# Mass stabilization – a method for the reuse of TBT-contaminated sediments as a part of the harbour field in Helsinki, Finland

# La stabilisation de masse – une méthode pour la réutilisation des sédiments contaminés par la TBT comme part de la zone portuaire de Helsinki, Finlande

J. Havukainen, M. Leppänen & A. Piispanen
*Ramboll, Finland*

ABSTRACT
In Helsinki, at the new Vuosaari Harbour a 90 hectare area was to be filled from the sea. The analyses starting in the spring 2003 indicated high tributyltin (TBT) concentrations in surface sediments at a 75 hectare area. All the soft sediments were to be dredged from the harbour area before structural filling. The mass stabilization of contaminated sediment was considered to be the most economical and environmentally safe method to solve the environmental problem. The contaminated area was isolated from the surrounding sea by permanent protective embankments and a temporary silt curtain. The former Niinilahti Bay in the inner harbour area was prepared to receive the contaminated sediment to be stabilized. The surface dredging was carried out by accurate techniques and the contaminated sediment was transported into the stabilization area by barges and by pumping. In 2006 the five metre sediment layer, about 0.5 million cubic metres of material was spread over 10 hectares. The sediment was stabilized with cement and utilized as a harbour field structure. During the mass stabilization work the stabilized sediment was immediately covered by a fabric and one meter sand embankment (first stage preloading). Later the stabilized area was covered by a higher preloading. The QC/QA procedure was approved by the environmental authorities and it was based on the controlling of permeability and shear strength. Also the settlements under preloading were carefully observed. After preloading the stabilized layer was covered with a drainage and surface layers with an asphalt layer on top.

RÉSUMÉ
A Helsinki, dans le nouveau port de Vuosaari, une zone de 90 hectares devait être remplie à partir de la mer. Les analyses qui avaient débuté au printemps 2003 indiquaient de hautes concentrations de tributyltine (TBT) dans les sédiments de surface dans une zone de 75 hectares. Tous les sédiments doux ont dû être retirés de la future zone portuaire avant le remplissage structurel. La stabilisation de masse du sédiment contaminé a été considérée comme étant la méthode la plus économique et la plus environnementalement sûre pour résoudre le problème environnemental. La zone contaminée a été isolée de la mer environnante par des digues protectrices permanentes et un rideau de limon provisoire. L'ancienne baie de Niinilahti qui se trouvait dans la zone portuaire intérieure a été préparée pour recevoir le sédiment contaminé à stabiliser. Le dragage de surface a été effectué à l'aide de techniques précises et le sédiment contaminé a été transporté dans la zone de stabilisation par des péniches et par pompage. En 2006 la couche de sédiment de cinq mètres, soit environ 0,5 million de mètres cubes de matière, a été répandue sur 10 hectares. La sédiment a été stabilisé avec du ciment et utilisé comme structure de zone portuaire. Durant l'opération de stabilisation de masse, le sédiment stabilisé était immédiatement recouvert d'un tissu et d'une digue de sable d'un mètre (première phase de précharge). La zone stabilisée a été par la suite recouverte d'une plus haute précharge. Le procédé QC/QA a été approuvé par les autorités environnementales et il était basé sur le contrôle de la perméabilité et de la résistance au cisaillement. Les tassements sous la précharge ont également été soigneusement observés. Après la précharge, la couche stabilisée a été recouverte d'un drainage et les couches de surface d'une couche d'asphalte en plus.

Keywords : mass stabilization, contaminated sediment, harbour

## 1 INTRODUCTION

The construction work for the new Vuosaari Harbour in Helsinki began in January 2003. Of the area, about 90 hectares was to be filled from the sea. Before filling, the sediment of the sea bottom had to be removed by dredging. In addition, water depth adjacent to the quays had to be increased by dredging to fulfil the rated safe clearance depth.

When the dredging of clay masses, as a whole about 5 million cubic metres, was about to start, elevated concentrations of tributyltin (TBT) were detected in the seabed. Masses that had planned to be dredged could not be dumped in the sea dumping area and the dredging operation could not proceed.

The TBT-containing surface sediment of the Niinilahti Bay was peeled by careful grab bucket dredging and the peeled sediment was transferred to a temporary storage basin. After this operation the clean clay masses were dredged from the Niinilahti Bay and these masses could be dumped in the sea dumping area. But, based on the data collected, in the area of 75 hectares there were still left surface sediments which were considered not suitable for sea dumping because of the high TBT concentrations (mainly over 200 µg/kg dw (normalised)). The sediment analyses indicated that there was 97,6 kilograms of TBT in the seabed in this area. To continue the work a method for reconditioning the seabed had to be developed. The overall solution consisted of three main phases. First, the contaminated area was isolated from the surrounding sea area by protective embankments and a silt curtain structure. Next, the contaminated sediment was removed from the seabed by decontamination dredging carried out by accurate dredging techniques. Finally, the contaminated sediment was transferred to the filling area into four lagoons and after that the sediment was decided to utilize as a filling material in a part of the harbour field with a help of mass stabilization technique.

*Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering*
*M. Hamza et al. (Eds.)*

*doi:10.3233/978-1-60750-031-5-2284*

## 2 PERMISSION REQUIREMENTS

The mass stabilization method was considered to be the most economical and pro-environmental technique. Other possible solutions, for instance the transportation to the treatment plant for hazardous wastes were significantly more expensive and did not contribute the sustainable development. In order to put the idea into practice there was a requirement for three different permits by the environmental authorities.

The contamination dredging itself was guided according to the requirements of two different permit applications by the environmental authorities. For instance, the contaminated area had to be isolated from the surrounding sea area by permanent protective embankments and a temporary silt curtain structure before dredging the contaminated surface sediment.

The mass stabilization method was approved by the environmental authorities provided that TBT will be permanently isolated from the aqueous environment before and after mass stabilization. The utilization area was to be filled by sea sand to the level of -4.0 m. The embankments surrounding the utilization area lagoons had to be built of rock ballast and the inner sides of the embankments had to be covered by a sealing layer of moraine.

The compressive strength had to reach the value of 140 kPa in 90 days and the permeability value $k \leq 5 \times 10^{-9}$ m/s. Furthermore, there were requirements for the QC/QA procedure during the mass stabilization work and also the later controlling measures of the drainage waters in the completed structure.

## 3 PRINCIPLES OF DESIGN

A part of the stabilization area was planned to serve as a container area and other parts were reserved for premises and location areas for harbour traffic. Therefore the stabilized structure was designed to be an almost non-compressive layer with a good bearing capacity. However, the layer might not be too hard for possible piling measures in the area.

The compressive strength of 200 kPa was required in the laboratory so that value 140 kPa would be achieved in field conditions. Analogously the shear strength of 70 kPa was required in the column soundings for quality controlling. The permeability of the test samples was measured with an applicable equipment in the laboratory.

The allowed maximum value of the settlements in the operation conditions was restricted not more than 50 mm under the wide areal loading of 70 kPa. Preloading by permanent and temporary embankments was planned to ensure that the settlement requirements would be fulfilled.

## 4 PREPARATORY TESTING

In addition to the environmental sampling and testing also geotechnical testing was carried out since the beginning of dredging of contaminated surface sediments. The tests included the main geotechnical characterization tests and the hardening properties of the sediment masses with different types of additives.

Besides the commercial binders, also mixtures containing by-products from industry, for example fly ash and desulphurization residue from coal burning power plant and ballast furnace slag from steel industry, have been tested.

The mixtures were also tested in field conditions to ensure the applicability of the mass stabilization technique and the performance of the mixtures in practice, see Figure 1. The results were considered carefully together with designers, environmental experts and the project owner. Two types of cement were selected to the final testing in the beginning of the coming mass stabilization work.


Figure 1. Mass stabilization test in the temporary storage basin of TBT -sediment..

Later, when all the TBT -contaminated sediment masses had been transferred to the stabilization area in the fore lagoons, more laboratory tests were done for the geotechnical planning of the actual mass stabilization project, Figure 2. It was taken test samples in 17 different points, part of them from several layers six different times. Among others, it was made the tests shown in the Table 1.

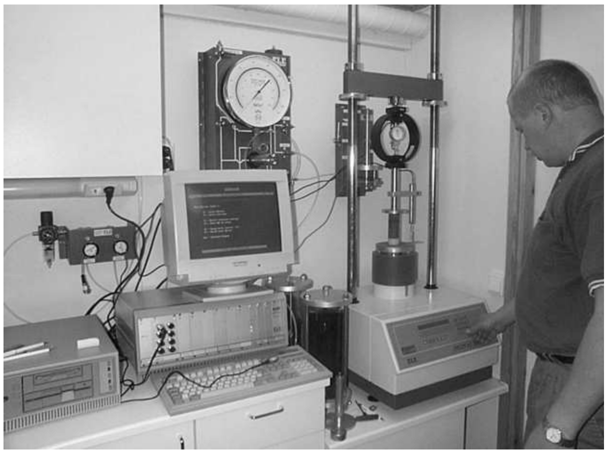

Figure 2. Laboratory testing.

Table 1. The main results from the geotechnical laboratory

| The test | Number of tests | Range |
|---|---|---|
| w [%] | 71 | 30 - 150 |
| $\gamma_w$ [kN/m$^3$] | 46 | 13 – 19,5 |
| loss of ignition | 34 | 1 - 5 % |
| pH | 9 | 7.7 – 8.4 |
| grain size distribution | 21 | muddy clay - fine sand |
| 1-axial compressive strength [kPa] | 427 (of 617 test samples) | $\geq$ 200 kPa finally selected |
| permeality k [m/s] | 7 sediment specimens / 23 tests of 34 test samples | $< 5 \times 10^{-9}$ 22/23 (one under the required) |

## 5 MASS STABILIZATION

The sediment was deposited as a layer of about five metres on the sea sand filling in the four lagoons, Figure 3. Before the actual stabilization work the contractor made the trial stabilization in the lagoon A1 with two different binders and three different amounts of the binder as required in the geotechnical design. Based on the test results the Portland cement was selected to be mixed with the sediment. The amount of cement was 130 kg/m$^3$ of sediment. The stabilization work started in December 2005 and finished in December 2006.

Mixing was carried out by an accurate mixing tool which was installed on an excavator machine. Mixing was done both in horizontal and vertical directions so that a homogeneous hardening soil slab was formed, see Figure 4.

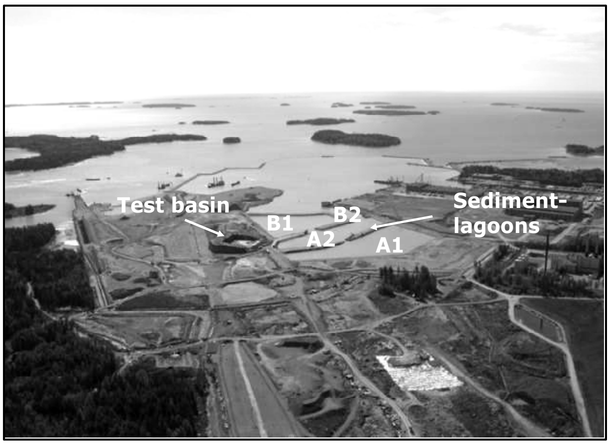


Figure 3. The sediment lagoons A1, A2, A3 and A4 formed the filling area of the contaminated sediments to be stabilized. The temporary storage basin which served as a test basin is seen on the left.

Figure 4. The mass stabilization of dredged TBT -contaminated sediment.

The mass stabilized sediment was covered immediately with a filter textile and no more than one or two days after the stabilization the first 1 m preloading embankment was made on the mass stabilized area.

In every step of the work the safety regulations were followed in order to avoid any risks for failures. After 90 days hardening the higher preloading embankment was constructed on the primary preloading layer. The safety against the failure was controlled during the work by the calculations based on the shear strength measured by the soundings, Figure 5.

The average preloading time was 14 months. The preloading embankment was removed between June and November 2007. The removal time was decided according to the results of settlement obseravitions.

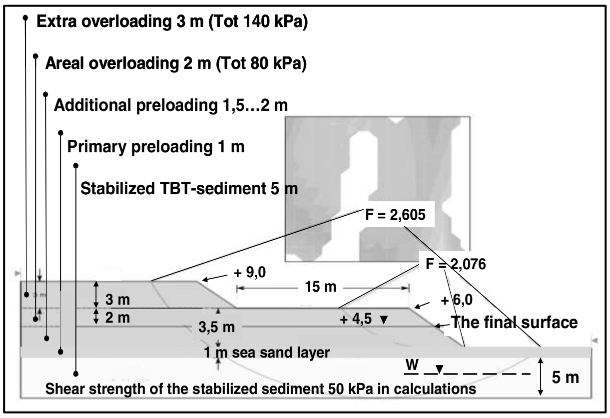


Figure 5. The stability was secured during the different stages of the work.

## 6 QUALITY CONTROL AND QUALITY ASSURANCE

### *6.1 Control soundings*

The testing of the shear strength of the stabilized layer was carried out by so called column soundings. The total number of soundings was 352 of which 294 were included in the mass stabilization contract. Before the elevation of the preloading embankment the quality control soundings (included in the quality control of the contract) were done in each area 14, 28 and 90 days after the stabilization had been completed. The rest 58 of the column soundings were made after the preloading for the final acceptance by the authorities. In order to estimate the results of the column soundings eight vane tests were made.

The results of the soundings represented the shear strength in each level of the stabilized layer. In the design it was required that the values of the measured shear strength at each level must be at least 60 kPa after 14 days hardening. Respectively after 28 days the required value was 65 kPa and after 90 days 70 kPa.

The quality of the completed stabilized structure was controlled according to the quality control program approved by the environmental authorities. It was based on the required minimum shear strength value ($\tau \geq 70$ kPa) after the removal of the preloading embankment and at least after 90 days hardening time and on the maximum permeability value of the stabilized sediment ($k \leq 5 \times 10^{-9}$ m/s). The permeability requirement did not cause any problem during the project.

The test results showed that the range of the shear strength is very wide, Fig 5. The minimum values of the shear strength after 90 days were around 50 kPa and maximum values around 2 000 kPa. That is a consequence of the heterogeneity of the dredged sediment and the inaccuracy in the mixing work. The water content of the sediment varied from 30 % to 150 % and the obtained strength was strongly dependent on the water content of the dredged material. In addition, the grain size distribution of the sediment varied a lot which has a direct influence to the result.

Because the authorities required the shear strength value of 70 kPa in every point of the stabilized structure, the quantity of the binder was kept the same 130 kg/m$^3$ during the whole project and the main interest was focused to the weakest points of the mass stabilized structure. The average diagrams of the column soundings tests (90 days and after preloading) in the lagoon A1 are shown in Figure 6. The most difficult zone to obtain the required shear strength has been the upper 1 m layer of the sediment. The main reason has been the surplus water on the lagoon surface.

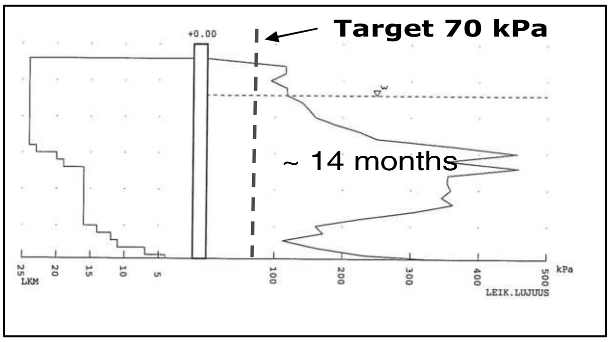


Figure 6. The average diagram of the column sounding tests in the lagoon A1 after 14 months preloading (25 tests).

The shear strength has increased under the preloading most significantly at the weakest points of the stabilized mass.

## 6.2 *Settlements*

The regular settlement observations of the field were made during the preloading. In the four stabilized lagoons 23 settlement observation plates were installed. Furthermore, four settlement observation hoses (l = 50 m) were installed on the stabilized lagoon A1 (Fig. 7).

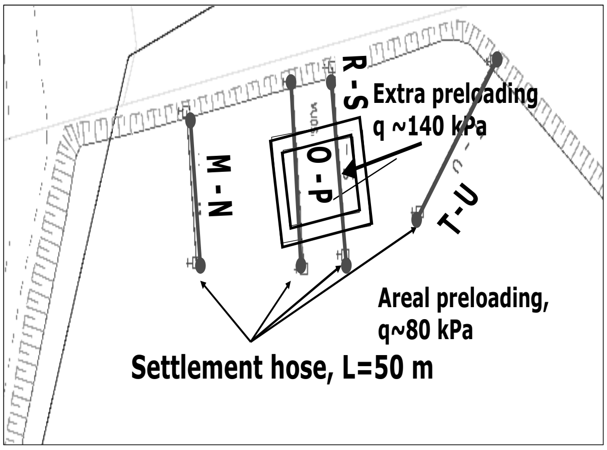


Figure 7. The settlement observation hoses on the stabilized field in the lagoon A1.

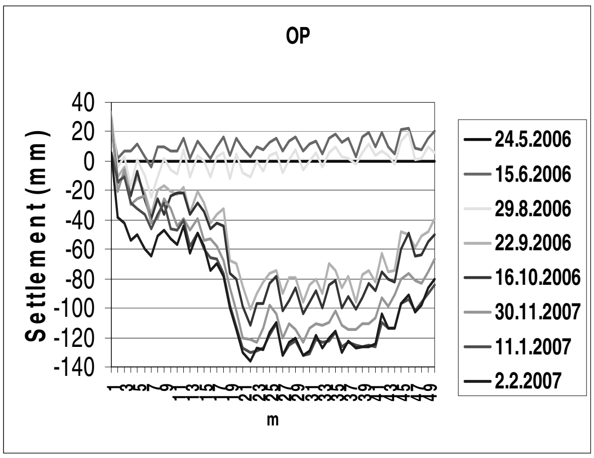


Figure 8. An example of the results of settlement observation hose OP on the stabilized field in the lagoon A1.

The first metres of the hose OP show lower settlements than in the middle of the hose, Figure 8. This is caused by the fact, that the sediment layer has been thinner upon the slope of the embankment than farer away in the lagoon. Furthermore, the area near the slope has been stabilized several weeks before the other parts of the field. Anyway the observed settlements measured in every hose were less than 200 mm.

The settlement plates were installed about 0.5 m above the surface of the stabilized field. So the compression of the embankment did not falsify the results. The results from the settlement plates were equal with the results of the settlement hoses, Fig 9.

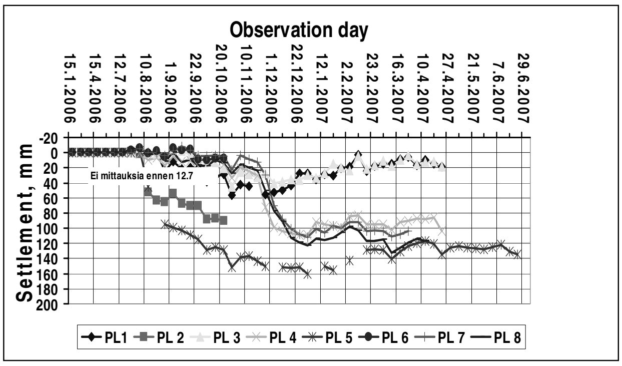


Figure 9. The settlement observation results of 8 plates installed on the lagoon A1.

## 7 COMPLEMENTARY WORKS

The stabilized layer has been covered with a drainage layer with the drainage pipe system. The final construction layers were made after that and an asphalt layer was constructed in summer 2008 on top. The becoming harbour area between the Niinilahti area and the sea area was filled by sea sand and the heavy background embankments of the quays. The outermost quay wall are a concrete structure. Thus the Niinilahti filling and utilization area is thoroughly encapsulated and permanently isolated from the sea area.

## 8 SUMMARY

The total of about 0.5 million $m^3$ of dredged TBT-contaminated sediment has been successfully stabilized in the new Vuosaari Harbour during 12 months mainly in the year 2006 + preloading time. According to the numerous column soundings the required shear strength $\tau \geq 70$ kPa was obtained in every point of the stabilized layer. The shear strength has increased under the preloading most significantly at the weakest points of the stabilized mass. In this case the highest values of shear strength raised even too high. Therefore, before the piles were driven, the best way was to bore a hole for the piles through the stabilized layer. It raised a little the pile driving costs but it was a triviality when we compare them with the benefits of the whole project. Settlements have been observed with 23 plates and 4 hoses. The measured settlement values did not exceed 200 mm. The required permeability values were obtained, $k \leq 5 \times 10^{-9}$ m/s. The mass stabilization method has proved to be an applicable technique to treat contaminated sediment. At the same time the conventional filling material could be saved.