Cement stabilization and solidification – STSO

Review of techniques and methods

Binders, methods and techniques to stabilize / solidify polluted soil and sediment

2006 - 2008

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Summary:

By combining the two techniques stabilization and solidification (STSO or S/S) waste, soil, sediment or sludge are transformed to a more stable material chemically and physically[1]. In the process soil, peat or sediments are mixed with cement or admixtures of cement and other stabilizing agents. The technique does not destruct, but eliminates, prevent or delay the mobility of pollutants in the material. The **stabilization** technique produces more physical and chemically stable constituents which reduce the potential environmental risk the material represent without necessarily changing its physical structure. The **solidification** technique transforms a material to a stable, monolithic structure which reduces access by external agents (e.g. rainfall), without necessarily involving chemical interaction between contaminants and the solidification agent.

This review presents different types of STSO techniques, mixing methods and usages. The main techniques are column stabilization, mass stabilization and layer stabilization. The different techniques serve different purposes e.g. improving the strength of subsoil and or prevent leaching of contaminants from soil. Different purposes require different stabilizers or mixtures of stabilizers and mixing technology. The review does not deal with legislation or other governing approaches to construction, waste treatment or treatment of contaminated soil.

KEYWORDS	ENGLISH	NORWEGIAN
	Stabilization Solidification	Stabilisering Solidifisering
	Technical application	Teknisk anvendelse
	STSO techniques	STSO teknikker
	S/S techniques	S/S teknikker

[1] According to the EU -list of wastes (19 03 stabilized / solidified wastes): Stabilization processes change the dangerousness of the constituents in the waste and thus transform hazardous waste into non-hazardous waste. Solidification processes only change the physical state of the waste (e.g. liquid into solid) by using additives without changing the chemical properties of the waste. After stabilization a waste is considered as partly stabilized if dangerous constituents, which have not been changed completely into non-dangerous constituents, could be released into the environment in short, middle or long term.

ST&SO
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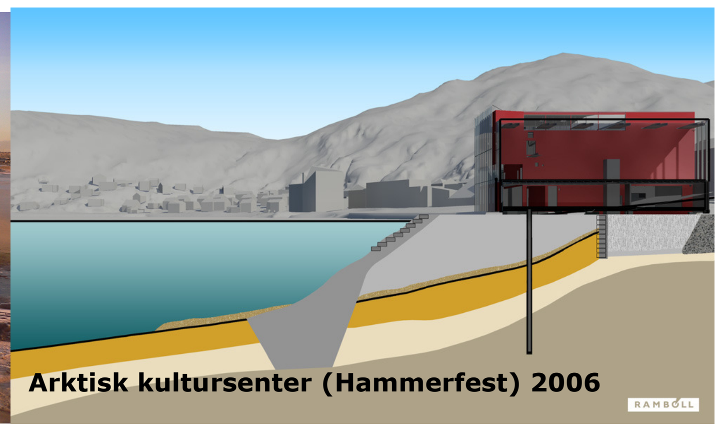
Review of techniques and methods ---



Norcem AS

Cement stabilization and solidification – STSO

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Preface

This work is part of a R&D project coordinated by Norcem AS and supported by The Research Council of Norway.

Project manager has been Liv Margrete Bjerge in Norcem AS.

Project manager at Ramboll Norway has been Arnt-Olav Håøya and Aino Maijala at Rambøll Finland. Co-workers making this report were Juha Forsman, Dr. Pentti Lahtinen and Mikko Leppänen, Dr. Aud Helland and Roger M. Konieczny.

This review is a compact overview for information purposes only. The review and the background information provided for it do not constitute a basis for design. Each project site has unique soil conditions and functional requirements. Therefore careful investigation and planning are always required before stabilization. The authors do not take any responsibility for misinterpretation or misuse of this text.

Table of content

1. Introduction

By combining the two techniques stabilization and solidification (STSO or S/S) waste, soil, sediment or sludge are transformed to a more stable material chemically and physically[1]. In the process soil, peat or sediments are mixed with cement or admixtures of cement and other stabilizing agents. The technique does not destruct, but eliminates, prevent or delay the mobility of pollutants in the material. The **stabilization** technique produces more physical and chemically stable constituents which reduce the potential environmental risk the material represent without necessarily changing its physical structure. The **solidification** technique transforms a material to a stable, monolithic structure which reduces access by external agents (e.g. rainfall), without necessarily involving chemical interaction between contaminants and the solidification agent.

Solidification has a longer tradition than stabilization. The term stabilization has however been used for what actually the solidification process represent. Solidification in the meaning of stabilization has been utilized through the years on many construction sites and harbor areas to improve the strength in soil and dredged sediment to make it suitable for diverse purposes.

In the later years it has become evident that solidification is a suitable technique also for contaminated soils, sediments and other types of waste materials to interlock and reduce mobility of the contaminants by preventing or reducing access of air and water by achieving reduced permeability and porosity of the material. An additional reduction of mobility of contaminants is achieved by stabilization with cement or composites of cement and other stabilizers.

STSO treatments include a wide range of processes that usually involve mixing inorganic binders (like different types of cement) into the soil or waste to transform it into a new, solid and non-leachable material. Binders will usually be selected according to some mix design criteria which depend on the application. The application could be e.g. ordinary infrastructure construction on weak ground, development of a contaminated site, reuse of waste as aggregate in the construction, or land filling.

A STSO alternative should be based on a cost – benefit analysis. The solution is beneficial when the cost is lower than the alternative of excavation and delivery on land fill and refill of new material. STSO treated material has a number of advantages, it reduces risk, increase reliability and reduce process costs. Additionally, in most cases STSO is an environmentally beneficial technology both by reducing contaminant flux and exchange and transport of materials.

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[1] According to the EU -list of wastes (19 03 stabilized / solidified wastes): Stabilization processes change the dangerousness of the constituents in the waste and thus transform hazardous waste into non-hazardous waste. Solidification processes only change the physical state of the waste (e.g. liquid into solid) by using additives without changing the chemical properties of the waste. After stabilization a waste is considered as partly stabilized if dangerous constituents, which have not been changed completely into non-dangerous constituents, could be released into the environment in short, middle or long term.

This review will present different types of STSO techniques, mixing methods and usages. The main techniques are column stabilization, mass stabilization and layer stabilization. The different techniques serve different purposes e.g. improving the strength of subsoil and or prevent leaching of contaminants from soil. Different purposes require different stabilizers or mixtures of stabilizers and mixing technology. The review does not deal with legislation or other governing approaches to construction, waste treatment or treatment of contaminated soil.

The main part of information and data sources is from Northern Europe, mainly from work performed by Ramboll Finland for different clients. Information is also extracted from relevant other sources like newest conference papers (see references). The review includes figures and photos where available. Chapter 4 includes data from various laboratory tests for different projects on cement stabilization.

2. Stabilization and solidification techniques

Different STSO techniques require different mixing methods. The operation may be *in-situ* (in-place) or *ex-situ*. ***In-situ* operations** take place within the ground or site where the processed material originally was located (e.g. an originally contaminated site or lagoons filled with contaminated material). ***Ex-situ* operations** and processes take place away from the original contamination location – either on-site or off-site.

On-site / off-site operations refer to the final disposal location: On-site typically means that the mixed material is placed back in its original location, compacted and left to cure. Off-site placement or use involves transports to the final location site.

There are many systems to classify the different STSO techniques, regarding mixing method and or type of binders being used. Massarsch et al (2005) classify deep mixing methods as wet/dry, rotary/jet-based, auger-based or blade based, and the type of binder as wet or dry. In this review the STSO techniques are classified into layer stabilization, mass stabilization or column stabilization. Mass and column stabilization can be performed as a deep or shallow stabilization processes.   In practice one or several methods can be utilized in a single project.

2.1 Mass Stabilization

Mass stabilization is a relatively new ground improvement technique, especially with reference to soft soils (like mud, clay and peat) or contaminated soils. The method is to mix an appropriate amount of dry or wet binder throughout the volume of the soil layer. The mixing is carried out both horizontally and vertically to set depth. There is no clear distinction between surface and deep stabilization, though the standard EN 14679:2005 "Execution of special geotechnical works - Deep mixing" specifies deep mixing as treatment of the soil to a minimum depth of three (3) meters.

The mixing equipment could be a stationary / fixed (off-site) mixer or a mobile (on-site) mixer. The mixing can be mechanical in batches or a continuous process. Figure 1 gives an example of a mobile **on-site** but ***ex-situ*** mixing unit. The admixture is transported a short distance to the construction site (e.g. a road) for spreading and compaction.

Figure 1: Mass stabilization with stack mixing of excavated soils or by-product materials. Method is applicable for all types of soil.

Mass stabilization as an ***in-situ*** and **on-site** process is an advanced technique which can involve a hydraulically operated mixing unit for the binder mixing and feeding, and an excavator. This kind of system is suitable for treatment of different types of soils (mud, clay, peat, sand, gravel), clean or contaminated. In general the maximum working depth of available machinery is five meters. (See e.g. Ideachip 2005).

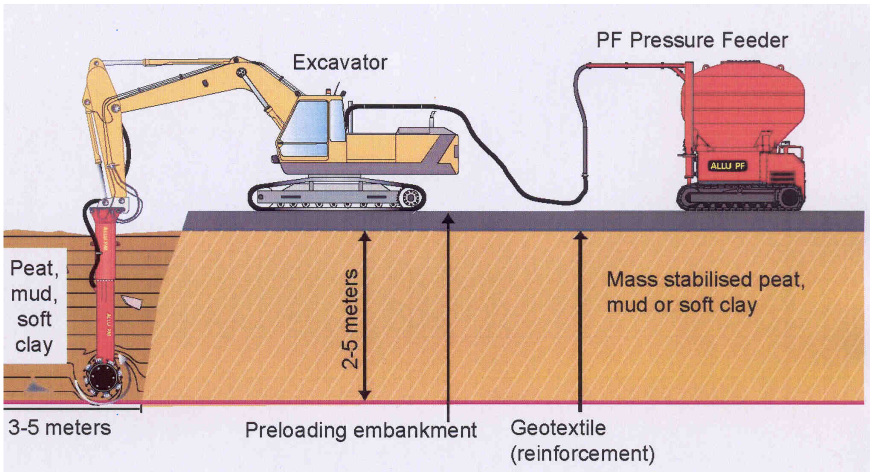

Figure 2: Mass stabilization technique as deep mixing (Ideachip 2005). Method is applicable for soft soils like peat, mud and clay.

Stabilization may take place in several layers (Figure 3). This method is suitable for solid / noncohesive soil. The water content is usually quite high in peat, clay or mud. In such cases STSO in blocks can be an effective treatment (Figure 4).

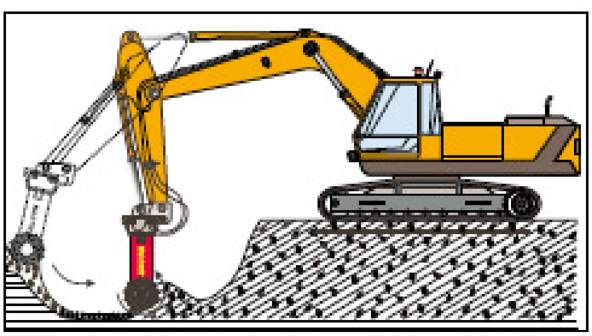

Figure 3: Stabilization in layers. Here the binder is spread on the upper surface or fed through the rotating mixing head. During the mixing process the excavator shaft is taking the mixed soil towards the excavator. The stabilization depth is not limited by the length of the arm. (Ideachip 2005)

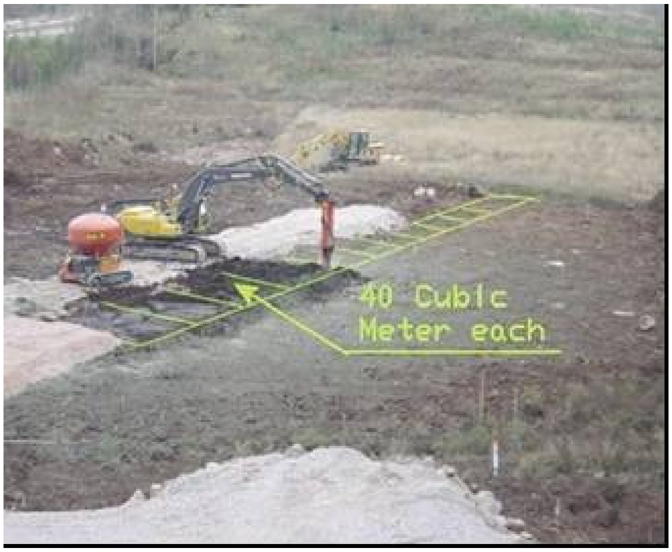

Figure 4. Stabilization in blocks, here for a railroad foundation. The total area is divided into blocks or square areas which are marked (e.g. with sticks). The stabilization takes place block by block. The mixing head in the excavator arm is moving up and down the required depth. The depth of stabilization depends on the length of the arm, maximum 5 meters. (Ideachip 2005)

Mass stabilization is suitable for reduction of settlement and for improvement of stability of soft ground and are applicable in infrastructure projects like roads and railways. It is also used for foundation of smaller buildings and bridges, and for stabilization of excavations, lagoons and natural slopes. In general, the method is found technically, economically and environmentally favorable compared to other alternatives.

Additional information can be found on the web-pages of the Swedish Deep Stabilization Research Centre.

2.2 Column Stabilization technique as deep stabilization

Deep stabilization performed as column stabilization is known at least since the beginning of the 1960s and used in Europe since the 1970s. The mixing method could imply wet mixing, which uses cement slurry as a binder or dry mixing. Principles for the latter method are shown in Figure 5, and will be discussed further in this review.

The dry mixing method implies that soil is mixed with a binder *in-situ* to create a STSO column with a diameter of 0,5 - 1,2 meters down to at least 25 meters depth (e.g. Marrarsch et al 2005, Al-Tabbaa et al 2002). The mixing and monitoring process has improved gradually and is today carried out using electronic process control system. Very often the chosen binder is an admixture of lime and cement – and the resulting products are lime-cement columns.

A deep stabilization project may combine different stabilization methods, like mass stabilization and column stabilization. Figure 6 shows such a combination. Further examples are given in Chapter 3.

2.3 Layer Stabilization technique

Layer stabilization is often performed in the upper soil layer to improve the bearing capacity and other properties of different structural courses, embankments etc. The binder admixture is spread on the soil / embankment / structural course and mixed into the ground by a stabilization cutter or miller cutter which in the process cuts and pulverizes the soil. The treated soil is then compacted. This method makes it possible to stabilize soil without excavating the existing soil and even more makes replacement with virgin soil unnecessary.

A feasible application of layer stabilization is to renovate an existing surface, for instance a road. The process is as follows: leveling of the surface, spreading a thin layer of a binder on the surface, mixing the binder into the ground, in a layer mostly 200-300 mm of thickness with help of stabilizing cutter (or milling cutter), compacting of the stabilized course and covering it with a new pavement or crushed aggregates. Figure 22 in Ch. 3.4 shows the process. The method is also applicable on asphalt pavement. A result of this treatment is shown in Figure 23 (Ch. 3.4).

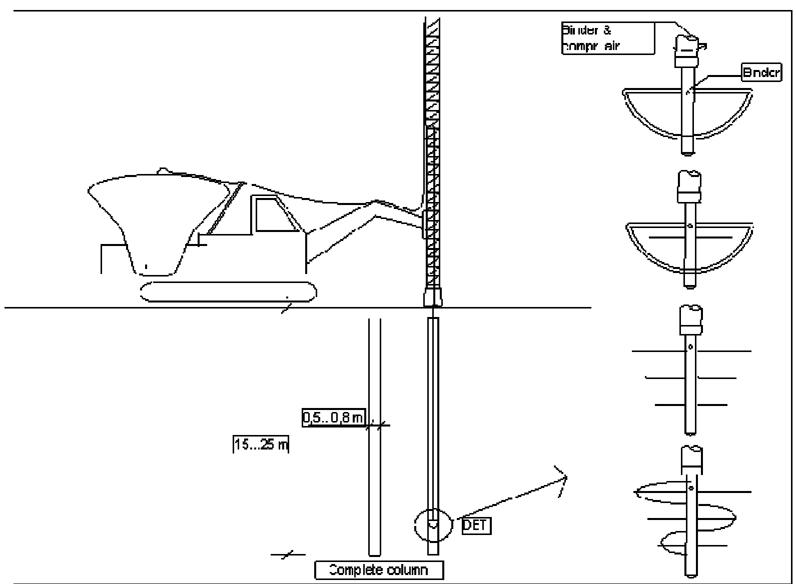

Figure 5. The illustration shows column stabilization equipment and some mixing heads. (Ramboll Finland Oy)

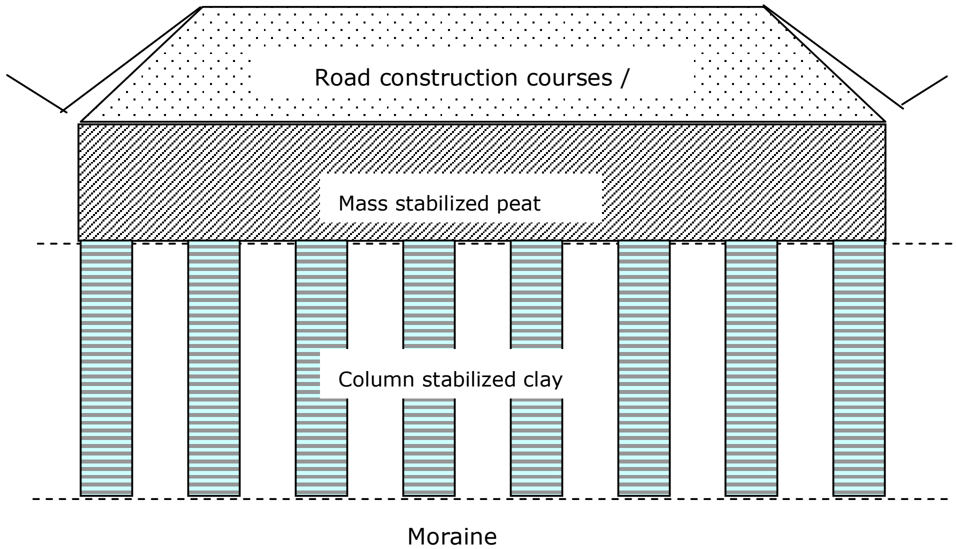

Figure 6. Combining mass- and column stabilization techniques; e.g. for a road (illustration by Ramboll Finland Oy)

3. Challenges and solutions

3.1 Binder selection

Each project site has unique soil conditions and functional requirements. Therefore careful investigation and planning are always required before stabilization or solidification. Strength, leachability and durability are the three main properties considered when designing planning an STSO construction. The design criteria is based on required properties of the end products taking into account the natural conditions on the site, the nature of the material, including contaminants of concern.

During a comprehensive test system an appropriate binder combination is selected for a specific site. The system tests the effect of various binders on unconfined compressive strength or shearing strength, leachability of contaminants based on an appropriate leaching test, permeability, and freeze-thaw and wet-dry durability. In some cases (e.g. EC directive on landfill 1999) the criteria include also e.g. ANC or acid neutralization capacity which is a measure of the stability of the chemical environment in the contaminated material.

Cement is one of the most frequently employed binders for different stabilization purposes. In case of STSO of contaminated soil the contaminated material is mixed with cement and appropriate amounts of water. If the soil material has sufficient water content an addition is not needed.

Cement-based stabilization is suited for both inorganic and organic wastes. Metals could be bound in the matrix due to chemical fixation, whereas others are immobilized due to physical encapsulation. Organic contaminants are often adsorbed to organic material. High organic content may interfere with the curing process and could affect the final strength and impaired the STSO.

Additives like pulverized fuel ash or fly ash (FA) and ground granulated blast-furnace slag (BFS) are sometimes used as partial replacement materials for cement. (e.g. Al-Tabbaa et al 2002).

Several projects have shown that admixtures of elementary iron reduce leaching of metals from STSO material (Maurice 2007, Kumpiene 2006, Kita 1983). According to Sultz (1989) elementary iron as admixture reduce leaching of mercury from STSO treated harbor sediments. Elementary iron in combination with active carbon as admixtures in polluted harbor sediments in UK has also shown a positive effect on reduced leaching of mercury (Guha 2006). Other organic additives as lignin products are thought to have a similar positive effect on binding organic contaminants in stabilized material. In untreated contaminated sediments the presence of active carbon and lignin make the contaminants less available and hence less leachable.

There are some thumb rules when choosing quantity of binder for a laboratory design experiment (Table 1).

Table 1: An example of guidelines to choose binder for different soil types (e.g. Public presentation of Stig Jansson / Cementa in 2003). For mass stabilization the required amounts are smaller than for column stabilization.

SOIL	TYPICAL QUANTITY OF BINDER [kg/m^3]
Clay	120-200
Peat	150-250
Dredged sediment	70-200

3.2 Mixing methods

The challenges in mixing binder and material are related to the mixing itself in getting a homogeneous mix and also the capacity. When the mix is homogeneous a better result is achieved with a more stable and durable construction. The capacity is more or less crucial, varying from one project to another.

Five main systems of mixing material and binders are in use, screen crusher, window turner, stack mixer, a mass a stabilizing system that can vary according to specific demands. The systems are adapted to different use.

The screen crusher can be attached to an excavator or a wheel loader (Figure 7). The window turner is a track driven unit powered by a diesel engine and has higher capacity (up to 6000 m3/h) than a screen crusher. The mixing window could be up to 8 m width (Figure 7).

Figure 7. Pictures show STSO mixing equipment of binders and material. Left fig: Screen crusher, right fig: Window turner (Lasse Lintermo, Allu Finland OY).

The stack mixer is fed with soli or sediment and binder on top of the mixer. After processing the STSO material is spayed out in the bottom of the mixing chamber (Figure 1)

A mass stabilization system is developed to feed right amount of binder and mix it into the raw material *in-situ* and *ex-situ* (Figure 2 and Figure 8). All process data are stored assuring good quality control.

Figure 8. The picture shows process stabilization unit (approx. capacity 200 m3/hr). The binder is fed into the mixing chamber by the conveyor belt to the left and from two silos. The grab-dredger feed soil and sediments into the chamber on the top.

Process stabilization (Figure 8) treats the material *ex-situ* in batches. Based on regular analyses of grain size, water and organic content every batch receives the designed amount of binder. The mixing is homogeneous and performed in a large mixing unit (Figure 8). Binder is fed from a tape guide (fly ash) and from two silos (slag and cement). The stabilized material is transported in trucks or conveyor belt to the actual site. Process stabilization gives better control of the STSO-quality than other mass stabilization units ensuring a better core of STSO-material in the final construction.

Figure 9 gives a listing of different STSO equipment and techniques and its applications.

SOFT SOIL	DREDGED SEDIMENT	CONTAMINATED SOIL	EXCAVATED POOR QUALITY SOIL
Peat, clay, mud • Mass stabilisation unit	Soft sediments, clean/contaminated • Mass stabilisation unit • Process stabilisation unit • Stack mixer	• Mass stabilisation unit • Stack mixer • Screening scoop	Peat, clay, mud • Mass stabilisation unit •Stack mixer • Screening scoop •Process stabilisation unit
Roads, streets, pipelines, parking areas, sport fields, commercial area, residential areas, industrial areas, harbors, storage areas			

Figure 9. Different soil types and suggestions for applied equipment (after P.Lahtinen October 2008).

3.3 Design

STSO design should include laboratory testing, functional design, field trials and process design (CEN EN 14679#). Figure 10 gives an overview of the design process.

The decision of STSO as an adequate solution for the locality should be based on soil investigations as soil profiling and laboratory tests. If STSO is an adequate solution calculations regarded stability is performed followed by settlement calculations. From these calculations dimensions and strength of the STSO construction are determined. Drawings and specifications are made and acceptance of the design is given.

3.4 Environment

STSO as a solution to prevent pollution is a rather new application. Both reduced permeability by solidification and the binding of the pollutants to additives or additive products by stabilization reduce the mobility of the pollutants from a STSO treated material. Laboratory tests measuring leaching (NS-EN 12457) from STSO material show that the mobility of pollutants is reduced.

Since the permeability is very low, a typical target value is $k \leq 1 \cdot 10^{-8}$ m/s, the leaching of pollutants from a STSO construction is by diffusion. The surface area of the construction exposed to water is therefore an important factor for potential leaching.

In order to be in agreement with the basic principles of risk assessment it is necessary to have control of the diffusion in the term of flux (mg/m^2/yr) from the construction. Diffusion tests (modified NVN 7347) shows that the diffusion is significantly reduced by STSO treatment and varies according to binder recipe. Most tests are performed at lab scale and there is a need for more realistic tests reflecting natural conditions.

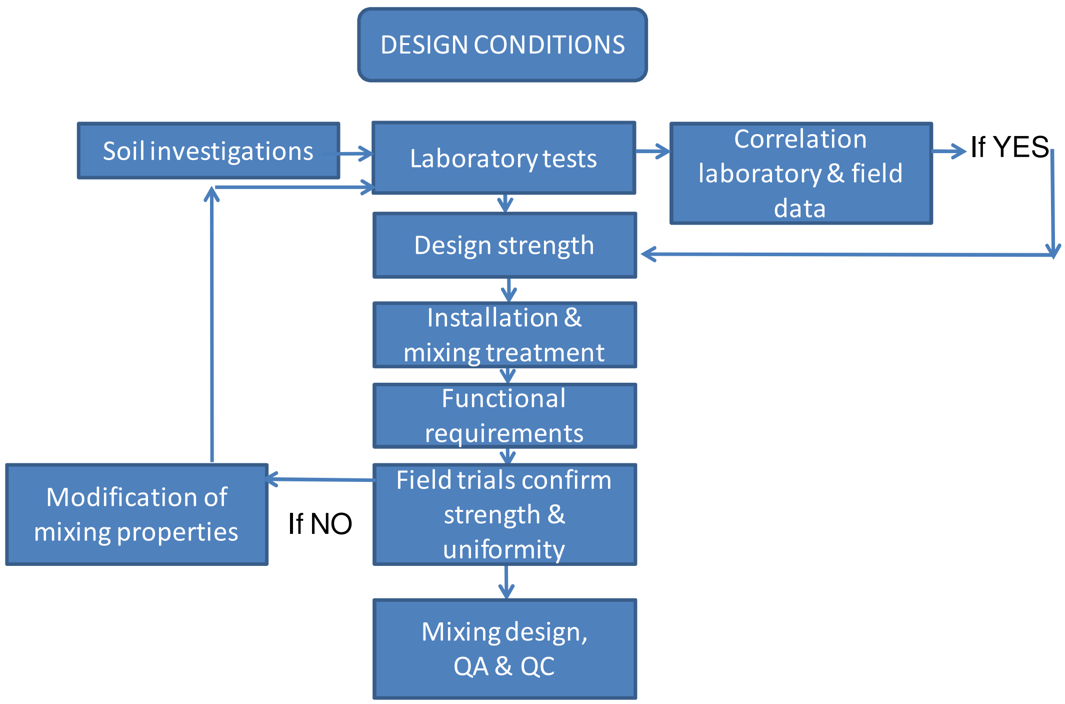

Figure 10. The illustration shows a flow sheet for reaching appropriate design of binder and soil mixture (after J. Forsman October 2008).

Water is the transport medium of the pollutants and also the ruling factor concerning durability. From an environmental point of view the correct mixing design is therefore to a large extent the most important factor to prevent water access.

When correct mixing is optimized weathering is reduced to a minimum and the durability could be similar to concrete, though it should be emphasized that STSO treated material is not concrete. Concrete has a life time of >100 years. The oldest STSO construction is 15 years old a verification of the durability in a long perspective is not yet possible. Investigations have however shown an increasing strength of the construction within these years.

In order to estimate the environmental gain the reduction of flux of pollutants to the environment from untreated (e.g. *in-situ* sediments) and the STSO construction should be evaluated. In addition the LCA perspective should be calculated including local building materials, CO2 budgets and environmental pollutants released to the environment.

4. Technical application of Stabilization and Solidification

This chapter shows different techniques in practice. The different applications are from case studies in Finland.

4.1 Improving the strength of the subsoil

4.1.1. Column stabilization of clay

Retaining wall with column stabilization	
In general	A filling area of the Old City Bay Area, Arabianranta in Helsinki was planned to become the foundation for a new residential building area. The filling was very weak, of soft mud and mud/clay layers, and needed reinforcement to prevent the horizontal movements of the foundation after building. The implemented solution is a retaining wall based on cell construction with stabilized columns.
Project site	Arabianranta, Helsinki; *Figure 7*
Project period	October 2000 – November 2005; *Table 2*
Dimensions	Total quantity of columns more than 7000; column diameter 900 mm; column length varying from 2 to 24 meters
Soil	Clay, soft mud
Stabilization technique	Column stabilization; some mass exchange of the upper soil layers; *Figure 8*
Binder	Cement 100 – 250 kg/m3; depending on the soil type at different depths of the foundation and on the depth of the column
Additional data	Targeted shear strength: 400 kPa from 0 to -10 meters and 750 kPa at lower levels. Achieved shear strength: in average 1300 kPa. Binder quantity varying in relation to the recipe; maximum ± 50 kg/m^3.
Source(s)	Forsman et al 2006

Table 2: Arabianranta. Data on the progress from 2000 to 2005 (Forsman et al 2006)

Section	Columns					Stabilization period
	Total [m]	Quantity	max length [m]	min length [m]	diameter [mm]	
1	33191	1835	24	17	900	Oct 2000 – June 2001
2	16148	1279	15	9	900	Aug 2001 – Oct 2001
3	25081	2186	18	3	900	July 2002 – Oct 2002
4	10665	1008	15	2	900	2004
5	nd	nd	nd	nd	900	May 2005 – Nov 2005

Note: The contractor changed after Section 3 was finished. The total quantity of columns in sections 1 – 4 is 7208 pieces.

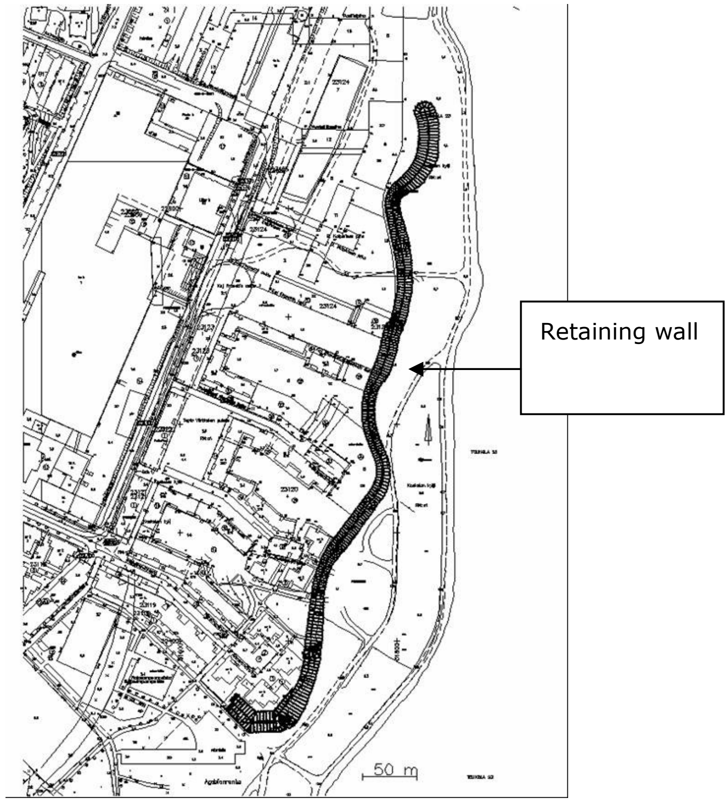

Figure 11. Five sections of column stabilized zone wall of Arabianranta, Helsinki (2000-2005). The wall stiffens and strengthens making a retaining wall. (Forsman et al 2006)

Figure 12: Column stabilization in Arabianranta. (Forsman et al 2006)

4.1.2. *Mass and column stabilization of soft soils in Finland*

Veittostensuo

Stabilization of peat for a highway embankment	
In general	The information is given on a test embankment which encouraged Ramboll Finland in carrying out this and other projects further with this methodology.
Project site	A swamp area, Veittostensuo, in southeast Finland
Project period	Construction period from 1989 to 1993
Dimensions	Length of the soft swamp area for the highway: 1.2 km. Size of the first test area 13*18 m^2. Size of the total swamp area around 200 hectares.
Soil	Peat (w = 1200 – 1700 %), 3 m thick layer; under this various clay layers (w = 50 – 100 %) to a depth of about 18 m
Stabilization technique	Mass stabilization of peat and column stabilization of clay; *Figure 9*
Binder	Mass stabilization of peat: cement + BFS; target 300 kg/m^3; column stabilization of clay: Finnstabi® + lime; target 125 kg/m^3
Additional data	Mass stabilization: The targeted shear strength 50 kPa; the achieved shear strength (30 days after stabilization) 40 - 150 kPa. Column stabilization: The targeted shear strength 100 kPa; achieved in average 90 – 140 kPa. The successful test embankment encourages the Finnish Road Administration to carry out full-size projects with the stabilization methodology.
Source(s)	Andersson et al 2003; Ramboll Finland Oy (project data)

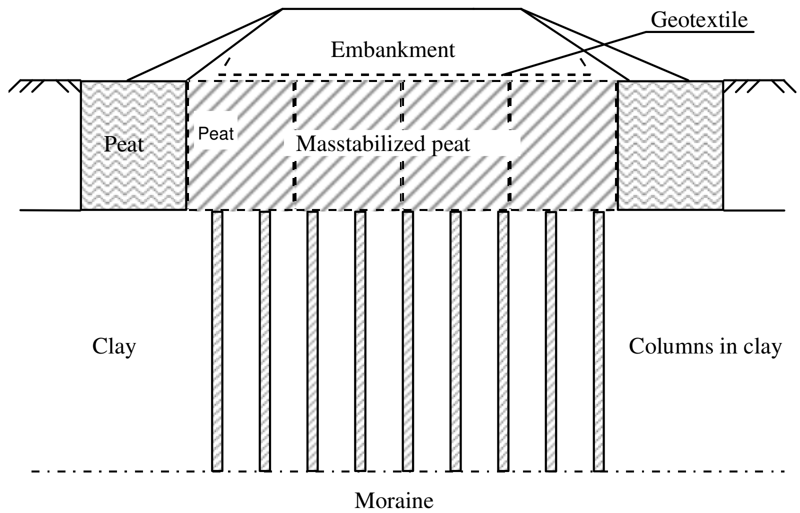

Figure 13. The structure of the test embankment in Veittostensuo 1993 (Andersson et al 2003)

Kivikko

Stabilization of a swamp area for a foundation of a industrial site	
In general	The project objective was to strengthen the soil for the foundation for a parking lot and industrial site. The total area is 23 hectares, but almost a half of it situates on soft swamp.
Project site	Kivikko, Helsinki
Project period	1997 – 2003; 1997 – 2000 field tests and full scale stabilization during 2001 – 2003; unfinished project
Dimensions	About 12 hectares of the lots and streets situate on soft swamp area; 4 hectares mass stabilized by the end of 2003 Mass stabilization: depth max 3 m
Soil	Peat (w = 400 – 1000 %), clay (w = 35 – 150 %), stiff silt thinly between clay layers and sand/moraine
Stabilization technique	Field tests with combined mass and column stabilization; in full scale mainly as mass stabilization until 2003. Combined mass and column stabilization has been planned to continue in the year 2006.
Binder	Field tests; *Table 3* - mass stabilization with Finnstabi+cement 140 – 225 kg/m^3 - column stabilization with different binders, e.g. lime+cement 80 – 120 kg/m^3 Full scale works: sand as additive, 150 kg/m^3, and cement 100 kg/m^3 as binder
Additional data	The shear strength after mass stabilization and column stabilization has been investigated by CPT-tests, approx. 3 months after stabilization. In the undisturbed mass stabilization the values were 90 – 160 kPa. The targeted / designed shear strength was 100 kPa. The column stabilization was not as successful; none of the columns reached the designed shear strength 120 – 150 kPa. It indicates that lime-cement binder does not work in the organic muddy clay as well as it does in pure clay.
Source(s)	Ideachip 2006; Hautalahti 2004; Puumalainen et al 2004; Ramboll Finland Oy (project data)

Table 3: The binder choice for EuroSoilStab-test structures in 1999 (Hautalahti 2004)

	Binder	Amount of Binder [kg/m^3]		
		Test structure 1	Test structure 2	Test structure 3
Mass stabilization	F + Ce (1:1)	225 170 (under slopes)	170	140
Column stabilization	F+THK+BFS (1:1:1)	150 (75 kg/m)	-	
	Lime+Ce (1:1)	-	2A 120 (60 kg/m)	80 (40 kg/m)
	F+THK (1:1)	-	2B 120 (60 kg/m)	-

F = Finnstabi®, Ce = Ordinary cement, THK = industrial lime, Lime = CaO BFS = blast-furnace slag (ground)

IKEA

Reinforced swamp area for a foundation of a department store	
In general	The second department store of IKEA in Finland was chosen to be on swamp area between rocky hills. This area had previously been a landfill for secondary soil materials and construction waste. Also, it includes part of foundation for an old highway. However, the logistical location was more important than the construction technical qualifications.
Project site	Vantaa, Finland
Project period	- Test stabilization: March 2002 - Stabilization of yards: April 2002 – September 2002 - Stabilization of the driveway: December 2002 – February 2003 - (The department store area was reinforced with concrete piles and bearing slab)
Dimensions	The department store is three stories high and takes 26000 m^2. The acreage of surrounding yards, parking lots and traffic areas is 50000 m^2 altogether.
Soil	Diverse compressible and soft soil layers between 5 and 13 meters e.g.: peat (w = 50 – 500 %), mud (w = 70 – 290 %), clay from -1 … -3 meters and below (w = 40 -140 %) and silty mid layer (w < 50 %). Under the clay layer at -9 meters there is silt / sand and finally glacial till down to -30 meters. The ground water level has varied at the depth of 1 – 1.5 meters from the ground surface.
Stabilization technique	Combined mass and column stabilization of yard- and driveway area. Columns were made before mass stabilization. Mass stabilization was extended to the base of the peat layer. *Figure 10* gives a look at the foundation works.
Binder	Mass stabilization: Cement; 100 kg/m^3 Column stabilization: Finnstabi® + lime + cement; 90 kg/m^3
Additional data	The designed shear strength for the columns was 90 kPa and for the mass stabilization 40 kPa at the age of 30 days.
Source(s)	Koivisto et al 2004

Figure 14. Photos of the on-going foundation works at the IKEA site (Koivisto et al. 2004)

4.1.3. Mass stabilization of Irish peat

Mass stabilization of peat for a foundation of a residential area	
In general	The example is a test field and one of several stabilization projects on-going in Ireland. This test stabilization was carried out in order to ascertain the binder for the foundation of a residential area.
Project site	Clonmullen, Edenderry, Ireland
Project period	Test stabilization in September 2005. Unfinished project. *Figure 11*
Dimensions	Total amount of peat to be stabilized is around 100000 m^3. The small test area was about 80 m^2.
Soil	Pseudo-fibrous peat: w = 300 – 900 %, LoI (at 800°C) = 40 – 90 %
Stabilization technique	Mass stabilization; after stabilization the stabilized area was preloaded with a surcharge of crushed aggregates (thickness 650 – 750 mm)
Binder	Ordinary cement; 200 kg/m^3
Additional data	Designed shear strength was 100 kPa at an age of 28 days. Probably due to high sulphate content of the soil as well as other factors, the target was not met. The cement will be changed into a sulphate resistant type.
Source(s)	Niutanen 2006b

Figure 15. Test field for deep stabilization of Irish peat in September 2005. (Niutanen 2006b)

4.2 Stabilization of low-quality soils

4.2.1. Cement stabilized clay as liner for a disposal basin

Cement stabilized clay liner for a disposal basin	
In general	Lead-contaminated soils were planned to be disposed off in a disposal basin and encapsulated with thick soil layers for a subsequent use as a recreational area. The bottom lining of the disposal basin was made of stabilized clay. This kind of barrier would guarantee a sufficient environmental protection.
Project site	Kivikko, Helsinki
Project period	Summer – autumn 2001
Dimensions	-
Soil	Post-glacial clay; w = 50 – 90 %, clay content = 40 – 88 %
Stabilization technique	Mass stabilization. The liquefied clay was transported in watertight truck platforms from the borrow site to the landfill site of Kivikko and it was stored in earth-basins the bottoms of which were isolated from the subsoil by geotextiles. After this the clay was treated by mixing cement into it in the basins. The equipment used to complete this task was originally constructed for the mass stabilization of natural peat, clay and silt layers down to a depth of 4 m and it was modified to mix cement into clay. After the treatment, the mixture of clay and cement was allowed to set for a period of 6…12 hours after which it could be handled and used. The reason for adding cement was only to improve the workability of the clay while its plasticity and permeability properties remained as the same. Spreading and compaction could now be performed in the same way as those for dry crust clay. *Figure 12*
Binder	Cement; 30 – 90 kg/ton
Additional data	Permeability of clay liner after stabilization in average k = 4,7 x 10^{-10} m/s
Source(s)	Ravaska et al 2003

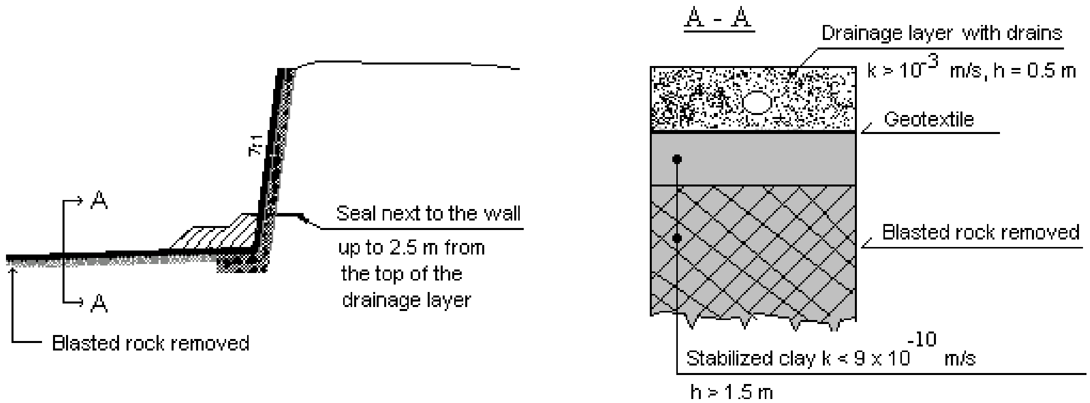

Figure 16. Structure of the Kivikko disposal basin (Ravaska et al. 2003)

4.2.2. *Mass stabilization of a lagoon containing dredged mud*

Mass stabilization of dredged sediment in a lagoon	
In general	The information is based on a quality control report of a test site. The test was carried out in order to ascertain the methodology and binder (type and amount) to carry out a full-scale stabilization for a foundation of a harbor container storage field.
Project site	Valencia, Spain
Project period	August - September 2005
Dimensions	Total lagoon around 5 hectares; test area a small section only; *Figures 13 and 14*
Soil	Mainly clay; heterogeneous (hard and dry in the surface and at lower layers relatively soft and plastic)
Stabilization technique	Mass stabilization, *Figure 14*
Binder	Cement; during test 70 – 110 kg/m^3 Final choice not known; anyway more than 90 kg/m^3 – see "additional data"
Additional data	Designed shear strength ≥ 225 kPa; field test results not satisfactory (around 75 kPa)
Source(s)	Niutanen 2006a

Figure 17: Lagoon for stabilization (within the white circle). Spain 2005 (Niutanen 2006a)

Figure 18: On-going works of test stabilization. Spain 2005 (Niutanen 2006a)

4.3 Stabilization and solidification of contaminated soils

Stabilization and solidification or S/S is a remediation method which without removal of the contaminants prevents their further spreading and hence offers an immediate solution. It also offers rapid implementation of the treatment hence enabling immediate redevelopment of contaminated sites (or reuse of waste materials). In addition, it is a cost-effective method which is competitive with other remediation methods, including transport to landfill. (Al-Tabbaa et al. 2002).

There exist different stabilization technologies to change the contaminated materials – like excavated and dredged masses - into acceptable construction materials – e.g. for landfill construction or other infrastructure purposes. The possibilities for this kind of beneficiary recycling depend on the rate of contamination, the technical properties of the soil material, the available treatment alternatives, the economics and the environmental permits for the alternatives.

One of the treatment alternatives is stabilization and solidification (S/S). This is possible on site or off site, the latter involving massive mass exchange procedures. Mainly, the stabilization is possible in case the contaminated material can be successfully stabilized and is not classified as hazardous material. Cement stabilization / solidification can be effective in case the contaminants are inorganic and/or rather insoluble and environmentally stable compounds. In case of organic contaminants stabilization with bitumen may be effective.

The following case examples are from Finland.

4.3.1. *Contaminated dredged mud for infrastructure development*

Stabilization of contaminated dredged sediment	
In general	In the coast of Helsinki city a new parking lot has been constructed by filling the sea area, within a basin constructed between a new edge embankment and the previous shore line. Due to the slightly contaminated top layer of the sediment of this area the dredged sediment was disposed off into this basin and stabilized for the foundation of the new parking lot. Contaminants were mainly heavy metals, PCB and oil.
Project site	Sörnäinen, Helsinki
Project period	1998 – 2001 (including follow-up)
Dimensions	Area of the basin surface 30 m x 150 m (4500 m^2); see also *Figure 15*
Soil	Mud (w = 80 – 140 %) and clay (w = 60 – 120 %); *Figure 15*
Stabilization technique	Mass stabilization; depth of mixing in average 3 meters; *Figure 15*
Binder	Rapid cement 110 kg/m^3; see *Table 4*
Additional data	Designed shear strength: 30 kPa Obtained shear strength: 115 – 207 kPa Environmental follow-up with leaching tests indicate no risk to the environment after stabilization. See *Table 5*.
Source(s)	Mehtälä et al 2000, Jelisic et al 2005 and Ramboll Finland Oy (project papers)

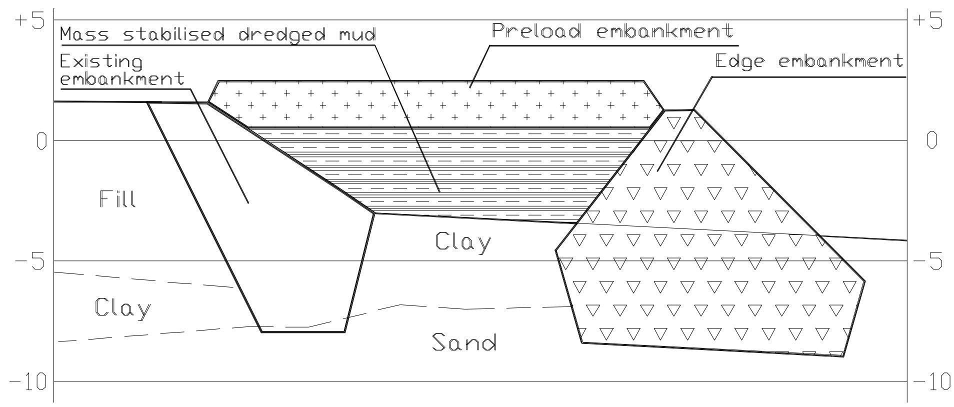

Figure 19: The principle of the structure in Sörnäinen, Helsinki (Mehtälä et al 2000)

Table 4: Unconfined compression strength (q) and permeability (k) of stabilization tests of contaminated top layer sediment of coast of Sörnäinen, Helsinki (Mehtälä et al 2000)

Binder	***amount***	***q***	***k***
	(kg/m^3)	(kPa)	(m/s)
Rapid cement	50	<10	
	80	39	22,0*10^{-9}
	110	93	
FTC	50	<10	
	80	19	
	110	20	
Ekomix	50	<10	
	80	33	9,6*10^{-9}
	110	60	

Table 5: The table shows the chemical content and chemical leaching from dredged sediment after mass stabilization. Note: Finnish guide values are preliminary, statutory guide values pending. (Jelisic et al 2005; Ramboll Finland Oy).

Element / compound	**Results on analysis of stabilised samples from site in 2001**			**Total content, guidevalues (SYKE 2000)**		**Leaching, guidevalues (SYKE 2000)**	
	Total content	**Leaching**					
	ICP-AES	EN 12457-3	NEN 7343	Clean soil	Limit value	**Group 1**	**Group 2**
		L/S 10	L/S 10				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
As	6,1	0,020	0,015	4,0	60,0	0,141	0,85
Cd	0,6	0,0003	0,000	0,2	10,0	0,011	0,015
Cr	44,9	0,074	0,037	37,0	500,0	2	5,1
Cu	25,5	1,389	0,863	18,0	400,0	1,1	2
Ni	24,7	0,562	0,422	19,0	300,0	1,2	2,1
Pb	20,0	0,053	0,001	15,0	300,0	1	1,8
Zn	97,6	0,018	0,072	23,0	700,0	1,5	2,7
Rec. arom. HC-compounds	< 0,1	<0,1	-	<0,1	<1	Group 1: pavement not required; Group 2: pavement required	
Rec. alif. or cyclic HC-sompounds	< 0,1	<0,1	-	<0,1	<1		

4.3.2. *Contaminated masses to a recreation site*

Stabilization of contaminated masses for a recreation site	
In general	The case is shortly describing stabilization and solidification of diverse contaminated soil masses at a disposal site that will be developed further to a recreation site. The contaminated masses contain mainly inorganic contaminants like heavy metals and have been collected from the Helsinki city area since the year 2000.
Project site	Vuosaari (Nordsjö), Helsinki
Project period	2000 – 2007; after this the site will be closed as a disposal site and finished with the covering courses until 2008
Dimensions	The area of disposal site is 15000 m^2; space for stabilized soil for 100000 m^3
Soil	Diverse, heterogeneous
Stabilization technique	Moveable mixing equipment, *Figure 16*; after mixing the mixture of soil and binder is spread and compacted on the disposal site. The thickness of one compacted layer is around 300 mm. The most important criteria for a successful S/S process are the strength and hydraulic conductivity of the stabilized soil.
Binder	Cement
Additional data	Targeted (designed) unconfined compression strength = 1 MPa and permeability $k \leq 1*10^{-8}$ m/s. These target values have been achieved partly. The environmental control tests indicate that leaching of heavy metals and arsenic was below the limit values given by environmental permit authorities.
Source(s)	Helsinki City 2005; Mroueh 2001

Figure 20: Ekomen system to mix and stabilize/solidify inorganic contaminated soils. The equipment is movable to the treatment site. (Ekokem / Österbacka)

4.3.3. Contaminated soil for the construction of landfills

Most applications based on the use of solidified / stabilized contaminated soil have been *in the construction of landfills*, e.g. for the closing structure of a landfill. One of the latest examples in Finland is in Ähtäri. Here the plan is to solidify slightly contaminated soil masses, maybe together with industrial waste like fly ash, for the impermeable barrier of the landfill. In case of inorganic contaminants like As, Cr and Cu, cement will be used as binder. (Ähtärin kaupunki 2005).

4.3.4. *TBT-soil for harbor infrastructure development*

Stabilization and solidification of TBT-contaminated dredged sediments	
In general	The case combines the stabilization of low-quality soil and solidification of contaminated soil. Here the dredged sediment containing TBT and other organic tin compounds is being placed and stabilized on shore in a basin. The stabilized foundation will later be used as a container storage area of the harbor. *Figure 17*
Project site	Vuosaari (Nordsjö) harbor, Helsinki
Project period	2005 – 2007
Dimensions	The estimated volume of dredged masses to be stabilized and solidified is more than 450000 m^3
Soil	Soft clay
Stabilization technique	Mass stabilization
Binder	Cement, in average 130 kg/m3; probably also coal fly ash will be used (partly) – see results in *Figure 18*
Additional data	Targeted unconfined compression strength of stabilized masses: around 140 kPa. There are many binder alternatives to meet this target, according to preliminary laboratory tests like shown in *Figure 19*
Source(s)	Vuosaari publications; report data of Ramboll Finland Oy

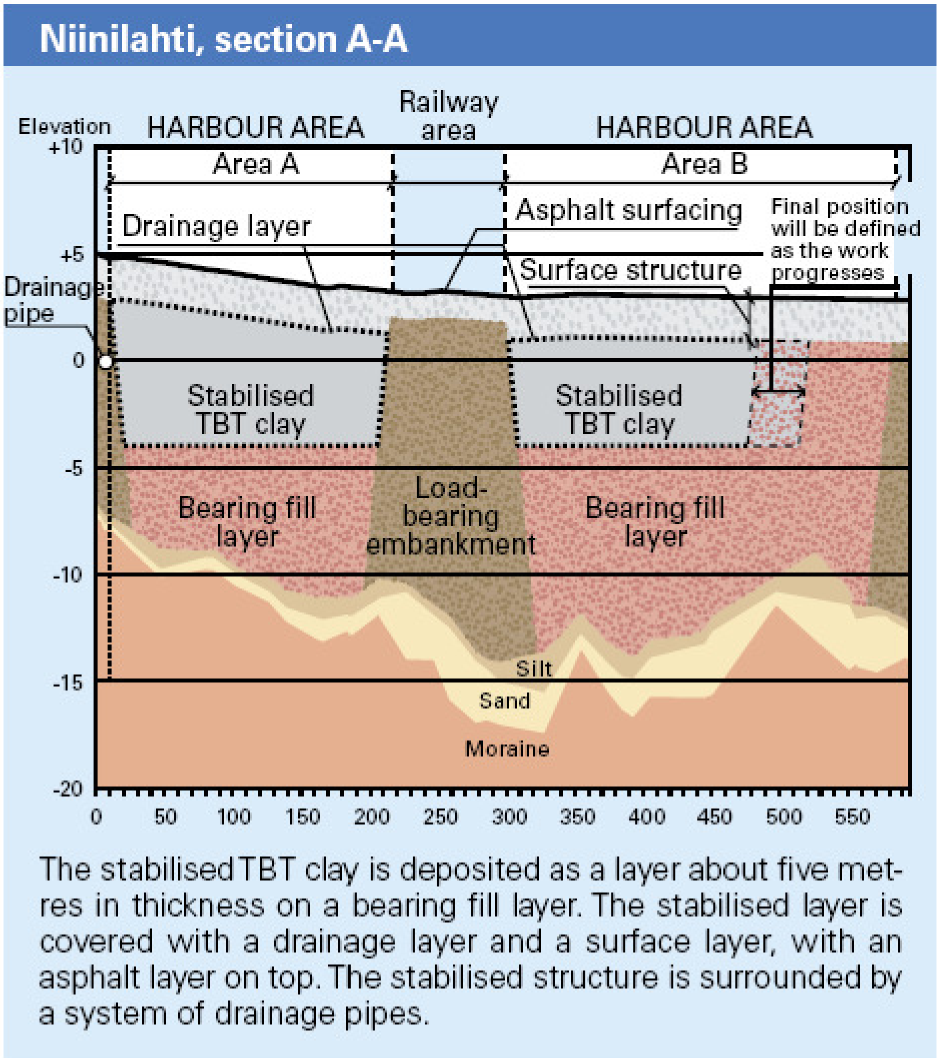

Figure 21: Vuosaari (Nordsjö). Structure of the area with stabilized, TBT-contaminated dredged sediment (i.e. clay). (Vuosaari)

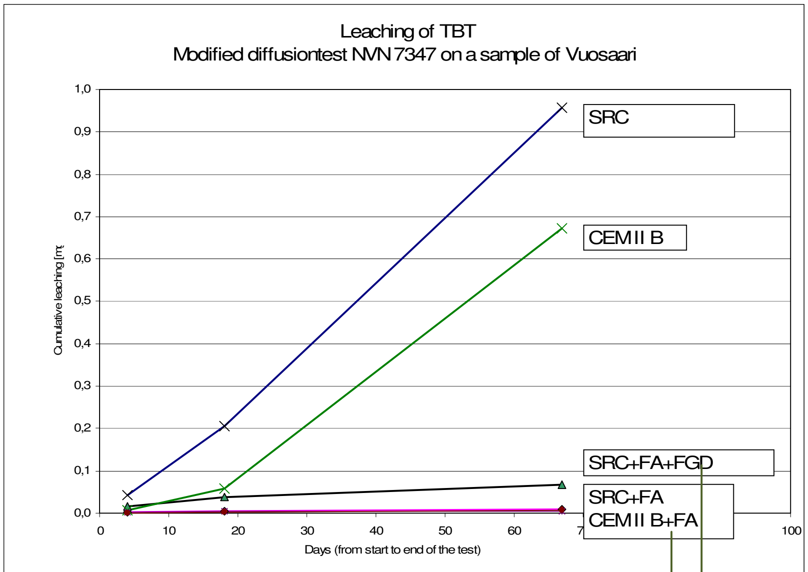

Figure 22: Diffusion test showing leaching potential (mg/m²) of different stabilized TBT-contaminated samples. SRC = Sulphate resistant cement; CEM II B is a more ordinary type of cement; FA = coal fly ash; FGD = flue gas desulfurisation residue (Ramboll Finland Oy). Unit mg/m2 (Y-axis) and days (X-axis)

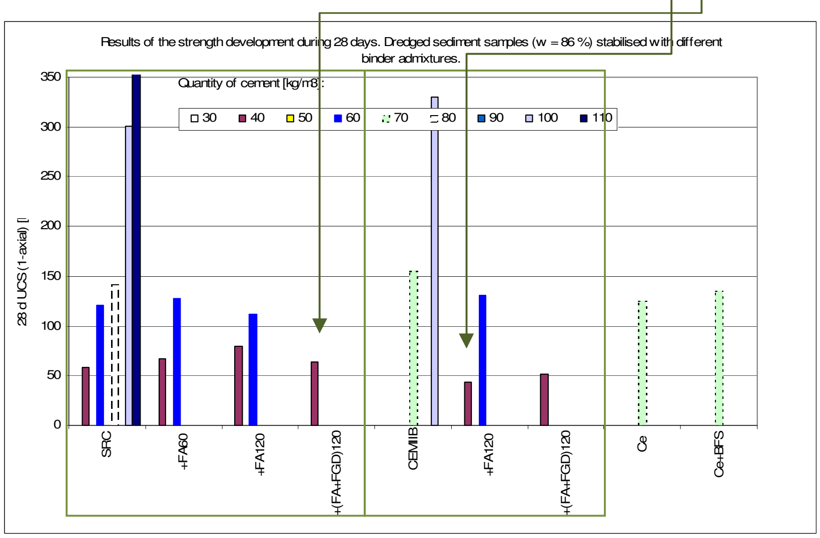

Figure 23: Strength development of different stabilized TBT-contaminated samples. Quantity of the different cements in the binder admixtures is given in the separate specification bar; an exception is Ce+BFS, the quantity of which is also given as "cement"-quantity (here 70 kg/m³). Quantity of other components is given after the specific letters. FA = coal fly ash; FGD = flue gas desulfurisation residue; BFS = blast furnace slag; SRC = sulphate resistant cement, CEM IIB and Ce are ordinary types of cement. (Ramboll Finland Oy). Arrows show the binder selections giving the best environmental properties.

4.4 Layer stabilization

Shallow or layer stabilization of secondary roads	
In general	Two cases of this new alternative for the renovation of secondary roads are shortly presented; the cases are from Finland.
Project site	Luopioinen and Rautavaara
Project period	Luopioinen: 2002 Rautavaara: 2004
Dimensions	Luopioinen: Stabilized sections 4000 meters; Rautavaara: Stabilized section 1000 meters
Soil	Luopioinen: upper courses of existing gravel road – mainly gravel and sand Rautavaara: gravel road with pavement
Stabilization technique	Layer stabilization of relatively thin upper soil layers is a method to improve the bearing capacity and other properties of different structural courses, embankments etc. In principle, the binder admixture is spread on the soil / embankment / structural course and mixed into the soil while the soil is cut and pulverized. The treated soil is then compacted. This way it is possible to stabilize soil without excavation of existing soil and its replacement with virgin soil. *Figure 22*
Binder	Cement admixtures; cement content 25 – 40 %
Additional data	The experience so far indicates success with respect to strength development and durability of the stabilized roads. *Figures 21 and 23*
Source(s)	LIFE02 ENV/FIN/329; S14 Rautavaara

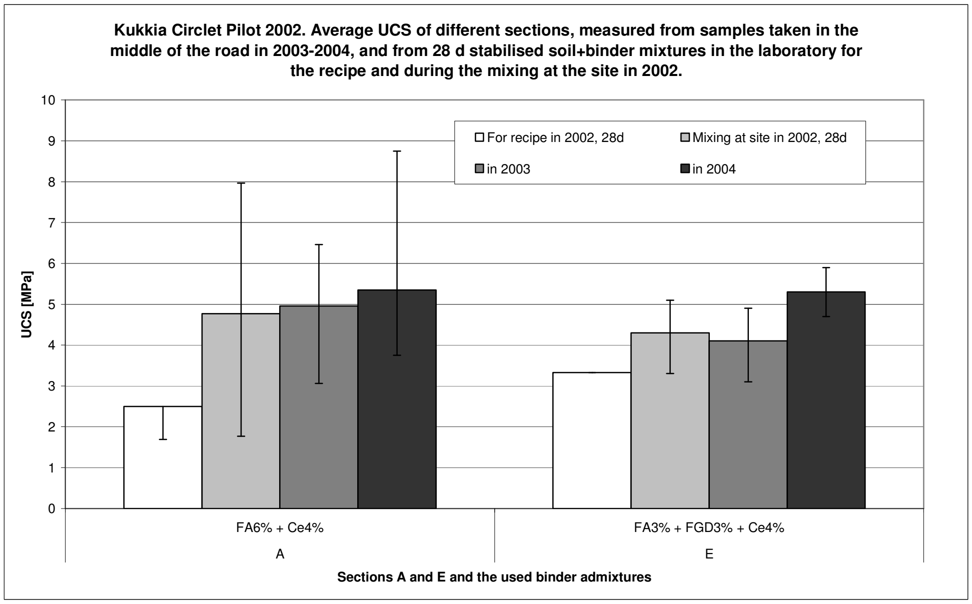

Figure 24: Kukkia Circlet pilot 2002. Unconfined compression strength (UCS, MPa) of samples drilled from the site in 2003 and 2004, and of samples made of binder+soil mixture at site in 2002 and in the laboratory (for the recipe before stabilization) and tested 28 d after stabilization. The total amount of binder was 10 % of soil materials dry weight, and one of the components was ordinary cement. (Ramboll Finland Oy)

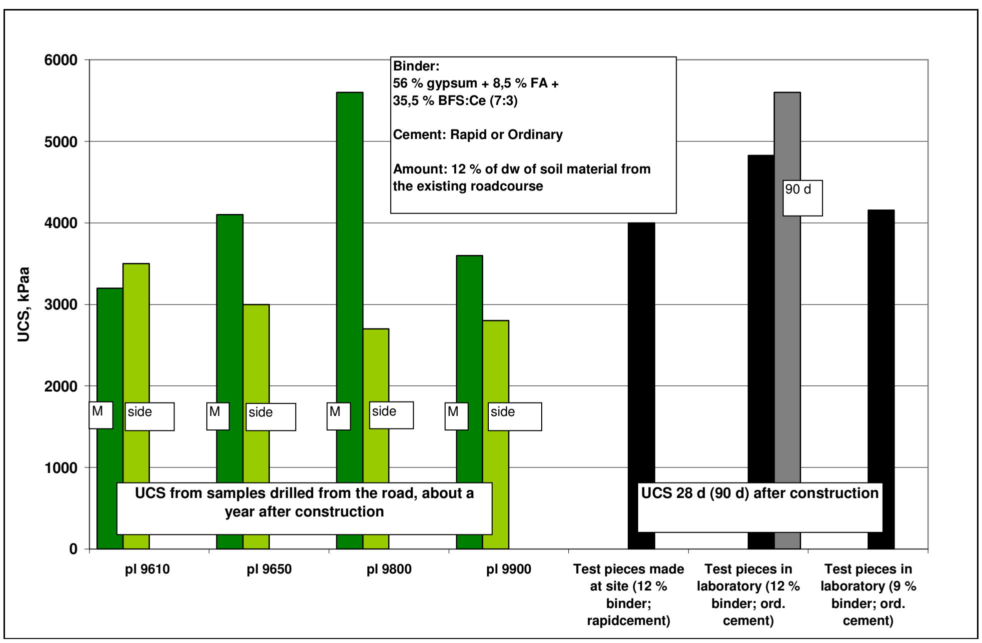

Figure 25: Rautavaara pilot. Unconfined compression strength (UCS, kPa) of samples drilled from the site one year after stabilization, and of samples made of binder+soil mixture at site and in the laboratory and tested 28 d / 90 d after stabilization. The total amount of binder was 12 % of soil materials dry weight, and one of the components was cement (Ramboll Finland Oy)

Figure 26: On-going stabilization in Rautavaara in 2004, on the left lane of the road. In front goes the lorry and asphalt spreader for the binder. After this come the stabilization cutter and the first compacting roller (Ramboll Finland Oy).

Figure 27: A follow-up sample from a layer-stabilized road in Rautavaara in the autumn 2005. The project was carried out in the summer 2004. Here, the existing asphalt pavement was crushed and mixed into a depth of 200 – 300 mm with the binder (a composite of cement and fly ash). After stabilization a new pavement was spread on the surface. (Ramboll Finland Oy)

5. Data on stabilization systems

Following Tables 6 -13 compile selected data from laboratory tests for different projects on cement stabilization. Because of proprietary rights there are no detailed specifications of the location, binder producer etc. Terminology in Tables is as follows

<table>
<tr><td>Nr:</td><td colspan="2">A reference number to the project or source of data (internal and not published data of Ramboll Finland Oy)</td></tr>
<tr><td>Material Nr:</td><td colspan="2">A reference number to a certain soil material or sample material. Same number refers to same material</td></tr>
<tr><td rowspan="5">Type of Material:</td><td colspan="2">The stabilized material will be characterized as follows:</td></tr>
<tr><td colspan="2">1) Type
- DS = dredged sediment
- M = mud or "”””””””””””””””””””””””””””””””””gyttja”””””””””””””””””””””””””””””” ”””””"
- C = clay
- S = silt
- P = peat</td></tr>
<tr><td colspan="2">2) D = density of the material (wet) without binder</td></tr>
<tr><td colspan="2">3) w = water content of the material in relation to the dry mass of the material; without binder</td></tr>
<tr><td colspan="2">4) LoI = Loss of incineration; indicates the content of organic material in the soil sample</td></tr>
<tr><td rowspan="5">Binder:</td><td>OC</td><td>Ordinary cement</td></tr>
<tr><td>PC</td><td>Portland cement</td></tr>
<tr><td>SR</td><td>Sulphate resistant cement</td></tr>
<tr><td>CL</td><td>Cement-Lime admixture</td></tr>
<tr><td>CM</td><td>Cement-Blast-furnace slag admixture</td></tr>
<tr><td>Quantity:</td><td colspan="2">1) Total quantity or in composites the quantity of cement, [kg/m^3]
2) Quantity of other components in the admixture, [kg/m^3]</td></tr>
<tr><td>UCS:</td><td colspan="2">Unconfined compression strength after a certain time of strength development</td></tr>
</table>

Table 6: *Different types of mud /"gyttja" (M) stabilized with ordinary cement. Results from laboratory tests*

Nro	Soil					OC 1 Quantity	UCS [kPa]												
	Material					Total													
	Nr	Type	Density	w	LoI														
			kg/m^3	%	%	kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
9	4	M	1662	54	12	100						189		256					
17	7	M	1180	260	19	100								165					
114	43	M	1020	183	12	100								74					
140	47	M	1200	242	10	100								108					
30	12	M	1470	92	8	130					199			265					
32	13	M	1370	117	16	130					59			68					
34	14	M	1380	111	17	130					59			68					
16	6	M	1230	176	12	150						191		234					
18	7	M	1180	260	19	150								298		385			
25	10	M	1086	333	28	150						125							
28	11	M	1294	153	14	150						158							
40	19	M	1310	130		150						68		74					
41	20	M	1430	100	14	150						118		159					
42	21	M	1300	150	11	150								104		127			
44	22	M	1380	118	9	150								129					
45	22	M	1380	118	9	150								114					
49	23	M	1390	119	7	150						102		150					
141	47	M	1200	242	10	150						278		275					
151	49	M	1240	154	6	150								60					
19	7	M	1180	260	19	200								458					
20	8	M	1221	239	13	200						500		612					
43	22	M	1380	118	9	200								250		304			
46	22	M	1380	118	9	200								240		255			
50	23	M	1390	119	7	200						224		335					
113	42	M	1270	97	19	200								134					
142	47	M	1200	242	10	200								439					
10	4	M	1662	54	12	250						226		304					
26	10	M	1086	333	28	250						188							
47	22	M	1380	118	9	250								422					
51	23	M	1390	119	7	250								551					
143	47	M	1200	242	10	250								813					
21	8	M	1221	239	13	300						993		1271					
115	43	M	1020	183	12	300								233					

Table 7: Different types of dredged sediment materials (DS), clay (C) and silt (S) stabilized with ordinary cement. Results from laboratory tests

Nro	Soil					OC 1 Quantity	UCS [kPa]												
	Material					Total													
	Nr	Type	Density	w	LoI														
			kg/m^3	%	%	kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
154	50	DS	1210	192	23	50				29				36					
220	61	DS	1180	237	24	50		62											
155	50	DS	1210	192	23	75				69				98					
221	61	DS	1180	237	24	100	88	146	178					226					
222	61	DS	1180	237	24	150		140											
336	112	C	1820	38	3	75								237					
340	113	C	1740	46	3	75								227					
347	114	C	1630	59	4	75								319					
342	113	C	1740	46	3	80				200									
311	97	C	1450	100	4	100								379		440			
337	112	C	1820	38	3	100								346					
341	113	C	1740	46	3	100								430					
348	114	C	1630	59	4	100								472					
343	113	C	1740	46	3	110				318									
312	97	C	1450	100	4	125								464					
321	102	C	1470	92	8	130					199			265					
344	113	C	1740	46	3	140				497									
271	75	C	1590	63	1	150						172		188					
272	76	C	1420	106	4	150						133		147					
273	77	C	1570	69	1	150						157		178					
313	97	C	1450	100	4	150								546					
314	98	C	1665	54	0	150						416		647					
316	99	C	1590	67	3	150				845		899		1202					
318	100	C	1440	97	7	150				735		944		1199					
319	101	C	1670	58	3	150				1020		1051		1492					
328	107	C	1500	79	3	150								336					
329	108	C	1450	93	6	150						101		159					
827	258	C	1860	32	0	150								407					
330	108	C	1450	93	6	200								351					
832	260	S	1600	64	2	150						75		95					

Table 8: Different types of peat (P) stabilized with ordinary cement. Results from laboratory tests

Nro	Soil					OC 1 Quantity	UCS [kPa]												
	Material					Total													
	Nr	Type	Density	w	LoI														
			kg/m^3	%	%	kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
893	279	P	1000	1901	96	150						128		160					
897	281	P	1000	992	97	150						16		29					
907	287	P	1021	438	0	150						46		39					
910	289	P	1048	463	0	150						122		123					
913	291	P	1004	940	98	150						61		90					
920	293	P	1025	558	74	150						85		104					
925	295	P	1010	827	96	150						135		139					
938	300	P	1034	538	0	150						76		80					
939	301	P	1001	1010	0	150						158		161					
940	302	P	990	1097	0	150						70		61					
946	306	P	1000	1489	71	150						335		218					
955	309	P	1310	130	21	150				195		219		259					
959	313	P	1052	552	48	150						69		74					
960	314	P	1013	715	89	150						50		62					
977	322	P	1000	1687	93	150						150		200					
979	323	P	1010	852	91	150				48		29		60					
1063	360	P	1000	1130	98	150								324					
1064	361	P	1030	673	54	150								89					
906	286	P	980	1500	99	200					411			413		432			
942	304	P	980	1400	99	200					434			431		391			
956	310	P	1180	187	37	200				184		192		206					
957	311	P	1220	189	17	200				346		460		567					
973	320	P	1440	32	9,8	200						241		627					
978	322	P	1000	1687	93	200						190		229					
980	323	P	1010	852	91	200						30		42		127			
983	324	P	1010	800	84	200						162		150					
892	278	P	1010	1539	94	250						229		365					
894	279	P	1000	1901	96	250						93		241					
896	280	P	1010	646	95	250						21		23					
909	288	P	995	942	97	250						124		162					
921	293	P	1025	558	74	250						173		181					
923	294	P	1010	523	79	250						188		196					
926	295	P	1010	827	96	250						176		223					
947	306	P	1000	1489	71	250						350		558					
976	321	P	1000	916	96	300						65		86					

Table 9: Different types of peat (P) stabilized with Portland cement. Results from laboratory tests

Nro	Soil					Binder	Quantity		UCS [kPa]												
	Material						Total	2nd comp.													
	Nr	Type	Density	w	LoI																
			kg/m^3	%	%		kg/m^3	kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
991	326	P	1023	625	48	PC	100											147			
1005	330	P	1001	749	84	PC	100											67			
992	326	P	1023	625	48	PC	150											222			
1006	330	P	1001	749	84	PC	150											125			
993	326	P	1023	625	48	PC	200											306			
1007	330	P	1001	749	84	PC	200											173			
994	326	P	1023	625	48	PC	250									375		420		397	385
1004	330	P	1001	749	84	PC	250									232		231		209	211
995	326	P	1023	625	48	PC	300											591			
1008	330	P	1001	749	84	PC	300											258			
996	326	P	1023	625	48	PC	400											894			
1009	330	P	1001	749	84	PC	400											428			

Table 10: Different types of mud (M), dredged sediment (DS), clay (C) and peat (P) stabilized with sulphate resistant cement. Results from laboratory tests

Nro	Soil					Binder	Quantity		UCS [kPa]												
	Material						Total	2nd comp.													
	Nr	Type	Density	w	LoI																
			kg/m³	%	%		kg/m³	kg/m³	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
48	22	M	1380	118	9	SR	150									133					
52	23	M	1390	119	7	SR	150							106		154					
148	47	M	1200	242	10	SR	150									201					
53	23	M	1390	119	7	SR	200									294					
138	46	M	1315	134	6	SR	263										3971				
212	59	DS	1600	64	3	SR	60									130					
159	52	DS	1250	214		SR	70							66		104					
233	63	DS	1350	125		SR	70									147					
174	56	DS	1370	129		SR	80							61		76		119			
177	56	DS	1500	90		SR	80							119		155		229			
179	56	DS	1270	200		SR	80							35		36					
175	56	DS	1370	129		SR	100									112					
180	56	DS	1270	200		SR	100									49					
176	56	DS	1370	129		SR	130							171		194		284			
178	56	DS	1500	90		SR	130							294		342					
181	56	DS	1270	200		SR	130							78		90		143			
201	58	DS	1170	296	8	SR	150									128					
182	56	DS	1270	200		SR	160									162					
804	248	C	1790	39	3	SR	100									919					
805	248	C	1790	39	3	SR	150									1136					
806	248	C	1790	39	3	SR	200									1621					
793	245	C	1469	81	2	SR	294										4295				
797	246	C	1736	44	0	SR	347										4116				
835	261	S	1571	63	5	SR	100							59		92					
840	263	S	1820	23		SR	175							350							
930	296	P	1218	193	32	SR	150									122					
916	291	P	1004	940	98	SR	250							119		128					
931	296	P	1218	193	32	SR	250							149		195					
969	318	P	1020	332	86	SR	300									652					

Table 11: Different types of mud (M) and clay (C) stabilized with cement + lime admixtures. Results from laboratory tests

Nro	Soil					Binder	Quantity		UCS [kPa]												
	Material Nr	Type	Density kg/m^3	w %	LoI %		Total kg/m^3	2nd comp. kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
23	9	M	1621	65	5	CL	37,5	37,5						56							
7	3	M	1120	436	21	CL	50	50						10		10					
8	3	M	1120	436	21	CL	50	50						10		10					
149	48	M	1210	215	17	CL	60	60					275			488					
31	12	M	1470	92	8	CL	65	65					65			67					
33	13	M	1370	117	16	CL	65	65					53			56					
35	14	M	1380	111	17	CL	65	65					53			56					
150	48	M	1210	215	17	CL	100	100					599			1000					
11	4	M	1662	54	12	CL	125	125						202		216					
27	10	M	1086	333	28	CL	125	125						63							
22	8	M	1221	239	13	CL	150	150						467		587					
349	114	C	1630	59	4	CL	37,5	37,5								75					
354	118	C	1730	63	4	CL	37,5	37,5								197					
357	119	C	1770	42	4	CL	37,5	37,5								168					
274	78	C	1830	39		CL	40	40								267					
276	79	C	1520	81		CL	40	40								104					
368	124	C	1420	112	2	CL	45	45								45					
372	126	C	1500	85	0,3	CL	45	45								45					
374	127	C	1490	90	1,7	CL	45	45								206					
378	129	C	1750	51	0	CL	45	45								428					
280	81	C	1460	128	4	CL	50	50						100		135		223			
310	96	C	1500	88	2	CL	50	50						77		108		162			
327	106	C	1500	102	0	CL	50	50						145		155		230			
335	111	C	1430	78	3	CL	50	50						168		214		301			
351	115	C	1550	110	1	CL	50	50						212		274		473			
352	116	C	1840	53	2	CL	50	50						275		326		491			
468	159	C	1510	82	7	CL	50	50					262			387					
626	216	C	1630	63	5	CL	55	55								145	161				
627	217	C	1800	42	4	CL	55	55								162	230				
275	78	C	1830	39		CL	60	60								492					
315	98	C	1665	54	0	CL	75	75						173		180					
317	99	C	1590	67	3	CL	75	75				607		641		912					
320	101	C	1670	58	3	CL	75	75				718		778		1066					
817	253	C	1530	83	5	CL	90	90					500			848					

Table 12: Different types of silt (S) and peat (P) stabilized with cement + lime admixtures. Results from laboratory tests

Nro	Soil					Binder	Quantity		UCS [kPa]												
	Material						Total	2nd comp.													
	Nr	Type	Density	w	LoI																
			kg/m³	%	%		kg/m³	kg/m³	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
844	264	S	1830	42	4	CL	37,5	37,5								150					
838	262	S	1910	44	4	CL	50	50								353					
845	264	S	1830	42	4	CL	50	50								214		207			
847	264	S	1830	42	4	CL	56,25	18,75								165					
846	264	S	1830	42	4	CL	62,5	62,5								263					
848	264	S	1830	42	4	CL	75	25								227		241			
849	264	S	1830	42	4	CL	93,75	31,25								313					
948	306	P	1000	1489	71	CL	75	75						105		105					
912	290	P	1055	596	92	CL	125	125						151		161					
919	292	P	1015	617	82	CL	125	125								116					
922	293	P	1025	558	74	CL	125	125						53		59					

Table 13: *Different types of clay (C) and peat (P) stabilized with cement + blast-furnace slag admixtures. Results from laboratory tests*

Nro	Soil					Binder	Quantity		UCS [kPa]												
	Material						Total	2nd comp.													
	Nr	Type	Density	w	LoI																
			kg/m^3	%	%		kg/m^3	kg/m^3	1 d	3 d	5 d	7 d	10 d	14 d	21 d	28 d	60 d	90 d	120 d	180 d	364 d
285	84	C	1400	118	6	CM	50	50								163		264			
287	85	C	1420	109	6	CM	50	50								429		754			
289	86	C	1490	90	5	CM	50	50								320					
291	87	C	1460	94	6	CM	50	50								147		139			
293	88	C	1390	117	7	CM	50	50								467		677			
286	84	C	1400	118	6	CM	60	60								207					
288	85	C	1420	109	6	CM	60	60								530					
290	86	C	1490	90	5	CM	60	60								400					
292	87	C	1460	94	6	CM	60	60								178					
294	88	C	1390	117	7	CM	60	60								563					
296	89	C	1450	99	5	CM	60	60								259					
298	90	C	1570	71	4	CM	60	60								213					
972	319	P	1190	254	35	CM	100	100								68					
1038	345	P	1040	360	65	CM	100	100								25					
1067	361	P	1030	673	54	CM	150	150								127					
966	317	P	1000	535	86	CM	200	200								142					
968	318	P	1020	332	86	CM	200	200								291					
1059	358	P	980	1158	91,5	CM	200	200								61					

Note: In Ramboll Finland R&D the laboratory tests on **peat** samples and test pieces always include strength gaining under a certain preload, mostly 7 kPa on test pieces (h=136 mm and Ø=68 mm); this corresponds roughly to a 90 – 100 cm thick preloading layer of crushed aggregates in the field conditions. The preloading is necessary in order to prevent excess settlements of the stabilized peat course during the use of the area.

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http://www.trl.co.uk/store/report_list.asp?pid=108

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