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LIFE+ 09/ENV/EE/227 OSAMAT project Verification Report

SKEPAST & PUHKIM

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ABBREVIATIONS

CC	- composite cement
CYCL	– oil shale ash from the cyclone filters, pulverized firing
EF	– electrostatic precipitator oil shale ash from pulverised firing
EF CFB	- electrostatic precipitator ash from circulating fluidised bed combustion
FT	- freeze-thaw
kPa	- kilopascal
LCA	- Life-Cycle Assessment
LCC	- Life-Cycle Costing
MPa	- megapascal, unit of measure for load capacity
Niton	- portable x-ray Fluorescence Analyzer
OSA	– Oil Shale Ash
OSAMAT	- Management of Environmentally Sound Recycling of Oil-Shale Ashes into Road Construction Products. Demonstration in Estonia.
Troxler	- portable x-ray based compaction and moisture measuring device
UCS	– Unconfined Compressive Strength

1. Introduction

Verification report is compiled in order to show that methods, materials and applications based on Oil Shale Ash (OSA) are environmentally safe and technically and economically feasible. The report describes the procedures and activities carried out during the pilots. Verification consists of *quality control procedures* during the pilots, *long-term follow-up procedures* and *environmental life-cycle assessment and life cycle costing* of the pilot applications. Pilot sections were Narva-Mustajõe and Simuna-Vaiatu. Verification report is compiled in accordance with project technical application form: Part B – Objectives and expected results (Action 5: Verification). Purpose of Verification Action is to give project stakeholders proof that project actions were carried out in accordance with targets and with high quality standards.

The main steps to ensure fulfilment of Verification Action were the following:

Construction permits for pilot sections were issued by Estonian Road Administration in accordance with corresponding legislation including environmental law. Preliminary environmental impact assessment was carried out during permitting procedures.

Quality control procedures involved 1) technical quality control, and 2) environmental quality control. Technical quality control was carried out during the piloting to control the properties of materials and applications match with the targeted properties. Environmental quality control begun before the start of the pilot process by determination of the background values at the piloting area. The environmental quality control and follow up results were compared with these values. The final stage of the environmental quality control was done after the end of the piloting.

Long-term follow-up procedures continued the quality control procedures after the pilot sections were constructed.

Environmental life-cycle assessment (LCA) and life-cycle costing (LCC) was carried out according to the principles of available standard procedures. LCA was compilation and evaluation of the inputs, outputs and the potential environmental impacts of a system throughout its life period or over a chosen lifetime period (EN ISO 14040:2006). LCC was determined as a methodology for systematic economic evaluation of life-cycle costs over a period of analysis in the agreed scope (ISO 15686-05:2008).

Verification Action is mainly based on following reports:

1. Materials action Pilot report including descriptions of applications: Application, Piloting and Verification actions **Narva-Mustajõe** Pilot Report

2. Materials action Pilot report including descriptions of applications: Application, Piloting and Verification actions **Simuna-Vaiatu** Pilot Report

3. Simuna-Vaiatu Quality Control Report

4. Environmental Survey Report

5. Life-cycle assessment (LCA) and life-cycle costing (LCC) Report

2. Quality control procedures

Technical quality control was carried out during the piloting to ensure that the properties of materials and applications were in accordance with the project goals. Environmental quality control/monitoring began before the start of the pilot sections construction with defining of the background environmental values at the piloting areas. Next stage of the environmental quality control (flora inventory, sampling and analyses) was done at the end of the piloting. The quality control results were compared with background values, with results from material tests, with the criteria from project Action 1 and with the stipulations of the environmental legislation.

Quality control and follow-up procedures were carried out with respect to technical and environmental aspects. The technical quality control and follow-up procedures were carried out by geotechnical on-site tests and soil/water sample taking from the sites to perform laboratory analysis.

The most common quality control procedures during the piloting include control of the water content and the start of the strength development of the material mixtures, and control of the compaction properties of the material mixtures. The long-term follow-up usually involves control of the long-term strength development and the bearing capacity of the applications.

2.1. Quality control procedures of NARVA-MUSTAJÕE pilot site

Quality control procedures included 1) technical quality control, and 2) environmental quality control. Technical quality control was carried out during the piloting to control if the properties of materials and applications match with the targeted properties. Environmental quality control begun before the start of the pilot process by determination of the background soil and water characteristics at the piloting area.

2.1.1. Technical quality control

During construction geometrical parameters (the depth, width and cross fall) of the stabilisation layer were measured and recorded. Portable Niton XRF Analyzer was used for the field material mixture tests.

Water content values were measured during the construction with (microwave) oven drying method. Each measurement took 10–20 minutes. Water addition through the rotary mixer required constant control. Now the body aggregate also contained considerable amount of bitumen since the milled asphalt concrete in it, which may have caused some of the inconsistencies in the results. The precise water content values are provided in Narva-Mustajõe pilot report[1].

Compaction parameters: Maximum dry density and optimal water content was assessed in the field using an amended version of modified Proctor compaction test. 8 hammer blows per layer were used. If aggregate material differs, it had to be estimated again. Proctor compaction test results on the right lane (Binding agent 5 % OSA CYCL. + 5 % CC) were as follows: the water content - dry density combinations were not completely consistent, but according to the results the maximum dry density was around 2080 kg/m3 and the water content around 8 %. It was experienced that the mixture of aggregate, binding agents and water transformed its state to more elastic when water content was just slightly above the optimum, and while it compacted seemingly well, it was not possible move on top of it with anything with smaller tire print than the roller without making any ruts.

[1] Narva-Mustajõe Pilot Report, January 2015

Bearing capacity of the stabilisation layer was measured with the "light weight Loadman" (Inspector-device). The samples of stabilisation layer were tested in the laboratory. There were tests for unconfined compression, density and freeze-thaw durability (the results in Narva-Mustajõe pilot report)[2].

Compressive strength and freeze-thaw durability. In total, nine unconfined compressive test specimen were made; four in the section with EF PF ash and five at the section with CYCL ash. The samples from the EF PF ash section was compared to earlier laboratory results. The comparable samples were tested for time-strengthening comparison between 7 and 28 days. According the results, the structure shows adequate strength after one month. The comparable samples were tested for freeze-thaw weathering comparison. The strength loss between normal UCS result and FT weathered result was measured to be only around 15 %, which points to successful stabilisation. Both of the sample pairs had almost the same results with 28 d UCS.

The technical quality control was conducted 28 days, 90 days and one year after construction. For technical testing of materials action, drilled samples comparison of 28 days and 90 days were made. Results of unconfined compression strength were good and values were higher than unconfined compression strength of 28 days after construction. This was very positive and it could be noted that strengthening of the structure was continuing. Strength of samples indicated that EF-binder gives much more strength than cyclone–ash binder despite of lower cement content. EF-binder gives very high strength results and cyclone-ash binder gives good strength results.

2.1.2. Environmental quality control

Initial monitoring (environmental quality control) was carried out before construction at the piloting sites began, to determine the flora, soil and water background values. Follow-up Monitoring results were compared with these values. The first pilot test section (No. 13109 Narva-Mustajõe road km 14.5 to 16) was located near the Estonian power plant and is heavily influenced by power plants' waste facilities (ash storage sites). Pilot test site was surrounded by woods and farmlands, the nearest residential building was farther than 1 km.

To identify the chemical composition of water, the water samples were taken by certified water sampler as follows: road no 13109 Narva-Mustajõe monitoring point was located in the ditch upstream of the OSAMAT's works near road km 15.7.

Following tests were carried out in the water samples: pH, electrical conductivity, anions Cl^-, NO_3^- , SO_4^{2-}), cations (NH_4^+, K^+, Na^+, Ca^{2+}, Mg^{2+}) and metals that can get into the water from 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. Water samples near the road were taken before the piloting works and it showed that the water content is not natural as some of the elements as As, Pb, V, Mo and Cr are not found in Estonian natural surface water. So it can be concluded that the area had been affected by nearby oil shale ash fields. Still all investigated elements were below accepted contamination levels and so are not dangerous to the environment.

Hazardous substances in soil were analysed according to the monitoring program and data was obtained about the following substances: Sb, As, Ba, Hg, Cd, Cr, Cu, Pb, Mo, Ni, Se, Zn, V, Cl, F, SO_4 and pH. No contamination was found in pilot road sections' soil and 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, pH-start and pH-final total content and solubility (L/S 10) were analysed in raw materials and in road mixtures.

[2] Narva-Mustajõe Pilot Report, January 2015

Roadside vegetation conditions were investigated before and after construction works and no differences were noticed.

2.2. Quality control procedures of SIMUNA-VAIATU pilot site

Quality control procedures for Simuna-Vaiatu pilot site included technical quality control and environmental quality control.

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.

2.2.1. Technical quality control

Simuna-Vaiatu mass stabilisation quality controlling consists of X-ray fluorescence (XRF) analysis and column penetrometer soundings.

The XRF analysis was used to measure the binder contents of the stabilised soil during the stabilisation process. 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. In peat stabilization there is only one element of interest (Calcium content). 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. 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. 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. Mass-stabilisation was carried out block by block and samples for XRF testing from different depths were taken from each block. The measured calcium contents from the site were compared to the theoretically correct amounts that were 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 showed that the stabilisation work has been successful. Most of the measured calcium contents are nearly the same or over the calibration mixture amounts. Please see comparison tables in the Simuna-Vaiatu pilot final report[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 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 20 mm. 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. 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.

[3] Simuna-Vaiatu Pilot Report, April 2015

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.

Settlements of survey plates. In order to measure the settlement of stabilisation of the structure, five settlement plates were installed on the stabilised area. 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. Measurements of the settlements were carried out right after installation, 0.1-2 months after stabilisation works, 3-5 and 9-11 months after stabilisation works.

2.2.2. Environmental quality control

First environmental monitoring was carried out before the construction activity in Simuna-Vaiatu piloting site in order to obtain flora, soil and water 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 were completed. Environmental monitoring program included analyses of water, soil and flora. For the determination of the water samples chemical composition, a certified sampler took the samples.

Simuna-Vaiatu water samples were taken from the km 4.8 from both sides of the road. The 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. The results did not show a presence of any external pollution source and therefore the impact of stabilisation on the natural environment was well detectable. A month after the road embankment stabilisation works the water samples did not indicate any considerable 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. Repeated water quality samples' results did not differ a lot from previous analyses and were within natural water quality fluctuation.

Soil conditions monitoring included the analysis of the following substances presence in the soil: 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 and the limit values set out by the Estonian Ministry of the Environment were not exceeded. The solubility of the harmful substances was studied according to the survey program 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 and with the soil limit values of Estonia. Road mixtures had lower substance values than raw materials. 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'. 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. No 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 to 9.0-9.1 the same tendency was not determined in the water samples.

To clarify the vegetation communities the flora expert carried out the field works near both road sections. Simuna-Vaiatu road section passes through a drained swamp. The drained swamped forests have emerged from swamped forests as a result of drainage and usually do not have a high ecological value. In the vicinity of the road section (nearest point of 25 m), there is a high value habitat of the forest which aims to protect the old forest communities. 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. The species is common and widespread in the region and the area adjacent to the road is not an important habitat for the species. 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. 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 utilization of OSA.

3. Long-term follow-up procedures

Long-term follow-up procedures included technical and environmental monitoring activities after the pilots were constructed.

The environmental procedures were the same before and after the piloting: appropriate soil and groundwater samples were taken close to the piloting site, i.e. at spots and distances which could be affected by the OSA (the sampling spots are to be determined on the basis of soil and hydrological conditions of the site). Samples were also taken from the pilot construction area at a depth which was directly below the structural course that will contain OSA material. The samples were analysed for those contaminants which OSA contains in noteworthy amounts and which might be a risk to the environment.

3.1. Narva-Mustajõe Long-term follow-up procedures

Load bearing measurements were made in three consecutive autumns (2012- 2014). Target value for the road according to the design is 260 MPa. Measured lowest values were about 260 MPa and highest values above 600 MPa. Bearing capacity of the road is high. It is typical for structures of stabilised layer and base course stabilisation.

The defect count analysis have also been made in three consecutive autumns (2012-2014). On the first 450 m there were more transverse cracks than on the following 450 m. It is typical for stabilized structures that there are narrow cracks. They were caused by shrinking of the stabilized layer, very typical for stabilisation of coarse materials with hydraulic binders. Comparing the results of measurements, bearing capacity raised ca 40% (2012-2013) as well as in average, as in the lowest values achieved. Lower strengthening was identified in sections without renovation. This indicates the hardening of stabilized layer within first year of use.

During the follow-up investigations also the rut depth has been recorded. The average rut depth in different test sections was between 2.3-3.6 mm. The highest rut depth values were in the locations of fatigue cracking e.g. STA 9+00 and STA 12+75, the highest rut depth is 14-17 mm. However no general conclusions could be made based on the differences in rut depth as the differences are very small. Rutting, in general, develops fast during first year (after-densification of bitumen-bound layers), continuing with much lower speed during pavement maturing and increasing in last phase of pavement lifecycle together with other defects.

Also swelling and shrinking effect was observed during technical quality control. On the road, mixture of OSA and cement was used as binder material. After construction cracks occurred on the road pavement. Estonian and Finnish expert's position is that the main and most important reason of cracks is shrinking effect of the monolith body, which formed after stabilisation.

Vegetation conditions were investigated in June 2011 and the same investigation were done in June 2012 and June 2013. Investigation purpose is to find out if some vegetation changes can be found after stabilisation works.

The environmental procedures were the same before and after the piloting: appropriate soil and surface water samples were taken close to the piloting site, i.e. at spots and distances that could be affected by the OSA (the sampling spots are to be determined on the basis of soil and hydrological conditions of the site). Samples were also taken from the pilot construction area at a depth that will be directly below the structural course that will contain OSA material. The samples were analysed for those contaminants which OSA contains in noteworthy amounts and which might be a risk to the environment.

Because this area is still influenced by nearby ash fields it was not possible to find out how much stabilisation would affect natures chemical composition. So it was decided, that water sample will be taken 12 and 24 months after background water tests, as this will only show if the work area is still below accepted contamination levels, not how much stabilisation changes water content. Water sample tests were the same as before construction works.

During the course of the environmental follow-up monitoring in 2014 and 2015 following sampling campaigns were conducted in Narva-Mustajõe road: two soil sampling episodes and seven surface sampling episodes. In addition two surface water sampling episodes in Narva-Mustajõe pilot section were conducted in 2015 for checking the sulfate content and natural background level of barium. Sampling reports as well as results of analysis are presented in Final Report of post-project environmental monitoring[4].

Soil samples were taken from the banks of both pilot road sections at depth 0.2-0.4 m in 2014 and 0.05-0.2 in 2015. The content of trace elements in soil samples was compared to the legal limits and natural background level. Content of all trace elements was below target values set by the national regulation in all samples. In Narva-Mustajõe pilot section the content of selected elements in composite sample taken in 2012 and mean value in samples taken in 2014 and 2015 is in the same order of magnitude. Only the mean content of Ba and Mo is over 10% higher in samples taken in 2014 compared to 2012. At the same time the content of Ba in soil samples taken in 2015 is almost two times lower compared to 2012. The conclusion after long-term follow up is that the effect of OSA in road construction onto content of trace elements in soil is negligible.

For following the long-term trends (2011-2015) of selected parameters in **surface water** in the pilot areas it is possible to use only those parameters that were measured in previous monitoring campaigns i.e. pH, EC, chloride, sulfate, As, Cr, Pb, Mo, V. Content of Cr and V in all water samples is below limits of detection therefore these metals are not included in the analysis. For the calculation of average concentrations, values below the limit of quantification were set to half of the value of the limit of quantification concerned. The results of the analysis revealed that road construction with OSA has mostly affected the content of sulfates in surface water. In Narva-Mustajõe the content of arsenic has decreased over an order of magnitude compared to first sample taken in 2011. Even if we take the first point as an error no significant changes in content of arsenic can be observed during the monitoring period. One element, which water-soluble concentration is above national legal limits is barium.

It was not possible to assess the impact of OSA road construction to **groundwater** based on the data obtained from the follow-up program. Water samples were taken from the roadside ditches. These ditches act as a discharge for the upper layer of groundwater and infiltration from ditches to groundwater is therefore minimal. No groundwater samples were taken throughout the monitoring program.

On the basis of the follow-up **vegetation** monitoring[5] in 2012 and 2013 it can be concluded that the vegetation of road edges and ditches of the test section was quite common with given habitat. Species preferring neutral environment dominated, but also slightly lime-loving species occurred. Considering rather calcareous soils of the area as a background and the influence of alkaline pollution, there are no clear signs of using oil shale ashes as alkaline substrate on the site in case of the vegetation. It can be concluded that there were no negative impacts on the wildlife next to the Narva-Mustajõe road section due to the use of oil shale ashes.

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[4] OSAMAT – post-project environmental monitooring in 2014 and 2015. Final report, 2015. National Institute of Chemical Pysics and Biophysics Estonia.

[5] Environmental Survey Results. Survey report, January 2015 by Ramboll Eesti AS.

3.2. Simuna-Vaiatu Long-term follow-up procedures

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 one block 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.

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.

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. Measurements of the settlements were carried out right after installation, 0.1-2 months after stabilisation works, 3-5 and 9-11 months after stabilisation works. Results showed that the settlement of the stabilised peat layer was between 1-4 centimetres which corresponds to the Finnish experience. In addition to the laboratory test results it is clear that OSA behaves on site similar way as other binder materials (cement, different fly ashes) in mass-stabilisation process. The more detailed results can be seen in Simuna-Vaiatu Pilot Report[6].

During the course of the environmental follow-up monitoring in 2014 and 2015 following sampling campaigns were conducted in Simuna-Vaiatu road: two soil sampling episodes and seven surface sampling episodes.

Soil samples were taken from the banks of both pilot road sections at depth 0.2-0.4 m in 2014 and 0.05-0.2 in 2015. The content of trace elements in soil samples was compared to the legal limits and natural background level. Content of all trace elements was below target values set by the national regulation in all samples.

In Simuna-Vaiatu road previous soil sampling was conducted in 30.05.2012. In the final report of post-project environmental monitoring[7] the content of trace elements in composite sample taken in 2012 and mean content of elements in the soil samples taken in 2014 and 2015 were compared. It must still be noted that the dry weight of one sample taken in 2015 at Simuna-Vaiatu pilot section was 53.2 wt-%, which makes the sample relatively wet. The conclusion after long-term follow up is that the effect of OSA in road construction onto content of trace elements in soil is negligible.

For following the long-term trends (2011-2015) of selected parameters in **surface water** in the pilot areas it is possible to use only those parameters that were measured in previous monitoring campaigns i.e. pH, EC, chloride, sulfate, As, Cr, Pb, Mo, V. Content of Cr and V in all water samples is below limits of detection therefore these metals are not included in the analysis. For the calculation of average concentrations, values below the limit of quantification were set to half of the value of the limit of quantification concerned. Long-term follow-up showed that the content of sulfates in surface water of Simuna-Vaiatu pilot section had decreased. The content of chlorides and values of pH and electronic conductivity were similar to natural background levels. Content of fluoride in surface water is well below limit concentration. There are same fluctuations in the content of

[6] Simuna-Vaiatu Pilot Report, April 2015

[7] OSAMAT – post-project environmental monitoring in 2014 and 2015

molybdenum in water samples of Simuna-Vaiatu pilot section in 2015. But it is well below the national legal limit. One element, which water-soluble concentration is above national legal limits is barium. It was not possible to assess the impact of OSA road construction to **groundwater** based on the data obtained from the follow-up program. Water samples were taken from the roadside ditches. These ditches act as a discharge for the upper layer of groundwater and infiltration from ditches to groundwater is therefore minimal. No groundwater samples were taken throughout the monitoring program.

The **vegetation** monitoring[8] of Simuna-Vaiatu renovated section was conducted in September 2014 after the renovation works had completed. The monitoring data and photographic material was compared with the monitoring results from 2012. Based on the monitoring results in 2014, it can be concluded that no negative effects on the neighbouring wildlife occurred that could be associated with the use of fly ash in Simuna-Vaiatu section.

[8] Environmental Survey Results. Survey Report, 2015 by Ramboll Eesti AS.

4. Environmental life-cycle assessment and life-cycle costing

The environmental life-cycle assessment (LCA) and life-cycle costing (LCC) were carried out according to the principles of available standard procedures. LCA is compilation and evaluation of the inputs, outputs and the potential environmental impacts of a system throughout its life period or over a chosen lifetime period (EN ISO 14040:2006). LCC is determined as a methodology for systematic economic evaluation of life-cycle costs over a period of analysis in the agreed scope (ISO 15686-05:2008). The system can described as a collection of unit processes which perform one or more defined functions and model the life cycle of a product. The product can be a certain civil-engineering application which can be implemented with the demonstrated OSA-materials (OSA-stabilised application) or its conventional alternative based on natural aggregates.

4.1. LCA of Narva-Mustajõe

Narva-Mustajõe pilot was about constructing a part from an existing road with the layer stabilisation method. In total four different alternative structures were studied in the LCA[9]. Three of the structure alternatives were layer stabilisation alternatives using cement and/or fly ash as binders. Mining waste was used in the layer stabilisation in addition of the old road base course to get a good body for the structure layer. The fourth alternative was a traditional alternative for layer stabilisation, which according to the contractor, is a cold in place complex recycling. The complex recycling is similar to the layer stabilisation but uses new aggregate, cement and bitumen in the stabilisation instead of the old road paving and dry binders. The alternatives were:

- Alt 1: layer stabilisation using a binder mixture of cement and oil shale ash (EF PF oil shale ash)
- Alt 2: layer stabilisation using a binder mixture of cement and oil shale ash as a binder (CYCL oil shale ash)
- Alt 3: layer stabilisation using cement as a binder
- Alt 4: complex recycling using a mixture of cement and bitumen as a binder.

In material production stage the Alt 4 has the biggest depletion of natural resources as the road is constructed with crushed stone. Alt 3 generates more global warming potential than other alternatives. This is caused by the use of cement. The negative aspect in oil shale ash transportation in alternatives Alt 1 and Alt 2 is due to the compensation when OSA is not transported to the landfill in 5 km distance.

Alt 3 has the highest GWP (Global Warming Potential) and results from the highest use of cement in stabilisation. Alt 1 has the lowest value of GWP, although Alt 4 has the same magnitude in GWP result.

Depletion of natural resources is highest in Alt 4 as the structure alternative uses new natural aggregate in the construction.

4.2. LCC of Narva-Mustajõe

Life-cycle costing (LCC) was based on the standard ISO-15686-5:2008. The assessment was based on the investment calculations of costs of certain product or functional unit during a life-cycle. The purpose of the life-cycle costing should be to quantify life-cycle cost (LCC) into decision making process. In this calculation the construction costs were the initial costs created during constructing. The operation costs were neglected since they are considered insignificant or identical, and they

[9] LCA/LCC Report by Ramboll Finland OY, January 2015

don´t therefore give variation to the calculation. The maintenance costs included repair and structural renovation costs, which were discounted into net present values. Certain assumptions needed to be made concerning the long term durability of structures, since no monitoring data was available of the long term durability or integrity assessments of structures.

For the OSAMAT project the life cycle cost analysis (LCC) was made for 1 kilometre of road constructed with layer stabilisation technology in Narva-Mustajõe pilot. The utilisation of OSA and substitution of cement were studied. In LCC calculations no costs of use and operation, or costs of road accidents, delays or rush hour were taken into consideration.

In Narva-Mustajõe case the stabilization height was kept constant in 250 mm, with the exception of Alt 4 (cold in place stabilisation) where height was 150 mm. The transportation price used in cement transportation was chosen and used in transportation of all materials. Cement: 100 t*km is 8 € equals 0,08 €/ (t*km). In addition powder-like materials need staying time unloading/loading, which in the case of cement was 0,0454 €/ (t*km). In total the transportation costs sums up to 0,1254 € / (t*km). In general, cost of construction can be divided into cost of materials and work done. The basic road renovation method here was the layer stabilisation method. For each structure type, the original binder mixture was used and calculated. Therefore the chosen material recipe had an impact on the material costs side of the application. The general constructing unit prices used in the LCC calculations included the price of material and work. Depending on the type of the work, the prices were between 1,20 and 10,46 EUR/m^2. More information can be found in OSAMAT LCA-LCC report[10]. During the 40 years' time horizon, the structure will be repaired and renovated many times. There were different repair and renovation methods for different structure material solutions. According to LCA-LCC report, there were 3 different scenarios, where the repair methods were used in different intervals. The scenarios were assumptions as there was no experience yet how durable the structure is for real. The paving methods REP (17,10 €/m^2) and U-REP (1,40 €/m^2) were used many times for these structures. However the structural renovation will be done once during the 40 year time horizon. The time point of this renovation varied in Scenarios 1 – 3. Time point had an impact on the overall calculation. The calculation contained 3 scenarios, where the first has the shortest life-time for structural renovation. The third scenario had the longest life-time until structural renovation. Different structure solutions and traffic loads created needs for different maintenance and renovation actions. In some cases computational damage modelling and forecasts, could be used to evaluate the renovation time periods. However, if accurate, they could only be valid for some traditional solutions. In these structures repair costs would follow repair needs derived from damage assessments and prognosis. For the time being, only empiric evaluation of the repair and maintenance costs were considered viable alternative. No generally accepted reliable models were developed for damage assessment. Normally the costs from end of life stage of the studied product/service were included in the LCC calculation. As the studied product in this case was a road, and when the use of a road stops, the road structure will be usually left on place. So in this LCC calculation the end of life stage is not taken into account in the LCC calculations.

Performed calculation results showed how the discounted annual cost per 1 kilometre of road (9.5 m wide) was lower for structures with alternative construction materials postponed structural renovation time horizons. In Scenario 3, the structural renovation time periods are done between 28 – 40 years after construction. In Scenario 1, the structural renovation time periods are done between 20 – 28 years after the construction. According to these results it can be seen, that the life cycle costing with alternative construction materials will be also lower. Throughout LCA/LCC report different calculation principles were presented. In the beginning situation cheaper material purchasing costs can be achieved due to use of alternative construction materials. It should be noted that using repaving solution means intensive and heavy costs. Also that reduction in stabilization work costs might lower the overall costs. According to the results the annual costs of Alt 4 is approximately 10 % higher than the costs in Alt 1. The calculation result includes also the benefit of avoiding the landfilling of OSA.

[10] LCA/LCC Report by Ramboll Finland OY, January 2015

4.3. LCA of Simuna-Vaiatu

In Simuna-Vaiatu pilot part of the road no 17192 was constructed with mass stabilisation. The length of the reconstructed road was 0.9 km. In total four different alternative structures were studied in the LCA. All alternatives include stabilisation in some of the techniques; mass stabilisation, layer stabilisation or complex stabilisation. The alternatives are:

- Alt 1: The bottom of the construction is mass stabilised with OSA (EF CFB) and cement and the top of the construction is layer stabilised with OSA (EF CFB)
- Alt 2: The bottom of the construction is mass stabilised with OSA and cement and the top of the construction is complex stabilised with bitumen and cement
- Alt 3: The bottom of the construction is mass stabilised with cement and the top of the construction is complex stabilised with bitumen and cement
- Alt 4: The bottom of the construction is mass exchanged from peat to natural aggregates and top of the construction is complex stabilised with bitumen and cement

The inventory results from the material production stage showed that alternatives Alt 1 and Alt 2 were quite equal within the studied impact categories. The use of natural resources was remarkably higher in Alt 4 as it is the mass exchange alternative. The global warming potential was highest in Alt 3 resulting from the use of cement (9 %) in mass stabilisation.

Alt 4 had the lowest and Alt 3 had the highest GWP. The high figures of GWP with mass stabilisation alternatives were due to the use of cement that is also used in the top layer for complex stabilisation. The results with Alt 1 and Alt 2 were equal and in the same magnitude.

The mass exchange alternative Alt 4 depleted most of natural resources. Alt 1…Alt 3 results were in the same magnitude[11].

4.4. LCC of Simuna-Vaiatu

Life-cycle costing (LCC) was based on the standard ISO-15686-5:2008. The assessment was based on the investment calculations of costs of certain product or functional unit during a life-cycle. The purpose of the life-cycle costing should be to quantify life-cycle cost (LCC) into decision making process. In this calculation the construction costs were the initial costs created during constructing. The operation costs were neglected since they are considered insignificant or identical, and they don´t therefore give variation to the calculation. The maintenance costs included repair and structural renovation costs, which were discounted into net present values. Certain assumptions needed to be made concerning the long term durability of structures, since no monitoring data was available of the long term durability or integrity assessments of structures.

For the OSAMAT project the life cycle cost analysis (LCC) was made for 1 kilometre of road constructed with mass stabilisation technology in Simuna-Vaiatu pilot. The utilisation of OSA and substitution of cement were studied. In LCC calculations no costs of use and operation, or costs of road accidents, delays or rush hour were taken into consideration.

In Simuna-Vaiatu pilot section, the pavement was equal in all alternatives what it comes to material and work costs. General assumptions (equal with Narva-Mustajõe case) were made about the materials and their transportation costs. For each structure type, the original binder mixture was used and calculated. Therefore the chosen material recipe had an impact on the material costs side of the application. In addition to material prices, the costs of constructing needed to sum up for the LCC calculations. The general constructing unit prices used in the LCC calculations include the price of material and work. The prices were between 0,79 €/m^2 and 10,46 €/m^2 depending on the work

[11] LCA/LCC Report by Ramboll Finland OY, January 2015

type. During the 40 years' time horizon, the structure will be repaired and renovated many times. There are different repair and renovation methods for different structure material solutions. In the calculation there were 3 different scenarios, where three different repair methods (REP, U-REP and Structural Renovation) were used in different intervals. The paving methods REP and U-REP are used many times for these structures. However the structural renovation will be done once during the 40 year time horizon. The time point of this renovation varies in Scenarios 1 – 3. Time point had an impact on the overall calculation. The calculation contained 3 scenarios, where the first had the shortest life-time for structural renovation and the third scenario had the longest life-time until structural renovation. In Simuna-Vaiatu case the patching starts from year 6, continuing every 10 year. The re-paving takes place beginning from year 10, continuing every 8 year. In year 26, both patching and re-paving takes place, but in the LCC analysis only re-paving was taken into account. The structural renovation starts from year 25 (Scen1). In scenario 3 the longest period taken into account is 35 years until the structural renovation is done for Alt 1. Although the complex stabilisation is considered to last 20 years before it has to be renovated, in Simuna-Vaiatu case the renovation is considered to start from year 25, as the traffic amounts in Simuna-Vaiatu are much lower than in Narva-Mustajõe. Different structure solutions and traffic loads create needs for different maintenance and renovation actions. In some cases computational damage modelling and forecasts, could be used to evaluate the renovation time periods. However, if accurate, they could only be valid for some traditional solutions. In these structures repair costs would follow repair needs derived from damage assessments and prognosis. For the time being, only empiric evaluation of the repair and maintenance costs is considered viable alternative. No generally accepted reliable models are developed for damage assessment. Normally the costs from end of life stage of the studied product/service are included in the LCC calculation. As the studied product in this case is a road, and when the use of a road stops, the road structure is usually left on place.

In scenario 3, the structural renovation time periods are done between 31-35 years after construction. In Scenario 1, the structural renovation time periods are done 25 years after the construction. The calculation used a total time horizon of 40 years. According to these results it can be seen, that the life cycle costing with Alt 1 (mass stabilisation with OSA and cement + layer stabilisation with OSA) and Alt 2 (mass stabilisation with OSA and cement + complex stabilisation) is lower. In the beginning situation cheaper material purchasing costs can be achieved due to use of alternative construction materials. It should be noted that using repaving solution means intensive and heavy costs. Also that reduction in stabilization work costs might lower the overall costs.

5. Summary

In **Narva-Mustajõe** pilot, the technical follow-up studies showed that the strength values and load bearing measurements gave good results. Bearing capacities in all the test constructions were clearly higher than the target value 260 MPa. Strength results were also very high. Laboratory tests proved that it is possible to utilise OSA (and mining waste) to construct road base courses.

The environmental tests showed that the use of OSA didn't cause any additional immediate negative impacts on the environment.

Simuna-Vaiatu mass stabilisation quality controlling consisted of XRF analysis, column penetrometer soundings and vane test. According to the field test results the stabilisation has been successful and the technical targets have been fulfilled. In Simuna-Vaiatu two oil shale ash qualities and peat mix (made of 5 different peat samples) were tested for environmental properties to give the background information. Also mixtures with peat mix and oil shale were tested. The results were compared to the limit values of the Finnish degree 403/2009 (degree of utilization of recycled materials). The solubilities of chromium, fluoride and sulphate were elevated in the binders but low on the stabilized peat samples. For reasons that need to be discussed also the solubility of nickel is low on the raw materials but yet little elevated on the stabilized peat samples. Also the environmental targets have been fulfilled.

According to LCA/LCC report one can say that OSA and the implemented methods can be environmentally and financially feasible for civil engineering purposes. The environmental follow-up procedures so far indicate that OSA has no negative effects on the environment of the pilot cases as the analyses of water and soil samples have given no harmful leaching or elevated total concentrations of harmful substances or elements.

According to the material tests done previously and LCA/LCC report, OSA can be a very interesting substitute for cement and natural aggregates. Utilising OSA is a re-use action according to European Union Waste Hierarchy, where primary action is to reduce waste and landfilling is the final alternative if re-use, recycling or energy recovery cannot be made. By utilising OSA in civil engineering applications, it is possible to reduce CO_2 emissions and thus climate change. Also the savings in the use of natural aggregates is a major issue, as already crushed rock and gravel is imported to Estonia for construction purposes.

The results achieved in the LCA/LCC studies of OSAMAT indicate, that the expected end result of the project are what was expected – utilizing OSA is feasible technically and environmentally[12].

[12] LCA/LCC Report by Ramboll Finland OY, January 2015

6. References

1. Narva-Mustajõe Pilot Report, Ramboll, January 2015
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3. OSAMAT – post-project environmental monitoring in 2014 and 2015. Final report by National Institute of Chemical Physics and Biophysics Estonia, 2015
4. Environmental Survey Results, Ramboll, January 2015
5. LCA/LCC Report by Ramboll, January 2015