Tallinn – Tartu
Soft soil stabilization possibilities in road construction

REPORT
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1 Backgrounds and purposes

Background

Replacement of soils is a potential environmental challenge. High quality soils for infrastructure constructions are needed in larger quantities. More often these particular soils are needed to excavate and transport to construction sites from longer distances every year. This is raising the overall costs of these infra projects.

On the other hand, high volume of lower quality soils are excavated from the same infrastructure projects described above. Furthermore it is difficult to find places for dumping the soils, because of EU-landfill regulations etc.

There is a need to investigate alternative cost effective soil treatment options and furthermore where the environmental impacts are minimized.

Mass Stabilisation

Mass stabilisation is a relatively new ground improvement method, especially with reference to soft soils (like mud, clay and peat) or contaminated soils. The main principle is to mix an appropriate amount of dry or wet binder throughout the volume of the soil layer. In mass stabilisation the upper part of soil is mixed horizontally as well as vertically. Mass stabilisation can be used for surface or deep stabilisation.

Mass stabilisation as a in-situ and on-site process is an advanced technique primarily used for reduction of settlements and for improvement of stability mainly in infrastructure projects like roads and railways on soft ground. It is also used for foundation of smaller buildings and bridges, and for stabilisation of excavations, lagoons and natural slopes. In general, the method is found technically, economically and environmentally favourable in comparison with other alternatives.

Binder selection

Each project site has unique soil conditions and functional requirements. Therefore careful investigation and planning are always required before stabilisation. During treatability studies an appropriate binder system is selected for a specific site and contaminants. The selection is based on a set of design criteria in terms of specified properties or parameters and their target values. The design criteria usually depend on the required properties of the end products taking on account the nature of the material and contaminants to be treated. Commonly used design criteria include: unconfined compressive strength or shearing strength, leach-ability of contaminants based on an appropriate leaching test, water permeability, and freeze-thaw and wet-dry durability.

Cement is one of the frequently employed binders for different stabilisation purposes. Additives like pulverised fuel ash or fly ash and ground granulated blast-furnace slag are used as partial replacement materials for cement. There exist several thumb rules to guide the choice of binder, cement or its admixture with some additive having high mineral content for different projects.
Goal of the study

Overall goal of the study was to minimise the costs and negative environmental impact. Specific goal of the study was getting the overview of soil stabilisation possibilities, potential costs and environmental impacts of soil stabilisation alongside the new TALLINN-TARTU-VÕRU-LUHAMAA ROAD alignment in Kose-Mäo section.

Material studies have been done in the Ramboll Finland Ltd geotechnical and environmental laboratory in Luopioinen. Laboratory personnel are highly qualified and experienced with various industrial by-product and waste utilization especially in different soil and structure constructions (over 250 different industrial by-product materials have been tested in the laboratory). Furthermore, the research equipments are highly appropriate for the investigation. The laboratory has many international references, especially on peat, clay and silt material stabilization projects.

In the material studies, the local materials and possibility to stabilize local materials is the first priority. This approach enables especially cost efficiency of the project particularly when moving into execution stage of the structures.

2 Research methods

2.1 Basic laboratory studies

In the first stage of testing, the basic and chemical testing of soft soils were carried out with following studies:

- water content (\(w\%)\)
- organics content (\(Hh\%)\)
- \(pH\)
- conductivity
- redox potential
- \(SO_4^{2-}\)
- \(Cl^-\)

In the first stage of testing, the basic and chemical testing of ashes (potential binders) was carried out with following studies:

- granularities of ashes
- Selenium (Se)
- Arsenic (As)
- Mercury (Hg)
- Antimony (Sb)
- Cadmium (Cd)
- Barium (Ba)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Molybdenum (Mo)
- Nickel (Ni)
- Zinc (Zn)
- Vanadium (V)
- PAH
Basic and chemical testing analysis were determined to program geotechnical and environmental testing.

In the first and second stage of testing the various binders and binder dosages were tested. Binder dosages are usually tested with 100 ... 250 kg binder per treated m$^3$ of test soil. Binders are mixed to test soil and special test pieces are made in the geotechnical laboratory. The analyzed characters of stabilised specimens during the study were:

- compression strength (kPa)
- curing time effect on test pieces
- freeze and thaw effect on compression strength (kPa)
- frost heaving
- water permeability
- environmental acceptance

Each binder type were tested itself and alongside with mixtures to other binder types.

Alongside with technical testing the most potential alternatives are tested in order to examine the harmful substance leach-ability of the mass stabilized material. In the leaching testing the column or diffusion tests were used.

### 2.2 Repairing of specimens and stabilisation

The soil samples were homogenised before laboratory tests (figure 1).

![Figure 1. The peat samples before and after homogenisation.](image)

The specimens were packed in the specimen tubes (diameter 68 mm and high about 190 mm). The specimens were placed immediately in the preloading bank (figure 2). The load over the specimens was $\approx 18$ kPa during the consolidation time of the specimens. The peat specimens are kept in room temperature (about +20 degrees) and the bottom of the specimens are in the water (water depth is about 3...4 cm) during the period of stabilisation. It is monitoring the compressibility (vertically, accuracy about 0,5 mm) during the period of stabilisation (results are joined as annexes 5 and 8).
2.3 Unconfined Compression Strength tests

Unconfined Compression 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 there does not occur any noticeable failure, the maximum value of the compression strength is taken when the deformation (change of height) is 10 %. Usually, the test will be made on test pieces after at least 28-30 days stabilisation. Figure 3 below shows the test in progress. The stress-strain curves are joined as annexes 7 and 10.
2.4 Additional tests

Freeze-thaw durability test will determine the material’s resistance to freezing and thawing cycles. Freeze-thaw tests are made according to a suggested test method of the Technical Research Centre of Finland (VTT: "Tien rakenneroreksissa käytettävän hydraulisesti sidotun materiaalin pakkas-sulamiskestävyyyskokeen suoritus"): The test piece that has been stabilised for 28 days will be placed in a container on a capillary carpet. Water will be absorbed by the test piece through this capillary carpet. After 4 hours the test piece will be placed in a freezer, the temperature of which will be decreased from room temperature to freezing (-18 °C). The test piece will remain at this temperature for 8 – 16 hours. The test piece will then be rotated by 180° and placed on the capillary carpet for thawing, after which the former stages will be repeated. These cycles will be repeated 12 times. The condition of the test piece will be controlled at all times during the test. After the test is completed, the strength (UCS) of the test piece will be determined.

Frost susceptibility test will determine the material’s resistance to frost. A test piece will be compacted in a plastic cylinder and the test will start after 28 days stabilisation, and after the test piece has been saturated with water. The frost susceptibility will be tested with special test equipment that allows the upper side of the test piece to become frozen (-3°C) and the under side to remain thawed (+1°C) and absorb water on a capillary carpet. At the start, during water saturation, the load on the test piece is around 20 kPa. The load on the test piece can be varied during the test, but normally it is around 3 kPa. The frost susceptibility will be determined by measuring the settlements or frost heave of the test piece over a certain time period. Segregation potential, SPo [mm²/h], can be calculated on the basis of the frost heave. The bigger the value of SPo, the more susceptible to frost is the material. After the test, the frost susceptibility can additionally be assessed by visual assessing the condition (eg. softening and lenses) and by determining the strength (UCS) of the test piece after the frost susceptibility test.
**Soft wall permeability test with constant pressure** is carried out according to the recommendations of the Environment Centre of Finland. A test piece inside a rubber membrane will be subject to a 3-dimensional pressure in a test cell. Water will be conducted through the test piece from a front container to a back container, and the water level differences of the containers will be measured. Water flows upward inside the test piece when there is higher pressure in the front water container than in the back container. The simple formula to calculate the water permeability factor is as follows:

\[
k = \frac{Q \cdot L}{A \cdot t \cdot H},
\]

where \( k \) = water permeability \([\text{m/s}]\); \( Q \) = quantity of water seeping through a test piece \([\text{m}^3]\); \( L \) = height of the test piece \([\text{m}]\); \( A \) = area of the cross-section of the test piece \([\text{m}^2]\); \( t \) = time \([\text{s}]\); \( H \) = height of the water level \([\text{m}]\).

![3-axial water permeability test equipment.](image)

3. Samples of soft soils and ashes

3.1 Definition of potential soils for stabilization testing

Sample locations are based on geotechnical report made by IPT, entitled as “Tallinn-Taru Maantee Anna Ümersõit”. According to above mentioned report there are several potential locations in where stabilisation of soft soils is possible. The four (4) major sampling sites were identified (PA4, PA1, PA3 and PA5; other sites were PA2, PA6 and PA7).

For study the potential areas for soil stabilization, there is need to take relatively large amount of samples. In the preliminary stabilisation study it is suggested following sample taking program:

- 5…7 major sampling sites from peat and clay areas and
- 20 …25 minor soil samples from peat, clay and other areas

For stabilisation testing, the samples should be as representative as possible. Major samples will be taken be excavator and minor samples with drilling machinery. Sample
size should be 50 l in each examined layer of soil to be tested. Sample size from minor samples will be depended on the machinery to be used in sample taking.

Figure 6. Larger sample from point PA4.

Figure 7. Smaller sample from point PA4a.

Figure 8. Smaller samples from point PA4b (left), point PA4c (right) and point PA4d (below).

The results of basic and chemical testing of soft soils are presented in annexes 1…2.
3.2 Definition of soil stabilizers/ binders

In the mass stabilization, the aim is to utilize as much as possible the local materials as binders, especially ash products. In the binder mixtures also the use of cement and possible other additive components (ashes) and their potential in mass stabilization were studied and tested. The tested binders were:

- Ordinary Portland Cement
- Road Cement
- Local ashes
  - Ash 1 (electric filter)
  - Ash 2 (cyclone)
  - Ash 3 (fluidized bed)

The granularities of ashes are presented in annex 3. The concentrations of ashes are presented in annex 4. The ashes are potential as binder for stabilizations of soft soils. The concentrations are below the limit values from VNa 591/2006.

4 Stabilisation testing

4.1 Tests during the I-stage

4.1.1 Target

The goals of the tests made during I – stage were:

- to find better cement to use for these materials
- to find how useful ashes are
- general idea of stabilisation and what are the possible benefits by using ashes
- only tests of technical functionality

After I-stage it was possible to choose binders and soils for more detail tests. The tests during I-stage gave us base knowledge for optimizations.

4.1.2 Samples of soft soils

Mixtures were made of samples from different depth from points PA4, PA3 and PA1 (peat). In the point PA1 the samples from depth 2,1…3,1 m were tested (sand/silt).

The choice for majority of tests was to make one mixing from samples from point PA4 (depth 0,5…3 m, see figures 4…6). The mixing can be compared in field case there minority structure will be broken by real scale machinery. So the specimens represent possible mass stabilisation of peat.

The minority of tests was made by using specimens prepared by samples from points PA1 (peat and sand/silt) and PA2 (peat). The purpose was to get knowledge of differences and similarities from local sites.
4.1.3 Soil stabilizers/ binders

The tested binders were:
- Ordinary Portland Cement
- Road Cement
- Ash 1 (electric filter)
- Ash 2 (cyclone)
- Ash 3 (fluidized bed)

4.1.4 Settlement

The results from settlement measurements are joined as annex 5.

4.1.5 Compression tests

After the period (after 28 days/ 96 specimens) of stabilisation specimens were tested 1-axial, loading speed 2 mm/min. The results of tests are presented in figures 9 and 10. The results from compression strength tests are joined as annex 6. The stress-strain curves are joined as annex 7.

4.1.6 Preliminary notices of results

Portland cement was more suitable than Road cement in this case. The values of compression strength were approximately at least 2 times better for Portland cement than Road cement.

The best binder combinations contain Portland cement (100 kg/m$^3$) and Ashes 1…3 (200 kg/m$^3$). The values of compression strength samples with ashes are approximately 1,5…3,5 times better than using Portland cement lonely as binder. Especially the combination of Portland cement and Ash 3 (fluidized bed) has 3,5 times better compression strength compared with specimens containing only Portland cement and 6 times better compared with specimens containing only Ash 3.

Combinations of Road cement with ashes were not so powerful. Values of compression strength were 1,2…2,4 times better than specimens containing only Road cement.

The test results of the specimens TT-44…48 from point PA1 containing sand/silt (depth 2,1…3,1 meters) were extra good. The needed portion of cement is less than used in the specimens TT-44…48.
Figure 9. The values of compression strength from the peat tests during I–stage.

Figure 10. The values of compression strength from the sand/silt tests during I–stage.
4.2 Tests during the II-stage

4.2.1 Target

The goal of the tests made during II-stage was to have more detail tests for the most potential mixtures found in tests during I-stage:

- tests using only one cement and 1…2 ashes
- optimization in binder dosing and mix contents - to find right amount of PortlandCe and Ash3
- differences in stabilisation in varying soils - to find how suitable Ash3 really is
- time-stabilisation (=increment of strength during time)

4.2.2 Samples of soft soils

The majority of tests were made from one mixing of samples from point PA4 (depths 0,5…3 m). The mixing can be compared in field case there minority structure will be broken by real scale machinery. So the specimens represent possible mass stabilisation of peat.

The minority of tests were made by using specimens prepared by samples from points PA1 (peat and sand/silt) and PA3 (peat). The purpose was to get knowledge of differences and similarities from local sites.

4.2.3 Soil stabilizers / binders

The tested binders were:

- Ordinary Portland Cement
- Ash1 (electric filter)
- Ash3 (fluidized bed)

4.2.4 Settlement

According the measurements made from the laboratory specimens (figure 11):

- the settlement during hardening time is about 10…21 % for specimens which have binder combined PortlandCe and Ash3
- the settlement is about 15…21 % for specimens which have binder combined PortlandCe and Ash1
- the settlement is about 15…29 % for specimens which have PortlandCe as only binder

The results from specimens TA-20…23 are different from others, because the height of specimens were different (about 172-182 mm, normally 196 mm; the amount of peat from PA1a was short for the specimens).

The results from specimens TA-28 and TA-32 are different. The binder is PortlandCe in both cases.

The results from settlement measurements are joined as annex 8.
4.2.5 Compression tests

After the period (after 7 days/ 10 specimens and after 28 days/ 62 specimens and after 90 days/ 60 specimens) of stabilisation specimens were tested 1-axial, loading speed 2 mm/min. The results of tests are presented in figures 12, 13, 14 and 15. The results from compression strength tests are joined as annex 9. The stress-strain curves are joined as annex 10.

The binder of PortlandCe and Ash1 (100+200 kg/m$^3$) seems to be effective (TA-3, see also TA-6, figure 12). The binder of PortlandCe and Ash3 (140+150 kg/m$^3$) is as effective as first mentioned.

The binder of PortlandCe kg/m$^3$ and Ash3 (100...140+250...200 kg/m$^3$) seems to be effective (TA-19, TA-23 and TA-27, figure 13). After 90 days it seems that the specimen TA-18 (PortlandCe and Ash3 (100+200 kg/m$^3$)) is as good as the specimen number TA-19. After 90 days the level of unconfined compression strength had not increased according specimens TA-23 and TA-27.

The combination of PortlandCe and Ash3 (100+150...200 kg/m$^3$) seems to be effective (TA-29, TA-30, TA-34 and TA-38, figure 14). The unconfined compression strengths after 90 days are at nearly same level as after 28 days for these specimens (except TA-33, TA-37 and TA-38).
The test results of the specimen TA-40...44 from point PA1 containing sand/silt (depth 2.1...3.1 meters) are good. The needed portion of cement is about 50 kg/m$^3$, if it is used with Ash3. The ash portion is depending the structure there stabilisation method is solved.

Figure 12. Unconfined compression strength from TA-1...15. The peat is a mix from point PA4 and from layers depth 0.5...3.0 meters.
Figure 13. Unconfined compression strength from TA-16...27. The peat is a mix or a special layer from point PA1 and from layers depth 0.5...2.0 meters.
Figure 14. Unconfined compression strength from TA-28...39. The peat is a mix or a special layer from point PA3 and from layers depth 0.5...2.0 meters.
Figure 15. Unconfined compression strength from TA-40 … TA-44. The sand/silt is a mix from point PA1 and from layer depth 2,1…3,1 meters.

4.2.6 Preliminary notices of results

In figure 12 all results are from same peat-mix PA4. From these we can see that the combination PortlandCe + ash (70...100+200 kg/m$^3$) is rather good (TA-7 and TA11, notice also TA-7...9 and TA-10...12). You get better results from specimens TA-13…15, but the amount of cement is 1,4...2,0 times greater than specimens TA-7…12.

Notice also results from TA-3...5 - increasing amount of ash does not give us better result after 28 days. It seems that Ash1 works better, if we have less ash compared with amount of cement (better result from TA-3 (100+200 kg/m$^3$) and TA-6 (140+150 kg/m$^3$). After 90 days the unconfined compression strengths are better from TA-4 and TA-5.

The binder of PortlandCe (100 kg/m$^3$) and Ash1 (200 kg/m$^3$) seems to be effective (TA-3, see also TA-6, figure 2). The binder of PortlandCe (140 kg/m$^3$) and Ash3 (150 kg/m$^3$) is as effective as first mentioned.

The binder of PortlandCe (100…140 kg/m$^3$) and Ash3 (250…200 kg/m$^3$) seems to be effective (TA-19, TA-23 and TA-27, figure 13). After 90 days it seems that the specimen TA-18 (PortlandCe (100 kg/m$^3$) and Ash3 (200 kg/m$^3$)) is as good as the specimen number TA-19. After 90 days the level of unconfined compression strength had not increased according specimens TA-23 and TA-27.

The combination of PortlandCe (100 kg/m$^3$) and Ash3 (150…200 kg/m$^3$) seems to be effective (TA-29, TA-30, TA-34 and TA-38, figure 14). The unconfined compression strengths after 90 days are at nearly same level as after 28 days for these specimens (except TA-33, TA-37 and TA-38).
The test results of the specimen TA-40...44 from point PA1 containing sand/silt (depth 2.1...3.1 meters) are good. The needed portion of cement is about 50 kg/m$^3$, if it is used with Ash3. The ash portion is depending the structure there stabilisation method is solved.

4.3 Tests during the III-stage

4.3.1 Target

The goal of the tests made during III-stage was to have more detail tests for the most potential mixtures found in tests during I- and II-stage:

- tests using only one cement and one ash
- optimization in binder dosing and mix contents - to find right amount of PortlandCe and Ash3
- tests of environmental functionality: leaching (solubility)
- frost, freezing-thawing-resistance, water permeability

4.3.2 Frost

4.3.2.1 Influence of freezing-thawing treatment

![Figure 16. The influence of the freezing-thawing treatment to values of the unconfined compression strength.](image)

The specimens were freezeed and thawed 12 times during 14 days before measurements of unconfined compression strength. The unconfined compression
strength were 2...22% lower after the freezing-thawing treatment (according specimens TA-60~TAJ61, TA-64~TAJ65 and TA-68~TAJ-69).

The unconfined compression strength was 27% lower after the freezing-thawing treatment according the results from the specimens TA-28 and TAJ-61 (PortlandCe 250...300 kg/m³, the difference was 7% between the specimens TA-60~TAJ-61).

The unconfined compression strength was 24% lower after the freezing-thawing treatment according the results from the specimens TA-69 and TA-30 (PortlandCe and Ash3 100+200 kg/m³, the difference was 2% between the specimens TA-68~TAJ-69).

The unconfined compression strength was 22% lower after the freezing-thawing treatment according the results from the specimens TA-64 and TAJ-65 (PortlandCe and Ash3 70+200 kg/m³).

The results are joined as annex 11.

4.3.2.2 Frost heaving

In the test the specimen is freezed from the top and given water from the bottom. The temperatures are measured on the top, under the bottom and from side the specimen. The frost heaving is measured as growth of the height of the specimen. The segregation potential is counted from the result and the classification is made according the results. The classification gives the same result for all binders – medium frost susceptible (see table 1).

The results from the frost heaving tests are joined as annex 12. There are results from total frost heaving from measured period, frost heaving ratio and frost heaving rate (frost heave ratio and rate during 24 hours and 48 hours), segregation potential, depth of frost in the specimen, temperatures (water above the specimen, freezing temperature on the top and temperatures from side of specimen).

Table 1. The segregation potential results from frost heaving tests.

<table>
<thead>
<tr>
<th>Code</th>
<th>Binders</th>
<th>Amounts of binders [kg/m³]</th>
<th>Segregation potential [mm²/Kh]</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAR-62</td>
<td>PortlandCe</td>
<td>300</td>
<td>1.2</td>
<td>medium frost susceptible</td>
</tr>
<tr>
<td>TAR-66</td>
<td>PortlandCe + Ash3</td>
<td>70 + 200</td>
<td>1.7</td>
<td>medium frost susceptible</td>
</tr>
<tr>
<td>TAR-70</td>
<td>PortlandCe + Ash3</td>
<td>100 + 200</td>
<td>1.4</td>
<td>medium frost susceptible</td>
</tr>
</tbody>
</table>

4.3.3 Water permeability

In the test it is measured water amount and speed passing the specimen. The water permeability from untreated peat is about $10^{-2}$ ... $10^{-6}$ m/s according literature. After stabilisation the water permeability is about $10^{-8}$ ... $10^{-9}$ m/s according the laboratory tests. There was also made one test with a specimen without any binder and the result was at same level (about $10^{-9}$ m/s).

The results from water permeability tests are joined as annex 6.
Table 2. The results from water permeability tests.

<table>
<thead>
<tr>
<th>Code</th>
<th>Binders</th>
<th>Amounts of binders [kg/m³]</th>
<th>Water permeability [10⁻⁹ m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAV-63</td>
<td>PortlandCe</td>
<td>300</td>
<td>6,2</td>
</tr>
<tr>
<td>TAV-67</td>
<td>PortlandCe + Ash3</td>
<td>70 + 200</td>
<td>5,4</td>
</tr>
<tr>
<td>TAV-71</td>
<td>PortlandCe + Ash3</td>
<td>100 + 200</td>
<td>5,3</td>
</tr>
<tr>
<td>TAV-72</td>
<td>Specimen made from peat</td>
<td>-</td>
<td>0,54</td>
</tr>
</tbody>
</table>

4.3.4 Environmental acceptance

The leaching of harmful particles was measured with the column tests (according to the draft of standard CEN/TS 14405). The specimens were stabilised 28 days before testing. The results (table 3) were compared with Finnish codes dealing with covered or surfaced structures of layers made from industrial by-products (materials like fly ash, furnace slag or gypsum; VNa 591/2006).

These data can be used to evaluate environmental acceptance of the structure. We should know more detail about structure to actually do the evaluations. DOC-leaching value is high, but it is due from the peat material itself.

Table 3. The amounts of binder in the specimens for leaching tests.

<table>
<thead>
<tr>
<th>Code</th>
<th>PortlandCe [kg/m³]</th>
<th>Ash3 [kg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAL-45</td>
<td>200</td>
<td>-</td>
</tr>
<tr>
<td>TAL-47</td>
<td>75</td>
<td>200</td>
</tr>
<tr>
<td>TAL-48</td>
<td>100</td>
<td>200</td>
</tr>
</tbody>
</table>

The report of results is joined as annex 14 (in Finnish).

Table 4. The leaching of harmful particles from the column tests.

<table>
<thead>
<tr>
<th>Harmful particles</th>
<th>Leaching cumulative L/S-ratio of 10 l/kg Covered structure</th>
<th>Surfed structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TAL-45</td>
<td>TAL-47</td>
</tr>
<tr>
<td>DOC</td>
<td>3037</td>
<td>2606</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>59,1</td>
<td>48,2</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>&lt;32</td>
<td>580</td>
</tr>
<tr>
<td>Sulphate (SO₄²⁻)</td>
<td>67</td>
<td>165</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>&lt;0,010</td>
<td>&lt;0,011</td>
</tr>
<tr>
<td>Arsenic (As)</td>
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<td>0,036</td>
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<td>Mercury (Hg)</td>
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<td>&lt;0,010</td>
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<tr>
<td>Antimony (Sb)</td>
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<td>0,005</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>&lt;0,005</td>
<td>&lt;0,005</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>13,4</td>
<td>8,1</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
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<td>&lt;0,02</td>
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<tr>
<td>Copper (Cu)</td>
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<td>&lt;0,1</td>
</tr>
<tr>
<td>Lead (Pb)</td>
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<td>&lt;0,02</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
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<tr>
<td>Nickel (Ni)</td>
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<td>0,3</td>
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<tr>
<td>Zinc (Zn)</td>
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<td>&lt;1,0</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>&lt;0,01</td>
<td>&lt;0,01</td>
</tr>
</tbody>
</table>
5 Results and conclusions

5.1 Comparison of ashes

Figure 17. Unconfined compression strength from TA-1...15. The peat is a mix from point PA4 and from layers depth 0.5...3.0 meters.

In figure 17 all results are from same peat-mix PA4. From these we can see that the combination PortlandCe 70...100 kg/m$^3$ + Ash3 200 kg/m$^3$ is rather good (TA-7 and TA-11, notice also TA-7..9 and TA-10...12). There are better results from specimens TA-13...15, but the amount of cement is 1.4...2.0 times greater than specimens TA-7...12.

Notice also results from specimens TA-3...5 - increasing amount of ash don’t give us better result after 28 days. It seems that Ash1 works better, if we have less ash compared with amount of cement (better result from specimens TA-3 (100+200 kg/m$^3$) and TA-6 (140+150 kg/m$^3$). After 90 days the unconfined compression strengths are better from specimens TA-4 and TA-5.

5.2 Time - stabilisation

The result (figure 18) from specimens with PortlandCe as only binder vary between 21...95 kPa (age 7 days) and 27...154 kPa (age 28 days). The result from TA-32 is poorer than others – notice the values of w and Hh.

The result (figure 18) from combination of PortlandCe and Ash1 (100+200 kg/m$^3$) is the best of these (about 280 kPa, age 28 days). The results from combination of PortlandCe and Ash3 (100+200 kg/m$^3$) are about 225 kPa from TA-11, TA-34 and TA-38 – notice the values of w and Hh. The effect of ashes compared with PortlandCe appears clearly from result of age 28 days.
The result from combination of PortlandCe (100 kg/m$^3$) and Ash1 (200 kg/m$^3$) is the best of these (about 280 kPa, age 28 days). The results from combination of PortlandCe (100 kg/m$^3$) and Ash3 (200 kg/m$^3$) are about 225 kPa from TA-11, TA-34 and TA-38 – notice the values of $w$ and $Hh$. The effect of ashes compared with PortlandCe appears clearly from result of age 28 days.

Figure 18. The result of unconfined compression strength tests after 7-28-90 days stabilisation period in the laboratory.

5.3 Water content of peat

Next there are some figures (figures 19 and 20) of influence of water content of peat layers. When the water content of peat layers increase, it seems that binder combinations PortlandCe and Ash3 are better than PortlandCe as only binder. From figure 17 it seems that unconfined compression strengths are at the level of 70…100 kPa after 28 days and 70…160 kPa after 90 days stabilisation period when the only binder is PortlandCe and water content of peat is over 800 %. From figure 18 it seems that unconfined compression strengths are at the level of 200…250 kPa (except specimen TA-18) after 28 days and 230…330 kPa after 90 days stabilisation period when the binder is combined from PortlandCe and Ash3 and water content of peat is over 800 %. The binder combined from PortlandCe and Ash3 seems to be better alternative when the peat is wet (notice: also the value of $Hh$ is higher).

In figure 19 it is compared how the amounts of PortlandCe influence to values of the unconfined compression strength while the water content of peat increase (the amount of Ash3 is 200 kg/m$^3$). In figure 20 it is compared how the amounts of Ash3 influence to values of the unconfined compression strength while the water content of peat increase (the amount of PortlandCe is 100 kg/m$^3$). In both figures 21 and 22 there are shown also results from specimens having PortlandCe as only binder (colour: light red) and the unconfined compression strengths for them are at lower level (except after 7 days stabilisation period).
Figure 19. The unconfined compression strength depends on water content of peat. PortlandCe as only binder seems to work poorly when the water content of peat increase.

Figure 20. The unconfined compression strength depends on water content of peat. PortlandCe and Ash3 as binders seem to work better, when the water content of peat increase.
Figure 21. The influence of the increasing amount of PortlandCe with Ash3 (200 kg/m³), when the water content of peat increase.
Figure 22. Influence of amount of Ash3 with PortlandCe (100 kg/m³), when water content of peat is increasing.
5.4 Conclusions

It is possible to stabilise soft soils and the layer under them according the performance studies. It is possible to achieve the needed strength level with reasonable amounts of binders.

Potential binders have been found to be used in field. The draft design of the structures can be done according these results. There will be need of some more tests to find out optimal amounts of binders for structures depending on what is acceptable shear strength on field.

The optimal binders and the dosages were studied. In the binder selection the technical and environmental characteristics were tested and paid extra attention. In the technical studies the priority was to find binder materials which will act towards the best shear strength and furthermore fulfilling the cost effectiveness of the final performance. Optimizing of the binder material included amount of binder and curing time effects.

There are technical and economical useful binder combinations of PortlandCe and Ash3 (70…100+150…200 kg/m³). These results do not give enough information about Ash1 usage in field (results only from point PA4). It seems that it can be more demanding to use PortlandCe as only binder because the amount of PortlandCe is quite high. These amounts of binders are consider to be suitable for structures under 1,5…2 metres thickness of road embankments. These results should be checked out when the structure and loading conditions are known in actual placement.

The strength obtained in a stabilised soil depends not only on the specific combination of soil and binder, and quantity of binder, but also on a number of other factors, such as the degree of saturation, the stress conditions and the drainage conditions. The effects of these factors will vary according to applications, but must be taken into consideration in the design of deep mixing. In the laboratory tests are performed to simulate the conditions expected in the field.

In the field an loading fill is important in order to squeeze out air and achieve high strength in the stabilised peat. It is also important to apply the load in a uniform manner in order to avoid shear deformations and uneven quality in different sections of the treated area. Using the same load intensity, the strength can be expected to become lower in the field compared to measurements in the laboratory tests. In the field, where layers of several metres are to be compressed, the drainage paths are much longer than in the laboratory samples and the compression becomes correspondingly slower.

It is also relevant to consider how the stabilisation layer will stand freeze-thaw-cycles under the road embankment. According these studies the strength of the stabilised peat will shrink at least 20…30 %. These results are from the laboratory specimens.

On the other hand the stabilised peat does not have considerable frost heaving. The amount of frost heaving under the road embankment (1,5…2 metres) will not be a problem according these results.

The stabilised peat has lower water permeability than untreated peat. So it will not pass considerable amounts of water. When the peat is treated (mixed, compressed) without added binders, the water permeability will also lower. The water permeability of the treated peat (without added binders) is ten times smaller than the stabilised peat. The lower water permeability may reduce the transportation of possible harmful particles.
According these studies it is possible to use Ash 3 as a binder from environmental view. The high values of some particles (DOC) are due from the peat material itself. The values higher than limit values (fluoride and nickel) should be consider when the actual structure is known better. These arguments should be evaluated also against the local conditions (ground water level, value of ground water reserves).

5.5 Further research

Mass stabilisation field test of highway section Kose-Mäo

The E263 Tallinn-Tartu-Võru-Luhamaa highway with the total length of 288.5 km progresses in the south-east direction from Tallinn uptil the Russian border in Luhamaa. A part of the road section Kose - Mäo is designed to be built on a soft soil area. Soft soil areas (such as clay and peat) should be reinforced. Soft soil should be designed to be stabilised for better stability and bearing capacity.

Mass stabilisation field test will present the best stabilisation methods with different binders before construction. Stabilisation field test will prove the reliability of binders in practise. Research results present the best type of binder and the minimum reliable rate of binder will be optimised for the minimum costs. Field test will show also the possible difficulties of mass stabilisation at Kose – Mäo section.

Utilisations of Ash 3

The soils of many construction sites and the dredged sediments around the harbour areas are too weak in their natural state but can be stabilised with cement or admixtures of cement and other stabilising agents. This improves the strength of soil material and makes it a suitable material for diverse purposes.

The contaminated soils (and other types of waste materials) establish another heterogeneous group of materials which could be used for the infrastructure construction in case the contaminants can be immobilised or solidified within the material. This is possible in many cases with help of composites of cement and ashes. Stabilisation and solidification treatments include a wide range of processes that usually involve mixing binders into the soil or waste to transform it into a new, solid and non-leachable material. In case of waste or contaminated soil, the treated product encapsulates potentially hazardous contaminants, reducing contact between the waste / contaminated soil and any potential leachate (like rain water). In addition to this, various interaction and chemical effects may occur that lock contaminants into the product, further reducing the potential for pollutant transfer into the environment.

In general the stabilisation process is economical only when the cost of overcoming a deficiency in one material is less than the cost of material exchange including importing another material which is satisfactory without stabilisation. However, stabilised materials often have a number of advantages that can reduce risks, increase reliability and reduce process costs. Additionally, in most cases stabilisation is an environmentally beneficial technology especially because of reduced exchange and transport of materials.