Rostock 12 th Baltic Sea Geotechnical Conference, 31 May – 2 June 2012

MASS STABILISATION IN CONSTRUCTION OF SOFT SUBSOILS AND IN ENVIRONMENTAL GEOTECHNICS AT CITY OF HELSINKI

Juha Forsman / Ramboll Finland Oy, Osmo Korhonen / City of Helsinki, Jorma Havukainen / Ramboll Finland Oy, Kata Kreft-Burman / Ramboll Finland Oy

ABSTRACT

The city of Helsinki is under a continual process of constructing the new districts and improving the already existing ones. The examples of typical ground construction and preconstruction problems faced in Helsinki include the following issues:

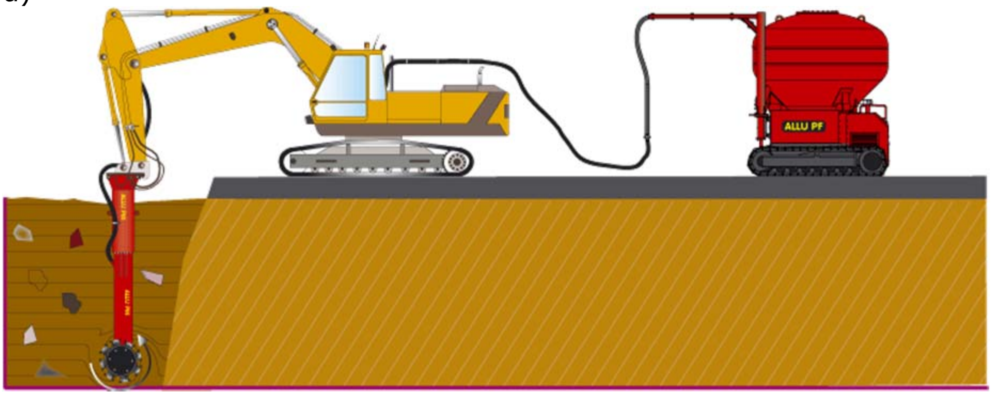
- construction has to be performed in an area with very soft postglacial clay or peat as the areas considered more suitable from the geotechnical point of view have already been constructed,
- shortage of fill and embankment materials, and
- shortage of landfill areas for surplus soils.

The mass stabilisation technology proves to be a cost effective solution to these challenges. This article presents some examples of how mass stabilisation has been applied to solve challenges in various construction sites in the city of Helsinki during the last 20 years.

1. INTRODUCTION

Mass stabilisation is a ground improvement method where binder is mixed into peat, mud or soft clay. The procedure is carried out with the help of a mixing tool installed on an excavator machine (Figure 1). The mixing tool has been invented in Finland in the beginning of 1990's. The technology was initially developed for the purpose of stabilising soft peat and clay. As the mass stabilisation technology has evolved new fields of application have been introduced, for instance the treatment of dredged mud and contaminated soils. The new applications have also led to the development of the process stabilisation method and new equipment for the treatment of dredged or excavated soft soil masses. The phases of the development of mass stabilisation technology are presented more comprehensively by Lahtinen & Niutanen [2009]. Different types of mass stabilisation equipment are depicted in Figure 1.

a)




b)


c)

Figure 1. Different kind on mass stabilisation equipment. Mixing tool installed on an excavator machine and binder storage tank (a) windrow turner (b) and screener crusher (c).

From the point of view of construction needs the stabilisation process brings about significant improvements to the properties of the treated soils. In the last two decades mass stabilisation has been used in tens of various projects in Finland. The method has been applied for such purposes as settlement reduction in embankments, stability improvement, support of slopes and excavations, improvement of bearing capacity, reduction of vibrations, immobilisation and/or confinement of polluted soils. One rapidly increasing application type is the stabilisation of contaminated sediments.

Due to the continual urbanisation process the city of Helsinki is involved in construction of new districts and improvement works in the already existing ones. In many cases the new constructions are carried out in the areas located on very soft postglacial clay or peat as the places more suitable from the geotechnical point of view have been already used. The city also faces the shortage of fill and embankment materials which usually need to be transported from remote sites and a shortage of landfill capacity for the excavated soils of poor quality.

Mass stabilisation technology offers a cost effective solution to these challenges. By improving the chemical and physical properties of the excavated or dredged 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, together with the associated needs for transportation. The Table 1 presents examples of the various construction sites in the Helsinki area where mass stabilisation has been applied and their location is marked on the map (Figure 2). The abbreviations used in the table are: msm = in situ mass stabilisation with the use of mass stabilisation equipment, csm = in situ mass stabilisation with the use of column stabilisation equipment, fss = stabilisation with screener crusher and wts = stabilisation with windrow turner.

Table 1. Examples of different applications of the mass stabilisation method in the Helsinki area.

	Site	Volume m^3	Soil	Equipment	Year
1. Improvement of soft clay and peat layer as a ground improvement method					
A	Pikkuhuopalahti – housing area	test stab.	clay	msm	1993
B	**Kivikko** - industrial area	≈ 270.0000	peat, mud, clay	msm	1997-2010
C	Vuosaari harbour – yard (”Rice field”)	85.000 + ≈100.000	mud, clay	msm + csm	2003-2004
D	Haaga, Laajasuo - sports park	78.000	peat, mud, clay	msm, csm	2006
E	Ormuspelto housing area	31.500	clay	msm	2008
F	Mellunkylä, Virtasalmenkatu, street	50.000	peat and clay	msm	2011
2. Solidification of contaminated sediments and their use as filling material					
G	Sörnäinen – contaminated sediments	20.000	dredged sediments	msm	1998-1999
H	Vuosaari harbor - TBT-contaminated sediments	500.000	dredged sediments	msm	2006-2007
I	Jätkäsaari – contaminated sediments	20.000 80.000	dredged sediments	msm msm	S-2011 W-2011
J	Kalasatama – contaminated sediments	12.000	dredged sediments	msm	2011
3. Lightening old embankments floating on soft clay and mud layers					
L	Toukoranta - park, KTK-embankment	69.000	peat	msm, wts	2005-2006
M	Toukoranta – streets and housing area, Mertakatu	35.000	clay	msm	2007-2008
N	**Kyläsaari,** Arcada 2 - streets and housing area	35.000	clay	msm	2010-2011
4. Substituting rock material with stabilized clay in road construction					
O	Tattarisuo – embankment	test stab.	clay	fsa	1991
P	**Viikki** - clay street	500	clay	fsa, msm	1997
5. Isolating landfill for contaminated soil with mass stabilized clay					
Q	Kivikko – landfill for lead contaminated soils	25.000	clay	msm	2001
R	**Vuosaari, Melumäki** – landfill for contaminated soil	25.000	clay	csm, msm	2004-2007
6. Utilisation of mass stabilized surplus clay in earth constructions					
S	Vuosaari and Herttoniemenranta – landscape creation	≈ 10.000	clay	fsa	≈1998

Figure 2: The location of the sites. The references (A…S) match the ones in the table above.

2. KIVIKKO

Approximately 10 hectares of the lots and streets in Kivikko are situated on soft swamp which had to be stabilised as otherwise the area was unsuitable for construction purposes. The mass stabilisation method was applied in Kivikko for the first time in 1997, and the latest stabilisation work was completed by December 2010. Over years the stabilised area has gradually been expanded. At the beginning of this project, two separate stabilisation projects were carried out - EuroSoilStab (ESS) and Deep Stabilisation Development (DSP). Both took place in the street area. In the first case the mass stabilised layer was placed on the layer which was column stabilised till the depth of 7 m (Figure 5). The DSP project was the first attempt to perform column stabilisation through the mass stabilised layer. [Hautalahti at al. 2007]

The combination of column stabilisation and mass stabilisation was used under the street and pipelines and mass stabilisation at the yards of industrial buildings. In the cases the clay layers were thick, column stabilisation was performed under it also in the yard areas. Soil material treated included soft peat and clay (the top layer down to about 3 m was peat and under that the soft layer of clay started, see Figures 3-4). The clay layer stretches from 3-18 m deep until the moraine starts. [Ilander et al. 1999]

The binding agent in the mass stabilisation process was cement and fine sand. By adding sand it was possible to decrease the amount of binder needed. Depending on circumstances, in one day 800–1000 m^3 was mass stabilised by one mass stabilisation unit.

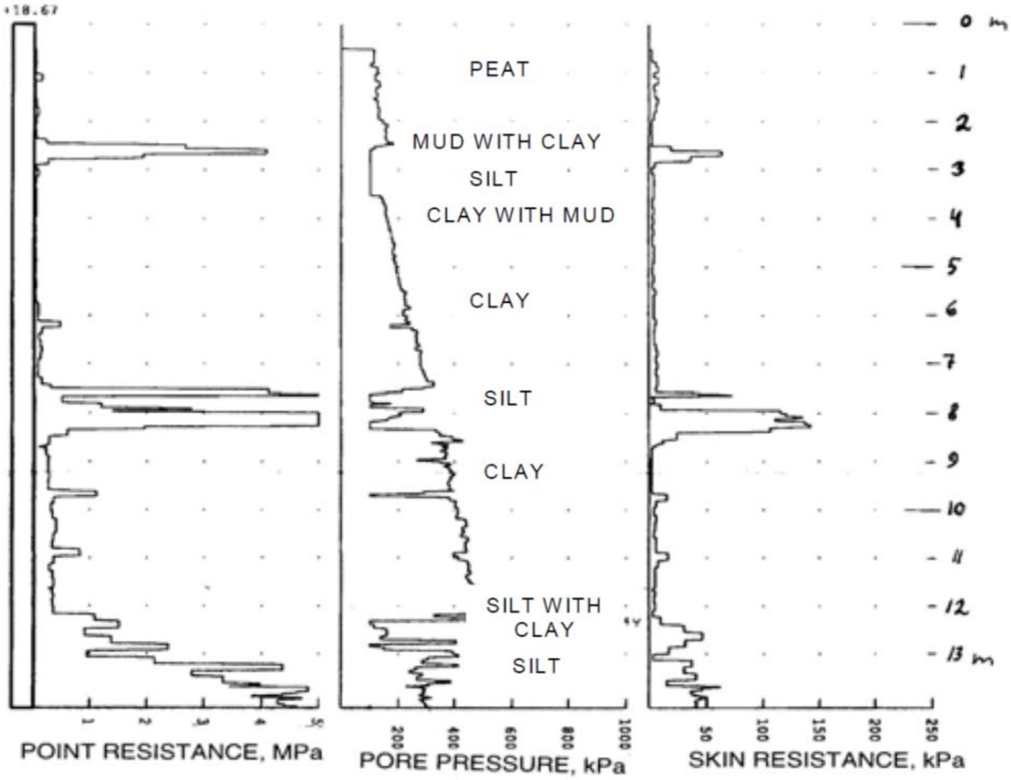
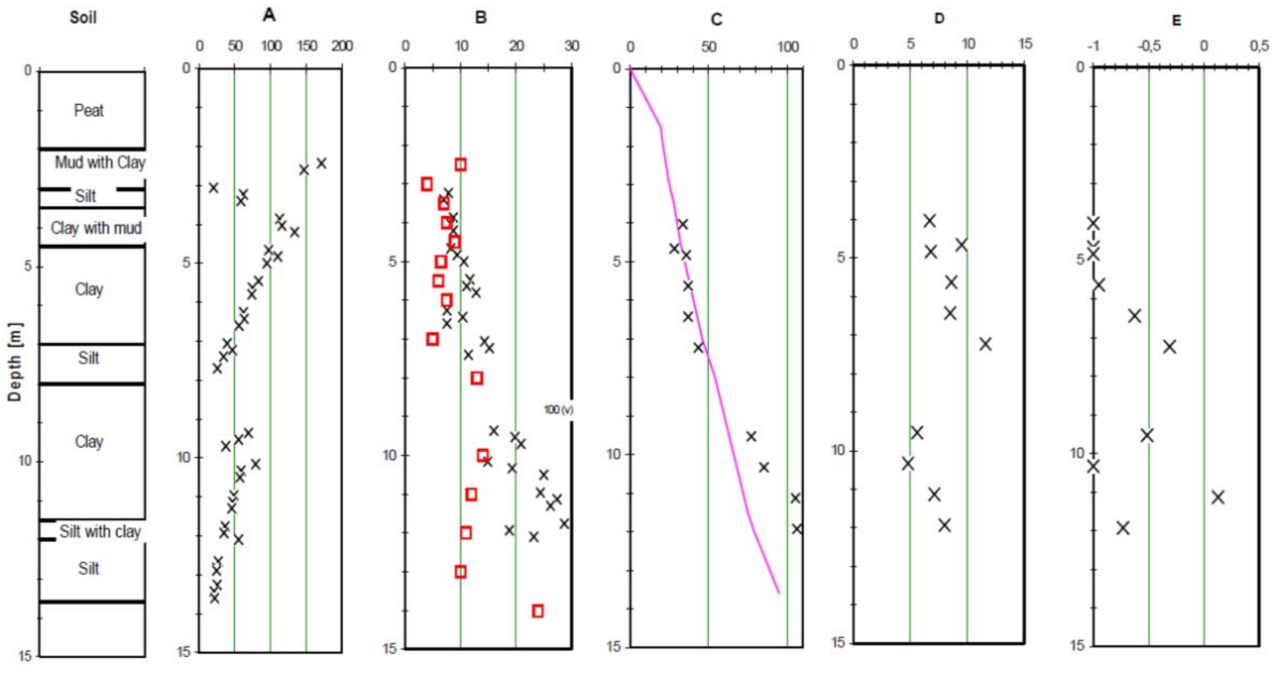


Figure 3. Result of a CPTU test at Kivikko site.



Water content w (A), Shear strength c_{uv} "□" (vane) and c_{uc} "×" (cone) (B), preconsolidation stress σ_c' (C), modulus number m_1 (D) and stress exponent β_1 (E) of Kivikko peat and clay

Figure 4. Geotechnical parameters of Kivikko peat and clay.

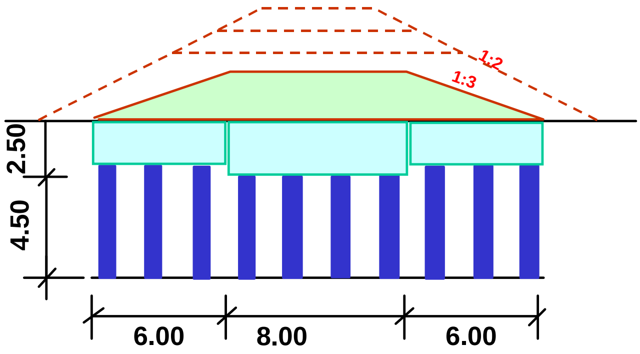


Figure 5. Kivikko. ESS-test embankment, cross section

3. Kyläsaari, Arcada 2

Arcada 2 is located in the Kyläsaari area of Helsinki. The on-going project includes the construction of the street Kyläsaarenkuja to a pile slab, the removal of contaminated soils and existing blasted rock embankment, filling with mass stabilised surplus soils and the construction of a new driveway connection to the Hermanninrantatie road.

The area was filled from the sea in the 1960's. The clay reaches to -15…-25 level from the surface of the sea. The fillings made mainly from blasted rock embankment float on top of the clay. Their thickness is over 20 meters at largest. Other fillings than the above-mentioned floating embankment are about 2-5 m thick.

Because the thickness of the fillings placed above the clay layers varies a lot, this causes horizontal load and lateral displacement. In order to decrease the load and lateral displacement, the heavy blasted rock fillings are replaced with light weight soil up to level -5. The replacements have been made with mass stabilised clay. Also areas from where contaminated soil has been removed are filled with stabilised clay. At Kyläsaarenkuja under a concrete slab a pile structure is constructed, which prevents the lateral movement. The stabilised clay decreases the load on the soils below and diminishes the horizontal displacements, which consequently also decreases the horizontal load on the pile structure. The replacement of the blasted rock boulders makes the installation of the driven steel piles also much easier.

To meet the unit weight requirements set for clay, a pre-treatment method has been developed to decrease its density. The abandoned clay materials are transported from construction sites where utilisation is impossible.

4. Viikki

An experimental street section was built in 1997 at Tilanhoitajankaari in Viikki. Stabilised clay was packed down at the lower part of the bearing layer of the street instead of gravel and crushed aggregate. This was an attempt to find a use for the surplus clay excavated during the building works, and at the same time to spare non-renewable gravel resources. The experimental building proved that surplus clay can be utilised in road construction. [Hakaste et al. 2005]

The clay street –project started with extensive laboratory tests of the properties of Viikki clay stabilised with different binders and binder amounts. The water content of clay used in the test was 54…84 %. The laboratory test included: index tests, 1-axial compression tests, frost heave test, thaw weakening susceptibility test, thermal conductivity test, CBR-test, dynamic 3-aksial test, water permeability test and leaching tests.

The best stabilisation results were achieved with binders consisting of blast furnace slag + cement (70:30), cement + slag (95:5) and fly ash + cement. These binders were applied also in the test structures and the amount of the binder was 14 % from the wet unit weight. The mixing of the binder and clay was carried out with two methods: with fine screening attachment ex-situ and with mass stabilization equipment in-situ. After the curing time of 2-3 h the mix of binder and clay was moved over the filter layer and compacted with vibratory roller. The 550 mm thick layer of stabilised clay constitutes the sub-base part of the structure.

After the construction the comprehensive measures have been carried out: bearing capacity (plate load test, falling weight deflectometer), frost heave, frost depth and damages of surface.

The following issues have been discovered in the test structures:

- frost heave decreases, even though according to the laboratory tests' results, stabilised clay was strongly frost susceptible
- bearing capacity has been higher than expected (136 MPa on top of the clay layer)
- the pavement has remained unbroken
- the condition and bearing capacity of the pavement are corresponding to benchmark sites at this street [Mäkelä et al. 2000].

5. Vuosaari Harbour

During carrying out the Vuosaari harbour project various types of soils were encountered and had to be handled. Different methods of stabilisation were implemented. For instance, a combination of column and mass stabilisation was carried out in a place called "Rice field" for the purpose of ground improvement. The total clay volume of the Rice field was ≈350.000 m^3. Other example of stabilisation works is the restoration of the TBT-contaminated sediments by dredging and mass stabilisation with cement in the lagoons [Leppänen at al. 2009].

In the Vuosaari port area, during the works in the former dock yard soils containing heavy metals and arsenic were excavated. It was decided to utilise them as filling material in the construction of a noise barrier at the area of Melumäki. The environmental permit allowed for the disposal of maximum 140 000 m^3 of contaminated soils which were capsulated in the noise barrier with insulation course at the bottom, side and top. The bottom and the sides of the noise barrier were insulated with compacted stabilised clay.

The Melumäki construction site was situated on soft clay and the bearing capacity and the stability against failure was increased by mass stabilisation and mass replacement. A part of the mass stabilisation work was performed with the use of column stabilisation equipment using large diameter columns (ϕ 1.13 m) which were intersecting each other. The mass stabilisation was made in 2004. After that the construction of the Melumäki was carried out in five stages (2004-2008).

The mineral insulation course at the bottom of the structure was made of mass stabilised clay excavated from the mass replacement area under the Melumäki front side and stored in hips in the vicinity of Mellumäki. It was not possible to construct a sealing layer with the natural clay coming from that area because of its high water content and low shear strength. However, after the mass stabilisation, local clay turned into excellent material for construction of the sealing. The binder used in the stabilisation process was cement in the amount of 50 kg/m^3. The required permeability $k \leq 5.7 \cdot 10^{-8}$ m/s was reached with 0.4 m thick sealing layer. The measured permeability was mostly at level $10^{-9} \ldots 10^{-10}$ m/s in the laboratory and in the situ tests.

Currently the noise barrier serves as an outdoor recreation area in the neighbourhood of the Vuoasaari harbour and the Natura conservation area. [Forsman et al. 2009]

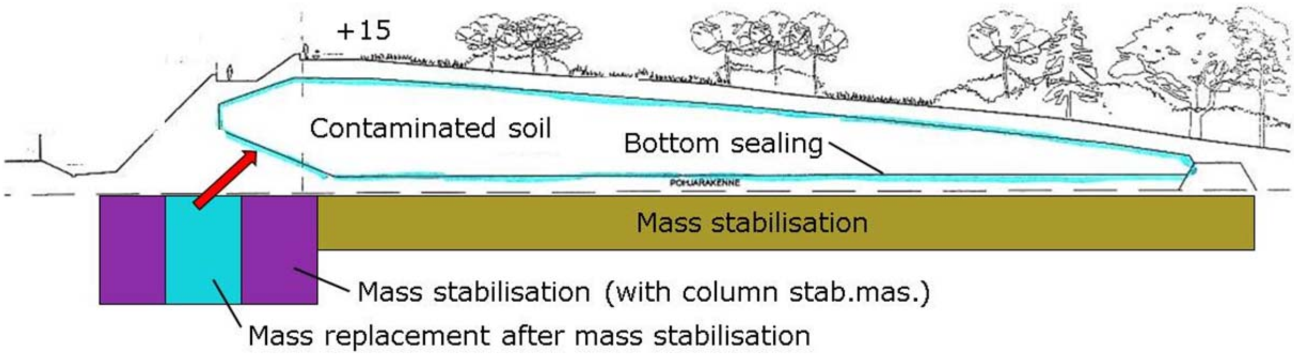


Figure 6: The cross section of the Melumäki noise barrier.

6. FUTURE SCENARIOS

Building activities in the city of Helsinki often occur at areas with poor bearing capacity. There is a shortage of good quality rock material and construction works result in large amounts of excavated contaminated sediments and surplus soils. The city of Helsinki has faced a situation when all the landfills that receive poor quality soils have reached their capacity and the same problem will soon appear in other cities in the capital area – therefore they have imposed a ban on receiving surplus soils from Helsinki. This causes a need for transportation of soil and sediment masses for long distances. In order to solve this problem, the city of Helsinki has started actions to diminish the amount of poor quality surplus soils by half by the year 2012. One of the solutions which is meant to be implemented in a significant scale suggests mass stabilisation and fillings of the shore and sea areas for the construction purposes.

Also, an on-going EU-project called ABSOILS aims at the development of utilisation of surplus soils. ABSOILS is a LIFE+ project which demonstrates the conversion of abandoned and low-quality soils like soft clay into construction materials. The ABSOILS project is carried out in co-operation of the beneficiaries Biomaa Ltd, Rudus Ltd and Ramboll Finland Ldt, and with the support of the Ministry of the Environment and the cities Helsinki, Espoo and Vantaa. The project is co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575). The project started in September 2010 and will finish in December 2014. The project aims to determine the most efficient recipes for the stabilisation of abandoned soils with commercial and non-commercial binder components. The project also addresses some crucial factors in the pilot-scale: the efficient mixing of different, soft clay materials and powdery binder materials for the stabilisation and construction of different applications.

REFERENCES

Forsman, J., Tengvall, J., Hakari, M., Stenvall, M. & Juppi, I. 2009. Vuosaaren satama, Melumäki, pilaantuneiden maiden välivarastointi ja hyötykäyttö meluvallissa, loppuraportti. (in Finnish)

Hakaste, H., Jalkanen, R., Korpivaara, A., Rinne, H. & Siiskonen, M. 2005. Eco-Viikki - Aims, Implementation and Results. City of Helsinki, Ministry of the Environment. 54 p.

Hautalahti, P., Halkola, H., Puumalainen, N., 2007 Kivikon Teollisuusalueen Stabiloinnin Koerakentaminen (in Finnish) Helsinki 105 p.

Ilander, A., Forsman, J. & Lahtinen, P. 1999. Combined mass- and column stabilisation in Kivikko test embankment – Designing by traditional and FE-methods. Dry Mix Methods for Deep Soil Stabilisation. Stockholm 13.-15.10.1999. p. 185-191.

Lahtinen, P. & Niutanen, V. 2009. Develomentof In-Situ Stabilisation Technique in Finland. International Symposium on Deep Mixing & Admixture Stabilization – DM’09, Okinawa, Japan, 19.-21.5.2009.

Leppänen, M., Havukainen, J., Piispanen, A., 2009. Mass Stabilized TBT –contaminated sediment as a Part of the Harbour in Helsinki. International Symposium on Deep Mixing & Admixture Stabilization – Okinawa, Japan. pp. 477-482

Mäkelä, H., Höynälä, H., Halkola, H., Kettunen, A. 2000a. Viikin savikatu. Helsinki: Helsingin kaupunki, kiinteistövirasto, geotekninen osasto. 61 p. GEO 81/2000 (in Finnish)