Project number:	**2010-0130**
Intended for	**Eesti Energia**
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Date	31.05.2016

LIFE+ 09/ENV/227 OSAMAT
Guidelines for European Practice

Stabilization with Oil Shale Ash

SKEPAST & PUHKIM

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1. Introduction

This Guidelines for European Practice gives information and advice for the mass-stabilization of peat on weak surfaces before road construction and for layer-stabilisation with coarse materials on road base using Oil Shale Ash (OSA). This Guidelines is based on the results and experiences of the LIFE+ OSAMAT project and Finnish experiences in development regarding mass-stabilization method.

One of the objectives of OSAMAT pilot project was to demonstrate utilisation of OSA in mass-stabilization of peat on construction of Simuna-Vaiatu road section, km 3,0-4,0, located in Centre Estonia and in road layer-stabilisation on Narva-Mustjaõe road section, km 14.0-16.1, located in Eastern Estonia.

The objective of current Guidelines is to promote the use of the mass-stabilization and road layer-stabilisation methods with help of OSA. The Guidelines offers basic information on the mass-stabilization and road layer-stabilisation methods and equipment, as well as practical instructions on the issues concerning binder, geotechnical survey, engineering, construction and quality control. The Guidelines is meant to serve the needs of all the parties involved in a stabilization project, including developers, permitting authorities, experts, engineers, contractors, quality controllers, binder and equipment suppliers and researchers.

OSA is an industrial by-product of energy production from oil shale. OSA can be used in high volumes in the local construction markets, and for the wider European market OSA can become an interesting and cost-effective replacement of cement and other expensive commercial additives.

2. Guidelines for mass-stabilization method using OSA

2.1. Principle of the mass-stabilization method

Mass-stabilization is a method to stabilise soft soils by adding binders in order to reduce settlements and/or to improve the stability. The most commonly used binders include cement, lime or a mixture of both. Additionally, other substances can be added as a binder component. For instance, these include furnace slag powder, fly ash or gypsum.

The main purposes of mass-stabilization are:

1) To increase the strength of the soft soil in order to:
   - increase the stability of an embankment;
   - increase the bearing capacity;
   - reduce the active loads on retaining walls;
   - prevent liquefaction.

2) To improve the deformation properties of the soft soil in order to (static loads) reduce the settlements in order to:
   - reduce the time for settlements;
   - reduce the horizontal displacements.

3) To increase dynamic stiffness of the soft soil in order to:
   - reduce the vibrations to the surroundings;
   - improve the dynamic performance.

4) To remediate contaminated ground (soil) by:
   - creating an environmental barrier (solidification);
   - stabilization of the contaminated ground;
   - creating a geohydrology barrier.

The most commonly observed advantages of mass-stabilization as compared to other foundation engineering methods are:

- Mass-stabilization allows for avoiding soft soils replacement resulting in reduced transportation and landfilling needs.
- Mass replacement requires considerably more natural aggregates than mass-stabilization and produces more spoil that overburdens landfill capacity.
- Mass-stabilization provides an economically feasible alternative to mass replacement.
- Mass-stabilization is more risk-free to surrounding structures than mass replacement. It is also often technically a more reliable solution than mass replacement.

2.2. Design of mass-stabilisation

2.2.1. Mass-stabilisation binders

OSA is a fine grained residue from a combustion process of oil shale. Composition of OSA varies depending on burning process of oil shale. OSA is collected from flue gases in some type of filter.

The choice of a binder or a binder mixture depends on soil properties. The optimization of binder quality and quantity is completed in advance in the laboratory.

When the ashes are used alone, the compressive strength is poorer than when used together with cement.

As the results of LIFE+OSAMAT project the different type of OSA and cement listed in Table 2-1 can be used in mass-stabilisation.

Table 2-1 Qualities of binder material

Acronym	Name
OSA EF PF	Oil shale ash, bag filter, Pulverized Firing
OSA EF CFB	Oil shale ash, electric filter, 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)

As the results of stabilization tests of LIFE+OSAMAT project showed that both filter ashes (EF PF and EF CFB) and CYCL have potential for mass-stabilization. The Normal Cement gave better results than Composite Cement with the second part of the mass-stabilization studies, but the results with Composite Cement were also fulfilling the criteria for using it in stabilization works.

Based on LIFE+OSAMAT project experiences the following binder material ratios for mass-stabilization works are proposed:

- CYCL 200 kg/m3, Composite Cement 60 kg/m3;
- EF PF 190 kg/m3, Composite Cement 90 kg/m3;
- EF CFB 200 kg/m3, Composite Cement 80 kg/m3.

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-stabilization equipment should be done beforehand, for example during the laboratory testing period.

2.2.2. Preliminary investigations and tests

The aim of the mass-stabilization tests is to find out how the potential binders components, as well as their ratio and amount in the binder mixture affect the following aspects of the stabilization process:

- compression strength to be reached;
- necessary hardening time;
- compression occurring during hardening time;
- susceptibility to changes of the hardening process due to alterations in the properties of the stabilized material, i.e., the impact of changes in water content.

Successful and cost effective application of mass-stabilization requires a combination of laboratory and field tests in order to assess the engineering and environmental properties. The most important results from the laboratory tests are enhanced knowledge of suitable types and amounts of binders.

In the first stage of the project laboratory testing including mixing soil and binder and testing the stabilized soil in the laboratory should be performed to judge the effects of mass-stabilization for the actual soil(s).

In the second step the engineering and environmental properties are determined in situ which is done by installing and testing an appropriate number of trial pads of mass-stabilization.

Based on these test results the type of binder, amount of binder, installation method etc. and the design values for the final engineering are chosen.

The following in-situ tests are executed:

- Cone Penetration Tests (CPT with pore pressure measurement) and boreholes are executed for determination of the geotechnical profile and taking samples for laboratory testing to identify and describe characteristic soil layers. For the CPT a minimum of 3 tests with a maximum distance of 40 meter is required. In general, extra CPT's and drillings are recommended. Pore pressure measurements are necessary to determine the hydrological situation. In the Eurocode 7 part 3, a general description of these techniques is given.
- CPT test results or vane tests are used for determination of the in-situ undrained shear strength. The undrained shear strength will be needed for a stability analysis. The tests are minimally performed each 50 metres.
- The level of the ground surface should be measured relative to a reference coordinate system.

The laboratory tests can be divided in tests for classification, engineering properties, chemical properties and environmental properties.

1) The classification tests are performed to obtain knowledge on the type and consistency of the subsoil and to assess of the suitability of the soil layers for mass-stabilization. The tests should be performed for each individual soil layer. In these tests the following parameters are determined:
    - liquid limit;
    - plastic limit;
    - plasticity index;
    - organic content;
    - water content;
    - density;
    - sensitivity;
    - Von Post (for peat classification);
    - grain size distribution;
    - clay content.
2) The most important engineering properties are the undrained shear strength, the compressibility and the permeability.
    - The shear strength properties are determined by e.g. unconfined compression tests, triaxle tests or the fall-cone test. In case of a high organic material the undrained shear strength is rather high. Another method is to use the CPT-results. A good estimation is that the undrained shear strength is 5 - 10% (depending on the type of soil) of the cone resistance of a particular soil layer. In case of soils with high organic content this method is recommended. The determination of the undrained shear strength for example gives an idea of the suitableness of stabilising the soil.
    - The deformation properties compressibility and permeability are determined using odometer tests (incremental loading or Constant Rate of Strain). The tests should be executed with loading, unloading and reloading stress paths.
    - The permeability can be determined using falling head tests, constant head tests or odometer tests (incremental loading or CRS). The permeability can be determined in situ by performing the same type of tests or a rising head test in a standpipe. In this test the water in a standpipe is lowered. An estimation of the permeability can be made using the time needed for the groundwater to fill the standpipe again.

    The engineering properties of the original soil are used in the design. They can also be used as a reference for the results of the stabilized soil. This gives the engineer an impression of the improvement of the soil.

    For the determination of a representative set of engineering properties, tests should be performed in each individual soil layer.

3) The chemical properties should be established to give empirical guidelines and to support the choice of the amount and type of binder. The following parameters are determined:
   - sulphate content
   - chloride content
   - carbonate content
   - humid acids/TOC
   - cation exchange capacity (according to ISO 13536 or 11260)
   - pH of the groundwater

   These tests are also described in the Eurocode.

4) To determine the environmental impact of the stabilization, tests should be carried out. The environmental properties are:
   - pH (according to ISO 10390)
   - cation exchange capacity (according to ISO 13536 or 11260)
   - sulphide content
   - carbonate content
   - type and total concentration of ion and metals. These tests are used as a reference measurement.
   - available concentration of ion and metals from leaching tests.

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

Total concentrations of the elements are determined for the OSA samples according to the standards ISO 17294-2, EPA 3051A, SFS-EN ISO 15587-1. Samples are digested with microwave assisted extraction (*aqua regia*) and the elements are analysed by inductively coupled plasma mass spectrometry (ICP-MS);

Leaching tests are 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 is 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 Aerometer 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' stabilization.

2.2.3. Properties of stabilized soft soils

As a result of stabilization, the chemical and physical properties of clay, mud and peat will significantly change. The pH-value of the stabilized soil will quickly rise up to 11 – 12 and the curing will start. Depending on the type of binder some of the chemical reactions will take place relatively quickly (during the first month) but some of the reactions may develop more slowly; and may take months or even years.

The strength of the stabilized soil depends on the type and quantity of binder as well as the properties of the natural soil. Additionally, the homogeneity of the mixing clearly affects the resulting strength. However, the undrained shear strength of stabilized soil is normally within the range of 50 – 150 kPa.

The relation between the curing time and the strength of the stabilized soil is important since it governs the acceptable rate of loading. This relation depends on the soil type and the type of binder. However, when using only cement most of the strength develops during the first month after stabilization. When using OSA the strength will still continue increasing after the first month.

2.3. Mass-stabilisation operation

2.3.1. General principle

The general principle of the mass-stabilization method is presented in Figure 2-1. With the current equipment, the attachment of a mixing unit to an excavator allows for carrying out stabilization to the depth of 7-8 meters, providing the conditions are favourable. A pressure feeder injects the binding agent (one or two binders, or a binder mixture) through the hose directly to the mixing drums of the mixing unit. The rotating drums mix the binding agent into the ground and simultaneously homogenize the soil. Mixing is executed by moving the mixer unit vertically from the surface to the desired depth, as well as laterally.

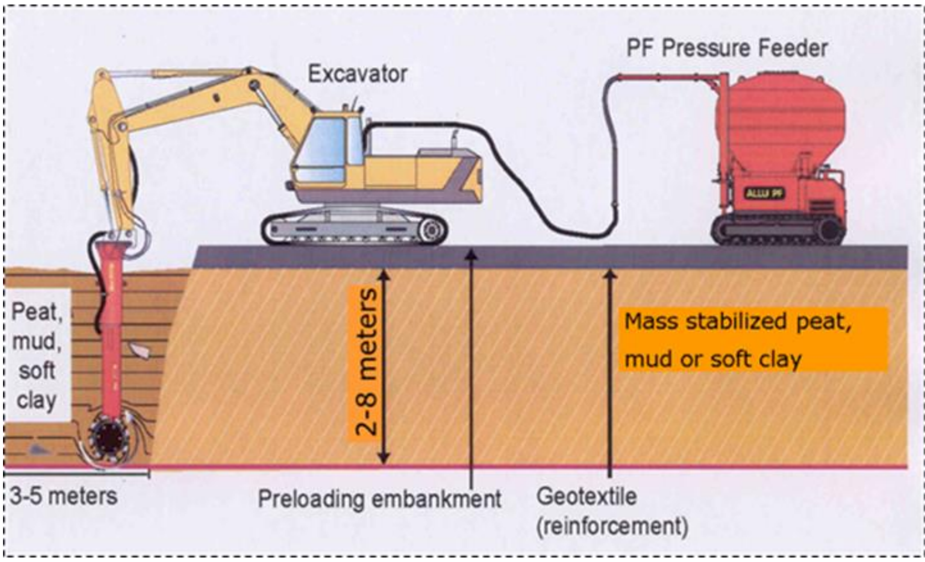

Figure 2-1 Principle of the mass-stabilization method and equipment [2]

The work area is commonly divided into segments, or areas, of equal size depending on the site geometry. Typically, work proceeds from segments to segments, with the size of a segment between three and five square meters. A working platform is constructed after completion of a segment or segments to enable the excavator to move on into the site. The working platform also serves as a primary compaction embankment. After stabilization work is complete, a preloading embankment is also constructed at the location under which final strength development takes place. Particularly in areas containing peat and organics, the preloading embankment is indispensable to ensure the consolidation of the stabilized material during the strengthening process (cf. curing of cement). The target strength of the mass-stabilization is usually achieved over a period of 1…3 months.

2.3.2. Mass-stabilisation equipment

The basic unit of mass-stabilization machinery is an excavator onto which a separate mixing unit and a pressure feeder are attached. The binder is supplied from a unit which composes of the binder silos, compressor, air drier and supply control unit.

Depending on the type of mass to be treated, different types of mixing heads can be applied for stabilization work (Figure 2-2). The mixing unit should be able to process at least two different dry binders.

Figure 2-2 Mixing drums of the mixing unit used in mass-stabilization [2]

Feeding of the binder and the mixing process are controlled with the control unit that allows for adjusting, for instance, the amount of air and the binder flow. These issues have an impact on feeding pressure. It is also possible to adjust the speed of rotating drums. The aim is to feed dry binder into the mass as evenly as possible.

It is also possible to use a separate controlling unit that continuously gathers data.

Mass-stabilization equipment currently in use allows for achieving the maximum depth of 7…8 meters in favourable circumstances, but the maximum depth achievable always depends on working conditions and on the quality of stabilized soil. When deeper mass-stabilization is required, it is possible to use column stabilization equipment and make columns intersect each other. The optimal result is achieved for the layer stabilized to the depth of approximately 3…5 meters. However, thinner layers can also be mass stabilized.

The efficiency of stabilization is affected by such factors as the amount of binder, the quality of aggregate soil and the fact whether there is a need for pre-homogenization or pre-mixing in the site before the start of actual mass-stabilization works. Also, the air temperature, especially in winter has an impact on the stabilization capacity.

A few examples of approximate efficiency levels observed for some typical aggregate types are presented below. The data was gathered in typical conditions. In general, it has been observed that depending on the case and due to some exceptional conditions, there might occur considerable variations in efficiency:

- peat stabilization approx. 100…150 m^3/h;
- clay stabilization approx. 80…100 m^3/h;
- mass-stabilization if dredged masses approx. 100…200 m^3/h;
- firm clay or silt stabilization approx. 50…80 m^3/h.

It is imperative that binders fed with the hose of the mixing unit are fine grained and dry in order to allow for their pneumatic transportation with compressed air.

2.3.3. OSA storage, transportation

The quality control of OSA includes the monitoring of water content of OSA. Also the condensation and clumping of OSA are monitored. It is essential that the stored OSA is homogeneous and usable and the desired properties and quality are in advance determined.

Binder storing in the site requires special preparations. Binder agents need to be dry and powder, to be used by pressure feeder. Most commonly, binder is transported in cement tracks.

2.3.4. Mass-stabilisation operation

Prior to the start of the actual stabilization work, trial stabilization may be executed. It allows to test whether the designed strength can be achieved with the planned amount of binder.

Preliminary work includes the removal of the old road layers and top soil to the sides of the road, identification and marking the location of pipelines, cables, culverts and other structures on the ground.
Stones, tree trunks, stumps and other obstructions in the ground belong to the factors slowing the process of stabilization and they can be harrowed from the area to be stabilized before the start of the actual stabilization work.

The road is divided in to stabilization segments. The size of the stabilization segment is commonly about 5 × 5 m^2. Many variables affect the size of the segments. Such variables are the moisture content and strength of stabilized soil, the radius of the stabilization equipment and the final width of the stabilized site.

The ground on which the stabilization 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-stabilization equipment, geotextile, pre-loading embankment and stabilized soil are represented on the Figure 3-1.

The mixing agent is mixed uniformly with the soil down to the prescribed depth 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 mixing agent is pumped out into and mixed with the soil continuously monitoring shall be carried out automatically for following parameters and typical values:

- binder output, kg/m3 — 100-400 kg/m3
- 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

When stabilization segment is used as the basic unit, the amount of binder to be fed is calculated for each segment separately. Generally, the amount of binder fed must not deviate from the designed value more than 5%. If necessary, samples can be collected and binder amount can be checked with content measurement tests. Binder should be fed to the planned depth which is marked on the design drawings. Binder mixing efficiency surveillance is part of the overall quality control. The efficiency of mixing work can be also monitored with various 3D-system units if the stabilization machinery is equipped with such.

Special attention should be paid to OSA processing through the tubes that are connected between binder tanks and work equipment. OSA particles may choke the tube and block binder material to run smoothly through it. There are no similar problems with cement material but different ashes behave differently.

Based on the opinions of different experts it can be said that important OSA characteristics for proper mass-stabilization process are:

- **Unit weight**: the lower the better. Cement unit weight is lower than any other OSA unit weight 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-stabilization process.

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 stabilized surface. Compaction is made with a heavy roller.

It is particularly important to construct a compaction embankment during the same working shift in stabilization of peat. It can function as the lowest component of the structure or the embankment fill, in which case the choice of a suitable material depends on the type of structures to be constructed afterwards.

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.

In some cases, there is a need to drain the mass-stabilized area by pumping or by constructing ditches. Water flowing away from the mass stabilized area needs to be monitored visually or, if necessary, by sampling, in order to ensure that no harmful substances are released to the environment. In some cases, it is also possible to construct a settling basin to collect and then to remove water from the area. In other cases, it may be required that water is added to the stabilized mass in order to ensure a successful stabilization process allowing to reach a target strength. Water addition is applied to such soils as, for instance, dry silts.

It is typical to mix successive soil layers with each other during the mass-stabilization process. For example, an upper peat layer is mixed with the lower layer of clay, silt or sand (or with the upper part of this layer) so that mineral soil is added to peat thus improving its stabilization properties. For this reason, while preparing aggregate sample for the needs of stabilization tests it is reasonable to mix soils from the overlapping layers. It is also possible to improve the stabilization properties of peat or mud by spreading sand or stone dust on top of the stabilized layer and mixing it with the stabilized soil material.

Heavy equipment movements in the stabilized area immediately after stabilization should be avoided. Embankments can be constructed to the full height only when the planned strength is achieved. Excavation works are also not allowed to be carried out in the stabilized area and its immediate vicinity before the strength has become adequate.

Stabilization can be carried out in winter conditions but very severe frost slows down the process. If the ground is frozen, it might be necessary to use a drop-hammer to enable excavation works. This will, however, reduce work efficiency.

Air temperature can affect strengthening process occurring in the stabilized structure. OSA belongs to slow binders with curing reactions persisting for a long time after mixing. On the contrary, cement is a hydraulic binder that hardens faster. In mass-stabilization, it is common to apply mixtures of cement and OSA.

A report of stabilization work progress for each segments is compiled and it includes the following information:

- Identification number and location of the stabilization area;
- Identification number and location of the stabilization segment;
- Coordinates of the stabilization segments (x,y,z);

- Stabilization segments area; bottom and top surface level; depth of the stabilization segment;
- Amount of binder fed (kg/soil-m^3);
- Binder quality (e.g. OSA, cement type used);
- Amount and quality of binder-consignment;
- Potential problems with binder feeding and other observations.
- Date of stabilization work implementation;
- Weather conditions during stabilization work.

2.4. Quality assurance

The quality control tests carried out in the field during stabilisation work and for the completed structure include soundings, test pits, settlement plates and, if necessary, sampling.

- Niton test, the XRF (X-ray fluorescence) analysis are used to measure the binder contents of the stabilized soil during the stabilization process;
- In order to acquire the results for the quality control soundings column penetrometer soundings are conducted to measure indirectly the shear strength of mass-stabilization;
- Settlement plates are installed on the stabilized area, which are used to measure the settlement of the stabilized structure.

The most common methods of sounding include column and vane penetrometer tests. Soundings are conducted on uncovered surface of the mass-stabilized layer. Depending on the target, they are usually conducted 7…90 days after stabilization. Tests carried out after 7…14 days are only tentative, whereas test carried out between days 28-90 give some approximate information on the final result quality. Depending on binder type, the final strength can be achieved only after longer period of time. Therefore if needed, part of the quality control soundings can be conducted in 6…12 months after the completion of stabilization work.

The test results obtained with vane penetrometer are used for calibrating column penetrometer bearing ratio. Depending on the length of the columns or depth of mass stabilized soil and the desired measurement density, vane penetrometer test is carried out at intervals of 0.5 or 1.0 meter. It is customary for vane penetrometer tests to be conducted much less frequently than normal penetrometer tests.

Also the CPTU test method is employed for the needs of quality control investigations. Its application depends on the type of soil to be tested and the desired strength.

Since the cross-sectional area of a typical cone tip is small, the results of one test are not representative enough. Thus, it is advisable to conduct more CPTU tests in comparison to, e.g., column penetrometer tests, and not to replace column and vane penetrometer tests with this method only.

Test pits allow for visual evaluation and documenting the quality and homogeneity of mass stabilized soil. Also samples can be collected in test pits in order to determine pH and water content of the stabilized mass. In addition, test pits enable collecting samples for determination of strength and conducting penetrometer, miniature vane shear, and/or Niton tests.

Settlement plates are employed to measure the settlement of stabilized mass. Settlement plates allow also for some rough estimations of lateral displacements but the measurement accuracy is only indicative. The settlement plates are installed on the top of the stabilized structure.

The quality control investigations carried out in the laboratory include compression strength tests, determination of the level of homogenization with the analysis of binder amount, determination of water content, pH tests, and for contaminated soils, also leaching tests.

2.5. Environmental monitoring and follow-up program

Environmental monitoring program included analyses of water, soil and flora. Overall purpose of the monitoring is to understand if utilization of binder in mass-stabilization process has an impact on the surrounding environment.

First monitoring (environmental quality control) is carried out before the stabilization works in order to obtain background values. These values are used for the comparison with the results acquired during follow-up monitoring. Follow up is carried out after the construction activities.

3. Guidelines for road base layer-stabilisation method using OSA

3.1. Design of road base layer-stabilisation method using OSA

The design, construction and quality control of road base constructed with oil shale mining waste based aggregates and stabilised with OSA have the similar procedures and requirements as in cement stabilisation of road base described in Guidelines for construction of stabilised pavement layers [7] except the properties and features related to OSA described in the following paragraphs.

As the properties of OSA 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.

The design value for the required load-bearing capacity is determined from the traffic volumes according to the current regulations.

3.1.1. Binder selection

The laboratory tests are executed to assess the feasibility and identify the properties and content of OSA and aggregates to prepare the mix recipes for the road base layer-stabilisation.

The feasibility in stabilisation is tested with unconfined compressive strength and freeze-thaw weathering tests on stabilised mining waste based aggregates and gravel samples. All materials are also tested with geotechnical index tests (loss on ignition, initial water content, pH and particle size distribution and compaction parameters).

In approach to find an adequate binding agent composition, while the overall yielded unconfined compressive strength (UCS) is regarded important, the main emphasis is put on the difference between the 28 day UCS result and the corresponding 28 day UCS test result after the freeze-thaw weathering test (FT).

According to layer-stabilisation pilot project LIFE+ OSAMAT results the OSA EF CFB ash worked better than the other ashes. Using 9% of it without any cement addition yielded good results. OSA EF PF and OSA CYCL need addition of cement to withstand the freeze-thaw cycles.

The producer of OSA has adequate facilities to separate and store different OSA types.

According to the regulation, recommended content of road cement or Portland cement in cement stabilisation is at 2-3%. Despite currently there are no valid regulations for ash-stabilisation, former regulations specified ash content of 4-5% in stabilized material. In wider scale, it can be considered that ash as binder is twice weaker than cement to achieve comparable results.

3.1.2. Aggregate layer for stabilisation

The aggregate layer for stabilisation can be designed to be constructed with limestone aggregate or oil shale mining waste aggregate (MWA) and/or adding milled asphalt concrete (MAC). The properties and grain size distribution of aggregate for stabilisation layer shall meet current regulations for cement based stabilisations.

The soft aggregate will be milled to finer grain size, the binder can influence more effectively. In addition, it has to be noted that the amount of binding agents used is higher than in typical cement based stabilisations, which will move the overall grain size distribution a little bit more to the finer particle side. So the grain size curve of aggregate is not easily possible to determine after stabilisation mixing.

The aggregate layer are constructed so that the MWA is spread first onto the milled surface of the stabilised ash layer and MAC above the MWA layer. The whole layer are compacted for traffic usage before the stabilisation works.

3.2. Construction of road base layer-stabilisation method using OSA

Construction of test strip prior to the actual construction of the layer-stabilisation base course section with OSA is recommended in order to evaluate the adequacy of designed stabilisation mixture and compaction equipment to be used in job.

Spreading of the binding agents

The binding agents can be spread with wet or dry methods. In the wet method, the binding agents are mixed and wetted with off-site mixing facilities and transported to the construction site in ready-to-use form. The wet binding agent mixture is spread with an asphalt paver.

According to the experience of LIFE+OSAMAT the dry binding agent mixing method worked a lot better than its wet counterpart. Dry method always induces some dust formations, which should be taken into account if the work is performed close to housing or settlements that might be affected by the high pH dust. One solution is that mixing equipment feeds binder during mixing the layers.

In the dry method tractor-pulled cement spreading device is used (Photo 3-1).

Photo 3-1 Tractor-pulled cement spreading device

Binding agents can be spread, mixed and compacted either all at once or in two phases. The dry binding agents are spread and mixed in two phases. Cement are spread first and mixed into the aggregate layer without any added water. The surface of the road is quickly graded after the first round of mixing. After that, OSA is spread and mixed into the road with added water. All binding agents are mixed in advance determined depth and finally compacted with vibratory roller according to the required compaction rate. The compaction have to be performed after mixing as fast as possible in the same shift. Subsequent compaction of stabilised layer with roller is not allowed.

During layer-stabilisation works the optimum water content is determined, that is important factor to achieve required quality end results. Special attention have to be paid to the water content of mixture.

Stabilisation mixing

Stabilisation mixing is performed using a rotary mixer with water adding feature. The mixing is done either all at once or in two phases – first phase after spreading of cement and second phase after spreading of OSA. Water is added during the second phase to prevent the cement reacting too quickly.

Surface grading

The surface of the mixed layer is graded quickly after the second phase of mixing with a road grader.

It is recommended to cover the stabilised layer with bitumen emulsion right after the compaction. Bitumen emulsion protects stabilisation layer against drying and provides tack coat for pavement layer.

Compaction

Immediately after grading the layer is compacted with a vibrating roller with at least six compaction rounds. The first round of compaction is done without vibration and the rounds after that with vibration. Compaction and measurement of load-bearing capacity is followed with Inspector during the construction works. The results of the measurements are recorded.

It has been experienced that typically, the actual roller compaction is easier in OSA based stabilisations when the water content is at least or a little bit above the optimum content, which is also recommendable since the hardening reactions start rapidly consuming water. The mixture of aggregate, binding agents and water transformed its state to more elastic when water content is just slightly above the optimum, and while it is compacted well, it is not possible move on top of it with anything with smaller tire print than the roller without making any ruts.

3.3. Quality control and follow-up

To achieve desired results of layer-stabilisation with OSA the effective quality control have to be performed in all steps of layer-stabilisation process including quality control of OSA producer, storage, stabilisation works and follow-up activities.

Quality control of OSA producer

The quality control includes monitoring of essential process data, testing and monitoring of OSA technical properties and environmental aspects.

It is proposed to determine the following main technical properties of OSA:

1) Main properties:
   - Grain size;
   - The loss on ignition;
   - Water content of storaged OSA;
   - Optimum water content;
   - Maximum dry bulk density;
   - Water permeability;
   - Capillarity;
   - Thermal conductivity;

2) Strengthening properties:
   - Compressive strength;
   - Freeze-thaw resistance;
   - Suitability for stabilization.

Based on the main properties the feasibility and application of OSA are determined.

The quality control of storage and handling of OSA

The quality control of OSA includes the monitoring of water content of OSA. Also the condensation and clumping of OSA are monitored. It is essential that the stored OSA is homogeneous and usable and the desired properties and quality are in advance determined.

In spreading and mixing of OSA the water content, homogeneity and mixture ratio are inspected and controlled. In initial tests water content and maximum dry bulk density are determined with Proctor test. The Proctor test is renewed in mixing progress if the quality of used material might have been changed.

Quality control of stabilisation works

During the layer-stabilisation works the following measurement and tests are performed:

- Geometry - the depth, width and cross fall of the stabilisation layer.
- Niton test with field test equipment (Portable XRF Analyzer) for the assessment of the amount of binder by measuring calcium content in the stabilized mass and by comparing the obtained results with the "calibrated results" prepared for the aggregate and binding agent.
- Proctor compaction test for the determination of maximum dry density and optimal water content.
- Bearing capacity with Inspector-device and Falling Weight Deflectometer (FWD).
- Compressive strength.
- Freeze-thaw durability.

It is important that the OSA tested in laboratory and OSA, used in stabilisation process on site, should have same age and storage conditions, because the CaO content is changing in time through contact with water vapour (reaction, CaO+H2=Ca(OH)2).

Water content

Water content is measured on construction site using microwave oven. It would be also possible use normal drying oven, but that microwave works faster. The measurement tolerance has to be tested before in laboratory. The differences in water contents and dry densities have an effect on the strength results. Usage of microwave oven for measurement of water content is simple and usually very accurate, but it isn't completely adequate for construction as each measurement takes 10–20 minutes and the water addition through the rotary mixer required constant control.

Bearing capacity

FWD is proposed to use for measurement of bearing capacity of the stabilisation layer. The "light weight Loadman" (Inspector-device) doesn't work well with coarse materials. Also Troxler is not suitable for measurements of compaction degree or moisture content because in Finland it has been tested many times for fly ash stabilisation. Troxler device doesn't work with OSA and milled asphalt concrete. The heavy metals of ash or the hydrogen of asphalt may disturb the measurements.

Compressive strength and freeze-thaw durability

The samples of stabilisation layer are tested in the laboratory. The unconfined compression, density and freeze-thaw durability tests are performed.

According to the results of pilot project, the structure shows adequate strength after one month, and the strengthening is not too fast.

There is no official target value for UCS or UCS (freeze-thaw) tests for road construction. Based on previous experience it can be said that UCS-values over 1 MPa are good and over 3 MPa very good. UCS values should not exceed 12 MPa, to reduce risk of transverse cracking from shrinking of layer.

Technical follow-up

The technical survey of the layer stabilisation and mining waste structures includes:

- Technical testing of drilled samples - 28 days and 90 days UCS.
- Load bearing rate measurements after one year of construction.
- Paving quality measurements.
- Defect counting analysis and IRI measurements.

It is possible that drilling is so hard action that it breaks the samples during sampling.

It is typical for stabilized structures that there may be narrow cracks. They are caused by shrinking of the stabilized layer, very typical for stabilisation of coarse materials with hydraulic binders. Typically they are transverse-type cracks. Such cracks are often formed immediately within hardening process of material and generally not growing further. There may be also some longitudinal cracks, usually caused by frost. The joint crack is in the asphalt joint.

It is assumed that the main and most important reason of cracks is shrinking effect of the monolith body, which formed after stabilisation. Big amount of binder material is used in stabilized layer and this created very hard monolith. Reasons for shrinking is impact of cold weather and water/moisture leaving the material. Expanding material does not induce reflecting cracks but only uneven surface (higher IRI/unevenness rate).

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