



ALLU STABILISATION SYSTEM

MASS STABILISATION MANUAL



ALLU Finland Oy
P.O. Box 22,
16301 Orimattila, FINLAND
Tel: +358 (0)3 882 140
Fax: +358 (0)3 882 1440
Email: info@allu.net
www.allu.net



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Note! This publication is intended for information purposes only, for those who are interested in mass stabilisation method. The background information provided in this report does not constitute a basis for design. Each site has unique soil conditions and functional requirements and therefore careful investigation and planning are always required before the stabilisation. ALLU Finland and Ramboll do not take any responsibility for misinterpretation or misuse of this text.

ALLU FINLAND AND RAMBOLL FINLAND

1. ALLU FINLAND AND RAMBOLL FINLAND – PROFESSIONAL SOLUTIONS FOR MASS STABILISATION

ALLU Finland Oy is a private Finnish company, which since 1985 has specialised in developing, manufacturing and selling products for environmental care, improvement of recycling methods and processing of various materials. ALLU Finland is an respected global supplier of accessories and appliances for both the environmental and earth construction fields. To date, ALLU Finland has delivered products to more than 40 countries throughout the world.

ALLU's headquarters and factories are located in Finland. Currently, it maintains an active and skilled distributor network in more than 30 countries and it has delivered products to more than 40 countries all over the world. The main product lines of ALLU Finland are ALLU Screener Crushers and ALLU Stabilisation System.

ALLU Finland has actively followed up with the changing requirements of the customers, developing new technical solutions and methods and its target is to be a pioneer of its branch. As an important part of the product development process ALLU Finland is continuously looking, together with its customers, for new application possibilities for ALLU products and develops new technically realisable solutions.

ALLU Stabilisation System

ALLU Stabilisation System is a new working method to increase the strength and dynamic stiffness of soft soil, in order to improve the engineering characteristics of soft soil and to remediate contaminated soil.



Picture: ALLU Stabilisation system at work

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The ALLU Stabilisation System consists of three components. The first component is the ALLU PM Power Mix, a versatile hydraulic accessory for excavators. The second component is the ALLU PF Pressure Feeder, which injects the binder via hoses into the ground. The third component is the ALLU DAC Data Acquisition System, which measures, controls and provides data during the stabilisation project.

The mass stabilisation method is a quick and cost effective solution to improve soft soils by mixing binder into clay, peat, mud or dredged sediments. The stabilisation method can also be used in treatment of contaminated soils, by encapsulating contaminants within the ground and preventing migration to the surrounding areas. It is a quick, cost effective, and environmentally-friendly method in comparison with traditional methods of piling or soil replacement.

With the continued goal of being a leader in its field, ALLU Finland has actively adapted to the changing demands of its customers, developing new technical solutions and methods. As an important part of the product development process, Ideachip, together with its customers, is continuously searching for new application possibilities for ALLU products and developing new technically and economically feasible solutions.

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Ramboll Finland Ltd. (previously SCC Viatek Ltd.) is part of the Ramboll Group, a leading Nordic consulting group with more than 4 200 employees in over 70 offices. The Ramboll Group operates in environment, construction, infrastructure and traffic. Ramboll Finland Oy operates currently in 14 regions in Finland, and employs over 600 people.

The Ramboll Finland units in Helsinki, Espoo and Luopioinen offer specialist services on mass stabilisation project dimensioning, planning and coordination as well as in quality control work. The company has completed hundreds of stabilisation projects, ranging from cases such as single-family houses to the expansion of major harbours, and has participated in most of the significant stabilisation research and development projects in Finland since the 1980's. Additionally, Ramboll Finland in Espoo and other locations offers field services in soil investigation, production services and quality control work from start to a final product.



Picture: Mass stabilisation in a residential area.

R&D laboratory of Ramboll Finland in Luopioinen has been operating in the development of technologies and materials for environmental and geotechnical applications since 1989. It has completed over 250 R&D projects in column, mass, and layer stabilisation in Finland and internationally. In addition to stabilisation laboratory services, the R&D unit offers services in geotechnical and environmental testing, in-situ testing and quality control work, ground penetrating radar investigations, and instrumentation of field test sites.

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Mass stabilisation has traditionally been accomplished using cement and lime admixtures, but mass stabilisation using industrial by-products as stabilisers is becoming more common and gaining widespread acceptance. Industrial by-products including fly ashes, blast furnace slag or calcium sulphate products are used to replace more expensive commercial binders, and these solutions are often less expensive and perform better than traditional methods. Approximately 200 industrial by-products have been investigated by Ramboll in Luopioinen, and it is currently the leading laboratory in the Nordic countries for promoting by-products as potential binders.



Picture: Vuosaari harbour, Helsinki Finland

A brief list of Ramboll Finland's stabilisation projects includes :

- Mass stabilisation of clay and peat in Limerick, Edenderry and Mossfield, Ireland (2005-)
- Mass stabilisation in Valencia harbour, Spain; stabilisation tests and quality control (2004-)
- Mass stabilisation of approximately 500 000 m³ of dredged sediments contaminated by TBT (tributyl tin) in Vuosaari Harbour, Helsinki, Finland; services included construction planning, binder selection and optimisation (2003)

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- Stabilisation and utilisation of surplus materials (low quality soils) in Vuosaari harbour, Helsinki (2003-2004)
- Combined mass and column stabilisation of the yards of IKEA in Vantaa, Finland (extremely difficult subsoil conditions); services included dimensioning, construction assistance and quality control work (2002-2003)
- Laboratory services for stabilisation of dredged sediments in Trondheim Harbour, Norway (2002)
- Mass stabilisation and combined mass and column stabilisation of peat and muddy clay in Kivikko and Haaga, Helsinki, Finland (parking lots and industrial area); several test fields and stabilisation projects; services included dimensioning, instrumentation, quality control and follow-up studies (1998-)
- EuroSoilStab – European R&D project on soft soil stabilisation; leading project partner in Finland, binder development and testing, planning, dimensioning and follow-up studies of test stabilisations (1997-2000)

For more information: www.ramboll.fi

RAMBOLL FINLAND OY

Offices:

Piispanmäentie 5
02240 ESPOO Finland

Tel. + 358 20 755 611
Fax + 358 20 755 6206

Manager Mikko Leppänen (mikko.leppanen@ramboll.fi)
Manager Juha Forsman (juha.forsman@ramboll.fi)

Vohlisaarentie 2B
36760 LUOPIOINEN Finland

Tel. + 358 20 755 6740
Fax + 358 20 755 6741

Manager Pentti Lahtinen (pentti.lahtinen@ramboll.fi)
Project manager Harri Jyrävä (harri.jyrava@ramboll.fi)

MASS STABILISATION

2. MASS STABILISATION

2.1 What is mass stabilisation?

Mass stabilisation is a relatively new ground improvement method for soft soil layers. Stabilisation is done by mixing an appropriate amount of dry or wet binder throughout the volume of the treated soil layer. The binder can consist of a single substance or be a mixture of various substances like cement, lime, fly ash or furnace slag. New binders and binder mixtures using different industrial by-products are being introduced to the market continuously. Mass stabilisation may also be combined with another stabilisation method known as column stabilisation.

The main purposes of soil stabilisation are:

- To increase the strength of the soft soil
- To improve the deformation properties of the soft soil (reduce settlements)
- To increase dynamic stiffness of the soft soil
- To remediate contaminated soil

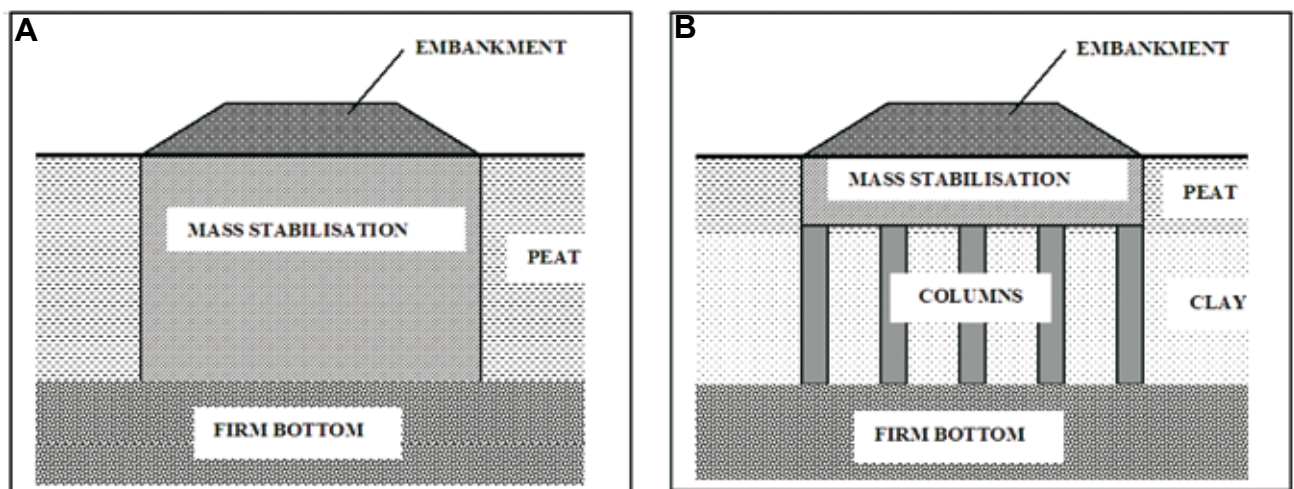


Figure: a) Mass stabilisation and b) combined mass and column stabilisation

The mass stabilisation method has many benefits, including:

- It is a rapid ground improvement method, and can be adapted to varying soil conditions
- It is in most cases economically efficient and saves materials and energy
- It improves the engineering properties of the soil and can be flexibly linked with other structures and with the surroundings (no harmful settlement differences)
- Transfer of the natural soil elsewhere is not needed, so there is less transportation and traffic pollution and no need for disposal sites and offsite transport.

MASS STABILISATION

Environmentally, the mass stabilisation has only minor effects to the surroundings. Vibration and noise levels are low during stabilisation. Leaching and transport of harmful substances due to binder materials is insignificant, which has been confirmed by extensive laboratory work in many stabilisation projects.

The future of mass stabilisation methods looks quite encouraging. Results obtained from different projects clearly show that it is possible to construct fields and embankments of a high quality at a moderate price. Active research to develop both more effective binders and mixing tools has created new application areas, and has improved the competitiveness of mass stabilisation in comparison with traditional techniques

2.2 Applications of mass stabilisation

Mass stabilisation is especially suited as a ground improvement method for projects where economical reinforcement of wide areas are required. Natural applications of mass stabilisation include road, street and railway embankments, and yard and storage areas, where the thickness of the softest soil layers is at least a few meters (yards) thick and located at a maximum depth of 5 meters (yards) below the ground surface.

In areas where subsoil layers of higher load-bearing capacity are located a few meters (yards) from ground level, mass stabilisation may be used instead of soil replacement. In the case of thicker soft soil layers, mass stabilisation may in many cases replace the embankment piling under the road or street embankment. The mass-stabilised layer distributes the loads over a wider area, thereby limiting settlement.

A relatively new application for mass stabilisation is solidification of dredged mud, which has traditionally been considered unsuitable for any type of construction. Usually, dredged sediments are transported to disposal areas; however, problems are encountered when disposal areas are filled or when sediments are contaminated and thus unsuitable for standard disposal sites. Mass stabilisation can be utilised for both improving the properties of poor soil masses and binding the harmful particles into the stabilised soil. In a typical operation, the contaminated sediments are transported into a basin close to the dredging site, and transformed for example into a city park or a much-needed harbour shipping container field.

Mass stabilisation can be implemented also by mixing binders to soil that has been excavated and placed on the ground. Mass stabilisation improves the properties of the excavated, poor quality soil mass, so that instead of transporting this material to a landfill it may be used for other construction purposes such as road structures, fill, noise barriers, etc

Mass stabilisation technology advances continually. As the stabilisation equipment and binder technology are developing, it is possible to adapt new modifications to mass stabilisation.

MASS STABILISATION



Pictures: Mass stabilisation in Trondheim harbour; Norway

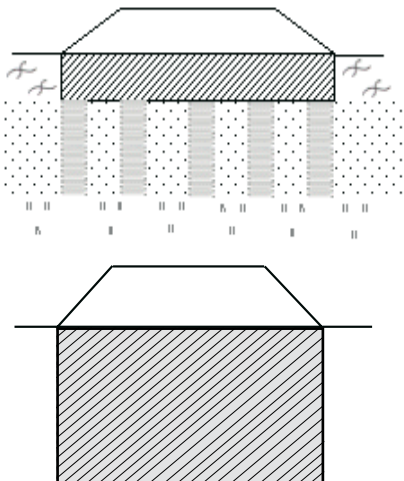
A few examples of projects in which mass stabilisation may be feasible are:

- Road, street and railway construction sites
- Yards, parking lots, sports fields, and storage construction sites
- Foundations for industrial buildings and bridges, pools, and landfill areas
- Noise barriers and slopes of rivers, lakes, roads, etc.
- Traffic vibration elimination
- Solidification/stabilisation of dredged sediments
- Stabilisation of very soft soils for tunnel boring
- Cable/pipe channel construction sites
- Protection of adjacent structures
- Reduction of earth pressure
- Protection layers under the water
- Ground water protection layers
- Protection layers for permafrost and frost
- Handling of waste and contaminated soil: solidification, isolation and neutralisation

MASS STABILISATION

2.3 Mass stabilisation versus other methods

Mass stabilisation



Merits:

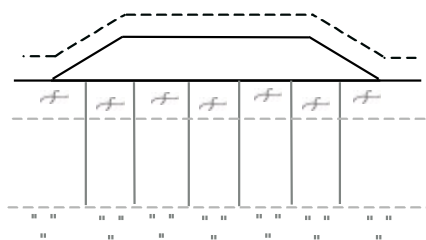
- Economics
- Flexibility
- Savings of material and energy
- Exploiting of the properties of the soil at the site
- Soil remain in place. Zero spoil production. No transfer of the natural soil elsewhere

Drawbacks:

- not for high embankments
- limited possibilities to increase stability of high embankments
- poorly stabilisable soils
- time needed for curing
- maximum depths: for mass-stabilisation $\leq 5,0^*$ metres; columns $\leq 40,0$ metres

Other methods compared to mass stabilisation

Vertical drains



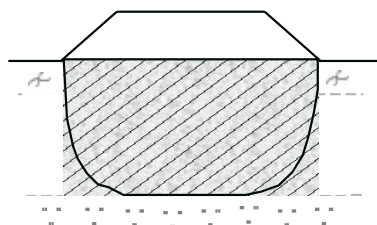
- less expensive
- more time consuming
- more mass consuming
- more stability problems
- larger settlements during serviceability state

Piling



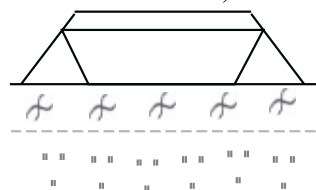
- more expensive
- settlements differ significantly with the settlements of the surrounding area
- faster
- often clearly deeper foundation

Exchange of mass



- costs depend on the case
- significantly more mass consuming
- higher risk of failure
- larger impact on environment

Reduced weight of embankment (can be combined with deep stabilisation)



- often more expensive

Figure: Mass stabilisation compared with other methods

* 6 m depth projects have been made successfully with ALLU mass stabilisation system

MASS STABILISATION

2.4 Cost savings

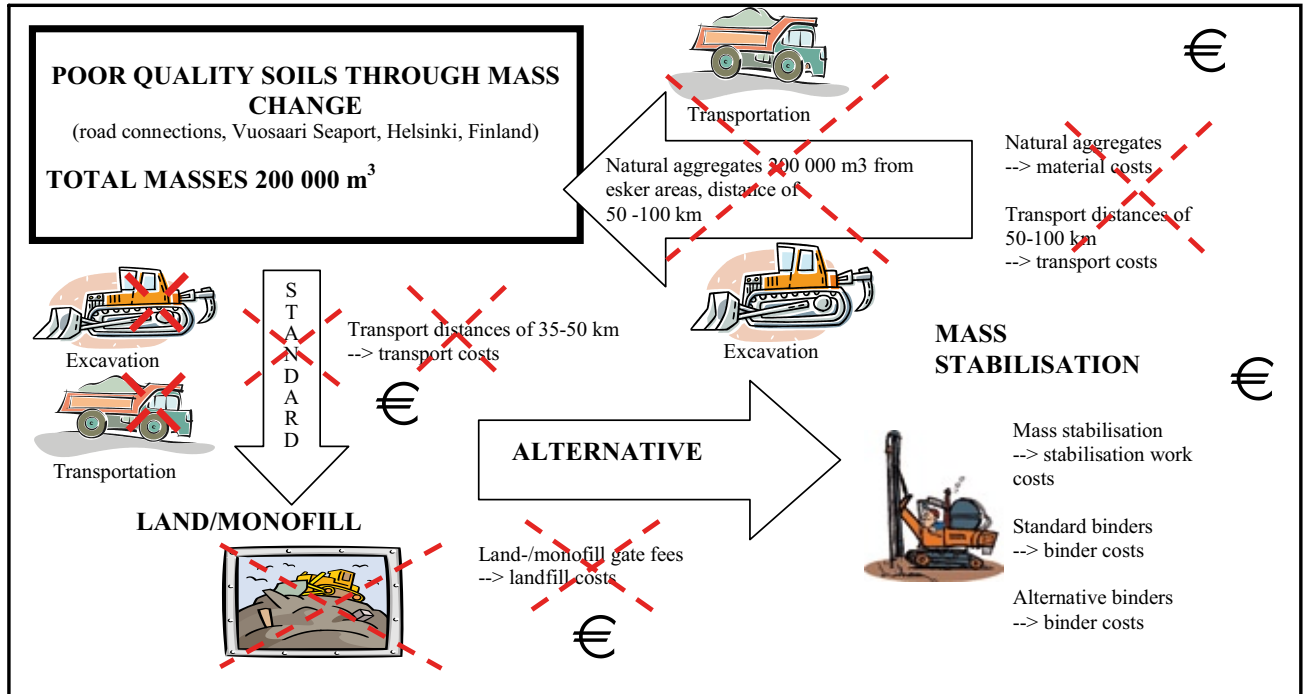


Figure: Mass stabilisation process as an alternative for mass exchange in the Vuosaari Seaport project (Helsinki, Finland)

Amount	Mass exchange	Stabilisation commercial binders A	Stabilisation by-product binders B	Save A	Save B
				A	B
m ³	€	€	€	€	€
150.000	4.240.000	2.400.000	1.740.000	1.840.000	2.500.000

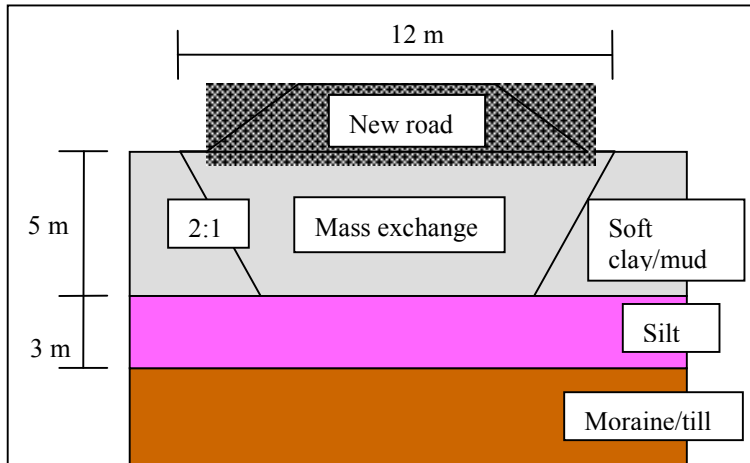
Cost savings through mass utilisation within the Vuosaari Seaport project (Helsinki, Finland)

The total cost of project is one of the principal factors when choosing the soil reinforcement method. Following example gives an idea how different alternatives can be roughly compared to each other.

MASS STABILISATION

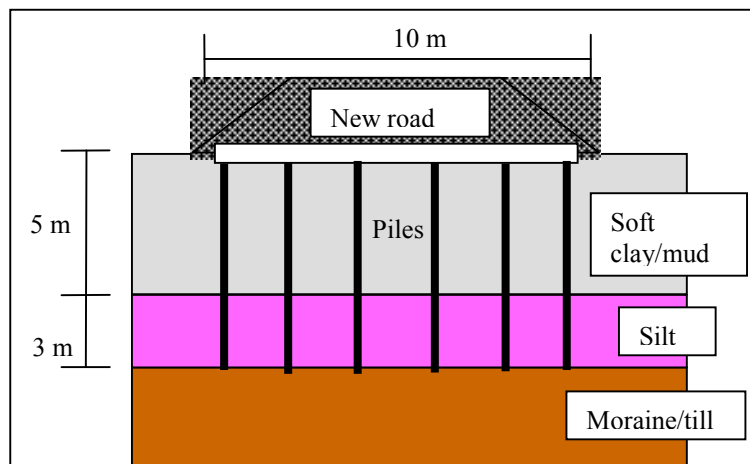
Example

New road (length 100, width 10 m) is planned to build on a very soft clay/mud. Alternative reinforcement methods for this road are mass exchange, piling and mass stabilisation. The costs of the methods are compared here.



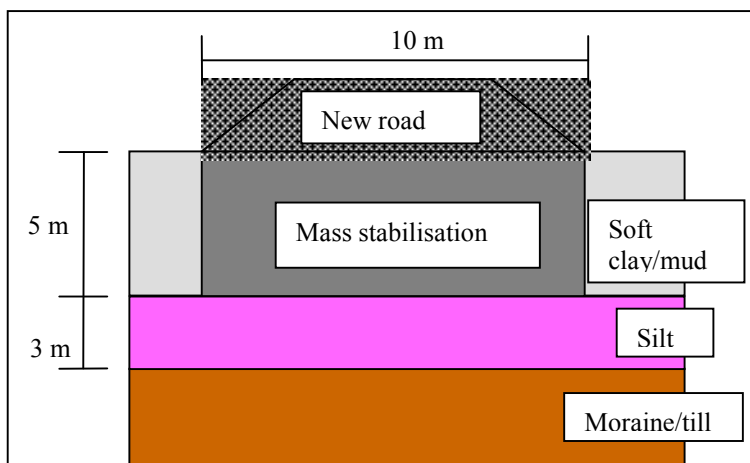
A. Mass exchange

- Volume of material to be excavated = 47 m³ ≈ 50 m³
- Cost of the surplus material ≈ 15€/m³
- Cost per 1 m of road = 750 €/m
=> **75 000 € / 100 m**



B. Piling and slab

- Concrete piles, diam. 250 mm, c/c = 2,0 m
- Cost of one pile 20 €/m x 8 m = 160 €
- Cost of piles (160 x 6)€ / 2 m = 480 €/m
- Slab h=250 mm, 40 €/m²
- Cost of slab 40 €/m² x 10 m = 400 €/m
- Cost per 1 m of road = 880 €/m
=> **88 000 € / 100 m**



C. Mass stabilisation

- Volume of material to be stabilised = 50 m³
- Cost of the stabilisation ≈ 12 €/m³
- Cost per 1 m of road = 600 €/m
=> **60 000 € / 100 m**

ALLU STABILISATION SYSTEM

3. ALLU STABILISATION SYSTEM

3.1 ALLU stabilisation machinery

ALLU Stabilisation System is developed for mass stabilisation of soft soils, but it can also be used in the treatment of contaminated soils, by encapsulating contaminants within the soil and preventing them to leach to the surrounding areas. Stabilisation is successful only when using equipment and techniques that can homogenise the soil mass effectively and accurately. Additionally, the feeding accuracy is essential, along with quality control and reporting.

ALLU Stabilisation System consists of three elements:

- ALLU PM Power Mix (PM)
- ALLU PF Pressure Feeder (PF)
- ALLU DAC. Data Acquisition Control (DAC.)

ALLU Stabilisation System uses dry binder and dried compressed air to transport the binder from the container into the soil. The binder is fed through the hose directly into the middle of the mixing drums of the PM. With the DAC. the operator can control all the functions of the PF and can also accurately set the amount of the binder to be fed into the soil. With these elements the mass stabilisation can be completed successfully and economically.

The ALLU Stabilisation System is now patented throughout the world.

More information on ALLU Stabilisation System machinery is found on the ALLU web site (www.ALLU.net).

3.2 Technical information of the ALLU PM

ALLU PM Power Mix is a versatile hydraulic operated mixing unit for excavators. When the Power Mix is attached to an excavator, the combination converts to an easily movable and effective mixing plant.

ALLU PM Power Mix is able to handle very difficult and different kinds of materials effectively, such as clays, peat, sludge, mud and contaminated soil. The mixing effectiveness is based on the intelligent horizontal positioning of the drums and unique construction of the mixing elements. The drums move and mix material in all three dimensions simultaneously. The horizontal drums can transfer soil during the treatment and it enables to process materials in thinly layered sections to the desired depth. The reaching limit for Power Mix depends on the reach of the excavator and the size of the PM.

ALLU STABILISATION SYSTEM

TYPE	WEIGHT (kg)	BASIC MACHINE (EXCAVATOR)	MAXIMUM WORKING DEPTH (m)
PM 200	1900 kg (+adapter 200 kg)	20 - 30 t	2 m
PM 300	2360 kg (+adapter 200 kg)	25 - 35 t	3 m
PM 500	4200 kg (+adapter 200 kg)	30 - 40 t	5 m

Other working depths on request.



Picture: ALLU PM 300

ALLU STABILISATION SYSTEM

3.3 Technical information of the ALLU PF and ALLU DAC.

The ALLU PF Pressure Feeder feeds dry binder from the container, through the hose, and directly into the middle of the mixing drums of the PM. The unit is mounted on a tracked chassis and is remote controlled, allowing the unit to follow behind the excavator onto the site.

Two PF models are available: PF 7 with one 7 m³ container and PF 7+7 with two 7 m³ containers, which are pressurised with a compressor. The maximum pressure is 8 bars and air productivity 5 m³/min. Feeding capacity is up to 5 kg/sec and the amount of the binder can be set and adjusted accurately (accuracy 0,1 kg/s), also during the working with the DAC. system.

ALLU DAC. Data Acquisition Control system measures, controls and reports the feeding operation. ALLU DAC. enables control of the entire Stabilisation System, making the system user-friendly, and provides the facility to transfer data onto other computers. Thus the work done is properly documented for quality control purposes.



Pictures: ALLU PF 7+7 with dust filter system and ALLU DAC.

ALLU STABILISATION SYSTEM

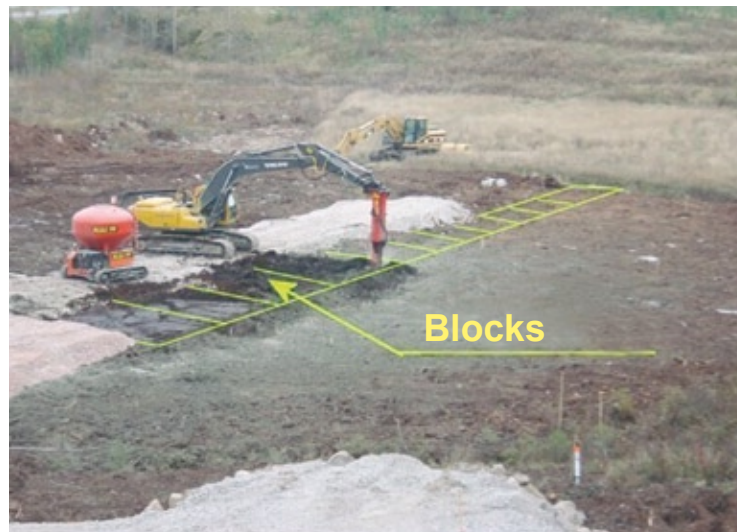
3.4 Principles of ALLU mass stabilisation

There are three different working principles for the ALLU Stabilisation Systems.

3.4.1 Stabilisation in blocks

The method is used when the material is very wet (peat, mud or soft clay). The binder is always fed into the middle of the mixing drums while the drums are rotating and simultaneously moved vertically. This method is most common used mass stabilisation method.

The depth of the stabilisation is limited by the length of the PM. The total area is usually divided into 10 to 25 meters square areas which are marked on the ground with the sticks and the stabilisation is done in one sequence. The driver moves the PM up and down to the required depth in every area so that the whole volume is homogenised. The amount of the binder is also controlled, adjusted and reported by using the DAC. system.



Picture: Stabilisation in blocks

3.4.2 Stabilisation in different layers

The method is used when material is solid enough. The binder material is either spread on the surface or fed directly to the mixing drum while the drum is rotating. While mixing the binder and soil the PM is also moving the stabilised material towards the excavator. The depth of stabilisation is not limited by the length of the PM.

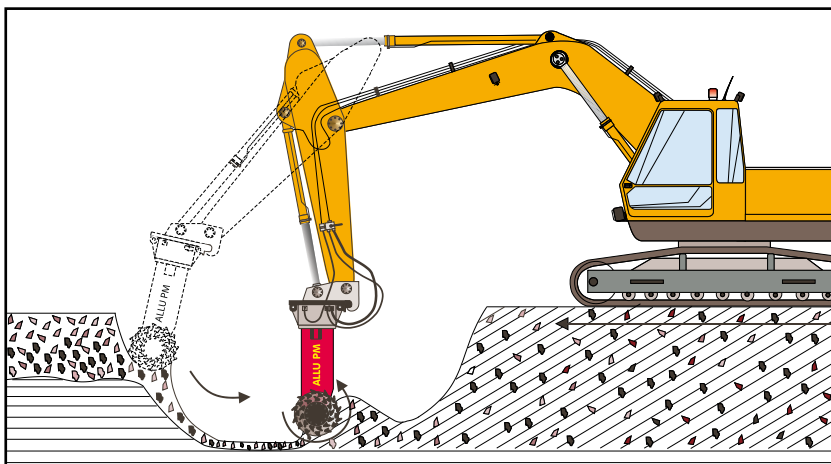


Figure: Stabilisation in layers

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3.4.3 Stabilisation in recycling area

Stabilisation in container or in pile could be a combination of methods mentioned earlier.

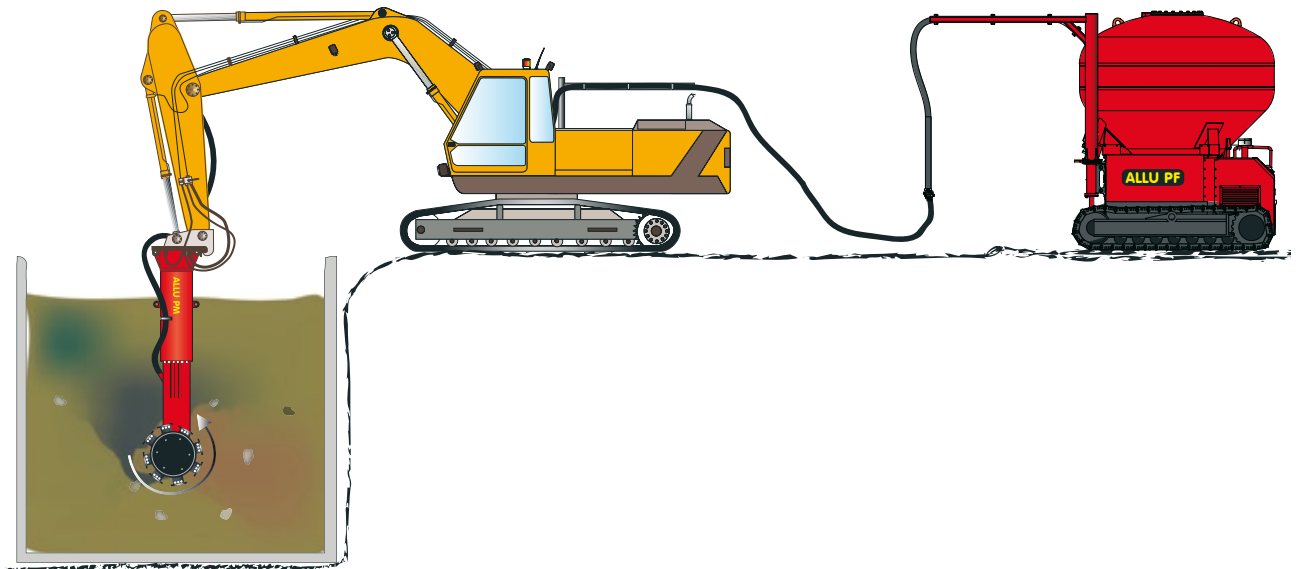


Figure: Stabilisation in recycling area

3.5 Cost Savings with the ALLU Stabilisation system

The ALLU system represents an advance in terms of cost savings during mass stabilisation projects. Most of the expenses in a stabilisation project come from the binder, which represents about 50-70 % of the total project cost. Here is one example of how accuracy of binder feeding affects to a cost of a project.

Case

The amount of the soil planned to be stabilised is 50 000 m³ and the optimised binder quantity is 120 kg/m³

- Binder quantity is 120 kg/m³ x 50 000 kg = 6 000 t
- The cost of the binder is 70 - 120 € / t
- The total cost of the binder ranges from 420 000 € to 720 000 €
- If the feeding of the binder is not accurate, 10 % excess binder could potentially be used.
In this case additional project costs could be 42 000 € - 72 000 €

This example case clearly illustrates that accurate measurement of binder quantity is essential to the cost-effectiveness of a mass stabilisation project. Therefore, one of the main focus points in the design and development of the ALLU stabilisation system was accurate measurement of binder feeding rates.

MASS STABILISATION IN A NUTSHELL

4. MASS STABILISATION PROJECT IN A NUTSHELL

Every stabilisation project is unique and different soil conditions and functional requirements, but a typical mass stabilisation project consist of sections listed below.

A. SITE AND REQUIREMENTS

- The subsoil conditions are unsuitable for construction, need for subsoil reinforcement
- Shear strenght / bearing capacity needed
 - Comparision of different reinforcement methods, basic designing
 - Choosing the mass stabilisation method (alone or combined with other methods)
- Environmental requirements

B. COLLECTION OF INFORMATION

- Existing information on soil conditions and structures located in the site
- Possible pollution of the site
- Field surveys
- Pretests

C. LABORATORY WORK

- Selection of binder quantity and quality by stabilisation tests
- Properties of untreated and stabilised soil for the designing
- Optimisation of binders

D. DESIGNING

- Calculation and designing of mass stabilisation
- Quality instructions for construction

E. CONSTRUCTION

- In-situ stabilisation tests
- Execution of work
- Documentation

F. QUALITY CONTROL

- Quality control before, during and after construction

FIELD SURVEYING

5. FIELD SURVEYING

5.1 Field tests and investigations

Prior to the mass stabilisation project, field investigations and laboratory tests are performed to determine the characteristics of the soil layers, the requirements for the binders, the area of the mass stabilisation and the lay-out of the design. In general, the site investigation will take place before the design process of the project is started. Because of the local subsoil is used as a constructive part of the mass stabilisation method, mass stabilisation requires a detailed site investigation. It is important to know the characteristics of the subsoil, in order to be able to make a proper decision on the exact location of the project, and to be able to make a plan of good quality.

Field investigations should be completed as early as possible, because then a volume of stabilisation (m³) can be calculated, and a cost estimate and time schedule can be developed. Also the most economical method of stabilisation (mass stabilisation, combined stabilisation) can be chosen and technical difficulties of the project can be predicted and resolved before the stabilisation work. If further investigations are required, they can be completed well before the stabilisation work starts

The main purpose of the site investigation is the identification and description of the characteristic soil layers. A secondary objective is to identify the presence of obstacles in the subsoil. If necessary, the site investigation can be done in two phases.

The preliminary investigation provides details regarding geological contacts and soil types prevalent at the site, and can be used to develop a preliminary design and cost estimate. Additionally, technical challenges can be identified. The investigation can be completed using CPT-tests and geotechnical borings to obtain sufficient information for preliminary design purposes. Ground penetrating radar (GPR) investigation is suitable for peat layer surveys. Also in this stage samples for the laboratory are collected.

In the second phase, the final design is developed based on a detailed site investigation, which is required to complete a high-quality design for mass stabilisation.

Picture: Sounding with middle-heavy drilling machine with static-dynamic penetration test and drilling equipment.



FIELD SURVEYING

5.2 Investigation methods

A variety of in-situ testing methods have been employed to obtain information for stabilisation projects in different countries. The table below lists some of the available methods used, but also other investigation techniques do exist. Selection of exploration method(s) depends on the size of site, its soil conditions, and on the planned use of the site after of the stabilisation. When fibrous peat is present, special attention must be paid to the reliability of the test results.

Method	Information
Collection of existing information	- Existing information on soil conditions Possible contamination Existing structures on the site (pipe lines, old dumping places, ect.)
CPT (cone penetration testing) or other type of sounding CPTu (CPT with pore pressure measurement)	- Thickness of layers Relative range/variation of strength Hydrological situation
Vane shear testing	- In-situ undrained shear strength of clay layers
Test pit	- Thickness and soil type of layers Disturbed samples for the laboratory
Georadar investigation	- Thickness of peat layers
Disturbed samples	- Properties of soils (soil type, water content, density, grain size distribution, clay content, pH, organic content, sulphides) Samples for stabilisation tests in laboratory
Undisturbed samples	- Compression properties of clay layers Consolidation degree and bulk density Samples for stabilisation tests in laboratory
Standpipe Piezometer	- Ground water level
Rising head test in a standpipe or other in-situ permeability test	- Permeability estimate (in-situ)

5.3 Samples for the laboratory

Stabilisation testing and optimisation of the binder quality/quantity can take up to 6 months, if done properly, and therefore it is recommended to collect samples as soon as possible in a beginning of a project.

Samples are collected in the field by means of a special sampler or from a test pit. Samples should be taken vertically down to the planned stabilisation depth, which generally is a harder bearing layer beneath softer soil layers. The number of samples depends on the size of the planned stabilisation and variation of the soil conditions. Samples should be representative of the site to the extent possible, so that suitable binder type and quantity (kg/m³) may be selected.

The number of soil samples needed for laboratory testing is determined after collecting the basic information about the site and its intended future. Sealed samples with information of sampling place, depth and date should be stored in cool place before sending to the laboratory. Undisturbed samples must be handled with care.

LABORATORY WORK

6. LABORATORY WORK

6.1 Determination of soil properties

Geotechnical properties of stabilised soil are dependent on the physical and chemical properties of the natural soil reserves and on the properties of the binder. The most important geotechnical properties of organic soils that have effect on the stabilisation are grain size distribution, natural water content, organic content and decomposition degree, and pH.

The laboratory testing program can be divided into the following: tests for soil classification and chemical properties, tests for engineering properties, and tests for environmental properties. Tests excluding environmental tests are described in detail in Euro Code 7, Part 2 “Design assisted by laboratory testing”, which covers requirements for the execution, interpretation and use of results of laboratory tests to assist in the geotechnical design of structures.

Classification and chemical properties

Tests are performed to obtain information on subsoil and to support the choice of the type and amount of binder. The tests should be performed for each individual soil layer. The following parameters may be determined:

- Water content and density
- Grain size distribution and fines content
- Organic content
- Decomposition degree for peat (Von Post)
- Liquid limit (LL), plastic limit (PL), plasticity index (PI) and sensitivity
- pH
- Sulphate, chloride and carbonate content
- Humic acids/TOC and cation exchange capacity
- Electric conductivity
- Groundwater pH

Engineering properties

For the determination of a representative set of engineering properties, tests should be performed for each individual soil layer. Engineering properties are important mainly for the stabilised soil samples, but in some cases they are measured for the original soil as well, for the purposes of comparison and to facilitate design. This gives the designer an estimate of the improvement of the soil. Following parameters may be determined:

- Unconfined compressive strength after 7, 28, 90, or more days after mixing
- Development of strength over time
- Compressibility
- Permeability (capacity to allow fluid to infiltrate or to flow through the stabilized soil)

LABORATORY WORK

The shear strength properties are determined using, for example, unconfined compression tests, triaxial tests, or the fall-cone test. In the absence of laboratory testing, another method for estimating the engineering characteristics of the in-situ soil is to use CPT sounding results. A good estimation is that the undrained shear strength is 5 - 10% (depending on the type of soil) of the cone resistance of a particular soil layer. In case of soils with high organic content this method is recommended.

Environmental properties

To determine the environmental impact of the stabilisation, tests should be performed. The relevant environmental properties are:

- Available concentration of ion and metals from leaching tests
- Type and total concentration of ions and metals. These tests are used as a reference measurement for leaching tests.
- pH
- Cation exchange capacity
- Sulphide and carbonate content

6.2 Properties of the stabilised soft soils

As a result of stabilisation, the chemical and physical properties of clay, gyttja and peat will change significantly. The pH-value of the stabilised soil will quickly increase to 11-12, and the curing process starts. Depending on the type and quantity of binder some of the chemical reactions will proceed rather quickly (during the first days) but some of the reactions may develop more slowly; total reaction time may be months or even years.

The strength of the stabilised soil depends on the properties of the natural soil, type and quantity of binder, curing time, and homogeneity of the mixing work. The undrained shear strength of stabilised soil is normally within the range of 50 to 150 kPa. Samples of stabilised soil prepared in a laboratory may have undrained shear strength of several hundreds of kPa, but such high values are rarely obtained in-situ due to natural variation in soil conditions and in accuracy in mixing work.

The relation between the curing time and the strength of the stabilised soil is important, because it governs the acceptable rate of loading. This relation depends on the soil type and the quality and quantity of binder. Additionally, the temperature during curing time can affect to the speed of curing, but usually the impact is relatively small. If only cement is used as a binder, most of the strength develops during the first month after stabilisation. When using binders including lime, gypsum, furnace slag and/or ash the strength will still continue increasing after the first month.

The geo-mechanical properties of the stabilised material largely depend on the type of binder. In general, strength and brittleness of the stabilised soil increases with increasing cement content. In contrast, ductility increases with increasing amount of lime.

LABORATORY WORK

6.3 Stabilisation testing

To ensure the quality of the final stabilised product, a number of stabilisation tests must be performed in the laboratory beforehand to determine the most suitable binder, to optimise the binder quantity, and to determine the engineering characteristics of the stabilised soil for the actual case. Prediction of the properties of stabilized soil can be made after classification tests and preliminary estimation of stabilisation properties, binder type and quantity.

Stabilisation testing and optimisation of the binder quality/quantity can take up to 6 months, if done properly. Testing can be done in a shorter time, but then the number of test specimens and performed tests increases, because there is no time for result evaluation and further optimisation during stabilisation testing. Also the long term curing effects of different binders cannot be taken in consideration, if tests are discontinued after only one month.

In principle the stabilisation testing is done according to the flow chart presented in this chapter. Parameters determined by laboratory tests are described in Chapter 6.1.

LABORATORY WORK

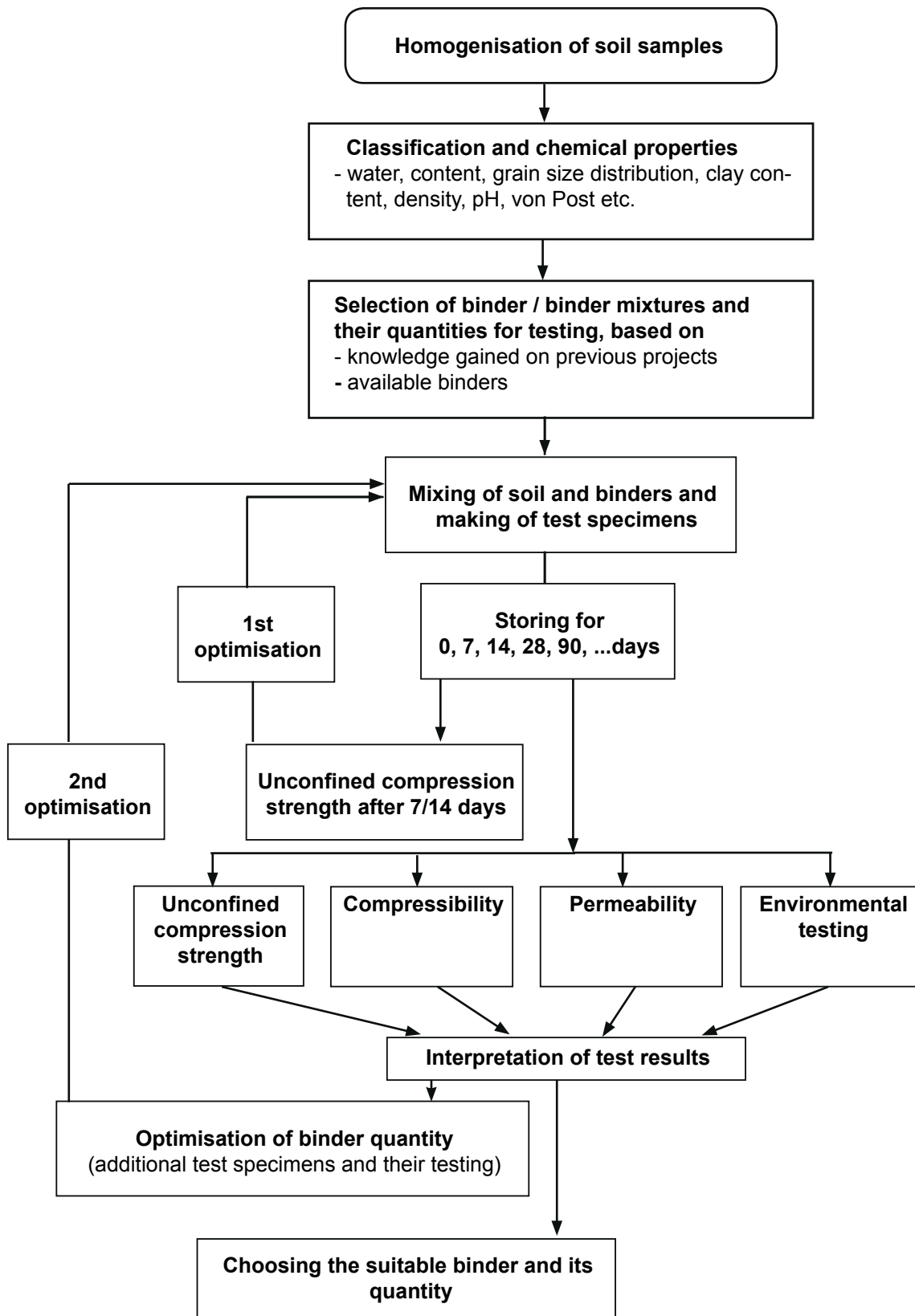


Figure. Laboratory procedure in a stabilisation testing

LABORATORY WORK

In some cases the frost susceptibility (resistance to frost) and freeze-thaw durability (resistance to freezing and thawing cycles) should be determined. Permeability of the stabilised mass should be measured in laboratory, in case mass stabilisation is being used for solidification of contaminated soils.

In the environmental laboratory the binder content of stabilised sample is determined by x-ray fluorescence measurements. Additionally, the amount of total hydrocarbons and leaching of harmful particuls can be tested, but these test are performed only when the subsoil is contaminated or when an untested industrial by-product is used as a binder component.

In Ramboll, choosing binders or binder mixtures for testing is based on extensive knowledge from over 250 R&D projects since 1989 on deep, mass and layer stabilisation. Ramboll has specialised in utilisation of industrial by-products and about 200 by-product materials have been investigated and tested for the different applications.



Pictures: Making, loading and testing of a stabilised peat specimen

About 50-70 % of the total costs in stabilisation project is caused by the binder. By careful laboratory work the suitable binder and its optimised quantity [in kg/m³] is selected and thus considerable savings are reached.

Example

- The amount of the soil planned to be stabilised is 100 000 m³.
- Binder A, required quantity 120 kg/m³, price 100 €/t
=> $(0,12 \times 100\,000 \times 100) \text{ €} = 1\,200\,000 \text{ €}$
- Binder B, required quantity 150 kg/m³, price 70 €/t
=> $(0,15 \times 100\,000 \times 70) \text{ €} = 1\,050\,000 \text{ €}$

BINDERS

7. BINDERS

7.1 Binder types

Binders may be hydraulic or non-hydraulic. A hydraulic binder is self curing in contact with water, while a non-hydraulic binder requires a catalyst to initiate curing. Non-hydraulic binders may be used to activate latent hydraulic materials to produce reactive blended products. A hydraulic binder will stabilise almost any soil but the mechanical mixing of the binder into the soil must be very precise, otherwise the result will be heterogeneous. Non-hydraulic binders generally react with clay minerals in the soil, which will result in stabilised material with improved geotechnical properties.

New binders, produced as by-products of industrial processes, can be used for mass and deep stabilisation. In some cases, they can be even more suitable for stabilising organic soil and peat materials than traditional binders. Binders available as by-products, or by-product based mixtures, are much cheaper on a mass basis than traditional lime-cement binders. About 50-70 % of the cost of a mass stabilisation is caused by a cost of a binder, and therefore cheaper binder means savings for the mass stabilisation project.

Cement

Cement is a hydraulic binder and is not dependent on a reaction with minerals; generally, it may be used to stabilize almost all soil material. There are various types of cement, and in general ordinary Portland cement is used for stabilisation purposes. Cement with finer grain size is more reactive. Different additives such as slag, ash or gypsum may be added to other types. Care must be taken to ensure homogeneous mixing, because cement, unlike lime, does not diffuse into the surrounding soil mass.

Lime

For stabilisation purposes, lime is used in two forms: quick lime (CaO) and hydrated lime (Ca(OH)_2). Lime stabilisation is based on a reaction with minerals in soil or with added mineral materials. Quick lime reacts with the water in the soil and forms hydrated lime. In addition to chemical binding of water, this reaction also releases heat which will contribute to faster reactions and a reduction of water content. During the reaction, ion exchange reactions occur which affect the stabilised soil structure. Long term stabilisation reactions, like pozzolanic reactions, may continue for years after completion of stabilisation work.

Blast furnace slag

Slag needs to be granulated and ground to be reactive; finer grain size produces more reactive slag. Slag is activated with lime or cement to achieve a faster reaction. Chemically, slag is similar in composition to cement but its quality and reactivity varies. Blast furnace slag may be regarded as a low cost substitute for cement and is normally used as part of a blended product. The long term curing effect (strength development) of slag continues even years after stabilisation and in many cases cement-slag mixture is more efficient than cement alone, if results are compared later on.

BINDERS

Ash and FGD

Ash is a fine grained residue from a combustion process. Composition of ash varies depending on the fuel and the burning process. Most common fuels are coal, peat and bio fuels. Fly ash is collected from flue gases with filters.

FGD is the end product of flue gas desulphurisation and its composition varies from pure gypsum to almost inert calcium sulphate. Limestone or lime is often used as a sorbent to capture sulphur from the flue gases.

Pozzolanic reactivity of ash varies within wide ranges, and therefore should be determined for each product separately. Ashes are as a rule not very reactive by themselves, but may reduce the cost of a blended product. If fly ash is mixed with FGD it may have reduced reactivity.

Calcium sulphate products

Calcium sulphate may be derived from a number of industrial processes as a secondary product. Solubility of gypsum produces Ca- and SO₄-ions, which activate for example blast furnace slag and fly ash. In combination with soluble aluminates gypsum reacts to form ettringite. Calcium sulphate products are used as components in blends.

Blends of dry binders

The above-mentioned materials may be blended with each other in different proportions to optimise technical performance and economy with respect to the soil that will be treated. Blends may be factory-produced or mixed at site by the stabilisation equipment.



Picture: Materials from laboratory testing: dredged sediment, cement and fly ash; gypsum, stabilised specimen and fibre clay (paper industry by-product)

7.2 Binders for different soil types

The geotechnical and chemical properties of the soil and the choice for the appropriate binder have a significant affect on the results of stabilisation. Typical binder quantity values vary from 100 kg/m³ up to 250 kg/m³.

The most important binder components are cement, lime, blast furnace slag and gypsum. Additionally, fly ash is commonly utilized, most notably for the stabilisation of peat. Binder mixes consisting of 2-components are widely used, but 3-component binders are more versatile and can be more effective for many cases.

BINDERS

	Silt	Clay	Organic Soils Gyttja/Mud, Organic Clay	Peat
Typical organic content	0-2 %	0-2 %	2-30 %	50-100 %
Binder				
Cement	xx	x / x(x)	x / x(x)	xx / xxx
Cement+gypsum	x	x	xx	xx
Cement+furnace slag	xx / xx(x)	xx / xx(x)	xx	xx / xxx
Lime+Cement	xx	xx	x	-
Lime+gypsum	xx	xx	xx	-
Lime+slag	x	x	x	-
Lime+gypsum+slag	xx	xx	xx	-
Lime+gypsum+cement	xx	xx	xx / xx(x)	-
Lime	-	Lime	-	-

xxx very good binder in many cases

xx good binder in many cases

x good binder in some cases

- not suitable

Table: Approximation of suitability of binders or binder mixtures on a stabilisation of Nordic soils. Based on relative strength increases after 28 days in a laboratory. (EuroSoilStab 2002)

7.3 Added sand in mass stabilisation

In some projects sand is added in order to ease the stabilisation work and it is believed to guarantee more homogeneous result. Sand should be clean and frost-resistant. A typical addition rate for sand is 100-150 kg/m³, which is used in soft peat stabilisation. Sand is spread on top of the cleared and stripped ground before the stabilisation, and is mixed in during the process.

7.4 Effects of binder quantity, curing time and preloading

The effect of binder quantity on the strength of the stabilised soil has been tested in the Ramboll laboratory and the results are shown in the following figure. It should be noted that the quantity vs strength curves are not linear; that is, some binders have a threshold value point in which the strength starts to grow more rapidly. In other cases, some binders are almost insensitive for the quantity (quantity affects only a little for the strength).

The effect of curing time differs between different mixes of binder and soil. When using only cement as binder the stabilisation reactions will almost totally be finished during the first month. In contrast, the stabilisation process of materials containing lime, furnace slag, gypsum or fly ash can continue for several months after mixing. As a result, laboratory tests should be extended for

BINDERS

some time, to optimize the binder mixture: the results may show greater applicability for a slow curing binder that produces higher long term effects, but these results may not be observed if tests are discontinued after only one month.

Preloading of a mass stabilised area will significantly affect the stabilisation of peat. Therefore, the importance of preload embankment should be considered, and the scheme of preloading should be planned accordingly. The possible preloading scheme will be determined by the stability of the embankment. The use of embankment will be taken into consideration while planning

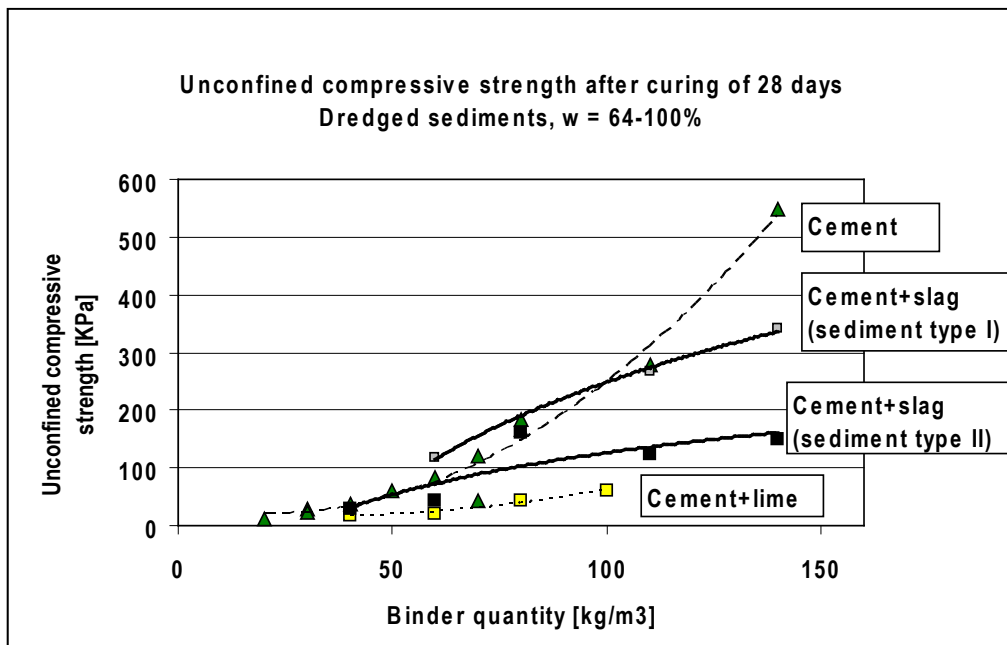


Figure: Example on the effect of binder quantity on unconfined compressive strength 28 days after mixing

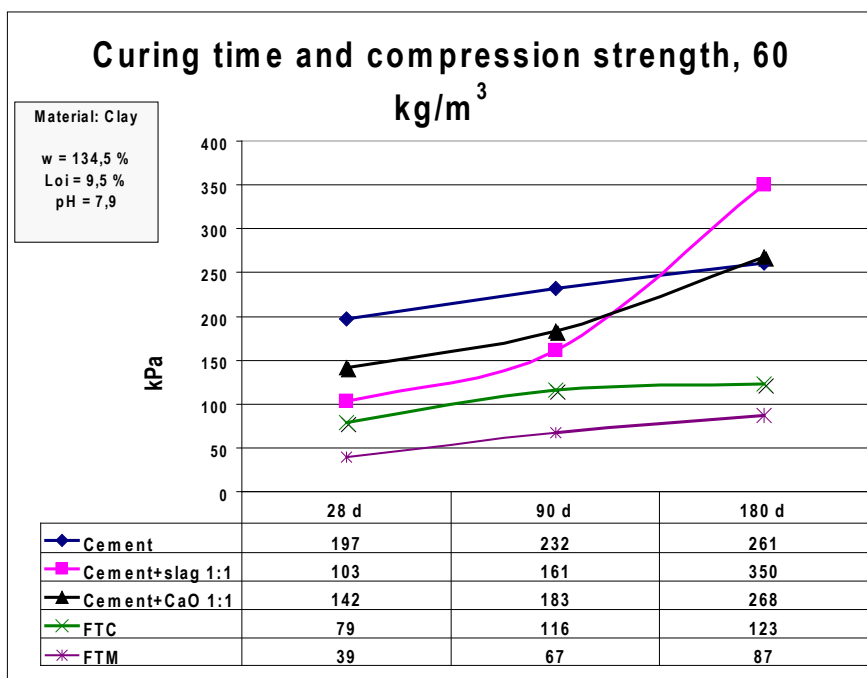


Figure: Example on the curing time effect and compression strength of different binder mixtures. FTC and FTM are lime/gypsum based commercial binder materials.

BINDERS

7.5 Effect on permeability

Stabilisation affects the permeability of the soil significantly. Binders based on lime or lime-cement mixes might increase considerably the permeability of clay. In contrast, gypsum and cement binders generally decrease the permeability. While binder addition causes a change in permeability, the change is relatively insensitive to time. For example, permeability tests on peat with different binders indicate that the permeability (k) of stabilised peat is between 10^{-9} ... 10^{-8} m/s as well after 28 days as after 180 days.



Picture: 3-axial permeability test

7.6 Environmental acceptability

Environmental tests are usually required by environmental authorities and performed before a stabilisation in a contaminated soil area. Testing is done to assure that harmful particles will not migrate from the stabilised area to the surroundings. Sometimes environmental testing is required when using industrial by-products as binders or binders components.

Leaching tests are chosen to determine the leaching behaviour and potential environmental harm of the stabilised soil when using different types of binders. Normally, leaching of stabilised clay and gyttja is tested by the diffusion test (NEN 7345, NEN 7347 or similar). The column test (NEN 7343, CEN/TS 14405 or similar) is suitable to test leaching of stabilised peat.



Picture: Leaching tested with column test

In the EuroSoilStab-project (1997) the leaching tests were made on different stabilised soils and for comparison on natural soils as well. The stabilised soils were chosen to contain binders based on industrial by-products like fly ashes, furnace slag and gypsum. The results indicate that there is no increased risk to the environment by using binders, based on lime and cement as well as the tested industrial by-products.

DESIGNING

8. DESIGNING

Note! This chapter contains only an outline of a mass stabilisation designing and with this information no actual designing can be implemented.

8.1 Design requirements

The design is developed for the most critical section of the design, which is the most unfavorable combination of load effect and bearing capacity likely to occur during construction and in service. For design purposes mass stabilised soil is assumed to be a homogeneous elasto-plastic soil layer. The uncertainties of the result of mixing and homogenisation of the stabilised soils must be considered in the design.

The stabilisation program must be designed and executed such that during its intended life the supported structure will remain serviceable for its required use and serve its intended purpose, with reasonable reliability and economy. This requires that it will satisfy ultimate and serviceability limit states.

The requirements for the service life and ultimate and serviceability limit states must be specified by the client based on the project needs. The design must be in accordance with the requirements of Euro Code 7 and/or with national regulations. In soil parameter values a distinction is made between measured, derived, characteristic and design values.

The derived value is the value of a ground parameter obtained by theory, correlation or empiricism from the measure test results. A characteristic value is determined from the derived values to give a conservative estimate of the value affecting the occurrence of a limit state.

Service life

The stipulated service life is specified in construction specifications.

Limit states

The design of stabilised ground must satisfy ultimate and serviceability limit states.

To satisfy ultimate limit requirements, the design of the stabilised ground must be such that there is a low probability of collapse or other failure which would limit its function, a risk of danger to people, or significant economic loss. Mass stabilisation is designed so that a structure or embankment and its close surroundings have satisfactory overall stability, and so that failure of the structure or its parts does not occur due to excessive deformation.

To satisfy serviceability limit state requirements, a mass stabilised area, including transition zones to unstabilised embankments, must be designed so that the total and the differential settlements along and example across the road surface satisfy the requirements for serviceability. Additionally, long-term creep movement should be considered.

DESIGNING

8.2 Loads

The loads are specified by the client. Calculation of stability during construction often yields the lowest factor of safety. Traffic load during construction can be restricted by agreement with the client. The restrictions are set out in construction specifications.

8.3 Characteristic material values

Characteristic values are set out in construction specifications and are chosen as conservative selected values taking the design situation into consideration.

Characteristic values of mass stabilisation properties may be based on field tests, on field trials, or on the results of laboratory tests made on specimens mixed in the laboratory. Characteristic values based on laboratory-mixed samples must consider the difference between laboratory and field strength.

The characteristic unit weight, Y_k , (kN/m^3), of mass stabilised soil shall be based on results from laboratory tests made on specimens mixed in the laboratory.

The characteristic undrained shear strength, c_{uk} (kPa), is generally based on the results from field tests on trial stabilisation or on unconfined compression test on specimens mixed in the laboratory. The difference in strength between laboratory mixed samples and field tests should be considered carefully.

The characteristic compression modulus, E_k , in mass stabilisation is generally set equal to 50-100 times c_{uk} . Organic soils generally fall at approximately 50 times c_{uk} and silty clays generally fall at approximately 100 times c_{uk} .

8.4 Design values

The partial factors applied to the characteristic value for ultimate limit state depend on the particular design condition. The partial factors applied for the final structure should be in accordance with local regulations, or determined on the basis of special investigation and specified in the construction specifications. Lower partial factors, as recommended below, may be used for some temporary design situations.

Unit weight of stabilised soil

Design values are equal to characteristic material values of Section 8.3.

Strength and deformation properties of soil

Parameters of unstabilised soil are determined by in-situ and/or laboratory tests.

In calculating the ultimate limit state, the value of γ_m for strength parameters is taken from Euro Code 7 or national regulations.

DESIGNING

In calculating the serviceability limit states, settlements are calculated with characteristic values in accordance with Euro Code 7 or national regulations. Total and differential settlements are then corrected with respect to the uncertainty of the calculated values (Euro Code 7 or national regulations).

Design values shall be based primarily on field tests. Design values based on laboratory mixed samples must consider the difference between laboratory and field strength.

Mixing trials are performed for characteristic soil strata. To provide a basis for the determination of the quantity of binder required in stabilisation, several mixes are normally tested in the laboratory.

8.5 Design

Calculation of settlements in the serviceability limit states

Settlements within the mass stabilised area are calculated by assuming the mass stabilised volume behaves as a homogeneous, linearly elastic and perfectly plastic layer. All of the load q is carried by the mass stabilised volume. The strength must be chosen such that the yield strength of the stabilised soil is not exceeded. The settlement is calculated in accordance with Equation (a). Note that considerable settlements can be derived during the curing period (when the load only consists of the working platform) and these settlements must be calculated separately.

$$S_m = \sum \Delta h \cdot \frac{q}{M_m} \quad (a)$$

where

S_m = settlement in the mass stabilised volume, m

Δh = stratum thickness, m

q = load on mass stabilisation, kPa

M_m = compression modulus of mass stabilised soil, kPa

When using mass stabilisation, a preloading embankment should be applied soon after the stabilisation work. The embankment compresses the stabilised volume and increases its strength. The amount of settlement varies depending on the soil to be stabilised. For peat and dredging mud, large settlement can occur due to the compression (compression could be up to 30-35 %). In the laboratory procedure suggested for preparation and storing of test samples for Mass Stabilisation Applications it is suggested that the compression of the test sample be measured in the laboratory. These recordings can be used for calculation of the immediate settlements. However, this settlement develops rapidly, and the settlements of the mass stabilised layer during service are usually small.

DESIGNING

Rate of settlement

When the effective stress in the soil is less than the preconsolidation pressure, settlement develops rapidly.

When the effective stress in the soil exceeds the preconsolidation pressure, the rate of consolidation settlement in the stabilised soil stratum is calculated in the same way as for vertically drained soil. Experience shows that the changes in the macrostructure of the stabilised soil may affect the permeability, but whether the permeability increases or decreases depends on the type of binder and stabilised soil.

As stated earlier, it is essential to make a prediction of the magnitude and rate of settlement during the preloading time. The rate of settlement as above holds only for the stabilised volume. Calculation of the rate of settlement below the stabilised volume is performed in the normal way, bearing in mind that the permeability of mass stabilised soil is often higher than the permeability of untreated soil and it can work as drain leading water into the top of the stratum.

The design and time of placement of the first preloading stage are of outmost importance due to the fact that 70 to 90 % of the total settlements occur during first 30 days.

STABILISATION WORK

9. STABILISATION WORK

9.1 Stabilisation tests

Stabilisation tests are done in order to get necessary information for the project and to confirm that used mixing time and binder quantity lead to satisfying stabilisation results i.e. strength values, homogeneity and settlements are according the plans. Types, numbers and execution procedures of tests are determined by customer or consulting company and they vary from case to case.

Mixing work

Mixing work is optimal when the mixing result will not improve by increasing mixing work time (m³/h). Optimal mixing time determination in mass stabilisation will reduce quality control costs. Additionally, reliability of the mass stabilisation will be ensured, and most importantly the total quality of the mass stabilisation will increase.

Mixing time (sec/m³) depends on stabilisation machinery used in the project and on soil conditions, but can be for example 20-30 sec/m³. ALLU Finland has wide experience on different kind of mass stabilisation conditions and thus it has collected extensive data base which can be utilised in new projects.

Mixing work quality i.e. homogeneous of mixing can be controlled by portable x-ray fluorescence equipment (Niton, Innov-X, ect.) or other in-situ method. In-situ measurements are calibrated by calibration curves made in a laboratory beforehand (more information see Section 10.2). Measurements are often checked by titration in a laboratory.

Binder quantity

Optimisation of the binder quantity is done by stabilising different blocks (like 4 x 4 m²) using different binder quantities. After certain time (2-4 weeks) the shear strength of stabilised blocks are determined by soundings (CTP, vane shear testing) and if necessary, samples are collected for laboratory testing.

Test areas/embankment

When the stabilised area is large and/or there is need for new stabilisation solutions, separate test areas are used and monitored for a longer time. In the test area mixing methods and times, different binders and different binder quantities can be compared by soundings, sample collection and analysis, and settlement measurements.

9.2 Mass stabilisation work

Every project is unique and accomplished in different way, but in principle the work is done in following order:

1. Clearing of wood etc. from the area
2. Harrowing and removal of underground stones, stubs etc, which might disturb

STABILISATION WORK

3. Marking of stabilisation fields and blocks
4. Surface excavation to the desired level
5. Spreading of sand on the ground (if additional sand is used)
6. Mass stabilisation, test blocks/fields
7. Production stabilisation
8. Quality control during work
9. Levelling of stabilised soil
10. Spreading of geotextile and making of compact layer and/or preload embankment
11. Quality control and follow-up of the stabilised area

A pre-loading embankment (usually 0,5 - 1,0 m) is used on the mass stabilised area, because it ensures consolidation of the stabilisation area, provides a working platform for machinery, and the mass stabilised area can be levelled to the desired elevation as a whole. The embankment should be constructed as soon as possible, for example within 24 hours, to get the full benefit of its presence



Picture: PF7 working

Picture: PF7+7 working

9.3 Mass stabilisation log sheet

Contractor should maintain a log sheet during stabilisation, and after work present data to the client, including:

- identification information of stabilised blocks
- starting and ending time of stabilisation of each block
- dimensions and locations of blocks
- top and bottom elevation of stabilised blocks
- binder quality, quantity and feeding pressures per each block
- mixing work done per block
- weather during stabilisation
- differences in stabilisation compared to the quality requirements
- realization of mass stabilisation (boundaries, elevations)

ALLU DAC. Data Acquisition System saves all data during the stabilisation project and provides the ability to transfer data onto other computers. Saved data includes basic information on stabilisation project, numbers of stabilised blocks, binder flow (kg/s) and working pressure (bar), starting and ending time of binder feeding, and total amount of used binders (kg).

QUALITY CONTROL

10. QUALITY CONTROL

10.1 Control procedure

Quality control work is performed in accordance with the following flow chart.

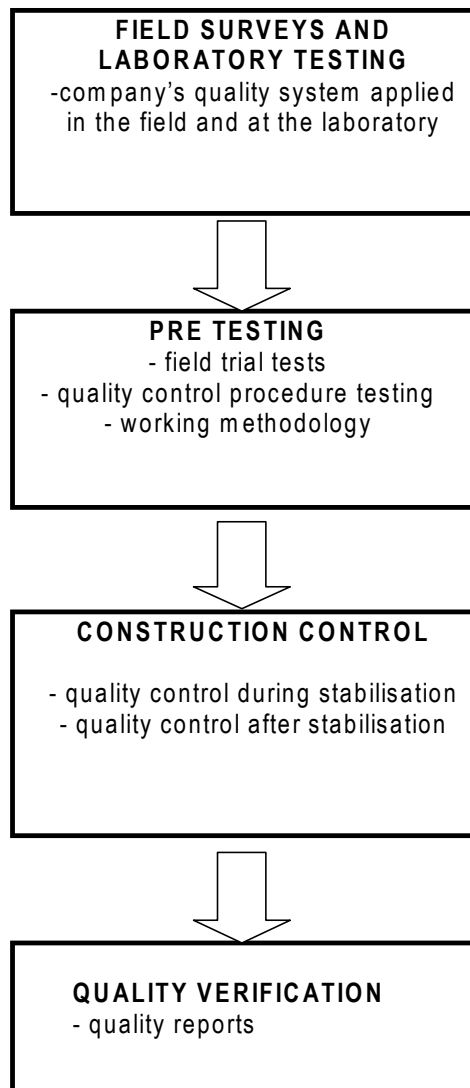


Figure: Quality control procedure

QUALITY CONTROL

10.2 Quality control before construction

Some laboratory work is required for the in-situ quality control. Calcium quantity in stabilised soil samples is used in binder quantity measurements. For the x-ray fluorescence equipment the calibration curves are determined and they show correlation between the calcium content of the soil and different binder quantities on soil samples prepared at the laboratory. Calibration curves should be checked by titration tests. In pre-testing, some compression strength tests may also be performed for reference purposes.

Soil conditions often vary significantly in different spots and depths of stabilisation site and in many cases it is recommended to use more than one calibration curve in a quality control work during construction. Soil samples for the calibration curves should be collected from representative spots and at least one or two samples should extend underneath the planned stabilisation.

Quality control work is also performed when a test field or stabilisation tests are done before construction (see Section 9.2).



Picture: Calcium content measurements with Niton XL-742S X-ray fluorescence

QUALITY CONTROL

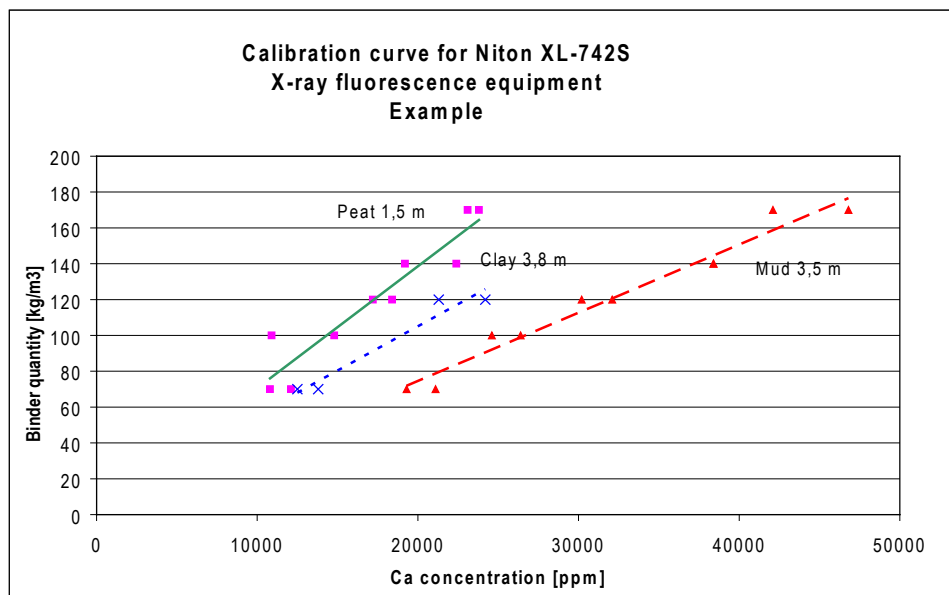


Figure: Calibration curve for binder quantity determination with Niton XL-742S

10.3 Quality control during construction

During the stabilisation process the binder contents of the stabilised layers are measured by using x-ray fluorescence analysis equipment and calibration curves (see Chapter 10.2). Titration tests are performed as an only method for binder content analysis or they are combined with x-ray fluorescence analysis for result checking purposes. If the titration results differ greatly from x-ray fluorescence analysis results then a new calibration curve should be determined. Homogeneity and depth of stabilisation is checked from the samples taken for the laboratory and with soundings. Quality control is done by the contractor or by an independent controller.

10.4 Quality control after construction

The shear strength of the mass stabilisation is examined in the field by CPT or other sounding methods. Soil samples are taken from the strengthened structure and the samples are examined in the laboratory by triaxial test, penetrometer tests and by checking the binder content of the samples. And if required, the pore water pressure and ground water level are monitored.

Example

Mass stabilisation for contaminated sediments was done by dredging mud into a basin surrounded by an edge embankment. The width of the basin was about 17 m, length about 80 m and depth 4-5 m. The quality control tests were made after one month. The bearing capacity of the mass stabilised mud was measured using soundings in 9 points (total 15 tests). Vane shear testing was used in 5 tests and deep stabilisation penetration test was carried out 10 times.

QUALITY CONTROL

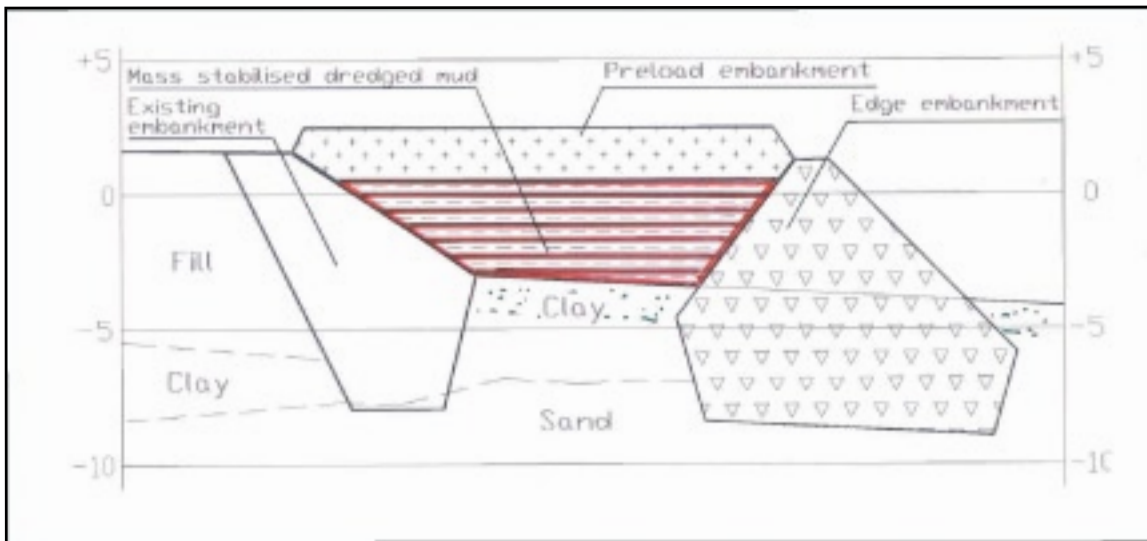


Figure: Mass stabilisation of dredged mud

Example

Mass stabilisation was done on an area with extremely difficult subsoil conditions (peat, construction waste, wood piles, old landfill). Stabilisation volume was 65 000 m³ and depth 2-5 m. For the quality control purposes 95 soundings were done 2-4 weeks after construction.

10.5 Settlement monitoring

Settlement calculation can be done by calculation programs like Limeset (Swedish Geotechnical Institute) or FEM-program Plaxis. The behaviour of the stabilised fields can be observed by installing settlement plates, inclinometers and pietsometers to the structures.

Acceptable level of settlement is determined by client and it depends on planned usage of stabilised area.

Example

Mass stabilisation (depth of 3 m) was done in an area with layers of peat (thickness 2-2.5 m), organic clay (0.5-2 m) and clay. A 2 m embankment was built on top of the area in the following year. The behaviour of the stabilised area was observed by installing settlement plates, inclinometers and piezometers to the structures. Settlements plates were primarily installed on top of the mass stabilized peat, but some plates were put to the middle and lower parts of mass stabilisation. During 3 years the total settlement was 500-650 mm and it has caused by the consolidation of the clay layers below the mass stabilisation. The measured settlement of peat was less than 20 mm and of stabilised muddy clay, 110-130 mm. According to settlement measurements the settling of the mass stabilised layer was relatively uniform.

QUALITY CONTROL

10.6 Environmental acceptability

Risks to the environment can be caused by leaching of harmful components either from the soil or from the binder. If needed, environmental acceptability of stabilisation is determined by making leaching tests in a laboratory. The leaching tests predict possible quantities of leaching for 10...100 years and often give higher values than actually occurs in stabilised structures. The results are compared to values given by national environmental administrative authorities.

The leaching test results gained in the EuroSoilStab project indicate that there is no increased risk to the environment by using binders, based on lime and cement as well as the tested industrial by-products.

Vibration and noise levels are low during construction.

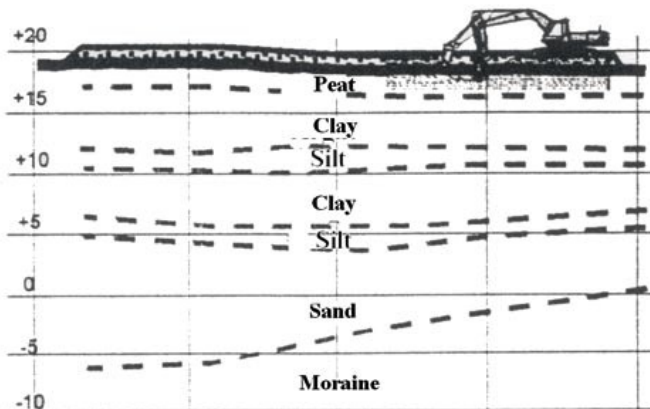
CASES

KIVIKKO IN HELSINKI, FINLAND PARKING PLACE AND INDUSTRIAL AREA INTO THE SWAMP AREA

Size: total of 4 ha mass stabilisation by end of the year 2003

Problem: Combined mass and column stabilisation for the whole area was too expensive

Solution: Cut down costs by using only mass stabilisation for the part of the area



Binder: Cement 100 kg/m³

Other additives: sand 150 kg/m³

Machinery: ALLU PM300



Soil conditions:

Wooded swamp area

Soft peat, $w=400-1000\%$

Muddy clay, $w=150\%$

Clay, $w=35-80\%$, $su=4-14\text{ kN/m}^2$, normally consolidated

Stiff silt (thin layer between the clay layers)

Clay, overconsolidated

Silt, sand and moraine

Ground water level +17.2 ... +18.2 m

CASES



Test mass stabilisation in summer 2000

In 1 ha test area 3 m of peat and muddy clay were mass stabilised. Mass stabilisation decreased the settlements remarkably and eliminated the stability problem. In 2001 the mass stabilisation was chosen as the ground treatment method for the Kivikko.



Mass stabilisation in 2001-2003

By the end of the year 2003 the total amount of mass stabilisation was 4 ha. As a stabilisation result there is now a strong and carrying layer used as a yard for industrial premises.



Settlements

The behaviour of the stabilised fields was observed by installing settlement measuring instruments to the structures. In three years the total settlement was 500-650 mm and it was caused mainly by upper normally consolidated clay below the mass stabilisation. The settling of the mass stabilised layer has been rather even.

Quality control

The binder contents of the stabilised layers was measured by using x-ray fluorescence analyse equipment. The shear strength of the mass stabilised layer was examined in the field by CPT-soundings. Soil samples were taken from the strengthened structure for the laboratory testing.

CASES

TRONDHEIM HARBOUR, NORWAY

STABILISATION OF CONTAMINATED SEDIMENTS DURING 2002-2004

Size: 11 000 m³ of sediments

Problem: Disposal of dredged sediments with low stability and containing PCB, PAH, TBT and heavy metals

Solution: Construction of a confined disposal facility (CDF), dredging and placing of contaminated sediments in the CDF and binding of harmful substances by stabilisation



Binder: Cement 80 kg/m³ + fly ash 40 kg/m³

Machinery: ALLU PM Power Mix

Laboratory tests

Stabilisation testing focused on reuse of industrial by-products in addition to cement. Stabilisation tests using binders containing cement, cement+silica or cement+fly ash were performed. Necessary axial compression strength was estimated to be 100 kPa and chosen binder mixture gave strength of 250 kPa. Also the leaching tests were done to evaluate the leaching of contaminants from the stabilised material.

Stabilisation tests were executed in the Ramboll Finland's R&D laboratory.

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Monitoring

An extensive monitoring programme was performed during and after the project. According to the results no elevated concentrations of metals or organic contaminants were found outside the CDF. Samples taken of the stabilised sediment had approximately the same strength as reached at the laboratory and results showed that the mixing of the binder in the field had been successful.

Costs

Estimated cost for stabilisation of $>100\,000\text{ m}^3$ of contaminated sediments: about 18 €/m³ for dredging and transportation, 19-25 €/m³ for stabilisation and 6-13 €/m³ for establishing the CDF. This gives a total of about 50 €/m³. Direct stabilisation in the CDF is more cost-efficient.

Stabilisation

Mixing was done first in a separate basin and after the initial hardening the material was excavated and transported to the nearby CDF. As the CDF was filled the dike became less permeable and the flow of water reduced. When the flow stopped the mixing could be done in the CDF.

The confined disposal facility and dredging

The CDF with storage capacity of $80\,000\text{ m}^3$ was constructed by creating a water permeable dike to enclose the necessary area. Dredging was done with an enclosed bucket dredger, which reduced the spill of contaminant material and the amount of surplus water.



CASES

Foundation for the high speed railway line in Luhdanoja, Finland

Basic info of the railroad

- New lines 63 km
- Bridges 76 pcs
- Earth excavation 2,6 milj m³
- Rock excavation 2,6 milj m³
- Embankments etc. 4 milj. m³
- Construction time from 2002 to 2006
- Max. speeds 220 km / h
- Travelling time 44 min
- 4,3 milj passengers in 2010
- Construction costs 331 milj Eur



Basic info of the mass stabilisation area

Mass stabilised area is 40m * 300m = 12 000m²
(extended later on)

The depth of the mass stabilisation will vary from 2 meters up to 5 meters.

As a binder, normal cement is used 200 kg/m³.

Basic target was to establish by mass stabilisation, such a working layer, which can carry up to 40-50 tons piling equipment. The needed bearing capacity was easily achieved.



Figure 21. The area consisted of two different kinds of areas. The blocks were marked with the sticks.

Area 1 : A soft peat down to 5 m deep

Area 2: Agricultural area clayey soil down to 1 m and soft peat down to 5 m deep.

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Figure 22. Stabilisation were carried out also in winter



Figure 22. Piling through the mass stabilised soil

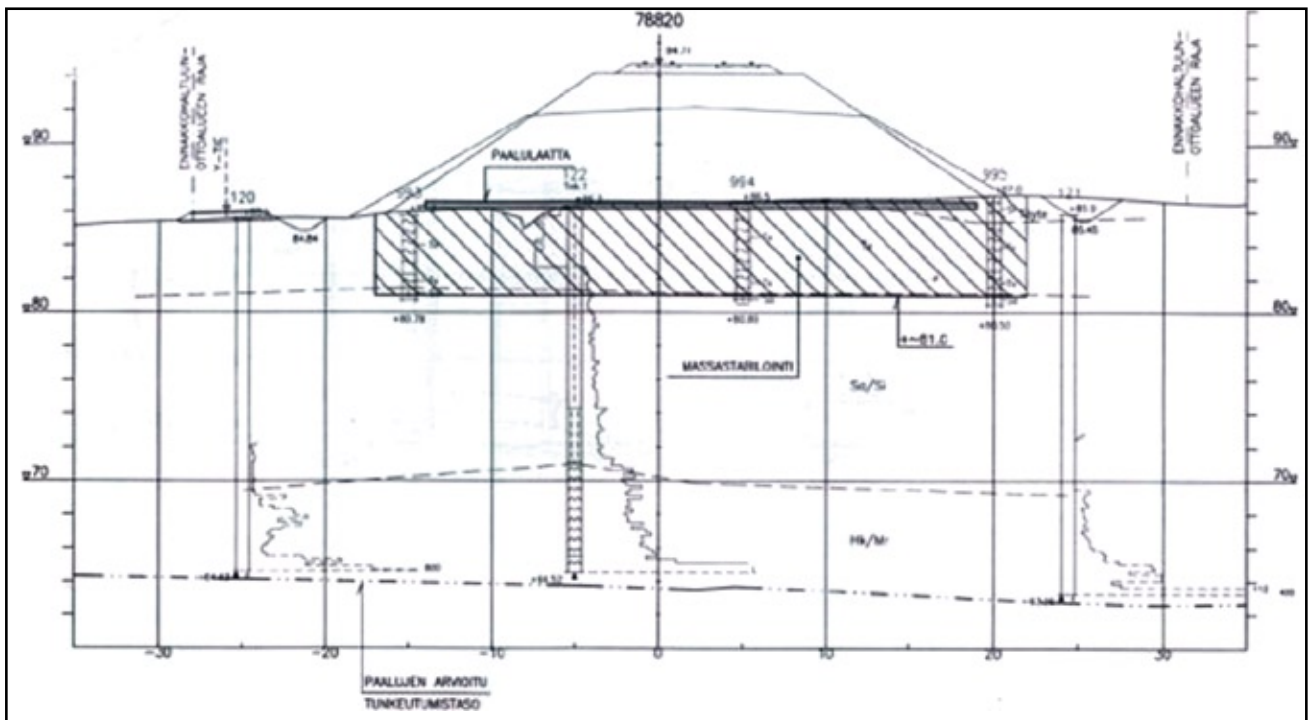


Figure 23. Typical cross section of the area

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Middle Haaga, Sports park and residential area, Finland

Basic info

Haaga is located in North-West Helsinki, 6 km from the city center. It's a peat swamp area of 54 000 m² (5.4 hectares).

The permitted building area is 10 250 m² (terraced houses and 4-5 floor apartment houses) and 800 m² kindergarten.

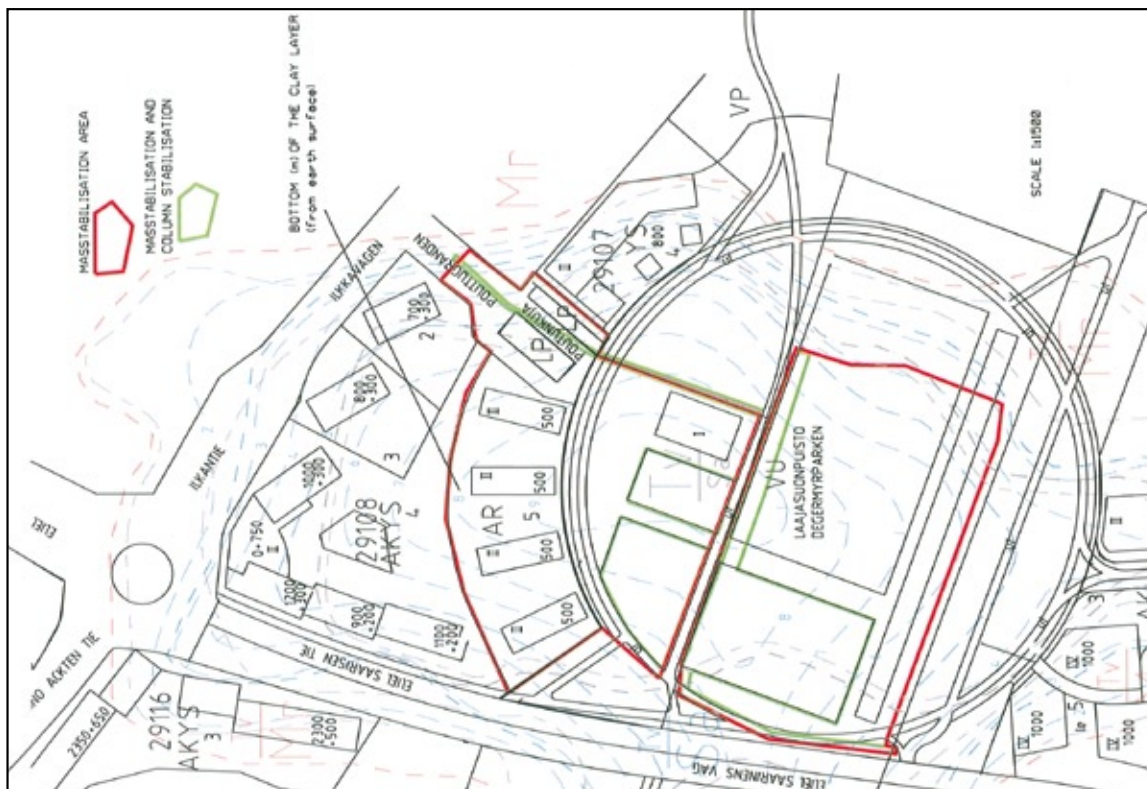


Figure 24. The areas to be stabilised

Ground conditions

The ground consists of four different soft layers:

First 2.0 – 3.5 m thick peat layer (upper part raw decayed and lower part middle decayed).

Second 0.3 – 1.0 m thick clayey mud (water content 110 – 200 %)

Third 0.2 – 0.6 m thick silty sand

Fourth 0 – 5 m soft clay (water content 50 – 90 % and shear strength 9 - 15 kPa)

Under these layers there are sand and moraine layers.

The maximum depth of soft soils is approximately 11 m.

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Stabilisation details

Most part of the sports field areas and sewer network will be founded on mass stabilisation.

The area is 26 000 m² and 78 000 m³

Cement (CEM II / A-M (S-LL) 42,5 N) 120 kg/m³ and 150 kg/m³ is used as a binder.

The shear strength should be 50 kPa and the settlements should be less than 100 mm when the area is in use.

The clay layer underneath the peat and mud will be column stabilised.

The diameter of piles 700 mm and total length 14 000 m

The shear strength of the columns should be 100 kPa.

The thickness of the compression embankment will be 0.5 –1.5 m over the stabilised peat and will stay there at least 6...12 months.

Quality control and instrumentation

Quality control soundings will be done by the contractor and the client to confirm the shear strength of the stabilised mass and homogeneity.

Contractor also defines the binder content of the mass (laboratory samples and portable x-ray fluorescence on site).

Settlements will be monitored with settlement plates and with flexible settlement tubes.

Pore water pressure will be monitored.

Ground water table is measured in many standpipes.

Stabilisation in Sundet, Finland

Basic info

The area is located in Kirkkonummi near the boarder of Espoo. It will be a residential area of 45 000 m² . The mass stabilised area is appr. 14 000 m² and the material amount to be stabilised is appr. 18 000 m³.

The ground of streets, parking areas and all the foundations for the pipelines will be mass stabilised.

Ground conditions

The area is a farming area consisting of firstly 0,7 –1,5 thick dry soil layer and secondly silt clay layer, which goes down to 25 m depth. The water content of the clay varies between 116 – 142 % and the shear strength between 9 –18 kPa.

Stabilisation details

The binder has been selected by testing the samples in laboratory. The binder to be used is cement CEM II/A-M (S-LL) 42,5 N 110 kg / m³.

The needed shear strength after 90 days is 80 kPa.

The depth of the mass stabilisation under streets and parking places is app. 1 m and

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beneath the pipelines also 1 m.

The stabilised area is covered with geo textile and loaded with the 1 m high gravel embankment.

Quality control and instrumentation

The quality of the stabilisation is controlled with the penetration tests for every 500 m² and also reported.



Figure 27 and 28. Stabilisation of soil for residential area in Kirkkonummi, Finland.

Stabilisation of contaminated soil in Trondheim harbour, Norway

The pilot project to stabilise 15 000 m³ of contaminated soil from the bottom of the sea was started together with authorities, consultants (Scandiaconsult and DVD consulting) and construction company (Selmer Skanska). The soil contained PCB, PAH, TBT and heavy



The contaminated soil was dug with a special crane from the place 1 in to the barge and then transported fully closed to place 2 Pier II

Figure 29 Air photo of stabilisation area

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Pier II. The material was dug with an excavator and loaded on a dumper (picture 2) to be transported to a stabilisation area (picture 3). Material was stabilised by mixing industrial cement and fly ash in 3 pieces of 150 m³ containers. The mixing was done with ALLU PM Power Mix (picture 4). After mixing, the material was transported into a landfill.

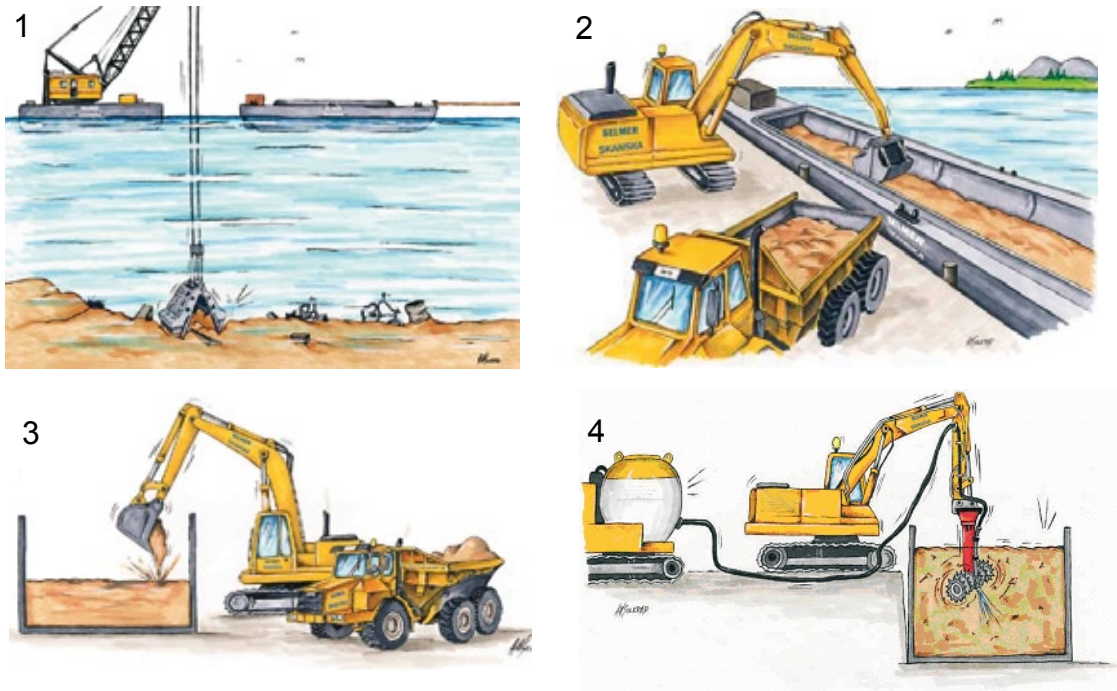


Figure 30 Stabilisation process

The experience of this pilot project will be utilised on the planned landfill area 3. The study of this area started in January 2003 and the project was ready at the end of 2004.

Mass Stabilisation of the railroad in Peräseinäjoki, Finland

Basic info

The need for mass stabilisation raised when there came the need to increase the speed of the personal trains from 160 km/h up to 200 km/h and cargo transport speed up to 100 km/h with the axle weight of 250 kN.

In this project the goal is to find out how suitable different strengthening methods are and what are the cost.

The testing area is divided into three sectors each of them 100 m long. The first is a reference area, the second mass stabilisation area and the third an embankment area.

Figure 31.

Ground conditions

The railroad goes through the peat area. There are almost 5 meter layer of peat, under the peat 2 to 5 meter layer of silt and under that moraine. Figure 32.

Stabilisation details

The stabilisation is done in 5 x 5 m² blocks.

The used binder is sulphate resistant cement and the amount is 100 kg/m³

The stabilised peat is covered by geotextile and preloaded of one meter thick layer of gravel.

The short term shear strength is 15 kPa and long term shear strength is 40 kPa which ensures the stability and zero settlement of the embankment of the railroad with the new loads and speeds.

The stabilisation is functioning in four ways (figure 32)

1. The edges of the railroad embankment don't penetrate into the stabilised peat.
2. The lower part of the railroad embankment cannot penetrate into the stabilised peat.
3. The upper part of the railroad embankment cannot fall in to the peat.
4. The stabilised peat round the railroad embankment prevents the formation of the sliding layers through the peat.

Quality control

All the areas will be monitored with piezometer and inclinometer. Also the settlements are measured. In the stabilised area the homogeneity and the amount of the binder will be tested, likewise the shear strength is measured.

FURTHER READING

FURTHER READING

ALLU Stabilisation System, Sales Manual in English, Spanish and Portuguese. Free downloads in [<http://www.allu.net/en/downloads.php>]

EuroSoilStab. Design guide soft soil stabilisation. Development of design and construction methods to stabilise soft organic soils. CT97-0351. (2002)

Puumalainen N., Halkola H., Rantala K., Forsman J. & Hautalahti P.. Mass stabilisation and combined mass and column stabilisation in Kivikko area, Helsinki. NGM 2004, Ystad, Sweden, 19.-21.5.2004. (2004)

Andersson, R., Carlsson, T., & Leppänen, M.. Hydraulic cement based binders for mass stabilisation of organic soils. Soft Ground Technology conference, The Netherlands. (2000)

Laugersen J. et al. Stabilisation of contaminated sediments in Trondheim harbour – Special challenges. Proceedings of the International Conference on Deep Mixing – Best practice and Recent Advances, Deep Mixing'05. Stockholm, Sweden, May 23-25, 2005. Also other mass stabilisation articles in this publication.

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Screening, crushing, mixing, aerating, and loading in one step operation



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ALLU Finland Oy

P.O. Box 22,
16301 Orimattila, FINLAND
Tel: +358 3 882 140
Fax: +358 3 882 1440
Email: info@allu.net

ALLU Deutschland GmbH

Klößnerstraße 3,
32257 Bünde, GERMANY
Tel: +49 5223 180 150
Fax: +49 5223 180 1515
Email: deutschland@allu.net

ALLU France S.A.R.L

4 rue du Docteur Guyot,
21420 Savigny-lès-Beaune, FRANCE
Tel: +33 3 80 24 04 34
Fax: +33 3 80 24 04 36
Email: france@allu.net

ALLU Group

700 Huyler Street, Teterboro,
New Jersey 07608, USA
Toll Free: 800-939-ALLU (2558)
Tel: +1 (201) 288-2236
Fax: +1 (201) 288-4479
Email: usa@allu.net

ALLU UK Ltd.

17 Victoria Road,
Holywood Co. Down,
N. IRELAND BT18 9BA
Tel: +44 2890 428 822
Fax: +44 2890 428 855
Email: uk@allu.net

ALLU Sales office China

Victoria Plaza A-24E,
1068 Xikang Road,
200060 Shanghai, P.R. CHINA
Tel: +86 21 6266 5999
Fax: +86 21 6266 5777
Email: china@allu.net

ALLU South America

Cerrito 1070 Piso 7,
C1010AAV Buenos Aires,
ARGENTINA
Tel: +54 11 4805 7287
Fax: +54 11 4805 7287
Email: sudamerica@allu.net

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