LIFE09 ENV/FI/575 ABSOILS

Final Report on the Pilot Applications and Quality Control of the Absoils project

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Introduction

ABSOILS was a five-year project which demonstrated the utilisation of surplus (excess, abandoned, redundant) low-quality soils - like for instance clays - as construction materials. The ABSOILS project was carried out in co-operation of Biomaa Oy (Lemminkäinen Oy), Rudus Oy and Ramboll Finland Oy. The cities of Helsinki, Espoo and Vantaa were involved in the project in the role of city developers or constructors. The project was co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575).

The currently prevailing trend in the city of Helsinki includes landfilling of its surplus poor quality soils in the surrounding cities and replacing them with crushed aggregate transported from other places (Figure 1.1). The target of the project is to demonstrate and promote eco-efficient utilising of the poor quality soils in-situ and owing to that to decrease the use and the transportation need of crushed aggregates. In the project surplus and low-quality soil is improved by stabilisation with fly ashes, cement, lime and sulphur removal by-products (Figure 1.2).

Helsinki and other cities of the capital area are under a continual process of constructing new districts and improving the already existing ones. Like many other Finnish cities, Helsinki, Vantaa and Espoo suffer from the shortage of areas that constitute geotechnically easy targets for construction and are relatively close to the city centre, so there is a need to utilise also areas which are challenging because of their geological structure. As a result, construction has to be performed in areas with very soft postglacial clay, mud or peat. According to the estimations, the amount of surplus low-quality soils generated in the capital area reaches to about 4 million tonnes annually. Other problems encountered include the shortage of fill and embankment materials, as well as the shortage of landfill areas for excess soils.

The utilisation of the excess soils is possible due to, for instance, mass stabilisation technology. Mass stabilisation is a ground improvement method where binder is mixed into peat, mud or soft clay. The binder agent reacts with the stabilised material forming bonds that enhance the compressive strength and modulus of the material. The stabilisation agent is usually cement, but also industrial by-products or waste can be utilised in this process. The procedure is carried out with the help of a mixing tool installed on an excavator machine. (Lahtinen & Niutanen 2009).

The aim of the Absoils project was to demonstrate the practical implementation of four challenging types of civil-engineering applications including fllod barriers, noise barriers, supporting banks and landscape construction. This report presents the results of the piloting works carried out in the following loacations: Arcada2, Jätkäsaari, Honkasuo (Helsinki) and Perkkaa Dog Park in Espoo.

1. Perkkaa Dog Park in Espoo

In the pilot application – the Perkkaa Dog Park in Espoo – stabilisation was carried out by utilising the low quality soil and industrial wastes as binders. The area of the park is 4 500 m^2 and it lies in the flood prone zone (Figures 1.3, 1.4, 1.5, 1.6). The soil of the area is soft clay with low load bearing capacity. The thickness of the clay is about 12…14 m and the area had been classified as a very difficult constructing target. The aim was to raise the area to prevent flooding. This was performed with poor quality excess soils from a neighbouring construction site by stabilising them together with the upper part of the original soil (the transportation distance is only 200…400 meters, Figures 1.4 and 5.2).

It was concluded that for this particular pilot site, the mass stabilisation was the only feasible solution. Since no high load bearing was required from the area, the utilisation amount of binders was small. The area of the dog park is owned by the ABSOILS steering group member - the city of Espoo. This pilot application required environmental permit due to the use of the industrial wastes in the stabilisation process.

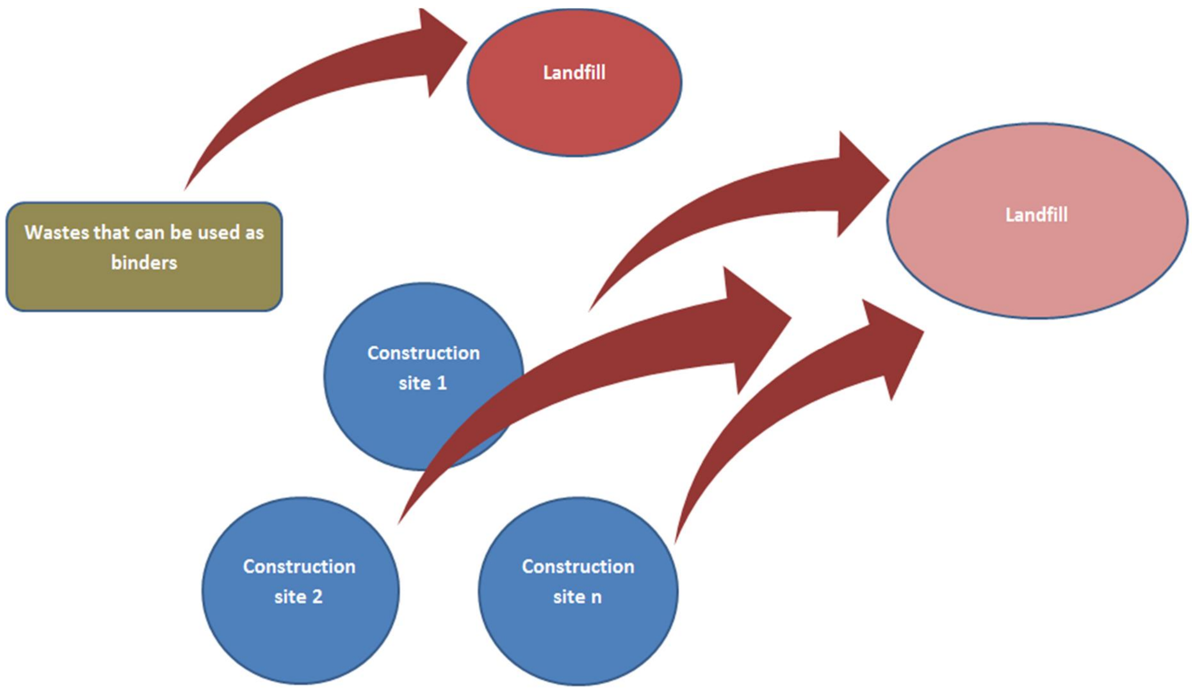


Figure 1.1 Currently predominant model of the material flow of low-quality surplus soils, fly ashes and sulphur removal by-products in infrastructure construction (Forsman et al. 2013)

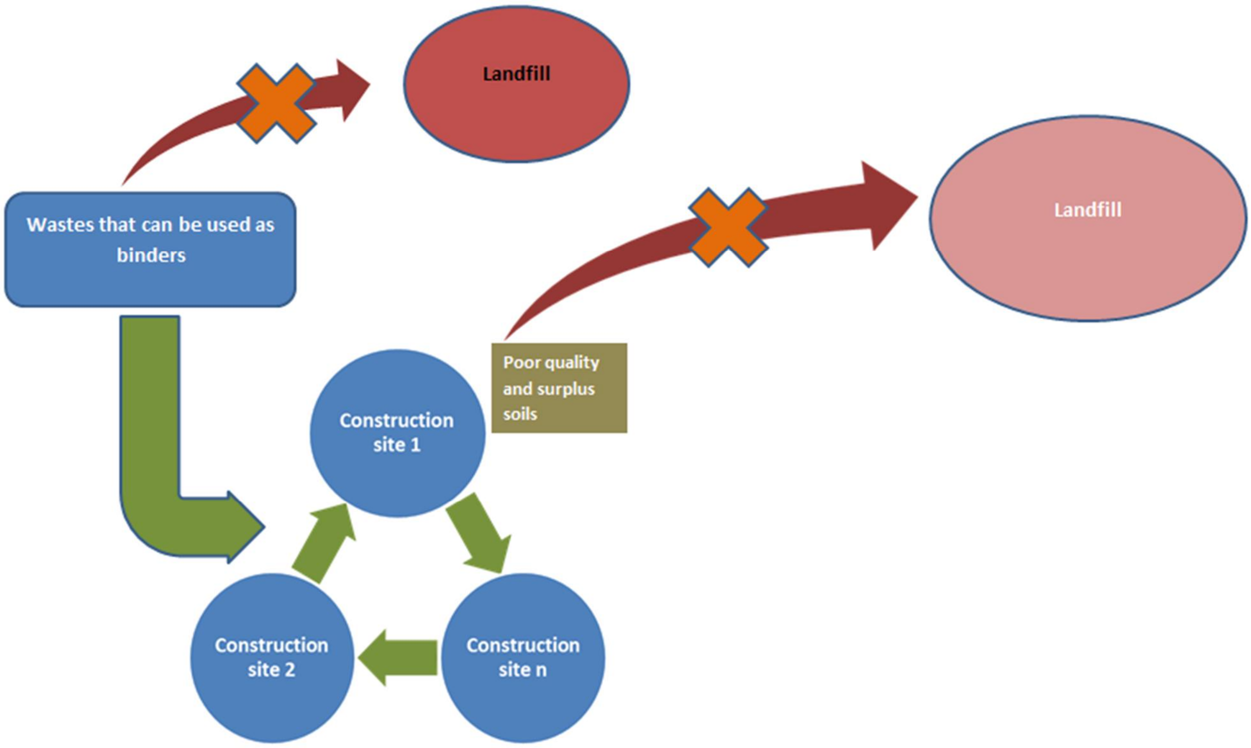
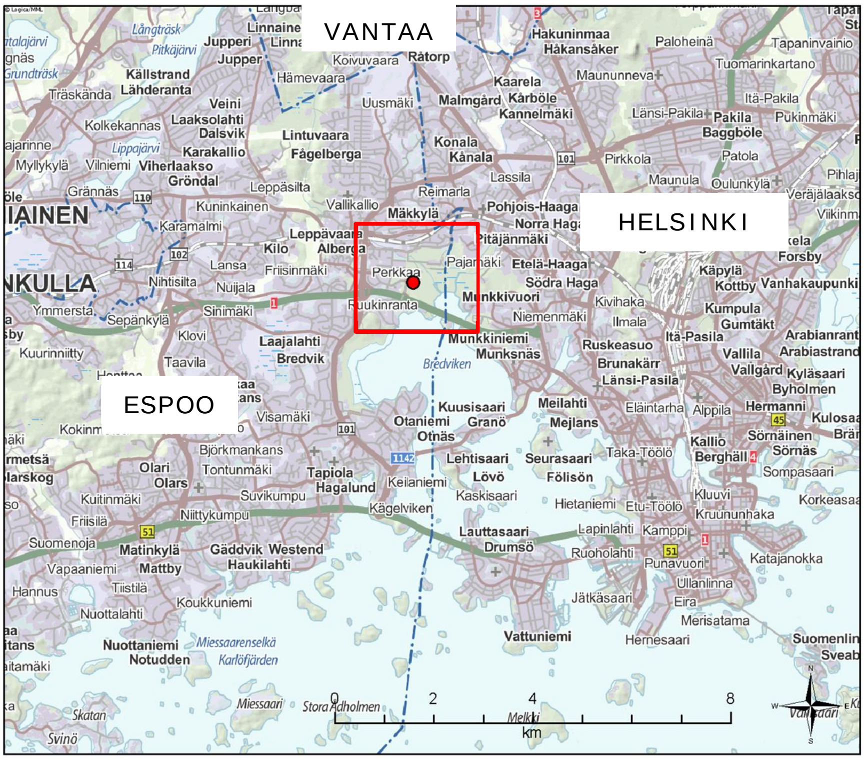


Figure 1.2 The desired material flow model in infrastructure construction (Forsman et al. 2013)

a)



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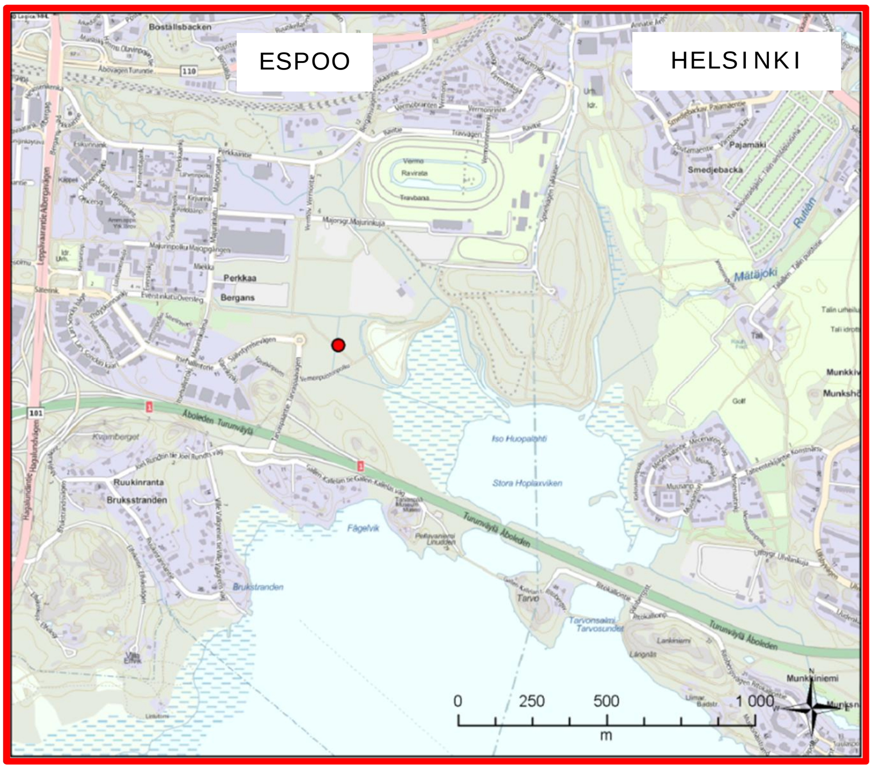


Figure 1.3 Location of the Perkkaa Dog Park, Espoo (red spot)

Figure 1.4 Area of the dog park marked with red circle.

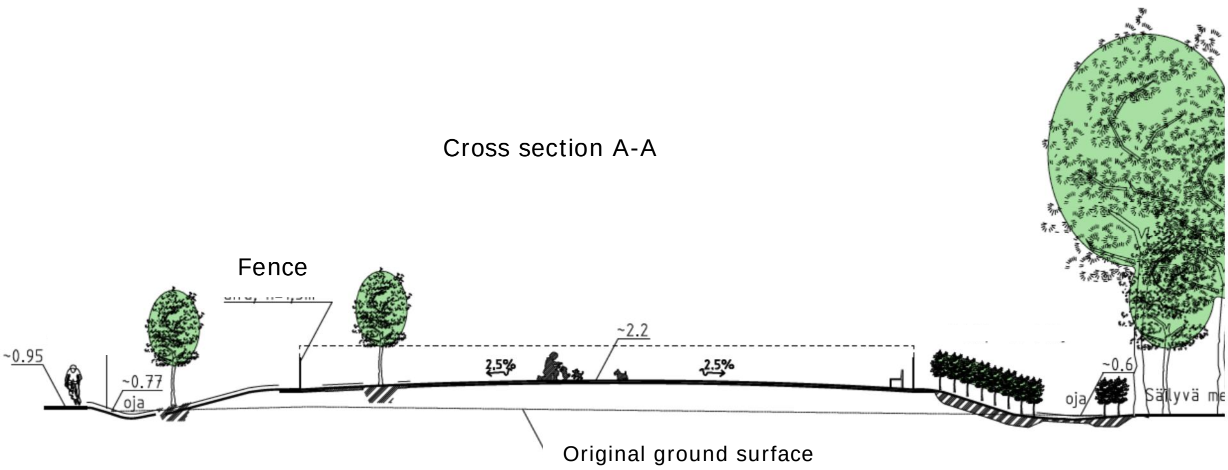


Figure 1.5 Cross section of Perkkaa Dog Park (Ramboll 2011b).

Figure 1.6 Area plan for Dog Park. A ≈4500 m^2. The red arrow indicates the area planned for big dogs, the yellow arrow indicates the area planned for small dogs"ISOT KOIRAT" = big dogs and "PIENET KOIRAT" = small dogs. (Ramboll 2011b)

2. Design and environmental permit

2.1 Design principles

The area of the park is ≈4 500 m^2 and it lies in the flood prone zone. The soil of the area was described as soft clay which used to be seabed. The thickness of the clay is ≈ 11 … 14 m (Figure 2.1) and the area has been classified as a very difficult constructing target due to its low load bearing capacity.

The ground level of the area is between +0.7…+1 and it is raised to prevent the flooding. The planned ground level is +2…+2.5. The raising of the ground level has been done with surplus soil which is stabilised together with the upper part of the original soil. The target is to reduce the occurrence of flooding to less than once in 20 years. The area plan is presented in Figure 1.6.

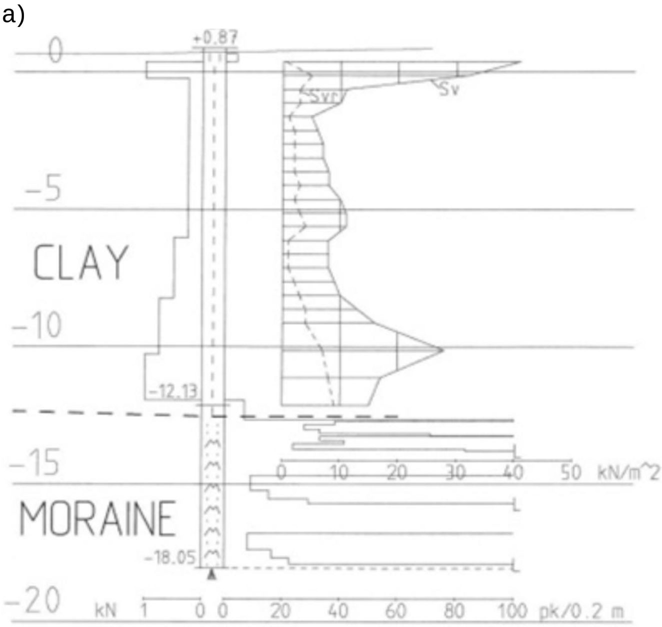
The topsoil of the area is 0.5…0.9 m thick dry crust clay and its unreduced shear strength changes between ≈ 30…40 kPa. The soft clay below the dry crust is divided to four layers:

- Clay 1: unreduced shear strength ≈ 9 kPa, water content ≈ 130 %, thickness ≈ 1…1.5 m,
- Clay 2: unreduced shear strength ≈ 8 kPa, water content ≈ 105 %, thickness ≈ 2.5…3 m,
- Clay 3: unreduced shear strength ≈ 11 kPa, water content ≈ 80 %. thickness ≈1.5…2 m and
- Clay 4 unreduced shear strength ≈ 10 kPa, water content ≈ 65 %, thickness ≈ 6…7 m.

Underneath the clay there is a silt layer. The bottom soil layer is sand or moraine. The elevation of the bedrock surface is undefined.

There are no available measurements of water level of the groundwater but the water level is assumed to be near the ground surface. The area of the park floods periodically.

a)



b)

z	w
0…1.5 m	≈ 130 %
1.5…4 m	≈ 105 %
4…6 m	≈ 80 %
6…12 m	≈ 65 %

Figure 2.1 Perkkaa Dog Park. Properties of subsoil. Swedish weight sounding test and vane test (a) and water content (b). (Ramboll 2011a)

2.2 Geotechnical calculations

Stability and settlement calculations were carried out using the Finnish GeoCalc 2.2 programme.

<u>Stability calculations:</u>

In the case of stability calculations, a nearby located gas pipe (northwest) and pile slab (southwest) had to be taken into consideration. Stability analysis was carried out using total safety factor – method.

Required total safety factor for slip surfaces reaching a gas pipe and the pile slab was 1.8. Toward other directions and shorter slip surfaces the total safety factor was 1.5. (Ramboll 2011)

Calculation parameters are presented in table 2.1.

Example stability calculation of excess clay embankment before mass stabilisation loaded with mass stabilisation machine and ready mass stabilised embankment with super structure layers and loaded with excavator are presented in Figure 2.2.

Settlement calculations:

Primary consolidation settlement is calculated on the basis of the water content of the subsoil clay. In the calculation first the water content is changed to Janbus tangent modulus method parameters m_1 and β_1 (modulus number and stress index).

The calculated consolidation settling of the embankment is about 200...300 mm during 30 a. Without stabilisation the calculated settling is ≈ 1 m.

Table 2.1 Soil parameters in stability calculations. a) Embankment and mass stabilisation and b) Subsoil on the basis of the sounding E5. (Ramboll 2011a)

a)	Unit weight [kN/m^3]	Shear strength cohesion [kPa]	Angle of friction [^{o}]
Embankment (excess clay)	15	2	-
Dry crust clay	14,2	12,5	-
Sand, Crushed rock	20	0	32
Mass stabilised clay	15	40	-

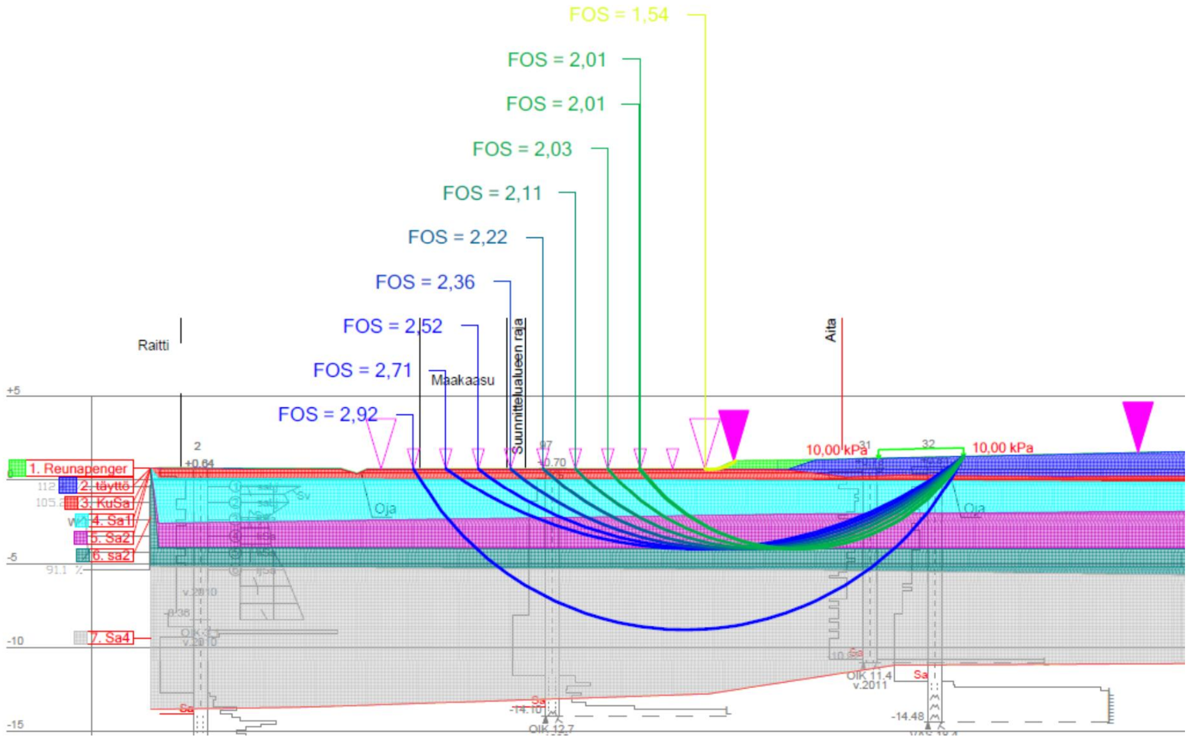
b) Sounding E5	Paksuus [m]	Unreduced S_u [kPa]	Reduction factor	Reduced $S_{u,red}$ [kPa]	Water content [%]	Unit weight [kN/m^3]
Dry crust clay	1	25	0,5	12,5	110	14,2
Clay 1 (Savi 1)	1,3	9	0,65	5,9	130,0	13,7
Clay 2 (Savi 2)	2,7	8	0,73	5,8	105,0	14,4
Clay 3 (Savi 3)	1,6	11	0,83	9,1	80,0	15,3
Clay 4 (Savi 4)	6,6	10	0,9	9	65	16,1
Total thickness [m]	13,2					

2.3 Designed structures

The targeted shear strength after mass stabilisation is 30 kPa after 28 d hardening time and 40 kPa after 90 d hardening time. The thickness of the stabilisation was planned to be about 3.5 m in the bordering area and about 2 m in the central part of the structure. The total volume of the stabilisation was 13.000 m^3. No wells for the rain water were built but the drainage was done by surface inclination. The planned cross sectional cut is presented in Figure 2.2 and 2.3.

In the bordering area, stabilisation was performed to the level -2.0 and in the central level to the level ±0. In the first case, stabilisation process embraced the soft subsoil and the surplus clays, whereas in the second case only surplus clays were stabilised.

a)



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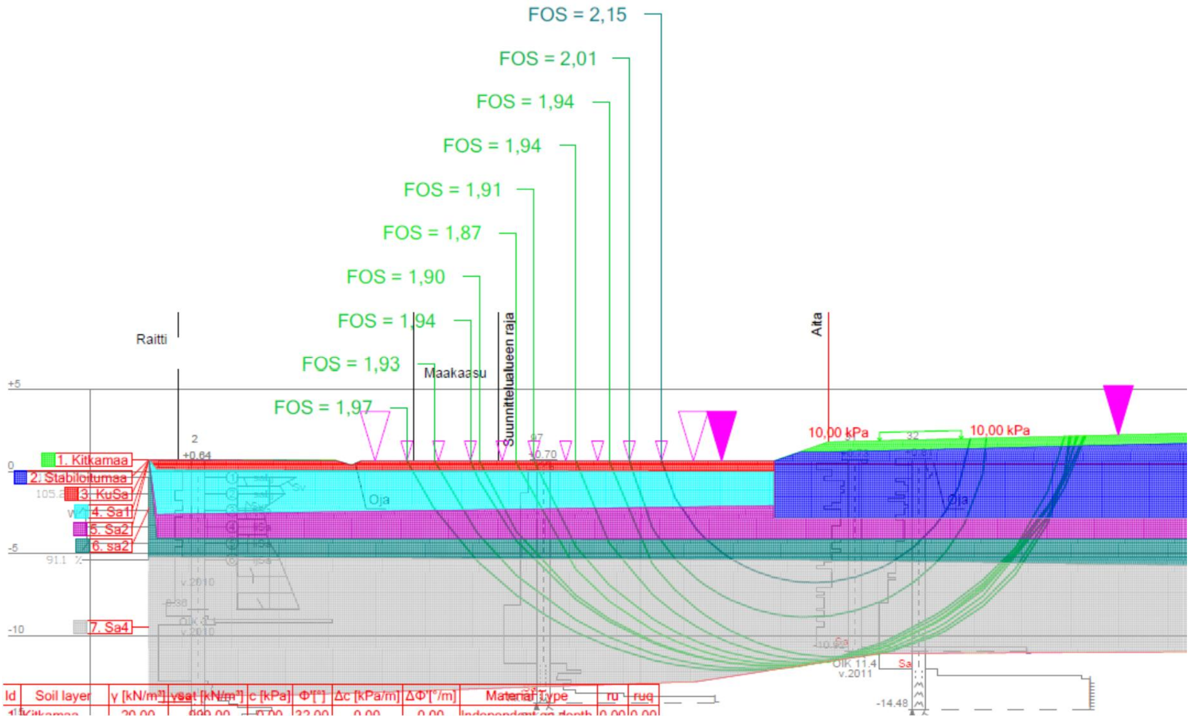


Figure 2.2 Stability calculation of a) surplus clay embankment before mass stabilisation loaded with mass stabilisation machine and b) ready mass stabilised embankment with super structure layers and loaded with excavator. Cross section 1-1. (Ramboll 2011a)

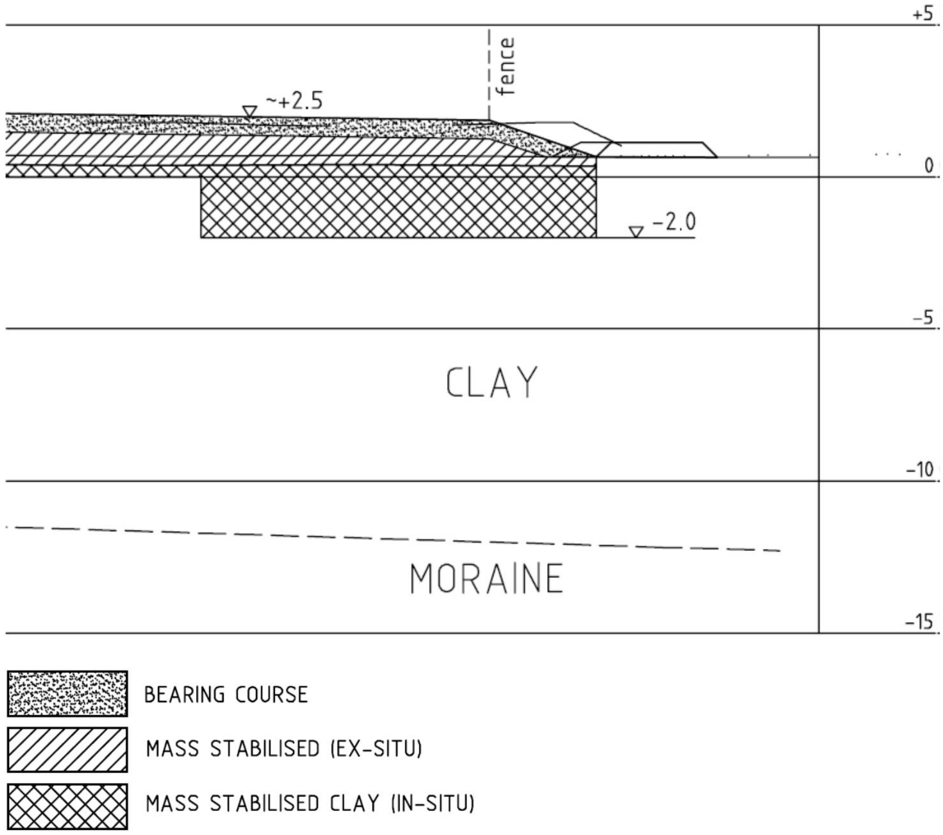
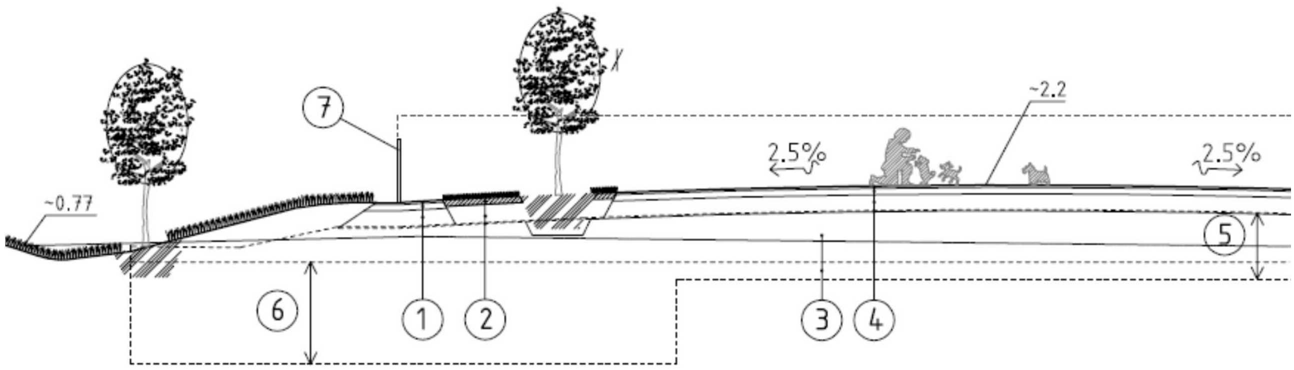


Figure 2.3 Dog Park. Cross section of the mass stabilised structure (embankment + subsoil).



Structural layers \ detail number	(1)	(2)	(3)	(4) *
Stone dust #0/4...0/6 mm	50 mm	-	-	50 mm
Substrate	-	150 mm	800 mm	-
Bearing layer #0/32 mm	150 mm	-	-	150 mm
Sub-base #0/90 mm	-	-		400 mm
Compaction bank of mass stabilisation #0/90 mm	100...500 mm	100...500 mm	n. 150 mm	0...100 mm
Non-woven	N3	N3	N3	N3
(5) Ex-situ mass stabilised excess clay+mud and (6) In-situ mass stabilised subsoil clay+mud				

* area for service cars is with thicker bearing layers than 150 mm (7) = Fence

Figure 2.4 Designed cover and stabilisation layers (Ramboll 2011b).

2.4 Environmental permit process and its implications to the design

The improvement of the technical and chemical properties of surplus soils can be obtained owing to stabilisation. In order to make stabilisation economically feasible and to enhance the utilisation of the industrial wastes fly ashes, flue gas desulphurisation gypsum and other gypsum by-products are tested and used as binder components. From a legislative point of view, the utilisation of ashes is nowadays possible in Finland on the basis of the decree number 403/2009 with only a notification to the authorities, if the fly ash alone is used as an own layer structure in road/field. However, if the fly ash is used as a binder in uncontaminated soil material the legislation requires an environmental permit.

As mentioned above, there was a need to apply for environmental permit for pilot application because of the use of fly ash. The permitting process is rather lengthy and creates a threat to the planned piloting applications, especially due to the fact that the timetables have to be synchronised with other construction works as the source of the surplus soils. There is also a lack of a consistent approach towards the issue of using industrial wastes in the stabilisation process and there seem to be considerable differences among various local permit authorities throughout the whole country. In general, the permitting issue in connection with the binders for the stabilisation process other than cement, constitutes a considerable hinder for the establishment of the eco-efficient practices in the field of surplus soils and their utilisation.

The problem was communicated to the Ministry of Environment when the subject of the permit for the piloting in Espoo – the Dog Park was discussed. This has led to a discussion with a wider audience and the recognition of a need for a change. The Ministry of Environment hosted a seminar devoted to this issue on in September 2011 and the process of development of the legislation has been initiated. It is difficult to foresee whether the changes in the national legislation will occur during the ABSOILS project lifetime. However, the project will continue to be actively involved in this process. (Kreft-Burman et al. 2012)

One of the ways how the ABSOILS project is contributing to the development of the local legislation is by providing the authorities with the results of the current and previous projects that add to the creation of a database concerning various aspects of stabilisation. For instance, the results of the leaching tests performed by the Rudus Oy for the Jätkäsaari sediments stabilised with an admixture containing cement, fly ash (Hanasaari hard coal power plant) and FGD products were part of a broader report on the environmental acceptability of using fly ash as a binder component in the stabilisation of the sediments. (Ramboll 2011d)

Environmental permit and the requirements

The environmental permit was granted for the Perkkaa Dog Park pilot application in June 2012 (Espoo City 2012). The permit set out certain requirements concerning the use of waste materials as binder components:

- The amount of the surplus soil that could be stabilised with a binder including fly ash was limited to 4000 t (≈ 2700 m^3). The maximum amount of fly ash from coal combustion allowed to be used for the stabilisation process was 3000 t and the maximum amount of the FGD was 1000 t.
- For the stabilisation process, a quality control plan was required and it was to be delivered to Espoo environmental centre 4 weeks before the stabilisation works. It was to include, among others, a plan for pH measurement for the subsoil clay before and after stabilisation, quality and the amount of the waste material.
- Stabilisation process cannot be executed during birds nesting season.
- The holder of environmental permit must be aware of the waste material origin and quality used in the stabilisation.
- During the stabilisation process amounts of the used material must be recorded.
- Project final report must be delivered to Espoo environmental centre at the latest 2 months after the project finishes.

Because of the permit conditions, the original design of the Perkkaa Dog Park had to be altered. According to the new design, in the central part of the area only surplus clay was to be stabilised, and the borders of the area were to be stabilised with cement only. Moreover, stabilisation was now planned to extend more deep at the border parts in comparison to the original plan.

3. Preliminary examinations

3.1 Stabilisation tests

The piloting action includes material tests in the laboratory before the launch of the construction works and the follow-up studies after the construction. The stabilisation properties of the materials are studied in laboratory by making specimens and studying the compressive strength of the specimen (diameter 42 mm and height 84 mm) after specified curing time. Unconfined compressive strength test is done according to the SFS 179-2 – CEN ISO/TS 17892-7:fi standard. Usually several different binders and binder amounts are tested to determine the most suitable binder mixture for the construction. This is a way to gather data about the structures and to create information about the properties and possibilities of the surplus soils. (Kreft-Burman et al. 2012)

The stabilisation tests were done:

a) with the soft soil material from subsoil of the park area,
b) with samples from mass replacement excavation (Tarvonsalmenkatu) and
c) with a mixture of the subsoil clay (a) and the clay from excavated clay (b).

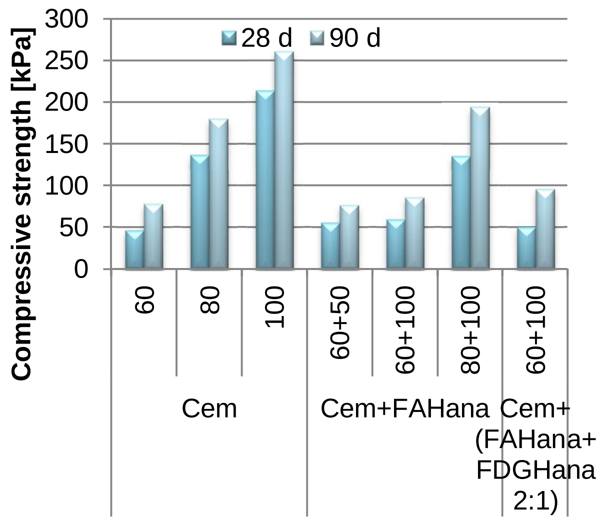
The index properties of the subsoil of Dog Park are presented in the table 3.2a and the index properties of the clay from mass replacement excavation are presented in the table 3.2b. The index properties of the samples from clay embankment before mass stabilisation are presented in the table 3.2c.

Both, commercial and alternative binder materials were tested. The alternative materials included fly ash (FA) from two different power plants (both wet and dry), gypsum (gyp.) and flue gas desulphurisation gypsum (FDG). The commercial binders tested were cement and lime-cement (KC).

The results of the stabilisation tests with cement and cement mixtures are shown in Figure 3.1 a and b. The results show that cement mixtures work similarly to when only cement is used but the mixtures bring a small benefit for the compressive strength. The two different fly ashes worked similarly when they were dry. The wet Inkoo fly ash did not improve the compressive strength with cement. The flue gas desulphurisation gypsum improved the 90 days compressive strength result slightly. The differences between the binder options could be clearer with longer curing time.

The results of the stabilisation tests with lime-cement (KC) mixtures are presented in Figure 3.1c. The results show that by using gypsum-KC -mixture the amount of KC can be dropped at least 30 kg/m^3. The other binder mixture options were not as feasible. By dropping the amount of cement or KC savings can be made and also the carbon footprint of the project decreases. The best binder option according to the stabilisation tests was KC-gypsum mixture. (Ollila et al. 2012)

a)



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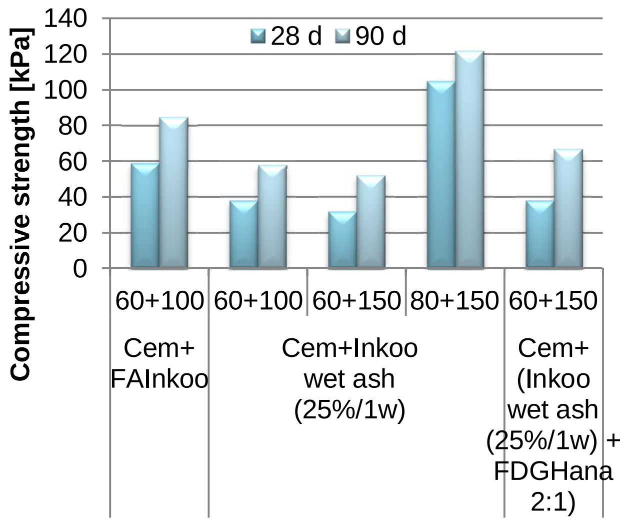
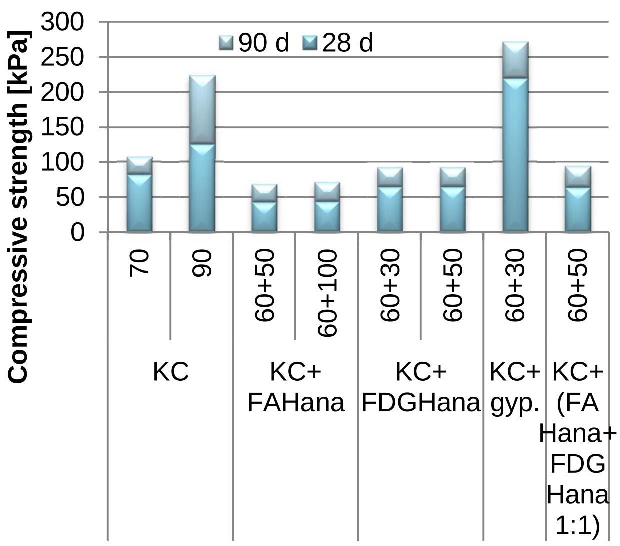


c)



FAHana – fly ash from the Hanasaari power plant
FDGHana – flue gas desulphurisation gypsum from Hanasaari
Cem – cement
FAInkoo – fly ash from the Inkoo power plant
Gyp – gypsum
KC – lime cement

Figure 3.1 Stabilisation test results made with subsoil samples of the dog park. Compressive strengths with: a) cement + fly ash (Hanasaari) + flue gas desulphurisation gypsum mixtures, b) cement + fly ash (Inkoo) + flue gas desulphurisation gypsum mixtures. 25 % /1w means that the ash has been put in a water content of 25 % and held there over a week before using the ash as a binder and c) KC and KC mixtures. (Ollila at al. 2012)

Table 3.1 Stabilisation test results made with subsoil samples of the dog park 2011 (a), with samples from mass replacement excavation 2012 (Tarvonsalmenkatu, b) and with a mixture of the subsoil clay and the excavated clay 2012 (c). Compression strength, 1-axial test. (Ramboll 2011c and Ramboll 2012c).

a) Code of the stab.area	Binder type	Binder amount	z	Subsoil clay and mud Compressive strength [kPa]	
				28 d	90 d
area A, B	CEM/B-M (S-LL) 42.5 N	80 kg/m^3	0…2 m	137	180
			0…1 m	105	118
			1…2 m	230	308
			2…3 m	368	512
area C	Se + FA:FGD (1:1)	60 + 100 kg/m^3	-	-	-
area D	Se + FA	60 + 100 kg/m^3	0…2 m	60	86
area E	CaOSe (3:7) + FGD	60 + 50 kg/m^3	0…2 m	65	92

b) Code of the stab.area	Binder type	Binder amount	z	Adjacent construction site clay Compressive strength [kPa]	
				28 d	90 d
area A, B	CEM/B-M (S-LL) 42.5 N	80 kg/m^3	0…2 m	502/462	482
			2…3.8 m	636/620	628
area C	Se + FA:FGD (1:1)	60 + 100 kg/m^3	-	-	-
area D	Se + FA	60 + 100 kg/m^3	0…2 m	341/332	337
			2…3.8	539/566	553
area E	CaOSe (3:7) + FGD	60 + 50 kg/m^3	0…2 m	389/392	391
			2…3.8	329/284	307

c) Code of the stab.area	Binder type	Binder amount	z	Subsoil clay and mud + adjacent construction site clay Compressive strength [kPa]	
				28 d	90 d
area A, B	CEM/B-M (S-LL) 42,5 N	80 kg/m^3	0…2 m + 0…2 m (1:1)	275/299	287
area D	Se + FA	60 + 100 kg/m^3	0…2 m + 0…2 m (1:1)	157/178	168

Table 3.2 Index properties of soil samples from Dog Park subsoil 03/2011 (a), from mass replacement excavation 03/2012 (Ramboll 2012) (b) and from clay embankment before mass stabilisation 9-22.1.2013 (c). The locations of the sampling points K1, K2 and K3 are presented in the picture 5.3 (Ramboll 2013)

a) Depth [m]	Soil	Soil, EU	Soil, Fin.	Water content [%]	Loss of ignition [%]	Density [kg/m^3]
0...1	clay mud	-	SaLj	88.8	9.6	1460
1...2	organic clay	-	ljSa	111	5.9	1400
2...3	clay	-	Sa	103	3.6	1440

b) Depth [m]	Soil	Soil, EU	Soil, Fin.	Water content [%]	Loss of ignition [%]	Density [kg/m^3]
0...1	Clay	Cl	liSa	77.0	4.2	1540
1...2	Clay	Cl	liSa	93.5	3.6	1480
2...3	Silty Clay	siCl	laSa	42.7	1.7	1800
≈ 3.8	Silt	clSi	saSi	30.3	0.9	1960

c) Sampling point*	Depth [m]						
	0 m	0.5 m	1 m	1.5 m	1.8 m	2 m	$w_{average}$
K1	80.1 %	93.7 %	42.9 %	62.7 %	68.2 %	-	69.5 %
K2	30.0 %	43.0 %	49.7 %	-	-	83.1 %	51.5 %
K3	81.0 %	138.9 %	63.3 %	66.9 %	-	-	87.5 %
K4	-	29.6%	32.7%	47.5%	-	-	36.6%
K5	-	25.7%	30.4%	64.3%	-	-	40.1%

*Location of sampling point K1 – block 20; K2 – block 23; K3 – block 31; K4 – block 90; K5 – block 95

3.2 Leaching tests

The sediment samples used for the leaching tests originated from Perkkaa Dog Park subsoil. The test method applied was based on a Dutch standard NVN 7347/1999. The results indicate the amount of contaminants diffusing from the open surface of a test piece into the surrounding water during a certain time period. The amounts of the leaching contaminants are compared to the limit values set for a solidified material (a layer made of such solidified material cannot be thicker than 0.7m). The test results indicated that the leaching values were clearly below the limit. For diffusion tests there is no limit set by the Finnish Environment Institute for sulphate and chloride leaching. However, it was observed that leaching of sulphate and chloride occurs also in samples stabilised only with cement. (Ramboll 2012b)

The soil samples used in the leaching test were taken 03/2012 from the depth of 1-2 m from the mass replacement area (Table 3.1.d). The binders were Plus Cement, CaO, fly ash and FGD from Hanasaari plant (Helsingin Energia). The binder mixtures are presented in the Table 3.2.

Table 3.3 Leaching test samples and pH and Electricity conductivity test results.

Sample code	Binder type	Binder amount [kg/m^3]	Time of water change [d]	pH	Electricity conductivity +25 °C [mS/m]
PU-1A	Se + FA (PlusCement)	60 + 100	4	9.6	4.2
			14	9.4	7.3
			66	8.9	14.0
PU-2A	CaOSe (3:7) + FGD	18 + 42 + 50	4	10.2	24.4
			14	9.8	41.6
			66	9.2	76.7
PU-3A	CEM/B-M (S-LL) 42.5 N	80	4	10.0	6.4
			14	9.9	9.4
			66	9.7	18.4
PU-4A	-	-	4	8.3	3.2
			14	8.0	5.2
			66	8.3	11.9

For the clay specimen stabilised with cement only, the results reveal that the solubility of antimony exceeds the limit value set by the Dutch standards for the permanently and timely humid location. However, the results for antimony are below the Finnish limit values. For other harmful substances, the results are below the limit values.

In the case of a clay specimen stabilised with cement and fly ash from the Hanasaari power plant, the results for the solubility of harmful substances were clearly below both the Dutch and Finnish limit values. The use of fly ash and cement as a binder instead of cement only allows for lower solubility of antimony.

The test results for clay specimen stabilised with the mixture of CaO, cement and FGD reveal that the solubility of chloride and antimony exceeds the Dutch limit values. The high solubility of chloride results from the use of FGD. The result for antimony is below the Finnish limit value and it is also lower than for the sample stabilised with cement.

Based on the leaching test results, it can be concluded that the typically tested leaching parameters for fly ash remain on a low level. Therefore, fly ash from the Hanasaari power plant is a suitable component for a binder mixture in stabilisation of clays and it can also replace commercial binder components. As for the FGD, the solubility of chloride needs to be taken into consideration in each application as chlorides might have a corrosive impact on steal structures.

3.3 Sulphide clay tests

The surplus clay deposited in the Perkkaa Dog Park area originates from mass exchange works carried out in the Tarvonsalmenkatu Street. Mass exchange works in this target started in winter 2012 and lasted till spring, the same year. Clay samples were taken with excavator and tested in the laboratory in 2013. Index property and stabilisation test were carried out. The water content results for samples K1-K3 are presented in Table 3.2.c.

The Geological Survey of Finland (GTK) investigated the geotechnical and geochemical properties of the overburden from the Perkkaa Dog Park. The test results are presented in a report called “The properties and layer structure of the fine-grained soils in the Perkkaa and Mustalahti areas”. (Ojala 2009)

According to the results of the above-mentioned report and some earlier studies conducted by the GTK, the clay deposited within the Perkkaa Dog Park embankment contains sulphur. The sulphur content is on the same level according to the tests carried out currently and in 2009 (GTK). In all the samples apart from one, the pH level is >4.5. This means that the formation of sulphuric acid in consequence of oxidation is likely to happen unless the clay is treated with, for instance, stabilisation method which will increase the pH level.

The stabilisation tests made for the surplus clays reveal that the stabilised material hardens well. The water content of the “natural soil” which is under the stabilised clay layer is higher and therefore hardening is weaker there.

4. Construction of adjacent streets as a source of surplus soils

The construction process was designed so that the stabilisation work was done on site. The stabilisation was planned to be performed with the mass stabilisation method. Before the stabilisation work trees and their roots was removed. The surplus clay from the adjacent streets was transported to the stabilisation site where the material was stockpiled in the area surrounded with an embankment (Figure 4.1). The embankment purpose was to prevent the escape of the fluid clay material out from the stabilisation area (Figure 4.2).

The surplus clay is from the adjacent construction site to the Dog Park. Distance between the two construction sites is only 200….400 meters (see Figure 4.1). The clay is excavated before the mass replacement of the adjacent street foundation. The transportation distance to the landfill would have been about 22 km, if it wasn´t possible to use the surplus clays in the construction of the Dog Park. The surplus clay is very troublesome and expensive material to dump to the landfill site.

The transportation and the construction of the surplus clay embankment took place at January to March 2012.

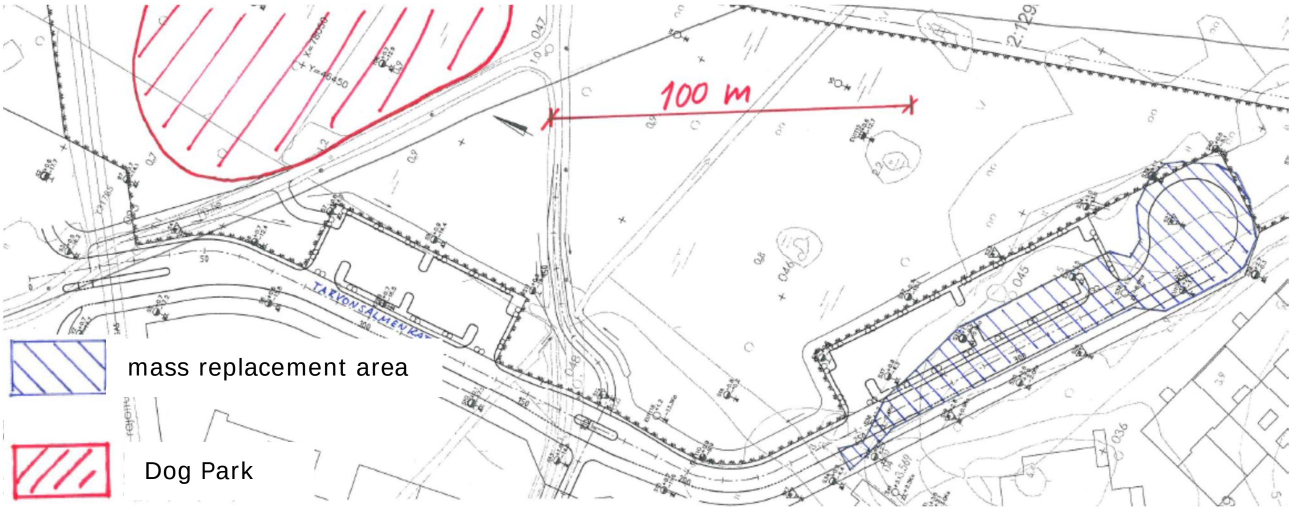


Figure 4.1 The location of the mass excavation area. The excavated excess clay and mud is used to the embankment of the Dog Park

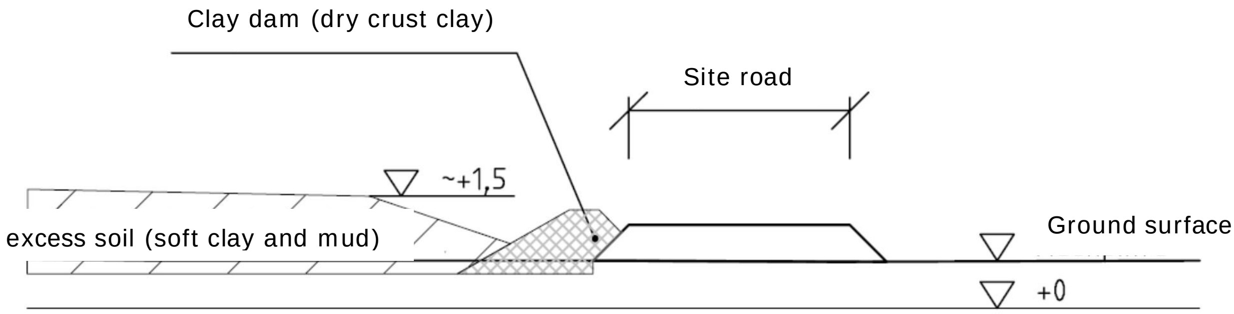


Figure 4.2 Principles of the surplus clay dumping in the area of the Dog Park. Dumping of the soft clay and mud were done inside the dry crust clay embankment (clay dam).

5. Mass stabilisation

5.1 Mass stabilisation method

Mass stabilisation is a ground improvement method for soft soils such as clays, silts and peat. Mass stabilisation is mixing technology where a predefined amount of dry and moist binders are applied to soft ground with special mixing equipment attached to excavator (Figure 5.1). Mixing is done in vertical and horizontal directions. Due to hardening reactions in the ground a strengthened block of soil is created.

Important aspect of stabilisation technology is winter adaptability. The method can be applied in winter conditions such as snow fall and minus temperature (as seen in Perkkaa Dog Park construction site in Figure 5.2).

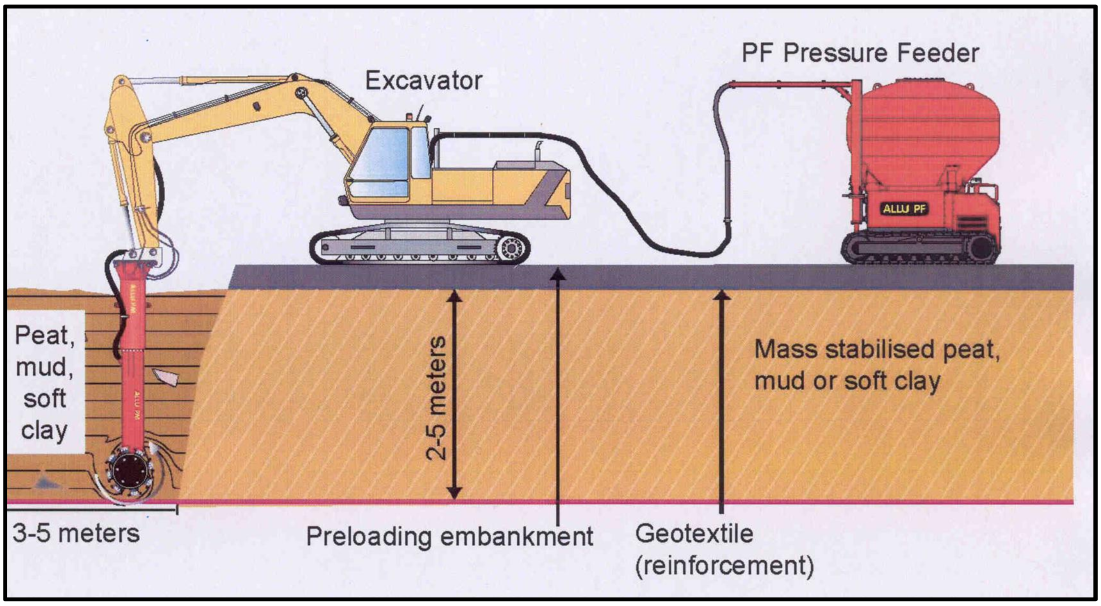


Figure 5.1 Illustration of the mass stabilisation method

Figure 5.2 Mass stabilisation work carried out in winter conditions in Espoo, Finland (15.1.2013)

5.2 Stabilisation areas and binders

The designed area was divided into different sections according to the binder recipes to be applied. The chosen binder recipes are presented in Table 5.1. The areas (code names) are presented it Figure 5.3.

Table 5.1 Binder recipes used in sections A – E.

Code name	Area	Binder recipe
A	Cement stabilised area, "big dogs"	CEM/B-M (S-LL) 42.5 N 80 kg/m^3
B	Cement stabilised area, "small dogs "	CEM/B-M (S-LL) 42.5 N 80 kg/m^3
C	Ash stabilisation area, TS1 west part	Se 60 kg/m^3 + LT/RPT (1:1) 100 kg/m^3
D	Ash stabilisation area, TS1 east part	Se 60 kg/m^3 + LT 100 kg/m^3
E	Ash stabilisation area, TS2	CaOSe (3:7) 60 kg/m^3 + RPT 50 kg/m^3

The pilot project was required to obtain the approval of the environmental authorities before the construction process could have begun because ashes from coal burning were planned to be used in the stabilisation. The environmental authorities categorise ashes as waste. The construction work began about 6 months after the environmental permit was granted.

5.3 Implementation

The designer creates a stabilisation map. The stabilisation contractor makes a stabilisation work plan on top of the stabilisation map. The stabilisation work plan shows the location of the areas and blocks to be stabilised. The contractors work plan is based on stabilisation blocks. Stabilisation block is a basic unit, and takes a certain amount of binder. The width and length of the block ranges normally from 4 … 5 m x 4 … 5 m.

Immediately after stabilisation, a 0.5 meter high compaction embankment is constructed of gravel or crushed rock, on top of the stabilised material. Before the construction of the embankment, a non-woven is spread over the mass stabilised clay. This embankment consolidates/compacts the stabilised material and finally remains as part of the surface structure of dog park.

Mass stabilisation includes the following work steps:

- harrowing and homogenisation of the stabilised surface
- plotting and marking the corner points of the stabilisation blocks
- construction of platform (e.g. timber grating)
- mass stabilisation work of surplus clay and subsoil
- construction of the compaction embankment on top of the stabilised layer
- quality assurance soundings and test pits after stabilisation and strengthening period

5.4 Weather

The weather conditions during the stabilisation are presented in this paragraph. The actual stabilisation work happened during the time period 7.1.2013 … 7.2.2013. During this period the minimum daily temperature was ranging between -27 °C … +1 °C. The average daily minimum temperature during the 31 days was -10 °C. During the period the daily maximum temperature was ranging between -15 °C … +2 °C. The average maximum temperature during that time was -4 °C. During the stabilisation, the weekly average minimum and maximum temperatures are shown in table 5.2.

During the stabilisation period, on 93 % of the workdays it was snowing. On 26 % of the days it was raining. After the stabilisation work, during the hardening period between 8. … 28.2.2013 the average daily minimum and maximum temperatures were -6 … 0 °C.

The weather observations originate from the Helsinki-Malmi weather station.

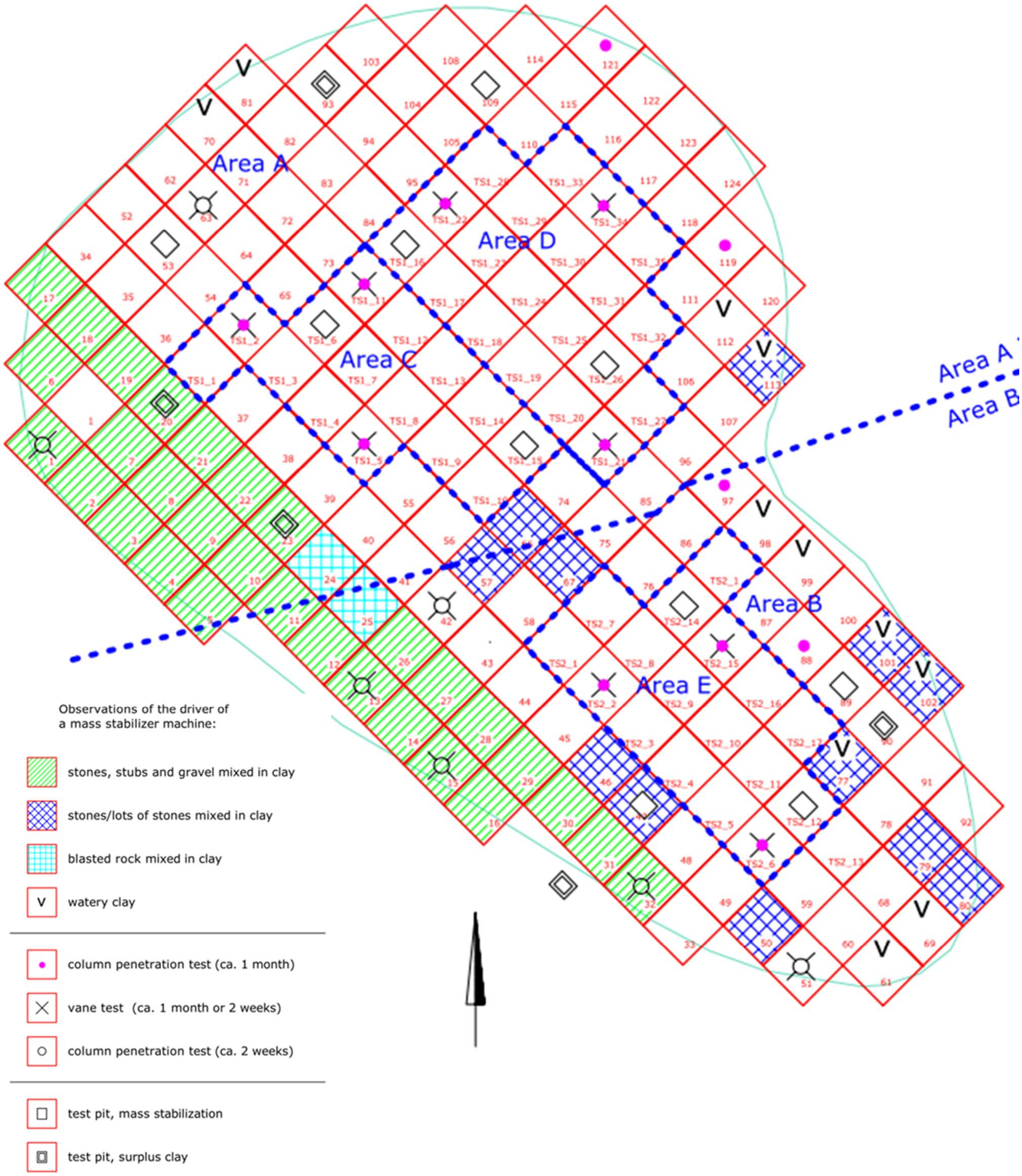


Figure 5.3 Mass stabilisation areas A...E and stabilisation block. The figure also presents the observations of the clay by a driver of a mass stabiliser machine and blocks in which had made quality control soundings and test pits (in some test pits there were samples before mass stabilisation).

Table 5.2 The average minimum and maximum temperatures.

Week	average minimum temperature °C	average maximum temperature °C
Week 2	-9	-4
Week 3	-16	-7
Week 4	-13	-5
Week 5	-3	0
Week 6	-4	-1

6. Quality control during stabilisation works

During the stabilisation work, the following quality control actions were carried out:

- Working practice for overseeing the mixing of binders (the machine operator of the contractor controls visually that the binder is mixed evenly to the stabilised material).
- The amount of used binder is confirmed by weighing on the scales used in binder tanks and the total amount delivered to the work cite.
- The designer went to the construction site and followed the construction process, photo- and video documented the work progress.
- The contractor keeps a record of the stabilisation process including the following information about the stabilisation block: width and length, stabilisation depth and date, used binder amount, other observations made by the machine operator including (stones, boulders, stubs and watery, etc.)
- Quality control soundings – to make sure that the material is strengthening.

The contractor records of the stabilisation process are presented in attachments (see ANNEX 1).

Nine test pits were excavated in the stabilised layer during the stabilisation work. In order to ensure the start of strengthening in the cement stabilised layer, 14…15 days hardened cement stabilised clay was controlled with quality control soundings between 21. – 22.1.2013.

The sounding methods applied in this target included the column penetration method and vane penetrometer for column method (the methods are presented in section 7.2 "Quality control soundings". The location of the test pits are presented in picture 5.3. The results of the soundings are shown as average diagrams in Figures 9.1 … 9.11. Based on the sounding results, the stabilisation and strengthening has started well and there was no reason to change the binder amounts during construction.

7. Quality control after stabilisation

7.1 Principles

The quality control (assurance) after stabilisation is easier in mass stabilisation than in column stabilisation. Different requirements for precision can be applied in control practices. Quality control after stabilisation can be done with geotechnical soundings and with test pit excavations.

In addition to routine quality control actions plenty of product development tasks of environmental geotechnics can be applied. Like in this project, lysimeters were installed made inside the stabilised structures.

7.2 Quality control soundings

Column penetrometer (Figure 7.1 and Figure 7.3.a) and vane penetrometer for columns (Figure 7.2 and Figure 7.3.b) are two most common methods for quality control soundings in mass stabilised structures. Column penetration sounding is by far the most used method of quality control for deep stabilisation (column stabilisation and mass stabilisation) in Finland and Sweden. In addition to this the selected surveying can be also vane shear testing with vane shear apparatus. The soundings give information about the strength properties of the material.

The column penetrometer sounding equipment is described in detail in Figure 7.1. The dimensions width of the column sounding tip is 375 mm. Other dimensions of the tip are presented in Figure 7.3.a). The two most important dimensioning values one-axial compression strength and shear strength can be defined with the column penetrometer test method. The method is relatively fast. The measured penetration resistance can be converted into shear strength value with a specific N_c-factor. The column penetrometer method, however, is not flawless. In some cases, on the basis of the column soundings it is virtually impossible to tell if the material examined is of a homogenous, continuous structure ("a monolith") or if there are strength variations within the material, e.g. the material is a non-uniformly strengthened mixture of strengthened granules/lumps and un-strengthened soil. To determine this test pits were made.

The vane penetrometer for columns method gives the shear strength of material. The method is slower, more complicated and more expensive than the column penetrometer method. In addition, the shear strength results are for singular measure points. The resulting strength curve is therefore not continuous. The method and the equipment are shown in Figure 7.2 and Figure 7.3. b). The dimension of the tip of the vane penetrometer for columns is defined according to the materials strength. A larger vane is suitable for softer material. One positive aspect of the vane penetrometer includes the possibility to obtain direct results of shear strength. The negative aspects are non-continuous measurement results, relatively slow method for surveying and high price. Although the method can be used to define the shear strength value of the material as it is, the method is mostly used in practice as an aid for interpreting the results of conventional penetrometer tests.

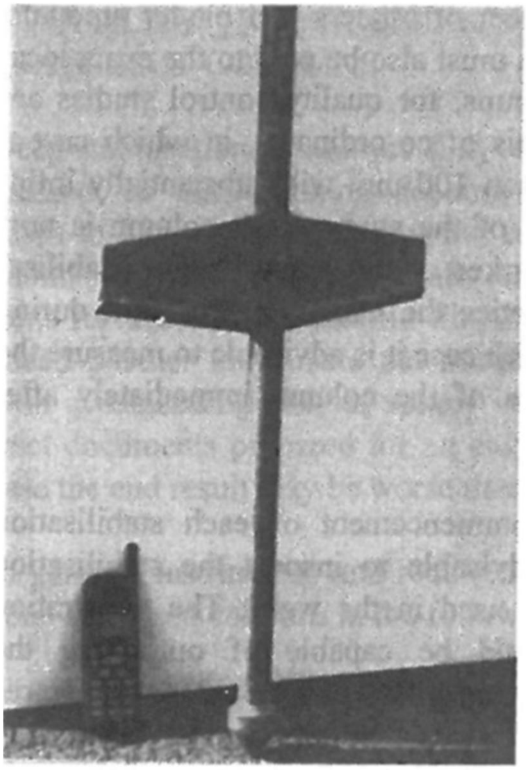


Figure 1. Column penetrometer

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON DRY MIX METHODS FOR DEEP SOIL STABILIZATION/STOCKHOLM/SWEDEN/13–15 OCTOBER 1999

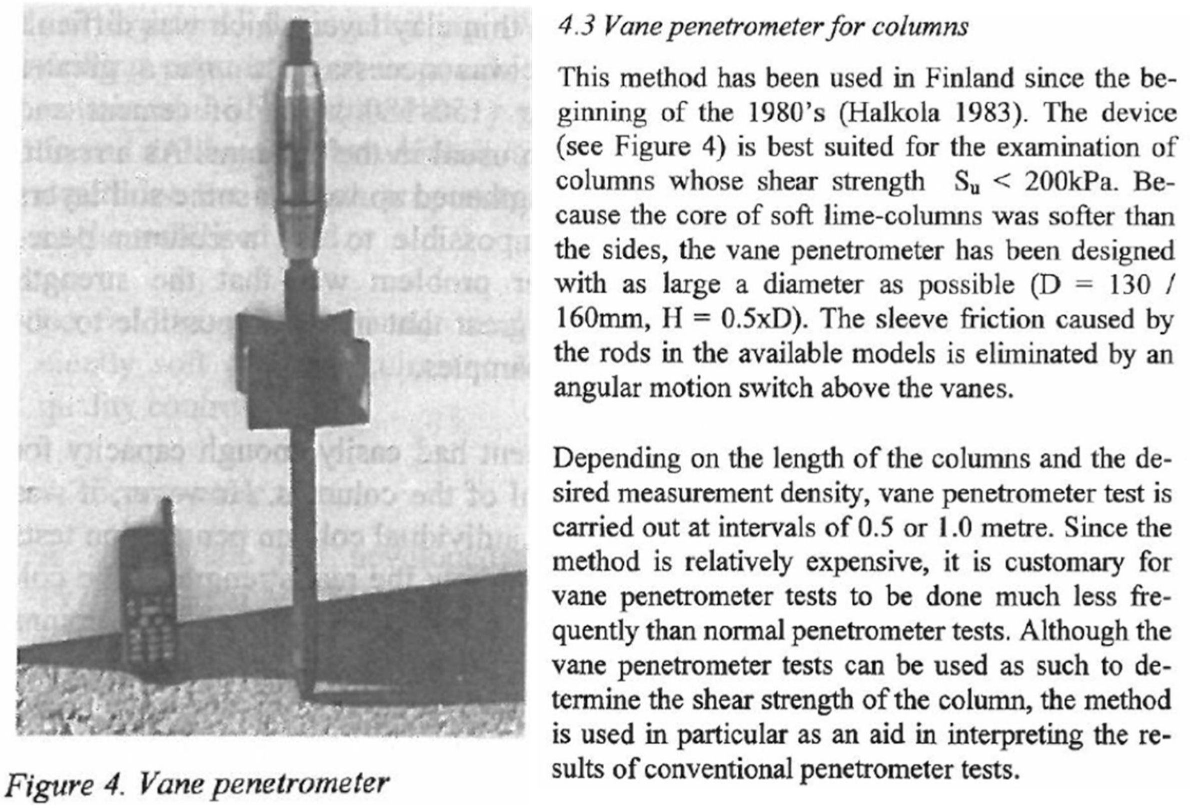
Dry Mix Methods for Deep Soil Stabilization

4.2 Column penetrometer

In this method a mechanical penetrometer equipped with two vanes (see Figure 1) is pressed down (without rotation), and the compressive strength employed is measured at the upper end of the penetrometer rod. The cross-sectional area of the penetrometer is A = 100cm2 and the diameter D = 375mm. The device was originally developed in Sweden at the start of the 1980's (Torstensson 1980) and a slightly adapted version was used in Finland from 1981 (Halkola 1983). The aim was to shape the penetrometer head so that the sleeve friction would be as little as possible and that the penetrating resistance would be mainly formed outside the centre part of the column.

Because the cross-sectional area of the column penetrometer is ten times as large as that of a normal CPT cone, its application area (due to its capacity) is in relatively soft columns in which the shear strength $S_u < 200$ kPa. Because the penetrometer is durable, the dynamic penetration method has been experimented with in the harder columns, although the interpretation of results has then proved more difficult. As the dimensioning value used in engineering is either uni-axial compressive strength or shear strength, the measured penetration resistance is converted into shear strength by dividing it by the factor $N_c = 10$ (in Sweden) or $N_c = 10\text{-}15$ (in Finland). In Finland the shear strength values measured by the vane penetrometer are used in defining the N_c-factor.

Figure 7.1 Column penetrometer method (Halkola 1999)



4.3 Vane penetrometer for columns

This method has been used in Finland since the beginning of the 1980's (Halkola 1983). The device (see Figure 4) is best suited for the examination of columns whose shear strength $S_u < 200kPa$. Because the core of soft lime-columns was softer than the sides, the vane penetrometer has been designed with as large a diameter as possible (D = 130 / 160mm, H = 0.5xD). The sleeve friction caused by the rods in the available models is eliminated by an angular motion switch above the vanes.

Depending on the length of the columns and the desired measurement density, vane penetrometer test is carried out at intervals of 0.5 or 1.0 metre. Since the method is relatively expensive, it is customary for vane penetrometer tests to be done much less frequently than normal penetrometer tests. Although the vane penetrometer tests can be used as such to determine the shear strength of the column, the method is used in particular as an aid in interpreting the results of conventional penetrometer tests.

Figure 4. Vane penetrometer

Figure 7.2 Vane penetrometer for columns method (Halkola 1999)

a) b)

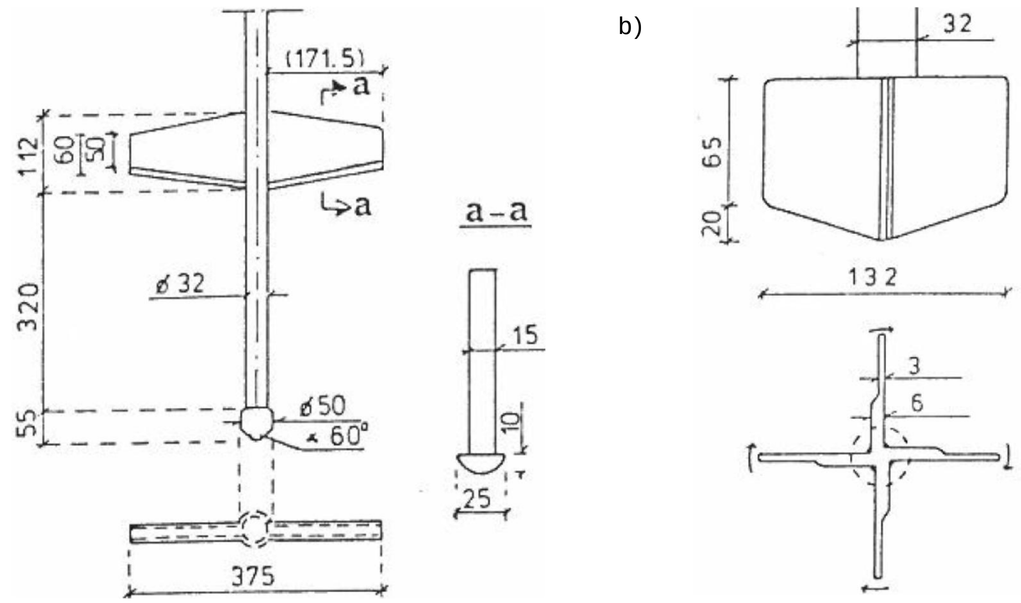
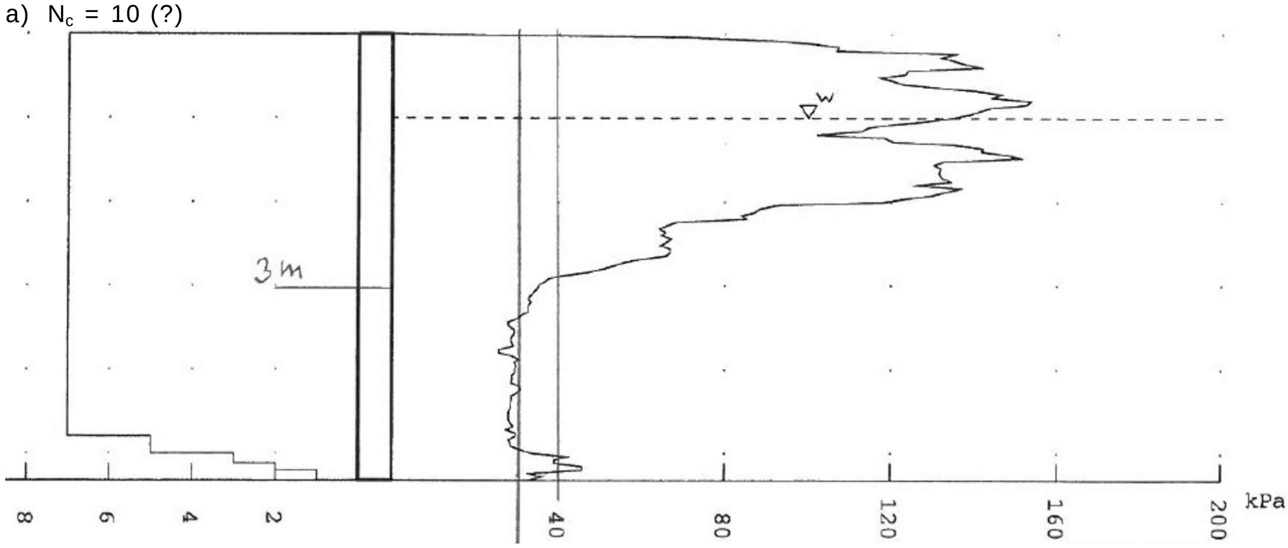


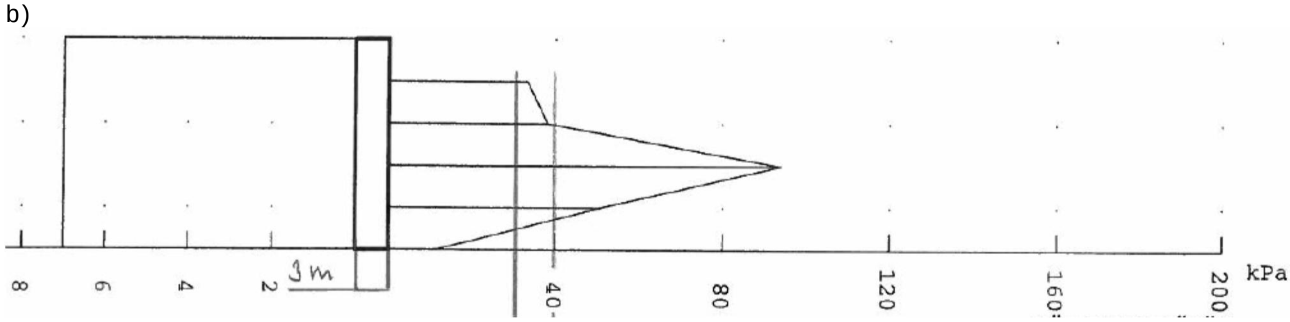
Figure 7.3 Dimensions for the sounding tip of (a) column penetrometer and (b) vane penetrometer for columns (Rakennusteollisuusyhdistys 1991)

a) N_c = 10 (?)



Number of soundings Shear strength

b)



Number of soundings Shear strength

Figure 7.4 Mass stabilisation control soundings (carried out in 21.-22.1.2013) results during mass stabilisation. The hardening time of the mass stabilisation has been 14...15 days before soundings. a) Column penetration method and b) Vane penetrometer for column method. In the Figure a) the N_c-factor has a “standard” value 10.

7.3 Quality Control test pits

7.3.1 Quality follow-up measurement equipment and test methods

In addition to soundings, the stabilised structure can be examined by making test pits. Plenty of different things can be tested in the field on-site and in the laboratory with test samples taken from the field. These include strength properties, variation of strength and spreading of binders, frost susceptibility or water permeability. The test pits are made with an excavator to each test pit to the objective depth. Different properties and parameters of the stabilised material can be tested in the field. Additionally material samples are taken for further laboratory testing. The used field-test methods were:

- Excavation of test pits and reporting
- Photograph documentation and depth profiling
- Pocket vane shear apparatus (hand held)
- Hand held penetrometer testing
- NITON XRF (hand held)
- Sampling for laboratory - defining water content, pH and block samples

Test pits are excavated in the stabilised structure. In total, 10 test pits were excavated. Documentation of field studies on supplemented with heavy photographing which will result in proper documentation. Documentation includes remarks about the condition of the test pit, possible slope failure and observations based on visual and smell observation about stabilisation processes. Possible anomalies are reported. Each test pit is well photographed in each depth level. The excavation proceeded step by step every 0.5 meter. The tested material was laying on the grab of the excavator. The sampling and test pit depth was verified with a measuring instrument and photographing. Field tests such as hand held penetrometer testing was done straight from the grab. In addition samples were taken straight from the grab. The pocket vane shear testing was done every 0.5 m in depth profile and hand held penetrometer testing was done every 0.2 m. The Niton XRF measurements were done partially in the field and there rest (each 0.5 m in depth profile) were done later in the laboratory from samples delivered there. Niton XRF measures the chemical substances in the material in this case the Ca-content. Ca-content is an indication of the binder spreading into the material. Material testing and sampling (defining water content, pH and block samples) were done until 3.0 m in cement stabilised area (A+B) and until 1.5 m in areas (C+D+E). In addition the objective was to take samples 0.2 m and 0.5 m below the end surface of stabilisation layer. Undisturbed test samples were taken from the stabilised test pits and delivered to laboratory, if the properties of the material were suitable for this.

The excavation process and documentation (photographing + depth profiling) are shown in Figure 7.5. Material testing and sampling from the grab is shown in Figure 7.6. Niton XRF field measurement process is shown in Figure 7.7. Pocket vane shear apparatus (hand held) is shown in Figure 7.8.a and material testing on a grab is shown in Figure 7.7.b. Hand held penetrometer test equipment is show in Figure 7.9. Sampling work for water content testing in the laboratory is shown in Figure 7.10.

The portable hand held NITON XRF analyser can be used to measure the amount of Ca in the test sample (Figure). These figures give an overall idea of the amount of binder in the stabilised material. The testing can be done in the field (Figure 7.7) or samples can be taken to the laboratory. The average values can be calculated from multiple measurements.

The hand held vane shear test apparatus (Figure 7.8.a) can be used to measure the vane shear strength of the stabilised material from a stabilised block. The test method is used on the material excavated and held on the grab see Figure 7.8.b. The material laying on the grab is tested. Three different vane sizes are available for the vane shear strength testing. In this case, the middle-sized vane was used. Different size gives the materials vane shear strength when calculated with a correction number.

In addition to hand held pocket vane shear testing, a method of using hand penetrometer testing can be applied. The penetrometer (see the device in Figure 7.9) has different (compression strings) and cones. A certain combination of string and cone is selected for expected strength of materials. The dimensions of the chosen cones define the calculation parameters. In the end, the method gives a result of compression strength. In this project the chosen cone size was 0.5 cm^2. The chosen spring pressure was 50 N.

Samples were collected from the test pits and they were their water content and pH were analysed. In addition, this testing was done for the surplus clay before stabilisation. *Figure* shows a step in laboratory water content characterisation testing.

a)

b)

c)

Figure 7.5 Excavating test pits; documentation and depth profiling

a)

b)

c)

Figure 7.6 Material on grab and sampling

Figure 7.7 NITON XRF - testing in the field

a)

b)

Figure 7.8 Hand held vane shear test apparatus a) source: (www.esands.com) b) testing in the field

Figure 7.9 Handheld Penetrometer (wwwi.eijkelkamp.com)

a)

b)

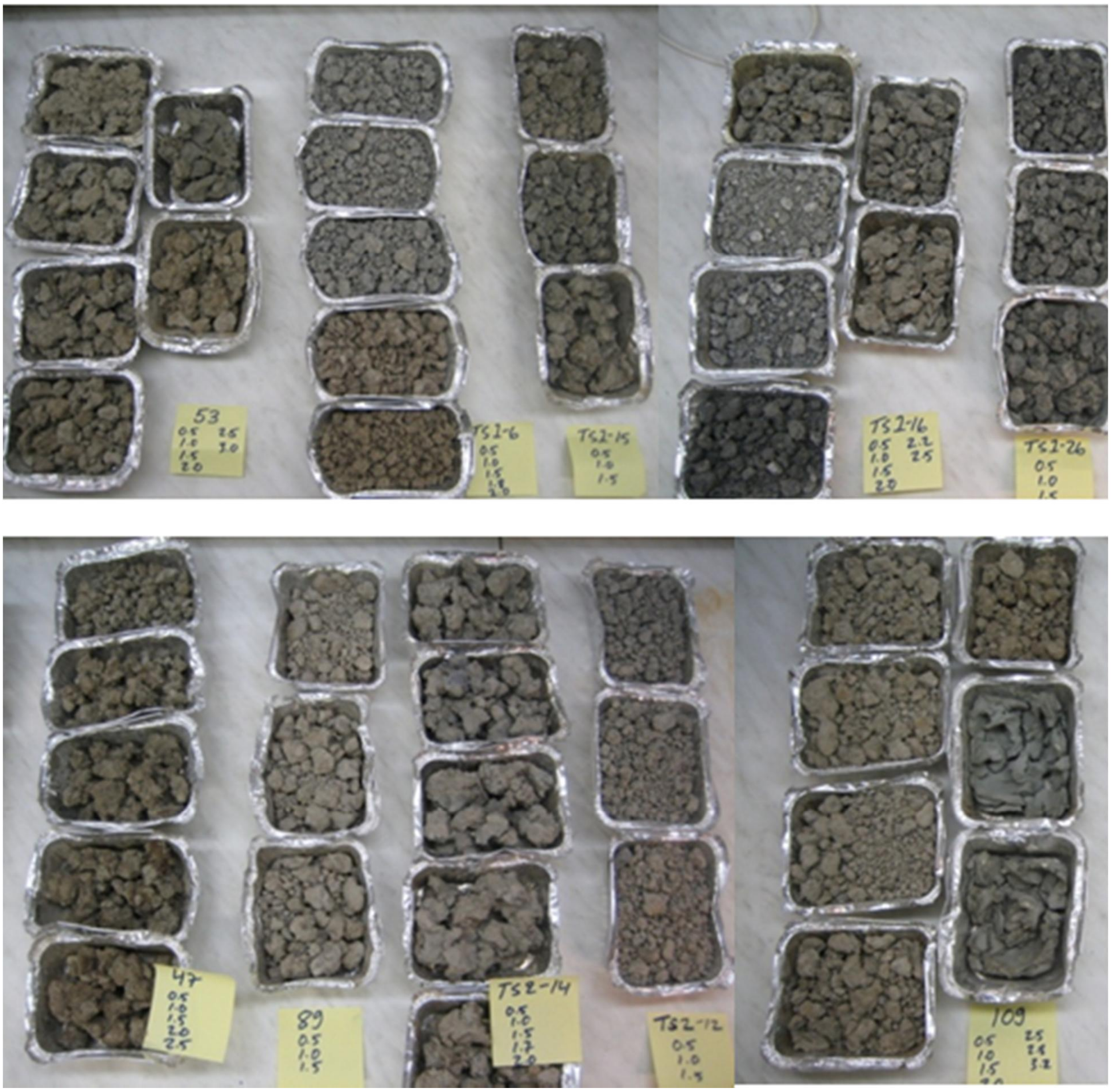


Figure 7.10 Material sampling in laboratory for water content testing a) test pits 53, TS1_6, TS1_15, TS1_16, TS1_26 b) test pits 47, 89, TS2_14, TS2_12, 109

8. Quality control test results

8.1 Before stabilisation

The surplus clay (to be stabilised) was tested for pH and water content while the work was in progress. The surplus clay samples were analysed in the laboratory for water contents and pH. A sulphide clay characterisation was also performed.

Table 8.1 Test results of surplus clay (water content & sulphide clay)

Sample	Stabilization block	Sampling date	depth (m)	w / water content (%)	pH	Sulfide clay characterization	Testing date
Surplus Clay	20	9.1.2013	0.0	80.1		II	11.1.2013
			0.5	93.7	5.5	DII	
			1.0	42.9	6.5	not sulfide clay	
			1.5	62.7	5.8	DIII	
			1.8-1.9	68.2		I	
Surplus Clay	23	9.1.2013	0.0	30.0		not sulfide clay	11.1.2013
			0.5	43.0	6.9	not sulfide clay	
			1.0	49.7	6.9	not sulfide clay	
			2.0	83.1	4.5	DIII	
Surplus Clay	next to 31	9.1.2013	0.0	81.0		II	11.1.2013
			0.5	138.9		I	
			1.0	63.3		II	
			1.5	66.9		I	
Surplus Clay	90	22.1.2013	0.5	29.6			31.1.2013
			1.0	32.7			
			1.5	47.5			
Surplus Clay	93	22.1.2013	0.5	25.7			30.1.2013
			1.0	30.4			
			1.5	64.3			

8.2 After stabilisation - excavation of test pits and photographing

The stabilisation area was divided into subareas. Two test pits were excavated in each subarea. Table 8.2 shows the categories for different areas and the excavated test pits. In order to make profound quality control testing, a group of test pits was needed for examination.

Table 8.2. Test pits in different areas

Area	TEST PIT number (number is a reference to the stabilised block)
A ("big dogs")	53, 109
B ("small dogs")	47, 89
C ("TS1 west part ")	TS1_6, TS1_15
D ("TS1 east part ")	TS1_16, TS1_26
E ("TS2")	TS2_14, TS2_12

In this paragraph short introduction is given to test pits. Plenty of test pits photographs were taken to ensure proper documentation. Photographing is a valid way of documenting the visual aspects of stabilised structures. In this paragraph, photos including comments about the visual aspects of each test pit are presented. Photographs from areas A and B are presented in Figure 8.1 and 8.2. Photographs from areas TS1 east and TS1 west are presented in Figures 8.3 and 8.4. Photographs from area TS2 is presented in Figure 8.5. The location of the examined test pits are shown in Figure 8.6.

Area A, BLOCK 53:

The excavation pit held form until 2.5 m depth. In depth 1.2 ... 1.4 m the material was more soft but stiff. In 2.0 m the material was sometimes so hard that vane shear apparatus could not penetrate the material. A bad slope failure came when excavating in depth of 3.0 meters. In 2.5 meters the sample in the grab contained a stream of binder. The sampling done in depth 2.5 ... 3.0 m is inaccurate. Here, it was impossible to keep track of exact layers of materials due to uncontrolled mixing.

Area A, BLOCK 109:

Every 0.5 meters until 2.5 meters the material can be categorised "hard" throughout the depth layer. Once the material was so hard that vane shear apparatus did not penetrate the material. The first slope failures were detected in level 2.5 m. Stabilisation ended about 2.6 m deep.

Figure 8.1 Cement stabilised areas A – one figure from each test pit.

Area B, BLOCK 47:

In the depth of 1.0 the material was once so hard that vane shear apparatus did not penetrate the material. In general, the material was coarse and seemed more stabilised. In depth 1.0 m were very hard pieces of stabilised material. A clear odour of stabilisation was present. In 1.5 m the material was more sticky. It was hard to make evened surface for penetrometer or vane shear apparatus. The last sample was taken in the depth of 2.5 m since it was clearly seen that the earth pressure was very high.

Area B, BLOCK 89:

Samples were taken from the test pit. No vane shear or penetrometer testing was able to be made in the test field due to practical reasons. The material however was stabilised and proper.

Figure 8.2 Cement stabilised area B – one figure from each test pit.

Area C, BLOCK: TS1_16

When opened the stabilised material was still going through stabilisation reactions. The mass was warm and warm water vapor was present in the air. In the depth interval of 0.75 … 1.5 m a clear white gray (clearly visible) monolithic layer of stabilised material was present. In depth intervals 1.0 … 1.5 m the material was very unhomogenious. In 1.5 m it was not possible to penetrate the material with vane shear apparatus.

Area C, BLOCK: TS_26:

In depth of 0.5 m the binder is spread evenly. In depth of 1,0 m the vane shear apparatus did not penetrate the material. In 1.0 … 1.5 the distribution of binder is uneven. There are occasionally very hard pieces of stabilised material. The orange coloured ground layer was visible in depth of 1.5 … 1.6 meters. 2 hard test pieces were taken from the test pit.

Figure 8.3 Stabilised test area C (TS1 west) - one picture from each test pit.

Area D, TS1_6:

The material was fairly homogenious and had characteristics of stiff stabilised material. Water came to the test pit in depth of 1.0 m. The spreading of binder was even – black spots were everywhere. Black spots indicate the presence of fly ash. In 1.5 m the material was stiff and very hard blocks of material were present. In general the excavation pit was very clean and held well its form. The non stabilised ground was visible in depth of 1.6 … 1.8 m. A test sample was taken in depth of 1.0 m.

Area D, TS1_15:

The material was fairly homogenious throughout the depth profile 0 … 1.5 m. The material was stiff-like stabilised mass. However it was not possible to take an undisturbed test sample.

Figure 8.4 Stabilised test areas, area D (TS1 east) - one picture from each test pit.

Area E, TS2_12:

The excavation pit and the test materials can be categorized as excellent. The material was hard. The material is black, has excellent stiffness and hard pieces of stabilised materials. Plenty of hard blocks present in the test pit. A sample was taken of a hard piece. Once in depth of 1.0 m and 1.5 m it was not possible to penetrate the material with vane shear apparatus.

Area E, TS2_14:

The stabilised mass seemed soft in 0.5 m. Material was vatery and soft in 1.0 m. In depth 1.5 the material was unhomogenious, soft and coarse containing a lot of organic material. The material was soft throughout. It was not possible to take a block like test sample due to soft material characteristics. In depth of 1.5 ... 2.0 m clearly visible earth pressure was identified. Deeper excavation would not have been adviced.

Figure 8.5 Stabilised test area (TS2) - one picture from each teat pit.

8.3 Quality follow-up measurement equipment

8.3.1 Test results stabilised areas A – E

The quality follow-up testing was done for the stabilised materials. The strength properties of the materials were tested in the field with penetrometer and pocket vane testing equipment. Samples were taken laboratory for water content, pH and calcium content testing. The results of the testing for each stabilisation area are shown in Figure 8.7 ... 8.10.

8.4 Installation of lysimeters and settlement plates

Lysimeters and settlement plates were installed in the Perkkaa Dog Park. The description of lysimeter installation is presented in paragraph 8.4.1. The description of the settlement plates is presented in paragraph 8.5. The locations of the installed lysimeters and settlement plates in the stabilisation blocks are presented in Figure 8.11.

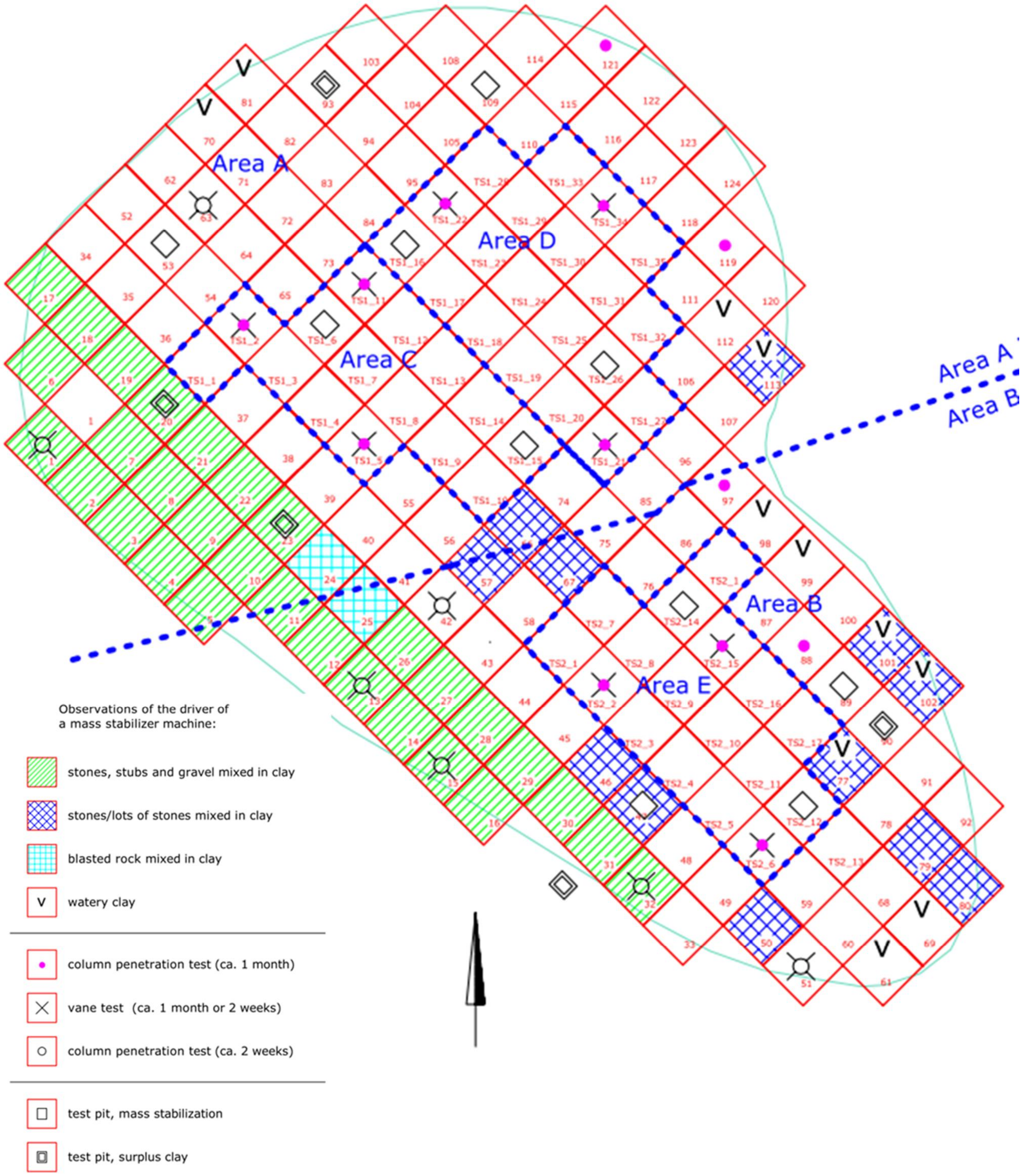
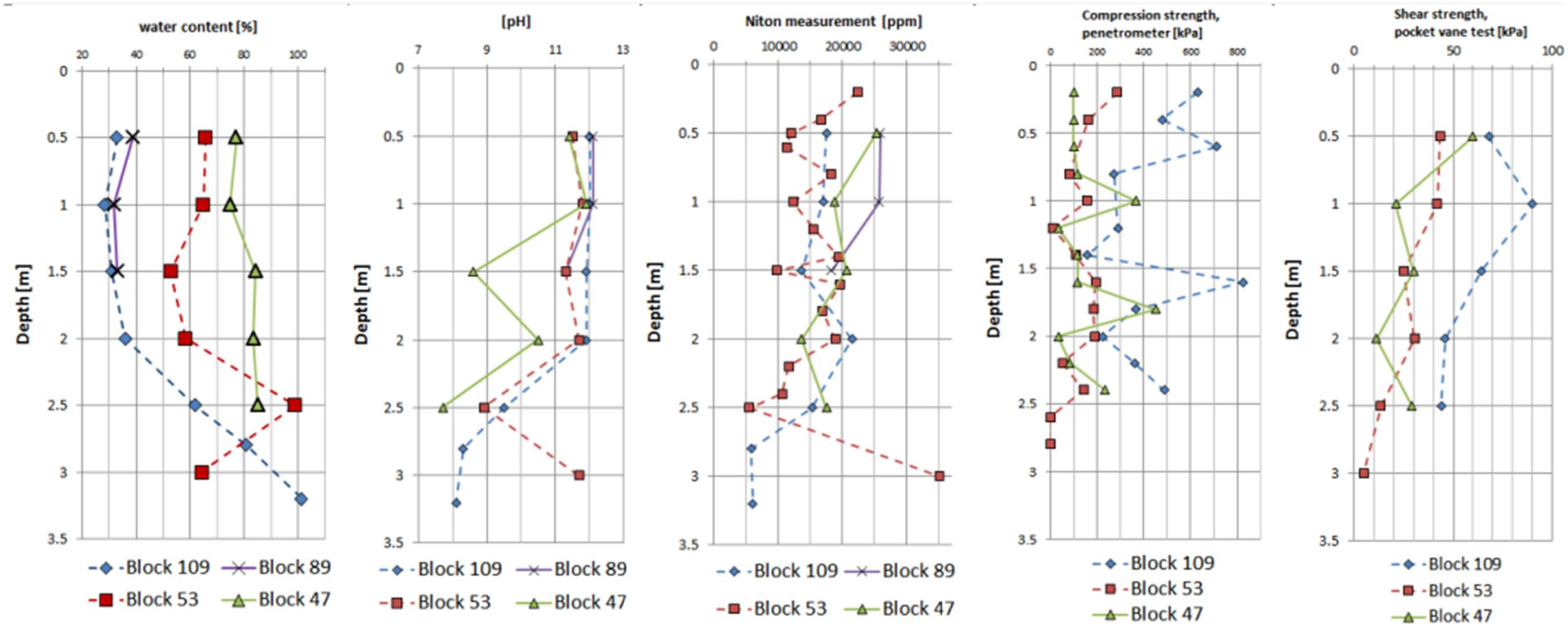


Figure 8.6 Location of the examined test pits

Perkkaa, dog park, test pit and laboratory test results, 25-27.2.2013

Cement stabilized areas *(A-area "dashed lines", B-area "straight lines")*



Visual comments made during the test pit excavations:

BLOCK 53:
The excavation pit held form until 2,5 m depth. In depth 1,2 – 1,4 m material was more soft but stiff. In 2,0 m the material was sometimes so hard that vane shear apparatus couldn´t penetrate the material. A bad slope failure came when excavating in depth of 3,0 meters. In 2,5 meters the sample in the grab contained a stream of binder. The sampling done in depth 2,5 – 3,0 m is inaccurate. Here it was impossible to keep track of exact layers of materials due to uncontrolled mixing.

BLOCK 109:
Every 0,5 meters until 2,5 meters the material can be categorized "hard" throughout the depth layer. Once the material was so hard that vane shear apparatus didn´t penetrate the material. The first slope failures were detected in level 2,5 m. Stabilization ended about 2,6 m deep.

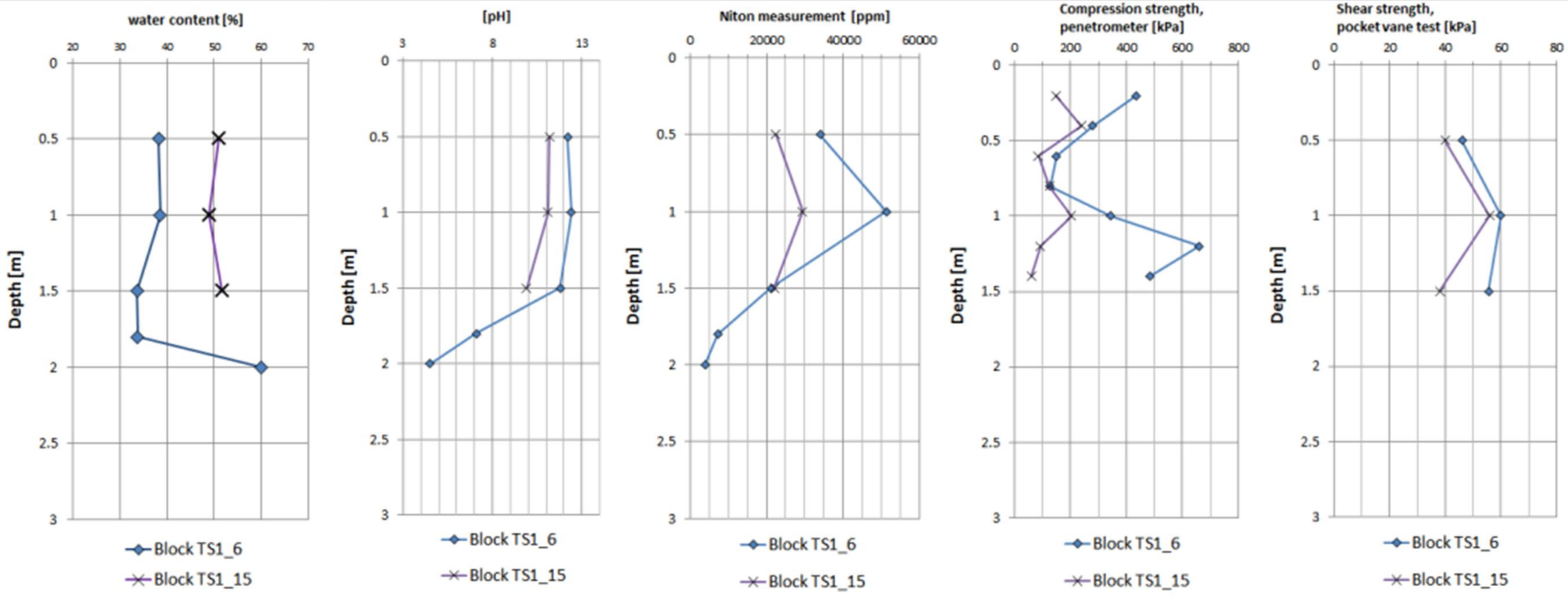
BLOCK 47:
In the depth of 1,0 the material was once so hard that vane shear apparatus didn´t penetrate the material. In general the material was coarse and seemed more stabilized. In depth 1,0 m were very hard pieces of stabilized material. A clear odour of stabilization was present. In 1,5 m the material was more sticky. It was hard to make evened surface for penetrometer or vane shear apparatus. The last sample was taken in the depth of 2,5 m since it was clearly seen that the earth pressure was very high.

BLOCK 89:
Samples were taken from the test pit. No vane shear or penetrometer testing was able to be made in the test field due to practical reasons. The material however was stabilized and proper.

Figure 8.7 Cement stabilised area (areas A and B)

Perkkaa, dog park, test pit and laboratory test results, 25-27.2.2013

TS1 Länsi



Visual comments made during the test pit excavations:

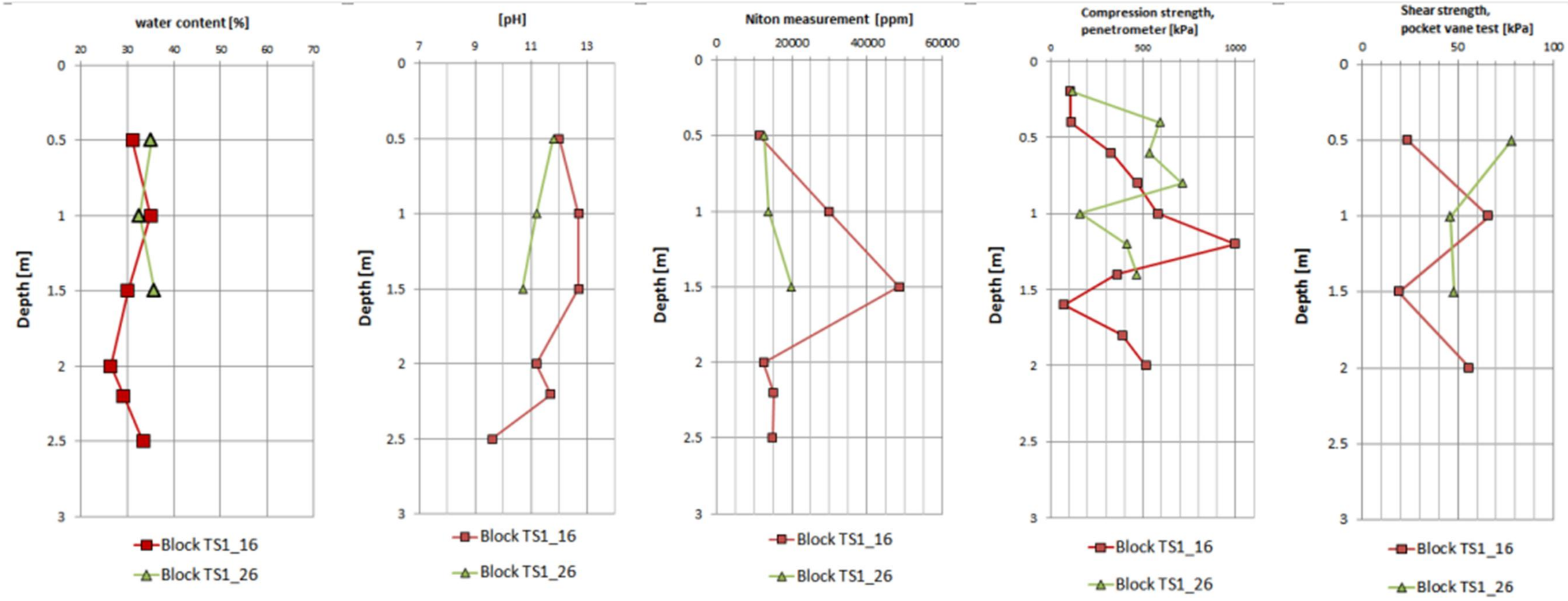
BLOCK TS1_6:
The material was fairly homogenious and had characteristics of stiff stabilized material. Water came to the test pit in depth of 1,0 m. The spreading of binder was even – black spots were everyevere. Black spots indicate the presence of fly ash. In 1,5 m the material was stiff and very hard blocks of material were present. In general the excavation pit was very clean and held well its form. The non stablized ground was visible in depth of 1,6 – 1,8 m. A test sample was taken in depth of 1,0 m.

BLOCK TS1_15:
The material was fairly homogenious throughout the depth profile 0,0 – 1,5 m. The material was stiff-like stabilized mass. However it was not possible to take an undisturbed test sample.

Figure 8.8. Area TS1 West part (area C)

Perkkaa, dog park, test pit and laboratory test results, 25-27.2.2013

TS1 East



Visual comments made during the test pit excavations:

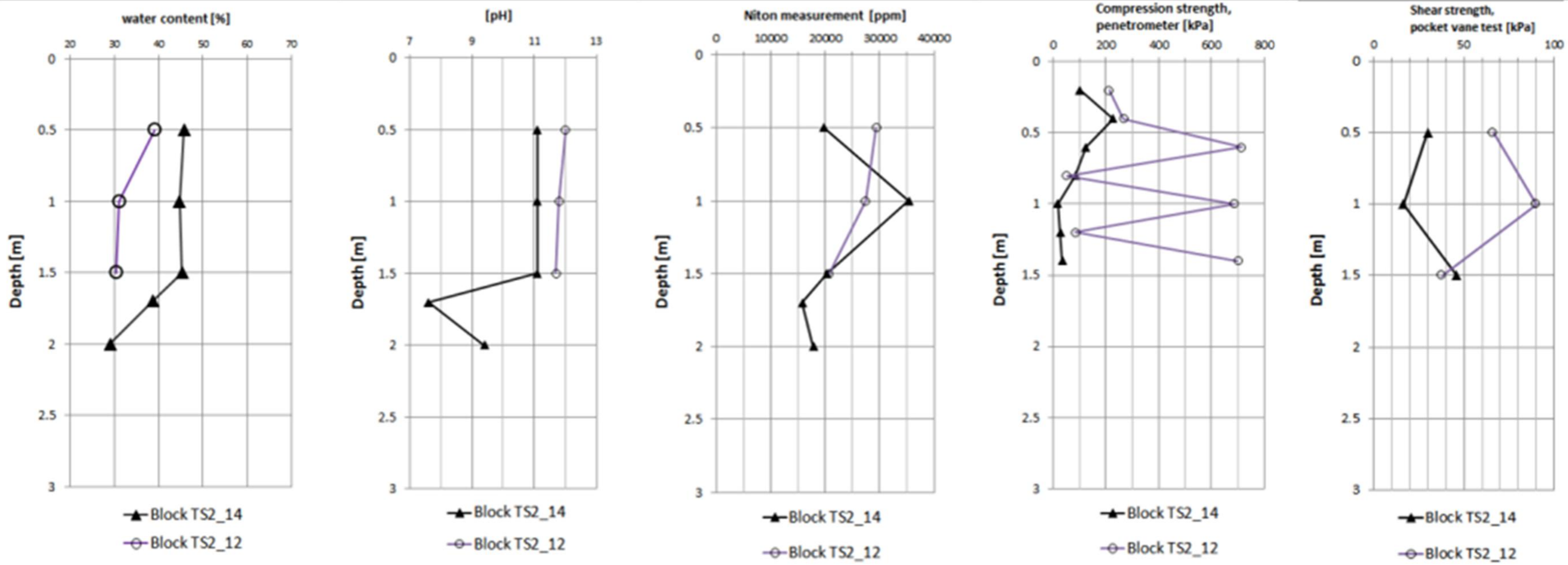
BLOCK TS1_16:
When opened the stablized material was still going through stabilization reactions. The mass was warm and warm water vapor was present in the air. In the depth interval of 0,75 – 1,5 m a clear white gray (clearly visible) monolithic layer of stabilized material was present. In depth intervals 1,0 – 1,5 m the material was very unhomogenious. In 1,5 m it was not possible to penetrate the material with vane shear apparatus.

BLOCK TS1_26:
In depth of 0,5 m the binder is spread evenly. In depth of 1,0 m the vane shear apparatus didn´t penetrate the material. In 1,0 – 1,5 the distribution of binder is uneven. The are occasionally very hard pieces of stabilized material. The orange coloured ground layer was visible in depth of 1,5 – 1,6 meters. 2 hard test pieces were taken from the test pit.

Figure 8.9 Area TS1 East part (area D)

Perkkaa, dog park, test pit and laboratory test results, 25-27.2.2013

TS2



Visual comments made during the test pit excavations:

BLOCK TS2_12:
The excavation pit and the test materials can be categorized as excellent. The material was hard. The material is black, excellent stiffnes and has hard pieces of stabilized materials. Plenty of hard blocks present in the test pit. A sample was taken of a hard piece. Once in depth of 1,0 m and 1,5 m it was not possible to penetrate the material with vane shear apparatus.

BLOCK TS2_14:
The stabilized mass seemed soft in 0,5 m. Material was vatery and soft in 1,0 m. In depth 1,5 the material was unhomogenious, soft and coarse containing a lot of organic material. The material was soft throughout. It wasn´t possible to take a block like test sample due to soft material characteristics. In depth of 1,5 – 2,0 m clearly visible earth pressure was identified. Deeper excavation wouldn´t have been adviced.

Figure 8.10 Area TS2 (area F)

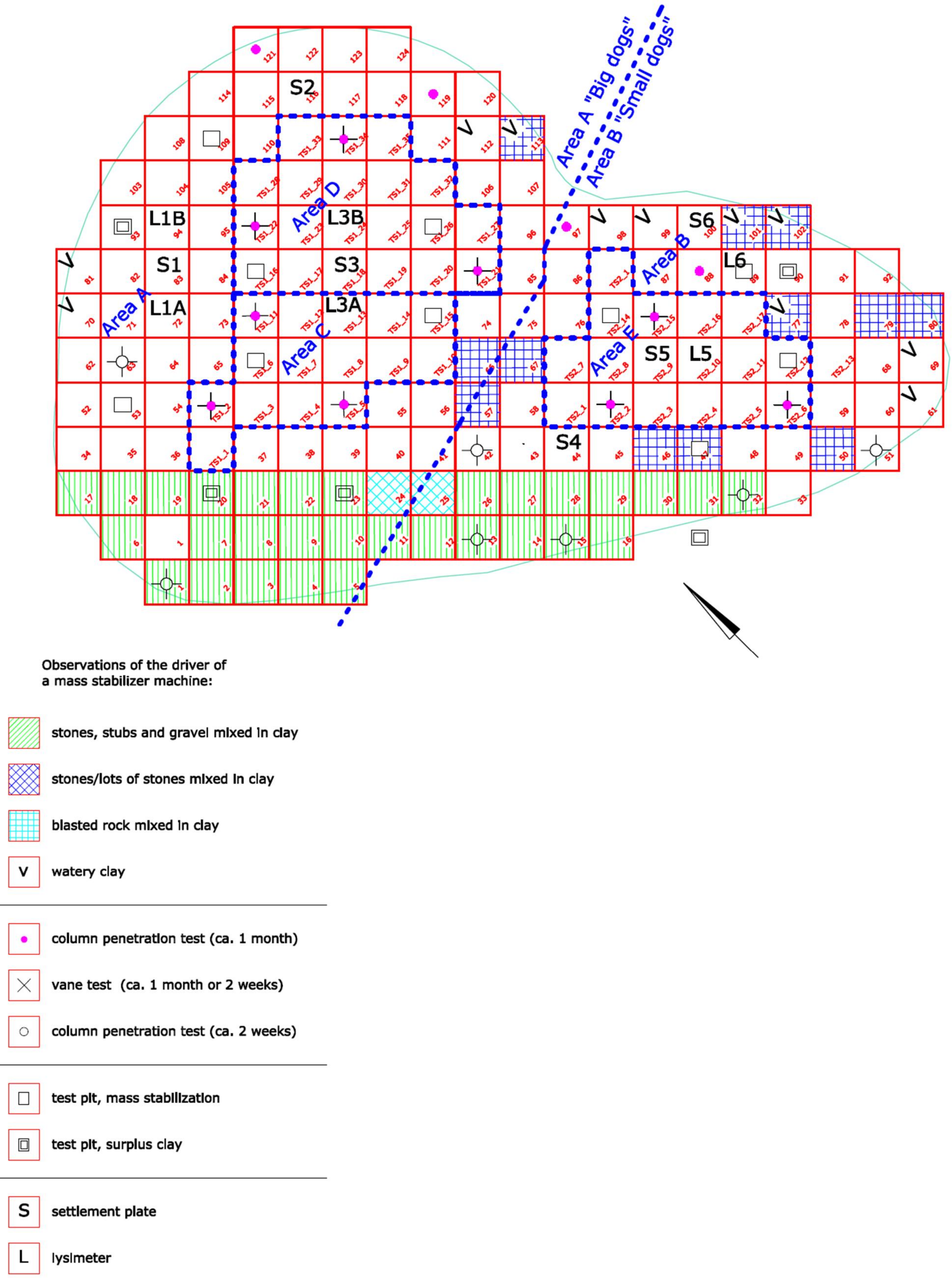


Figure 8.11 Location of the installed lysimeters and settlement plates (test pits included)

8.4.1 Installation of Lysimeters

Five lysimeters were installed in the test field. The basic principle of the lysimeters is shown in Figure 8.12. One set (2 lysimeter boxes) of lysimeters was installed in each stabilisation area. The boxes used in the testing were PE-HD plastic boxes and the installed water tubes were PA plastic. The water sample tubes were covered with protective tubing. The water sample tubes were placed under the 15 cm drainage layer in the bottom of the lysimeter. The surrounding of the aggregate was covered with a geotextile which ensures that the drainage layer does not get blocked. The stabilised material was compacted with a special field compactor to model the natural conditions. The top of the lysimeter was covered with the original stabilised material. Here the excavator was used for gentle compacting of the material on top of the boxes. The tubing was placed in protective casing and transported through the ballast embankment. Finally, the tubing was transported to the concrete well casings. The settlement plates were placed inside the concrete wells. The protective environment inside the concrete casings ensures proper measurement in the future. The final placement of the lysimeters and the protective casings are shown in Figure 8.13.

a) b) c)

Figure 8.12 Lysimeter installation a) lysimeter device b) excavation of a lysimeter test pit c) compaction of stabilised material to the lysimeter

a)

b)

c)

Figure 8.13 Lysimeter installation details a) installed lysimeters before filling b) & c) technical details of lysimeter tubing protection and covering in concrete wells

8.5 Installation of settlement plates

Six settlement plates were installed in the test field. The instrument is used to measure the settlement occurring during the consolidation period after the construction. Two settlement plates were installed in the cement stabilised area and one settlement plate was installed for each ash stabilised area (total 6). The settlement plate locations in stabilisation blocks are shown in Table 8.3. The principle of settlement plate is presented in Figure 8.14. The measurement of horisontal z-location gives the settlement of the mass stabilised layer and the subsoil below it.

Table 8.3 Areas and locations of the installed settlement plates

Stabilisation area	Stabilisation block
A (CEM)	83
A (CEM)	116
B (CEM)	44
B (CEM)	100
D (TS1 east)	TS1_18
E (TS2)	TS2_9

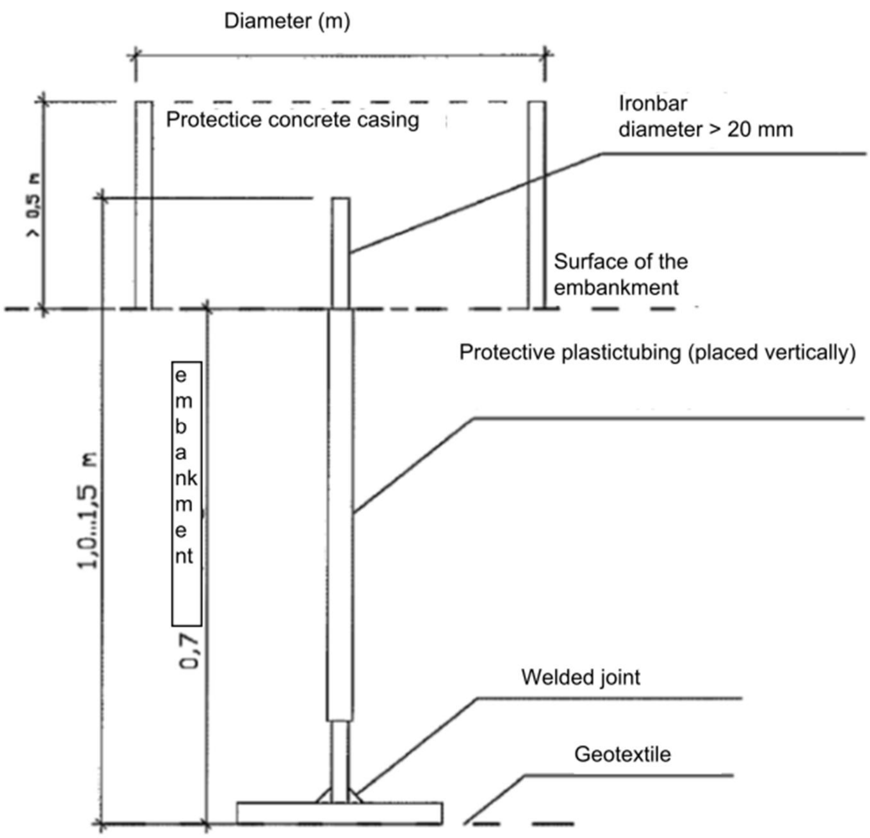


Figure 8.14 Settlement plate

8.6 Follow-up survey programme

The piloting action tests different ash binder mixes in surplus clay mass stabilisation according to the rules approved in the environmental permit. The mass stabilisation quality control and the follow-up survey programme consist of the settlement plate and lysimeter measurements.

At first, settlement is measured soon after the compaction embankment is constructed. The settlement follow-up measurements are scheduled to be carried out 1 week, 1 month, 3 months, 6 months, 1 year, 2 years, 3 years, 4 years, 5 years, etc. after the construction.

The lysimeter measurement follow-up programme will be determined in autumn 2013.

Table 8.4 Installed settlement plates and lysimeters (z = bottom level of the lysimeter)

	x	y	z
Settlement plates			
S1	78079.4	46435.5	-
S2	78082.1	46460.4	-
S3	78064.8	46449.7	-
S4	78033.5	46453.5	-
S5	78033.4	46466.7	-
S6	78039.9	46480.8	-
Lysimeters			
L1A	78075.6	46432.2	-0.9
L1B	78082.6	46439.5	-1.1
L3A	78061.6	46446.4	-0.8
L3B	78068.5	46453.5	-0.8
L5	78029.3	46471.2	-0.7
L6	78032.9	46481.8	-0.6

9. Quality controlling soundings

Mass stabilisation quality controlling soundings were carried out by Ramboll. Guiding control soundings for executing mass stabilisation were carried out at a mass stabilised layer after two weeks (21 … 22.1.2013) of mellowing time. Quality controlling sounding were carried out about one month (26 … 27.2.2013) and three months (6 … 8.5.2013) after mass stabilisation was finished.

Table 9.1 presents the results of the quality control soundings carried out about one month after mass stabilisation and the initial data for analysis.

The quality control soundings are plotted as single sounding graphs (measured observations) and also both areas and blocks average shear strength. The detailed information on quality controlling soundings can be found in a Finnish report "Stabilointitöiden laadunvalvontatutkimusten yhteenvetoraportti" (The report on the quality control tests of the stabilisation works). (Ramboll 2013)

A bearing factor N_c 10 was used to interpret the column penetrometer results. Column penetrometer hits were converted to shear strength using equation 10 hits/0.2 m corresponds 1 MPa.

The average shear strength graphs after one month of mellowing (z - τ) for areas and blocks are presented in Figures 9.1 … 9.7. The shear strength average graphs for three months mellowing time are presented in Figures 9.8 .. 9.11.

In the areas A and B, the results of the cement stabilisation exceeded the required average shear strength (one month/ 30 kPa) in all depths of the mass stabilised layer. The single sounding graphs reveal that not all the results fullfilled the requirements for shear strength at all depths. Three column penetrometer soundings failed (blocks 88, 97 and 121) to fullfill 3 kN requirement at a depth of about 2.3 … 3 m from the surface of the mass stabilised layer.

The average shear strength was lower in the ash stabilised areas (C, D and E) than in the cement stabilised areas.

In the ash stabilised areas C, D and E, the average shear strength was lower than in the cement stabilised areas A and B. The design strengths were not achieved in blocks TS1_21 and TSA2_6. In the blocks TS1_21 and TSA2_6, vane penetrometer tests results failed to meet the requirements (3 kPa) at any depth.

Column penetrometer requirement 3 kN was to the 3 months hardened mass stabilisation and the requirement was too high for 1 month hardened mass stabilisation.

Table 9.1 Quality control soundings (ca. 1 month hardening time)

Area	Column penetrometer ca. 1 month done/ presented in work specification	Vane penetrometer ca. 1 month done/ presented in work specification	Planned mass stabilisation bottom surface	Clay surface, mapped 10/2012	Mass stabilisation surface, mapped 01...02/2013**
Cement stabilised area, "big dogs" A	5 / 8 pcs + 2 pcs *	0 / 3 pcs + 2 pcs *	-2	+1.8...+1.0	+1.3
Cement stabilised area, "small dogs " B	4 / 8 pcs + 5 pcs *	0 / 0 pcs + 5 pcs *	-2	+1.9...1.8	+1.4
Ash stabilisation area, TS1 west part C	8 / 8 pcs	3 / 3 pcs	-2	+2.1...+1.8	+1.5...+1.4
Ash stabilisation area, TS1 east part D	8 / 8 pcs	3 / 3 pcs	±0	+2.0...+1.9	+1.5
Ash stabilisation area, TS2 E	8 / 8 pcs	3 / 3 pcs	±0	+1.8...+1.7	+1.4...+1.3
total	33 / 40 pcs	9 / 12 pcs			

* 2 weeks quality control sounding
** measured inside a dug hole of the compaction embankment

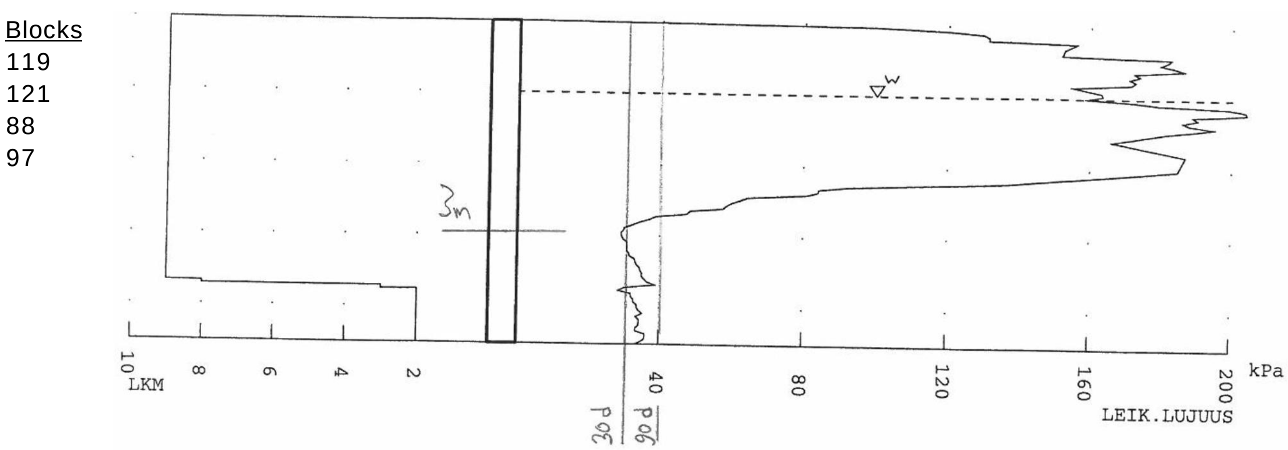
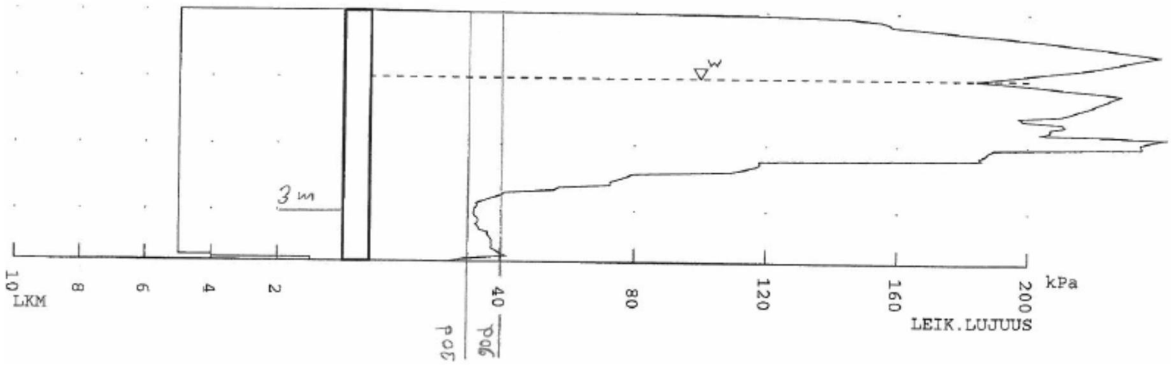
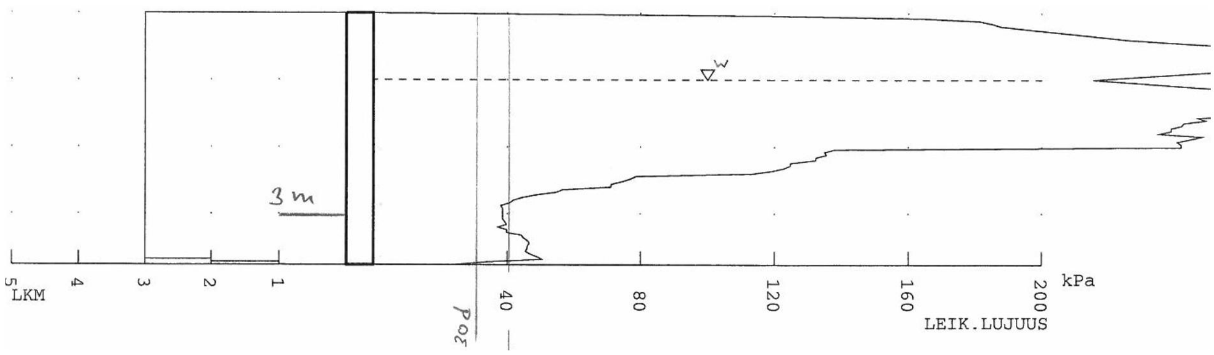


Figure 9.1 Area A+B, blocks 119, 121, 88 and 97.

Blocks
119
121



Block
119



Block
121

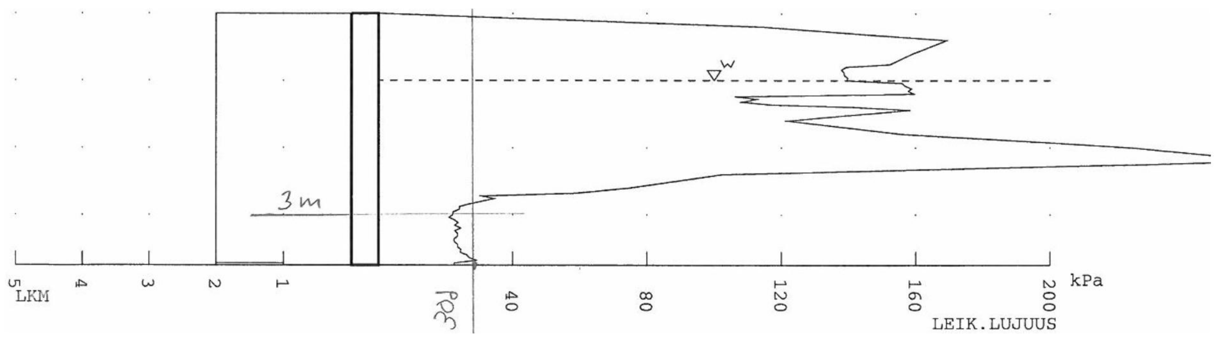
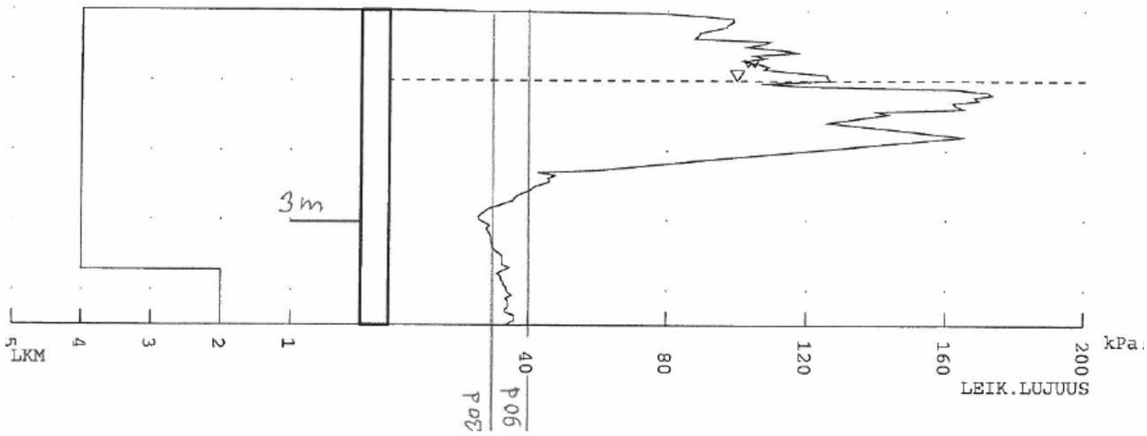
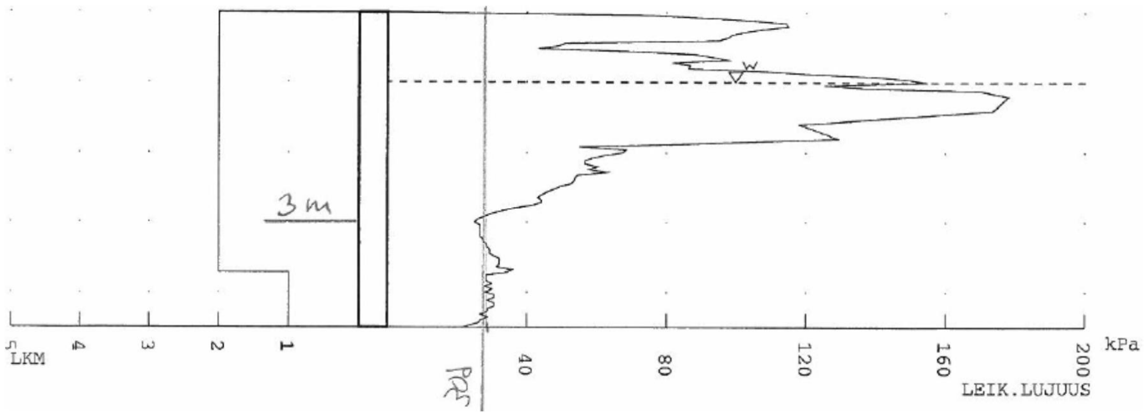


Figure 9.2 Area A, blocks 119 and 121.

Blocks
88
97



Block
88



Block
97

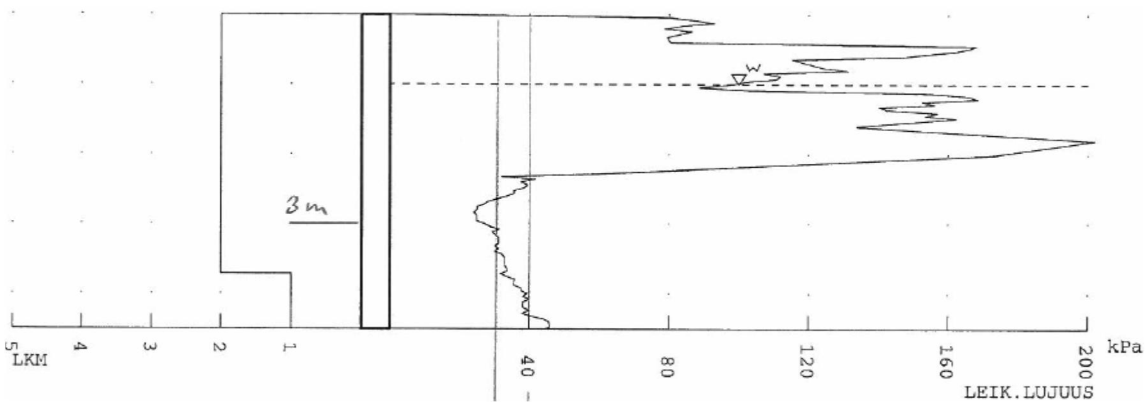
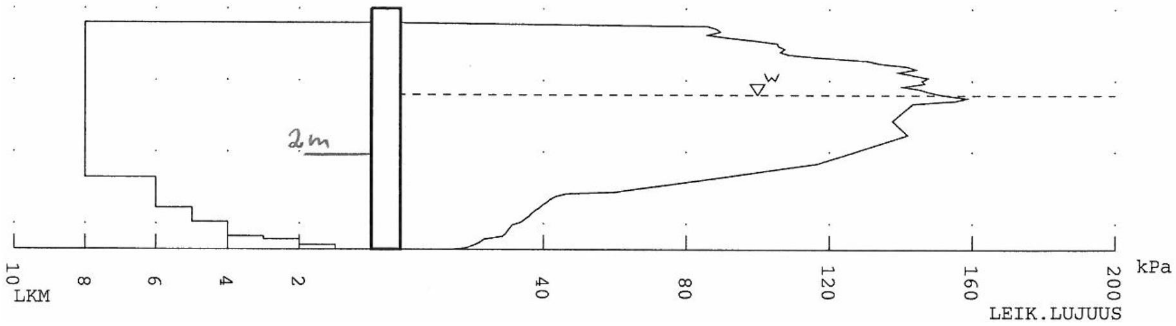
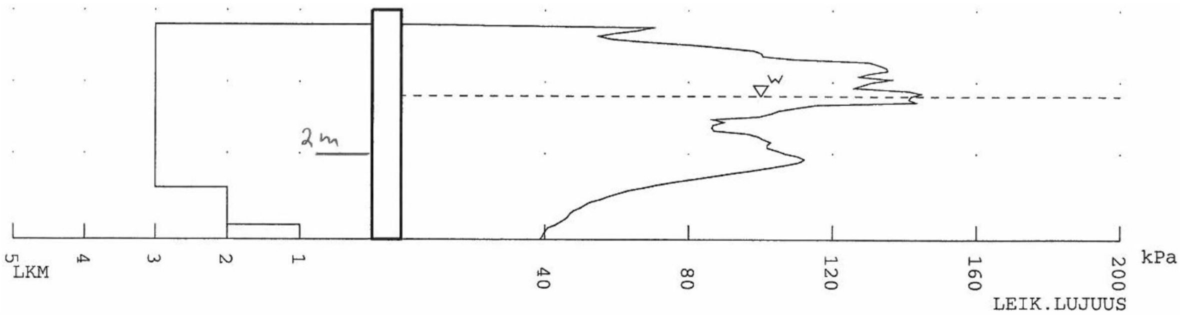


Figure 9.3 Area B, blocks 88 and 97.

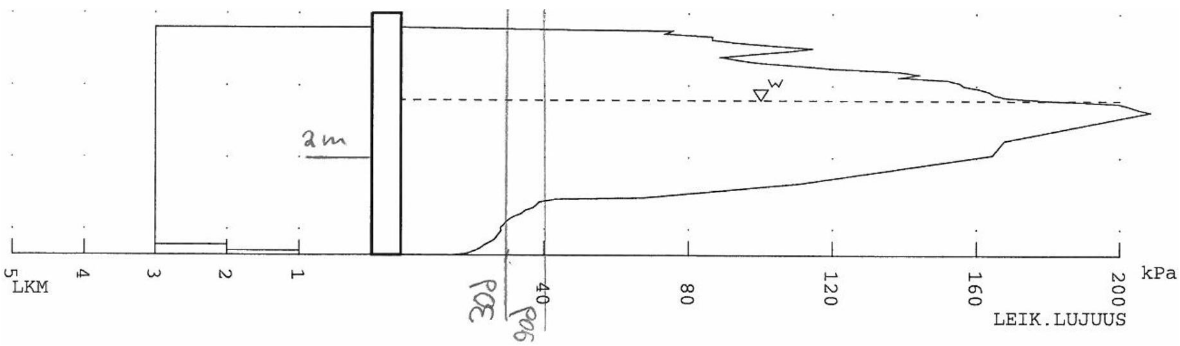
Blocks
TS1-2
TS1-5



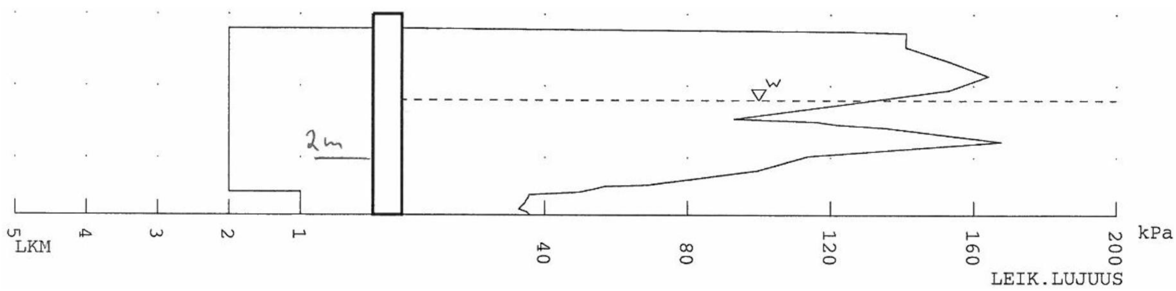
Block
TS1-2



Block
TS1-5



Block
TS1-1
1



Blocks
TS1-2
TS1-5
TS1-11

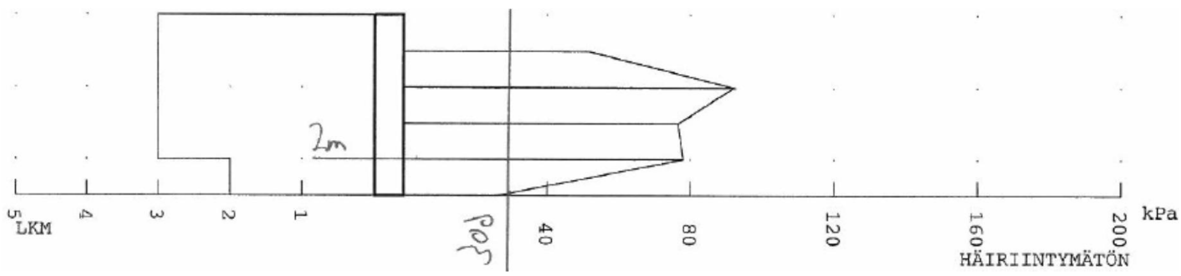
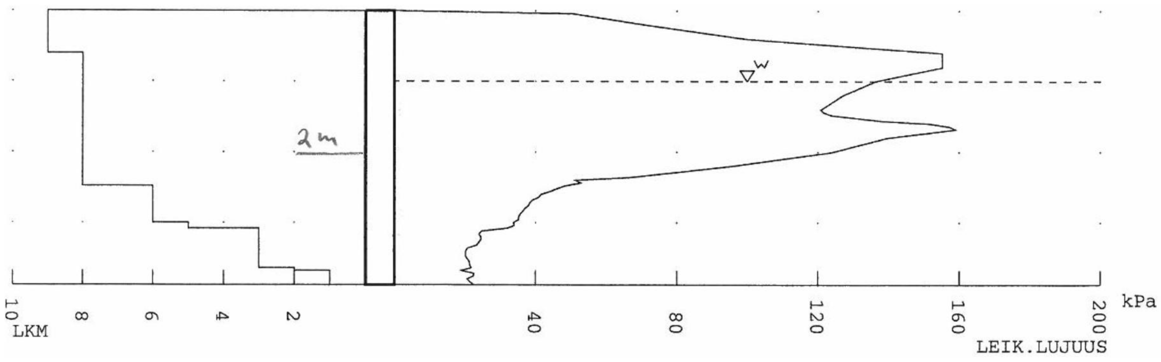
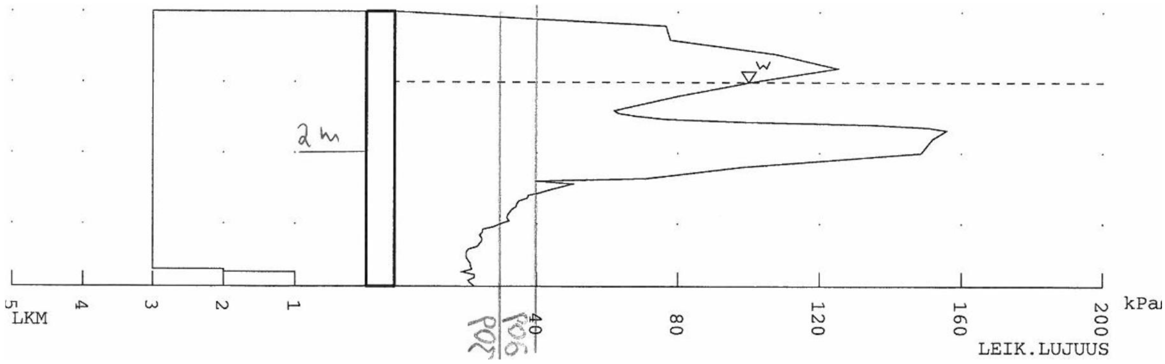


Figure 9.4 Area C, blocks TS1-2, TS1-5 and TS1-11.

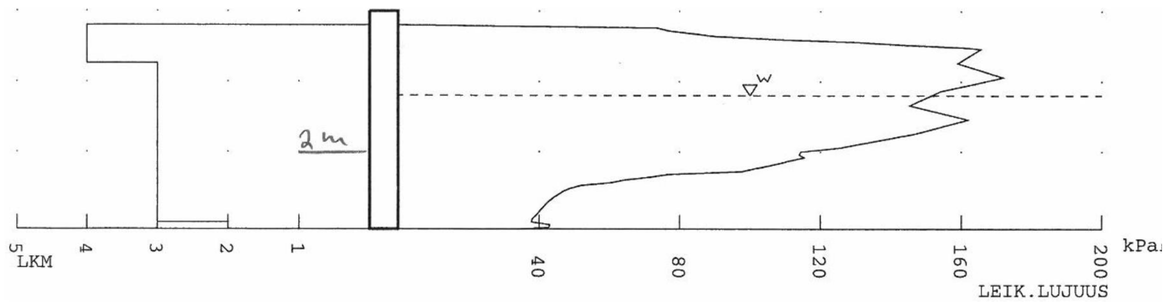
Blocks
TS1-21
TS1-22
TS1-34



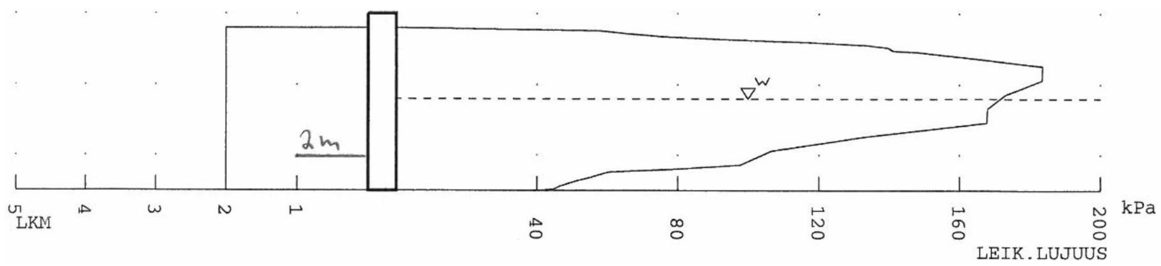
Block
TS1-21



Block
TS1-22



Block
TS1-34



Blocks
TS1-21
TS1-22
TS1-34

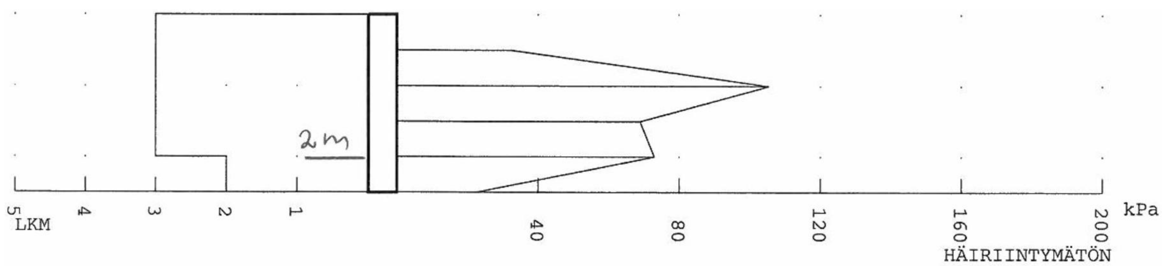
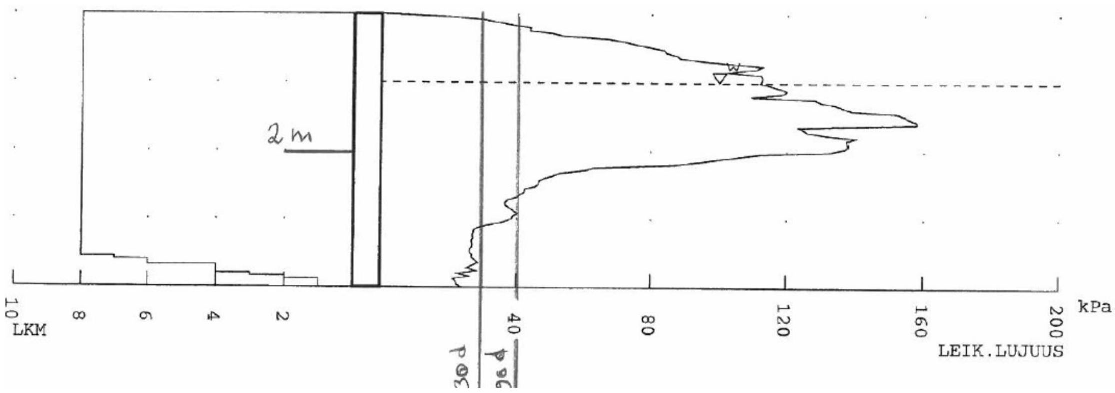
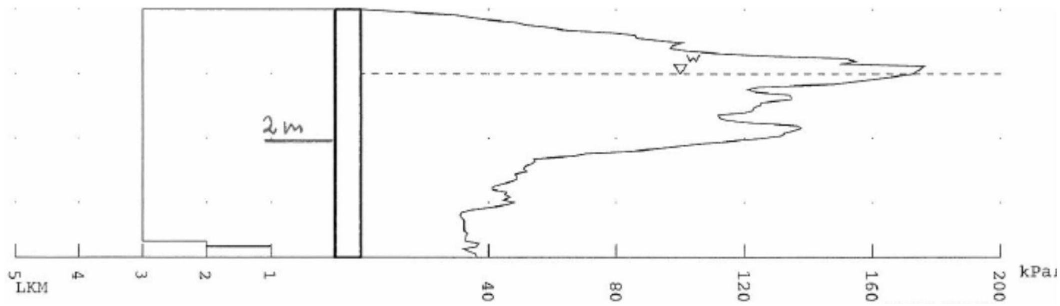


Figure 9.5 Area D, blocks TS1-21, TS1-22 and TS1-34.

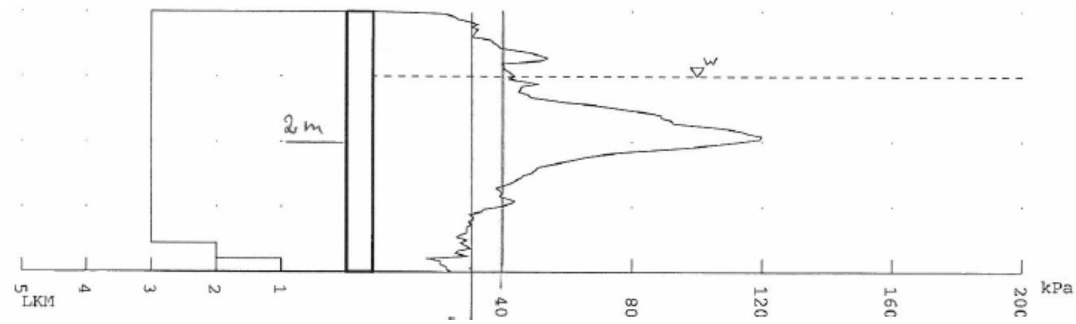
Blocks
TS2-2
TS2-6
TS2-15



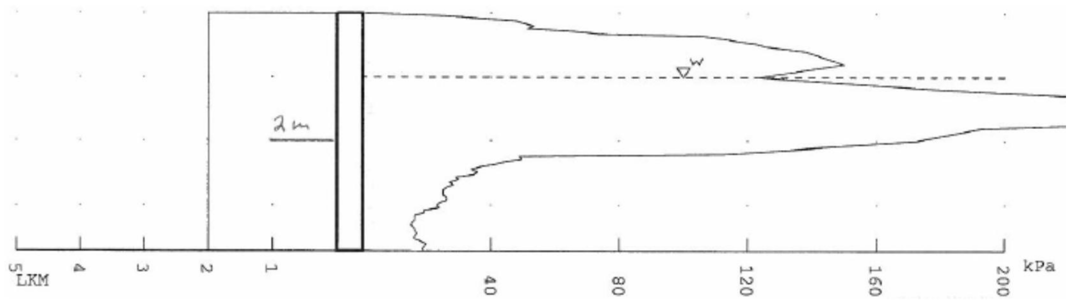
Block
TS2-2



Block
TS2-6



Block
TS2-15



Blocks
TS2-2
TS2-6
TS2-15

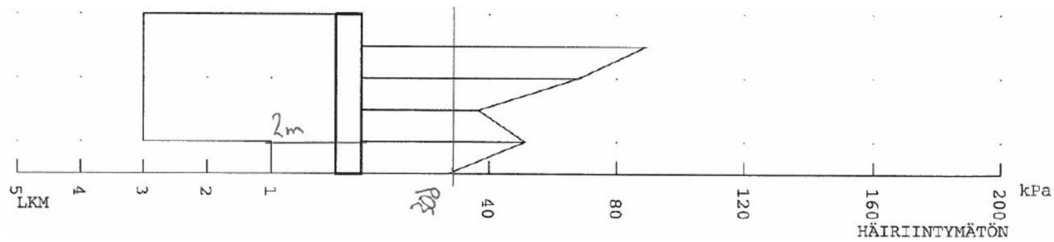


Figure 9.6 Area E, blocks TS2-2, TS2-6 and TS2-15.

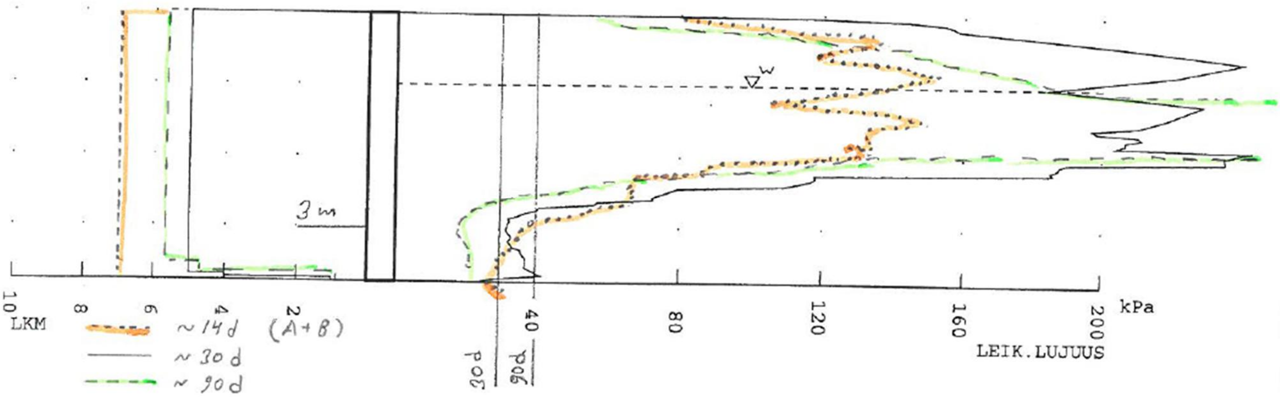


Figure 9.7 Area A: Cement stabilised area, "big dogs".

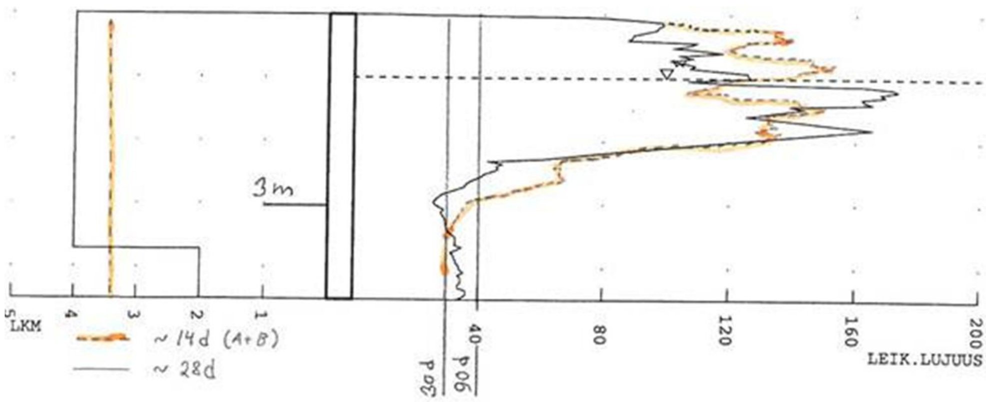


Figure 9.8 Area B: Cement stabilised area, “small dogs”.

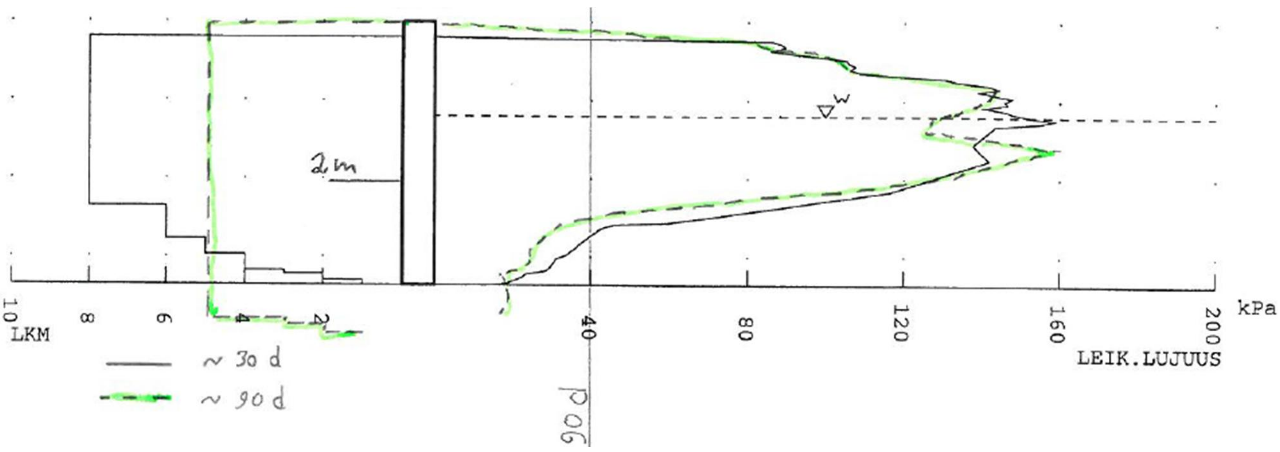


Figure 9.9 Area C: Ash stabilisation area, TS1 west part.

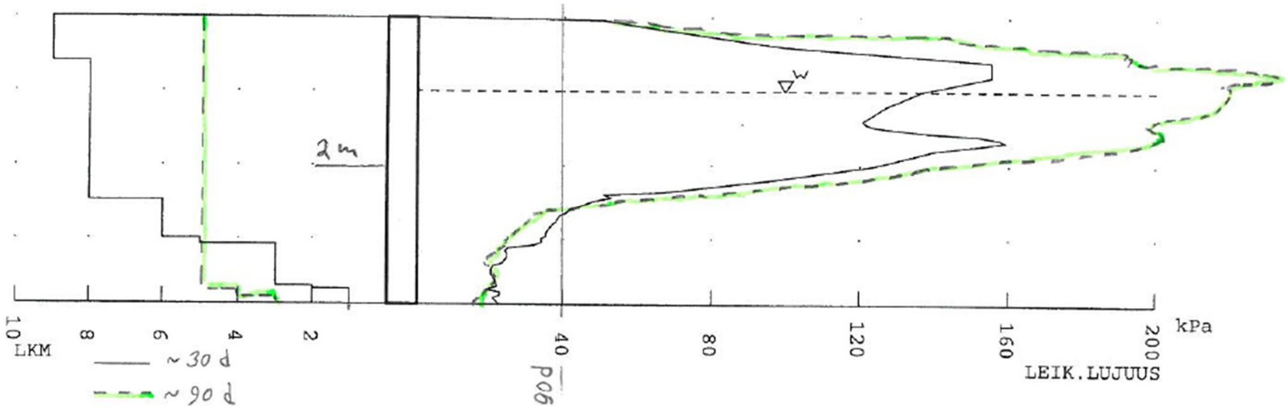


Figure 9.10 Area D: Ash stabilisation area, TS1 east part.

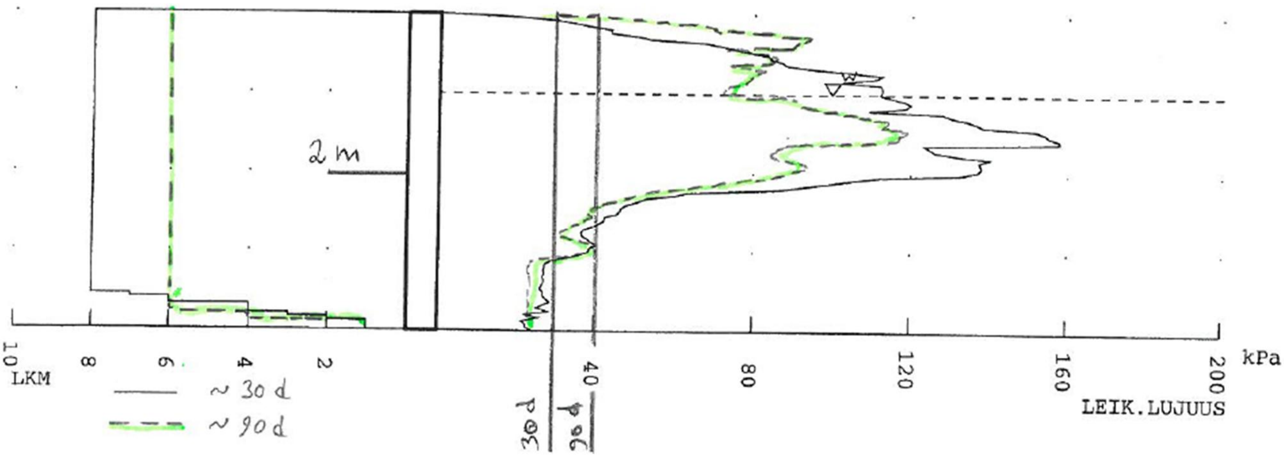


Figure 9.11 Area E: Ash stabilisation area, TS2.

10. Park construction

The park was constructed between 8 … 10. 2013 by the City of Espoo. During the costruction period it was necessary to take into consideration the installed lysimeters and settlement plates.

The park construction phase is presented at the pictures below (Figures 10.1 … 10.2).

Figure 10.1 Perkkaa Dog Park under construction in September 2013.

Figure 10.2 Concrete wells for lysimeters and settlements plates.

11. Arcada II in Helsinki

The first pilot carried out in the framework of the Absoils project was Arcada II where stabilised clay was used as a light weight structure. The structure was designed to replace an old embankment floating over a soft clay layer. A cross section of the embankment and the site is presented in Figure 11.3.

Arcada II is located in the Kyläsaari area in Helsinki (see the location in Figure 11.1). The area had low stability and load bearing capacity. The site was originally filled from the sea with blasted rock in 1960's. The original aim was to replace the existing clay with blasted rock to create a foundation for a new highway. However because of the deep clay layer and difficult circumstances the mass exchange failed leaving the blasted rock to float on top of the clay layer. The route of the highway was also changed and the area was left for secondary use for decades until 21st century when the development of the area has begun.

In the Arcada II, the aim of the project was to improve the area for construction use by removing contaminated soils, lightening the blast rock embankment, installing steel-pipe piles for a pile beam and plate structure on the road Kyläsaarenkuja area to stop the lateral expansion caused by the old embankment. In this case the Absoils project, the focus was on the construction of a stabilised "light weight" structure with abandoned clays brought to the Arcada II site form adjacent sites which could not utilise those clays.

"Light weight" material means in this case that the stabilised clay was actually lighter than the existing blasted rock material, which was replaced ($\gamma'_{clay} \approx 5$ kN/m^3 and $\gamma'_{blasted\ rock} \approx 10\text{-}13$ kN/m^3 under water level). That is why the stabilised clay is called "light weight" material, although it does not fill the criteria set for the light weight material in standard SFS-EN 13055-2.

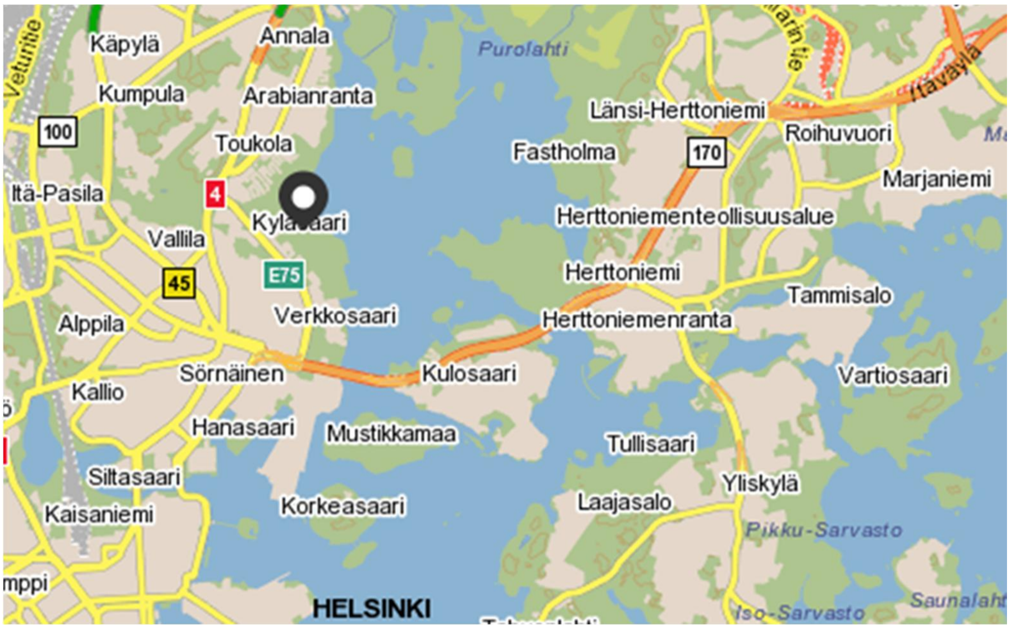


Figure 11.1 The location of the Arcada II pilot in Helsinki.

Figure 11.2 Arcada II before construction. (Google maps)

11.1 Planning and construction

In the Arcada II Absoils pilot the old structure material (blasted rock) was dug out from the floating embankment and abandoned clays were put to replace the rock aggregate. The density of the abandoned clays was decreased by adding water and the clays where stabilised on site with mass stabilisation machine. Test stabilisation in the area was performed in December 2010 and the construction work was performed from April 2011 to the end of August 2011.

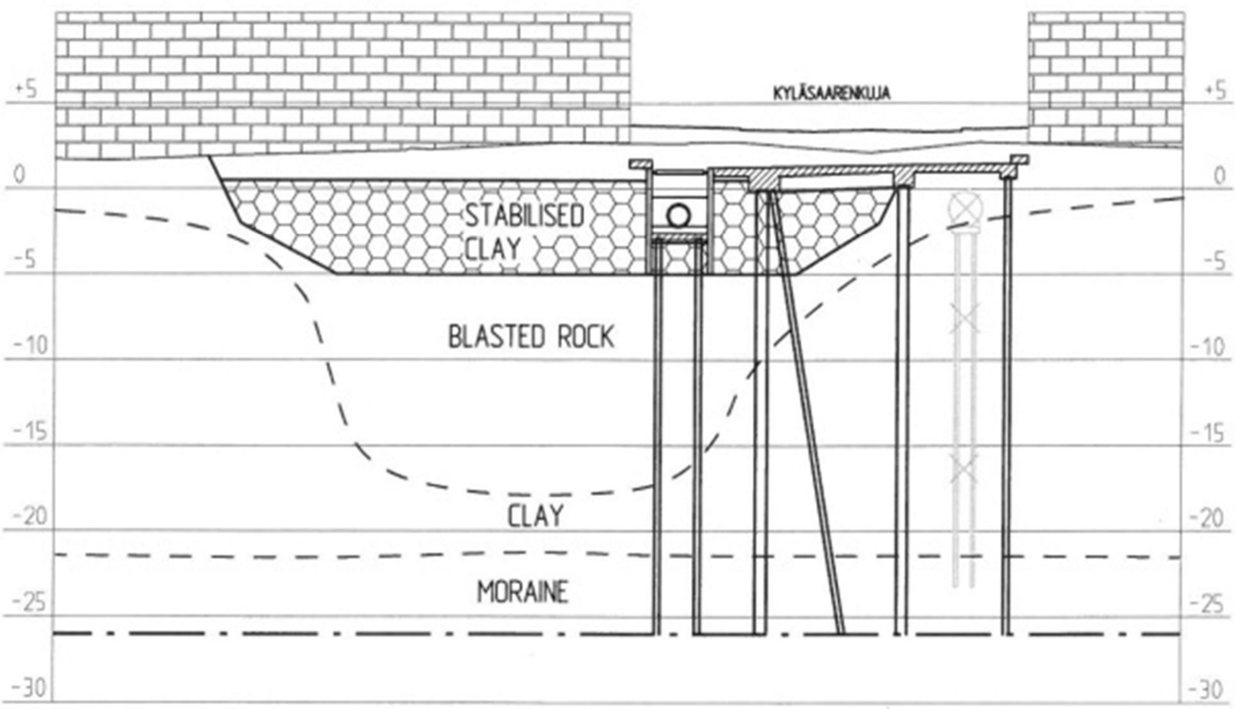


Figure 11.3 A cross section of the embankment in Arcada II

11.2 Laboratory testing for Arcada II

The light weight structure was constructed with surplus soft clays which were stabilised by controlling and reducing the density of the soil. Before stabilisation was carried out on site, the effects of water addition to density and to stabilisation properties were studied in the laboratory. After the density studies, different binder materials were tested in order to find out how alternative binders such as fly ash worked in the stabilisation process. In the first phase of stabilisation testing, different binders were tested with only one clay sample. In the last part of laboratory stabilisation testing, different abandoned clays were stabilised with only one binder, which was chosen to be used on site, in order to find out the suitability of the materials for stabilisation.

The density control studies were made with nine (9) different samples according to the description in chapter Error! Reference source not found.. The results of the density control studies are presented in Figure 11.4.

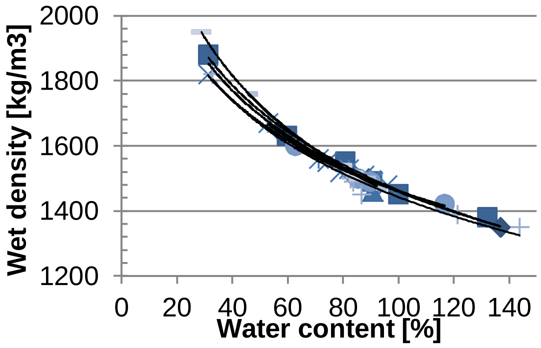


Figure 11.4 Density control studies.

The targeted wet density for the materials was 1500 kg/m^3 (γ ≈ 15 kN/m^3). The results of the density control studies showed that the optimum water content for the studied abandoned soils was approximately 83–93 %.

The stabilisation properties of soils in different densities were also studied by making specimens of the soils in three different densities. The studies were made with one soil material and with two different binders. The binder options were cement (100 kg/m^3) and the mixture of cement and fly ash (FA) (cement 50 kg/m^3 and fly ash 150 kg/m^3). The results of the specimens can be seen in Figure 11.6.

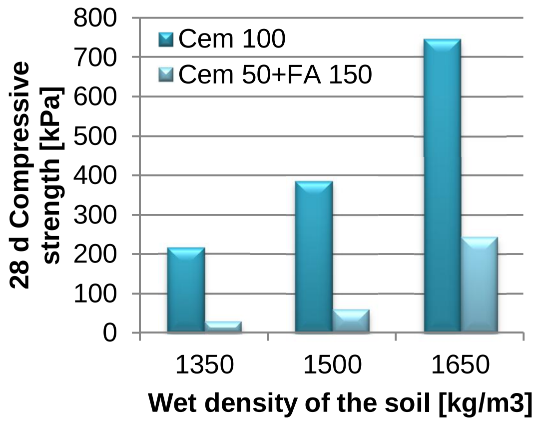


Figure 11.6 The effect of density to the 1-axial compressive strength (Cem=cement; FA=fly ash)

It can be seen in the figure that the density of the clay has a big impact on the compressive strengths. With higher density the water-binder ratio is lower and the compression strength is higher. The cement-fly ash mixture gave poorer results after 28 days of curing than the cement stabilised clays. The results show that raising the water content too high is dangerous and can lead to serious loss in compressive strength.

11.2.1 Testing of different binder options for stabilisation

The utilisation possibilities of alternative binder solutions were studied in the laboratory. The alternative binders were fly ash (FA) and flue gas desulphurisation gypsum (FDG). One abandoned soil material (clay) was used for the stabilisation studies and the targeted compressive strength was 100 kPa. The results of the stabilisation studies can be seen in Figure 11.7 and Figure 11.8.

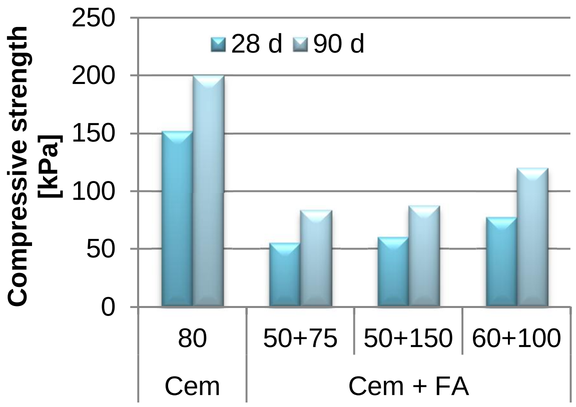


Figure 11.7 Compressive strengths with cement (Cem) and cement- fly ash mixtures (Cem + FA).

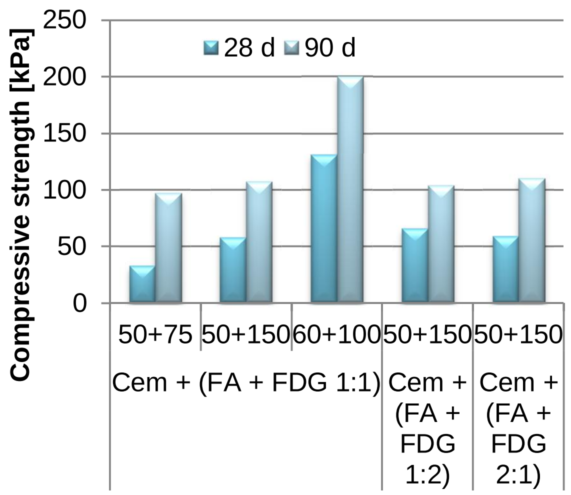


Figure 11.8 Compressive strengths with cement-fly ash-flue gas desulphurisation gypsum–mixtures.

The results from the stabilisation studies show that also with alternative binder options the targeted compressive strength can be achieved. The best alternative binder mixture was cement with fly ash and flue gas desulphurisation gypsum. The different fly ash-flue gas desulphurisation gypsum ratios (1:2/ 1:1 /2:1) did not have any effect on the compressive strength.

The utilisation of fly ash or flue gas desulphurisation gypsum as binder would have required an environmental permit. Because the schedule of the project was tight and the permit process is slow, there was not enough time to apply the permission meaning that the alternative binders could not be used in the project.

In the case the fly ash or flue gas desulphurisation gypsum could have been used on the site, the possible savings in the amount used cement would have been about 40 %, which would have meant about 1 300 tonnes of cement meaning about 120 000 € of savings in the binder costs.

11.2.2 Suitability of different clays for stabilisation

In order to find out if all of the available abandoned clays were suitable for the stabilisation with cement, the clays were tested in the laboratory. Several abandoned clays were tested as a single site cannot supply enough clay for the needs of the whole project.

In the tests the abandoned clays were stabilised with 100 kg/m^3 of cement in the 1500 kg/m^3 density. The results of the stabilisation tests of the abandoned clays are presented in the Table 11.1.

Table 11.1 Compressive strengths of stabilised abandoned clays.

Sample	**Compressive strenght [kPa]**	
	7 d	**28 d**
Koivukylä	< 10	< 10
Korpitie	101	127
Piloting site/basin 3	322	428
Korpitie area 4/1	583	747
Korpitie area 4/2	502	662

The compressive strengths of the stabilised clays varied a lot: from no strength development to compressive strengths of over 700 kPa. The Koivukylä sample had no strength development and was not used in the project. However, all the other samples reached the targeted compressive strength and could be used in the stabilisation.

On the basis of these results the stabilisation was performed with 100 kg/m^3 of cement and so that the density of the abandoned clay was adjusted to 1500 kg/m^3.

11.3 Construction process and Quality Control in Arcada II

The total volume of the stabilised abandoned clay was ≈32000 m^3, the surface area ≈7200 m^2 and average depth ≈4.5 m. The construction area was divided into separate stabilisation basins in which the stabilisation work was done in phases. First the old blasted rock aggregate was removed from the stabilisation basin area and transported for further processing and utilisation.

After the aggregate had been removed the basin was filled with abandoned clay. The basins were already naturally partially filled with water, and the density of the abandoned clay was adjusted by mixing a wanted amount of the abandoned clay with the water uniformly so that about 1500 kg/m^3 density was achieved. The mixing was done with the mass stabilisation machine. After that the binder was mixed with the clay using the mass stabilisation machine.

After the stabilisation a non-woven geotextile was spread over the stabilised mass and compression embankment was spread over the geotextile. The compression embankment also worked as a stabilisation platform for the stabilisation machine. The mixing of the binder, geotextile and the compression embankment can be seen in Figures 11.9...11.12.

A test stabilisation was carried out before the actual construction. The test stabilisation basin was divided into four stabilisation areas which were stabilised by using different binder amounts (kg/m^3).

Following the stabilisation and one month of curing time the strength properties of the stabilised mass was tested. The soundings showed that the stabilisation had been successful and all of the sounding points reached the required shear strength (about 50 kPa, compressive strength ≈ 100 kPa). In most of the sounding points the shear strengths were even many times higher than 100 kPa.

The actual stabilisation was made on the basis of the results of the test stabilisation. The water content and the density of the samples were followed at every stabilisation basin. Samples were collected from the basins to determine the water content and the density of the sample on site. One of the samples was sent to the laboratory to assure that the results were similar in the laboratory and on site.

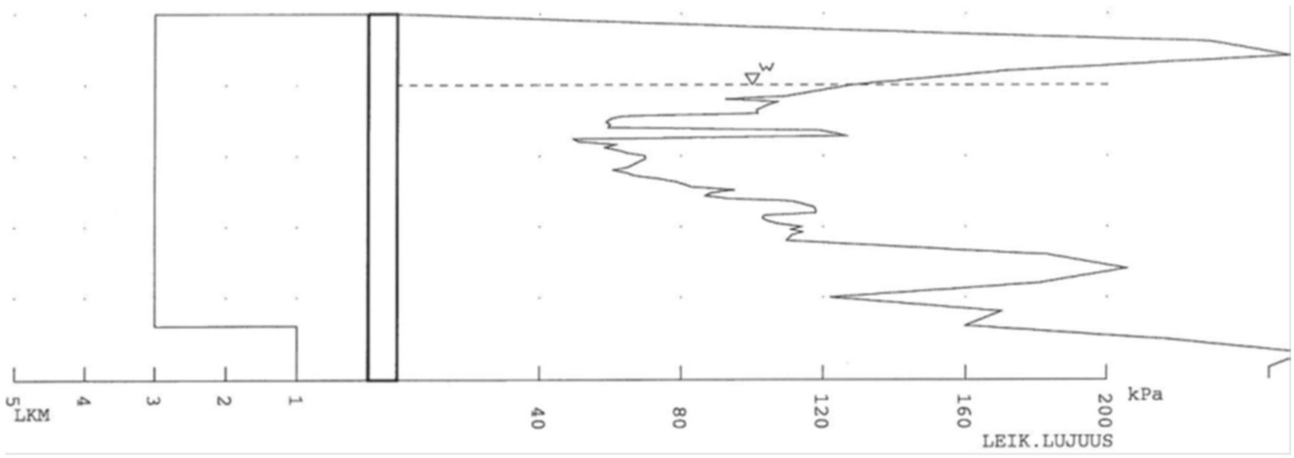
Soundings were performed also after the test stabilisation on the actual construction stabilisation. The results showed that the shear strengths were mostly over 100 kPa which fulfilled the criteria of 50 kPa shear strength (Figure 11.13 a-c).

Figure 11.9 Mass stabilisation in progress

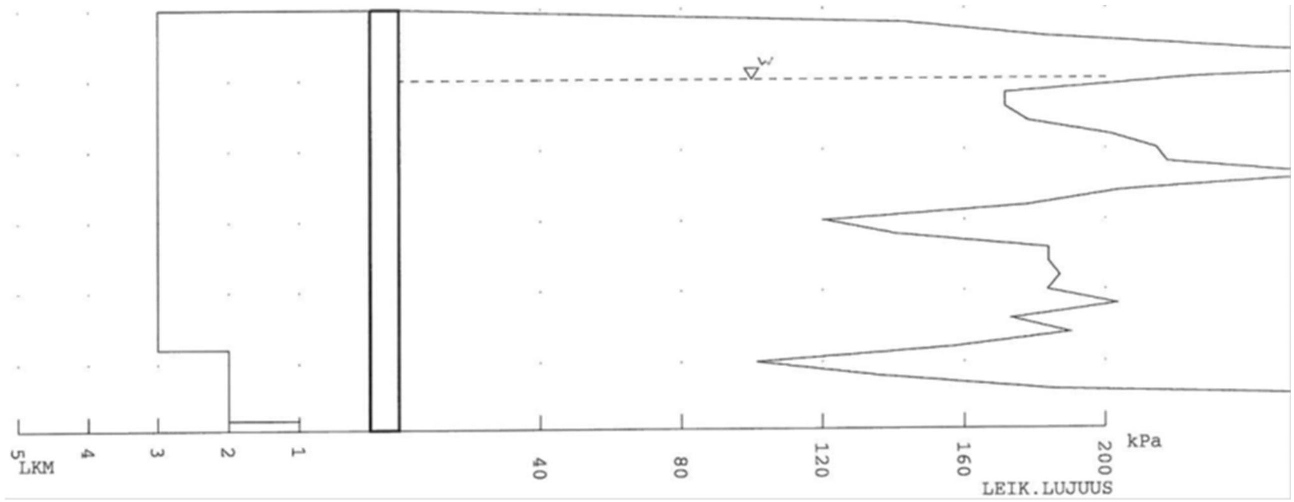
Figure 11.10 Piling works in progress

Figure 11.11 Removal of original filling

Figure 11.12 Stabilisation basin – satbilised clay in front, clay waiting for stabilisation at the back



a)



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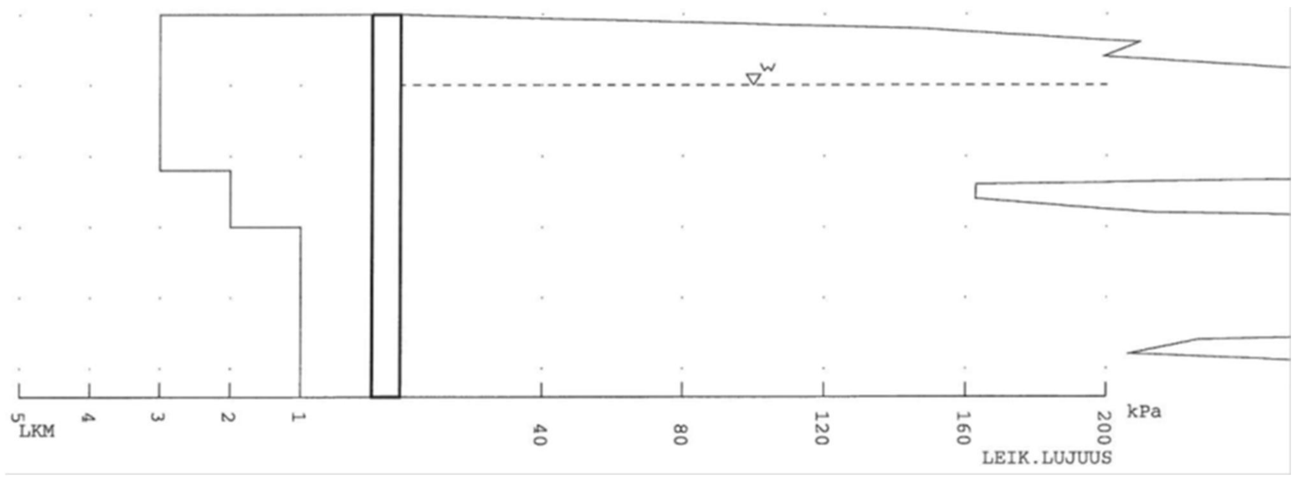


c)

Figure 11.13 a-c Some results of sounding tests in Arcada II.

11.4 Conclusions

As a conclusion, it can be claimed that surplus soft clays constitute potential materials for construction use. The laboratory test results and the pilot implementation in Arcada II show that the surplus soft clays can be used in construction by modifying the material so that the strength and the modulus of the material are enhanced.

The laboratory test results show that the alternative binder materials such as fly ash and flue gas desulphurisation gypsum can used to replace cement in stabilisation, without reducing the compressive strength of the structure.

By using alternative binder materials, the cost of the binders can be reduced and also CO_2 emissions can be reduced. However, the environmental permit is required in case alternative binder materials are used because of the classification of such products as waste.

The laboratory tests are important part in the utilisation of the surplus soils as the properties of the soils vary a lot and different binders work in different ways depending on the material properties. In the Arcada II case one material was disqualified from the stabilisation because the laboratory test results showed no increase in the compressive strength when the material was stabilised with 100 kg/m^3 of cement.

In case the utilisation of the industrial by-products is possible, then savings can most probably be made. The environmental permission processes need improving so that the slowness of the permission process does not become an obstacle in the utilisation of the by-products.

The sounding test results from Arcada show that by mass stabilisation on site the targeted shearing strengths can be achieved and even exceeded.

12. Jätkäsaari I, II, III

Marine sediments in the coastal areas are often contaminated as a consequence of industrial and port activities, as well as the influence of cities located there. Construction activities and reclamation of shore line require dredging and handling of contaminated sediments since the level of contamination inhibit dumping of dredged sediments into the sea. Based on their technical properties, most of these dredged soft and watery sediments (clay, gyttja, etc.) are regarded as too poor quality material for earth construction purposes.

Economic, sustainable and environmentally safe management of contaminated, dredged sediments is a key issue in many construction sites. The pilot application of the Absoils project carried out in the area of Helsinki called West Harbour (Jätkäsaari) offered a feasible solution to this challenge.

The location of the pilot site is shown on Figures 12.1…12.3.

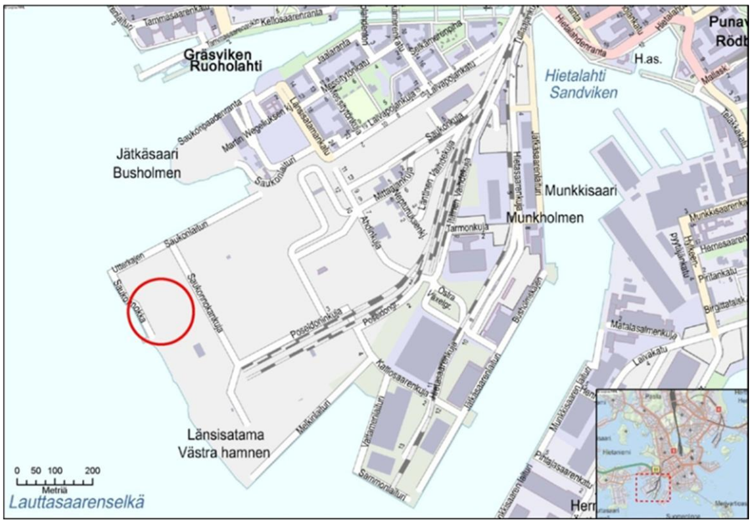


Figure 12.1 The location of the Jätkäsaari I-III pilot site

Fig. 12.2 Mass stabilisation phase II, autumn 2012. Basin number 1 right (near ready-mixed concrete plant) and no. 2...4 to left.

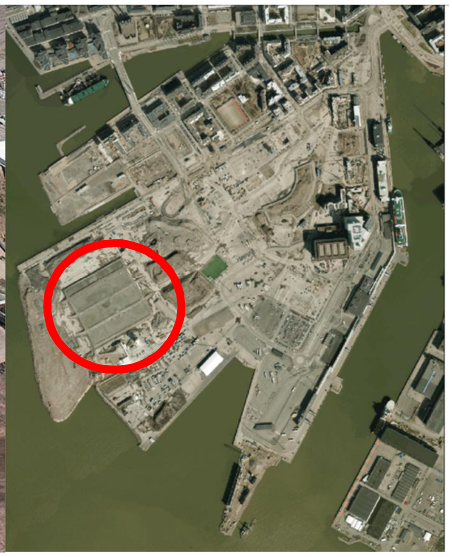


Fig. 12.3 Mass stabilisation basins in the West harbor.

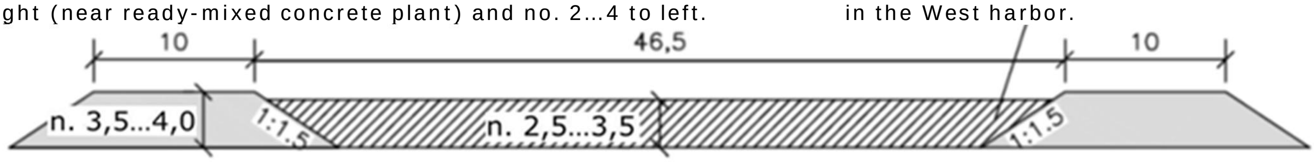


Fig. 12.4 Cross section of the mass stablilization basin (diagonal line screen) surrounded with blasted rock embankments (gray screen). Dimensions in meters [m].

Mass stabilisation in the stabilisation basins was carried out in three phases and the stabilised masses were used for various construction purposes.

12.1 Jätkäsaari I

The first stage of the Jätkäsaari pilot application was carried out in 2011 and it dealt with the stabilisation of dredged sediments ($V_{sediments} \approx 20\ 000\ m^3$) in the Helsinki West Harbour area (Jätkäsaari). In spring 2011 stage - part of the dredged sediments were stabilised with the use of commercial binder (cement). Since the environmental permit allowed only for cement stabilisation, there was a need for a new environmental permit in order to use fly ash and sulphur removal product in the stabilisation of the second stage of this pilot.

For the needs of this pilot application, three stabilisation basins were constructed.

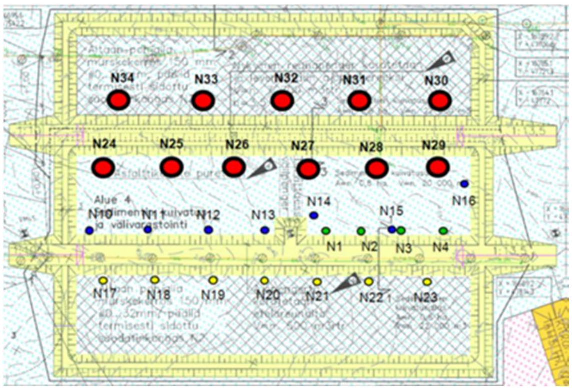


Figure 12.5 Jätkäsaari I – plans of stabilisation basins

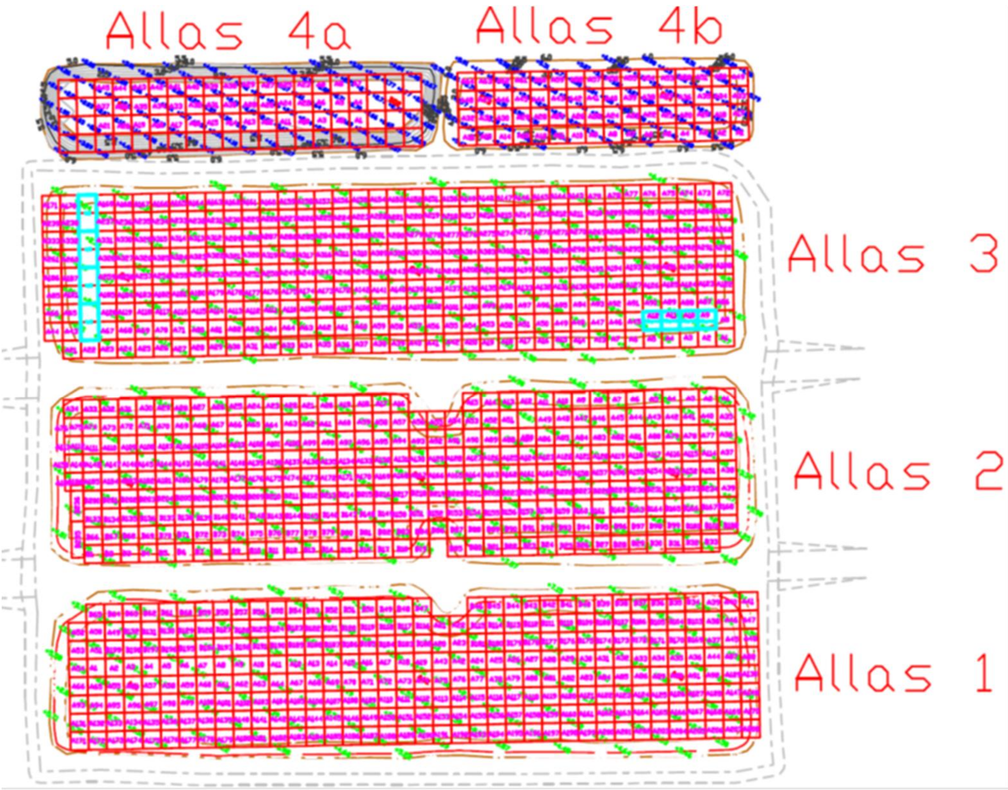
Figure 12.6 Jätkäsaari I – stabilisation basins

Figure 12.7-12.8 Jätkäsaari I – stabilisation works in progress

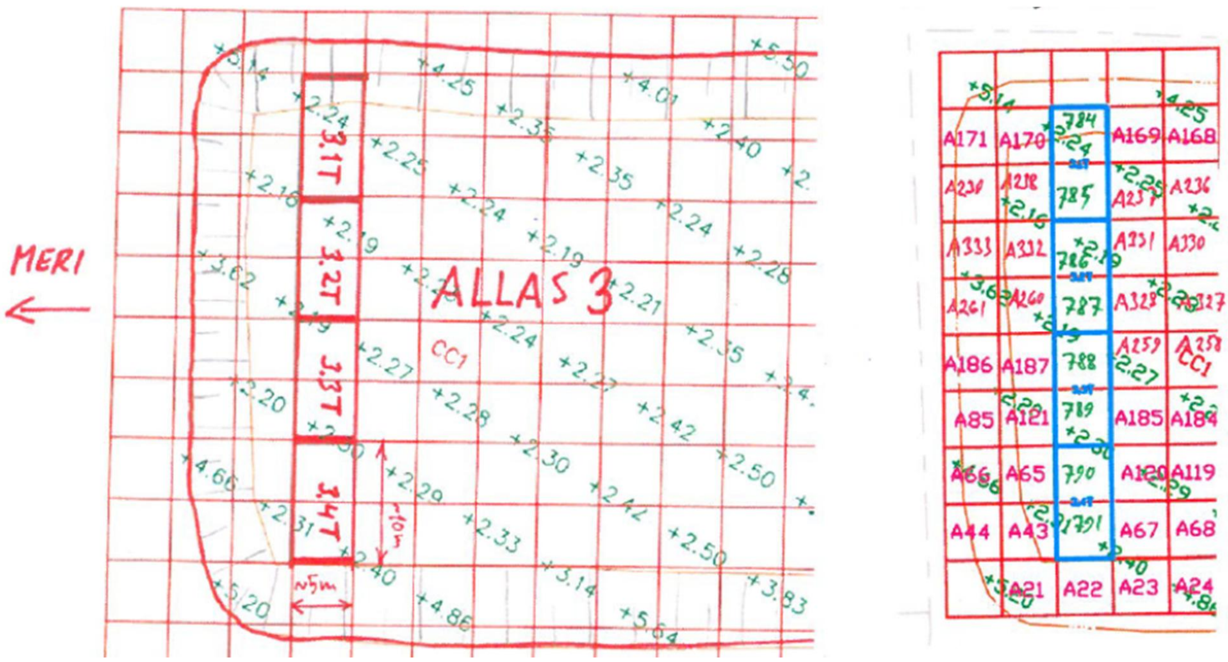
Figure 12.9 Mass stabilised sediments stockpiled and waiting for reuse in 2012

12.2 Jätkäsaari II

The stabilisation of the dredged sediments for the pilot Jätkäsaari II in Helsinki took place between August and Novemeber 2012. Mass stabilisation was carried out in five sedimentation basins. Plus cement was applied as binder in all the basins apart from the basin 3 which served as a trial field for fly ash stabilisation. Fly ash used as a binder in the binder mixture implemented in this case originated from the Helsinki Energia power plant in Hanasaari. Fly ash was transported directly to the pilot site from the power plant. Two new stabilisation basins were constructed next to the basins of the Jätkäsaari I stage.



a)



b)

Picture 12.10 Jätkäsaari II. a) Sedimentation basins 1, 2, 3, 4a ja 4b. b) Location of the blocks stabilised with binder including fly ash in Basin 3.

Picture 12.11 Sediments waiting for stabilisation in a basin.

Picture 12.12 Dredged sediments before stabilisation.

12.2.1 Preliminary tests in the laboratory

Disturbed samples of the soil to be stabilised were taken in order to determine the water content and for the needs of stabilisation tests. Surplus soils in this pilot are sediments dredged from the sea. Samples were taken from the fly ash stabilisation area and its proximity in June and September 2012 and the test results revealed that the water content was of 95 ... 110%. Also, on the 30th of October, 2012 two samples per a stabilisation block were taken to determine the water content. The results of the laboratory tests on the above mentioned samples are presented in Table 12.1.

Table 12.1 Basin 3 - sampling points for the sediments and sampling depths – sampling before stabilisation

Sampling point	Depth from the sediment top level [m]	Water content [%]	Water content, mean value
next to A 187	0,5	93,4	99 %
	1,0	102,6	
	1,5	101,6	
between A65 – A120	0,5	98,0	97 %
	1,0	90,7	
	1,5	101,3	

Picture 12.13 Preparations for sampling.

Picture 12.14 Sampling pit in the sedimentation basin. Depth determination


Picture 12.15 Sampling

Picture 12.16 Samples ready for laboratory tests

Stabilisation tests were performed in the laboratory in order to determine the most optimal binder mixture. Stabilisation tests were carried out for the sediment samples with two binder mixture variations. Both binders consisted of the Plus cement and dry fly ash – the binder volume in the first case was 40 + 150 kg/m3 (Subplot 3.1T), and in the second case it was 40 + 250 kg/m3 (Subplot 3.2T). The test results after 28 and 90 days for the compressive strength were 55/97 kPa for the first binder mixture and 86/108 kPa for the second binder mixture.

12.2.2 Implementation of the fly ash in stabilisation

The stabilisation trial work with the use of fly ash was implemented according to the work specification between 20.11.-21.11.2012.

Fly ash originating from the Hanasaari power plant was used in the stabilisation process as one of the binding agents. Dry fly ash was delivered to the site by a tank truck and ashes that had been previously moistened at the plant were transported by pick-up trucks under a tarpaulin cover.

The cement used as a binder in the stabilisation process was mixed with the soil in the usual way applied in such cases, that is by using a pressure feeder and a mixing tool attached to the excavator.

Picture 12. 17 Pressure feeders

The fly ash was fed in two different ways:

1. it was mixed with the sediment with the use of a pressure feeder and mixing tool– dry ash
2. it was spread on top of the sediment – moistened fly ash

The fly ash spread on top of the sediment layer was carefully mixed with the sediment before mixing cement. After mixing both binders with the sediment, a 1m thick sealing layer was constructed on top of the blocks where fly ash was used for the stabilisation process.

Pictrue 12.18 Stabilisation in progress

Picture 12.19 Sealing layer on top of the stabilised sediments

12.3 Quality control

Quality control soundings were performed in January 2013. The table below shows the locations and numbers of the sounding that were carried out. In order to carry out soundings, the sealing layer and the strainer cloth had to be removed.

Column penetrometer and vane penetrometer for columns are the two most common methods for quality control soundings in mass stabilised structures. Column penetration sounding is by far the most used method of quality control for deep stabilisation (column stabilisation and mass stabilisation) in Finland. The soundings give information about the strength properties of the material.

Table 12.2 Number of soundings

Block	Binder	Column sounding	Vane sounding
3.1T	Ce + FA (dry)	5	2
3.2T	Ce + FA (dry)	5	2
3.3T	Ce + FA (moistened)	5	2
3.4T	Ce + FA (moistened)	5	2
	total	20	8

Picture 12.20 Preparations for the quality control soundings

Picture 12.21 Test pit digging

Picture 12.22 Test pit

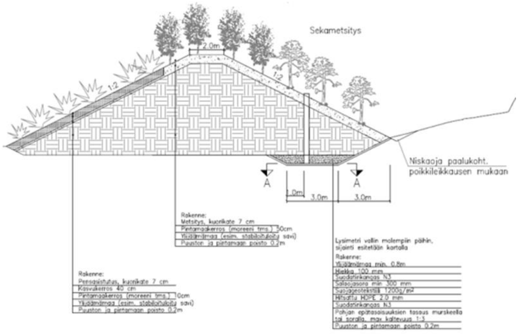
12.4 Jätkäsaari III

In the Jätkäsaari III pilot, stabilisation method was used to treat dredged sediments in the basins. Stabilisation works were carried out in spring 2014. Two different methods were used: mass stabilisaiton and windrow turner stabilisation. Various binders and binders' mixtures were applied. These include also such secondary materials as fly ash, FGD and oil shale ash from Estonia.

Picture 12.23 Jätkäsaari III: stabilisation work in progress

Picture 12.24 Jätkäsaari III: geotextile is spread after stabilisation and the settlement embankment load is placed on top

The stabilised sediments form the stabilisation basin 1 served as material for the construction of a trial noise barrier in the Jätkäsaari area, in the vicinity of the basin. The works were carried out in January 2015. Another trial noise barrier was constructed with sediments stabilised with a crusher screener. The aim has been to test the properties of stabilised sediments in order to use the stabilised material later on in some other noise barrier applications. The possible applications for the sediments from Jätkäsaari III is planned to the Sepänkylä noise barrier which is scheduled for construction in 2016 (this will take place outside the scope of the Absoils project).



Picture 12.25 Test embankment "noise barrier" with stabilised sediments – fly ash is planned to be used as binder

Picture 12.26 Test embankment – smaller noise barrier constructed with sediments stabilised with a crusher screener (2015)

Picture 12.27 Larger test noise barrier constructed with mass stabilised sediments (2015)

12.5 Sediment volumes and the properties of the sediments

In the Jätkäsaari site, mass stabilisation in the stabilisation basins was carried out three times in the framework of the Absoils project. The volumes of stabilised sediments are presented in Table 12.3. Mass stabilised sediments have been or will be utilised as earth construction material in various construction sites of the Helsinki city. Those utilisation sites are presented in Table 12.4. Some of the utilisation sites have been completed, some are under construction and some will be constructed starting from 2015 so it is possible, that the utilisation sites may change.

Table 12.3 shows also some index properties of dredged sediments before stabilisation, binders and binder amounts. The index properties of the sediments varied a lot but mostly they were very soft and watery ($w \approx 60\text{-}100$ %). Dredging was carried out with a bucket and grab dredger. Dredged sediments were disposed into the basins in the points 3-6 and as commonly occurs the finest grain sized sediments were floating farthest and the coarse sediment remained near the disposal point. Some stones were found at the disposal point and it affected the stabilisation work because it was necessary to partially harrow the basins before mass stabilisation work.

Table 12.3 Jätkäsaari, mass stabilisation phases, volumes and some index properties of sediment, binders recipes and in situ strength of stabilised sediment. (Ce = cement CEM II/B-M (S-LL) 42,5 N, FA = fly ash, FGD = desulphurization agent, LC = lime and cement 1:1, OSA = oil shale ash, type 5 or 8)

Phase and Year*	Volume [m^3]	Water content [%]	Loss on ignition [%]	Binder	Binder amount [kg/m^3]	Shear strength, variation and average τ / $\tau_{av.}$ [kPa] ***
I - 2010 / 2011	20.000	70-100	3-4	Ce	60	≈20-80 / ≈40-60
II - 2012 / 2012	90.000	26-159	1.5-8.7	Ce Ce+FA	40-80 (av. ≈70) 40 + 150-500**	≈10-80 / ≈40 ≈30-80 / ≈50
III - 2014 /2014	21.000	58-100	2.6-4.0	Ce+FA, LC+FA Ce/LC+FA+FGD OSA5, OSA8	50 + 150 50 + 75 + 75 150	≈40-250 / -

* year of dredging and year of mass stabilisation *** rough estimation based on QC soundings
** Ce+FA 40+150 dry kg/m^3, 40 + 250dry kg/m^3, 40 + 250wet kg/m^3, 40 + 250dry + 250wet kg/m^3

Table 12.4 Jätkäsaari, mass stabilisation, utilisation sites of the mass stabilised hardened sediments.

	Utilisation with environmental permit		Utilisation without environmental permit	
Phase	site and purpose	volume	site and purpose	volume
I*	Vuosaari landscaping (2014)	9 000 m^3	Myllypuro park (2014-2016)	20 000 m^3
II	Vuosaari landscaping (2012-2013)	66 000 m^3	Ida Aalberg park (2013) Vartiokylä flood barrier (2015?) Myllypuro park (2014-2016?)	100 m^3 10 000 m^3 13 300 m^3
III	Sepänkylä noise barrier (2016)	21 000	*not possible at the moment*	-
total volume ≈96 000 m^3 + ≈43 000 m^3 ≈ 139 000 m^3 where ≈9000 m^3 from Kalasatama mass stab. basins				

* In the reservoir stack there is also mass stabilised sediments from the Kalasatama basin

Mass stabilisation in the Jätkäsaari area was executed about 3-10 months after dredging and disposal of the material to the basins took place. Dry and warm summer weather makes the water content at the surface of the sediment decrease but drying of the sediment does not happen in the deeper layers. At rainy periods, the water content of the sediment increases.

12.6 Execution of mass stabilisation

In phases I, II and III, mass stabilisation was carried out in the basins with the mass stabilisation equipment. Stabilisation was executed mostly with one mass stabilisation unit but in the beginning of the phase I and II there were two units working. In phase III, the aim was to apply the process stabilisation method but the volume of sediment was too small for a big process stabilisation plant and it was not possible to use a smaller moveable plant in wintertime, 01-02/2014. As a test, part of the sediment in phase III was first stabilised in the basin with the mass stabilisation equipment using pure fly ash binder (FA) and after some weeks of hardening, the pre-stabilised soil was stabilised with screener crusher (SC) using cement as a binder. The pre-stabilisation was used because the sediment was so soft and watery that it was not possible to stabilise it with screener crusher without pretreatment.

12.7 Laboratory and field tests

The stabilisation technology requires technical and in many cases environmental material tests in the laboratory before the launch of construction works, in situ tests during the construction and in some cases follow-up studies afterward. Technical properties of the materials are determined with laboratory studies including compression strength tests after a specified curing time.

During the stabilisation phase I, II and III, a great amount of different kind of laboratory and field tests was performed. A list of the carried out tests is presented in Table 12.5. Some tests are still ongoing and the utilisation of those stabilised sediments continues, so some test results and site experience will still be gathered during the coming years. The processing of those results is ongoing and their verification with other Finnish and foreign results will continue.

Table 12.5 Laboratory and field tests carried out in mass stabilization phase I, II, III.

	Phase:	I	II	III
laboratory tests before mass stabilization				
1.	contamination tests (sediment before stabilization)	+	+	+
2.	leaching tests / 2 stage batch test	+/-	-/-	+/+
3.	water permeability tests	-	-	+
4.	index tests (w, H_h, grain size, ρ_d, pH, …)	+	+	+
5.	stabilization tests (1-axial compression test, 7-91 d hardening)	+	+	+
6.	sensitivity analysis of water content	-	-	+
7.	evaluation of the construction properties of stabilized samples	-	-	-
quality controlling tests during execution of mass stabilization				
8.	column soundings, tip area 100 cm^2	+	+	+
9.	static-dynamic penetration tests, tip area 50 cm^2	-	+	+
10.	column vane tests	+	+	+
11.	pocket vane and manual vane tests	-	-	+
12.	test pits and excavator sampling	-	+	+
13.	XRF-tests (in situ binder distribution)	-	+	+
other field tests after mass stabilization				
14.	sampling and contamination tests	+	-	-
15.	"index tests" of stabilized soil (w, pH, …)	-	+	+
16.	plate load tests	-	+	+
17.	light falling weight deflectometer tests ("loadman")	-	+	-
18.	settlement measurements under loading embankment	-	+	+
19.	strength increase under loading embankment	-	+	-
20.	test embankment constructions	-	+	+
21.	full-scale failure experiment	-	+	-
22.	environmental risk analysis for the utilization	+	-	-
23.	two stage batch test	-	-	+
other laboratory tests after mass stabilization				
24.	penetrometer tests	-	+	-
25.	cone tests	-	+	+
26.	fertility test (for park construction)	-	+	-

Environmental permits concerning the utilization of stabilized material sometimes set requirements for water permeability limits. For instance, the environmental permit for the Sepänmäki noise barrier (see Table 12.4 and 12.6) requires a limit value for water permeability smaller than 10^{-8} m/s.

Several different binders and their amounts were tested in order to determine a suitable binder mixture for a given application. The replacement of cement with binders based on fly ash and end product of desulphurization from coal combustion and fly ash from combustion of Estonian oil shale in the stabilization of dredged sediments was studied both in the laboratory and on site.

In the leaching tests (modified test according to standard NEN 7375:2004), the aggregate material of the test samples originated from the Jätkäsaari basins phase III (see Table 12.6). The binders used in the tests were cement (from Finsementti), lime (from Nordkalk), fly ash and desulphurization agent from Hanasaari power plant (Helsingin Energia) and oil shale ash generated by burning oil shale in the Eesti Energia power plant. The binders used in the leaching test and their abbreviations are listed in Table 12.6. The pH values of the stabilized samples varied from 10.9 to 11.7.

The leaching of the substances was studied as the materials from the West Harbor basins have been designed to be utilized in the Sepänmäki noise barrier and in the Vuosaari landfill for landscaping purposes. The height of the designed Sepänmäki noise barrier is 5-9 m, its slope inclination 1:2, surface layer 0.5-1 m and the instrumentation includes lysimeters and standpipes.

The cumulative leaching test results are compared to the limit values presented in the environmental permit applications. The used limit values come from the publication of the Finnish Environment Institute

(Sorvari, 2000). There were no given limit values for chloride and sulfate in the publication so the used limit values originate from the quality recommendations for domestic water and quality norms for groundwater. Also, the local precipitation is used as background information when the limit values are set. The limit values and the leaching test results are presented in Table 12.7. The leaching of metals, fluoride and sulfate did not exceed the presented limit values in any of the test samples. Many results were below the determination values of the laboratory.

Table 12.6 The index properties of the aggregate materials and the binder recipes. Water permeability tests results – results are from one test per binder recipe. Phase III.

Sample code	Aggregate (sediment)	w [%]	ρ [kg/m^3]	Binder	Binder amount [kg/m^3]	Water permeability [m/s]
JHL-1	5/13 0-3 m mixture	100	1450	Ce + FA	50+150	$1,1 \times 10^{-9}$
JHL-2	7/13 1-2 m	57	1640	Ce + FA	50+150	$7,4 \times 10^{-9}$
JHL-3	mixed sample	95	1470	Ce + FA	50+150	$1,7 \times 10^{-9}$
JHL-4	mixed sample	95	1470	Ce + FA + FGD	50+150	$1,1 \times 10^{-9}$
JHL-5	mixed sample	95	1470	LC 3:7 + FA	50+150	$1,2 \times 10^{-9}$
JHL-6	mixed sample	95	1470	LC 3:7+FA+FGD	50+75+75	$1,1 \times 10^{-9}$
JHL-7	mixed sample	95	1470	OSA8	150	$8,2 \times 10^{-9}$

Ce = cement (PlusSe), FA = fly ash, FGD = Desulphurization agent, LC = lime+cement, OSA8=oil shale ash, type 8

Table 12.7 Limit values presented in the environmental permit application of Sepänmäki noise barrier and test results summary. Tested materials are presented in the Table 12.6. Phase III.

Element	Limit value [mg/m^2] *	Test results** 64 d [mg/m^2]
Arsenic, As	58	0.4 - 0.6
Barium, Ba	2800	4.0 - 9.3
Cadmium, Cd	2,1	0.04 - 0.06
Cobolt, Co	280	0.21 - 0.25
Copper, Cu	250	0.7 - 3.3
Mercury, Hg	1,6	0.04 - 0.14
Molybdenum, Mo	70	3.6 - 22.9
Nickel, Ni	270	0.4 - 2.7
Lead, Pb	210	0.2 - 0.3
Antimony, Sb	36	0.8 - 16.8
Selenium, Se	14	0.5 - 1.9
Tin, Sn	280	1.5 - 6.5
Vanadinium, V	700	0.7 - 4.7
Zinc, Zn	330	2.4 - 4.0
Fluoride, F	2800	105 - 124
Sulfate, SO_4	162 500*** (97 500)****	738 - 2297
Chloride, Cl	162 500*** (16 250)****	45 982 - 106 855

* Sorvari (2000), ** leaching test results from West Harbor and limit values which are presented in the environmental permit application - based on the quality recommendations*** / quality standards**** and local precipitation

The effect of the aggregate variation can be seen by comparing the leaching test results of the samples JHL-1, JHL-2 and JHL-3, as they all had the same binder recipe of 50 kg/m^3 cement and 150 kg/m^3 fly ash from the Hanasaari power plant. The aggregates originated from different parts of the stabilization basin and from different parts of the dredging area. There were differences among the aggregates concerning leaching test results of chloride, sulfate, antimony and molybdenum, yet none of the substances exceeded the given limit values. As the chloride limit value was set on the basis of the quality norms for groundwater, the chloride leaching test result exceeded the limit value as it is very low. Neither of the designed utilization target (the noise barrier or the landfill) is located in an important groundwater area.

The results showed that the stabilized material from the West Harbor can be used in the Sepänmäki noise barrier as none of the leaching test results exceeded the given limit values.

12.8 Technical tests

12.8.1 Workability and transportability

The most important technical properties of mass stabilized sediment are the workability, shear strength, stiffness and the settlement properties. In case where the stabilized sediment is used as a landscaping filling, or in gentle sloped hills in parks, the demands for the material are low. When the stabilized sediment is utilized in angularly shaped deep sloped noise or flood barriers, the demands are higher. Stabilized clay can be used in a sub-base and embankment in roads etc., but in such applications the use of watery and soft dredged sediments as aggregate is not recommended.

The workability - including the resistance for transportation - can be estimated on the basis of the shear strength of the stabilized material but practical earlier experience is required to make such estimation. The workability and transportability are dependent on the weather – in case of a dry period or cold wintertime, the material quality is better but in case of rainy period, the stabilized sediment constitutes a challenging material for construction and transportation and in some cases it is better to wait for better weather conditions. When the shear strength is bigger, stabilized sediments are better fit for construction and transportation, and more resistant to negative impact of wet weather conditions. In good circumstances, shear strength of 50 kPa has been considered sufficient as a target value in sediment stabilization. Prior experience has proved it to be suitable in some targets but the target strength should be designed according to the application type and the site specific requirements (structure, transportation, weather conditions, etc.).

12.8.2 Economy

The shear strength of the stabilized sediment grows with the increase of the binder amount. Commercial binders (CE-marked products) are pricey and the value of stabilized sediment as a construction material is not so high. Because of that the amount of binder has to be optimized taking into consideration the requirements set by the utilization site. In case of the West Harbor and the utilization sites of Helsinki city, there are several items to be considered, such as the technical demands of the structure, environmental permit for the utilization site, contamination of the sediment, availability of the alternate binder material, etc.

Environmental permit is needed for stabilization of contaminated sediments and for the use of alternate binders like fly ash and FGD. Alternate materials have a high tax (currently 50 €/t in Finland) in case they are not utilized so the producers of that kind of waste materials are motivated to offer their material as stabilization binder. Replacing cement with fly ash, FGD or OSA outstandingly reduces the binder price in the process of sediment stabilization. To obtain good stabilization result, the amount of pure cement needed in practice is at least 80 kg/m^3 and the binder price is about 8-10 €/m^3 of the stabilized sediment. When the amount of cement can be reduced to, e.g., 40 kg/m^3 by adding, e.g., 150 kg/m^3 of fly ash binder, the price of binder mixture drops to 4-5 €/m^3.

12.8.3 Sensitivity to water content increase

Replacing cement and increasing the total binder amount (e.g. cement + fly ash) reduces the 1-axial compression strength in the laboratory tests but adding fly ash makes the in situ stabilization results much more homogeneous and the stabilization is not so sensitive to water content increase and changes. It has also been noticed that the relation between the in situ / laboratory strength is much lower with pure cement than with cement + fly ash, lime+cement + fly ash, or other alternate binder recipes.

The possible increase of the water content of the sediment can be an unpleasant surprise if water content increases during the storage of the sediment in the basins. This kind of surprise took place in the phase II of the project where the laboratory tests had been made soon after dredging and binder recipe had been defined in that phase. Before and during the stabilization the water content increased and it was not noticed in time, thus the cement amount was not correct in the first stabilized basins (water/ cement relation was too big).

After this lesson learnt, a lot of sensitivity analysis was made concerning water content increase in phase III. Figure 12.27 presents the relation between the water content and 1-axial compression strength with different binders - pure cement, LC+FA, LC+FA+FGD, Ce+FA and Ce+FA+FGD. It was discovered that pure cement is very sensitive to water content and in that kind of stabilization it is technically and economically much “safer” to use the mixture of a little amount of cement or lime+cement and 100-200 kg/m^3 of fly ash (or FGD). This kind of mixture is not so sensitive to water content changes and the stabilization result is much more homogeneous. The water content increase was made with fresh and salty water with binder recipe C+FA 30+100-200 kg/m^3. The compression strength was in practice the same with the fresh and salty water used to increase the water content. The sediment specimen in Figures a and b is the same and the water contend is adjusted in laboratory by drying sample or adding water to the sample before mixing of binder. In the Figure c the specimens with different water content are from different areas and depths of the sediment basin. The compression strength is an average of two parallel compression test results.

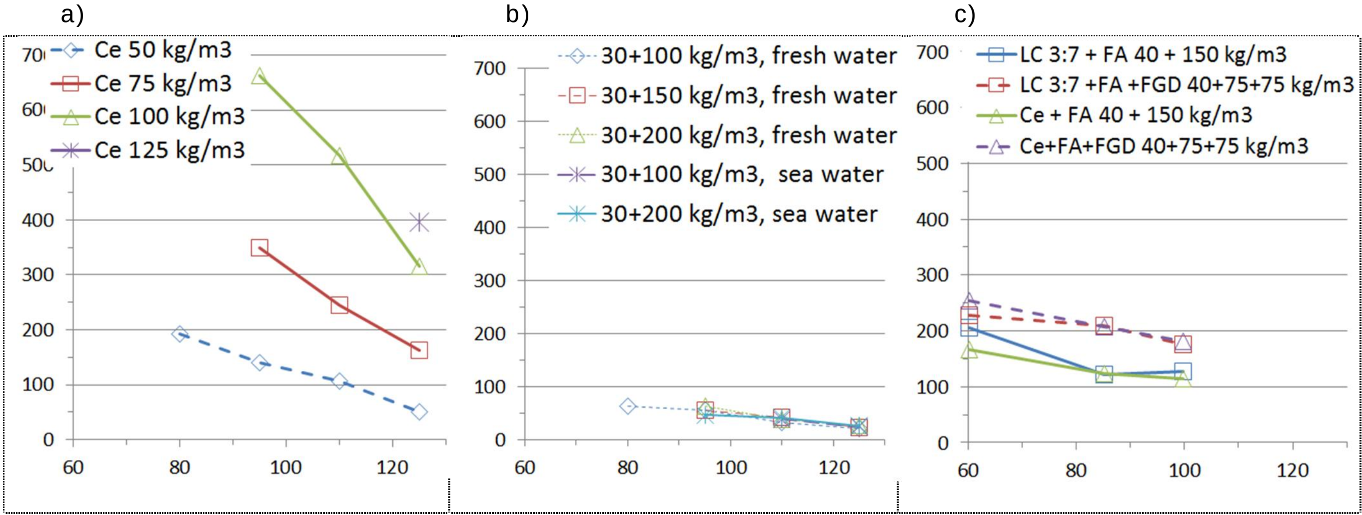


Fig. 12.27 Relation between water content and 1-axial compression strength with different binders – Ce (a), Ce+FA (b) and LC/Ce + FA or LC/Ce + FA + FGD (c). In Fig. a the water adding is made with fresh water and in Fig. b with fresh or salty water. Phase II (Fig. b) and Phase III (Fig. a and c).

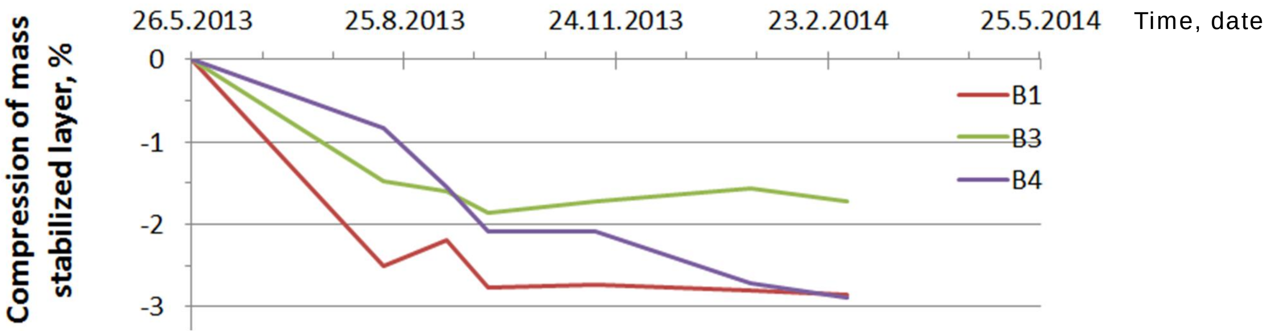


Fig. 12.28 Compression of mass stabilized layer under 3 m loading embankment. Phase II, basin 3.

12.8.4 Settlement properties

After executing mass stabilization in the basin 3 (phase II), the stabilized sediment was loaded with a 3 m high aggregate embankment. The compression of the mass stabilized layer after construction of the loading embankment was measured with 4 settlement plates – 3 plates over mass stabilization and 1 plate under the mass stabilization. The compression measured is presented in Figure 10. Settlement plates were installed during the construction of 3 m loading embankment and the settlement under working embankment before that had not been measured.

13. Conclusions

Based on the experience gained during carrying out this pilot application, it can be concluded that surplus clays and dredged sediments consitute potential materials for construction use. The laboratory and field tests' results show that the surplus clays and dredged sediments can be used in construction by modifying the material so that the strength and the modulus of the material are enhanced.

The laboratory test and the in-situ stabilisation results show that the alternative binder materials such as fly ash and flue gas desulphurisation gypsum can be used to replace cement in stabilisation, without reducing the compressive strength of the structure.

By using alternative binder materials, the cost of the binders can be reduced and also CO_2 emissions can be diminished as the carbon footprint of cement production is high. The use of alternative binder materials is hindered by the need to apply for environmental permit due to the classification of such products as waste. The length of the permitting process and the uncertainty of the final outcome are the major setbacks in the planning process that would take into consideration stabilisation of poor quality clays with alternative binder materials. This is in general hinders the effectice use of surplus soft soils, as stabilisation with cement only is rather pricy.

Laboratory tests are an important part in the utilisation process of surplus soft soils as their properties vary a lot and different binders work in different ways depending on the material properties. Quality control during construction phase and afterwards allows to verify the laboratory test results in real conditions and provides an important data that can be utilised in future applications.

In the case the utilisation of the industrial by-products is possible, financial savings can most probably be achieved. Environmental permitting needs improvement to speed up the process as its slowness constitutes one of the major obstacles in the utilisation of the by-products. There is also a need to imrove the legislation both on the national and EU level so that the targets of the “resource efficient Europe” can be achieved more easily.

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