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APPLICATIONS, PILOTING AND VERIFICATION ACTIONS SIMUNA-VAIATU PILOT REPORT

RAMBOLL

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Revisions

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CONTENTS

ABBREVIATIONS

BL	– Block
BOTT	– Bottom ash, retrieved from the bottom of burning chamber
Komp. CEM	– Composite Cement (also: KS)
CaO	- Calcium Oxide
CYCL	– oil shale ash from the cyclone filters, pulverized firing
EF	– electrostatic precipitator oil shale ash from pulverised firing
kPa	- kilopascal
LOI	- Loss of Ignition
MPa	- megapascal, unit of measure for load capacity
EF CFB	- electrostatic precipitator ash from circulating fluidised bed combustion
Niton	– Portable X-ray Fluorescence Analyser
OSA	– Oil Shale Ash
OSAMAT	- Management of Environmentally Sound Recycling of Oil-Shale Ashes into Road Construction Products. Demonstration in Estonia.
SKOL	– Finnish Association of Consulting Companies
SRC	- Sulphate resisting cement
STA	- unit of distance in road construction process
UCS	– Unconfined Compressive Strength
XRF	– X-ray fluorescence

ABSTRACT

The OSAMAT project encompasses the testing of two different technologies of using oil shale ash (OSA) in road construction – layer-stabilisation with coarse materials on road base and mass-stabilisation of peat on weak surfaces before road construction. Mass-stabilisation process is being tested on Simuna-Vaiatu road (current report) and layer-stabilisation is tested on Narva-Mustajõe road (covered in a separate report).

Aggregate materials and binders were selected and tested in the laboratory (Ramboll Finland). Three different binder combinations were selected for further road tests on site.

Road technical design documentation was compiled by Ramboll engineers and served as base documentation for construction permit issued by Estonian Road Administration.

Construction work on the Simuna-Vaiatu road section km 3.0-4.0 of the LIFE+ OSAMAT project was started in mid-July 2013 with mass-stabilisation works. The first phase of the work was completed in September and the whole section was done by August 2014.

On this test section, mass-stabilisation of peat and other unstable surfaces was tested with the help of oil shale ash on a 500-meters-long road section. Each 100-meter section was built with different materials recipes, i.e. with different ash-cement ratio. In the construction of the pilot section following ashes were tested - CYCL, EF PF and EF CFB.

During the construction process different technical monitoring actions were carried out to ensure work quality – XRF analysis, cone penetration and vane share tests and survey of the settlement plates. Also environmental monitoring was carried out for analysing impacts of pilot construction on soil, water and flora conditions.

1. INTRODUCTION

OSAMAT project has come into life on the firm belief of the beneficiaries that the eventual environmental problems connected to the recycling of OSA (Oil Shale Ash) for civil engineering purposes can be overcome by exploiting the technical properties of the OSA to transform it into strong and impermeable materials in favourable conditions. OSA can be used in high volumes in the local construction markets, and for the wider European market OSA will become an interesting and cost-effective replacement of cement and other expensive commercial additives. OSA is an industrial by-product of energy production from oil shale. The generation of OSA is not allocated to consume energy and generate airborne releases of greenhouse gases. This is a very significant aspect when promoting the utilisation of OSA in the European markets. In general, the project will address the challenges of the European policies and legislation, concerning waste, and promote waste recovery, sustainable recycling with a focus on life-cycle thinking, and the development of recycling markets. Conversion of OSA into valuable civil engineering material for different purposes will be an encouraging model for European societies, to recycle corresponding types of industrial waste materials in civil-engineering applications.

According to the original project plan, one of the main parts in OSAMAT project were the demonstrations of practical implementation of three types of civil-engineering applications with materials based on OSA: stabilisation of existing road base course, mass-stabilisation of peat e.g. for road and housing foundations and construction of new base course built on mixtures of oil-shale mining waste and OSA. This report covers the design and construction of Simuna-Vaiatu demonstration site, both of which were performed within actions Applications and Piloting. Objective of this pilot construction was to demonstrate utilisation of OSA in mass-stabilisation of peat.

While original plans included testing both fresh and stored ashes a decision was made during the initial phase of the project to exclude further testing of externally stored ashes as the quality of the product is unstable and therefore not suitable for stabilisation as binding material.

A quality management system (by Rakli SKOL in Finland, and ISO 9001 in Estonia) is in use in Ramboll, and all the equipment is calibrated in accordance with it. It was expected that subcontractors (for example drilling, bearing capacity etc.) had also a quality management system.

2. SITE INFORMATION

Sites for OSAMAT project demonstration were allocated in early 2011 and design of the pilot sections commenced after that. Layer-stabilisation with OSA was done in Narva-Mustajõe section and mass-stabilisation of peat in Simuna-Vaiatu road.

State owned road nr 17192 Simuna-Vaiatu is located in Lääne-Viru County in Eastern Estonia. It is a road with mainly agricultural traffic and low loading (see figures 2-1, 2-2 and photo 2-1). The road has little traffic with only 140 vehicles per day of which only 2% represent the amount of heavy vehicles.

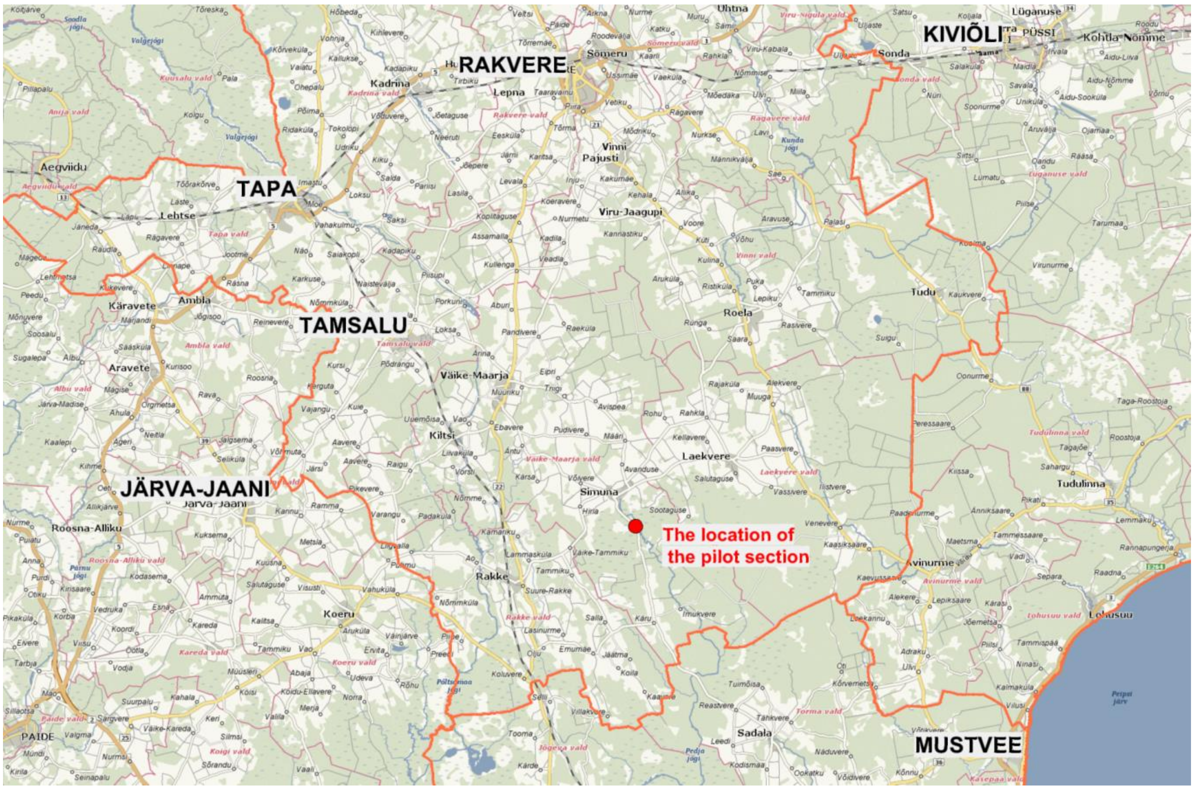

Figure 2-1 The location of the pilot section in Lääne-Viru County

The project road section on km 3.0-4.0 is located outside the settlements and there is speed limit 90 km/h. Before construction the road was narrow with several curves that have poor visibility and a small radius. Length of the existing pavement was about 5.6 m. Surface was paved and with crumbles on the sides and there were some uneven places and cracks all over the road. There are no road signs or pavement markings on this road section. There are two exits towards the end of the road section.

Figure 2-2 The location of the pilot section near Simuna village

Photo 2-1 Simuna-Vaiatu road section in 2011

3. LABORATORY TESTS AND TECHNICAL DESIGN

3.1. Earlier experience of using OSA in road construction

Fly ash has been used in road construction since 1961 in Estonia. In 1971-1986 about 100 – 120 000 tons of oil shale fly ash was used to stabilize road pavements, altogether ca 1000 km of stabilized pavements were built in Estonia. TECER (Teede Tehnokeskus) has studied the experience in 2005[1]. Test samples (after 35 years of use) indicated UCS of 20-34 MPa with average of 25.3 MPa resulting in with all negative aspects of concrete pavements (built without joints); also there were difficulties with adhesion of stabilized layers with bitumen-based top layers.

Ramboll Estonia has studied possibilities of mass-stabilisation of soft grounds[2] together with Ramboll Finland and continued the study with test site in Kose-Mäo section of Tallinn-Tartu road in 2007-2011[3]. Experience of this small site (900 m^2) has laid basis for mass-stabilisation tests within OSAMAT project.

3.2. Laboratory tests and used binding agent compositions

Flow chart (3-1) describes all steps of the project from designing principles (preliminary design) to follow-up studies. It describes how the stabilisation project of a road construction takes place. After preliminary and site investigations laboratory tests can begin with concrete site material. As the properties of ashes and aggregates may differ in every case, the mix recipes have to be prepared based on laboratory tests with exact materials available for particular project.

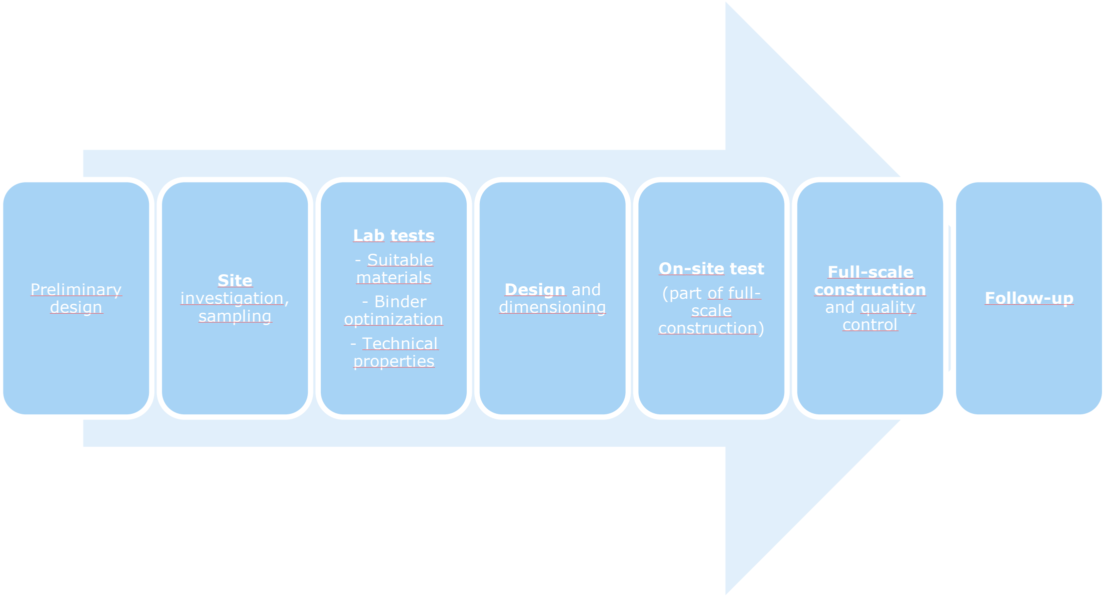

Figure 3-1 Flow-chart of pilot project phases

Laboratory test plans were designed according to the initial project plans and prior to allocation of the demonstration sites to assess feasibility of different oil shale ash fractions as road base stabilisation binding agents. The feasibility in stabilisation was tested with unconfined compressive

[1] AS Teede Tehnokeskus. 2005 (56): http://www.mnt.ee/failid/uuringud/tuhkkatted.pdf

[2] Pinnase mass-stabiliseerimisvõimaluste uuring. Ramboll Eesti AS 2007 (4): http://www.mnt.ee/failid/uuringud/2007-4_Mass-stabiliseerimise_voimalused_aruanne.pdf

[3] Pinnaste mass-stabiliseerimisvõimaluste katselõigu uurimistöö. Ramboll Eesti AS 2007 (4): http://www.mnt.ee/public/uuringud/2008_Pinnaste_mass-stabiliseerimise_katseloik_110427.pdf

strength and freeze-thaw weathering tests on several stabilised mining waste based aggregates and gravel samples taken from Narva-Mustajõe and Simuna-Vaiatu road structure. Thus the tests also gave information about the feasibility of different mining waste aggregates in road construction. All laboratory tests and their results are published in Material Report (Intermediate report of materials action, November 2012, Ramboll).

3.2.1. Peat samples

The stabilisation tests were done for the Simuna-Vaiatu samples represented in Table 3-1. The compressive strengths were measured in case of all samples after 28 days and in case of some samples also after 90 days. The targeted strength for the stabilised peat was 100 kPa. The stabilisation tests were done in two parts. The first part included stabilisation tests for samples S-7, S-9 and S-10. The second part included further testing for samples named “PR” which were taken from one sampling point but from different depths.

Table 3-1 Properties of the peat samples

Sample	w* [%]	Density ρ_m [kg/m³]	pH	Loss on Ignition LOI [%]
Simuna-Vaiatu S-7	352	1100	7.2	40.2
Simuna-Vaiatu S-9	**754**	1000	4.1	88.3
Simuna-Vaiatu S-10	553	1040	6.7	75.1
Simuna-Vaiatu PR1 0.2-0.7	458	1050		58.3
Simuna-Vaiatu PR1A 0.2-0.7	321			69.1
Simuna-Vaiatu PR2 0.1-1.3	632	1040		**90.6**
Simuna-Vaiatu PR2A 0.1-1.3	694			84.8
Simuna-Vaiatu PR3 1.3-2.05	543	1040		69
Simuna-Vaiatu PR3A 1.3-2.05	475			65.2
Simuna-Vaiatu PR4 2.05-2.50	37	**1360**		3.5

**w = water content*

The highest moisture content was found in sample S-9 that also had the lowest density. Sample PR1A had the lowest moisture content as the material was only partially peat. However, sample PR4 was found to have some clay in it which explains the high density and low loss of ignition (LOI). The new samples were combined so that the materials from different depth (0.2-0.7) were mixed together. All the peat samples were found to have similar densities and the water contents varied a little between the layers. It can be deduced from the last sample (PR4) that there is a clay layer under the peat layer. The clay starts somewhere between 2.05-2.50 m.

The pH measurements were done only for the first samples. The pH results varied amongst those samples. It could be assumed that the lower the water content and LOI, the higher the pH.

3.2.2. Binder selection

In suitable binder selection process different tests and analyses were made in laboratory for choosing correct binder recipes for mass-stabilisation works. More detailed information can be found from the Material Report (Intermediate report of materials action, November 2012, Ramboll).

The binder materials (OSA and cement) tested in the laboratory are presented in Table 3-2.

Table 3-2 Tested binder materials

Acronym	Name
OSA EF PF	Oil shale ash, electric filter, Block 3, pulverized firing

Acronym	Name
OSA EF CFB*	Oil shale ash, electric filter, Block 8, Circulated Fluidized Bed combustion
OSA BOTT EF CFB	Oil shale ash, bottom ash, Block 8, Circulated Fluidized Bed combustion
OSA CYCL	Oil shale ash, cyclone ash, pulverized firing
Komp. CEM	Composite cement CEM II /B-M(T-L) 42,5 R
Norm. CEM	Normal cement CEM I 42,5 N
SR	Sulphate resistant cement (CEM I 42,5 N)

**During construction in addition OSA EF CFB from block 11 was used, but its characteristics are equal with OSA EF CFB from block 8*

Following tests were made during binder selection::

- **Niton** is x-ray fluorescence analyser which were used for analysing the total amount of elements in binder materials.
- **Total concentrations of the elements** were determined for the OSA samples according to the standards ISO 17294-2, EPA 3051A, SFS-EN ISO 15587-1. Samples were digested with microwave assisted extraction (aqua regia) and the elements were analysed by inductively coupled plasma mass spectrometry (ICP-MS);
- **1-stage leaching tests** were made according to the standard SFS-EN 12457-2. The total concentrations and the solubility of the elements are compared with guideline values presented in Finnish Government Decree about the use of some waste materials in earth construction in the appendix 403/2009. The concentrations and solubility are expressed in mg per dry weight of the sample;
- **Particle Size Distribution** were determined by sieving and/or by sedimentation tests. For example, in the (dry or wet) **sieving** procedure a dried sample is poured through sieves of different grades (e.g. 2, 0.063 mm). The total quantity of fine particles (e.g. <0.063 mm) can be calculated from the difference with respect to the masses passing the grades (mostly with wet sieving). In case of a **sedimentation test** or the Areometer test, the grain size is determined on the basis of the settling rate of the particles in a liquid (according to Stokes' Law). The settling rate is measured by a specific gravity hydrometer which is placed on a prefabricated solution on certain intervals. The maximum grain size in sedimentation test is 2 mm and for some materials the sieving with 2 mm sieve is needed. If the sample contains more than 2% of organic matter, it should be treated with hydrogen peroxide to eliminate organic matter;
- The **compatibility** of the materials is determined by modified Proctor test which gives the maximum bulk density (dry), $\gamma_{d,max}$, and the optimum water content, w_{opt}, of the material. Obtained relative compaction or compaction rate is D [%]= $(\gamma_d/\gamma_{d,max})*100$. For example, during the follow up of the construction the real-scale compaction results can be compared with this maximum D-value. For each specific structure there are given quality criteria with respect to compaction etc and the acceptable compaction rate should meet the specified criteria.
- **Unconfined Compressive Strength**, UCS, is a standard test where a cylindrical test piece is subjected to a steadily increasing axial load until failure occurs. The axial load is the only force or stress applied. The rate of the load is 1 - 2 mm/min. If any noticeable failure does not occur, the maximum value of the compression strength is taken when the deformation (change of height) is 15%. Usually, the test will be made on test pieces after at least 28-30 days stabilisation. The Photo 3-1 shows the test in progress.

Photo 3-1 Unconfined compressive test in progress.

3.2.3. Niton measurement results

Niton measurements were done for all four oil shale ash materials. Results are represented in

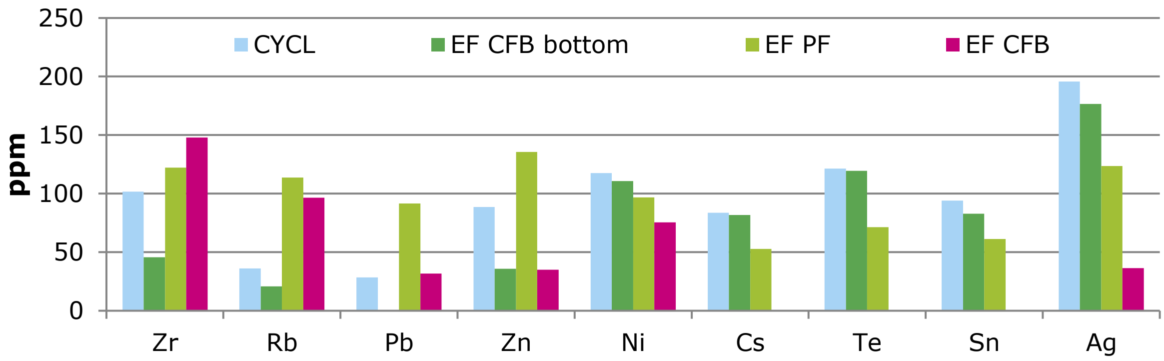

Figure -4, 3-5 and 3-6 in such order that the concentrations increase towards the last figure.

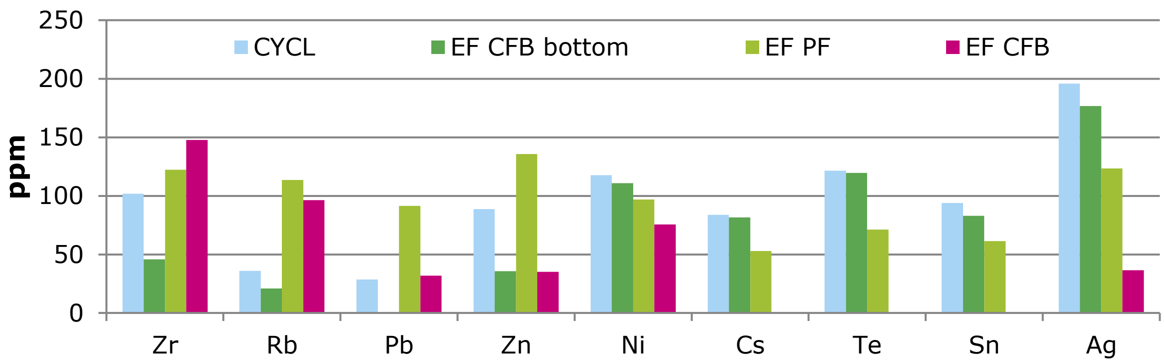

Figure 3-2 Concentration of zirconium, rubidium, lead, zinc, nickel, caesium, tellurium, tin and silver.

The results in

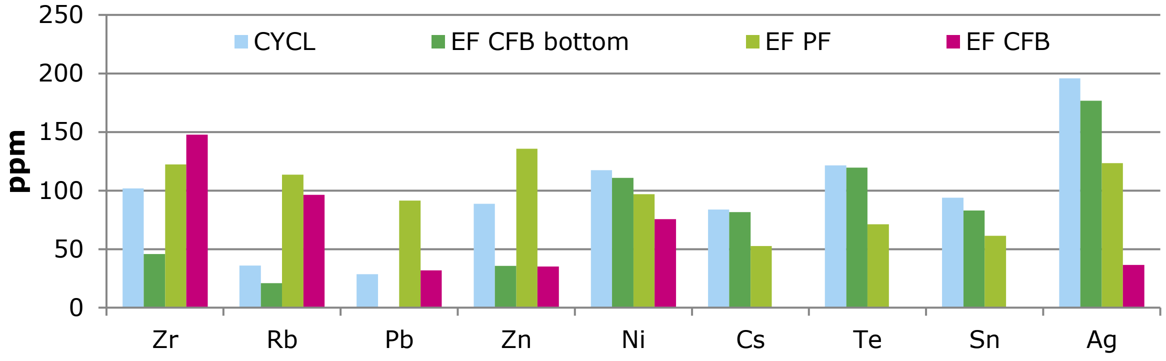

Figure -2 show that the biggest concentration difference is in case of silver concentration. CYCL has silver concentration of almost 200 ppm whereas the EF CFB has concentration below 50 ppm. Also bottom ash has high silver concentration. It needs to be noted also that the concentration of Cs, Te and Sn of EF CFB are below the detection limit. The concentrations of Zr, Rb, Pb and Zn were low in bottom ash, but the concentrations of Ni, Cs, Te, Sn and Ag were high compared to the other ashes. The concentrations of EF CFB were mostly lower than the concentrations of the EF PF except of zirconium.

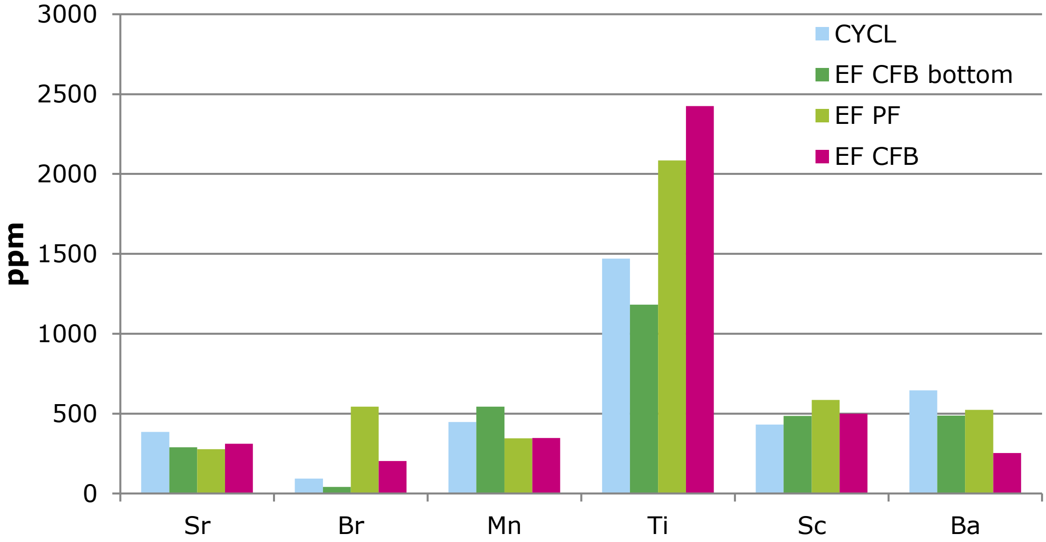

Figure 3-3 Concentrations of strontium, bromine, manganese, titanium, scandium and barium

The biggest concentration differences in

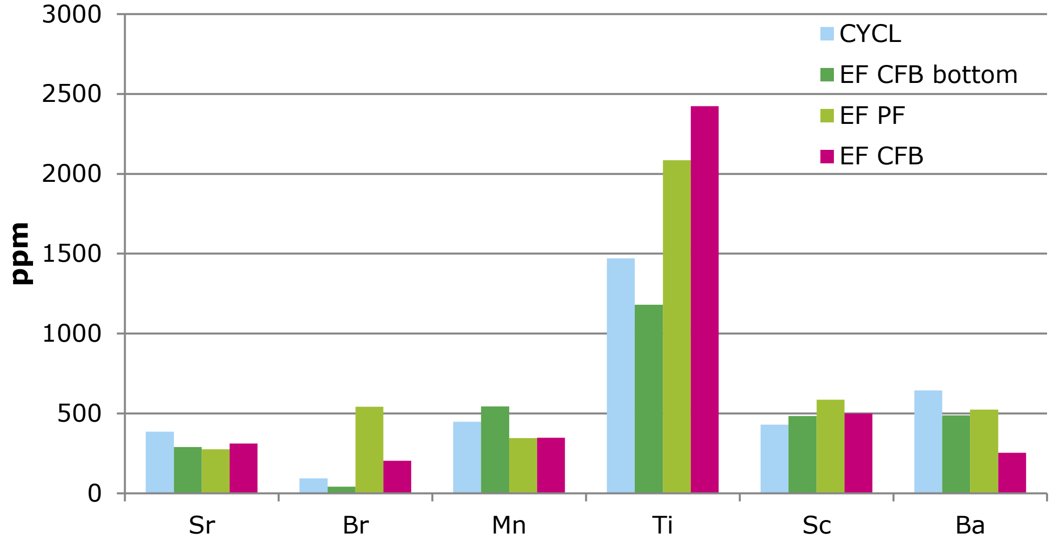

Figure 3-3 can be seen in titanium concentration. Electric filter ashes have the biggest titanium concentrations and the bottom ash has the smallest. EF PF has also the biggest bromine concentration. EF CFB had lower barium concentration than the other ashes.

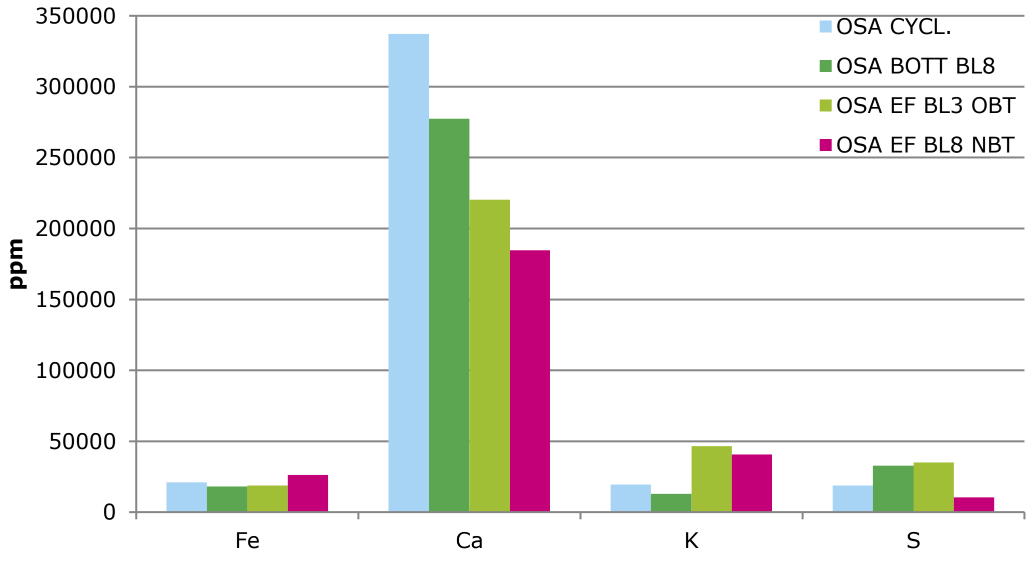

Figure 3-4 Concentration of iron, calcium, potassium and sulphur.

The figure 3-4 shows that all ashes have high calcium concentration, which is why they have potential to be used in stabilisation. The highest calcium concentration has the CYCL and the lowest has EF CFB. The iron concentration was similar in all of the ashes. The EF PF and EF CFB had more potassium than the bottom and CYCL. EF CFB had less sulphur than the other ashes.

In conclusion, the element concentrations were suitable to continue with next steps in binder recipe development.

3.2.4. Total content and leaching test results

In Simuna-Vaiatu samples the total contents of harmful substances were low. In some cases the solubility was a bit elevated, but nothing alarming was found from the stabilised peat samples.

The elements with the elevated solubility are presented in table 3-5. The solubility of chromium, fluoride and sulphate were elevated in the binders but low in the stabilised peat samples. The curious thing is that the solubility of nickel is low in the raw materials but a little elevated in the stabilised peat samples. All of the elevated solubility of the stabilised samples exceeds the limit value just a little. It has to be emphasized that solubility tests were done with pure material in laboratory conditions. Environmental monitoring carried out on the site after construction works showed that there are no environmental concerns (see chapter 6).

Table 3-4 Solubility of the elements which exceeded the Finnish limit values for ashes in Simuna-Vaiatu samples

		Chromium	Molyb-denum	Nickel	Chloride	Fluoride	Sulphate
		mg/kg dw	mg/kg dw	mg/kg dw	mg Cl/kg dw	mg F/kg dw	mg SO4/kg dw
Raw materials	**EF CFB 2/2011**	2.3	1.1	<0.020	2600	7.4	7100
	CYCL 2/2011*	0.6	0.54	<0.020	650	12	12000
	Peat sample: (PR1+PR1A)+(PR2+ PR2A) +PR4 mixture 3:3:2	<0.020	0.34	<0.020	28	<5.0	930
Stabilised peat samples	**Peat sample+ CYCL 200 kg/m^3+ Komp.Cem 80 kg/m^3**	<0.020	0.58	0.62	280	<5.0	260
	Peat sample + EF CFB 200 kg/m^3 + KompCem 80 kg/m^3	<0.020	0.77	0.56	800	5.6	290

* CYCL was tested in the Narva-Mustajõe tests

For comparison; limit values in Finnish regulation 519/2006 attachment 403/2009 about the utilisation of ashes in road construction

	Chromium	Molybdenum	Nickel	Chloride	Fluoride	Sulphate
Covered structure[1)]	0.5	0.5	0.4	800	10	1000
Coated structure[2)]	3	6	1.2	2400	50	10000

Values that exceed the limit value for covered road

Values that exceed the limit value for paved road

1) Covered road means a road with at least 10 cm thick gravel (or other natural material) coating to prevent the spreading of the ash.

2) Coated road means a road that is paved with asphalt or other material that provides the same kind of protection for the structure.

3.2.5 Results of stabilisation test for peat

The stabilisation tests were done with the soil samples taken from Simuna-Vaiatu road section. The compressive strengths were measured in case of all samples after 28 days and in case of some samples also after 90 days. The targeted strength for the stabilised peat was 100 kPa, which is marked in the figures with a line. The stabilisation tests were done in two parts; the first part included the stabilisation tests for samples S-7, S-9 and S-10 and the second part included the further testing made for samples named PR which were taken from one sampling point from different depths.

The results of the stabilisation tests for sample S-7 are presented in

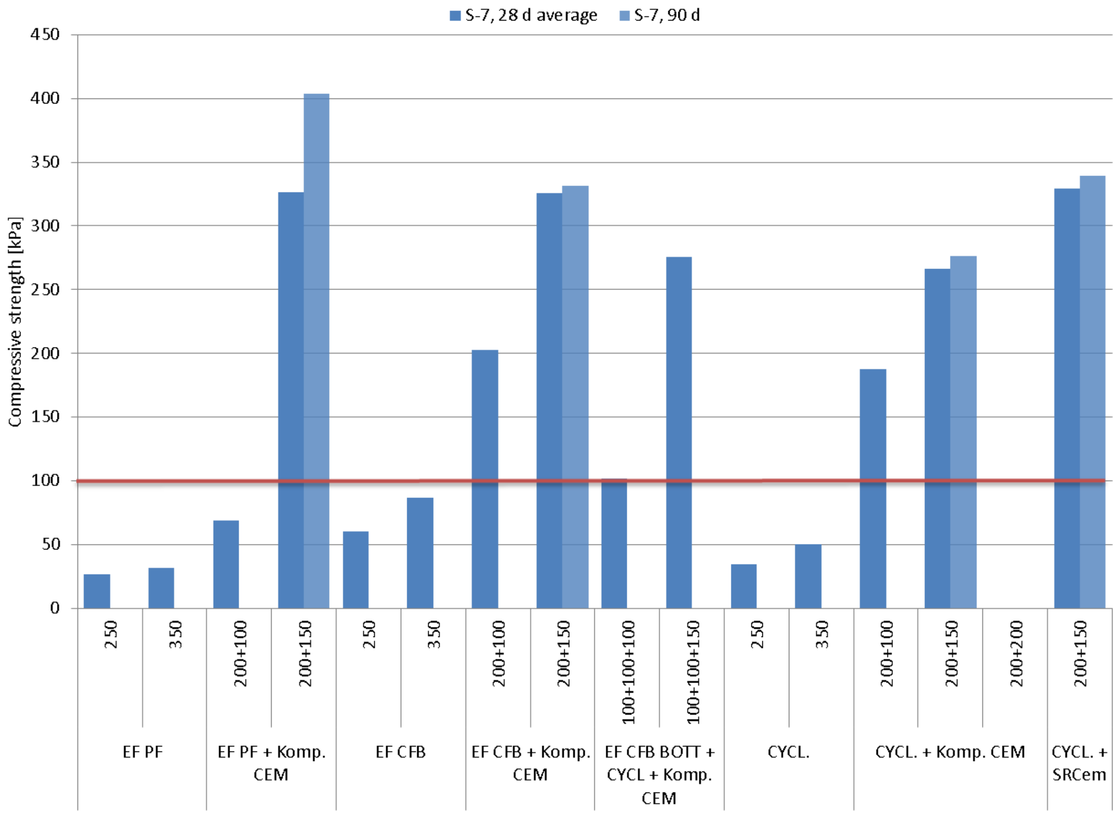

Figure 3-5. It can be seen from the results that in case the ashes are used alone, the compressive strength is poor, but together with cement much better results can be achieved. It can be seen that the difference between the 28 and 90 days compressive strengths is not big with other binders than EF PF + *Composite Cement* which has 150 kPa bigger compressive strength in 90 days rather than in case of 28 days. All of the stabilisation test results are presented in the Material Report (Intermediate report of materials action, November 2012, Ramboll).

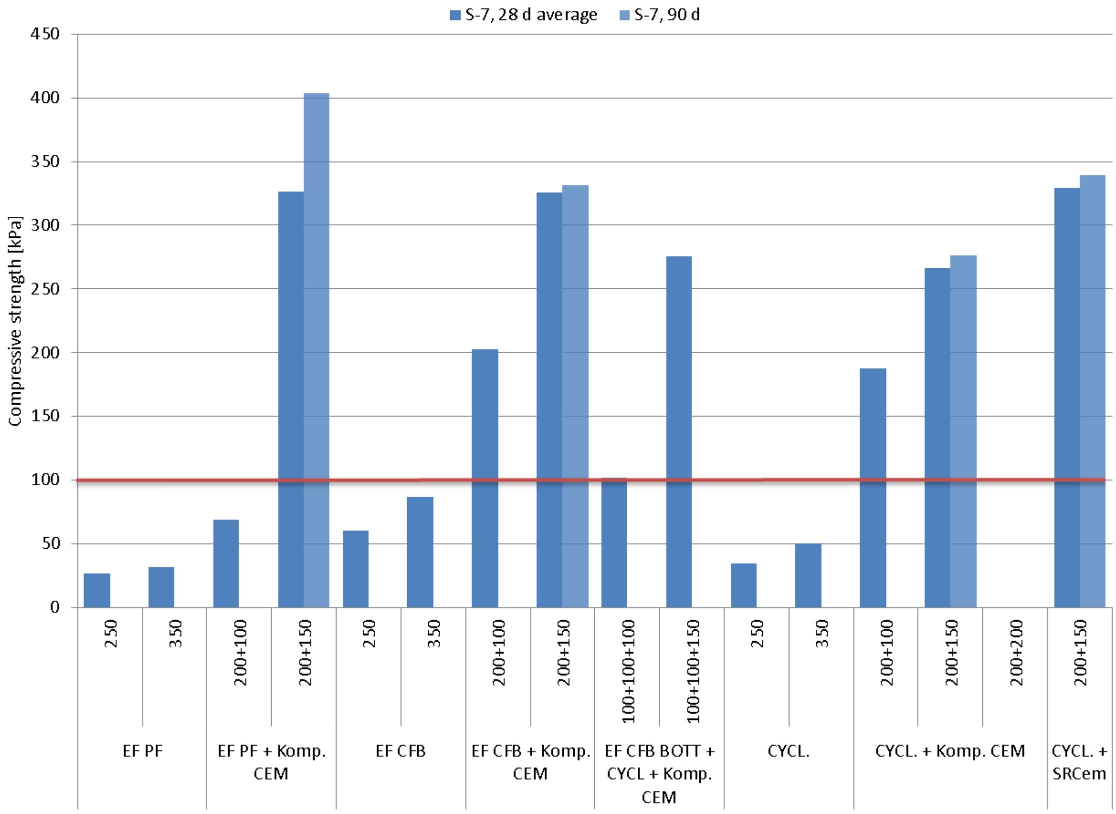

Figure 3-5 Results of stabilisation tests for sample S-7

The results of the stabilisation tests for sample S-9 are presented in figure 3-6. The stabilisation test results of sample S-9 were worse than for sample S-7. The difference between the 28 d and 90 d samples were also bigger than with sample S-7. *SR Cement* gives better results than *Composite Cement* in sample S-9. This indicates that the peat has some sulphates which decrease the compressive strength with non-sulphide resistance binders. These results also show that when the ashes are used alone, the compressive strength is poorer than when used together with cement.

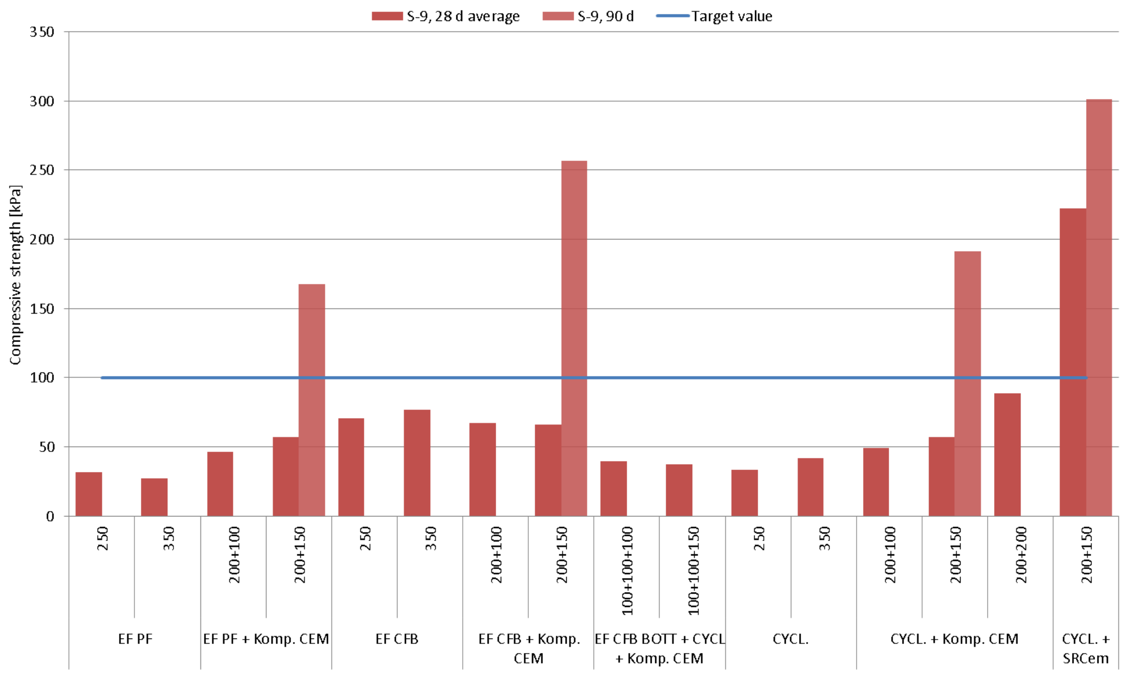

Figure 3-6 Results of stabilisation tests for sample S-9

The results of the stabilisation tests for sample S-10 are presented in

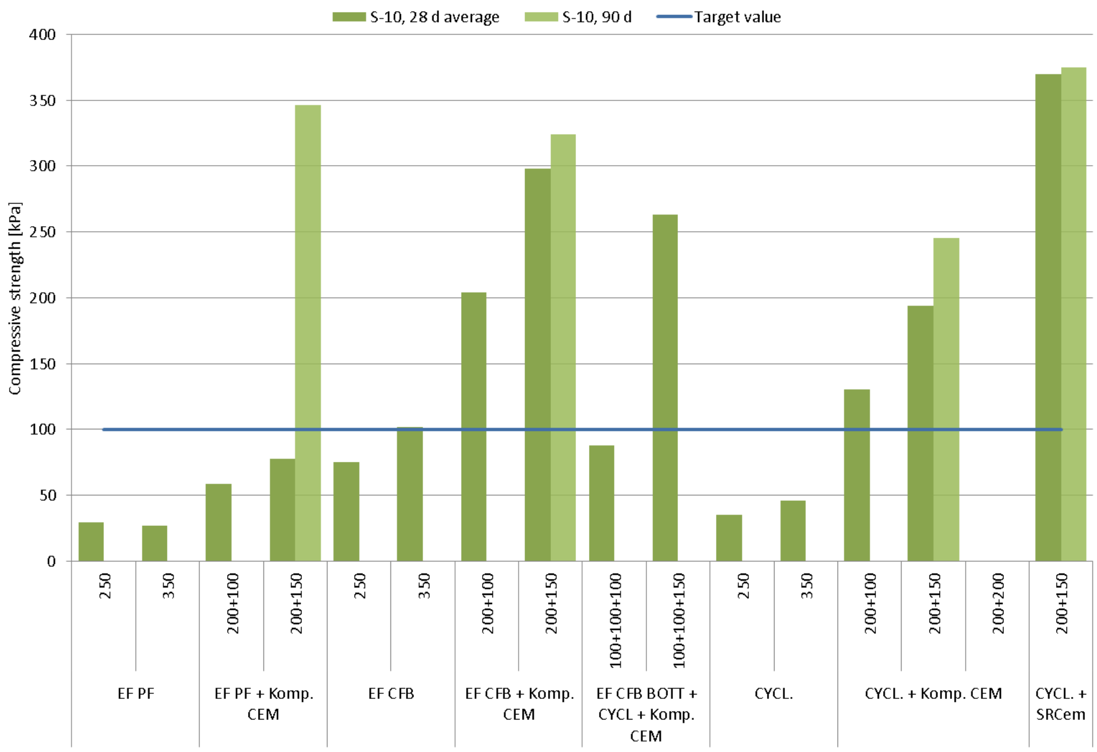

Figure 3-7. The sample S-10 gives similar compressive strengths compared with S-7. The difference between the 28 d and 90 d compressive strengths are small in all the other binder mixtures, but EF PF + *Composite Cement*, which has over 250 kPa difference between the 28 d and 90 d samples. All the peat samples achieved the targeted 100 kPa compressive strength.

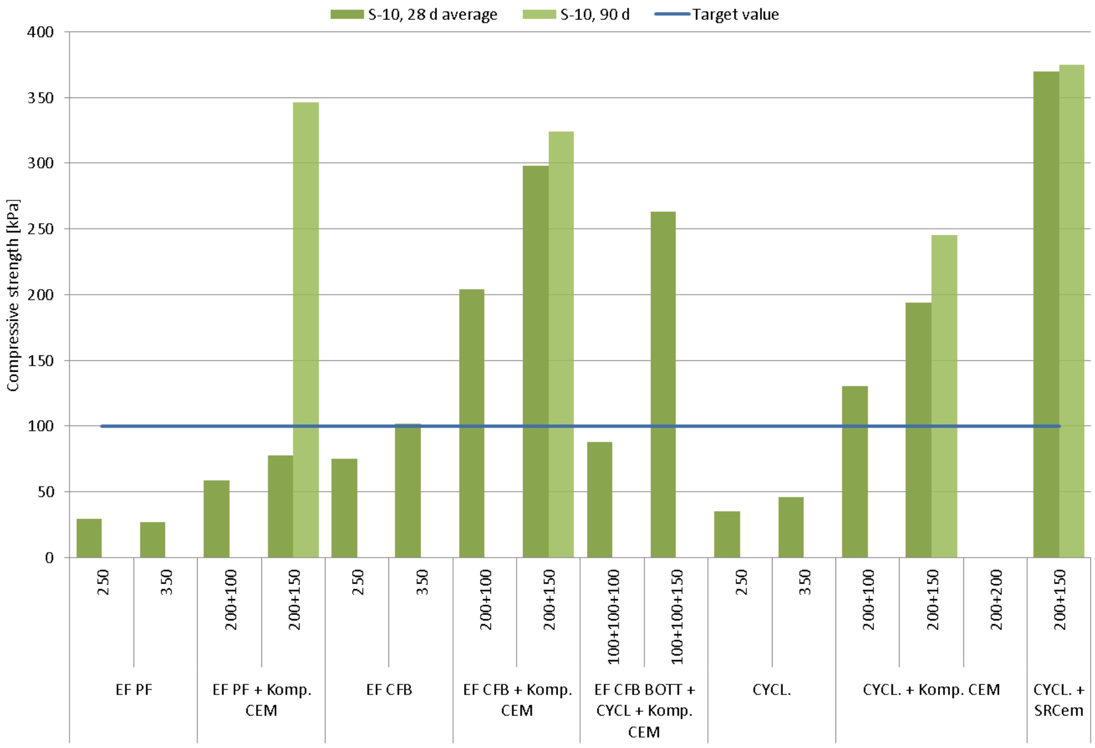

Figure 3-7 Results of stabilisation tests for sample S-10

The results of the second part of stabilisation tests for Simuna-Vaiatu mass stabilisation are presented in

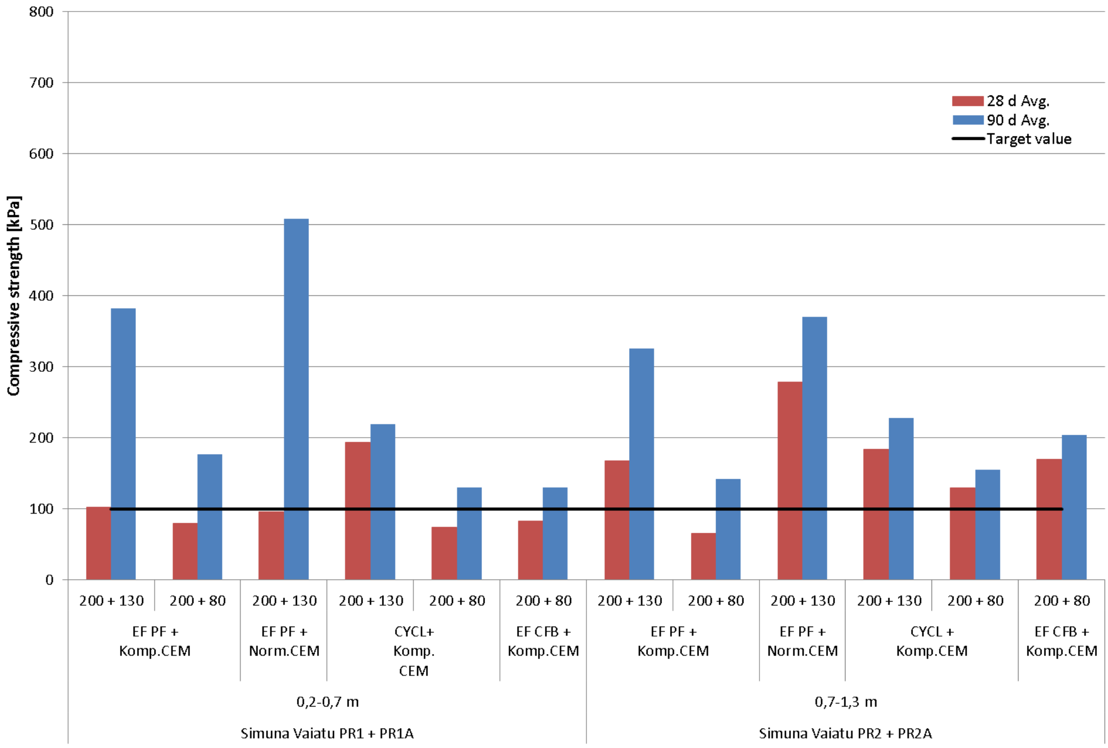

Figure 3.8 and

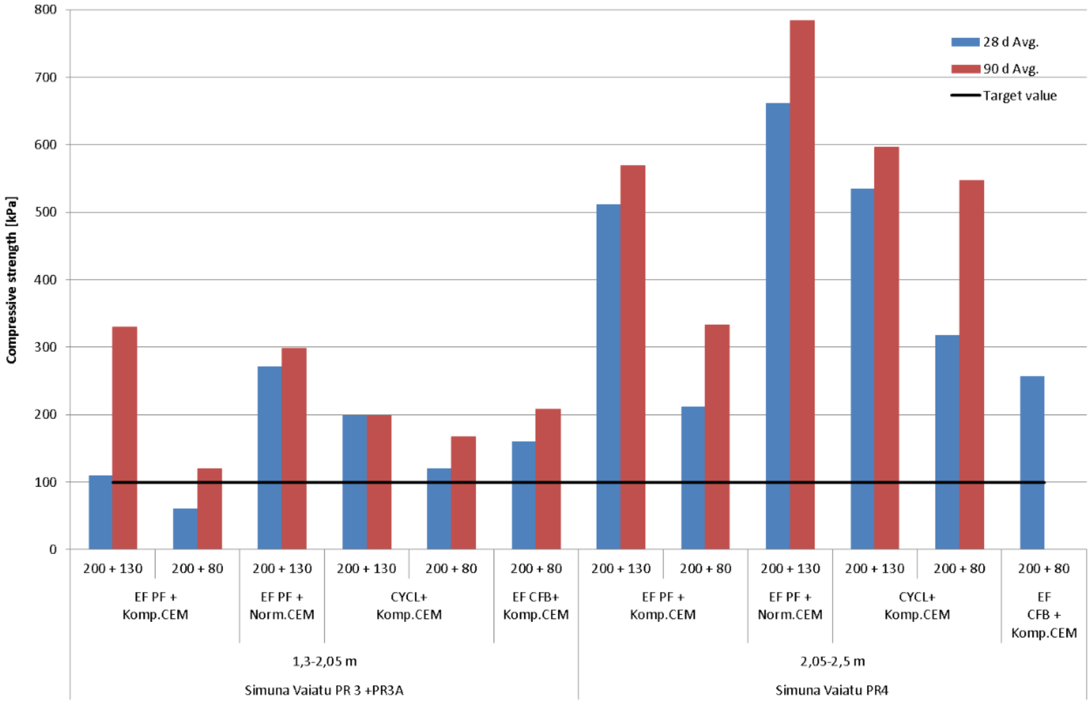

Figure 3.9. The results show that the peat samples had similar total strength development and no big differences between the samples (PR1-PR2-PR3) could be found. The peat-clay sample (PR 4) on the other hand gave high compressive strength results and less binder is needed to achieve the 100 kPa compressive strength. The sample 0.2-0.7 had better long term strength development than sample 0.7-1.3 and 1.3-2.05. Samples 0.7-1.3 and 1.3-2.05 gave similar results and no significant differences could be noted.

The biggest difference came when *Normal Cement* was used as a binder. According to the results *Normal Cement* works better than *Composite Cement*. When only 80 kg/m^3 cement is used, CYCL seems to be working better than EF PF (if the first sample is disregarded).

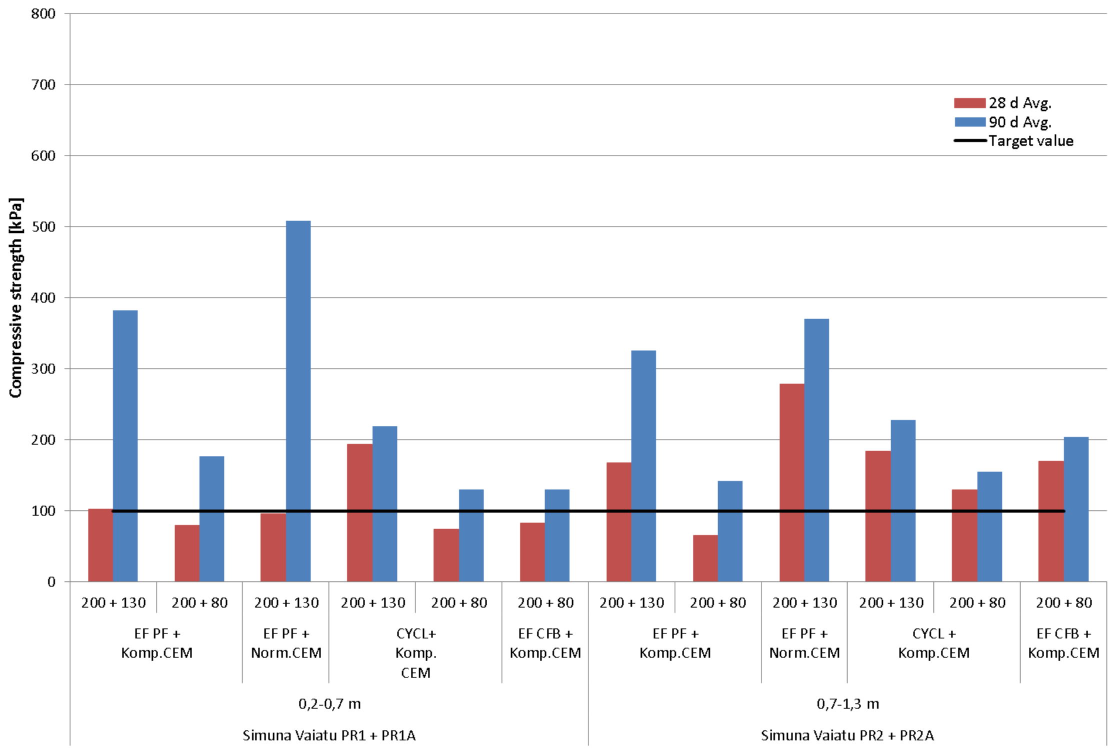

Figure 3-8 Results of the stabilisation tests for Simuna-Vaiatu PR -samples, two most upper layers.

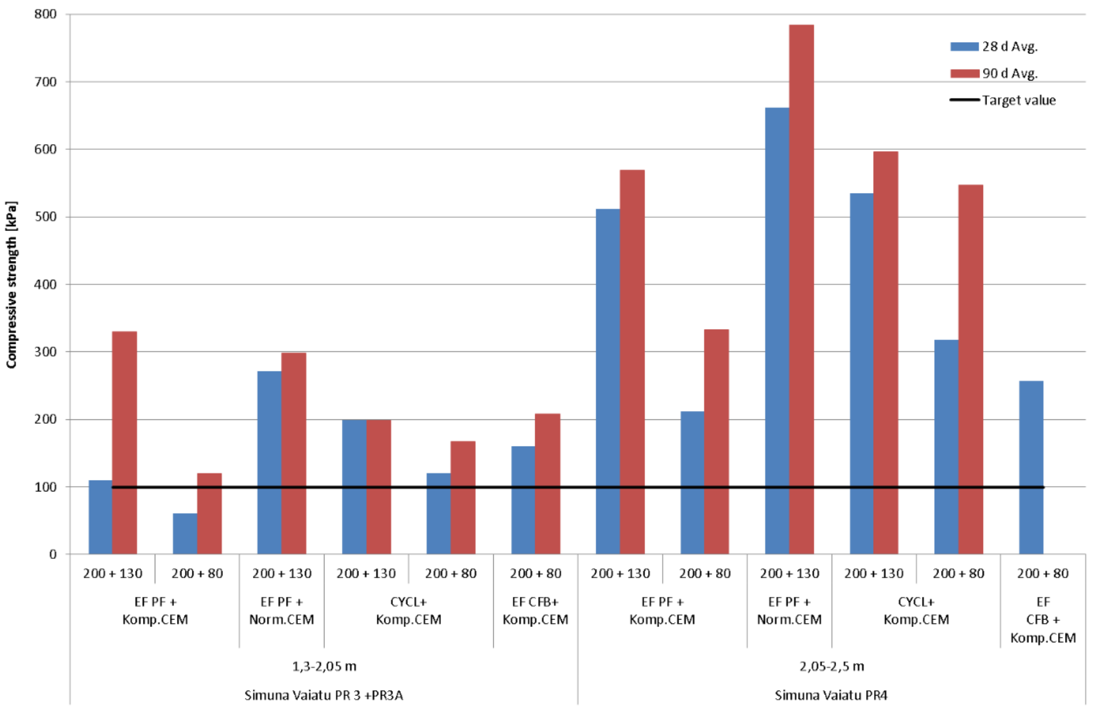

Figure 3-9 Results of the stabilisation tests for Simuna-Vaiatu PR -samples, two lower layers.

3.2.6 Conclusion about binder materials selection

The Niton tests showed that the elemental composition of the ashes differed a little but no substantial changes could be seen. The total contents and leaching test of harmful substances showed that the materials used in stabilisation of Narva-Mustajõe and Simuna-Vaiatu had a little elevated solubility but on the stabilised samples the solubility was insignificant or very little over the Finnish limit values. Thus it can be evaluated that the structures will not cause harm to the nature.

Stabilisation tests showed that both electric filter ash and CYCL are potential for mass stabilisation. The *Normal Cement* gave better results than *Composite Cement* with the second part of the mass stabilisation studies, but the results with *Composite Cement* were also fulfilling the criteria for using it in stabilisation works.

Bottom ash and CYCL together as well as the CYCL alone showed no potential for stabilisation use and didn't endure the freeze-thaw test. Also CYCL together with *Composite Cement* gave poor compressive strengths and didn't always endure the freeze-thaw test.

Based on laboratory analysis following binder material ratios for mass-stabilisation works were proposed:

1) CYCL 200 kg/m^3, *Composite Cement* 60 kg/m^3;
2) EF PF 190 kg/m^3, *Composite Cement* 90 kg/m^3;
3) EF CFB 200 kg/m^3, *Composite Cement* 80 kg/m^3.

3.3 Detailed construction design

The detailed construction design for Simuna-Vaiatu test site km 3.0-4.0 was made by Ramboll. This documentation was compiled as separate set of documents and it was a basis for Estonian Road Administration for issuing construction permit *(Tee nr 17192 Simuna-Vaiatu km 3,0-4,0 katendi remondi katselõikude tehniline projekt, Ramboll 2012)*.

The following methods were implemented for demonstration purposes on this section:

- layer-stabilisation of existing base course with OSA;
- mass-stabilisation of peat layer with different OSA qualities;
- traditional method – construction of complex stabilised base course or crushed stone base course.

Table 3-5 Road structures

Material	PK 30+20-32+60	PK 32+60-35+10	PK 35+10-37+60	PK 37+60-39+20
Paving PIN 2,5	+	+	+	+
Layer stabilisation, cm	20	20	-	-
Complex stabilisation, cm	-	-	20	20
Gravel sand, cm	30	30	30	30
Medium sand, cm	20	20	20	20
Mass stabilisation	-	+	+	-
Bearing capacity, MPa	180 (169)			
$E_{üld*}$, MPa	188	218	177	176

**General modulus of elasticity*

Normal detailed construction design consists of explanatory letter and technical drawings with construction volumes. Design process contains different activities starting with topo-geodetic and geological surveys. Geological survey gave important information about peat layer characteristics under the existing road surface. Material recipes for layer and mass stabilisation were worked out during laboratory tests in Ramboll Finland laboratory in Luopioinen. With the project new road pavement was engineered and drainage system was improved. Based on design documentation a construction permit was given out by road administration.

Average traffic density on this road was in 2009 140 vehicles per day, from which the proportion of heavy traffic was 2%. The traffic density is very low, which means that it is a highway with lowest road category - V. The load capacity for this road must be at least 169 MPa.

Road structure lies on peat layer under which are loam and moraine – soil category B. for the mass-stabilised peat the modulus of elasticity is 20 MPa.

Photo 3-2 Simuna-Vaiatu road section before construction works

3.3.5 Binder

About 2900 t of binder material was needed for the pilot section (OSA + cement). Firstly it was designed to use two OSA qualities: EF CFB and CYCL, but during construction changes were made and additionally EF PF ash was used. Total binder amount remained in the same level. Binder material usage in general was 170-200 m^3 (OSA) and 60-110 m^3 (cement).

3.3.6 Mass stabilisation

According to the design documentation, the length of mass-stabilised section is 490 m and width of road pavement is 7.0 m. Width of mass-stabilised area is 9.0 m (1.0 m wider from both sides). Amount of processed peat material was about 11 000 m^3 and area size ~4500 m^2. Thickness of peat layer varies between 1.0-3.3 m.

3.3.7 Road structures

According to the designed technical solution paving on top of the stabilised structures will be done. Cross section of the road with different road elements and dimensions (banks, sloping) are presented in the Figure 3.10.

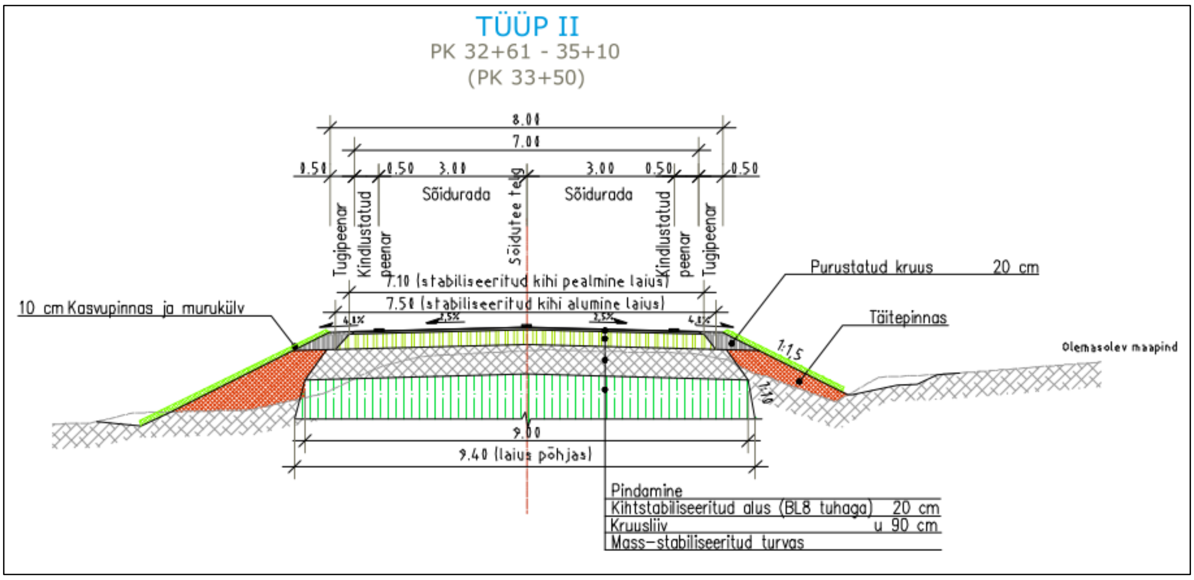

Figure 3-10 Road cross section and pavement structures

4 CONSTRUCTION

4.1 Mass-stabilisation works

In Simuna-Vaiatu mass-stabilisation works were carried out for the first time in Estonia on existing road which is in daily use. Therefore it is appropriate to give hereby general guidelines about mass-stabilisation working methods and equipment which were also implemented in Simuna-Vaiatu road.

4.1.1 Mass stabilisation equipment

Mass stabilisation equipment consists of an excavator and a separate unit which composes the binder silos, compressor, air drier and supply control instrumentation. Binder is transported from the binder silos to the tip of the mixing unit. The binder is mixed and fed to the stabilised soil. The mixing unit should be able to process at least two different dry binders.

The mass stabilisation equipment is equipped with a control unit which records and controls the amount of binders fed into the soil. Using the control unit the user of the mass stabilisation equipment can adjust the feeding speed, pressure and the flow of the binders.

4.1.2 Mass stabilisation work

The contractor makes a stabilisation work plan, which includes the locations of the stabilisation segments and numbering. Ground surface area is measured before beginning the stabilisation and the measurements are delivered to the contractor. The overall working order of mass stabilisation is presented below:

1. Preliminary work: Removal of the old road layers and top soil to the sides of the road
2. Dividing the road in to stabilisation segments. A horizontal surface area not larger than 5 x 5 meter is marked by means of 4 sticks pushed into the ground.
3. The binder is mixed uniformly with the soil down to the prescribed depth (1-3 meter) from surface. The amount of binder (kg/m^3) and the mixing energy (J/m^3) shall be defined in the site test description. The mixing pattern shall be as described in the test specifications. While the binder is pumped out into and mixed with the soil continuously monitoring shall be carried out automatically for:

	Typical values
- binder output, kg/m^3	100-400 kg/m^3
- input pressure at machine, kPa	0.2-0.4 kPa
- output pressure, kPa	0.2-0.5 kPa
- rate of rotation, rpm	100-200 rpm

4. After initial mixing with binder exhaust, remoulding of the soil volume is continued uniformly so that the prescribed mixing work is obtained for the complete volume. The volume is defined by the sticks and the depth of mass stabilisation. The remoulding pattern shall be carried out as specified in the specifications.
5. After mixing work is finished, a geotextile with sufficient bearing capacity and min. 500 mm pre-loading embankment from old road material are placed on the stabilised surface. Compaction is made with a heavy roller.

The ground on which the stabilisation equipment operates must provide a stable base. To assure a good stable base, a blanket granular material is placed and rolled into a flat working platform.
The mass stabilisation equipment, geotextile, pre-loading embankment and stabilised soil are represented on the Figure 4-1.

Figure 4-1 Mass stabilisation equipment stabilising clay

4.1.3 Preliminary work

The old road layers and topsoil are removed so that the peat layer is revealed. The peat layer is in average 90 cm below the top of the road and the thickness of the peat layer varies from 100 cm to 300 cm.

In some places there is a sand/clay layer (0-0.5 m thick) below the peat on top of the sandy moraine. The clay/sand layer is mixed with the peat to enforce the stabilisation layer. The old road and the top soil are removed according to the Figure 4-2.

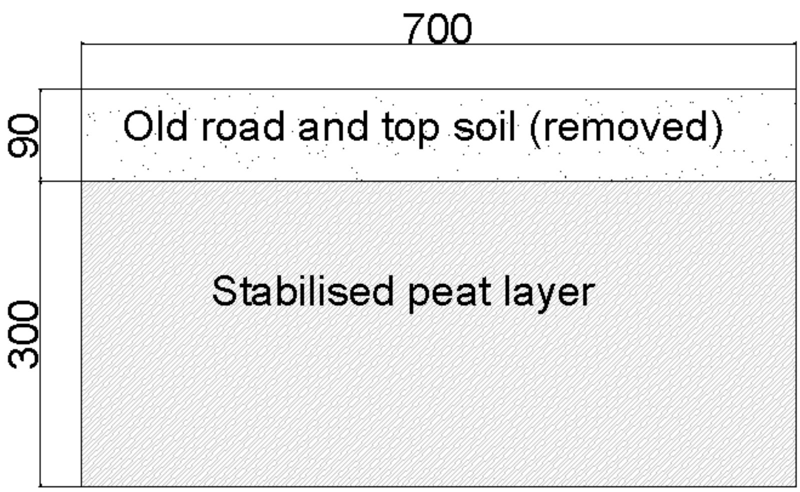

Figure 4-2 The cross cut of the road – old road and top soil removed and the stabilised peat layer.

The surface of the peat layer might rise above the 90 cm "removal line", but the removal of the top soil is done to the 90 cm level in order to have an even surface for the road structure. The good quality materials are separated from the low quality materials (peat) during the removal. The good quality materials are re-used in the pre-loading embankment. The removed layer, peat and sand/clay layers and bottom soil layer of the road are represented in Figure 4-3, where the sampling points and the depth of different layers can be seen. The soil that is to be stabilised is outlined with pink colour.

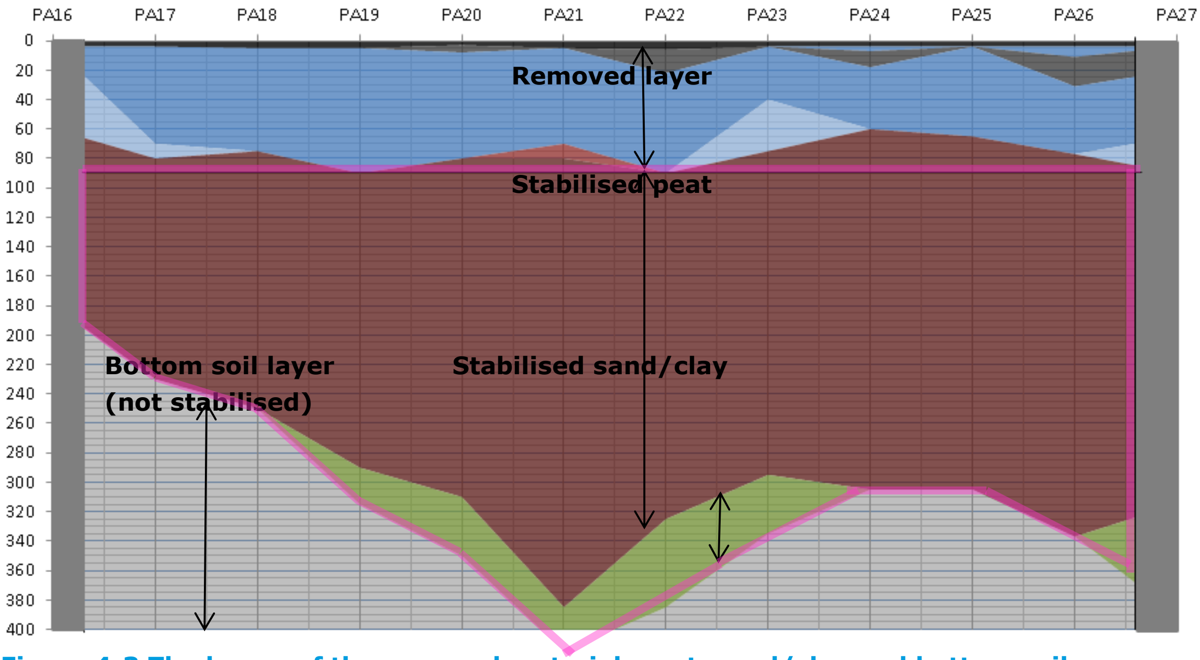

Figure 4-3 The layers of the removed material, peat, sand/clay and bottom soil. The depth is represented on left axis and the sampling points are represented on the top axis.

4.2.5 Stabilisation segments

The stabilisation site is divided into segments before the start of the work. The segment sizes could be for example 5 m x 5 m (25 m^2). Many variables affect the size of the segments. Such variables are the moisture content and strength of stabilised soil, the radius of the stabilisation equipment and the final width of the stabilised site.

The corners of the segment are marked on the stabilised soil with square shaped frames of with distance post on the edge of the embankment. Each segment is labelled with identification code, which can be used in locating after the stabilisation. The corners of the segment can differ from the exact location by ±0.25 m.

4.2.6 Stabilisation

Before stabilisation, the peat on the segment is homogenised with the stabilisation equipment. The depth of the peat layer is also measured with the stabilisation equipment by pushing the arm of the stabilisation equipment as deep as possible (until hits a firm ground / sandy moraine layer) in the middle of the segment and reading the depth of the segment from the markings on the arm. The depth of the stabilisation is measured with 0.1 m accuracy. The average stabilisation depth is registered separately for every segment.

The stabilisation work is done from a firm surface e.g. pre-loading embankment. The whole segment is stabilised and after right amount of binder is homogeneously mixed with the segment, the surface of the segment is levelled.

The fed binder amount is calculated on the basis of the segment volume. The fed binder amount can differ ±5% from the designed amount. The fed binder amount is checked when necessary with sampling.

4.2.7 Pre-loading embankment

After stabilisation a geotextile is spread on top of the stabilised peat. A pre-loading embankment is put on top of the geotextile. The pre-loading embankment will be a part of the future road base. The height of the embankment is 0.9…1.0 m. The old road material and top soil material (without peat) are used in the preloading embankment and it is possible that some other crushed aggregate must be used in addition. The additional materials can be used later in the road structure or some of the material can be removed and used in the other parts of the road. The embankment is compacted with an roller.

The embankment consolidates the stabilised soil and removes moisture and thus promotes the strength development. The embankment also divides the load to a larger area and is a working platform for the next segment in the stabilisation work.

The progress of the construction of pre-loading embankments by segments should be documented (the finishing date of pre-loading embankment). The effect of the pre-loading embankment to the settlement of the structure is monitored and documented.

4.2.8 Regulations

There are following regulations in Finland, which may be applied on stabilisation process:

- Stabilointiohje[4] (for testing; Tiehallinto 2002), design instruction concerning stabilisation with bitumen, cement and mixes;
- Päällysrakenteen stabilointi[5] (regular; Tiehallinto 2007), design instruction concerning stabilisation with bitumen, cement and mixes;
- Syvästabiloinnin suunnittelu[6] (Liikennevirasto 2010), design instruction for mass-stabilisation;
- Tuhkarakentamisen käsikirja[7] (Ramboll 2010), manual covering use of ashes from burning process of coal, communal waste, paper processing waste, water purifying process waste and biomasses;

Finnish Road Administration has released requirements about stabilisation of base layer in 2007[2]. According to the instruction cement content should be 2-5% in general. It must be mentioned that Finnish experience is based only on igneous rocks while Estonian experience is based on limestone aggregate. Finnish ashes typically originate from coal burning or forest industry (bio fuel – bark, wood, peat or paper industry waste). Compared to Finnish ashes OSA is more reactive containing more CaO and thus should be more suitable as a binder.

Estonian Road Administration has released instruction about construction of stabilized base layers on 2006. It is mostly based on Wirtgen manual, but within the concentration process essential aspects have been lost.

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[4] Stabilointiohje. Tiehallinto 2001: http://alk.tiehallinto.fi/thohje/pdf/2100009-02.pdf
[5] Päällysrakenteen stabilointi. Tiehallinto 2007: http://alk.tiehallinto.fi/thohje/pdf/2100055-v-07paallysrakenteen_stabilointi.pdf
[6] Syvästabiloinnin suunnittelu. Liikennevirasto 2010: http://www2.liikennevirasto.fi/julkaisut/pdf3/lo_2010-11_syvastabiloinnin_suunnittelu_web.pdf
[7] Tuhkarakentamisen käsikirja, Ramboll 2010: http://www.infrary.fi/files/3985_Tuhkarakentamisen_kasikirja.pdf

- Stabiliseeritud katendikihtide ehitamise juhis[8] (Maanteeamet 2005), construction regulation for stabilized pavement layers covers stabilisation with cement, bitumen and mixes (9 pages).
- Wirtgen külmstabiliseerimise käsiraamat[9] (Maanteeamet 2004), translation of German manual (267 pages).

According to the regulation, recommended content of road cement or Portland cement in cement stabilisation is at 2-3%. Despite that there are currently no valid regulations for ash-stabilisation. Former regulations specified ash content of 4-5% in stabilized material. In wider scale, it can be concluded that ash as binder is twice weaker than cement to achieve comparable results. Estonian Road Administration intends to replace the current instruction with updated release within 2014.

4.3 Description of construction works

The different steps of the whole construction work on the Simuna-Vaiatu road section km 3.0-4.0 are shortly explained below (Table 4-1). The period of road works was in July-October 2013 and in June-August 2014. In 2013 mass-stabilisation works were carried out and preloading layer was put in place and after that road was opened for transport. The pilot mass-stabilisation results showed that approximately 4-6 months is needed for peat to stabilise. In 2014 layer stabilisation and complex stabilisation was carried out and pilot section was completed in August 2014.

Table 4-1 The timing of construction process

Work description	Date (month, year)	Weather conditions
Asphalt milling, removing topsoil	July 2013	20-25°
Removing road material layer from top of peat	July 2013	20-25°
Mass-stabilisation works	July-September 2013	20-25°, partly rain
Placing geotextile and preloading layer (gravel)	July-September 2013	20-25°, partly rain
Embankment works	June 2014	15°, rain
Layer stabilisation with OSA	July 2014	16-18°, partly rain
Complex stabilisation	July 2014	20°
Ditch excavation, slope planning, traffic signs	July 2014	25°

4.4 Site journal – mass stabilisation works in 2013-2014

Week 1 (July 2013) started with milling a layer off the asphalt with a thickness of 5 cm and removing all of the milled substance onto a temporary storage site. A tipper lorry was used to conduct that action. The roadside area was cleared of individual trees and topsoil was also removed. The stabilisation equipment was put in place and the height of the road pavement was surveyed after the milling. Materials that were received during construction work that week include geotextile NW8 (5.25x100m), 10 rolls; OSA CYCL (29.06t) + OSA CYCL (31.48 t); and *Composite Cement* (CEM II / B-M (T-L) 42.5R) 28.52 t. During the first week, excavations of road pavement surfaces started. Mass-stabilisation was conducted on various road sections. The stabilised road sections were later on coated with geotextiles (30-40 cm thick layer; compressed with excavator's tracks). **Week 2** continued with working on the allocated road sections by removing the topsoil layer. During the week, the peat that had been excavated from the road section was watered. Mass-stabilisation was done on various road sections. A layer of the road pavement that was excavated

[8] Stabiliseeritud katendikihtide ehitamise juhis. Maanteeamet 2005 (2): http://www.mnt.ee/failid/juhised/stabiliseeritud_katendikihtide_ehitamise_juhis.pdf
[9] Wirtgen külmstabiliseerimise käsiraamat. Maanteeamet 2004: http://www.mnt.ee/failid/uuringud/wirtgen.pdf

up to the peat layer was then placed on the opposite side of the road and flattened out afterwards. This was done in both, left and right sides of the road. Amounts of natural and scrap gravel were hauled from the quarry. The stabilised road section was then coated with geotextiles. The road sections under construction in week two varied from STA 32+60-33+00 to STA 35+00-37+60.

Photo 4-1 Removal of topsoil

Week 3 continued with mass-stabilisation works on different road sections. Embankments were flattened out and preliminary planning took place. Watering of the excavated peat was continued as was the coating of stabilised road sections with geotextiles. The materials that were received during the third week include EF PF, EF CFB, CYCL, Composite Cement (CEM II / B-M (T-L) 42.5R) and natural gravel. Ditch planning works commenced on section STA 32+60-33+00.

Mass-stabilisation works carried on during **week 4** as also the road pavement excavation works. Scrap gravel was carried to the construction site from the quarry. Later on, the scrap gravel was profiled and squared off. Various stabilised road sections were coated with geotextiles and natural gravel was applied later on. During week four the following materials were received: EF PF, EF CFB and Composite Cement (CEM II / B-M (T-L) 42.5R).

Photo 4-2 Mass-stabilisation works ongoing

Week 5 the construction site consisted of excavating peat from the existing road surface and then levelling it off onto the edge of the embankment. Mass-stabilisation works continued on various road sections including STA 33+85-34+25, STA 34+25-34+50, STA 33+50-33+55, STA 34+50-34+60, STA 33+55-33+85, STA 33+85-34+15. The stabilised road sections were covered with geotextiles and later on a layer of gravel was put in place. Watering of excavated peat was continued. The received materials during week five included EF PF and Composite Cement (CEM II / B-M (T-L) 42.5R).

Week 6 carried on with similar work tasks as in previous weeks. Mass-stabilisation works resumed, however in this week the works were carried out on road sections STA 34+15-34+40, STA34+40-34+60, STA 37+10-37+25 and STA 36+95-37+10. A temporary ditch was dug up on STA 34+60-35+60 to ensure rainwater drainage. On STA 33+50-34+40 and STA 33+50-37+60 a pump was used to clear all the excess rainwater. Materials that were received on the construction site during week six include EF PF, Composite Cement (CEM II / B-M (T-L) 42.5R), EF CFB, scrap gravel, natural gravel.

Week 7 carried on with installing gravel, levelling off and profiling the embankments. Mass-stabilisation works were done on several sections from STA 35+95-36+20 RS to STA 36+80-36+90. Coating the stabilised road section with geotextiles and installation of natural gravel were finished on STA 36+80-36+90 RS, STA 36+70-36+80 RS, STA 35+95-36+20 RS, STA 36+35-36+40 LS, STA 35+75-35+95 RS, STA 36+20-36+35 LS, STA 35+70-35+75 RS, STA 36+05-36+20 LS, STA 35+60-35+70 RS and STA 35+85-36+05 LS. Also digging a ditch and profiling was carried out on couple of road sections. Materials received in week seven were: EF PF, Composite Cement (CEM II / B-M (T-L) 42.5R), EF CFB, scrap gravel, natural gravel.

Week 8 carried on with similar work tasks as in previous weeks. The works included mass-stabilisation, coating the stabilised road section with geotextiles and installation of natural gravel, excavation of the left side road pavement surface up to the peat layer and placing it on the right-hand side and flattening it out afterwards. Included activities were also digging a ditch and profiling, rolling embankments and pumping in order to clear the rainwater. Received materials were EF CFB, Composite Cement (CEM II / B-M (T-L) 42.5R), natural gravel, EF PF and scrap gravel.

Photo 4-3 Binder material tanks (OSA and cement)

In **week 10** mass-stabilisation works on 5 road sections were carried on. Excavation of the left side road pavement surface up to the peat layer and placing it on the right-hand side with flattening it out afterwards was finished for five road sections as well. Watering the excavated peat was also one of the activities that were done. The materials that were used in week ten were EF PF, Composite Cement (CEM II / B-M (T-L) 42.5R) and EF CFB.

Week 11 continued with mass-stabilisation works on the road section STA 36+60-36+65 on the first day. The day also included excavation of the left side road pavement surface up to the peat layer and placing it on the right-hand side, flattening it out and watering the excavated peat. The ditch was dug on the right side of the STA 34+10-35+10. The following days included hauling gravel from the quarry and distributing the gravel together with digging ditches where required. Received materials were natural gravel, scrap gravel.

Table 4-2 Lengths of stabilized sections and amounts of binder materials

OSA quality in binder	Length of section (m)	OSA (kg)	Cement (kg)
EF CFB	100	489	160
EF PF	300	1 234	436
CYCL	90	221	355
Total	**490**	**1944**	**951**

In **week 12** ditches were dug on the left side of the STA 34+60-36+00 and STA 36+00-37+60. Profiling and rolling the embankment of STA 32+60-37+60 were also carried out.

Photo 4-4 Mass-stabilisation works are completed (autumn 2013)

The amounts of the materials for the pre-loading embankment are represented in the table 4-3.

Table 4-3 The amounts of the materials used in pre-loading embankment

Material	Amount [m³]
Old road material	1500
Crushed stone / Gravel	3100

In week 13 (June 2014) works continued and contractor removed topsoil from road sides and ditches STA 37+60-39+20. They installed culvert in STA 38+55. Road embankment was extended, profiled, loosened. Milled asphalt material was spread along the embankment.

In week 14 embankment and ditch excavation works continued.

In **week 15** the contractor built gravel material base course for layer stabilisation and after that stabilisation with OSA was finished. Also complex stabilisation was started and finished same week. With that most important parts of the works were completed.

In **weeks 16-19 (end of July)** they worked with road ditches, slope planning, lawn seeding, verges and culverts.

In September 2014 Admission Committee (with representatives from Eesti Energia, Estonian Road Administration, contractor, supervision team and road maintenance company) approved officially the construction works.

Photo 4-5. Simuna-Vaiatu road section in November 2014

4.5 Challenges with OSA processing in mass-stabilisation equipment

During mass-stabilisation works problems occurred with OSA processing through the tubes that were connected between binder tanks and work equipment which was completely unexpected. OSA particles seemed to choke the tube and blocked binder material to run smoothly through it. Tube had to be opened and cleaned manually and therefore the work process was very slow during some periods. Normal mass-stabilisation work speed is about 500 m^3 of soil in one day (based on Finnish experience), but in Simuna-Vaiatu the speed was only about 150-170 m^3 in some days. There were no similar problems with cement material.

CYCL was the most difficult one compared with other OSA qualities (EF PF and EF CFB). Tubes were choked very often and more than half of the working time they were cleaned causing serious delays in the work process. A maximum of only 1-1.5 hours was possible to constantly mass-stabilize without stops. One possible reason for that is that the unit weight of the CYCL was bigger than the other OSA qualities or cement. Because of its weight the mobility was prevented. Most probably the different temperature of the ash was also a factor for difficulties. It is expected that OSA is in cooled condition for working process. CYCL is chemically highly reactive.

EF PF ash was better than CYCL but still there were chokings 1-3 times every day. Cleaning process of the tubes was easier. Unit weight of EF PF was lower compared with CYCL which made the work process easier. EF PF was transported to the site in cooled condition.

EF CFB ash contained small stones which caused chokings (see photo 4-5). One cargo was not usable at all because of very high quantity of stones. After technical improvements in plant the quality of ash was significantly improved and work process was going well compared with other two OSA qualities. Unit weight of EF CFB was smallest and that was one important factor. The temperature of the ash was higher in all loads.

Photo 4-5 Small stones in EF CFB

Based on the opinion of laboratory expert, the chemical structure of the ash was not reason for “clots”. The reaction for the “clots” must be caused because of air moisture and its reaction with calcium.

Another work site was in Helsinki where EF CFB was also used in mass-stabilisation and according to the contractor there were no chokings at all. However, same technical equipment and work processes were used. OSA was probably driest as cold air blowing “turbulence” was used during transfer and probably this transferring has also caused loosing and separation for the ash particles.

In conclusion, it can be said that the important OSA characteristics for proper mass-stabilisation process are:

- **Unit weight**: the lower the better. Cement unit weight is lower than any other OSA unit weight used in Simuna-Vaiatu and it ran through the tubes without any problems;
- OSA should be **very dry** as (air)moisture can cause “clots” in the tubes because of its reaction with calcium oxide;
- OSA should be **cooled down** for better transportation and secondly it can have an effect during the mass-stabilisation process.

5 QUALITY AND TECHNICAL CONTROL DURING CONSTRUCTION

Simuna-Vaiatu mass stabilisation quality and technical control during construction works consisted of different activities. Material samples from each ash quality, cement, peat and mass-stabilized mixture was taken. All samples were sent to laboratory for further analysis. A series of vane auger tests were made in place in each section during the works to ensure good quality of mass-stabilisation works. For more information see for separate Simuna-Vaiatu Quality Control report, Ramboll 2014.

5.2 XRF analysis

The XRF (X-ray fluorescence) analysis was used to measure the binder contents of the stabilised soil during the stabilisation process. Calcium content of the stabilised soil was determined with Niton XL3t X-ray fluorescence device (see photo 5-1). XRF is a type of spectroscopy that relies on the release and identification of element-specific wavelengths. The XRF device irradiates the sample causing a discharge of surplus energy. The device measures the wavelength and intensity of the emitted energy for element and recognizes amount, respectively.

Photo 5-1 XRF analysis ongoing

The Niton XL3t is a handheld device that is suitable for both on-site and laboratory measurements. This method is suitable for an application such as quality control of a peat stabilization project. In peat stabilization there is only one element of interest and it should be very abundant which makes the use of the device suitable for the purpose. The assumption behind this method is that the calcium content in the samples corresponds to the amount of binder and thus the success of the actual stabilisation work can be followed.

Measuring time of 20 seconds on the low range setting was determined to be sufficient for reliable calcium quantity readings. The samples were taken on-site every half a meter with a light auger sampler and stored in re-sealable plastic bags. The measurements were carried out around a week and a half after the sampling. Some consolidation will take place in that time but the reaction should not affect the accuracy of the XRF analysis. Five readings per sample were recorded.

Pilot site was divided into different sections according to binder recipe and binder amount. Respectively each section consisted of different blocks. The size of one block was about 5m * 5m and during work the edges were marked with sticks (see photo 5-2). Mass-stabilisation was carried out block by block and samples for XRF testing from different depths were taken from each block. In this way we have detailed information for the whole section about consistency of binder material.

Photo 5-2. Size of one block was 5m * 5m..

In tables 5.1-5.5 the measured calcium contents from the site are compared to the theoretically correct amounts (named calibration mixture in the tables). The theoretical amounts are based on the laboratory mixtures with the same binders and their XRF measurements. Presumably measured values on site should be on the same level or higher compared with calibration mixture. Comparison shows that the stabilisation work has been successful. Most of the measured calcium contents are nearly the same or over the calibration mixture amounts. In other words the amount of the binder in the stabilised peat is as planned. Only in Block 10 in the section 1, the stabilisation may have been failed according to the measurement.

In the tables the result of XRF analysis is left without bolding if the value is more than 10 % less than the result of the calibration mixture. The lower values can indicate that the binder amount is smaller than it should be or that the binder is spread unevenly.

Measured calcium contents from site were compared to the calibration mixture amounts (see tables below), (VP means left lane of the road and PP means right lane of the road, L1 marks section and its number).

Table 5-1 Section 1 XRF-analysis

	XRF-analysis Concentration of Ca (10^3 ppm)		Calibration mixture Concentration of Ca (10^3 ppm)	
	Depth (m)	Result	Binder recipe	Result
Section 1 Block 6 (VP-L1) (25.07.2013)	0,5	**132**	CYCL + KS 200 + 60 kg/m^3	**119**
	1	**123**		
Section 1 Block 10 (PP-L1) (22.07.2013)	0,5	67		**123**
	1	31		
	1,5	17		
Section 1 Block 13 (PP-L1) (24.07.2013)	0,5	113		**131**
	1	**163**		
	1,5	**151**		
	2	**178**		
Section 1 Block 15 (PP-L1) (PP-L1) (23.07.2013)	0,5	101		**131**
	1	103		
	1,5	98		
	2	118		

Table 5-2 Section 2 XRF-analysis

	XRF-analysis Concentration of Ca (10^3 ppm)		Calibration mixture concentration of Ca (10^3 ppm)	
	depth (m)	Result	Binder recipe	Result
Section 2 Block 5 (VP-L2) (16.08.2013)	0,5	**120**	EF PF + KS 190 + 90 kg/m^3	**113**
	1,0	**130**		
	1,5	**137**		
	2,0	**135**		
	2,5	**133**		
Section 2 Block 6 (PP-L2) (14.08.2013)	0,5	**127**		**113**
	1,0	101		
	1,5	**103**		
	2,0	**139**		
	2,5	**138**		
Section 2 Block 12 (VP-L2) (22.08.2013)	0,5	**131**		**113**
	1,0	**127**		
	1,5	**126**		
	2,0	**111**		
	2,5	82		
Section 2 Block 15 (PP-L2) (16.08.2013)	0,5	**119**		**113**
	1,0	**132**		
	1,5	**137**		
	2,0	**130**		
	2,5	**105**		
Section 2 Block 19 (VP-L2) (22.08.2013)	0,5	**148**		**113**
	1,0	**131**		
	1,5	**134**		
	2,0	**138**		
	2,5	71		

Table 5-3 Section 3 XRF-analysis

	XRF-analysis Concentration of Ca (10^3 ppm)		Calibration mixture Concentration of Ca (10^3 ppm)	
	depth (m)	Result	Binder recipe	Result
Section 3 Block 1 (VP-L3) (12.09.2013)	0,5	91	EF CFB + KS 210 + 70 kg/m^3	**110**
	1,0	**100**		
	1,5	89		
	2,0	97		
	2,5	90		
Section 3 Block 13 (VP-L3) (18.09.2013)	0,5	93		**110**
	1,0	**104**		
	1,5	**117**		
	2,0	**113**		
	2,5	**113**		
Section 3 Block 17 (PP-L3) (20.09.2013)	0,5	**112**		**110**
	1,0	**127**		
	1,5	**114**		
	2,0	**101**		
	2,5	92		
Section 3 Block 18 (PP-L3) (24.09.2013)	0,5	97		**110**
	1,0	**118**		
	1,5	**110**		
	2,0	**109**		
	2,5	**103**		
Section 3 Block 20 (VP-L3) (24.09.2013)	0,5	**108**		**110**
	1,0	**100**		
	1,5	**111**		
	2,0	**115**		
	2,5	**118**		

Table 5-4 Section 4 XRF-analysis

	XRF-analysis Concentration of Ca (10^3 ppm)		Calibration mixture Concentration of Ca (10^3 ppm)	
	depth (m)	Result	Binder recipe	Result
Section 4 Block 3 (VP-L4) (04.09.2013)	0,5	**130**	EF PF + KS 180 + 100 kg/m^3	**102**
	1,0	**127**		
	1,5	**129**		
	2,0	**121**		
	2,5	**120**		
Section 4 Block 8 (VP-L4) (30.08.2013)	0,5	**114**		**102**
	1,0	**133**		
	1,5	**127**		
	2,0	77		
	2,5	**109**		
Section 4 Block 9 (PP-L4) (28.08.2013)	0,5	**133**		**102**
	1,0	**110**		
	1,5	**129**		
	2,0	**109**		
	2,5	**97**		
Section 4 Block 16 (VP-L4) (28.08.2013)	0,5	**120**		**102**
	1,0	**120**		
	1,5	**136**		
	2,0	**127**		
	2,5	63		
Section 4 Block 19 (PP-L4) (02.08.2013)	0,5	**139**		**105**
	1,0	**135**		
	1,5	**121**		
	2,0	**121**		
	2,5	**112**		
	3,0	86		

Table 5-5 Section 5 XRF-analysis

	XRF-analysis Concentration of Ca (10^3 ppm)		Calibration mixture Concentration of Ca (10^3 ppm)	
	depth (m)	avg	Binder recipe	avg
Section 5 Block 1 (VP-L5) (24.09.2013)	0,5	**123**	EF CFB + KS 200 + 80 kg/m^3	**101**
	1,0	**94**		
	1,5	**96**		
	2,0	83		
Section 5 Block 6 (PP-L5) (28.08.2013)	0,5	**122**		**103**
	1,0	**123**		
	1,5	**117**		
	2,0	**139**		
	2,5	**110**		
	3,0	71		
Section 5 Block 14 (VP-L5) (12.09.2013)	0,5	**82**	EF CFB + KS X+X kg/m3*	**-**
	1,0	**82**		
	1,5	**89**		
	2,0	**77**		
	2,5	**77**		
Section 5 Block 16 (PP-L5) (08.08.2013)	0,5	**108**	EF CFB + KS 200 + 80 kg/m^3	**103**
	1,0	**93**		
	1,5	**101**		
	2,0	**96**		
	2,5	**95**		
	3,0	56		
Section 5 Block 19 (PP-L5) (04.09.2013)	0,5	**96**		**103**
	1,0	**103**		
	1,5	86		
	2,0	**101**		
	2,5	**106**		
	3,0	49		

*The used oil shale ash quality was called "BL11" which was said to be pretty much exactly like "BL8" (both under the code EF CFB), but the readings here are very low. Either the stabilisation failed, or the used "BL11" is not like "BL8".

5.3 Cone penetration and vane share tests

In order to acquire the results of the quality control soundings column penetrometer soundings were conducted. The aim was to test uniformity and homogeneity of the mass stabilised peat. The column penetration sounding is by far the most used method for the quality control of the column and mass stabilisation in Finland and Sweden. The method involves mechanical penetrometer that is equipped with two vanes. The penetrometer is pressed down and the compressive strength employed is measured at the upper end of the penetrometer rod. The width of the column sounding tip is 375 mm so the research area under the tip is about 400 mm x 80 mm (see photo 5-3). The 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 homogenous, with continuous structure (“a monolith”) or if there is strength variations within the material, e.g. the material is a non-uniformly strengthened mixture of strengthened granules/lumps and un-strengthened soil.

Photo 5-3 Cone penetration and vane share tests ongoing

The results show the average shear strengths detected in five different stabilisation sections in relation to depth. Each section has a different mixture of binder used in the stabilisation of the peat. The first quality control soundings were conducted when the age of mass stabilisation was 76 - 133 days. The second quality control soundings were conducted when the age of mass stabilisation was 10 months. Results show that the shear strength is over the target strength in every tested block. Only in block 11VPL-2 (Figure 5-1) the average shear strength is just above the target strength. However, the strength of stabilised peat increased between the first and the second quality control soundings.

Section 2: Block 11

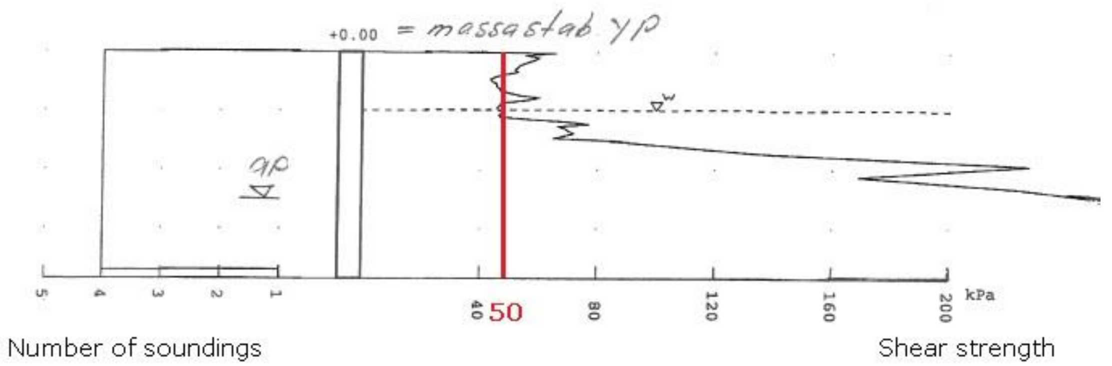

Figure 5-1 The average shear strength of stabilised peat in block 11VPL-2. The age of mass stabilisation is 104 days. Used binder material mixture is EF PF + KS (190 + 90 kg/m³).

A few more examples of column penetration soundings are presented in figures below.

Section 1: Block 16

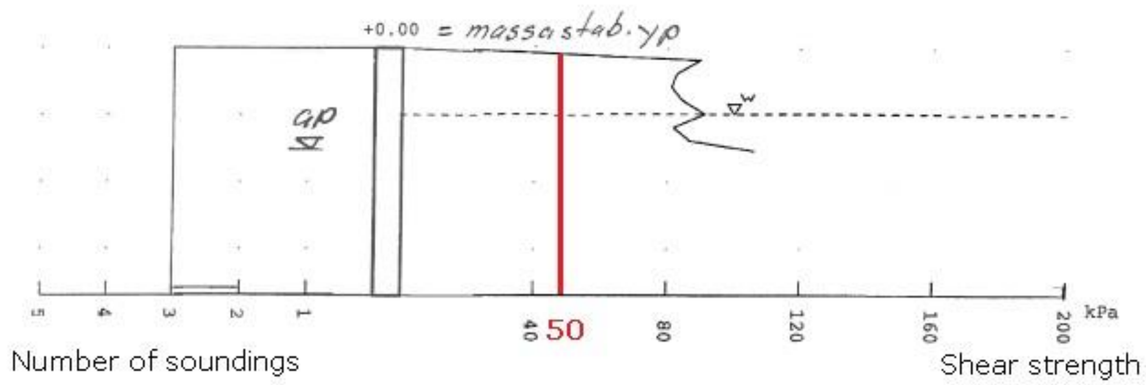

Figure 5-2 The average shear strength of stabilised peat in block 16PPL-1. The age of mass stabilisation is 122 days. Used binder material mixture is CYCL + KS (200 + 60 kg/m³).

Section 4: Block 3

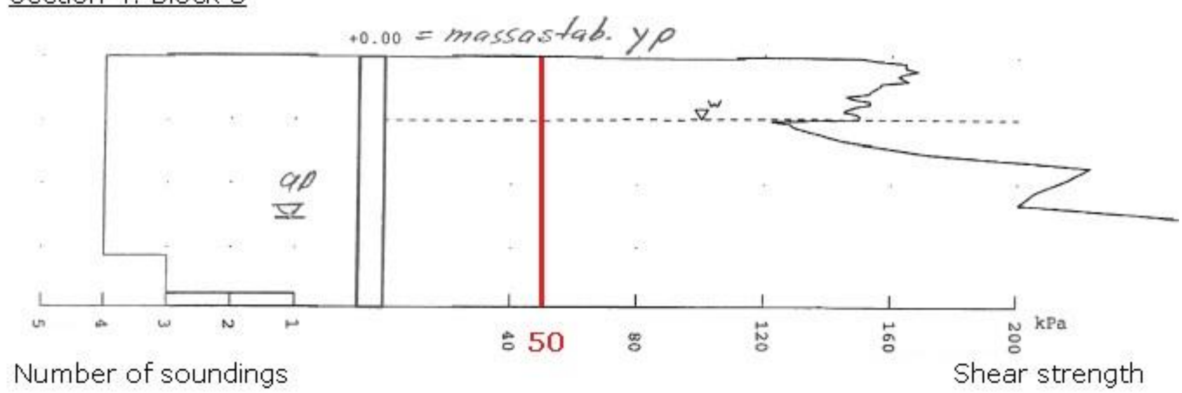

Figure 5-3 The average shear strength of stabilised peat in block 3VPL-4. The age of mass stabilisation is 87 days. Used binder material mixture is BL3 + KS (180 + 100 kg/m³).

According to the penetrometer soundings the stabilised sections have achieved shear strength of 50 - 160 kPa in two to three months. The target shear strength was 50 kPa. The highest strength level was achieved in section 4 with EF PF + KS (180 + 100 kg/m^3) binder mixture. In the second quality control soundings the stabilised sections have achieved shear strength of 60 over 200 kPa at the age of ten months. In all stabilised blocks the shear strength has increased or remained constant between the first and the second quality control soundings. In the second soundings the highest strength level of over 200 kPa was achieved in section 1 with CYCL + KS (200 + 60 kg/m^3) binding mixture. However, decreasing the amount of binder is not necessary or reasonable because some of the shear strength levels were quite close to the target strength of 50 kPa. In conclusion, the stabilisation has been successful as the technical and environmental targets and demands have been fulfilled.

5.4 Settlement of survey plates

Five settlement plates were installed on the stabilised area (five cross sectional cut), which were used to measure the settlement of stabilisation of the structure. Settlement plates are square shaped steel plates with measuring sticks (2.5 m) attached on the middle of the plate. The settlement information was read on the measuring stick with tachymeter and current height was compared to the level zero which was read right after the installation. The settlement plates were installed on the top of the stabilised structure. The pre-loading embankment material was put back carefully to prevent the deformation of the measuring stick (see photo 5-4).

Photo 5-4 Location of the survey plate on site

Measurements of the settlement were carried out as follows:

1) After installation in July-September 2013 (depending on the progress of mass-stabilisation works);
2) In September 2013; 0.1-2 months after stabilisation works;
3) In January 2014, 3-5 months after stabilisation works;
4) In June 2014, 9-11 months after stabilisation works

Results show that the main settlement of the stabilised peat layer took place 3-5 months after the stabilisation works and depth change was between 0.8-1.1 meters. After that the settlement was minor or even unnoticeable (see table 5-6). This corresponds to the experience in Finland which has showed that main settlement happens within 6 months after stabilisation works. Also partly based on this information second phase of the Simuna-Vaiatu construction phase (final road structure) could start in July 2014. It can be stated that in addition to the laboratory test results we can now say that OSA behaves on site similar way as other binder materials (cement, different fly ashes) in mass-stabilisation process.

Table 5-6 Results of the settlement of survey plates

Settlement of Survey Plates Measurements	**Plate 1 (STA 33+10)**	**Plate 2 (STA 34+10)**	**Plate 3 (STA 35+10)**	**Plate 4 (STA 36+10)**	**Plate 5 (STA 37+10)**
Height when installed	99.449 m (25.07.2013)	99.584 m (19.08.2013)	99.620 m (25.09.2013)	99.476 m (30.08.2013)	99.374 m (23.09.2013)
Height after cutting the pole	98.385 m (27.09.2013)	98.817 m (12.09.2013)	98.865 m (27.09.2013)	98.732 m (27.09.2013)	98.558 m (27.09.2013)
Height 08.01.2014	98.36 m	98.793 m	98.865 m	98.685 m	98.52 m
Height 27.06.2014	98.355 m	98.775 m	98.86 m	98.698 m	98.535 m

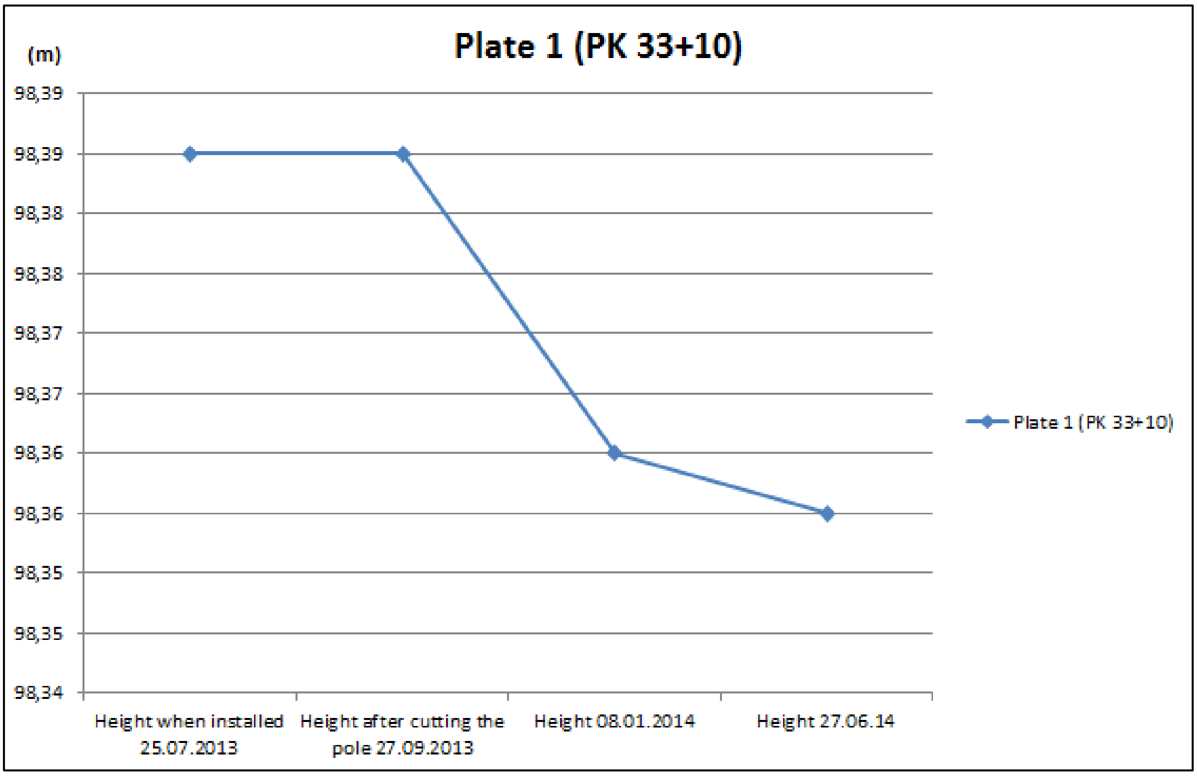

Figure 5-4 Settlement of plate 1

6 ENVIRONMENTAL MONITORING AND FOLLOW-UP PROGRAM

Environmental monitoring program included analyses of water, soil and flora. Overall purpose of the monitoring was to understand if utilization of OSA in mass-stabilisation process has an impact on the surrounding environment. Laboratory tests that were carried out previously showed that there shouldn't be any negative effect to the nature. More detailed information about monitoring can be found in separate Environmental Survey report, Ramboll, November 2014. In this chapter a summary is presented.

First monitoring (environmental quality control) was carried out before the construction in Simuna-Vaiatu piloting site in order to obtain background values. These values were used for the comparison with the results acquired during follow-up monitoring. Follow up was carried out in 2013-2014 after the construction activities.

6.2 Water environment

For the determination of the water samples chemical composition, a certified sampler took the samples on 27.07.2011 as follows: Simuna-Vaiatu water samples were taken from the km 4.8 from both sides of the road. The water sample from the west side of the road was taken from the ditch, but water sample from the east side of the road was taken from a hole next to the road. Water sample from the east side of the road had a higher rate of sediment and therefore also higher conductivity due to the peat soils among the water sample.

Following analyses were carried out in case of the water samples: pH, electrical conductivity, anions (Cl^-, NO_3^-, SO_4^{2-}), cations (NH_4^+, K^+, Na^+, Ca^{2+}, Mg^{2+}) and heavy metals that could get into the water during OSAMAT's works: As , Pb, V, Mo and Cr. Tests were carried out in accordance with the Water Act, laboratory test methods and testing requirements. The results did not show a presence of a large external pollution source and therefore the impact of stabilisation on the natural environment is detectable.

Following water samples was taken from the road section a month after the road embankment stabilisation works (on 18.11.2013). The water samples did not indicate any big alterations in water chemical composition compared to the previous analyses. The results showed that the concentration of hazardous substances (As, Pb, V, Mo and Cr) had not risen. Unlike soil samples where an alkalinity increase was observed water pH did not rise rather it slightly decreased (pH before was 7.3 and 7.,9 and now it was 7.1 and 6.9). Repeated water quality samples were taken on 09.09.2014 and the results did not differ a lot from previous analyses and were within natural water quality fluctuation.

6.3 Soil conditions

Hazardous substance samples were analysed according to the monitoring program and data was obtained from the following substances: Sb, As, Ba, Hg, Cd, Cr, Cu, Pb, Mo, Ni, Se, Zn, V, Cl, F, SO_4 and pH.

There was no contamination found in soil or ground; and the limit values set out by the Estonian Ministry of the Environment Regulation No. 38 'Limit values for hazardous substances in the soil' were not exceeded.

The solubility of the harmful substances was studied according to the survey programme with 1 step batch tests. Sb, As, Ba, Hg, Cd, Cr, Cu, Pb, Mo, Ni, Se, Zn, V, chloride, fluoride, sulphate and pH-range, total content and solubility (L/S 10) was analysed in raw materials and in road material mixtures. Test results were compared with the Finnish limit values for waste materials used in road construction as similar values have not been stated in Estonian legislation. In addition, test results were compared with the soil limit values of Estonia. As was expected road mixtures had lower substance values than raw materials. Test results remained within the limit values. In addition, none of the test results of the road mixtures were higher than allowed in Estonian regulation of the Minister of the Environment No. 38 'Limit values for hazardous substances in the soil'. In the end it is important that road mixture is within limit values and doesn't pollute the environment. Also road mixture raw materials were tested. In raw materials As, C, Pb, Mo, chloride and sulphate have in some cases higher concentration than in limit values of Finnish regulation 519/2006 attachment 403/2009 or in Estonian regulation of the Minister of the Environment No. 38 'Limit values for hazardous substances in the soil'.

The following soil samples were taken next to the road from 0-30 cm below the soil a month after the road embankment stabilisation works had finished (on 28.11.2013). No big changes in the soil samples in case of the hazardous substances concentration was determined compared to the tests taken before the works. At the same time the increase in Cl concentration in the soil samples can be brought out. However, this is not regulated by the law. The Cl concentration in the water samples taken 10 days earlier, remained below detection limit. Likewise soil pH increased from 7.4-7.5 to9.0-9.1 he same tendency was not determined in the water samples.

6.4 Local flora

To clarify the vegetation communities the flora expert carried out the field works near both road sections on 20.06.2011. Simuna-Vaiatu road section passes through a drained swamp. On kilometres 2.5-4, the road is lined by drained swamped forests that grow on fen and transition mire peat lands. The forests' usual habitats are wood sorrel-drained swamps and blueberry-drained swamps. The forests are middle-aged to old, dominant tree species are pine, spruce and birch. The drained swamped forests have emerged from swamped forests as a result of drainage and usually do not have a high value. In the vicinity of the road section (nearest point of 25 m), there is a high value habitat of the forest (VEP No. 143151) which aims to protect the old forest communities.

On kilometres 4-5, the road is lined with swamped forests strongly affected by drainage. The forests are middle-aged and have emerged from wooded marshes as a result of drainage. The dominant tree species in the forest is pine; to a lesser extent, there is also spruce.

In the forests surrounding the whole 2.5-5 km road section there are individually scattered Category III protected species - Lesser Butterfly-orchid (*Platanthera bifolia*) specimens (see photo 6-1). The species is common and widespread in the region and the area adjacent to the road is not an important habitat for the species.

Photo 6-1 Category III protected species - Lesser Butterfly-orchid (*Platanthera bifolia*)

Construction work was carried out within road area and therefore the monitoring focused on the possible effects of the immediate road section area (the potential impact zone), vegetation and aquatic life. Nature monitoring of the renovated section was conducted in September 2014 after the completion of all works. Fieldwork fell to the vegetation period. Monitoring assessed the embankment slopes, side ditches and river banks of vegetation, species composition, coverage, features and overall development (see photo 6-2). The overall composition of the vegetation habitats (roadsides) and typical vegetation were evaluated. Monitoring data and photographic material was compared to 2012 monitoring results. In conclusion, it is clear that there were no negative impacts on flora caused by utilisation of OSA.

Photo 6-2 Road side vegetation after work completion

7 CONCLUSIONS

7.2 Laboratory testing and feasibility of the materials

Binder recipe for Simuna-Vaiatu was worked out in laboratory. The purpose was to find optimal binder content and binder composition. A series of different analysis were carried out including Niton tests, concentration of elements, leaching tests, Unconfined Compressive Strength tests etc. The results of the stabilisation show that the peat samples had similar total strength development and no big differences between the samples could be found. One peat-clay sample in the other hand gave high compressive strength results and less binder is needed to achieve the 100 kPa compressive strength. The sample depth of 0.2-0.7 m had better long term strength development than sample of depth 0.7-1.3 m and 1.3-2.05 m. Samples from 0.7-1.3 m and 1.3-2.05 m gave similar results and no significant differences could be noted. All the peat samples achieved the targeted 100 kPa compressive strength. The biggest differences came when *Normal Cement* was used as a binder. According to the results *Normal Cement* works better than *Composite Cement*. But the economical possibility is still *Composite Cement*. Based on laboratory testing proper binder recipes were proposed for construction action. These results are feasible only in this section. A new area needs a new testing in laboratory.

7.3 Construction and quality control

Technical design of the road section was carried out to obtain construction permit from the Estonian Road Administration.

Construction activities were carried out in Simuna-Vaiatu road section in two phases. Firstly, mass-stabilisation of peat layer and preloading was done in July-September 2013 and then the stabilised layer had to settle at least for 4-6 months. Second phase started in June 2014 and was completed in August 2014 and it included embankment works, complex and layer stabilisation, ditch works, slope planning and traffic signs instalment.

During both phases a series of quality and technical control activities were carried out. Material samples from each ash quality, cement, peat and mass-stabilized mixture was taken. All samples were sent to the laboratory for analysis.

1) The XRF (X-ray fluorescence) analysis were used to measure the binder contents of the stabilised soil during the stabilisation process;
2) In order to acquire the results for the quality control soundings column penetrometer soundings were conducted. The aim was to test uniformity and homogeneity of the mass stabilised peat;
3) Five settlement plates were installed on the stabilised area, which were used to measure the settlement of the stabilisation of the structure.

All tests showed good quality of mass-stabilisation works in different phases.

During mass-stabilisation works problems occurred with OSA processing through the tubes that were connected between binder tanks and work equipment. OSA particles seemed to choke the tube and blocked binder material to run smoothly through it. Tube had to be opened and cleaned manually and therefore the work process was very slow during some periods. Normal mass-stabilisation work speed is about 500 m³ of soil in one day (based on Finnish experience), but in Simuna-Vaiatu the speed was only about 150-170 m³ in some days. There were no similar problems with cement material. Different ashes behaved differently. Bigger choking problems were caused by CYCL. This situation was completely unexpected and neither contractor nor laboratory experts have experienced similar circumstances before. Therefore we cannot state clearly the reasons for choking and make 100% confident proposals that will avoid similar situations in the future. But based on the opinions of different experts it can be said that important OSA characteristics for proper mass-stabilisation process are:

- **Unit weight**: the lower the better. Cement unit weight is lower than any other OSA unit weight used in Simuna-Vaiatu and it ran through the tubes without any problems;
- OSA should be **very dry** as (air)moisture can cause "clots" in the tubes because of its reaction with calcium oxide;
- OSA should be **cooled down** for better transportation and secondly it can have positive effect during mass-stabilisation process.

7.4 Environmental monitoring and follow-up program

Environmental monitoring program included analyses of water, soil and flora. Overall purpose of the monitoring was to understand if utilization of OSA in mass-stabilisation process has an impact on the surrounding environment. Laboratory tests that were carried out previously showed that there shouldn't be any negative effect on the nature. First monitoring was carried out before the construction in Simuna-Vaiatu piloting site in order to obtain background values. These values were used for the comparison with the results acquired during follow-up monitoring. Follow up was carried out in 2013-2014 after the construction activities.

Monitoring of water, soil and flora showed clearly that utilisation of OSA had no negative impact on the surrounding environment.

In sum, it can be concluded that mass-stabilisation works succeeded well taken into account that it is a demonstration project and first time test in Estonia on existing road. There were unexpected issues with processing OSA through the tubes and it caused delays in time-schedule. It is important to take this experience and use it in next mass-stabilisation projects to avoid similar situations. Mass-stabilisation has potential in Estonia as we have number of areas with weak or unstable soil conditions. It is clear that using OSA in mass-stabilisation is much more environmental friendly than taking excavated material from mines.

8 RECOMMENDATIONS

Based on the OSAMAT project experience there are some recommendations for further discussions and implementation:

1) In OSAMAT project the amount of binder material per unit was rather big. It is possible to decrease the binder material unit amount in future projects to save cost and time of work process;
2) Based on Finnish experience peat layer settlement time is about 4-6 months which makes the work process remarkably longer compared to traditional methods. This can make it more expensive and unattractive taken into account that construction season is limited in Estonia. Efforts should be made together with laboratory to shorten settlement time to 1-2 months. Although there may be projects where long settlement time is not very critical;
3) According to the specialists today in Estonia mass-stabilisation with OSA is not economically feasible compared to traditional methods which are digging out the unstable material, storing it to the landfill and replacing it with quarry material. Feasibility is mainly related to the transport cost as OSA is coming only from Eastern Estonia. But in the future environment-related legislation and rules will become most probably stricter and it will balance the situation. From the environmental point of view usage of OSA is most reasonable as there is no need for natural material instead. For example in Finland already the situation is different and usage of industrial by-products in infra projects is common. As a proposal there should be in Estonia for example transport dotation from state, because OSA is created in the energy production process anyway and today it is mainly stored on the landfill and it causes environmental problems. There should be political support to use industrial by-products and to minimize the opening of new quarries.
4) OSA quality should be homogenous similarly to every other product (like cement). All loads that arrive to the site should be with same quality and correspond to the same characteristics. It adds reliability and perspective to the larger scale utilisation. OSA should be very dry and cooled down before utilisation. If possible then pre-testing with mass-stabilisation equipment should be done beforehand, for example during the laboratory testing period.
5) Mass-stabilised road section must be closed for traffic, because there is need for larger working zone. Traditionally one road lane is open for traffic. Therefore a proper bypass is needed when mass-stabilisation technique is implemented.

The overall recommendation is that mass-stabilisation certainly has potential in Estonia in road, port, commercial or industry developments and it is worth to carry on with other initiatives after OSAMAT project. OSAMAT project is only first step in Estonia regarding mass-stabilisation technology. There should be other pilot or development projects where mass-stabilisation is implemented. OSAMAT project is good example to demonstrate to different stakeholders and decision-makers that it is great possibility to use industrial by-products efficiently.

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