,4	0,00	5,77	15,6	0,00	6,16
	13,5	10,1	0,00	6,54	9,0	0,00	12,76	12,2	0,00	5,28	12,5	0,00	6,52
P8	1,0	16,6	0,00	6,78	18,0	0,00	12,61	17,5	0,00	5,67	18,2	0,00	5,84
	7,0	16,5	0,00	5,94	16,5	0,00	13,27	14,5	0,00	5,25	16,0	0,00	4,46
	13,5	9,8	0,00	7,15	9,6	0,00	12,95	12,0	0,00	4,73	12,8	0,00	5,34
P9	1,0	17,2	0,00	5,05	18,2	0,00	12,29	17,4	0,00	6,00	18,5	0,00	4,44
	5,0	16,6	0,00	6,84	17,2	0,00	12,95	16,7	0,00	5,88	16,4	0,00	4,34
	10,0	12,2	0,00	5,65	10,0	0,00	12,31	12,5	0,00	5,26	13,9	0,00	5,05
P10	1,0	17,0	0,00	6,98	18,0	0,00	12,74	17,5	0,00	6,33	17,2	0,00	5,37
	5,5	16,5	0,00	6,39	17,5	0,00	13,19	17,2	0,00	6,32	16,4	0,00	4,53
	10,0	14,0	0,00	5,44	12,0	0,00	12,35	12,0	0,00	5,67	13,3	0,00	4,73
P11	1,0				17,7	0,00	12,66	17,1	0,00	5,76	18,1	0,00	7,00
	6,0				17,0	0,00	13,21	14,2	0,00	5,32	15,5	0,00	5,55
	12,0				11,2	0,00	13,63	11,2	0,00	4,95	11,2	0,00	4,66
P12	1,0				18,0	0,00	12,91	17,5	0,00	6,31	17,7	0,00	5,73
	6,0				17,0	0,00	13,55	12,7	0,00	5,48	16,4	0,00	5,54
	12,0				10,7	0,00	12,96	12,0	0,00	4,45	13,0	0,00	5,18
P13	1,0	17,4	0,00	5,86	18,0	0,00	12,81	17,6	0,00	5,15	18,0	0,00	6,22
	4,5	16,5	0,00	6,41	17,5	0,00	13,13	17,0	0,00	5,58	16,7	0,00	4,98
	9,0	15,0	0,00	6,40	13,0	0,00	12,49	12,5	0,00	4,61	13,3	0,00	4,63
P14	0,7		1,93	6,55		9,63	13,52		2,61	6,33		3,88	6,64
P15	0,7		3,31	6,61		2,86	12,34		2,52	3,60		2,29	6,68
P16	0,7		5,35	5,69		1,83	12,64		8,99	5,01		2,38	6,59
E	1,0				17,0	0,00	14,16	16,7	0,00	5,00	17,5	0,00	5,17
	7,5				16,0	0,00	14,58	15,8	0,00	6,67	15,0	0,00	6,48
	15,0				9,5	0,00	13,34	9,2	0,00	5,42	9,5	0,00	4,87
D	1,0				18,2	0,00	12,31	17,5	0,00	5,11	18,3	0,00	5,82
	4,5				17,2	0,00	12,51	16,6	0,00	5,36	16,2	0,00	6,58
	9,0				13,0	0,00	12,03	13,0	0,00	5,50	14,3	0,00	5,16

Sampling point	Sampling depth (m)	25.7.2011			27.7.2011			29.7.2011			1.8.2011		
		Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)
P1	1,0	18,3	0,00	5,04	17,4	0,00	6,31	19,0	0,00	6,74	17,7	2,32	5,90
	5,0	16,2	0,00	4,98	16,8	0,00	6,59	18,5	0,00	6,51	14,6	5,81	5,71
	9,5	11,2	0,00	5,67	13,0	12,30	5,26	17,5	14,80	5,66	9,2	0,85	5,35
P2	1,0	18,3	0,00	5,77	17,5	0,00	5,57	19,9	0,00	7,05	17,6	1,60	5,75
	5,0	16,8	0,00	5,70	16,7	0,29	6,44	18,8	0,00	6,82	14,2	4,21	5,84
	9,5	11,2	3,47	4,63	12,6	6,11	5,64	16,5	2,82	6,51	9,4	0,00	5,81
P3	1,0	18,2	0,00	5,79	17,5	0,00	6,94	19,0	0,00	5,65	18,0	5,49	5,86
	5,5	12,7	6,00	6,24	16,4	9,11	5,13	18,8	0,00	6,94	12,3	33,90	6,10
	11,0	10,0	0,00	5,17	13,0	30,00	6,12	15,5	16,10	5,92	9,0	1,75	6,48
P4	1,0	18,4	0,00	5,96	17,7	0,00	4,97	19,0	0,00	5,83	18,2	0,00	6,20
	6,5	11,0	0,00	5,64	15,2	7,62	4,85	18,3	0,00	6,23	10,6	1,65	5,92
	13,0	9,7	0,00	6,98	13,0	1,80	5,11	12,5	20,70	5,81	8,6	0,00	7,07
P5	1,5	18,4	0,00	5,63	18,0	0,00	6,31	19,2	15,70	6,82	18,4	0,00	6,00
	4,0	13,9	0,00	4,82	16,3	0,66	5,93	19,0	0,00	6,62	16,2	1,21	5,73
P6	1,0	18,4	0,00	5,19	18,0	0,00	6,50	19,0	0,00	6,78	18,2	0,00	6,23
	4,0	16,6	0,00	5,12	17,0	0,00	6,08	19,0	0,00	6,87	16,2	0,00	5,74
	8,0	11,0	0,00	4,51	14,0	0,00	6,13	18,0	0,00	6,51	10,0	0,00	5,60
P7	1,0	18,2	0,00	5,87	17,4	0,00	6,76	19,0	0,00	6,69	18,2	0,00	6,80
	6,5	12,0	0,00	6,03	14,0	0,00	5,24	18,2	0,00	6,82	10,1	1,77	5,43
	13,5	9,5	0,00	5,58	12,8	1,27	6,55	17,5	0,00	6,90	8,7	0,00	5,44
P8	1,0	18,0	0,00	6,44	17,2	0,00	5,59	18,8	0,00	6,78	18,2	0,00	6,53
	7,0	13,0	0,00	6,42	14,3	1,23	5,08	18,0	0,00	7,11	11,2	0,00	5,50
	13,5	9,5	0,00	5,51	9,5	0,00	4,75	10,0	0,00	5,94	9,2	0,00	5,42
P9	1,0	17,5	0,00	5,41	18,0	0,00	6,94						
	5,0	14,6	0,00	5,77	16,2	0,00	5,94						
	10,0	9,8	0,00	5,16	11,6	0,00	5,51						
P10	1,0	18,0	0,00	5,20	17,0	0,00	6,78				18,3	0,00	5,93
	5,5	15,5	0,00	5,47	15,5	0,00	6,02				12,2	0,00	6,97
	10,0	10,2	0,00	4,51	12,0	0,00	6,06				9,5	0,00	5,08
P11	1,0	17,4	0,00	5,81	17,7	0,00	6,62						
	6,0	14,6	0,00	5,22	14,2	0,00	5,55						
	12,0	9,5	0,00	5,26	11,0	0,00	5,11						
P12	1,0	17,8	0,00	6,07	17,5	0,00	5,10						
	6,0	13,6	0,00	5,04	16,9	0,00	5,56						
	12,0	9,2	0,00	4,91	12,2	0,00	5,16						
P13	1,0	18,3	0,00	5,23	17,8	0,00	6,85						
	4,5	17,9	0,00	5,29	15,3	0,00	5,49						
	9,0	11,2	0,00	6,39	13,4	0,00	5,31						
P14	0,7		5,40	6,56		0,53	5,80		4,43	5,21		3,37	6,78
P15	0,7		1,07	6,42		0,00	3,71		1,45	4,51		4,30	5,17
P16	0,7		16,01	5,08		1,31	5,09		6,41	6,60		5,90	2,34
E	1,0	15,0	0,00	5,02	18,8	0,00	5,94						
	7,5	12,3	0,00	4,84	13,8	0,00	5,74						
	15,0	9,0	0,00	4,44	9,2	0,00	4,85						
D	1,0	17,0	0,00	6,07	18,5	0,00	5,25						
	4,5	15,0	0,00	5,03	16,6	0,00	5,04						
	9,0	10,2	0,00	5,28	13,2	0,00	4,19						

Sampling point	Sampling depth (m)	3.8.2011			5.8.2011			9.8.2011		
		Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)	Temperature (°C)	Turbidity (NTU)	Electric conductivity (mS/cm)
P1	1,0	18,0	0,00	6,61	13,0	0,00	6,84	12,4	0,00	6,29
	5,0	17,0	0,00	6,19	12,6	0,00	6,71	11,3	0,00	6,56
	9,5	8,9	2,22	5,24	10,2	5,40	6,30	8,0	0,00	5,85
P2	1,0	18,0	0,00	6,44	15,0	0,00	7,14	12,4	0,00	6,38
	5,0	17,1	0,00	6,89	13,4	0,00	6,87	11,0	0,00	6,42
	9,5	7,2	0,00	5,23	10,0	3,48	6,47	7,8	0,00	6,06
P3	1,0	18,1	0,00	6,92	14,2	0,00	6,91	12,2	0,00	5,67
	5,5	10,4	15,80	6,60	13,0	13,50	6,93	10,0	0,00	6,79
	11,0	7,5	8,80	5,74	9,8	0,90	6,33	7,7	0,00	6,28
P4	1,0	18,0	0,00	6,96	14,4	0,00	6,85	12,0	0,00	7,00
	6,5	8,7	0,45	6,22	12,0	10,00	6,88	9,3	0,00	5,96
	13,0	7,0	0,00	5,87	8,0	0,00	6,34	7,1	0,00	6,42
P5	1,5	18,2	0,00	6,69	15,2	0,00	6,99	12,2	0,00	6,50
	4,0	17,6	1,23	6,76	14,0	0,00	6,84	12,0	0,00	6,32
P6	1,0	17,8	0,00	7,03	14,5	0,00	6,71	11,7	0,00	6,29
	4,0	16,2	0,00	5,80	14,1	0,00	6,82	11,5	0,00	6,62
	8,0	6,8	0,00	5,55	11,4	0,00	6,49	7,8	0,00	6,02
P7	1,0	18,0	0,00	7,11	14,5	0,00	7,08	11,7	0,00	6,55
	6,5	9,1	0,00	5,96	12,4	0,00	6,75	8,4	0,00	6,51
	13,5	6,6	0,00	5,93	8,1	0,00	6,21	7,3	0,00	6,40
P8	1,0	17,7	0,00	6,86	15,0	0,00	6,91	11,2	0,00	6,68
	7,0	9,0	0,00	6,22	12,0	0,00	7,04	8,2	0,00	6,27
	13,5	6,7	0,00	5,88	7,9	0,00	6,04	6,7	0,00	6,37
P9	1,0	18,0	0,00	7,04	15,2	0,00	6,95	10,6	0,00	6,49
	5,0	10,0	0,00	6,32	14,2	0,00	7,04	7,2	0,00	6,30
	10,0	6,6	0,00	5,47	9,2	0,00	6,29	6,5	0,00	5,47
P10	1,0	18,0	0,00	5,98	15,4	0,00	6,94	11,2	0,00	6,63
	5,5	17,9	0,00	6,88	12,5	0,00	6,90	9,0	0,00	6,21
	10,0	8,2	0,00	5,08	8,8	0,00	6,18	8,0	0,00	6,33
P11	1,0	16,5	0,00	6,70	14,5	0,00	7,04	9,6	0,00	6,40
	6,0	9,0	0,00	6,31	11,0	0,00	6,54	8,4	0,00	6,09
	12,0	6,7	0,00	5,51	8,2	0,00	6,11	6,8	0,00	5,64
P12	1,0	17,6	0,00	6,65	14,5	0,00	6,59	11,0	0,00	6,22
	6,0	11,5	0,00	6,01	12,5	0,00	6,47	9,5	0,00	6,25
	12,0	7,2	0,00	5,36	10,0	0,00	6,15	7,0	0,00	5,63
P13	1,0	18,2	0,00	6,76	14,1	0,00	6,93	11,3	0,00	6,57
	4,5	16,0	0,00	6,48	13,1	0,00	6,73	10,2	0,00	6,31
	9,0	7,1	0,00	5,62	10,4	0,00	6,20	8,3	0,00	5,77
P14	0,7		4,20	6,90		7,46	3,96		6,99	6,54
P15	0,7		5,26	5,16		3,91	5,43		3,39	3,86
P16	0,7		6,11	4,12		7,68	6,05		9,68	4,60
E	1,0				14,5	0,00	6,79	8,0	0,00	5,76
	7,5				11,5	0,00	6,35	7,0	0,00	5,72
	15,0				6,5	0,00	5,73	5,2	0,00	5,44
D	1,0				15,2	0,00	6,97	11,2	0,00	5,64
	4,5				14,5	0,00	6,89	9,4	0,00	6,07
	9,0				10,5	0,00	6,42	6,2	0,00	2,33

11.5 Quality control, results

82128371-08 SMOCS Kokkola, stabilization quality control

General						NITON-XRF Ca-content [ppm]					Compression strength [kPa]						Water permeability		Diffusion test	Batch test	Titration	Directional shearing strengths for strength level, measured with vane auger after the stabilization *
Date	**Box**	**Sampling depth [m]**	**Visual estimate of soil type**	**Recipe [kg/m³]**	**Age of mass [day]**	**Deter.1**	**Deter. 2**	**Deter. 3**	**Deter. 4**	**Average**	**Test specimen numbering**	**7 days**	**28 days**	**90 days**	**180 days**	**Spare**	**Test specimen numbering**	**k [m/s]**				
13.9.2011				LT		119800	121300	114800		118633											x	
13.9.2011				Rapid-Se		422000	427000	417000		422000											x	
13.9.2011			hkSi	0-massa kokooma		10800	9100	10100		10000											x	
13.9.2011	1	0,0-1,0	hkSi	Rapid 30 + LT 100	0	26100	28800	25700		26867	SC-2a,b,c,d		279	570	830	x						0,5m=56kPa 1,0m=46kPa (0days)
13.9.2011	1	1,0-2,0	hkSi	Rapid 30 + LT 100	0	17900	31100	37500		28833												1,5m=39kPa 2,0m=32kPa
14.9.2011	2	0,0-1,0	hkSi	Rapid 30 + LT 100	0	28400	29300	29600		29100											x	0,5m=52kPa 1,0m=50kPa (0days)
14.9.2011	2	1,0-2,0	hkSi	Rapid 30 + LT 100	0	25500	23600	24500		24533												1,5m=44kPa 2,0m=34kPa
20.9.2011	10	0,0-0,5	siHk	Rapid 30 + LT 100	0	24400	22600	24000		23667	SC-3a,b,c	174	280			x					x	0,5m=54kPa (1days)
20.9.2011	10	0,5-1,0	siHk	Rapid 30 + LT 100	0	23600	24600	24000		24067												1,0m=46kPa
20.9.2011	10	1,0-2,0	siHk	Rapid 30 + LT 100	0	21700	24600	16800	17600	20175											x	1,5m= 50kPa
20.9.2011	12	0,0-0,5	hkSi	Rapid 30 + LT 100	0	37800	32800	29300		33300												
20.9.2011	12	0,5-1,0	hkSi	Rapid 30 + LT 100	0	25800	26600	25400		25933												0,5m=62kPa 1,0m=52kPa (0days)
20.9.2011	12	1,0-2,0	hkSi	Rapid 30 + LT 100	0	20600	16000	26400		21000												1,5m=54kPa
20.9.2011	14	0,0-0,5	hkSi	Rapid 30 + LT 100	0	26200	38100	27500	19200	27750	SC-4a,b,c,d,e	87	207	314	372	x	SCV-5	3,2x10^{-8}		done	x	0,5m=57kPa (1days)
20.9.2011	14	0,5-1,0	hkSi	Rapid 30 + LT 100	0	21700	21100	21000		21267												1,0m=38kPa
20.9.2011	14	2,0	hkSi	Rapid 30 + LT 100	0	13200	25800	27900	13300	20050	SC-6a,b,c,d,e	79	133	233	169	x					x	1,5m=72kPa
21.9.2011				LT		102500	106500	105400		104800												
21.9.2011	18		siHk	0-massa		11200	10400	10800		10800											x	
21.9.2011	18	0,5	siHk	LT 200	0	22600	25300	24100		24000	SC-7a,b,c,d,e	74	117	193	272	x	SCV-8					
21.9.2011	18	1,0	siHk	LT 200	0	19300	18800	15700	20500	18575												
21.9.2011	18	2,0	siHk	LT 200	0	16300	20400	13300	19000	17250	SC-9a,b,c,d,e	54	73	111	118	x	SCV-10				x	
26.9.2011	32	0,0-1,0	(sa)hkSi	LT 150-200	1-2	22300	15600	26900		21600												0,5m=47kPa 1,0m=40kPa (1-2days)
26.9.2011	32	2,0-3,0	(sa)hkSi	LT 150-200	1-2	13300	15900	15400		14867												1,5m=32kPa 2,0m=34kPa
26.9.2011	35	0,0-1,0	(sa)hkSi	LT 150-200	1-2	11900	14800	27700		18133												
26.9.2011	35	2,0-3,0	(sa)hkSi	LT 150-200	1-2	11300	13700	13600		12867											x	
26.9.2011	37	0,0-1,0	Si	LT 150-200	0	27200	22300	23900		24467												
26.9.2011	37	1,0-2,0	Si	LT 150-200	0	37500	27200	25300	27400	29350											x	
26.9.2011	38	1,0	saSi	LT 150-200	0	17400	16900	19800		18033	SC-11a,b,c,d,e	26	35	68	111		SCV-12	2,3x10^{-8}	done	done	x	0,5m=54kPa 1,0m=38kPa (1days)
26.9.2011	38	3,0	saSi	LT 150-200	0	24200	20700	19000		21300	SC-13a,b,c,d,e	28	58	67	80	x	SCV-14	3,5x10^{-8}				1,5m=38kPa 2,0m=32kPa
26.9.2011	39	0,0-1,0	Si	LT 150-200	0	29100	13100	19000		20400												
26.9.2011	40	0,0-1,0	Si	LT 150-200	0	21000	17700	22400		20367											x	
26.9.2011	40	1,5-2,5	Si	LT 150-200	0	14100	17100	22400		17867												
26.9.2011	44	1,0	hkSi	LT 150-200	0	20300	17900	18100		18767	SC-15a,b,c,d,e	38	34	57	93	x	SCV-16					
27.9.2011	47	1,5	(sa)hkSi	0-massa		10200	9765	9668		9878							SCV-28	1,6x10^{-8}			x	
27.9.2011	47	1,0	(sa)hkSi	LT 150-200	0	20800	19500	22200		20833	SC-17a,b,c,d	66	85	100	149		SCV-18					0,5m=52kPa 1,0m=60kPa (0days)
27.9.2011	47	3,0	(sa)hkSi	LT 150-200	0	16200	15100	20300		17200	SC-19a,b,c,d	37	59	55	98		SCV-20				x	15m=42kPa 2,0m=30kPa
27.9.2011	49	0,5	(sa)hkSi	LT 150-200	0	33500	30000	28700		30733												
27.9.2011	49	2,0	(sa)hkSi	LT 150-200	0	20200	26900	28000		25033	SC-21a,b,c,d	85	112	157			SCV-22	2,9x10^{-8}	done	done	x	
27.9.2011	50	0,5	(sa)hkSi	0-massa		10100	9765	11100		10322												
5.10.2011	63	1,0	siHk	LT 150-200	~ 7	16000	15200	15900		15700											x	
5.10.2011	72-74	0,0-1,0	(sa)hkSi	LT 150-200	5-7	27700	19000	20000		22233											x	0,5m=70kPa 1,0m=66kPa (5-7days)
5.10.2011	72-74	1,0-2,0	(sa)hkSi	LT 150-200	5-7	13300	24800	15300		17800												1,5m=76kPa 2,0m=58kPa 2,3m=24kPa
5.10.2011	91	0,5	(sa)hkSi	LT 150-200	2-4	25100	27000	27700		26600											x	
5.10.2011	94	0,5	(sa)hkSi	LT 150-200	2-4	15900	19200	16400		17167												
5.10.2011	x	0,0-1,0	siHk	Kokooma 3A (0-massa)		6402	8174	7496		7357												
5.10.2011	x	2,0-2,5	Hk	Kokooma 3B (0-massa)		7243	5143	5535		5974												
6.10.2011	98	0,5	(sa)siHk	LT 150-200	1	35400	29900	29400		31567												
5.10.2011	100	1,5	hkSi	0-massa		7207	5532	7395		6711												
6.10.2011	101	1,0	(sa)siHk	LT 150-200	0	31300	28100	27200		28867												
6.10.2011	104	0,5	(sa)hkSi	0-massa		10000	8141	10400		9514												
6.10.2011	104	0,0-1,0	(sa)hkSi	LT 150-200	0	32500	30400	27300		30067	SC-23a,b,c,d,e	40	76	122	151	x	SCV-24	1,9x10^{-8}			x	
6.10.2011	106	1,0	(sa)hkSi	0-massa		9480	9254	10200		9645												
6.10.2011	106	2,0-2,5	(sa)hkSi	LT 150-200	0	21000	19400	18500		19633	SC-25a,b,c,d,e	41	75	97	144	x	SCV-26					
			siHk	Karkean alueen 0-massa													SCV-27	1,1x10^{-7}		done		

11.6 Permeability test results

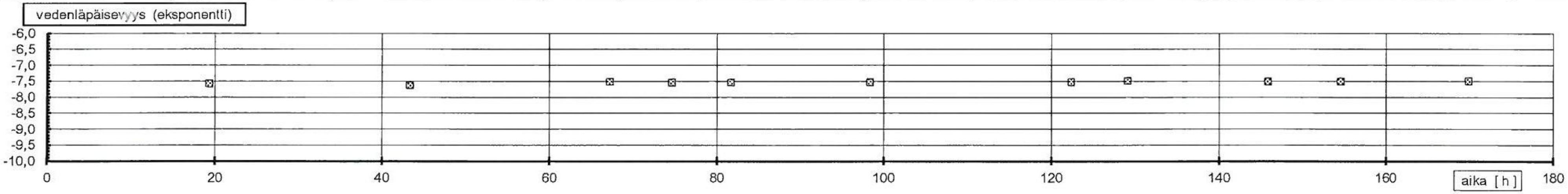
VEDENLÄPÄISEVYYS

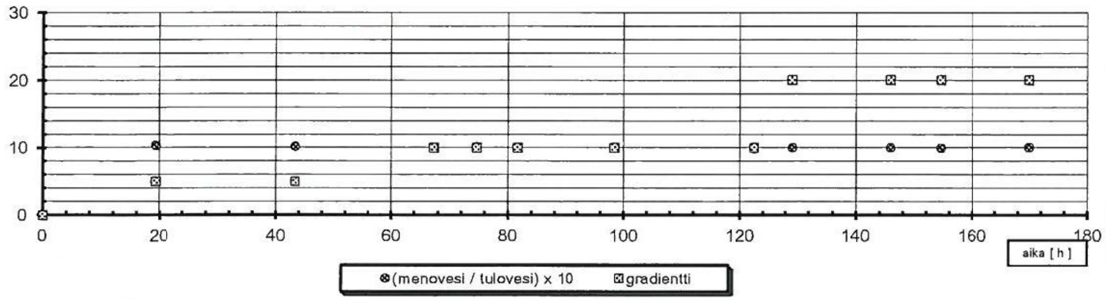
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

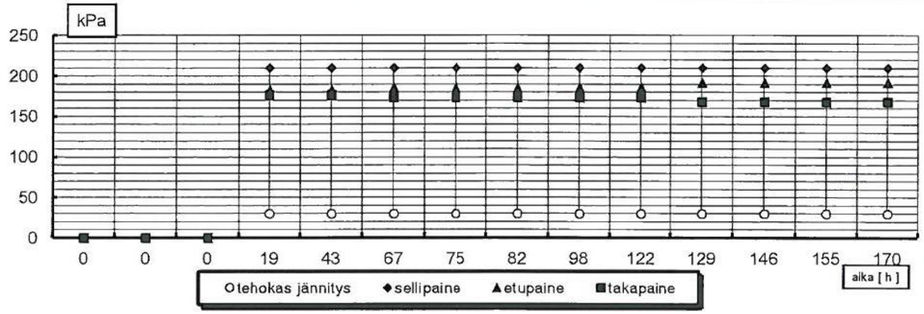
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]		$k_{20°C}$ (keskiarvo)	-7,5	3,2E-08	m/s
MATERIAALI	SCV-5	MAX. KUIVAIRTOTIHEYS [kg/m3]		$k_{20°C}$ (mediaani)	-7,5	3,2E-08	m/s
Pvm./ käsittelijä	7.11.2011			keskihajonta	-9,1	8,5E-10	m/s
TILAAJA	Liikelaitos Kokkolan Satama			$k_{4°C}$ (keskiarvo)	-7,6		m/s

ENNEN KOETTA		KOEVAIHE					
MASSA [g]	1933	MASSA [g]	1979	HUOKOSLUKU			
HALKAISIJA [mm]	103	HALKAISIJA [mm]	103	HUOKOISUUS [%]			
KORKEUS [mm]	117	KORKEUS [mm]	117	KYLLÄSTYSASTE [%]			
VESIPITOISUUS [%]	18,1	VESIPITOISUUS [%	21,0	LÄMPÖTILA [°C]			21
MÄRKÄIRTOTIHEYS [kg/m3]	1983	MÄRKÄIRTOTIHEYS [kg/m3]	2030				
KUIVAIRTOTIHEYS [kg/m3]	1679	KUIVAIRTOTIHEYS [kg/m3]	1678				
				KYLL.ASTE ENNEN KOETTA [%]			







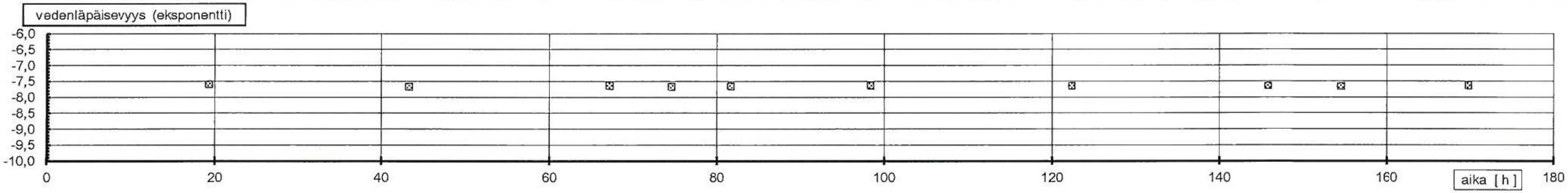
VEDENLÄPÄISEVYYS

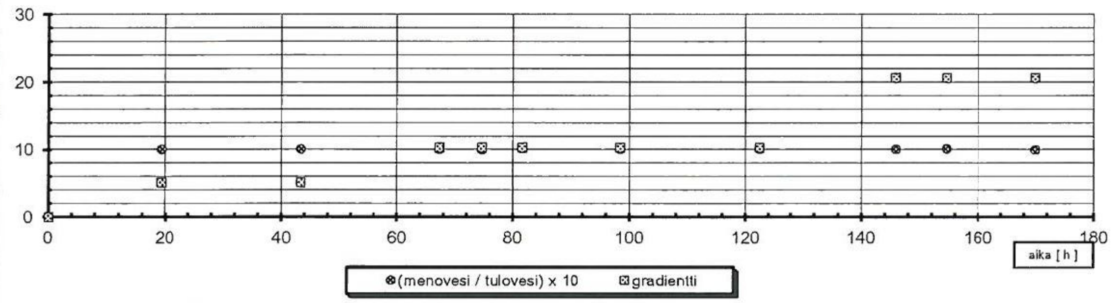
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

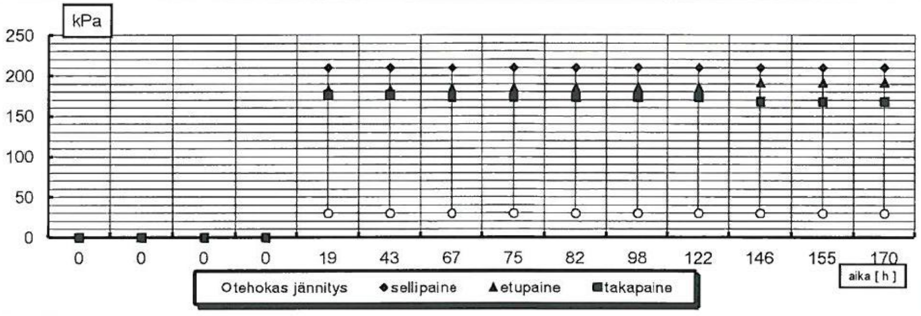
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]	k$_{20°C}$ (keskiarvo)	-7,6	2,3E-08	m/s
MATERIAALI	SCV-12	MAX. KUIVAIRTOTIHEYS [kg/m3]	k$_{20°C}$ (mediaani)	-7,6	2,3E-08	m/s
Pvm./ käsittelijä	7.11.2011		keskihajonta	-9,2	6,0E-10	m/s
TILAAJA	Liikelaitos Kokkolan Satama		k$_{4°C}$ (keskiarvo)	-7,8		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	2011	MASSA [g]	1997	HUOKOSLUKU	
HALKAISIJA [mm]	103	HALKAISIJA [mm]	102	HUOKOISUUS [%]	
KORKEUS [mm]	117	KORKEUS [mm]	114	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	21,5	VESIPITOISUUS [%	20,7	LÄMPÖTILA [°C]	21
MÄRKÄIRTOTIHEYS [kg/m3]	2063	MÄRKÄIRTOTIHEYS [kg/m3]	2144		
KUIVAIRTOTIHEYS [kg/m3]	1698	KUIVAIRTOTIHEYS [kg/m3]	1776		
				KYLL.ASTE ENNEN KOETTA [%]	







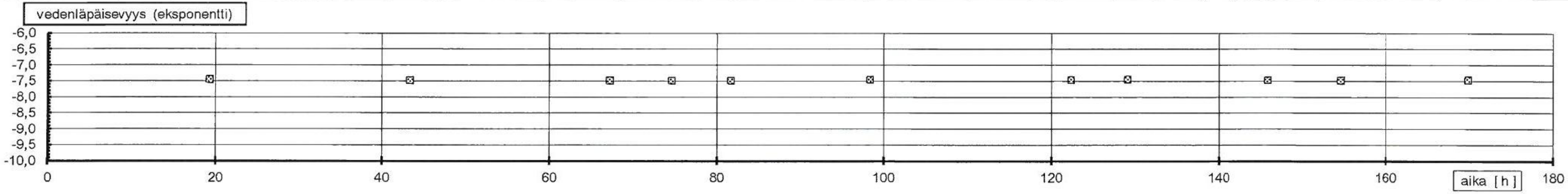
VEDENLÄPÄISEVYYS

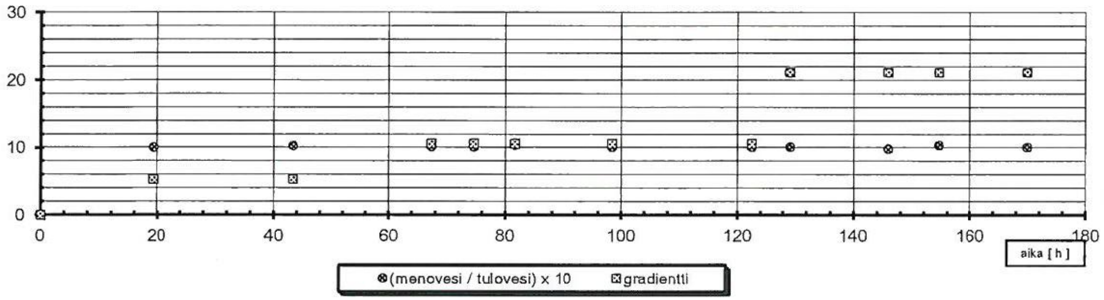
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

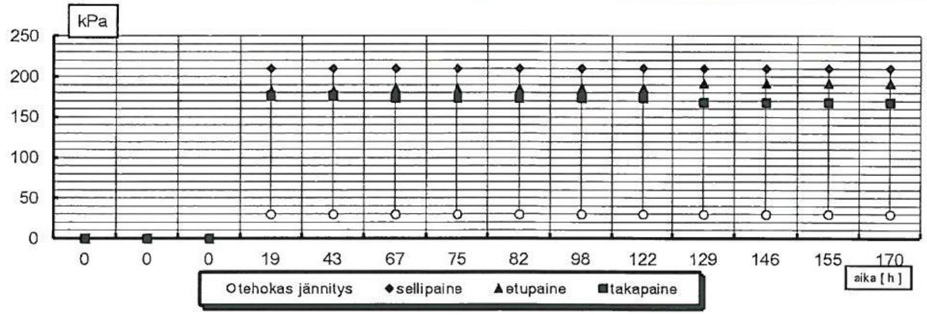
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]	$k_{20°C}$ (keskiarvo)	-7,5	3,5E-08	m/s
MATERIAALI	SCV-14	MAX. KUIVAIRTOTIHEYS [kg/m3]	$k_{20°C}$ (mediaani)	-7,5	3,5E-08	m/s
Pvm./ käsittelijä	7.11.2011		keskihajonta	-9,0	1,1E-09	m/s
TILAAJA	Liikelaitos Kokkolan Satama		$k_{4°C}$ (keskiarvo)	-7,6		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	**1891**	MASSA [g]	**1882**	HUOKOSLUKU	
HALKAISIJA [mm]	**103**	HALKAISIJA [mm]	**102**	HUOKOISUUS [%]	
KORKEUS [mm]	**114**	KORKEUS [mm]	**111**	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	**23,6**	VESIPITOISUUS [%	**23,0**	LÄMPÖTILA [°C]	**21**
MÄRKÄIRTOTIHEYS [kg/m3]	**1991**	MÄRKÄIRTOTIHEYS [kg/m3]	**2075**		
KUIVAIRTOTIHEYS [kg/m3]	**1611**	KUIVAIRTOTIHEYS [kg/m3]	**1687**		
				KYLL.ASTE ENNEN KOETTA [%]	







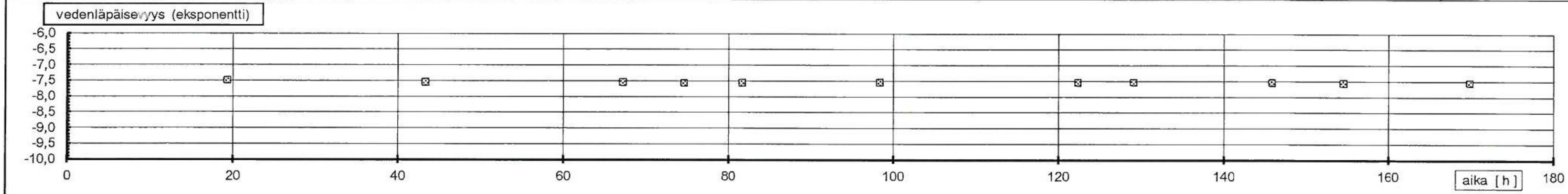
VEDENLÄPÄISEVYYS

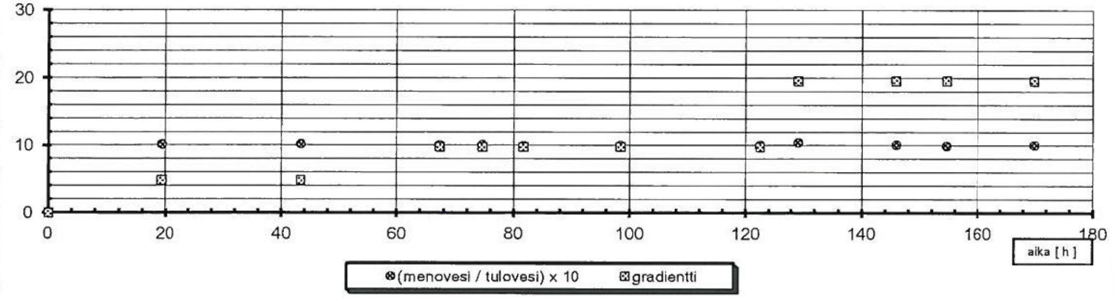
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

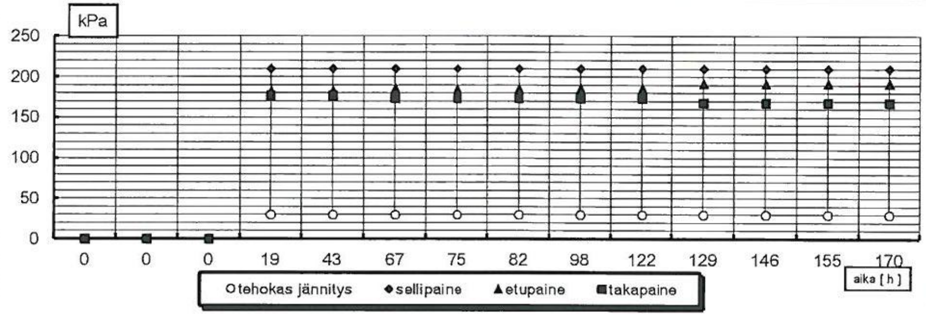
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]		$k_{20°C}$ (keskiarvo)	-7,5	2,9E-08	m/s
MATERIAALI	SCV-22	MAX. KUIVAIRTOTIHEYS [kg/m3]		$k_{20°C}$ (mediaani)	-7,5	2,9E-08	m/s
Pvm./ käsittelijä	7.11.2011			keskihajonta	-9,1	7,2E-10	m/s
TILAAJA	Liikelaitos Kokkolan Satama			$k_{4°C}$ (keskiarvo)	-7,7		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	1962	MASSA [g]	1997	HUOKOSLUKU	
HALKAISIJA [mm]	103	HALKAISIJA [mm]	103	HUOKOISUUS [%]	
KORKEUS [mm]	120	KORKEUS [mm]	120	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	22,6	VESIPITOISUUS [%	24,9	LÄMPÖTILA [°C]	21
MÄRKÄIRTOTIHEYS [kg/m3]	1963	MÄRKÄIRTOTIHEYS [kg/m3]	1998		
KUIVAIRTOTIHEYS [kg/m3]	1601	KUIVAIRTOTIHEYS [kg/m3]	1599		
				KYLL.ASTE ENNEN KOETTA [%]	







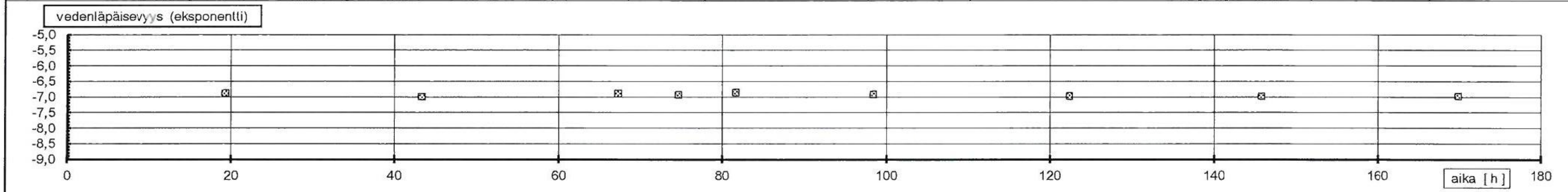
VEDENLÄPÄISEVYYS

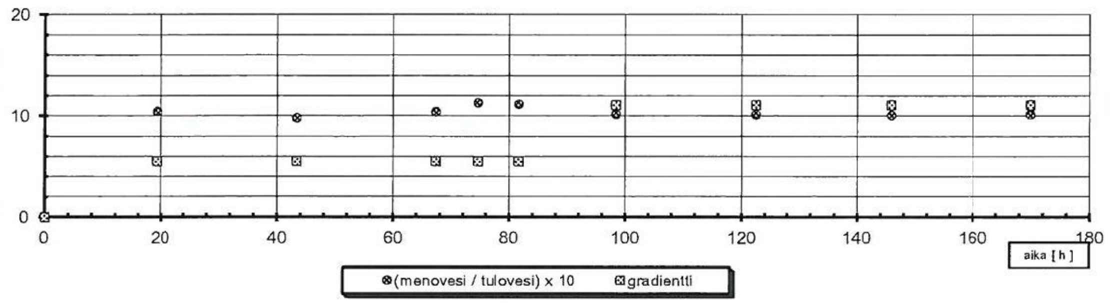
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

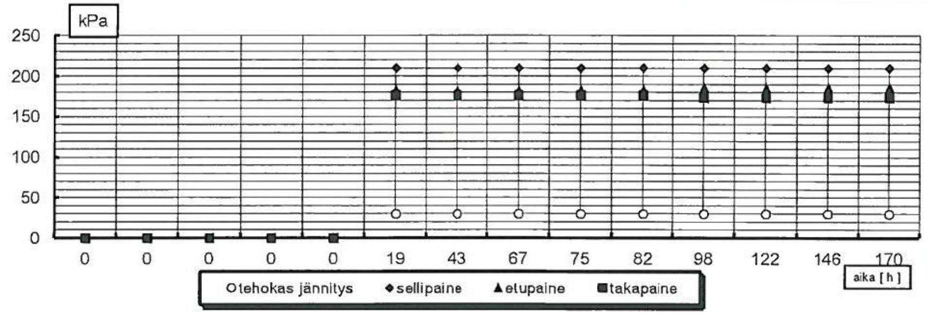
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]		$k_{20°C}$ (keskiarvo)	-7,0	1,1E-07	m/s
MATERIAALI	SCV-27	MAX. KUIVAIRTOTIHEYS [kg/m3]		$k_{20°C}$ (mediaani)	-7,0	1,1E-07	m/s
Pvm./ käsittelijä	7.11.2011			**keskihajonta**	-8,1	8,1E-09	m/s
TILAAJA	Liikelaitos Kokkolan Satama			$k_{4°C}$ (keskiarvo)	-7,1		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	**1985**	MASSA [g]	**1937**	HUOKOSLUKU	
HALKAISIJA [mm]	**102**	HALKAISIJA [mm]	**103**	HUOKOISUUS [%]	
KORKEUS [mm]	**116**	KORKEUS [mm]	**106**	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	**17,9**	VESIPITOISUUS [%	**15,1**	LÄMPÖTILA [°C]	**21**
MÄRKÄIRTOTIHEYS [kg/m3]	**2095**	MÄRKÄIRTOTIHEYS [kg/m3]	**2194**		
KUIVAIRTOTIHEYS [kg/m3]	**1777**	KUIVAIRTOTIHEYS [kg/m3]	**1906**		
				KYLL.ASTE ENNEN KOETTA [%]	







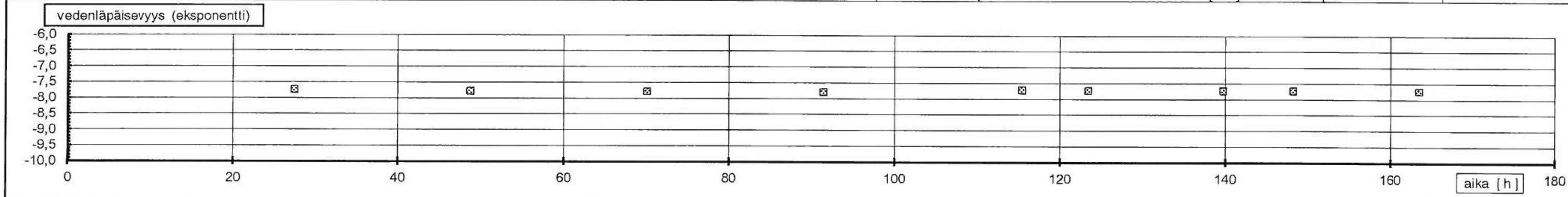
VEDENLÄPÄISEVYYS

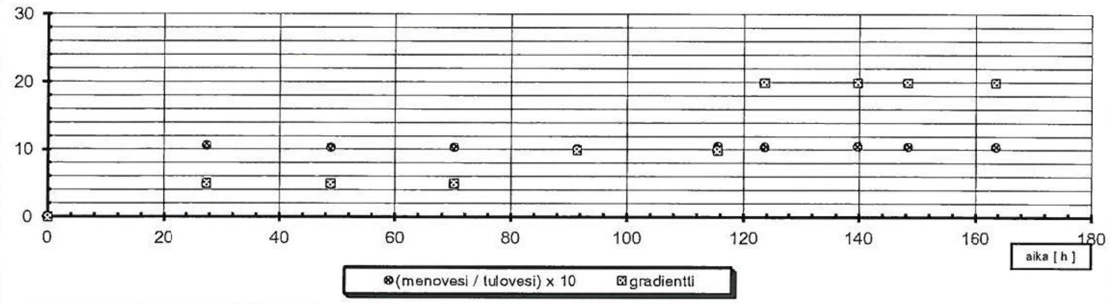
PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

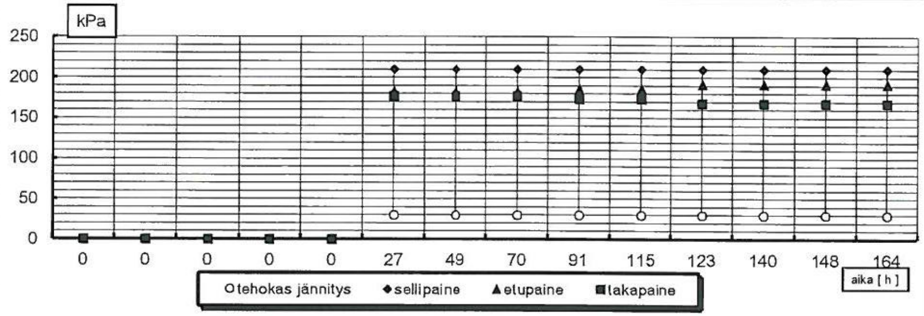
RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]		$k_{20°C}$ (keskiarvo)	-7,7	1,9E-08	m/s
MATERIAALI	SCV-24	MAX. KUIVAIRTOTIHEYS [kg/m3]		$k_{20°C}$ (mediaani)	-7,7	1,9E-08	m/s
Pvm./ käsittelijä	11.11.2011			**keskihajonta**	-9,8	1,6E-10	m/s
TILAAJA	Liikelaitos Kokkolan Satama			$k_{4°C}$ (keskiarvo)	-7,9		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	1963	MASSA [g]	1976	HUOKOSLUKU	
HALKAISIJA [mm]	103	HALKAISIJA [mm]	102	HUOKOISUUS [%]	
KORKEUS [mm]	119	KORKEUS [mm]	118	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	23,0	VESIPITOISUUS [%	23,8	LÄMPÖTILA [°C]	21
MÄRKÄIRTOTIHEYS [kg/m3]	1980	MÄRKÄIRTOTIHEYS [kg/m3]	2050		
KUIVAIRTOTIHEYS [kg/m3]	1610	KUIVAIRTOTIHEYS [kg/m3]	1656		
				KYLL.ASTE ENNEN KOETTA [%]	







VEDENLÄPÄISEVYYS

PEHMEÄSEINÄMÄISELLÄ LAITTEISTOLLA

RAMBØLL

NÄYTE N:o		OPTIMIVESIPITOISUUS [%]		$k_{20°C}$ (keskiarvo)	-7,8	1,6E-08	m/s
MATERIAALI	SCV-28	MAX. KUIVAIRTOTIHEYS [kg/m3]		$k_{20°C}$ (mediaani)	-7,8	1,6E-08	m/s
Pvm./ käsittelijä	11.11.2011 Aui Mälkiä			keskihajonta	-9,8	1,7E-10	m/s
TILAAJA	Liikelaitos Kokkolan Satama			$k_{4°C}$ (keskiarvo)	-7,9		m/s

ENNEN KOETTA		KOEVAIHE			
MASSA [g]	1880	MASSA [g]	1785	HUOKOSLUKU	
HALKAISIJA [mm]	102	HALKAISIJA [mm]	96	HUOKOISUUS [%]	
KORKEUS [mm]	116	KORKEUS [mm]	108	KYLLÄSTYSASTE [%]	
VESIPITOISUUS [%]	24,2	VESIPITOISUUS [%	18,0	LÄMPÖTILA [°C]	21
MÄRKÄIRTOTIHEYS [kg/m3]	1984	MÄRKÄIRTOTIHEYS [kg/m3]	2284		
KUIVAIRTOTIHEYS [kg/m3]	1597	KUIVAIRTOTIHEYS [kg/m3]	1935		
				KYLL.ASTE ENNEN KOETTA [%]