EXPERIENCES OF UTILISING MASS STABILISED LOW-QUALITY SOILS FOR INFRASTRUCTURE CONSTRUCTION IN THE CAPITAL REGION OF FINLAND – CASE ABSOILS PROJECT

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Abstract. Infrastructure construction activities in many Finnish cities are a considerable source of surplus soft soils which are traditionally transported to landfill sites and replaced with natural aggregates. With the application of stabilisation methods, soils characterised by poor geotechnical features can be converted into valuable construction material. Stabilisation also allows for the utilisation of fly ash and other waste materials as binder agents. In some cases it might also lead to the improvement of the environmental parameters of the stabilised soils. Currently, there is a lack of a holistic approach towards resource efficiency that would enable better utilisation of the redundant soils as construction material. The Absoils project was designed to meet the challenge of redundant soils. The project is carried out in co-operation of Biomaa Oy, Rudus Oy and Ramboll Finland Oy. The cities of Helsinki, Espoo and Vantaa are involved in the project in the role of city developers or constructors. The project is co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575). The possibilities to utilise excess soils are demonstrated with the pilot applications in the capital area where around 4 million tonnes of redundant soil is generated every year. The target of the project is to demonstrate and promote eco-efficient utilising of the poor quality soils in-situ and owing to that to decrease the use and the transportation need of crushed aggregates. In the framework of the project, the surplus and low-quality soils are improved by stabilisation with fly ashes, cement, lime, sulphur removal by-products and other wastes. The article presents the details of a project pilot application in the Perkkaa Dog Park in Espoo.

Keywords. stabilisation, surplus soils, fly ash, sulphide clays

INTRODUCTION

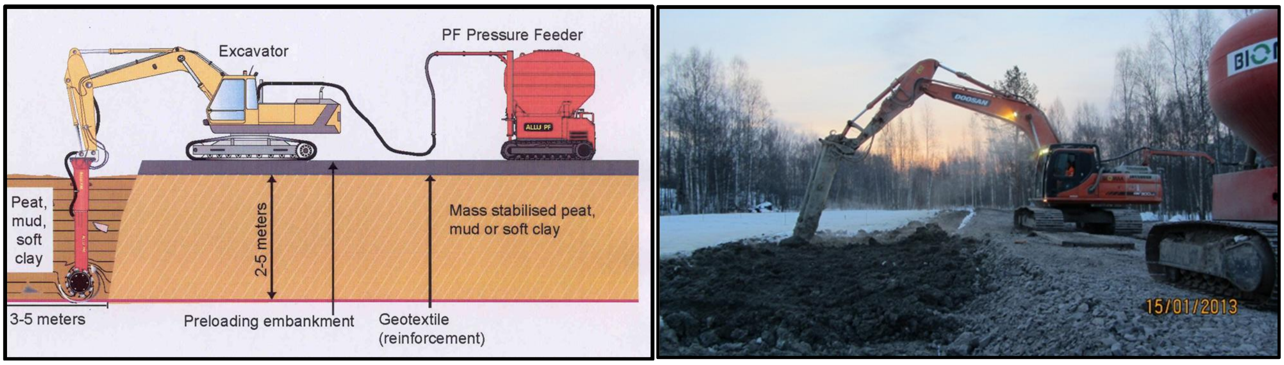
Owing to progressing urbanisation, Helsinki and other cities in the capital region are under an intensive development process. While constructing new districts and improving already existing ones, the cities face a challenge resulting from the fact that soft clays and peats are among the predominant soil types in Finland. In the past, the prevailing trend was to construct first in the areas that offered the best geotechnical conditions. Currently, Helsinki, Vantaa and Espoo suffer from the shortage of areas that constitute easy targets for construction and are relatively close to the city centre. As a result, construction has to be performed in areas with very soft postglacial clay, mud or peat. According to the estimations, the amount of surplus soils generated in the capital area reaches about 4 million tonnes annually. Current practice concerning surplus poor quality soils includes landfilling and replacing them with crushed aggregate transported from other places. This has led to such problems as the shortage of fill and embankment materials, as well as the shortage of landfill areas for excess soils. For instance, the capacity of the surplus soils landfill site in Helsinki reached its limits in 2011 and the transportation distance to the new site is more than 40…50 km.

To meet the above-mentioned challenges and offer some viable solutions, the Absoils EU Life+ project had been designed and eventually launched in 2010. The project has strived to demonstrate that the utilisation of poor quality soils in-situ results in the decreased use of crushed aggregates and diminished transportation from and to the construction site. In the framework of the project, various civil-engineering applications have been designed and demonstrated as pilots. The project also contributes to reaching the EU recycling targets set by the Waste Framework Directive.

The utilisation of the excess soils is possible due to, for instance, mass stabilisation technology. Mass stabilisation is a ground improvement method for soft soils such as clays, silts and peat. Mass stabilisation is a mixing technology where a predefined amount of dry and moist binders are applied to soft ground with special mixing equipment attached to excavator. Mixing is done in vertical and horizontal directions. Due to hardening reactions in the ground a strengthened block of soil is created. The phases of the development of mass stabilisation technology are presented more comprehensively by Lahtinen & Niutanen [2009]. Mass stabilisation method has been used for about 20 years in the Helsinki region in various applications [Forsman et al. 2012]. An important aspect of stabilisation technology is its winter adaptability. The method can be applied in winter conditions such as snow fall and temperatures below zero. Stabilisation offers also a solution to some other problem tackled in this paper, namely the fact that soils in some parts of Finland are highly sensitive to acidification.

The aim of this article is to present various stages and aspects of the surplus and poor quality soils utilisation process that took place during construction of the Perkkaa Dog Park pilot in Espoo. This pilot was carried out in the framework of the Absoils project between the years 2011 and 2013.

The location of the pilot site is shown in Figure 2.The Perkkaa Dog Park has not been the only Absoils' pilot site in the capital area – other pilots include such applications as Arcada II and Jätkäsaari I+II which were presented in the article by Kreft-Burman et al. [2012].



a) b)

Fig. 1. The principle of the stabilisation process (a) and stabilisation in progress in winter time (b)

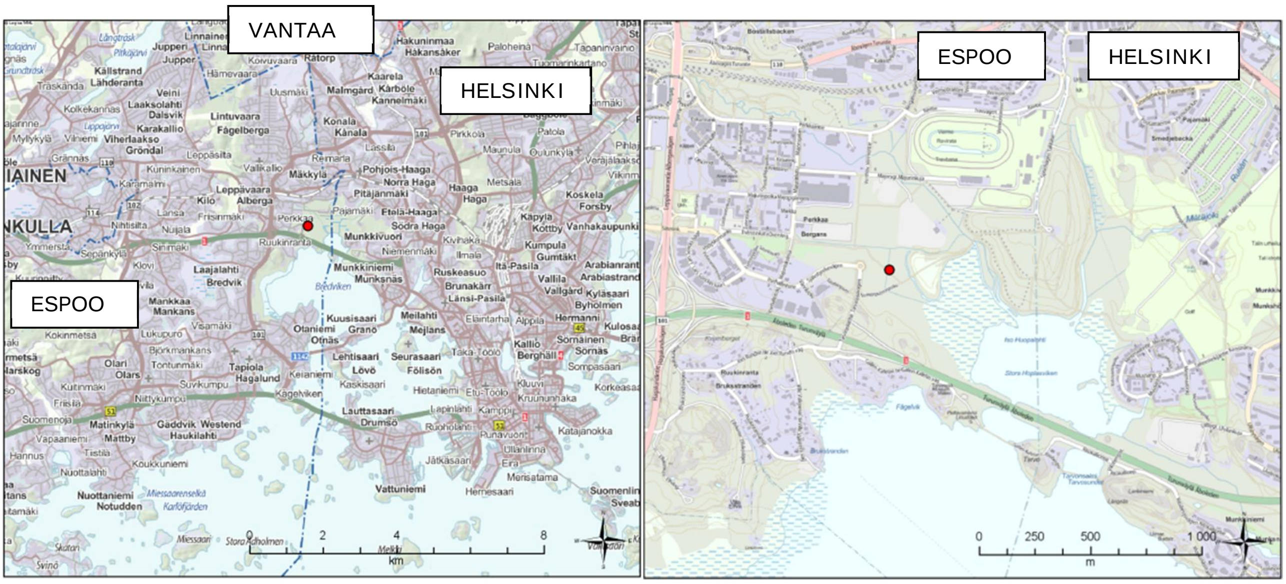


Fig. 2. The location of the Absoils project's pilot application - Perkkaa Dog Park in Espoo, Finland

1 LOGISTICAL AND TECHNICAL CHALLENGES

One of the challenges that needs to be tackled by many of the Finnish cities is the lack of a holistic approach towards the construction materials management in the infrastructure development process. The usual situation is that there are plenty of simultaneous operations that are not coordinated from the point of view of material flow and the sustainable use of natural resources. In most cases, excavation works result in considerable amount of poor quality soils. Since mass exchange is the predominant method of dealing with this issue, this has an impact on the amount of transportation from and to the construction site. The current situation is illustrated by Figure 3.

One of the aims of the Absoils project has been to demonstrate and promote the introduction of a material flow model that will enable utilisation of all the soils generated during the construction process in some other locations. Also the utilisation of various wastes such as fly ash, FGD, gypsum, etc., has been included. Figure 4 depicts the desired material flow model that will lead to considerably diminished landfilling, better material efficiency and less transportation.

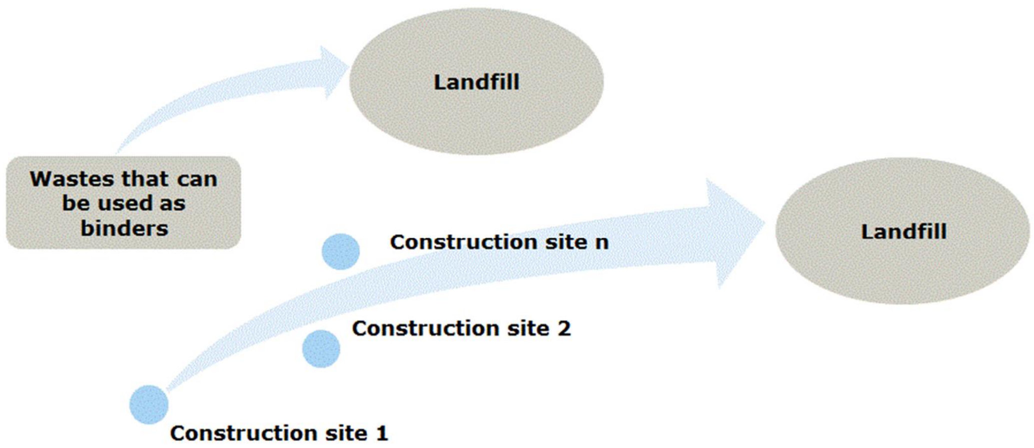


Fig. 3. Currently predominant model of the material flow in infrastructure construction

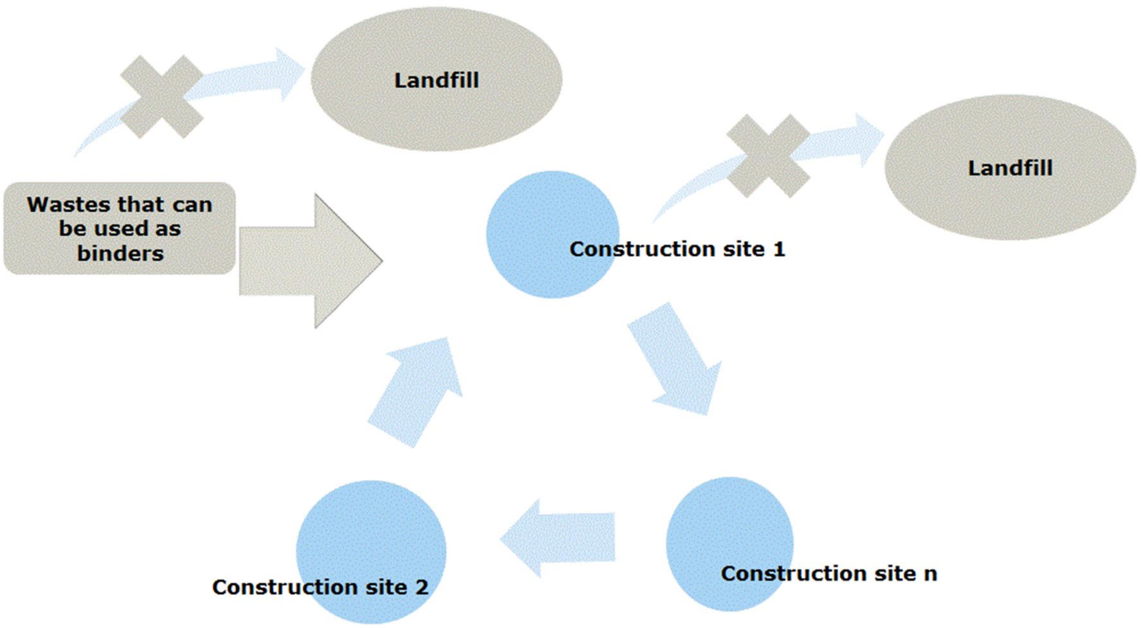


Fig. 4. The desired material flow model in infrastructure construction

1.1 Soils flow model in the Perkkaa Dog Park pilot

This model has been demonstrated in the Perkkaa Dog Park pilot application in Espoo (Figure 6). The area of the park is ≈4 500 m^2 and it lies in the flood prone zone. The soil of the area was described as soft clay which used to be seabed. The thickness of the clay is ≈ 11 ... 14 m (Figure 5a) and the area has been classified as a very difficult constructing target due to its low load bearing capacity. The purpose of the pilot was to raise the area to prevent flooding. In order to prevent mass exchange, landfilling of the soft soils and replacing them with other materials, it was planned to utilise both the poor quality spoils encountered in the target and the surplus clays obtained from an adjacent construction site – the construction of a street foundation with a mass replacement method.
The redundant clays from the neighbouring street were transported to the pilot site where the materials were stockpiled in the area surrounded with an embankment to prevent the escape of the fluid clay material out from the stabilisation area. The transportation and construction of the embankment tool place between January and March 2012. The transportation distance in this case was only 200…500 meters. The transportation distance to the landfill would have been about 25 km had it not been possible to use the redundant masses in the construction process of the Perkkaa Dog Park. Surplus soft clay is a very troublesome and expensive material to dispose at landfill.

1.2 Geotechnical calculations

Various tests were performed in order to determine the geotechnical conditions of the area prior to the design stage. Stability and settlement calculations were carried out using the Finnish GeoCalc 2.2 programme. In the case of stability calculations, a gas pipe located nearby had to be taken into consideration. Primary consolidation settlement was calculated on the basis of the water content of the subsoil clay. In the calculation first the water content was changed to Janbus tangent modulus method parameters m_1 and β_1 (modulus number and stress index) with the empirical correlation factors. The calculated consolidation settling of the embankment with partly mass stabilised subsoil was about 200…300 mm during 30 a. Without stabilisation the calculated settling would be over 1 m.

2 LEGISLATIVE FRAMEWORK

Stabilisation allows for the improvement of the technical and chemical properties of surplus soft soils. In order to make stabilisation economically feasible and to enhance the utilisation of the industrial wastes, fly ashes, flue gas desulphurisation gypsum and other gypsum by-products are usually tested and used as binder components. From a legislative point of view, the utilisation of ashes is nowadays possible in Finland on the basis of the decree number 403/2009 (the so called MARA decree) with only a notification to the authorities if the fly ash alone is used as a separate layer structure in road/field. However, if the fly ash is used as a binder in uncontaminated soil material the legislation requires an environmental permit.
Permitting is rather a lengthy process and in some cases in might even jeopardise the applications, especially if there is a need of synchronisation with other construction works functioning as a source of surplus soils. Moreover, there is also a lack of a consistent approach towards the issue of using industrial wastes in the stabilisation process and there seem to be considerable differences among various local permit authorities throughout the whole country. In general, the permitting issue in connection with the binders for the stabilisation process other than cement, constitutes a considerable hinder for the establishment of the eco-efficient practices in the field of redundant soft soils and their utilisation.
The MARA decree in currently under the novelisation process and it is expected that it might bring changes to the restrictions in the use of fly ash as a binder component in stabilisation. On the other hand, the on-going revision of the EU waste catalogue might result in the classification of fly as hazardous waste, which might be a considerable hinder for its utilisation in soft soils stabilisation.

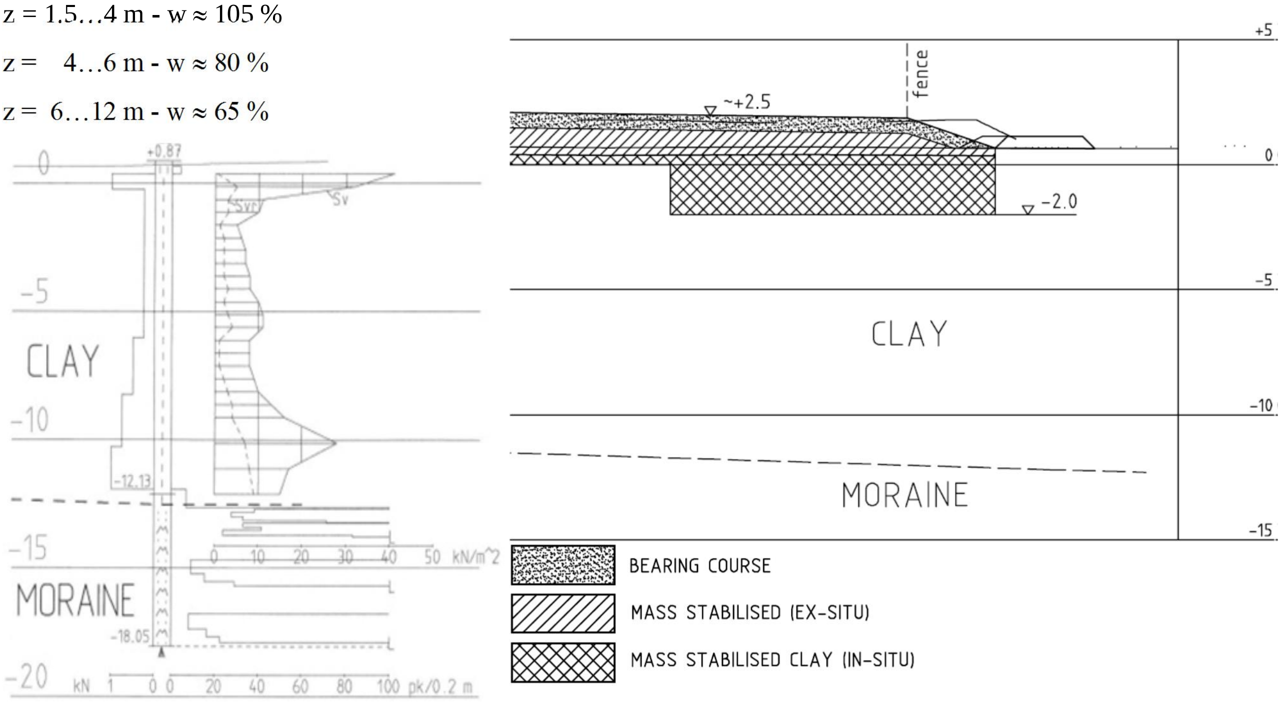
The Absoils project has been contributing to the development of the local legislation by providing the authorities with the results of the piloting activities that add to the creation of a database concerning various aspects of stabilisation.

z = 0…1.5 m - w ≈ 130 %

z = 1.5…4 m - w ≈ 105 %

z = 4…6 m - w ≈ 80 %

z = 6…12 m - w ≈ 65 %



a) b)

Fig. 5. (a) Properties of subsoil in the Perkkaa Dog Park, Swedish weight sounding and vane test and water content. (b). Cross section of the mass stabilised structure (embankment + subsoil)

3 DESIGNED STRUCTURES AND PRELIMINARY TEST

The ground level of the area was to be raised to prevent flooding and the planned ground level was +2…+2.5. The raising of the ground level was planned to be performed with surplus soils which were to be stabilised together with the upper part of the original soil. The target was to reduce the occurrence of flooding to less than once in 20 years. The area plan is presented in Figure 6.

The targeted shear strength after mass stabilisation was 30 kPa (28 d) and 40 kPa (90 d) – 28 d = hardening time. The thickness of the stabilisation was planned to be about 3.5 m in the bordering area and about 2 m in the central part of the structure. The total volume of the stabilisation was 13000 m^3. No wells for the rain water were built but the drainage was done by surface inclination. The planned cross sectional cut is presented in Figure 5b. In the bordering area, stabilisation was performed to the level -2.0 and in the central level to the level ±0. In the first case, stabilisation process embraced the soft subsoil and the redundant clays, whereas in the second case only redundant clays were stabilised.

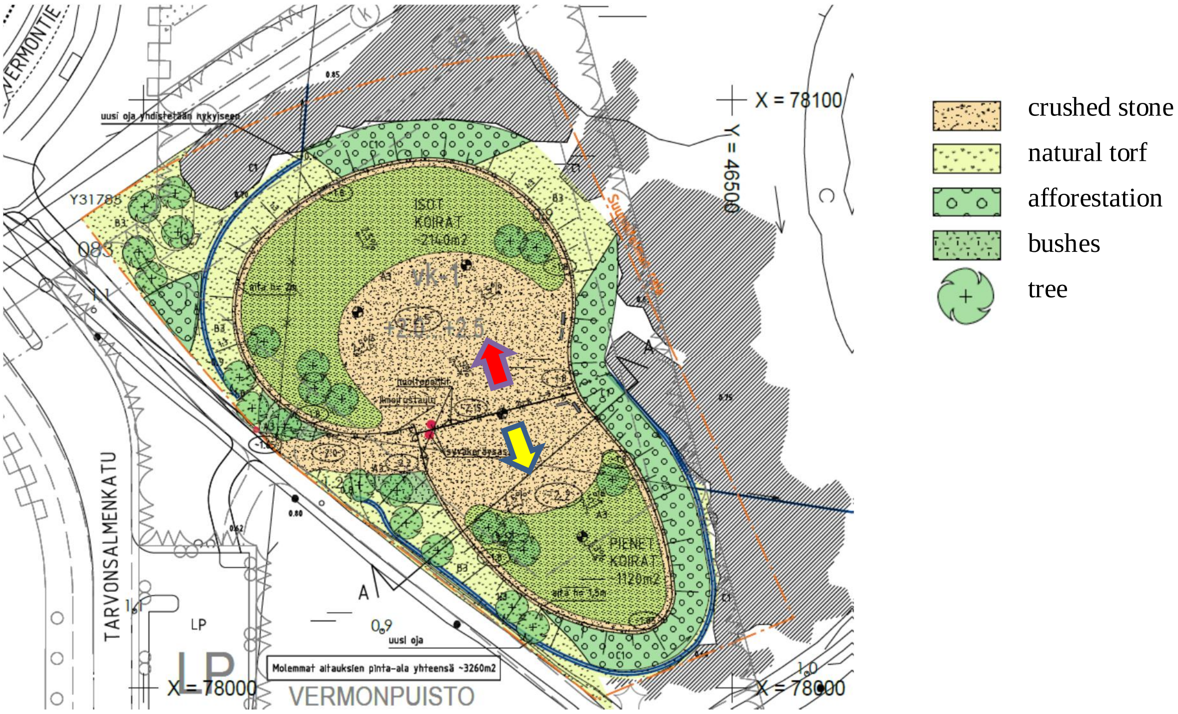


Fig.6. Perkkaa Dog Park area. The red arrow indicates the area planned for big dogs, the yellow arrow indicates the area planned for small dogs

3.1 Environmental permit

The environmental permit was granted for the Perkkaa Dog Park pilot application in June 2012. The permit set out certain requirements concerning the use of waste materials as binder components. The amount of the surplus soil that could be stabilised with a binder including fly ash was limited to 4000 t (≈ 2700 m^3). The maximum amount of fly ash from coal combustion allowed to be used for the stabilisation process was 3000 t and the maximum amount of the FGD was 1000 t. For the stabilisation process, a quality control plan was required. It was to include, among others, a plan for pH measurement for the subsoil clay before and after stabilisation. Because of the permit conditions, the original design of the Perkkaa Dog park had to be altered. According to the new design, in the central part of the area only surplus clay was to be stabilised, and the borders of the area were to be stabilised with cement only. Moreover, stabilisation was now planned to extend more deep at the border parts in comparison to the original plan.

3.2 Material tests

The Perkkaa Dog Park piloting action included material tests in the laboratory before the launch of the construction works and the follow-up studies after the construction. The stabilisation properties of the materials were studied in the laboratory by making specimens and studying the compressive strength of the specimen (diameter 42 mm and height 84 mm) after a specified curing time. The unconfined compressive strength test was carried out according to the SFS 179-2 – CEN ISO/TS 17892-7:fi standard. It is a common practice to test several different binders and binder amounts to determine the most suitable binder mixture for a given construction. This also allows to increase the general knowledge of the properties and possibilities offered by stabilised surplus soils.
The stabilisation tests were carried out for the samples of the soft soil material from the park area (2011) and the surplus clays from the neighbouring construction site (2012). In both test rounds, commercial and alternative binder materials were tested. The alternative materials included fly ash (FA) from two different power plants (both wet and dry), gypsum (gyp.) and flue gas

desulphurisation gypsum (FDG). The commercial binders tested were cement and lime-cement (KC). The results of the stabilisation tests from 2011 are presented in Figure 7.

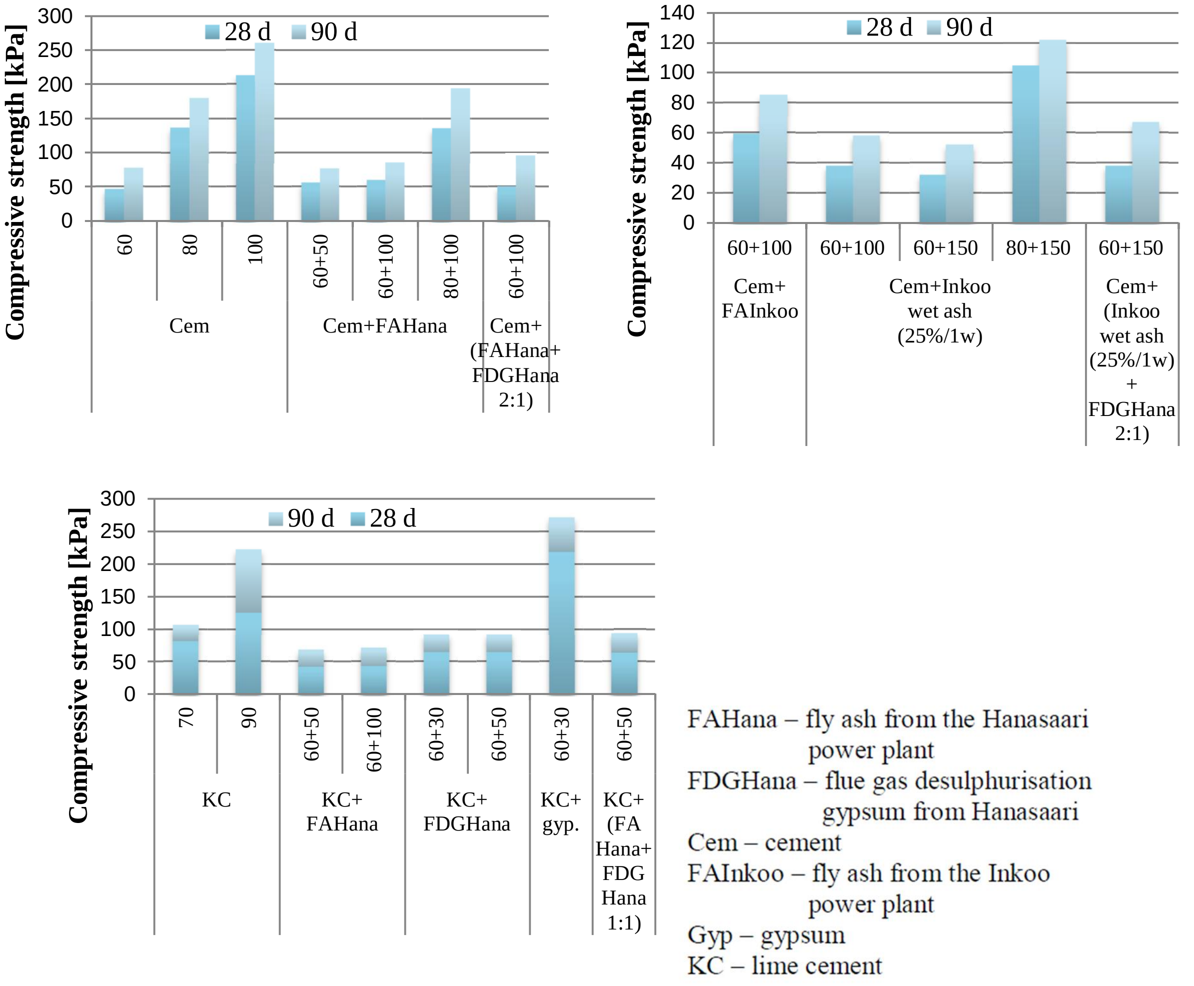


Fig. 7. Result of the tests in 2011 - compressive strengths with: cement - fly ash (Hanasaari) - flue gas desulphurisation gypsum mixtures (a), cement –fly ash (Inkoo) -flue gas desulphurisation gypsum mixtures. 25 % /1w means that the ash has been put in a water content of 25 % and held there over a week before using the ash as a binder (b), KC and KC + ash mixtures (c)

It was observed that the samples stabilised with the cement + ash mixtures worked similarly as samples stabilised with cement only, but the mixtures brought a small benefit for the compressive strength. The two different fly ashes worked similarly when they were dry. The wet Inkoo fly ash did not improve the compressive strength with cement. The flue gas desulphurisation gypsum improved the 90 days compressive strength result slightly. The differences among the binder options could be more clear with the application of a longer curing time. The results showed that by using gypsum-KC -mixture the amount of KC could be dropped by at least 30 kg/m^3. The other binder mixture options were not as feasible. In general, by dropping the amount of cement or KC some economic savings can be obtained and also the carbon footprint of a project can be decreased. The best binder option according to the compressive strength tests, was the KC-gypsum mixture.

Leaching tests were also carried out for the samples stabilised only with cement and for the samples stabilised with Hanasaari fly ash and FGD. The results revealed, for instance, that when using the mixture of cement and fly ash instead of only cement, a lower level of antimonial leaching could be achieved. In general, the results indicate that the Hanasaari fly ash offers a good alternative for commercial binders, as the typical leaching parameters are on a low level. For the FGD, chlorides leaching needs to be taken into consideration in every application. The increased level of chlorides leaching has a negative impact on steel structures.

4 MASS STABILISATION AND QUALITY ASSURANCE

4.1 Stabilisation areas and binders

The designed area was divided into different sections (Figure 8) where individual binder recipes were used. The binder recipes presented in Table 1 were chosen.
A stabilisation map was created by the designer for the needs of the contractor carrying out the work. The stabilisation work-plan created by the contractor on the basis of the stabilisation map shows the location of the areas and blocks to be stabilised. Stabilisation block is a basic unit which takes a certain amount of binder. The width and length of the block ranges normally from 4…5 m × 4…5 m. Immediately after stabilisation, a 0.5 meter high compaction embankment of crushed rock was constructed on top of the stabilised material. Before the construction of the embankment, a non-woven had been spread over the mass stabilised clay. Such embankment consolidates/compacts the stabilised material and finally remains as a part of the surface structure. Mass stabilisation in the Perkkaa Dog Park was performed in January and February, 2013 and it included the following work steps:

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

Table 1. Binder recipes used in the areas A – E.

Code name	Area	Binder recipe
area A	Cement stabilised area, "big dogs"	CEM/B-M (S-LL) 42,5 N 80 kg/m^3
area B	Cement stabilised area, "small dogs "	CEM/B-M (S-LL) 42,5 N 80 kg/m^3
area C	Ash stabilisation area, TS1 west part	Se 60 kg/m^3 + FA:FGD (1:1) 100 kg/m^3
area D	Ash stabilisation area, TS1 east part	Se 60 kg/m^3 + FA 100 kg/m^3
area E	Ash stabilisation area, TS2	CaOSe (3:7) 60 kg/m^3 + FGD 50 kg/m^3

4.2 Water content and pH issues

Finnish soils are prone to acidification in some areas. This concerns especially sulphide rich clays and silt sediments that occur in the coastal zone of western and southern Finland. As a result of the land uplifting process after the glaciation period, the former seabed has risen close to the surface. When close to the surface and above the groundwater, sulphide rich clays are in contact with oxygen and rainwater forming sulphuric acid. Low pH values increase the leaching of heavy metals into the soil. Moreover, acidic water causes corrosion in infrastructure.
According to the test results, the total contents of sulphur were >0,2 % and pH values were >4,5 in some of the clay samples from the Perkkaa Dog Park area, which indicates the clay to be a potential acidic sulphate soil. This means a high potential of oxidation resulting in the formation of sulphuric acid if the clays were not treated by, for instance, stabilisation which increases the pH level.
One other issue that had to be taken into consideration while planning the stabilisation process was the variation in the water level in the surplus clays stored within the embankment of the Perkkaa Dog Park. The water content in the samples from 01/2013 was about 10 % higher than for the samples tested in 03/2012. Both the pH and the water content issues might have had an impact on the impaired consolidation of the pilot structure. However, the binder recipes determined in the

laboratory included a sufficient safety margin (target shear strength of 40 kPa and based on the compression test results - the shear strength of 150...300 kPa) so that the increase of the binder amount for the stabilisation of the clay embankment was considered not necessary.

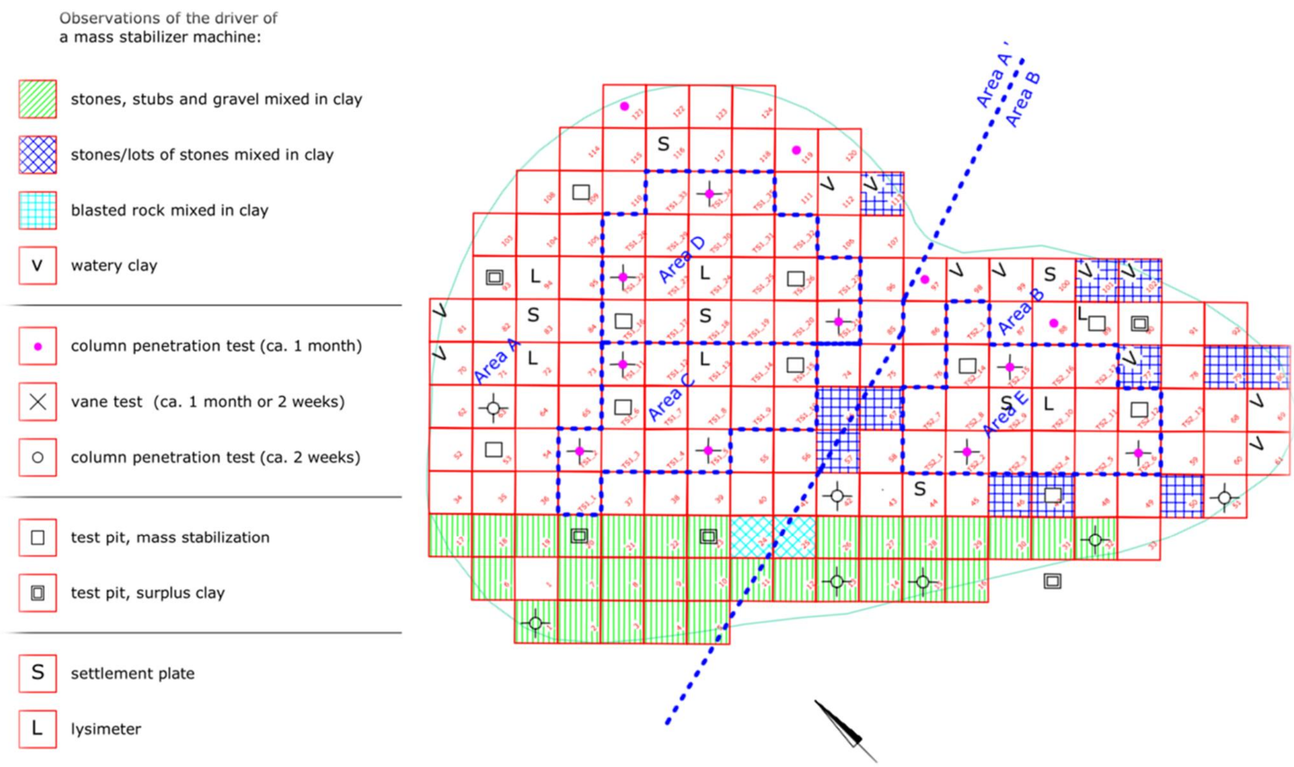


Fig. 8. Mass stabilisation areas A…E, stabilisation blocks, test and instrumentation points.

4.3 Stabilisation quality assurance and instrumentation

After consolidation of the mass stabilised soils, quality assurance was performed with the quality control soundings (column penetrometer and vane penetrometer for columns). They constitute the two most common methods for quality control soundings for deep stabilised structures in Finland and Sweden [Halkola 1999]. The soundings provided information about the strength properties of the material. The locations of the sounding points and test pits are presented in Figure 8. The quality control soundings after 28 days of hardening time were carried out at the end of February and the 90 days soundings will be carried out at the end of May, 2013. On the basis of the 28 d sounding results, it has been concluded that the hardening of the mass stabilised layer has been moderate or good with all the binder mixes.

In addition to soundings, the stabilised structure was examined by excavating of the test pits (all together 10 test pits). The field test methods applied with the test pits included photograph documentation and depth profiling, pocket vane shear apparatus, penetrometer testing (hand held), Niton XRF and sampling for the laboratory (water content and pH determination). These results together with the sounding results will be presented widely in the upcoming articles.

The lysimeters and settlement plates were installed in the Perkkaa Dog Park. Their location in the stabilisation blocks are presented in Figure 8. Five lysimeter sets were installed in the test field (one set = 2 lysimeter boxes). The water sample tubes were placed under the 15 cm drainage layer at the bottom of the lysimeter boxes. The surrounding of the aggregate was covered with a geotextile. Over the geotextile there was about 1 m layer of mass stabilised clay. The lysimeters were installed to carry out “full scale leaching” test in real circumstances in-situ to obtain more information on the

leaching of cement and ash binder stabilised clay. The water samples for the laboratory analyses will be collected first in the autumn 2013 and afterwards, during several years.
Six settlement plates were installed at the pilot site. These instruments are used to measure the settlement occurring during the consolidation period after the construction. Two settlement plates were installed in the cement stabilised area and one settlement plate was installed for each ash stabilised area. The measurement of horizontal z-location gives the combined settlement of the mass stabilised layer and the sub-soil below the mass stabilisation. The settlement measuring has started and it will continue for several years.

CONCLUSIONS

Rapid urbanisation process in Finland results in continual improvements and the construction of new infrastructure. Urban construction sites generate vast amounts of surplus soil when the quality of the encountered soil is considered too low for the building purposes. Landfilling of excess soil and replacing it with transported aggregates is not an eco-efficient practice. The cities in the capital area of Finland suffer from the shortage of areas that constitute geotechnically easy targets for construction. The shortage of fill and embankment materials, as well as the shortage of landfill areas for excess soils, force the cities to come up with some solutions. Mass stabilisation enables the utilisation of the excess soils. By improving the chemical and physical properties of the soft, low-quality masses they can be turned into construction materials and therefore, considerably reduce the amount of spoil and requirements for imported gravel or blasted rock as replacement. Through its pilot applications including the Perkkaa Dog Park in Espoo, the Absoils project has been demonstrating the eco-efficient way of utilising redundant soils. The project has led to raising awareness in this field and contributed to the development of the national legislation.

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