Saimaa University of Applied Sciences
Technology, Lappeenranta
Double Degree Programme in Civil and Construction Engineering

Darya Mokrousova

GROUND IMPROVEMENT, PRACTICES IN RUSSIA, AND FINLAND. POSSIBILITIES OF COOPERATION

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ABSTRACT
Darya Mokrousova
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Instructors: Matti Honkaniemi, Roman Timashkin, Matti Hakulinen, Tero Liutu

The study was commissioned by Finnish Consulting Group Oy. The purpose of this thesis is to facilitate the implementation of dry deep mixing (DDM) technology into Russian excavation support design and construction practices, and answer the questions of deep mixing technology design.

The aims of the research were to study the DDM method and compare it with ground improvement methods used in Russia nowadays; show the advantages of DDM to be used in Russia particularly in St. Petersburg; examine general and legal aspects to use DDM in Russia.

The thesis should be of interest to engineers and technologists working in the fields of deep soil excavations and the improvement of soft soil foundations to support heavy loads

The first part of thesis contains a description of the individual methods of ground improvement focusing on the equipment, the procedures, and the properties of the treated soil.

The bulk of the thesis consists of the more detail description of the DDM method including applications, materials, design principle, equipment, construction, execution, quality control and quality assurance and documentation.

The thesis continues by depicting the positive aspects of the usage of DDM in Russia. This part indicates the main advantages of DDM and its useful properties for improving difficult sick soils in St. Petersburg. Also geotechnical problems of St. Petersburg are discussed in more detail.

In the last part there is information about the possibilities of using DDM in Russia, about the availability of required materials and equipment. There is a list of some cement and lime plants near St. Petersburg. There are also the information about quality control in Russia, about problems in survey branch, and a list of the biggest organizations, which implement quality control.

The results of this work can be applied to using DDM in Russia for improving the permeability, strength and deformation properties of soils as a cost effective and environmentally sound method.

Keywords:Dry Deep Mixing, Soil Stabilization, Ground Improvement, LCcolumn

CONTENTS

1 INTRODUCTION

Traditionally buildings would be constructed in the areas of good quality ground that could require simple foundation techniques, but as more and more development takes place it is necessary to use land that is not initially suitable for building. As a result, ground containing soft soils such as alluvial silts, soft clays or even peat is being developed and ground improvement now plays a large part in any sizeable project.

The deep mixing method is today accepted world-wide as a ground improvement technology in order to improve the permeability, strength and deformation properties of the soil. Binders, such as lime or cement are mixed with the soil by rotating mixing tools. The stabilized soil, often produced in column shapes, has higher strength, lower compressibility, and lower permeability than the original soil. Experiences have been positive and the method has a great development potential. The method is undergoing a rapid development, particularly with regard to its applicability, cost effectiveness and export potential (Larsson, S., 2003).

Deep mixing methods for construction purposes in the past have been used extensively in Russia. However, the low level of equipment has not allowed to use these methods. Western companies have developed equipment to consolidate the soil to practical use. It seems promising to use these opportunities to prepare grounds for the construction of new buildings and fencing of pits. Even in dense urban conditions deep mixing technologies can be effectively used to consolidate the weak soils of St. Petersburg.

In my thesis, the present state of the practice of Dry Deep Mixing and its quality control is outlined. Recently published knowledge is reviewed. The mixing process in-situ and influencing factors are shown. Different test methods are reviewed. The thesis also examines the conception of quality. Information is collected from magazine articles, books on the deep mixing process and soil stabilization.

2 METHODS OF SOIL STABILIZATION USED IN RUSSIA

The construction of engineering structures is associated with the development of new territories located also on weak soils. Often it turns out that it is practically impossible to build engineering structures on a natural basis, due to the mismatch characteristics of the soil requirements. In these cases the methods of ground improvement have to be resorted to.

2.1 Definition

Ground improvement is any process that increases the physical properties of a soil, such as the shear strength, bearing capacity, and the resistance to erosion, dust formation, or frost heaving. Ground improvement by all methods, except for thermal method, should be carried out under a positive air temperature of soils. Verifying the design parameters and technical conditions for the production of works on soil stabilization should be implemented, directly in the production of the works in their infancy. After their intended use all wells in fixed or entrenched mass (exploration, injection, and control) must be eliminated by filling them with a cement solution. When the complete work of soil stabilization has been received the appropriate actual results with the requirements of the project must be ready.

2.2 Grouting

Grouting densities the soil, and significantly increases its bearing strength. Although the individual grains are forced into a tighter packing, they achieve little additional cohesion and improvement in the shear strength is usually not great.

Grouting consists of an injection of a fixed soil of cement milk (suspension), or a solution with water, through pipes submerged in the soil. After the end of the injection, the solution gradually hardens and forms a strong, not washed away, and weak-filtering base with a soil. Grouting is possible in soils with pores (or cracks), the size of which greatly exceed the size of the grains of cement.In practice, the average void size must be at least three to ten times larger than the maximum particle size in the grout medium (Karol, 1982 pp. 565-566), otherwise the injection becomes difficult. Therefore, grouting is effective in the medium and coarse sand and is inapplicable in fine-sand and in clays. Grouting especially in fractured rock and coarse-fragment soils is rational. Because the grout behaves as a growing solid in the ground, the risk of hydraulic fracturing or other damage resulting from out-of-control grout is minimal. Based on the cost per unit of improved soil, grouting is usually the least expensive means of soil improvement. In addition, it is readily performed in areas with poor access or other restriction and can result in the least disruption or messiness. It is thus particularly advantageous for use under or around existing structures.

As mentioned above the usage of cement grouts in low permeability soils is very difficult because the size of soil pores must exceed the size of cement grains, but today there is manufactured brand micro-cement, that differ in the granulometric composition: at D95 ≤ 9,5 24 μм. In addition, the brand is also divided into different grades depending on the type of the source of clinker and additives.

Micro-cement has opened new opportunities in geotechnics, due to particularly finely dispersed mineral binders (OTDV) to guarantee a smooth change in grain size. Micro-cement is a powder and is produced by air separation of dust during the grinding of cement clinker, so it is a hydraulic mineral binder.

The penetration range for microfine cement is approaching or equal to that of chemical grouts. Combined with water and an added dispersant, microfine cement can set in 4 to 5 hours. A sodium silicate additive in the mixture yields a rapid setting time of 1 to 3 minutes. MC-100, MC-300, and MC-500 are microfine cements that have varying soil penetration ranges (Karol, 1990).

The use of mixtures of different types of cement is allowed only after laboratory tests with the timing setting and hardening. The physical-mechanical properties of cement, intended for the preparation of grout should be checked for each batch of cement, regardless of the passport data. The quality of grout must be monitored in the laboratory.

The injector, used for introducing the solution into the soil, is a seamless pipe the diameter of which is 19 - 38 mm, ending at the bottom with a conical tip. At the bottom of the pipe there are holes a diameter of 3-6 mm, located at a distance of 2.5 diameters apart. The pipe consists of an element (length of 1, 5 m), connected through the interior muff. The injector is plunged into the soil by driving pneumatic or manual hummers, mechanical copras, with hammers weighing 50 - 100 kg or with a silent pile driver.

At a high depth immersion (reaching to 15 m), injectors enter in the pre-drilled wells. Before the buildup of the soil cement, wells are washed with pressurized water, to remove the fine particles of soil, and to cleanse the pores, as well as to ensure that wetted soil particles no longer spend water from solution. The weight ratio of cement and water in the solution is recommended to be in the range of 1: 10 to 1: 0.4 depending on the degree of water absorption of cemented soils. From this figure depends the distance between the injector, which may be in the range from 1 to 3 m. Cement should not be below grade 300. Pressure under which the injection solution should be done depends on the density of the soil and the size of pores and cracks. The required amount of the solution ranges from 15 to 40% of the volume of the fixed soil. The strength and water resistance of soil increases after grouting significantly.

2.3 Injection (Chemical stabilization)

Chemical grouts were developed in response to a need to develop strength and control water flow in geologic units where the pore sizes in the rock or soil units were too small to allow the introduction of conventional cement suspensions. Injection fills the interparticular soil pore system, essentially gluing the individual particles together. This greatly increases both the shear and bearing strength. It will also result in a significant decrease in the soil permeability and when thoroughly applied, will completely block the flow of water. Its use is limited to those soils that possess sufficient permeability to allow the thorough penetration of the grout. This means sands and gravels, although such materials containing minor amounts of silt-size particles are also treatable. Because injection behaves as fluids in the ground, the risk of loosing control including leakage and hydraulic fracturing of the soil is high. Based on the unit of soil treated, the cost of the injection is relatively high. (Warner, J. 2004).

Chemical grouting is done using a "one-shot" system or "two-shot" system (Fig. 2.3). In the "one-shot" system where all chemicals are injected together after pre-mixing setting times are controlled by varying the catalyst concentration according to the grout concentration, water composition, and temperature. In the "two-shot" system wherein one chemical is injected followed by the injection of a second chemical which reacts with the first to produce a gel which subsequently hardens. Two-shot systems are slower and require higher injection pressure and more closely spaced grout holes.

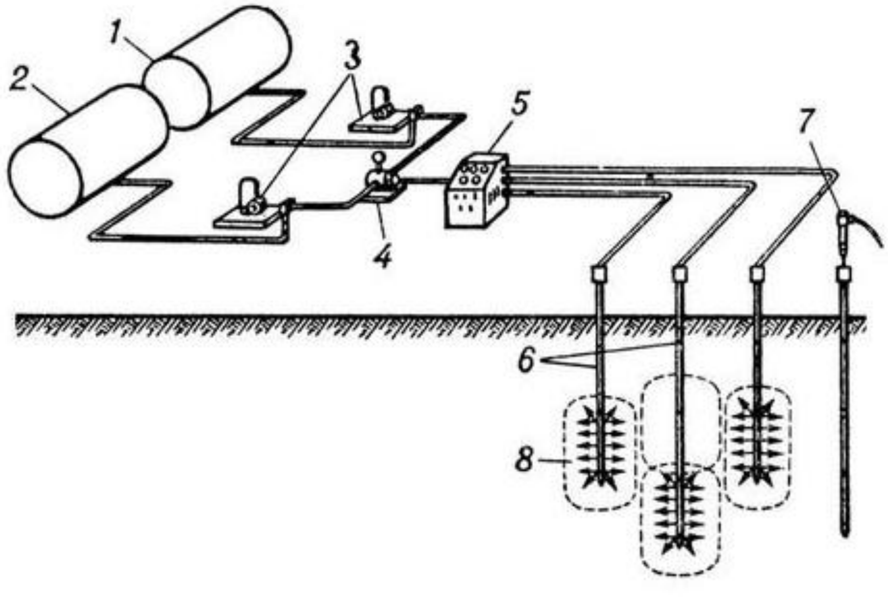


Figure 2.3 Equipment for the injection: 1 - tank with a binder, 2 - tank with acid, 3 - pump "ND" 4 - Mixer, 5 - Remote Control with recording equipment; 6 - injector; 7 - hammer to immerse the injector into the soil 8 - form line of fastening.

Chemical materials used in injection (water solutions of sodium silicate, urea and other synthetic resins as a binder, inorganic and organic acids and salts, some gases as a hardener, formulated additives for different purposes, gelling the mixture, working compounds) must satisfy requirements of relevant standards, specifications and the project. When selecting injection, equipment must comply with the designated project unit costs and pressure of injection, as well as the aggressiveness of reagents (SP 50-101-2004, p 13.6.12.).

To ensure the required shape, size and monolithic of stabilized mass by project, the injection of reagents must be made by individual single injections (portions) the estimated volume of which must be confirmed SP 50-101-2004, p 13.6.13.

On the basis of the unit of improved ground, injection is generally much more costly that grouting, so its use is typically limited to applications in which the primary requirement is either to block the flow of liquid or increase the cohesion of the soil. Obviously, the amount of grout that must be injected, and thus the cost of the work for water control, will be much greater than that required for most strengthening.

Toxicity and causticity are intrinsic characteristics for many of the chemical grouts. The degree of toxicity may range from causing a simple skin rash to the more serious effects of being carcinogenic or neurotoxic. Often, the grout, catalyst, or reactant is dangerous by itself, but when they are mixed and bonded to the soil, the toxic elements may become inert (Karol, 1990, p. 64). A major concern regarding chemical grouts is the health effects on work crews. If the chemicals are mishandled, the crew would endanger not only themselves, but also the public. Training personnel and providing proper equipment are essential preventive measures against accidents. Negligence, such as placing the grout in a known reactive environment, which causes the gel to leach into nearby groundwater, would endanger public health. However, once placed in the ground under appropriate conditions, the gel poses no significant hazard to the public. Chemical grouts could be used effectively when used with safe and proper handling procedures (Clifton, 1986, p. 8). These requirements relate to transportation, storage and preparation of chemical reagents, cleaning process equipment, and the evacuation process of waste and flushing water, as well as providing personnel with protective equipment.

Environmental changes may accelerate the degradation of chemically grouted samples. A freeze/thaw or wet/dry cycle can mechanically deteriorate a grouted mass containing high amounts of free water. Grouts placed in certain soil regions may never experience complete wet/dry cycles, such as closeness to the water table, or complete freeze/thaw cycles, such as below the frost line. In the vicinity of a leaky underground steam pipe, the wet/dry cycle phenomenon occurs often (Karol, 1990, p. 49). Dry environments cause cement grouts to shrink after setting, forming micro fissures that increase permeability (Littlejohn, 1982, pp. 42-46).

2.4 Electrochemical method

Electrochemical method is used in silt, clay, loam remained in the fluid and fluid plastic conditions. To enter the solutions of sodium silicate and calcium chloride, soils direct current voltage of 30-100 V and a current density of 0,5-7 A on 1m2 vertical cross-section of fastened layer of soil are passed. In this case, the electrodes are the metal bars or tubes, which clog the soil in parallel rows across 0,6-1m. When a current is passed in the soil electric-osmosis - movement of water arises in the pores of the anode to the cathode. This phenomenon is used to enter through the perforated anode into the soil chemicals.

As a result, the soil is dewatered and compacted. Exchange reactions occur at the same time in the electrode area they also contribute to the consolidation and compaction of the soil. Electrochemical indurations are divided into electric-drainage, electric-compacting and electric-solidification.

2.5 Thermal method

This method of soil stabilization is used to eliminate subsidence and increase the strength of loess. Thermal stabilization is amenable also to clay and loam, if they have air permeability.

The essence of the thermal method is to increase the strength of structural bonds in the soil under the influence of high temperature. Fuel (gas, liquid or solid) for charring the soil in drilled wells is burnt. Typically natural gas and other flammable gases, fuel oil, etc. are used as the fuel in order to maintain the combustion process in the wells delivering the pressured air. Fig. 2.5 shows the process of thermal stabilization schematically.

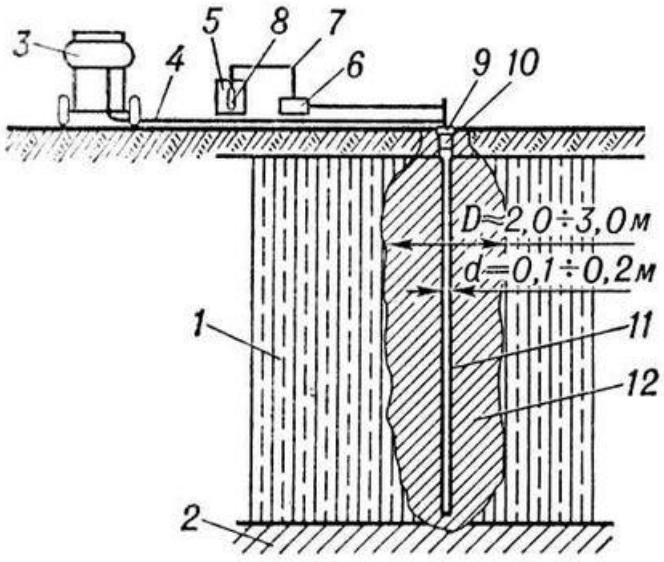


Figure 2.5 principal scheme of thermal stabilization: 1 - soil subsidence; 2 – baseground; 3 – compressor; 4 - pipeline for cold air; 5 - container for fuel; 6 - fuel pump in the well; 7 - pipeline for fuel; 8 – filter; 9 – injector; 10 - valve with a combustion chamber; 11 – hole; 12 - zone Fuser soil.

Air and fuel are delivered so that a temperature of about 800 C is maintained in the wells, and air and fuel penetrate into the pores. Hot gases heated the soil to a temperature not lower than 300 C.

Charring continues for 5-10 days. Column consolidated soil with a diameter of 1,5-3 m with the cube strength of 1-3 MPa when consumption of liquid fuels 80-180 kg per the 1-metre length of the borehole is formed.

To verify the compliance conditions of soil with the data of engineering research and design the technological sampling of stabilized soil, and appropriate laboratory tests to determine the characteristics should be produced (SP 50-101-2004, p 13.6.34.).

The commencement of charring soil in the wells should be preceded by test blow-by capacity wells. If there are layers of low permeability should be taken measures to equalize the ability by blow-by capacity wells, by cutting and blowing these layers or by increasing the filtration surface of the wells (SP 50-101-2004, p 13.6.35.).

In the charring process it must be checked that the maximum temperature of the gases is not causing the melting of soil in the walls of the well. The pressure and temperature of the gases should be recorded in the journal papers.

The strength, workability and water resistance of the samples, taken from monitoring wells should be monitored by the results of laboratory tests. This takes into account the data recorded in the workbooks on temperature and pressure of gas wells in the process of heat treatment of soils. When deemed appropriate by the project, the strength and deformation characteristics of soils are determined by field methods (SP 50-101-2004, p 13.6.39.).

3 SPECIFICATIONS OF DRY DEEP MIXING METHOD (DDM)

Deep mixing is an in-situ soil stabilization technique using cement and/or lime as a stabilizing agent. It was developed in Japan and in the Scandinavian countries independently in the 1970s. Scandinavian contractors have extensive experience in treating very soft, compressible clays with lighter equipment producing lime or lime/cement columns for settlement control and embankment stabilization. They are also promoting their systems internationally, directing their attention to the Baltic countries. Focusing on infrastructure applications, the Scandinavians have found their methods to be cost-effective, fast, and technically and economically favorable compared to traditional methods (Holm, 1997).

Based on design requirements, site conditions, soil and rock layers, restraints and economic, the use of deep mixing methods (DMM) is increasingly spreading. These methods have been suggested and applied for soil and rock stabilizing, slope stability, liquefaction mitigation, vibration reduction (along the railways), road and railroad and bridge foundations and embankments, construction of excavation support systems or protection of structures close to excavation sites, solidification and stabilization of contaminated soils etc.

Deep mixing technologies are usually categorized into "wet" mixing methods and "dry" mixing methods depending on how the binder is applied to the soil. In the wet mix method, cementitious slurry is injected through a large diameter to a specified depth. In the dry mix method the dry powder reacts chemically with the pore water during curing. Therefore, the dry method reduces the water content of the soil. This method is generally considered less expensive than the wet mix method. Dry-method rotary equipment is typically lighter than wet-method rotary equipment.

3.1 Dry Deep Mixing Method (DDM)

Dry deep mixing was developed in the mid 1970s in Sweden by principally one contractor. During the 1980s, the development of dry deep mixing was mainly provided by government clients, research institutes and universities. An extensive and rapid development started however in connection to a large investment program for infrastructure projects at the end of the 1980s. The first commercial project with the lime-cement column method in Finland took place in 1988 and in Norway in 1990. Today, the method is referred to as the Nordic Dry Deep Mixing Method (Holm, 2003). In the Nordic countries, about 3 to 4 millions linear meters of lime-cement columns are installed annually, especially for infrastructure projects. The “Dry Mix Methods for Deep Stabilization” conference in Stockholm 1999 (Bredenberg *et al*., 1999) and the GIGS conference in Helsinki 2000 (Rathmaier, 2000) provide surveys of dry deep mixing in the Scandinavian countries.

Dry deep mixing (Some Scandinavian literature uses the terms "lime-cement columns", "deep stabilization", "dry jet mixing method", "column stabilization") is a soil improvement technology used to construct cutoff or retaining walls and to treat soils in-situ. This is accomplished with a series of overlapping stabilized soil columns. The stabilized soil columns are formed by a series of mixing shafts, guided by a crane-supported set of leads. The column layout, diameters and spacing are determined by the performance requirements and the parameters of the improved and natural soils.

Soil improvement by dry deep mixing (DDM) is an environmentally sound and frequently the most economic improvement method for soft soils. DDM is a low vibration, quiet, clean form of ground improvement that is used in very soft and wet soil conditions with the advantage of producing no spoil for disposal. DDM works well in high moisture content (>50%) silty and clayey soils. The dry binder uses the in-situ soil moisture during the hydration reaction. (Keller Ground Engineering Pty Ltd).

Applications

Deep soil stabilization is widely used for the foundation of road and railway embankments but it can be applied in many other ways. Due to the increasing experience and results from research programs and development of the equipment new applications will arise in the near future. The examples of the configuration of columns of deep mixing for different purposes are illustrated in Fig. 3.1.1, and some case histories are presented in Appendix 1.

Typical applications of deep mixing comprise:

- Foundation support
- Retention systems
- Ground treatment
- Hydraulic cut-off walls

- Environmental remediation.

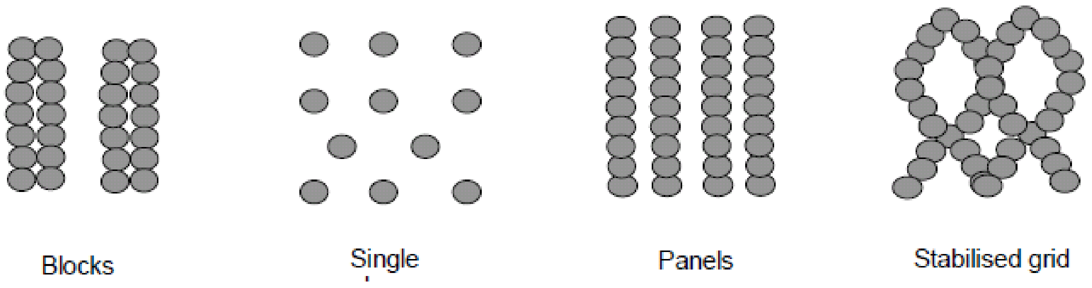


Figure 3.1a Examples of the placing of columns

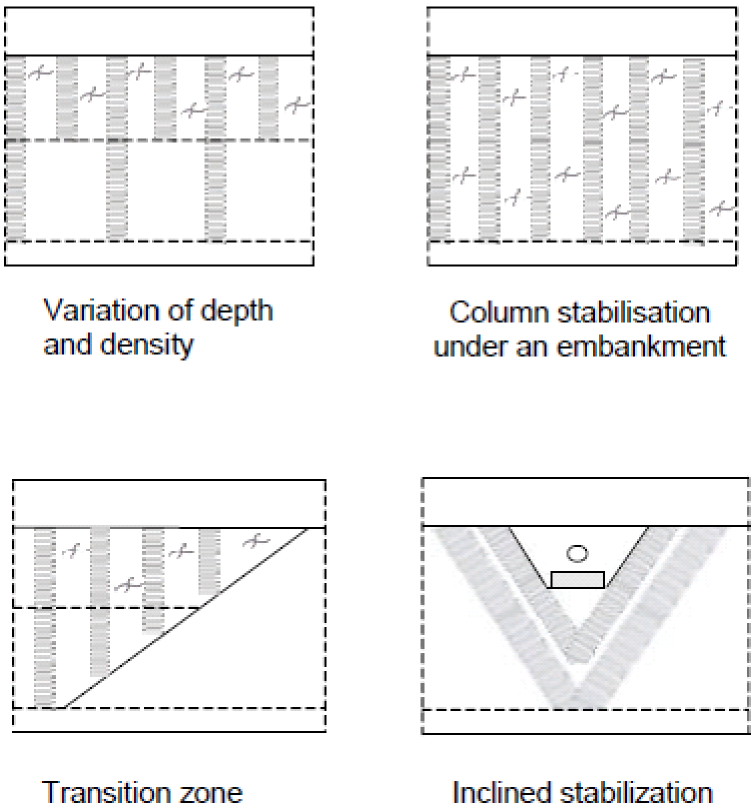


Figure 3.1b Examples of the placing of columns

Figure 3.1 Examples of the configurations for column stabilization (Soft Soil Stabilization)

3.2 Materials

Binders may be hydraulic, i.e. self setting in contact with water or they may be non-hydraulic, i.e. they need some material to react with in order to set. Non-hydraulic binders may be used to activate latent hydraulic materials to produce reactive blended products. A hydraulic binder will stabilize almost any soil but in order not to produce a heterogeneous end product the mechanical mixing of the binder into the soil must be very good. Non-hydraulic binders generally react with clay minerals in the soil, which will result in a stabilized material with improved geotechnical properties. (EuroSoilStab).

2-component binder mixes are widely used but 3-component binders are more versatile and can be more effective for many cases. The most important components are limes, cements, blast furnace slag and gypsum. In regard to the use of industrial by-products also high quality fly ashes can be exploited for certain cases, especially in the stabilisation of peat.

3.2.1 Amount and properties of binders

The cemented material that is produced generally has a higher strength, lower permeability, and lower compressibility than the native ground, although the total unit weight may be less. The amount of binder added during the mixing process is identified following initial laboratory trials and subsequently it is verified onsite during the installation of the initial columns. Amounts of binder range from 80kg/m3 in soft silt and clay to as high as 300kg/m3 in highly organic high moisture content peat. It is important to note that the results achieved in the laboratory cannot be directly applied to the field, correction factors of 0.25 to 0.50 being typical. (Keller Ground Engineering, Dry Soil Mixing Brochure, 2005)

3.2.2 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 stabilization 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. (ALLU, Mass Stabilization Manual, 2005).

3.2.3 Lime

For stabilization purposes, lime is used in two forms: quick lime (CaO) and hydrated (slaked) lime (Ca(OH)2).Lime stabilization 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 stabilized soil structure. Long-term stabilization reactions, like pozzolanic reactions, may continue for years after the completion of stabilization work. (ALLU, Mass Stabilization Manual, 2005).

3.2.4 Blast furnace slag

Slag needs to be granulated and soil 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 stabilization and in many cases cement-slag mixture is more efficient than cement alone, if results are compared later on. (ALLU, Mass Stabilization Manual, 2005).

3.2.5 Ash and FGD

Ash is a fine grained residue from a combustion process. The 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 desulphurization 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. The 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. (ALLU, Mass Stabilization Manual, 2005).

3.2.6 Calcium sulphate products

Calcium sulphate may be derived from a number of industrial processes as a secondary product. The 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. (ALLU, Mass Stabilization Manual, 2005).

3.2.7 Storage of binders

As most binders react with moisture they should be stored dry, in closed tanks. The precaution will also reduce dusting at the job site. Long storage time is not recommended for any binder because that could lead to decreased reactivity and flowability.

3.2.8 Safety

Due to high alkalinity most materials are irritant for eyes and skin. Inhalation should be avoided. In reaction with water or acids some binders develop heat. These products should be handled wearing protective gloves, mask and goggles. Special attention should be given to handling where high pressure is involved for instance when unloading lorry tanks or when filling tanks on stabilization equipment.

3.2.9 Properties of unstabilized soil

Characteristics and conditions of soil affecting the strength increase: physical, chemical and mineralogical properties of soil, organic content, pH of pore water, water content (Table 3.2.9)

Mud and peat, unlike clay, have high organic content. The organic material may include retarding substances such as humus and humic acids. During stabilization the humic acids react with (Ca(OH)2) to form insoluble reaction products which precipitate out on the clay particles. The acids may also cause the soil pH to drop. This affects negatively the reaction rate of the binders, resulting in a slower strength gain in mud and peat than in clay. In highly organic soils, whole blocks of soil may be stabilized down to depths of typically three to five meters.

Studies in Finland (Parkkinen) indicate that in soils with high organic contents, such as mud and peat, the quantity of binder needs to exceed a "threshold". As long as the quantity of binder is below the threshold the soil will remain unstabilized. A reason for this may be that the humic acids are neutralized when sufficient binder is added. (Larsson, 2005).

Research and practical applications in Europe have shown that organogenic and organic soils can be stabilized with lime cement columns (Holm 2002, EuroSoilStab 2002). Holm, Andréasson, Bengtsson & Eriksson (2002) reported a successful application of lime cement columns in very soft organic soil (gyttja) and clays for the stabilization of a low railway embankment in Sweden. A binder consisting of unslaked lime and cement in an amount of 120 - 150 kg/m3 was used. Despite an organic content of up to 20% and an embankment height of only 1.4 m, a settlement reduction factor of 5 at low train speeds and of up to 15 at train speeds of 200 km/h was achieved.

As a result of stabilization, the chemical and physical properties of clay, gyttja and peat will significantly change. The pH-value of the stabilized soil will quickly rise up to 11 – 12 and the curing will start.

Table 3.2.9 Range of water content in Russia corresponding to the upper limit of soil plasticity, depending on soil texture and mineralogical composition.

Texture and mineralogical composition	Water content (%)
Sand	8–20
Loamy sand	15–30
Sandy loam	20–40
Loam	35–60
Clay loam	40–65
clay	50–100

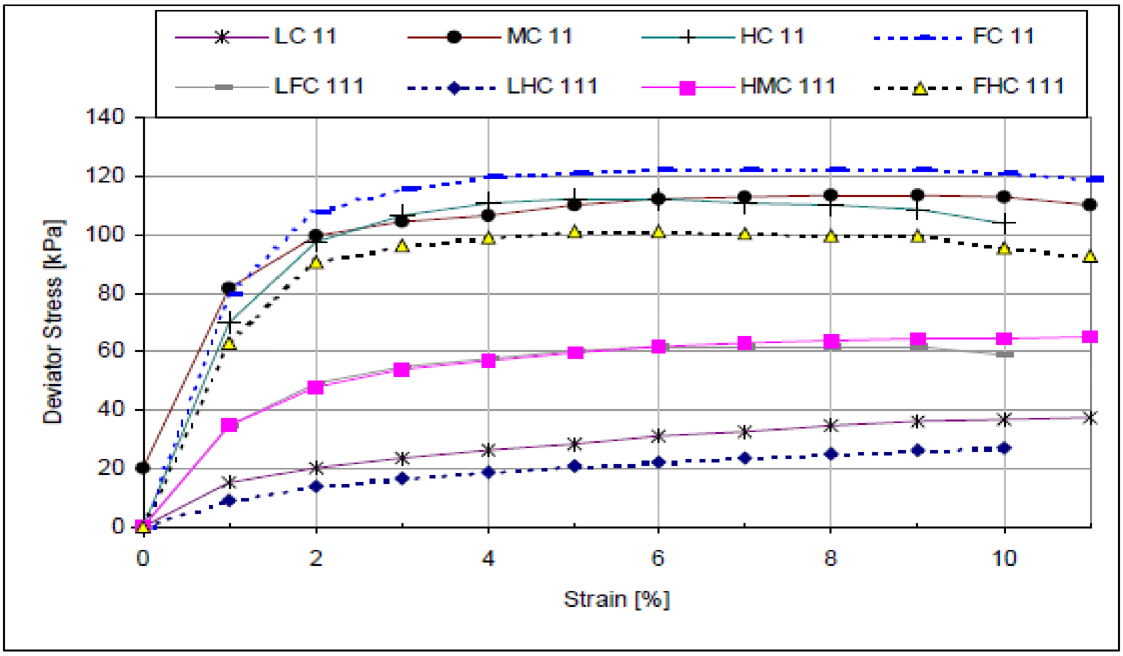
3.2.10 Chemical and mechanical interaction of the stabilized and natural soil

As a result of stabilization, the chemical and physical properties of clay, gyttja and peat will significantly change. The pH-value of the stabilized soil will quickly rise up to 11 – 12 and the curing will start. The above-mentioned materials may be blended with each other in different proportions to optimize technical performance and economy with respect to the soil that will be treated. Blends may be factory-produced or mixed at site by the stabilization equipment. (EuroSoilStab).

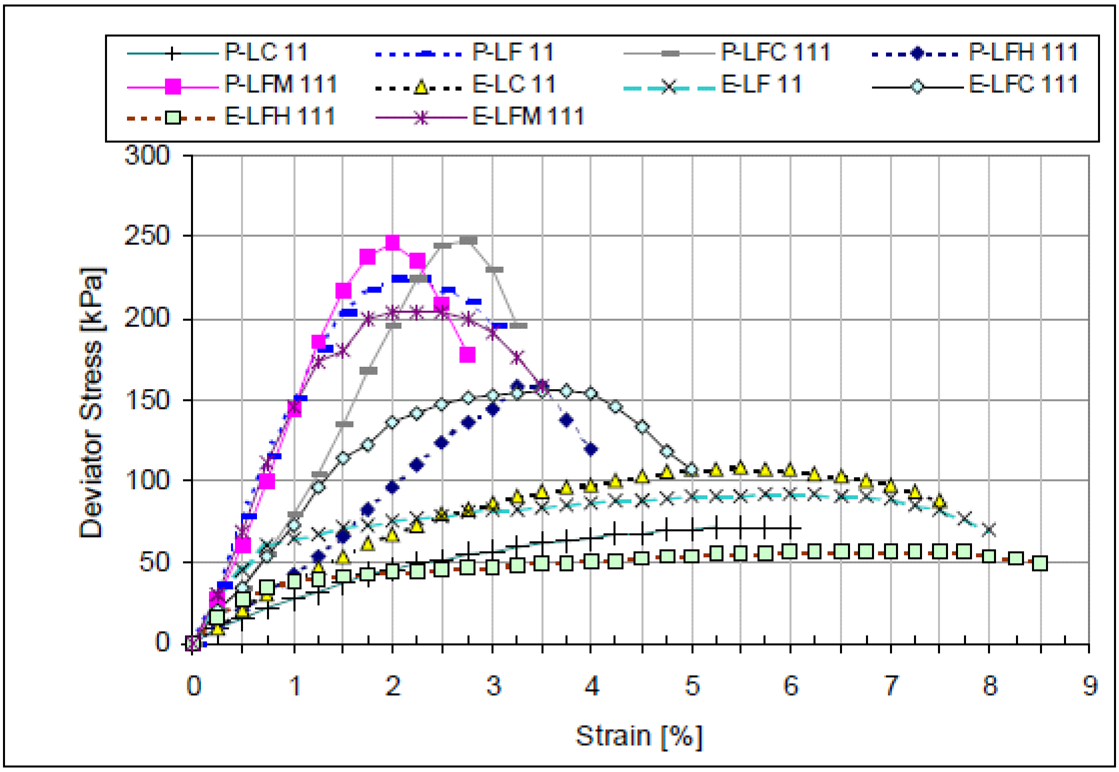
When mixing the binder with soil the chemical reactions start immediately. When cement is used a stabilizing gel between the soil granules is created due to pozzolanic reactions. A very homogeneous mixing is required since cement, unlike lime, does not diffuse. When using pulverized binders based on lime the soil reactions continue for several months:

- the water content of the soil decreases since water is consumed during the chemical reactions;
- the lime reacts with the clay minerals;
- calcium ions will diffuse from zones of high binder concentration both within the stabilized volume and to adjacent zones originally not involved in the mixing. Consequently, the homogeneity and strength of the stabilized volume is improved.

The geo-mechanical properties of the stabilized material largely depend on the type of binder. In general, the strength and brittleness of the stabilized soil increase with increasing amount of cement. On the other hand, the ductility will increase with increasing amount of lime. Typical stress-strain relations for different stabilized soils using different types of binders are shown in figure 3.2.10.1. (EuroSoilStab).



a. Stress-strain of stabilized peat



b. Stress-strain of stabilized gyttja

Figure 3.2.10.1 Stress-strain curves of stabilized soil. (EuroSoilStab).

In Figure 3.2.10.1 a. Examples of peat from Kivikko (Helsinki, Finland), and of gyttja from Porvoo (P-; Finland) are presented and examples from Enanger(E-; Sweden) are shown. In Figure 3.2.10.1 b. Symbols of binders: L=lime, C=cement, F=Finnstab-gypsum, M=blast-furnace slag, H = a Finnish fly ash and V= a Swedish fly ash . Numbers indicate the proportion of components. The tests have been performed in 1997.

It is important to understand that in the end, a hardened cement-ground system, strength to 1-2 MPa is formed. This is not a reinforced structure, which can not be a bearing structure, but the compressive strength of 0,6 MPa for these purposes is enough. Figure 3.2.10.2 gives examples of the values of the strengths of soil, soil cement and concrete.

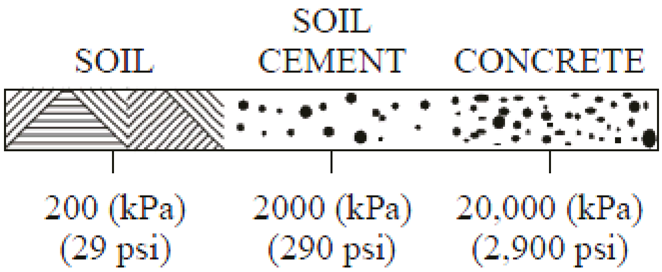


Figure 3.2.10.2 Compressive strength comparisons

Figure 3.2.10.3 shows the influence of soil type on the shear strength of stabilized soil.

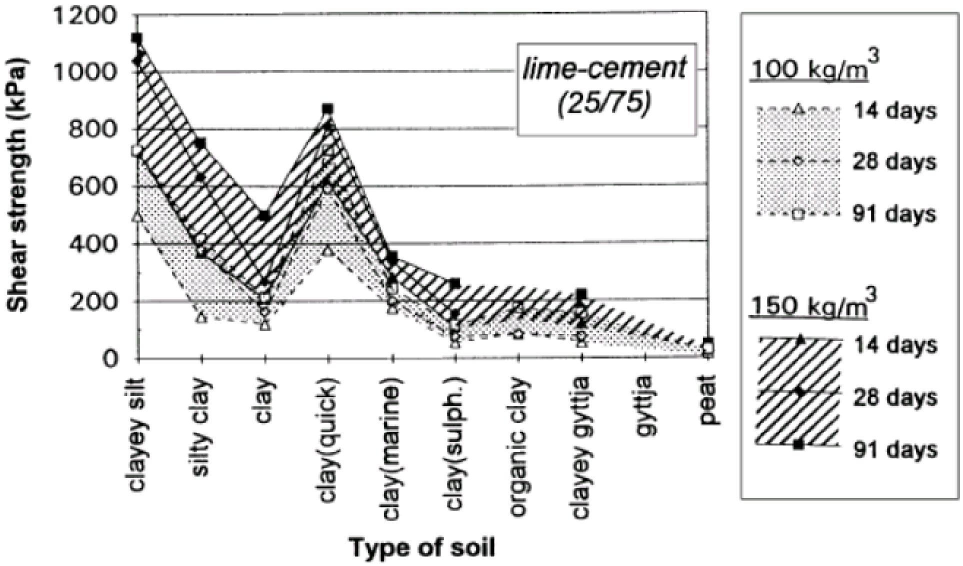


Figure 3.2.10.3 Shear strength of the different types of stabilized soils (Holm, 2005)

3.3 Design principle

The underlying design philosophy for deep stabilisation is to produce a stabilised soil that mechanically interacts with the surrounding unsterilized soil. The applied load is partly carried by the columns and partly by the unsterilized soil between the columns. Therefore, a too stiffly stabilised material is not necessarily for the best solution since such a material will behave like a pile.

Instead, the increased stiffness and strength of the stabilised soil should not prevent an effective interaction and load distribution between the stabilised and natural soil. This philosophy is schematically described in figure 3.3. (EuroSoilStab).

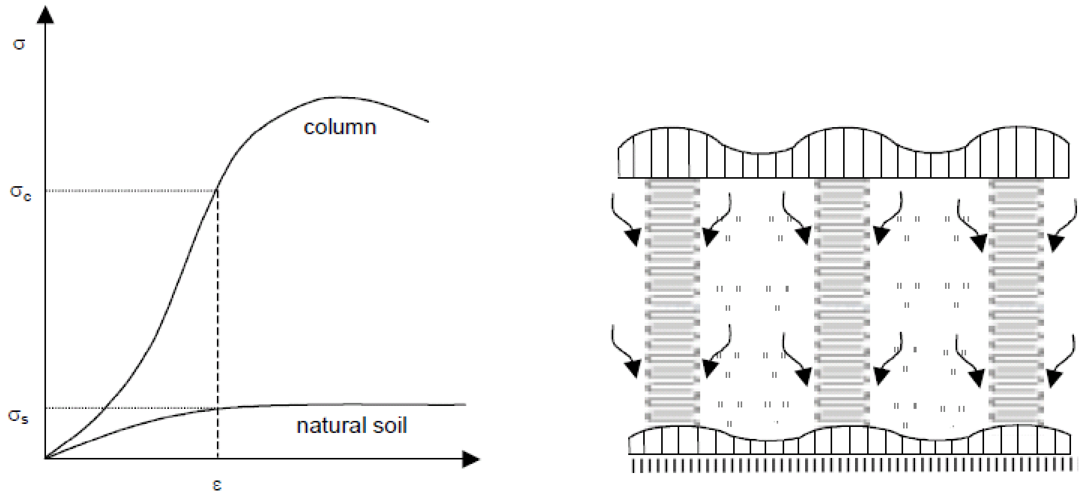


Figure 3.3 The geo-mechanical design philosophy for deep stabilization (EuroSoilStab)

In the European countries there is accordance with the Eurocode philosophy in relation to soil parameter values. A distinction is made between:

- Measured values
- Derived values
- Characteristic values
- Design values

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

The design is carried out for the most unfavourable combination of load effect and bearing capacity, which is likely to occur during construction and in service. Design models are based on the assumption of interaction between columns and unsterilized soil, which implies that the design models are valid only for semihard columns with the maximum shear strength of 150 kPa. The design should be based on column strength from field tests. (EuroSoilStab).

The ULS (Ultimate Limit State) mechanisms to be considered in the design of stabilised soil columns are to include the failure of the column itself and overall failure through the columns and the untreated ground. The design parameters for ULS should be based on the characteristic values divided by an appropriate partial factor.

Settlement calculations should also be based on the assumption that the distribution of load between columns and unstabilised soil is on the basis that at every level the same compression occurs in columns and in the unstabilised soil.

Single columns in the direct shear zone and passive zone must not be used since interaction can not be assumed. In order to ensure interaction in the direct shear zone and passive zone, the columns are placed in panels, grids or blocks. (EuroSoilStab).

3.4 Equipment

The Development of equipment for dry deep mixing was begun in Sweden in the early 1970s by Linden-Alimak AB. Research and development on dry deep mixing started in Finland at the same time (Rathmayer, 1997). The aim in the early stages of development was a device of high production capacity. The mixing equipment and the in-situ mixing process have remained practically unchanged.

Figure 3.4.1a shows a typical deep dry mixing plant with on-board binder material silos, air drier and compressor to produce compressed air to transport the binder to the mixing tool. Other designs for deeper work have the binder silos, air drier and compressor on a separate self propelled chassis (Figure 3.4.1b). The chassis is connected to the mixing machine by an umbilical through which passes the binder, under compressed air, and the monitoring information from the binder mixing and supply rate pass. The deep mixing machines weigh between 50 and 80 tonnes and have masts which can be up to 20 m high. (EuroSoilStab, 2002).

Figure 3.4.1a Deep dry mixing plant with on-board binder silos, air drier and compressor

Figure 3.4.1b Deep dry mixing plant with separate binder silos, air drier and compressor

Typical mixing tools used in the deep dry mixing are shown in Figure 3.4.2.
They usually consist of a single nozzle for the binder delivery, a horizontal and curved or angled cutting blade. These tools vary in size but are usually made to produce mixed columns in the 500 mm to 800 mm diameter range.

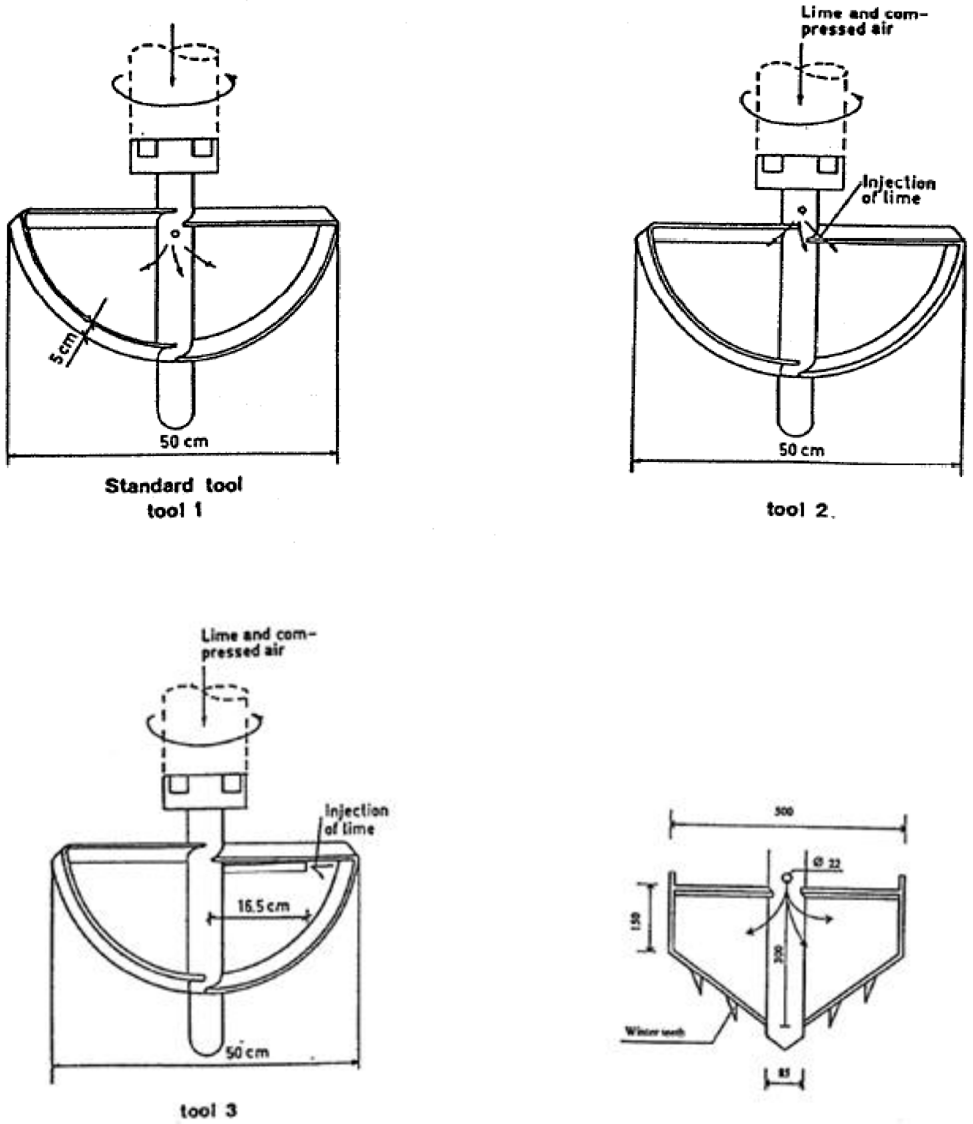


Figure 3.4.2 Typical end mixing tools used in the DDM method (Stabilator Technical Information, 1992).

A number of variations exist as shown in Figure 3.4.3, but the differences in terms of the basic mixing mechanisms are slight. The blades of the standard tool are generally tilted at a very small angle to the horizontal (-10-20). Since the initial development of mixing tools in the 1970s, most projects have been carried out with tools of the type in Figure 3.4.3. Further development has been very limited. (Larsson,2005).

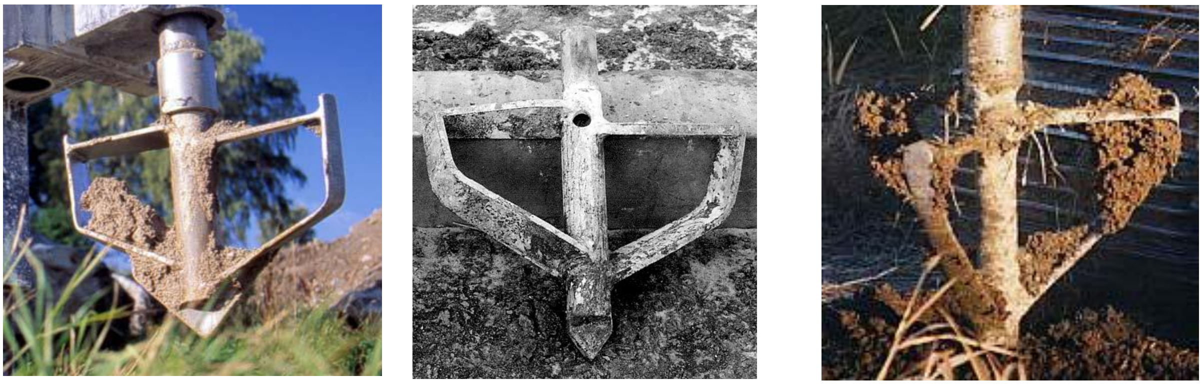


Figure 3.4.3 Three versions of the Nordic dry mixing “standard” tool (courtesy of Hercules Grundläggning and LCM)

Production rates for DDM equipment

- Typical diameters of column: from 1.0 to 1.5 m for Japanese equipment to 0.5 to 0.8 m for Scandinavian equipment
- Ascent/descent rates:
  Soft clay: < 25 mm per revolution at 200 RPM
  200 x 25 mm = 5000 mm/min = 5 m/min
  Silt/Sand: < 15 mm per revolution
  200 x 15 mm = 3 m/min
- Production:
  20 m deep: 20 m / 3m/min ≈ 7 min x 2 ≈ 15 min
  10 hrs = 600 min x 80% efficiency = 480 min
  480 min / 15 min/pt = 32 pt/shift x 20 m = 640 m
  -> 500 m to 800 m per 10 hr shift.
- Blade Rotation Number 100-500 per m
- Amount of binder is usually in the range 80 to 120 kg/m3 in marine clays, for field strengths (cu) of 40 to 60 kPa, whereas for organic soils a dosage of 250 to 350 kg/m3 can be required for field strengths (cu) of 100 to 150 kPa.
- The torque required by the mixing pipe and blades is typically 6 to 50 kNm at 150 rpm to 50 rpm.
- Contact ground pressure 50 to116 kPa

3.5 Calculation

Calculations are usually made in special programs developed on the basis of Excel. Examples of these programs you can find in Appendix 6. The first program is KPO – Kalkkipilarointiohje – “executives for calcium columns”, a program that was officially developed and used for the Espoo city. The second one was developed by Road Management in Finland and used in the Sipooranta project.

3.6 Construction

When the location of the construction site is known, the site investigation can be performed. In general, the site investigation will take place before the design process of the project is started. It is important to know the characteristics of the subsoil to be able to make a proper decision on the exact location of the project, and to make a design of good quality. If necessary, the site investigation can be done in two phases: first, a preliminary investigation and after that a more detailed, final site investigation. The preliminary investigation can be done using CPT-tests and other borings to get sufficient information for a preliminary design. The levels of the layer boundaries and the types of subsoils are known at that stage. The preliminary design can be used for a first approximation of the costs of the project, and to get an idea of the technical difficulties of the project. In the second phase, the final design will be based on the detailed site investigation which is needed to make a design of good quality with stabilised soil columns. (EuroSoilStab).

Before the site can be prepared for construction, a number of factors must be checked. Although all sites are to some extent different, in most cases, the following need to be addressed:

- accessibility to the stabilization area;
- bearing capacity of ground for the support of the mixing equipment;
- obstacles at, below and above ground level;

- objects around the site which can be harmed or damaged by construction works.

Access to the area of the site to be stabilized needs to be assessed for delivery of plant and materials. The areas for the storage and blending of materials need to be allocated so as not to impede the progress of the stabilization plant either because they are too distant from the stabilization area or are in an area to be stabilized. (Burke, 2001).

For all the stabilization processes the machinery and plant are heavy (50 to 80 tonnes) and very tall (up to 20 m). Therefore the ground on which they operate must provide a stable base. Since the ground is to be stabilized it follows that it is not very strong so in general to provide a stable working surface a blanket granular material is placed and rolled into a flat working platform. This working platform will spread the load of the equipment and thereby reduce the bearing pressure imposed and provide a sound working base. Usually the working platform is placed on a layer of geotextile to keep the granular material from being pressed into the ground. Because the stabilization will take place through the working platform it may be possible to incorporate it with the geotextile into the design of the subsequent structure. Care must be taken in the selection of the geotextile that it can be penetrated by the mixing tool and if used as part of the structure will function after being punctured during the soil mixing. (Burke, 2001).

Obstacles that impede the progress of the work can take many forms but the main ones are overhead power cables, which restrict the operation of the stabilization plant, and old or working underground constructions (tunnels, culverts, pipelines or old foundations). However all obstacles should be clearly identified at the site investigation stage of the works.

Consideration should be given to the effect of the soil mixing process on adjacent sites. The accidental spillage of binders in powder form could be carried by the wind to damage crops or, in the case of binders such as lime, people. If the adjacent sites contain steeply sloping ground the soil mixing could reduce stability during the mixing and hardening of the mixed soil when it is at its weakest. Heave can be a problem with some mixes with up to 50% of the added volume and this could affect an adjacent site. The volume of the heave can be controlled by, for example, trenching around the stabilized area, slowing down the mixing speed and/or changing the sequence of production.

3.6.1 Execution

Compressed air is fed into a tank containing the binder. The air is blown into the tank in such a way that the downward movement of the binder is eased, this is called fluidization. After that, the air leaves the tank from a pipe at the top at the tank. This external pipe goes down to the tank bottom, where the binder is fed into the air stream by means of a rotating wheel with wings, which is called a cell feeder. Other types of feeders exist, as for example the revolver feeder. (H.Bredenberg,G. Holm, and B.Broms, 1999).

The air and the binder are transported through the hollow kelly down to an outlet hole just above a mixing tool situated at the end of the kelly bar. There the air and the binder are blown horizontally out into the soil and mixed with the soil. The compressed air dissipates from the mixing tool in cracks and voids in the soil. The binder is mixed with the soil by the lifting and rotation movements of the mixing tool. (H.Bredenberg,G. Holm, and B.Broms, 1999).

The mixing is taken place when the kelly with the mixing tool is rotated and lifted simultaneously. The LC-column is formed below the mixing tool. The column diameter is the same as the mixing tool diameter. (H.Bredenberg,G. Holm, and B.Broms, 1999).

Within a few hours after mixing, the treatment area is preloaded with several feet of soil surcharge to provide confinement during curing. After curing for 2 to 6 weeks the soil will be 10 to 50 times stronger, and much stiffer. (H.Bredenberg,G. Holm, and B.Broms, 1999).

3.6.2 Sequence of mixing, plant positioning

The sequence of mixing for the deep column mixing will need to be adjusted to suit each specific site conditions but in general the most efficient sequence is to work the stabilization machine within its radius of operation as much as possible before it is moved. Most machines will have a limited angle of slew for maximum stability while mixing. A typical sequence for deep mixing in columns is shown in Figure 3.5.2.

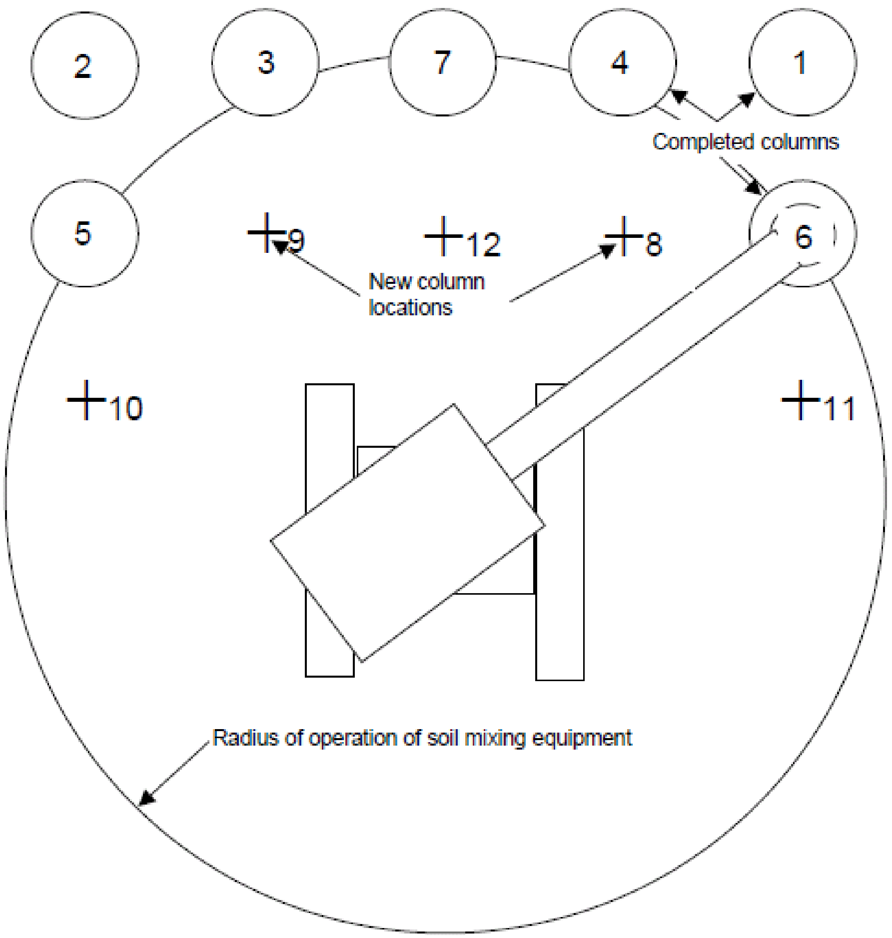


Figure 3.5.2 Sequence of construction for deep soil mixed columns (EuroSoilStab, 2002)

3.6.3 Effect on nearby structures

The most likely effect on nearby structures is from heave during the deep mixing. In the case of deep dry mixed column a 5 to 10 cm heave is not uncommon within 0.5 m of the edge of a column during stabilization work in soft clay. For deep wet mixing with high dosages and high slurry pressures heaves of up to 0.75 m have been measured. However these heaves are local to the columns and would only be a problem if the stabilization was within one column diameter of a building foundation.

3.6.4 Mixing shaft speed

The mixing shaft speed (RPMs) shall be adjusted to accommodate a constant rate of mixing-shaft penetration, based on the degree of drilling difficulty. This speed can be adjusted to aid mixing of the soil column when needed such as hard drilling.

3.6.5 Penetration rate

In the case of the dry mix method the binders are stored in separate silos and the feed rate into the air stream adjusted until the rate of loss of the material from the silos is as previously calculated to give the correct mix proportions. The penetration rate and maximum depth of each stroke shall be recorded on the Daily Quality Control form.

3.6.6 Binder agents intake

Generally, the injection rate will be approximately 80 percent while the augers are moving downward and 20 percent while moving upward. These rates may be adjusted for variable soil conditions. The overall application rate to each stroke can be monitored, calculated, and controlled. The injection of binder agents to each stroke will be monitored, checked by calculation, and recorded.

3.6.7 Mixing shaft refusal

If obstructions including, but not limited to, boulders or timbers are encountered that reduce the rate of penetration to 1-foot per minute for five minutes, the stroke should be completed in accordance with the specifications and remedial measures/investigation taken.

3.7 Quality control and quality assurance

Quality assurance and quality control play an important and necessary part of deep mixing works. As for a major part of ground improvement methods, it is necessary to investigate if the improvement will function as intended and to check that the pre-assumed strength and deformation properties have been reached. Thus, the quality assessment must be adapted to the present application and the purpose of deep mixing. For settlement reduction the deformation properties are of main interest whereas for improvement of stability the strength properties are of main interest. For other types of applications, other properties may be of main interest. Quality assessment may also refer to execution control, i.e. the control of the amount of binder incorporated, rotation speed etc. Quality assurance is a process tool that should guarantee that the client receives the ordered product. Figure 3.6 shows a flow chart for quality control and quality assurance. The quality control can be divided into laboratory tests, field tests on test columns, quality control during execution, quality verification after execution and follow-up measurements. (Larsson, 2005).

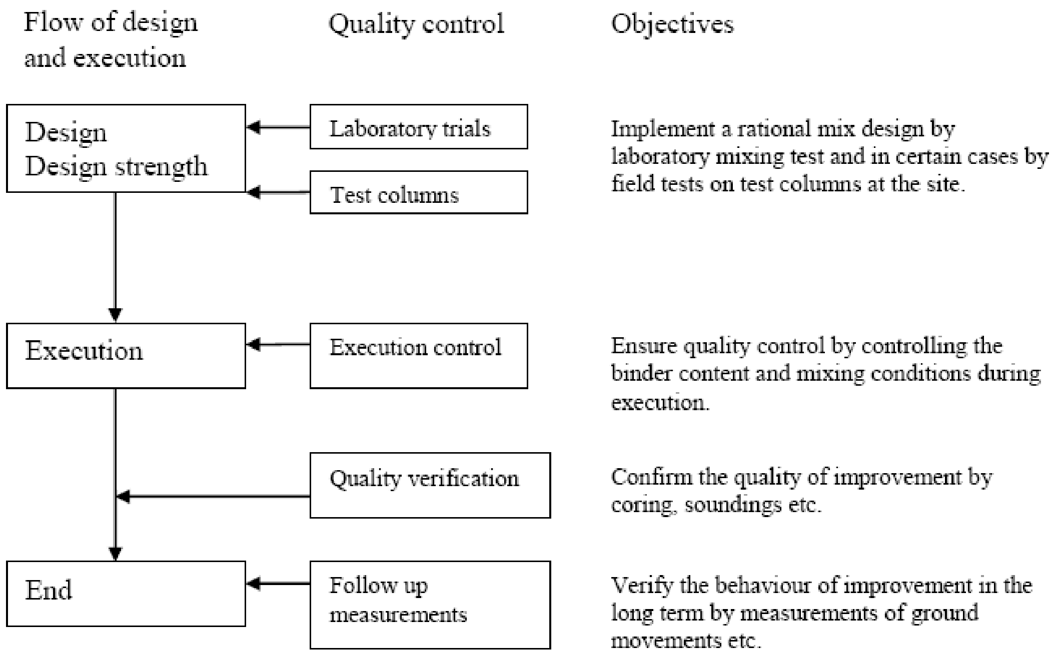


Figure 3.6 Flow chart for quality control and quality assurance (modified after CDIT, 2002)

The installation process is supervised by continuous monitoring and recording of a number of parameters. According to CENT C 288 the execution control must include:

- penetration and retrieval speed of mixing tool;
- rotation speed of the rotating unit of mixing tool;
- air pressure;
- feed rate of binder.

Normally the whole machinery process is fully automated and controlled by computer systems, examples of the outputs and displays during the production of the deep mixing are given in Appendix 2. The torque or some other energy-related parameter is normally measured, however not in the Scandinavian countries. In the Scandinavian countries the monitoring normally includes the amount of binder, retrieval rate and rotation speed. The installation process control may also involve the recording of mixing depth, start time, time at bottom, finish time, grout mix details, grout injection pressure, total grout injected and the density of the slurry. Pore water pressures, vertical and lateral movements are sometimes measured during installation.

There is a large number of test methods used for the quality assessment of stabilized soil. The reasons are the great differences in strength and deformation properties. According to Porbaha (2002), “The most commonly citied barrier to the use of deep mixing (DM) technology is practitioners´ lack of confidence in their ability to assess the quality of the finished DM product”. Unfortunately, this condition is still prevailing. There is a large amount of papers on quality control methods and case studies. However, there are some disagreements on the conclusions of tests reported and very few studies are published in scientific journals. Rathmayer (1997) stated in a regional report at IS-Tokyo´96 that “the only reliable test method today is total sampling, managed by lifting up the entire column”. Unfortunately, this statement is still prevailing. There is still a lack of simple reliable methods.

3.7.1 Laboratory tests

Laboratory tests are undertaken using samples of the soil to be treated mixed with different proportions of lime and cement. From these results we can prepare a design and drawings indicating spacing, the amount of binder, column diameter etc.

EuroSoilStab describes in detail the steps to be taken to produce stabilized soil samples to be tested for strength, stiffness, compressibility and permeability by a variety of standard geotechnical tests. You can find this information in Appendix 3.

A full report must be given on the conditions of sample preparation, as follows:

- classification of soil if determined
- origin and quantity of soil
- removal of isolated coarse particles etc. from soil
- specifications of soil mixer, and applied mixing tool, power, r.p.m., mixing time, storage conditions and time
- water content of the homogenized soil

- chosen sample diameter
- specifications of the chemical and physical properties of each stabilizer material as provided by its producer or supplier:
    - composition (m/m): at least CaO, SiO2 , Al2O3 , Fe2O3 , MgO, K2O, Na2O , SO3
    - (for quicklime record both total and active CaO)
    - reactivity
    - specific surface area (Blaine number)
    - density
    - particle size distribution
- quantity of stabilizer and if applicable the proportions of stabilizers
- specifications of soil/stabilizer mixer, and applied mixing tool, power, r.p.m., mixing time, storage conditions and time
- type of moulds used
- if a compaction press is used: description of the compaction press: diameter and geometry of stamp, applied pressure
- bulk density and water content of the mixed soil/stabilizer after mixing
- storage temperature and deviations from it during curing

The following facts must be reported per sample:

- bulk density after compaction and trimming into the mould
- height of sample relative to the top of the mould after curing
- roughness of the top end of the sample after curing
- any difficulty in removing sample from mould after curing
- any irregularities of the sample, e.g. visible holes and large voids, or the bottom end not being entirely flat and perpendicular
- treatment of the upper end surface prior to further testing.
- whether the top end is cut off and sample height after cutting
- bulk density after removal from the mould

3.7.2 Field tests

The primary objectives of installing trial columns is to perform tests to determine the properties in situ. Based on these results the final choice of type and amount of binder and installation method are made. Important aspects to consider when making this choice are:

- strength of stabilized soil and its increase with time
- stiffness of stabilized soil and its increase with time
- homogeneity of stabilized soil
- environmental impacts of the stabilized soil
- the amount of load the columns must be able to sustain at a specific (curing) time
- costs for binder
- installation costs. (EuroSoilStab, 2002).

The trial columns are normally installed very early in a project and the machinery may not be trimmed ideally. Thus the column quality may be lower than in “production”. On the other hand, the trial columns may be installed with special efforts since the outcome of the tests is of outmost importance. Thus the column quality may be higher than in “production”. Nevertheless, when evaluating the results it should not be forgotten that the properties of the columns improve with the curing time. When making the final choice it should also be remembered, that too high strength and stiffness of the columns are not necessarily desirable since the underlying design philosophy is that stabilized and unsterilized soils interact. (EuroSoilStab, 2002).

A number of columns with the same composition and installation technique must be tested in order to have sufficient data making the results reliable. If a road or railway embankment, or similar, is to be constructed it may also be necessary to perform field trials at several locations due to varying soil profiles and other geological conditions. Obviously, if all aspects listed above are to be studied the number of trial columns may become quite large. Therefore, the size of the test program depends on the type and size of the project.

Some general recommendations for the scope of tests of mechanical properties are:

- The tests should cover the whole length of the trial columns. The properties of the stabilized soil vary for different soil types (layers).
- For trial columns of a specific composition and installation technique the tests should preferably be performed at curing time(s) corresponding to the time(s) when the column must carry specific load(s). In order to assess the strength-time relation the tests should be performed at least at two different curing times and the results combined with results obtained from the laboratory investigations. Common curing times for testing are one or several of 7, 14, 28, 56 and 90 days.
- For trial columns of a specific composition, installation technique and curing time, a minimum of 5 columns should be tested in order to make the results reliable. (Axelsson, 2001).

3.7.2.1 Column Penetration Tests (CPT)

Post mixing testing is typically performed using a column penetration test (CPT). Column penetration tests are normally performed according to the Swedish guidelines (SGF, 2000), also described in prEN 14679 (2005). In this test, the probe should be as wide as possible, preferably 100 mm smaller than the column diameter. The test is executed by pressing the probe down into the centre of the column at a speed of 20 mm/s with continuous recording of the penetration resistance. A centre hole is prebored when necessary in order to facilitate verticality. According to Ekström (1994), columns up to 12-15 m length with compressive strength up to 600-700 kPa can be tested with this method. Local parts of high strengths may be penetrated by dynamic impact. The probe may be provided with several blades in order to improve the guidance of the probe and to test a larger part of the column cross section (Halkola, 1999). The force required to pull the probe is used to evaluate the shear strength of the column.

A penetration test such as a CPT Lunne et al (1997) has the disadvantage that the tip tends to deviate out of the column after 5 to 7 meters. Therefore penetration testing can be of limited value as a validation tool, especially for relatively long and strong columns. This tendency to deviate can be overcome by pre-boring and starting the penetration test from the base of the pre-bored hole. Figure 3.6.2.1 shows CPT results from tests on cement – lime columns at 1 month and 6 months after mixing. While the columns are obviously at different levels the increase in undrained shear strength, calculated from the CPT, is significant at all levels. (EuroSoilStab, 2002).

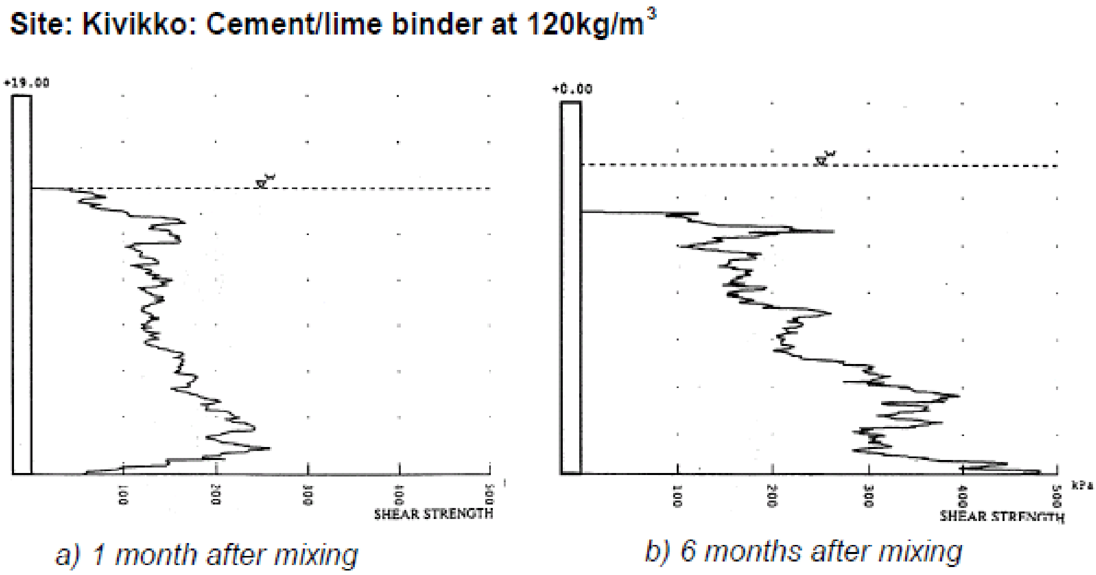


Figure 3.6.2.1 Examples of CPT results from soil mixed with cement – lime binder in columns at 1 month and 6 months after mixing (EuroSoilStab, 2002)

3.7.2.2 Examination with test pits

Sampling, testing and visual examination can be carried out in columns, which have been excavated in open test pits. The maximum depth without special means is roughly 2- 4m depending on the site conditions. Test pits are popular since they provide simple observations of column shape, diameter, overlap etc.

The rate of unsterilized or weak parts over the column cross-section may be evaluated by pocket penetrometer tests or similar (*e.g.* Futaki & Tamura, 2002). A major disadvantage is that the binder dispersion over the cross section and the strength and deformation properties may vary considerably over the column length, which is common in layered soils (Larsson, 2001). The tests performed on a shallow depth may therefore only provide limited information.

Visual examinations cannot be used for quality assessment since the visual impression is difficult to quantify and is not necessarily equivalent to the binder distribution (Larsson, 2001). Visual judgments are associated with human senses, and are therefore highly individual and subjective. For example, it is difficult for the human sight and feeling to detect strength variations for high strength material. However, since visual examination is simple it is tempting to judge the column quality based on individual visual assessments. The visual examination may be a complementary tool to other types of testing. Visual inspection of the column homogeneity may be performed through test pit digging, possibly in connection with sampling for laboratory investigations of e.g. the chemical composition.

There is no simple and established method for the control of the verticality and diameter of columns (Axelsson, 2001). The diameter is normally controlled in open test pits or by the extraction of whole columns. The verticality can be controlled by measuring the centre of the columns at some stages in a deep excavation. In the case of overlapping columns the verticality has a determining influence on the function. According to the Swedish guideline (SGF, 2000), the inclination tolerance should be in the interval 0.6° – 1.1° (1:100–1:50). The overlap between two columns is normally 50-100mm. As a result, even when the columns are installed within the given tolerances, the overlap may cease to exist with lengths exceeding 2.5-5m. The development of methods for the control of the verticality is a subject for further studies as emphasized by Axelsson (2001) and Massarsch & Topolnicki (2005).

3.7.2.3 Environmental measures (EuroSoilStab, 2002)

Some binders may be harmful to health, for example quick lime, which may cause damage to unprotected eyes and skin. Although operators and others in close contact with the process are most vulnerable to this, also humans not directly involved in the work may be in danger, for example pedestrians passing close to a site where soil stabilization is using potentially dangerous binder agents.

Further, large pressurized tanks must be inspected regularly in order to detect imperfections or damage that may result in decreased safety against unexpected behavior, in worst case an explosion. This risk is most pronounced where such equipment is used and the sufficient control of the equipment is not performed.

It is essential therefore that the appropriate measures are taken to mitigate the risk to the safety and health of the personnel. The risks can be listed and rated in a risk assessment for the site works. An example of a risk assessment is given in Appendix 4 and while this does not cover all risks it is intended as an illustration of the risk assessment process.

Another environmental risk may emerge from the surface heave produced injecting pressurized air or slurry into the soil. There are examples where a heave up to 0.75 m has resulted from using high jet pressures with high (> 0.5) ratios of treated area to column area. However, usually the heave eventually produced is smaller, rarely more than 10 cm. Nevertheless, also such a limited rise of the ground must be taken into consideration where motion sensitive structures in the ground are present, for example old water linings.

Some general recommendations for the scope of tests of environmental aspects are:

- Leaching tests combined with ground water monitoring are recommended for the assessment of the environmental suitability of a stabilizing object when results from the previous use of the actual binder in the actual soil conditions are lacking;
- Tests should include the measurements of parameters in the groundwater that are characteristic for the binder(s) such as pH and electrical conductivity in the downstream gradient from the stabilized area. This determines the

rate of transport and the distribution of the area influenced by the stabilization. To ensure that the content in the groundwater is representative for the long-term leaching quality, the sampling of potential harmful elements should be done after at least 90 days since the leaching quality is changing rapidly at the initial phases of curing;

- In general it is recommended that chemical and environmental tests of the soil and mixtures of soil and binders are carried out in the laboratory on field samples.

3.8 Documentation

All quality control and measurement for payment data must be recorded on specially prepared Quality Control forms.

The forms contain the following information:

- Summary of daily activities
- Quality control test results
- Location of test samples
- Measurement of the pay quantity
- Pay quantity
- Other comments as necessary
- Signatures. (Tektracker)

4 POSITIVE ASPECTS IN THE USE OF THE DDM METHOD

The analysis of current ground improvement methods revealed that almost all of them are tied to a very narrow range of the particle size of soils. Cementation is effective for gravel and coarse sand, with a pronounced pore space, electrochemical enforcement is applicable to cohesive soils, the chemical methods good in a noncohesive soils (from a fine grain size to a large one). Deep mixing technologies are the undisputed leader in the range of possible applications. A table of comparison of DDM with other ground improvement methods is found in Appendix 5.

Soil Improvement by Lime Cement Dry Soil Mixing is environmentally sound and frequently the most economic improvement method for soft soils, different kinds of clay, peat and sludge. The moisture content of cohesive soils is also reduced, leading to a considerable improvement in the bearing capacity. The stabilization method can also be used in the treatment of contaminated lands, by encapsulating contaminants within the ground, and preventing leaching to the surrounding areas. This technique is a cost effective alternative to importing aggregates for both temporary and permanent works.

The consideration of environmental issues and cost determine the type of ground improvement that may be used in a bid. To reduce the quantity of construction waste, simply going to landfill, a ground engineering solution that is being considered for use more and more is Deep Soil Mixing. Contaminated ground is also being developed these days, this equipment enables to carry out soil or silt stabilization which in turn is a remedial process utilized to bind or lock-in contaminates within the soil or silt matrix.

Environmentally, the Dry Deep Mixing 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 Dry Deep Mixing 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. Now after gathering and analyzing information, we can define the main advantages of Dry Deep Mixing:

- Allows development of otherwise unusable (cost/time-prohibitive) sites;
- Economical system (savings of materials and energy);

- Often combined with other ground improvement systems;
- Can be flexibly linked with other structures and with the surroundings (no harmful settlement differences);
- Generally more economical than remove-and-replace options;
- Accelerates construction Schedule;
- Low vibration and noise;
- Dewatering is not required;
- Rapid mobilization;
- No spoil for disposal;
- Applicability on various soil conditions;
- Various functions: ground improvement of a site, foundations, or retaining walls, etc.;
- Fits well for encapsulating contaminated soils.

5 PROBLEM SOILS OF SAINT PETERSBURG

The territory on which St. Petersburg stands is unique in its heterogeneity of soils, depth and thickness of layers, composition, physical and mechanical properties. The level and pace of development of the construction industry made the city an experimental platform for testing advanced technologies.

The demand for improving and stabilizing land for different purposes is expected to increase in the future and the best way to fulfil it is by using deep mixing methods (DMM). It is strongly suggested that, where sufficient space is unavailable, sliding and overturning stability should be augmented by using soil anchors. The main advantage of these methods is a long term increase in strength especially when some of the binders are used. The pozzolanic reaction can continue for months or even years after mixing, resulting in the increase in strength of cement stabilized clay with the increase in curing time. (Bergado, 1996; Roslan and Shahidul, 2008).

At the present level of complex construction tasks and the broad offering of new technologies to strengthen the grounds, the condition of the St. Petersburg geotechnology can be described as "depressing". The condition of geotechnical sciences is deplorable. Underground construction in weak soils is one of the most difficult geotechnical problems, especially if it is performed underground in dense urban areas. The problem is, that during the new construction of buildings in the adjacency to the existing building, the major risk factors are the technological impact when constructing the foundations, increased loads on the foundation and development of the sediment foundations.

Deep mixing methods for construction purposes have been used extensively in the past in Russia. However, the low level of equipment has not allowed to use these methods. Western companies have developed equipment to consolidate the soil to practical use. It seems promising to use these opportunities to prepare grounds for the construction of new buildings and fencing of pits. Even in dense urban conditions deep mixing technologies can be effectively used to consolidate the weak soils of St. Petersburg that has a lot of geotechnical problems, the main of which are:

- Deposits of soft clays with the thickness of 15 - 30 m with the inclusions of peat;
- Underconsolidated soils with the settlement of 2-3 mm per year;
- Use of timber elements, such as beams, piles and rafts for historical foundations;
- Lowering of the ground water level;
- Tunneling in soft soils causing damage to buildings.

Because of these problems, the territory of the city centre is very complicated from the geotechnical point of view. Furthermore, there are a lot of historical buildings in the centre, which are very sensitive to external influences. During stabilisation with the DDM vibration and noise levels are low, this construction technology has a minimal impact on nearby buildings, which makes it very useful for the centre of Saint Petersburg.

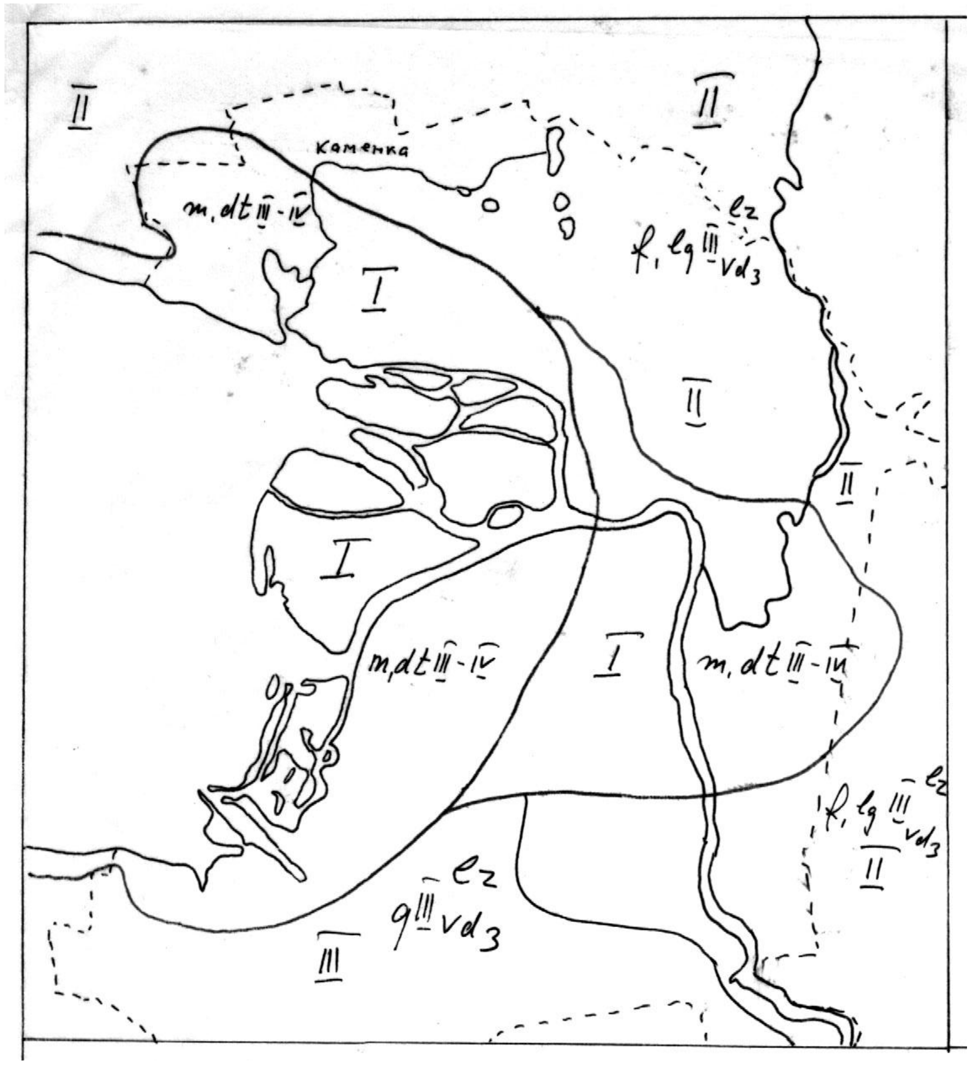


Figure 5.1 Engineering-geological map of St. Petersburg

s - discharges and flexures, limiting to Ust-Nevsky graben

---- - border of city

I – area of weak soils; II – area of fluvio-glacial sediments, outwash plains, kames and esker; III – area of a Luga moraine

The history of the geological development of the territory (paleogeography) in Quaternary helps to understand the formation of the physical mechanical properties of soil. Before Quaternary the north-western part of the East European platform in the borders of which Saint Petersburg is located, was the area of destruction and tearing down. Mesozoic, paleogenic and neogenic deposits were not found there. Before-Quaternary soils are only represented by the blue clay of vend and bottom chembry. Here in Quaternary the accumulation of deposits was influenced by several glaciations among which the last Valday glaciation of the late Quaternary left the most significant traces.

Sand and light sandy loam prevails in the northern part of the city. The level of ground water is close to the surface. In sand during the excavation of a foundation area, or a trench with open water outflow, the suffosion phenomena develop at 2-2,5 m depth. Sand and sandy loam behave as floating earth and make liquefaction soil liquefy during excavations. In such a soil boring piling is more complicated. Traditional technologies of foundation improving (their widening and deeping with the further excavation of the foundation area) are not effective.

The peculiarity of the southern part of the city is the moraine of Luga close to the surface; these soil conditions are favourable to reconstructions and new buildings including underground constructions. As a rule, there are no difficulties in the construction processes.

The third soil complex is located is the territory of the city centre and it is the most complicated from the geotechnical point of view. It is presented (under the technogenic layer of 2 m thickness) by the layer of fine silty delta sand (from 2 to 10 m thickness) and by the significant layer of soft Baltic loam and sandy loam. The roof of relatively strong moraine sediments is on the depth up to 20-30 m from the surface. In these geological conditions, in the limits of formed region of buildings in most cases, it is impossible to use neither foundations on natural base (including foundation plates) nor pile foundations if they are driven by pressing or striking. New buildings built on such foundations usually cause the development of additional settlements of adjoining historical buildings. In that territory foundations on natural base can only be used in the conditions of the preventive improvement of the foundations of adjoining buildings by boring piles.

The experience shows that the construction of buildings on soft soil without proper geotechnical basis of technologies and design solutions being used inevitable lead to accidents (see Figure 4.1) i.e. breaking down the buildings on the adjoining territory. (Ulitsky V.M., 1997).

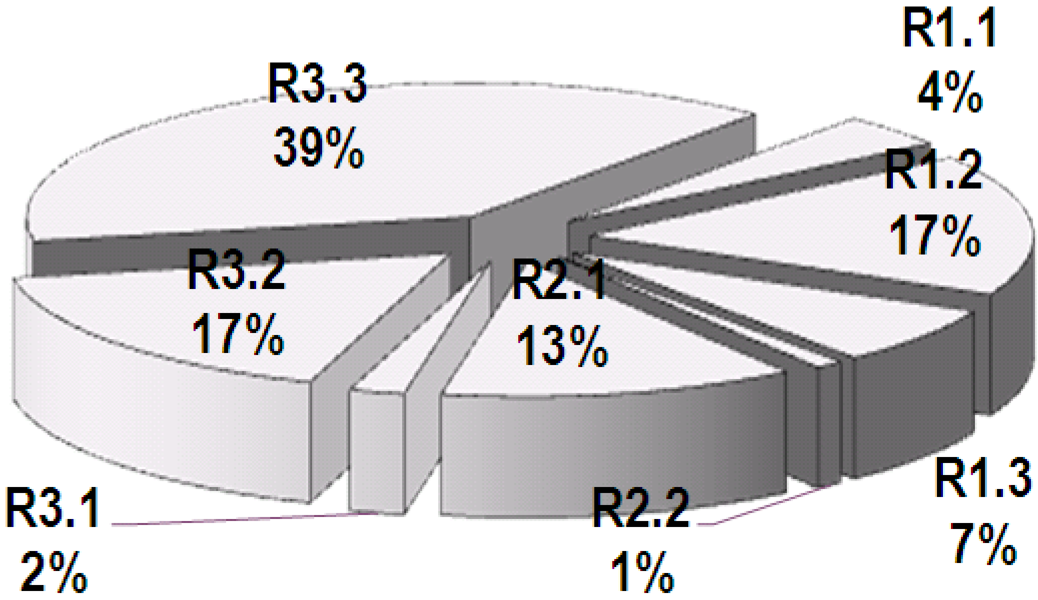


Figure 5.2 Causes for damage to existing buildings during adjacent construction in St. Petersburg (Ulitsky V.M.)

R1.1 – Deformation causes related to faulty site investigation/condition surveying; R1.2 - Deformation causes related to faulty design; R1.3 – Deformation causes related to faulty works implementation; R2.1 - Deformation causes related to faulty maintenance of building; R2.2 - Deformation causes related to faulty maintenance of adjacent area; R3.1 – Prospecting/Condition surveying drawbacks of adjacent construction; R3.2 – Design drawbacks of adjacent construction; R3.3 – Drawbacks of works implementation on adjacent construction.

6 DRY DEEP MIXING IN RUSSIAN NORMS AND REGULATIONS

6.1 Materials in Russia

Applying the DDM method in Russia requires preparation for possible problems with the delivery of materials. After looking through the market of production lime and cement in Saint-Petersburg, the following results were discovered:

There are a lot of plants near Saint-Petersburg which production lime and cement; Also there will be no problems with procurement, because there is a well-developed network of suppliers in the city who are prepared to provide required materials at reasonable prices. Below is a list of the biggest and well known plants in Saint-Petersburg with contacts and information.

Despite of the difficulties, the cement market in St. Petersburg and in Russia as a whole continues to grow at a rapid pace. In many ways, this contributes to the rapid growth of construction in St. Petersburg, including government programs for affordable housing. In 2007, according to experts, the growth rate has exceeded the global rate and amounted to about 11% (compared with the global market growth of 4-5% annually).

Table 6.1.1 Cement plants near St. Petersburg

producer / plant	contact information				product	price (rubles)	
	adress	tel	fax	e-mail or e-adress		50 kg	1000kg
"Molodoy udarnik"	192019, St. Petersburg, Glukhoozerskoe highway, 12	8 (812) 365-43-88	8 (812) 567-60-30	www.udarnik.spb.ru	PC 400-D20 PC 500-D0	145 185	2550 3150
Pikalevskiy cement (cempromservice)	187600, Leningrad Region., City Pikalevo, Sprjamlennoe highway, 1	(813) 664-9191	(813) 664-9191		PC 400-D20 PC 500-D0 PC 400-D20-B	145 175 180	2050 2100 2180
JSC Slantsy Cement Plant (JSC "Cesla")	188560, Leningrad Region, City Slantsy, Kingiseppskoye highway, 1	(81374)72-341	(81374)72-181	office@cesla.spb.ru	PC 400-D20 PC 400-D0 PC 500-D20 PC 500-D0	170 180 150 190	2700 2830 2880 2930
savinsky cement	164303, Plesetsky District, Arkhangelsk Region, City Savinsky	(81832) 611-86	(81832) 611-88	www.eurocement.ru cement@atnet.ru	PC 400-D0 PC 400-D20	145 130	2450 2320
oskol cement	309530, Belgorod Region., Stary Oskol	(0725) 44-0310	(0725) 44-0683	commerch@oskolcement.ru	PC 500-D0	200	2550

Table 6.1.2 Lime plants near St. Petersburg

producer / plant	contact information				product	price (rubles)
	adress	tel	fax	e-mail or e-adress		1000kg
BaltMiks Inc	St. Petersburg, avenue. Gagarin 2, Liter A	(812) 715-55-57	(812) 723-27-53	baltmix.spb@mail.ru	slaked lime	3400
OAO Alekseevskij Izvestkovyj Zavod	195027, St. Petersburg, Business Centre BAZEN, pr. Shaumiana, 4-1, liter A	(812) 448 94 54	(812) 448 94 53		quicklime	3500
"Uglovsky lime combine"	Novgorod region., Okulovsky district, settlement. Uglovka, Sports st., 2	(812) 440-9585	(812) 440-9585	office@cesla.spb.ru	quicklime	2880
Zabudova-Saint-Petersburg	196603, Saint-Petersburg, Pushkin, Krasnoselskoe highway 14/28	(812) 467-09-50	(812) 467-12-02	ZabudovaSPB@bk.ru	slaked lime	5050

6.2 Machinery park in Russia

The implementation of modern solutions in the field of underground construction and ground improvement requires the latest technologies. Geotechnical equipment is delivered to Russia from Japan, Italy, Germany, Finland, and the Netherlands. Unfortunately today all kinds of modern equipment for underground work is imported. None of Russian machine builders did produce analogues. Accordingly, the maintenance of complex equipment, components, too, comes from abroad. The companies of St. Petersburg are gradually importing specialized equipment from abroad, thus enhancing their own capabilities. Albeit the DDM method requires special equipment, which has not been in Russia a few years earlier, now some companies can give this equipment.

Table 6.2 European companies working in Russia:

company	adress	contact information		
		tel	fax	e-mail; web page
ZAO "YIT Lentek"	197374, St. Petersburg, Primorsky, 54/A	(812) 336 37 47 (812) 336 37 57 (812) 336 37 67	(812)4303951	yitdom.spb@yit.ru
Lemkon	190000, St. Petersburg, Pirogovskaja naberegnaja, 9	+7 812 7183486	+7 812 7183447	info@lemcon.ru
Keller	196066, St. Petersburg, Moskievski Prospekt 212 A / Office 4043	+48 227338282	+48 227338292	Keller-Polska@keller.com.pl
Bauer	119119, Moscow, Leninskij prospect 42, corpus 1	+7 495 663 93 91	+7 495 663 93 92	inbox@rusbauer.ru
Niska & Nyyssönen Oy	Koskelonkuja 4 B, FI-02920 Espoo	+358 9 849 171	+358 984 917 849	niska-nyyssonen.fi

6.3 Quality control in Russia

SNIP 10-01-94 does not restrict, but encourages the development of new building technologies:” Regulations should not prescribe how to design, build, and establish requirements for construction products. They do not state what requirements must be met, or what goals, must be achieved in the design and construction. Ways to achieve the goals in a design or technological solutions should be advisory”

SNIP 3.02.01-87 [12, § 1.12] also supports creativity in the development of the new methods of strengthening specific grounds: The projects are allowed to designate the methods of the production works and technical solutions, establish the value tolerances, quantities and methods of control that differ from those envisaged by these rules, with appropriate justification.

But there are a lot of problems in the survey branch:

- Problems of reliability primarily addressed through the creation of safety margin of foundations and structures. Although it is more economically advantageous to address them through a careful study of the mechanical properties of soils and development of new methods of calculation bases.
- There are no specialists with the required skill level to ensure the growing volume of construction. This affects both on the quality of the preparation of technical specifications and on the implementation of field and camera work, the forming of the documentation.
- No equipment required to perform field and laboratory work, despite the emergence of new devices and installations. In many existing survey organizations there is no laboratory base. The transfer of the laboratory determinations of characteristics to the building site leads to a significant decrease in the reliability of the results.
- Devices and methods for determining the strength and deformation characteristics of soils have not been updated for decades. Characteristics obtained for the obsolete equipment in the laboratory, are transferred to the array of soil, one to one

Valid GOST 12248-96 provides two methods of shear tests: a consolidated and unconsolidated-drainage - undrained, for 3-axis tests - three methods. All of them change the original state of the soil and form the basis of a critical situation with the mechanical properties. But all the modern State Standards (GOSTs) for the laboratory testing of soils developed on the basis of studies of the 30-s and 70-s. On the basis of the same research methods were developed for calculating the basis.

The bulk of research has been conducted e.g. “LenTisiz”, “LENMORNIIPROEKT”, “Universal”, “prospector”, “Fundamentproect”, “Construction Management 299” and “Trust GRII”.

6.4 General and the legal aspect

In Europe, the general principles and concepts of geotechnical design, are covered by Eurocode 7 ENV 1997–1 1993, Part 1: Geotechnical design, general rules; Part 2: Geotechnical design, ground investigation and testing. Design aspects related to the execution of deep mixing work are covered by prEN 14679 “Execution of special geotechnical works — Deep mixing”. This standard expands on design only where necessary, but provides full coverage of the construction and supervision requirements. These aspects refer to the installation method, the choice of binder, laboratory and field testing and their influence on the design of the column layout and performance.

In accordance with the paragraph 7 of Article 46 of the Federal Law "On technical regulation" of 27.12.2002, № 184-FZ from 1 July 2010 the entire building regulatory database will become a document of voluntary use in Russia. The future system of technical regulation of engineering survey for construction must meet two basic laws: "On Technical Regulation" (Federal Law of 27.12.2002, № 184-FZ) and the Development Code (Federal Law of 29.12.2004, № 190FZ). It is very difficult to understand them, even for a person with a legal background.

Thus, it was decided that, in the use of new materials and technology, the contractor can use any international standards, but it must be proven that they are no worse than the existing norms and state standards. According to Russian technical regulations, the level of harmonization of Russian standards with European standards is 44,7%. Today, any company may legally adapt and apply required European standards in Russia. New standards is opening the way to the markets of new technologies.

In the current regulatory documents, including the Urban Development Code of the RF, there are no binding complex engineering surveys for construction sites, and little attention is paid to the compilation of the job to conduct research.

The problems of foundation construction in high-density areas are addressed through TSN 50-302-2004 "Design of foundations of buildings and structures in St. Petersburg". Designers are faced with a deficit of information. Reports on the surveys of adjacent buildings, as a rule, contain a large amount of material e.g. photographs, historical and cultural information, but there is a shortage of technical data.

The Certification authority carrying out its functions requires the applicant to provide "evidentiary material in order to confirm the product compliance with technical regulations". Technical documentation, the results of the investigations (tests) and measurements and (or) other documents, served as a reasoned basis for the confirmation of product compliance with technical regulations must be used as such material. The composition of the evidentiary material must be determined by the relevant technical regulations (not yet existing and not to be developed in the nearest future).

In accordance with art. 56 Chap. VIII governmental regulation of the RF on March 5, 2007 № 145 for the cost of services for the state expertise of design documentation and engineering survey the constructor should provide the following materials:

- design assignment (copy),

- estimate for the project works (Stage "P" + stage " RD ") and engineering and surveying work, calculated at basic prices, 1 January 2001 with the conversion into current prices
- "Composition of the project "(copy).

7 CONCLUSION

The geological and geotechnical situation in Russia is complex. There is a potentially large market for deep mixing methods, for instance related to the increasing urbanization and expansion of the transportation infrastructure. Dry Deep Mixing is widely used for the foundation of road and railway embankments but it can be applied in many other ways. This technology can be effectively used for excavation support to increase bearing capacity, reduce movements, prevent sliding failure, control seepage by acting as a cut–off barrier, and as a measure against base heave, vibration reduction (along the railway), construction of excavation support systems or protection of structure close to excavation sites, solidification and stabilization of contaminated soils, remedial grout injection of building, etc. Due to the increasing experience and results from research programs and development of the equipment new applications will arise in the near future.

When used in conjunction with and in substitution of traditional techniques, DDM results in more economical and convenient solutions for the ground improvement. Design engineers in Russia are often not aware of the potential or the limitations of deep mixing, but using the information, gathered in this thesis, Russian engineers may have possibilities to make a decision of using deep mixing. Following the method and examples proposed here will provide the engineer with the fundamentals to implement deep mixing technology in the application of projects.

But it is important to understand that in the end, it is formed of hardened cement-ground system, strength to 1-2 MPa. This is not a reinforced structure, which can not be a bearing structure, but successfully works as a barrier, for example, to consolidate the soil in the walls of trenches and ditches during the construction and reconstruction. The compressive strength of 0,6 MPa for these purposes is enough.

Also characteristics and conditions of soil affecting the strength increase:

- physical, chemical and mineralogical properties of soil
- organic content
- pH of pore water
- water content

As we can see the optimal mixing method for a specific project depends on a variety of factors, such as the geological and geotechnical conditions (Research and practical applications in Europe have shown that organic soils can be stabilized with lime cement columns too), the structural requirements, the experience of the design engineer and the availability of suitable equipment and qualified personnel. Because of this, it can be difficult to use the DDM method at first in Russia.

Future research should be conducted to continue to facilitate the implementation of deep mixing technology into Russian excavation support design and construction practices.

FIGURES

CHARTS

TABLES

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APPENDICES

Appendix 1 Case histories

Dockways Waste Disposal Facility - Newport, Base Stabilisation by Deep Dry Mixing (DDM)

Project

Newport City Council was proposing an extension to the Dockways Landfill Site in Newport. However due to the soft sub grade soils they required improvement of the bearing capacity to permit heavy earth moving plant to access the site and install an artificial clay liner

Soil Conditions

The proposed area of the extension to the landfill was underlain by 6m of soft to very soft silty clay overlying river gravels. Due to concerns for the potential for an increase in the permeability of the existing clay dry soil mixed columns could not be installed beyond 2m depth

Solution

The Clients brief required KGE to provide a design and proposals for the provision of a temporary working platform to accommodate the construction of the clay landfill liner.

Construction

The dry soil mixed columns were installed using a low load bearing rig to a depth of 2m. 800mm diameter columns were installed at 800mm spacings on a 4m square grid.

Upon completion of the columns a continuous layer of geotextile was rolled out on top of the columns and a 300mm thick granular load transfer platform placed

Additional columns were installed in the area of the diverted river channel to accommodate the reduced shear strength of the existing. A total of 19149 columns were installed within an 11 week program

Consulting Engineer:
Peter Brett Associates

Contractor:
Keller Ground Engineering

Client:
Newport City Council

Work Completed:
April 2005
(Keller Geotecthnique, keller-geotechnique.co.uk)

Dry Soil Mixing for Stabilisation of Ground for construction of Foul Sewer

Project

As a part of construction of a new Foul Pumping Station at Thamesmead, London ground improvement was required to allow a new sewer to be constructed through a band of soft silty clay and peat.

Soil Conditions

The Ground Investigation for the site generally indicated 0-3.1m Made Ground, 3.1-6.4m soft, silty clay and peat, 6.4-7.9m Loose sand and 7.9-13.7m Medium dense sands and gravel.

Solution

Keller/LCM proposed to use dry soil mixing to treat 100m length of the proposed tunnel line and the break-out and break-in points for 8No shafts. For the 100m treatment block 600mm diameter columns were constructed in rows of four. Adjacent columns were offset by 450mm, therefore providing a 150mm over lap. For the break-in and break-out points at each of the shaft locations, 11 interlocking columns were constructed in two rows of 6 No and 5 No columns. The ground was treated 2m above and 2m below the line of the proposed tunnel.

Construction

The construction work was performed in March 2002 by an LCM Machine under the supervision of Keller. The column installation was tested using Pull Out Resistance Tests.

The tunnel drive was successfully completed through the treated ground.

Client:
Tilfen Ltd

Engineer:
Robert West Consulting

Main Contractor:
Clancy Docwra
(Keller Geotecthnique, keller-geotechnique.co.uk)

Norwich City Football Club - Stabilisation of an Access Road using Deep Dry Mixing (DDM)

Project

As part of the redevelopment of Norwich City Football Ground, ground improvement was required to improve the existing access roads.

Soil Conditions

The proposed area of the access road was Brick Rubble Fill overlain medium dense sand to a depth of 0.8m. Underlain by Brown fibrous peat. The peat had moisture contents between 300-400%.

Solution

The Clients brief required KGE to design and install dry soil mixed columns to achieve an undrained shear strength of 100kPa at 28 days and restrict the settlement to within 25mm. The layout of the column was designed by others

Construction

KGE installed 800 diameter columns to an average depth of 4.5m. The columns were installed to nominally 500mm into the competent strata below the peat.

10 No Pull Out Resistance Tests were carried out 7 days after installation. The results obtained exceeded the 28 day design strength.
A total of 86 columns were installed within a 2 week programme ensuring no disruption to matches at Norwich City Football Ground.

Consulting Engineer:
T A Millards

Contractor:
R G Carter

Client:
Norwich City Football Club

Work Completed:
April 2005
(Keller Geotecthnique, keller-geotechnique.co.uk)

Lekarekulle-Frillesås Line

Project

The Swedish Railway Authorities have been expanding the single railway tracks to double tracks for the West Coast Line (Vastkustsbanan). The client concluded that the subsoil underneath a 1.5 km section of the existing railway in Frillesas, Sweden needed to be stabilised. The new double track would be positioned 0-3m below the surrounding ground level. The most desirable option for stabilisation was chosen to be the lime-cement column method.

Soil Conditions

The ground investigation report showed a top layer of organic soil or filling and underneath a layer of sand and dry crust. The layer of sand was about 1m and the dry crust was about 1-3m thick. Beneath this layer was a sandy-silty-clay, which rested upon a layer of friction-soil on rock. The depth down to firm soil was about 12m. The clay was found to be of middle range sensitive and the density increased over depth. The dry crust had a water content of 20-45%, while the clay had a water content around 30-65%. The clay was weakly over-consolidated with about 20kPa. The shear strength of the clay varied between 10-90 kPa.

Solution

Following the soil investigation works and lime-cement column mixing tests, it was concluded that 3,260 lime-cement (50/50) columns, with a diameter of 600mm, spaced 1.5m in a rectangular grid pattern, and a total of 33,950 linear meters would have to be installed. The columns were designed to reach firm ground.

Client:
The Swedish Railway Authorities

Sipoonranta, Finland Finish Consulting Group

Project

Sipoonranta will be a new seaside residential area in Sipoo with own marina and abundant other amenities. Development consists of approximately 200 personalized apartments varying from loft apartments to city villas. Investment volume of the development is MEUR 100 and construction will be carried out gradually over next two years.

Soil Conditions

The Ground Investigation for the site indicated mud, clay, silty clay, with total depth 8...10m, W=50...60%, Cu= 7...10 kPa

Solution

Stabilization of ground by DDM method.

Construction

Following the soil investigation works and lime-cement column mixing tests, it was concluded that lime-cement columns with a diameter of 800mm, E-modulus= 40000 kPa, shear strength= 200 kPa and a total length of columns of 60000 linear meters would have to be installed. Spaces between columns are from 1,1m to 1,5m in different areas.

Contractor

Rakentajat Piippo & Pakarinen Oy (www.rppoy.fi)

Client

Konevuori oy (main contractor)
(FCG Oy).

Appendix 2 Examples of monitoring systems and their outputs during Deep Mixing production (EuroSoilStab, 2002)

An example of the monitoring systems for the soil mix process is that used by stabilator who have developed an advanced system which is now installed on their production equipment.

Installation process

The central verifying equipment in the soil mixing equipment are two computers. One computer gathers information from the machine and sends it to the other computer by communication. There the operator analyzes the installation process using the display consisting of graphics, indicators and numbers. Through this computer the operator also controls the installing process by starting and stopping it and, if necessary, making some adjustments.

Fig.1 shows the display units as fitted in the operators cabin on the installation equipment. At the top there is the computer and its operating monitor with which the operator works. Below the computer there are two devices which enable the operator to adjust the equipment to comply with the requirements of the specification.

Figure 1 The display units as fitted in the operators cabin on the installation equipment

Operating monitor

The operating monitor, as shown in Fig.2, displays all data from the monitoring computer to the equipment operator. The binder supply tank condition, rate of binder feed are in the top left hand corner with current depth of mixing tool, tool rotation and supplied binder below. The supplied binder should follow the design line which has an upper and lower tolerance line. Other parameters such as lift speed and hose pressures etc. that the operator needs to be aware of are given on the right hand side. As the system is updated it checks the recorded parameters with the design parameters previously entered and if the recorded parameters are outside the tolerances the monitor changes the color of the display for that parameter to warn the operator. The operator can then take appropriate action to bring the parameter back within tolerance.

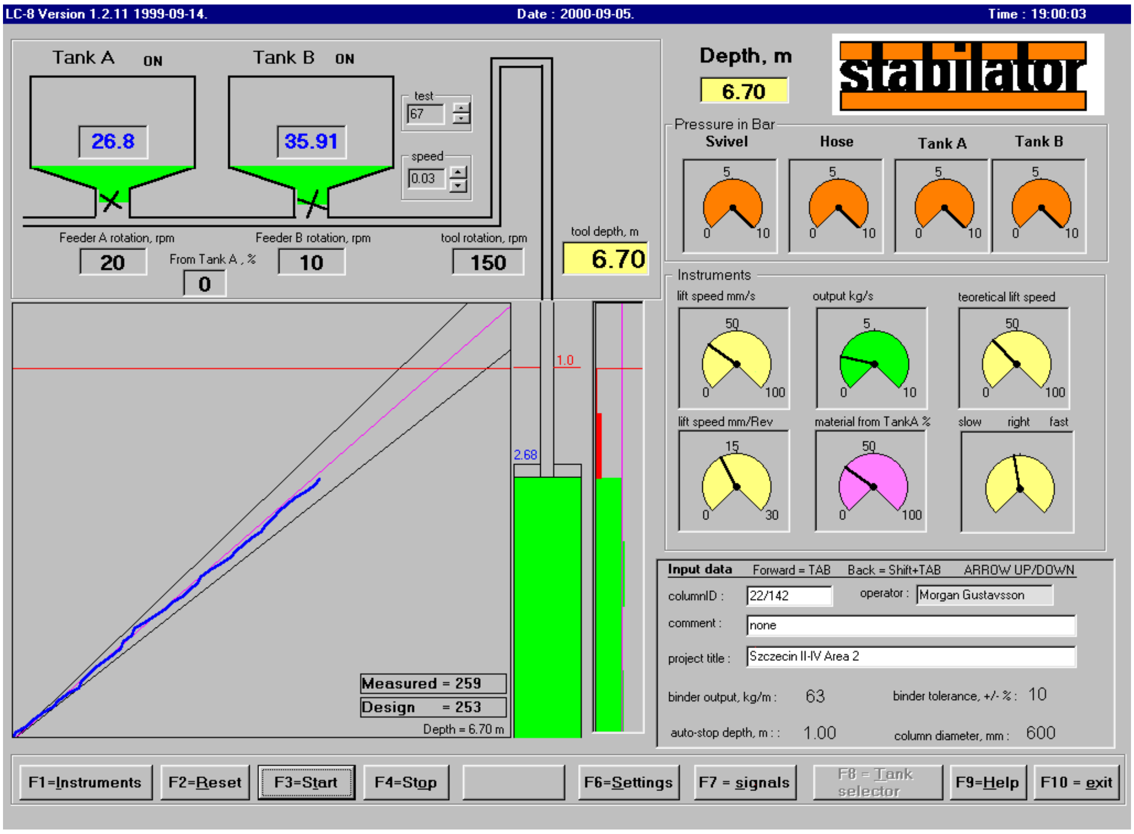


Figure 2 Typical operating monitor display showing the progress of Deep Dry Mixing in a column

After a soil mixed column has been installed, the computer saves the installation information in text files. These files are used to produce outputs to show the installation parameters for each individual soil mixed column. Fig.3 shows a series of graphs of the installation of column 102 as a function of time.

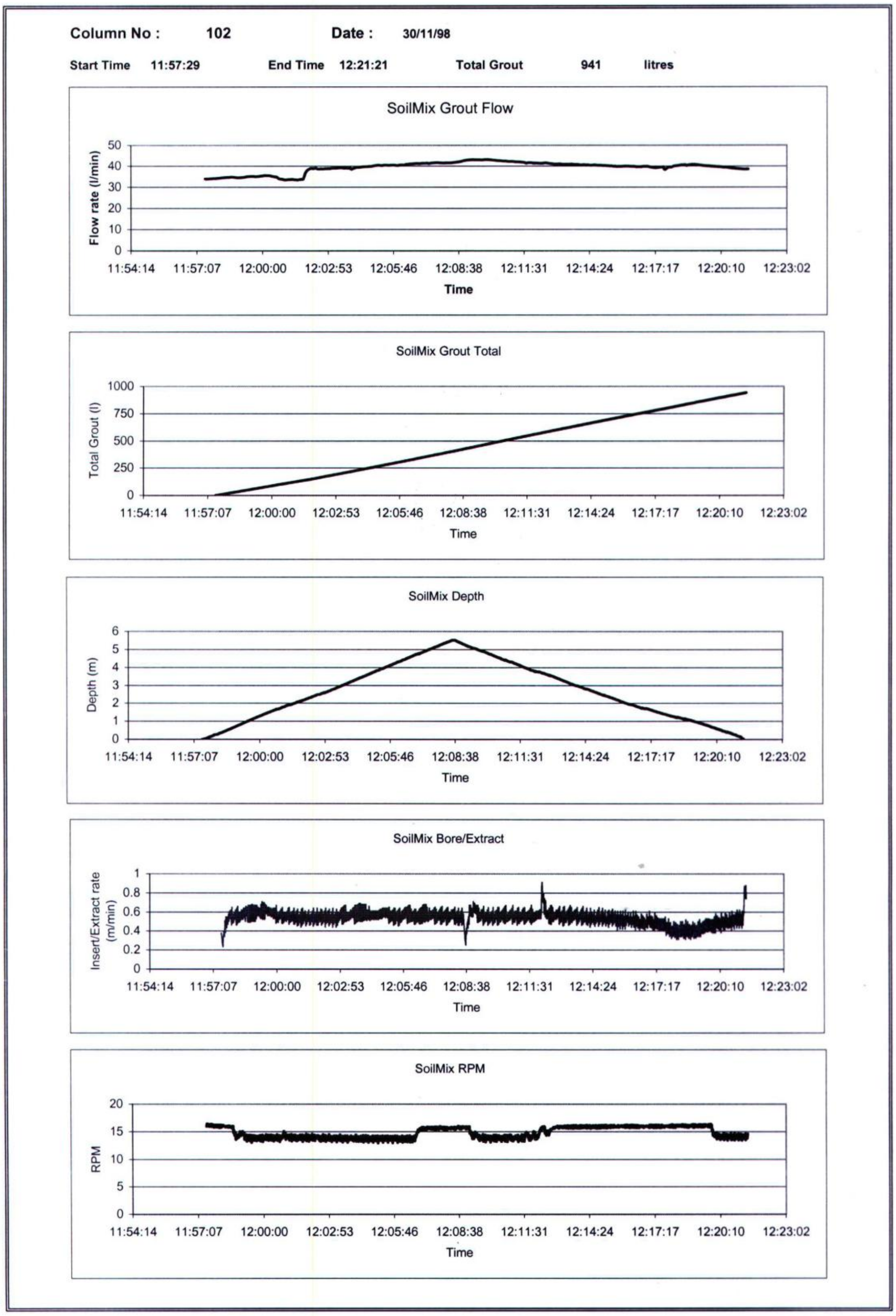


Figure 3 A series of graphs of the installation of column 102 as a function of time

Fig.4 shows a typical daily log sheet for soil mixing. The daily log sheet shows the numbers of the columns mixed, their length, nominal diameter, time taken, binder slurry volume and binder mix. Additional data is given at the bottom of the sheet concerning the operatives, design parameters, mix design details and total material use.

Keller Ground Engineering
Geotechnical Engineering Contractors
Tel 01937 541118

KELLER
A DIVISION OF KELLER LTD

DAILY SOIL MIXING REPORT NO. 8

AREA Section C-C and D-D | **CONTRACT** Euro Soil Stab - Dartford | **CONTRACT NO.** 1.6648

CLIENT BRE / Keller | **DATE** 30.11.98

Column No.	Datum Existing GL. Level (OD).	Depth to Top of Column (m)	Depth to Base of Column (m)	Column Length (m)	Nominal Column Diameter (m)	Insert Time (mins)	Lift Time (mins)	Total Time (mins)	Grout Volume (litres)	Testing grout cubes, U100s, insertion of double pipes, Etc.	Remarks. Interuptions to mixing, Etc
60			5.5	5.5	0.9	14.0	12.0	26.0	1008	Mix 2	
67			5.5	5.5	0.9	14.0	12.0	26.0	1036	Mix 2	
74			5.5	5.5	0.9	13.0	11.0	24.0	982	Mix 2	
81			5.5	5.5	0.9	14.0	12.0	26.0	1034	Mix 2	
88			5.5	5.5	0.9	15.0	12.0	27.0	1022	Mix 2	
95			5.5	5.5	0.9	12.0	11.0	23.0	869	Mix 2	
102			5.5	5.5	0.9	12.0	12.0	24.0	941	Mix 2	
61			5.5	5.5	0.9	12.0	12.0	24.0	1000	Mix 2	
68			5.5	5.5	0.9	13.0	12.0	25.0	1102	Mix 2	
75			5.5	5.5	0.9	12.0	11.0	23.0	965	Mix 2	

WORK SUMMARY

COLUMNS							
Nominal Dia. (m)	1.2	0.9		Nominal Dia. (m)	1.2	0.9	
No. Today	2	16		Length Today (m)	11	88	
Previous No.	57	45		Previous Total (m)	221.5	247.5	
Cum. Total	59	61		Cum Total (m)	232.5	335.5	

GROUT VOLUME	
Grout Today (l)	20209
Previous Total (l)	120287
Cum. Total (l)	140496

OPERATING PARAMETERS

Nominal Dia. (m)	Insertion Rate (m/min)	Lift Rate (m/min)	R.P.M	Grout Flow (L/min)
0.9-1.2	0.5	0.5	16	40-70

GROUT DESIGN DETAILS

Mix No.	OPC (kg)	PFA (kg)	GGBFS (kg)	Bentonite (kg)	Water (litres)	Other (kg)
1	400		400		400	
2	200		600		400	

Name	Trade	Hours		Trade	Hours
R Emerson	Driver	10			
A Walker	Mixer	10			
M Waddilove	Pump	10			
G Harvey	Driver	10	Time: Started 8.00	Finished	1800

Signed For

Client

Keller Ground Engineering

BLUE - HQ	YELLOW - CLIENT	YELLOW - CLIENT	WHITE - SITE

Figure 4 A typical daily log sheet for soil mixing site

Appendix 3 Laboratory tests (EuroSoilStab, 2002)

The soil to be used in preparing samples should be representative of the soil layers at the site to be stabilized. Organic deposits are notoriously variable in both vertical and lateral directions, so that often a thorough site characterization will be needed to determine representative locations of soil samples.

It is wise to test several stabilizers (each at several dosages) during the laboratory mix design program. A general rule for the choice of stabilizer is difficult to give, but the evaluation of tests performed in EuroSoilStab context in Finland on soils and stabilizers specific to these countries, may give some useful guidelines.

The present procedure is relatively simple and yields samples of stabilized soil suitable for the determination of strength and stiffness by means of laboratory strength tests on cylindrical samples such as the unconfined compression test, various kinds of triaxial test and direct shear tests. Other properties, such as permeability, physical and chemical durability, and compressibility may also be determined on such samples. The method yields samples, which may be used in determining type of stabilizer and dosage for deep mixing projects. The samples obtained by the method however do not reflect well the structure of soil stabilized in-situ by common deep mixing techniques. Conditions of mixing and curing in the laboratory deviate significantly from field conditions, and consequently laboratory strength and stiffness determined on samples prepared by this procedure will likewise deviate from field values. However, when planning a deep mixing project, a comparative laboratory investigation of the properties of different samples prepared with various stabilizer materials in varying dosages and after varying curing periods, is a useful, often indispensable aid. Further, empirical rules can be developed to allow for the differences in e.g. strength and stiffness between field-stabilized and laboratory-stabilized material. It is necessary to produce a number of trial columns ahead of or in the beginning of the actual project. Based on the results of the laboratory program, a few stabilizer combinations and dosages can be applied, and the results are used to assist the final choice and to determine the engineering parameters for use in the final design.

Materials and equipment

Soil is obtained from the site under investigation. It may be obtained by standard soil sampling devices such as tube and piston samplers and the continuous Delft sampler. Auger samples are acceptable if it can be shown that intermixing of different soil layers is kept within acceptable limits. Large diameter (>20 cm) augers have the advantage of allowing a large quantity of soil to be collected, while the soft soils in question are usually easily penetrated by them. However, large diameter tube samplers may yield better samples in sufficient quantities and at comparable cost in most soft deposits.

The stabilizer used in the laboratory preparation of samples must be representative of the materials to be used in-situ, and must be adequately stored such that their properties are not impaired by exposure to moisture or moist air or extreme temperatures. If stabilizer material has been stored for long periods, its reactivity should be checked.

Equipment:

- Mixing machine of sufficient capacity to mix soil for the entire test program (usually 20-50 liters).
- Mixing machine of sufficient capacity to mix a batch of soil with one binder (normally 3 - 5 liters).
- Cylindrical moulds, e.g. plastic tubes or plastic-coated cardboard, inner diameter 50 mm and length at least 100 mm. The ends must be flat and perpendicular to the length axis. The bottom of the mould may be closed by a flat and stiff lid, or placed on a flat plate. In both cases, the seal between mould and bottom should be tight enough to prevent loss of mixed soil. To allow minimum disturbance when removing the sample from the mould after curing the plastic moulds could e.g. have one lengthwise slit, allowing the mould to be pried open during sample removal, or plastic or metal split moulds could be used. The slit or splits must be sufficiently clamped and be

water-tight during sample placement and compaction. If cylindrical moulds without lengthwise slit are used the force used for removing of the sample from the tube should be minimized. If it is a problem to extract the sample from the mould form oil based on wax can be used. If this form oil is used it shall be shown that it does not influence the properties of the sample.

- Fork: a kitchen fork the prongs of which may be bent at right angles over a length of approx. 15mm.
- Compaction tool: a circular steel stamp, e.g. approx. 10 mm thick and with a diameter 5 mm less than that of the mould, with an attached steel rod e.g. approx. 50 mm long. Alternatively, a press capable of delivering a stress of 100 kPa on a stamp similar to that described above can be used. In sticky soils, it may be necessary to fit an inclined base to the stamp of such a press.

Preparation procedure

Homogenization of soil

A quantity of soil sufficient to prepare the required number of stabilised soil samples is placed in the mixer. If this exceeds the capacity of the mixer, a larger mixer should be used. It is not acceptable to mix one type of soil in a number of batches. Remove isolated roots and large fibres and coarse material if possible. Mix until the soil is visually homogeneous. In the case of fibrous peat, limit the mixing time to prevent destruction of fibres. If necessary, manually move soil stuck to the mixing bowl to the centre. Note the time used for mixing. Take out two small samples and determine their bulk unit weight and water content. Alternatively the unit weight can be judged from knowledge in the specific area and at the specific depth, preferably from determinations on undisturbed samples.

Choice of sample diameter

Choose the sample diameter based on the coarseness of the mixed soil. In the large majority of cases, 50 mm will be sufficient. Only when the soil contains many coarse particles or fibres should a larger diameter be used.

Preparation of stabilizer

When stabilizer is used which consists of two or more materials, mix these components together in the required proportions and in a quantity sufficient to perform the required tests.

Mixing of soil and stabilizer

A quantity of soil sufficient to prepare the required number of stabilized soil samples for the given soil and a given stabilizer at a given dosage, is placed in the mixer. Use the bulk unit weight as determined under ”Homogenization of soil” and the required dosage of stabilizer to calculate the necessary amount of stabilizer. Dry stabilizer is added to the soil in the mixer. Soil and stabilizer are mixed until the mass is visually homogeneous. In the case of fibrous peat, limit the mixing time to prevent destruction of fibers. If necessary, manually move soil stuck to the mixing bowl to the centre. Note the time used for mixing. Take out two small samples and determine their water content. Protect the mixed soil from drying out before it is applied to form a sample.

Compaction of mixed soil in mould

The compaction should be performed directly after mixing. The time from mixing to finished sample should be kept low. The entire batch of mixed soil must be formed into samples within 30 minutes of mixing. If many samples are to be prepared with the same dosage it can be advisable to split them into two or three batches. In case a slit mould is used, clamp it or place it in a tightly fitting thick walled tube to prevent lateral bulging during compaction.

Place a layer of mixed soil in the mould to a thickness of approx. 25 mm thick (aspect ratio 0.5 in case of differing sample diameter), prod it and press it in place with a fork. Take care to eliminate bubbles of liquid or air. Compact the layer with the compaction tool. Exert a pressure of approx. 100 kPa three times during approx. 2 seconds, each time with the stamp against the wall of the mould and its rod inclined inwards at approx. 10 - 15°, and rotate 120° along the circumference of the mould each time. Continue with three more such compaction strokes, but now with the rod held vertically, and rotate these strokes 60° relative to the first series. Scarify the surface lightly with a fork, and apply a second layer of mixed soil of approximately equal thickness to the first. Repeat the compaction procedure. Continue to place and compact the mixed soil in this manner, in 4 layers (for moulds with more than 100 mm length perhaps 5 or 6 layers) of approximately equal thickness to slightly above the upper rim of the mould, and trim off excess material above the rim, leaving the upper surface entirely flat. If the mould has a length of more than 100 mm the compaction will have to be done in more than 4 layers.

Alternatively, compaction can be performed with a press, which is calibrated to yield a pressure of 100 kPa. If the same kneading action as with manual compaction is desirable, a metal plate with an inclined base could be fitted to the bottom of the stamp during the first 3 compaction strokes per layer.

Storage

The storage temperature shall be specified in the order to the laboratory. Normally samples are cured and stored in sealed tubes at 18 - 22 °C.
Note: The chosen temperature will affect the rate of increase in strength.
Note: Normally no load is applied during curing and storage. Strength of stabilized soil generally increases if a load is applied during curing.

Removing sample from its mould

After the specified curing period, note the height of the sample relative to the ends of the mould, and note the roughness of the end surface of the sample. The removal of the samples from the mould should be made with a minimum of disturbance. E.g. in case taped slit moulds have been used, remove the tape from the slit and pry the slit open to allow the sample to be removed. In case of cardboard moulds, peel off the cardboard.

Preparation of sample ends

Preparation of sample ends is only needed if the upper end of the sample has become rough during curing: Cut off a small slice from the upper end of the sample to obtain a flat surface perpendicular to its length axis. Alternatively, if only unconfined compression tests or unconsolidated undrained triaxial tests are to be performed on the samples, it is acceptable to smoothen the upper surface with a thin layer of gypsum.
Note: Appropriate cutting equipment, e.g. diamond-tipped saws, which apply minimal disturbance to the sample, and ensure perpendicular and flat cuts, must be used.

Evaluation

Evaluation of the results of the laboratory mix design program will usually concentrate on unconfined compressive strength qu, stiffness E, and permeability k.

A typical stress - strain curve from an unconfined compression test is shown in Fig. 1. The compressive strength qu is taken as the peak value at P found in unconfined compression tests or undrained triaxial tests. The stiffness E is taken from the pre-failure part of the curve. Often the initial strain will contain bedding deformation, and the figure shows how to correct for this. The usual value of stiffness derived from the unconfined (relative values) or triaxial tests is the E50 value at a stress equal to 50% (point C) of the failure stress.

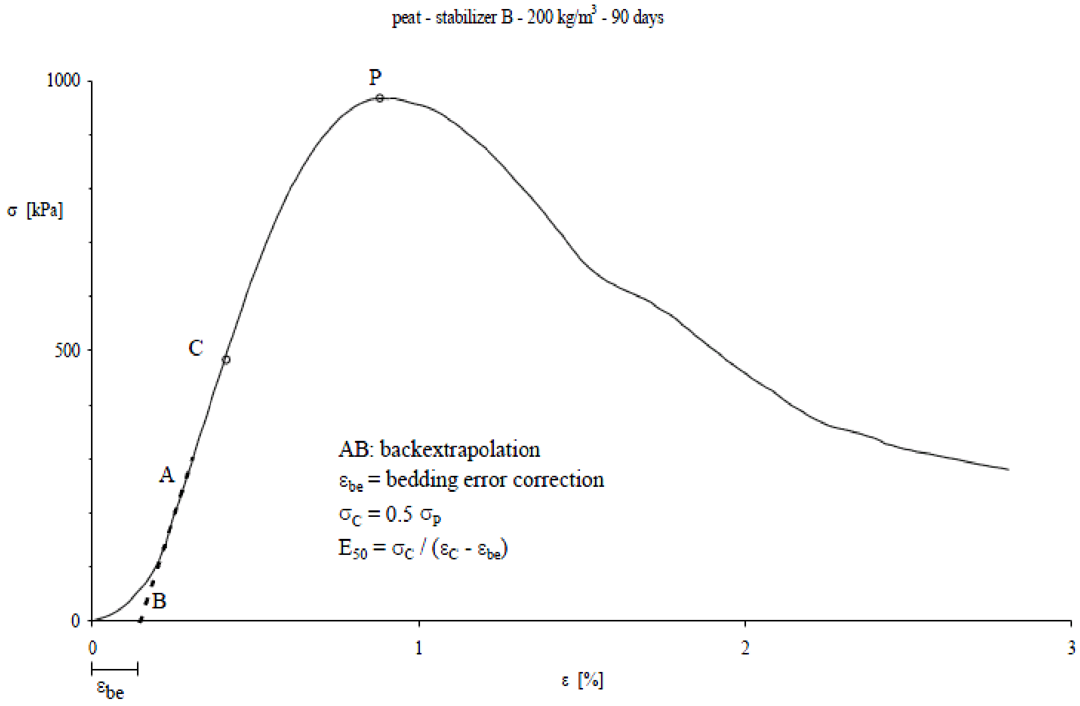


Figure 1 Evaluation of results from unconfined compression test

The bedding error correction is found by extrapolating the part of the curve beyond the initial bedding deformation; linearly back to the horizontal axis. This yields point B from which the stiffness is measured. It is common in the engineering of stabilized soil projects to determine stiffness E50 from a correlation with the unconfined compressive strength qu, preferably from drained triaxial tests. A fairly linear relation between E50 and the strength exists. Values of E50 in the range of 100 times the strength up to 200 have been reported. Fig. 2 shows such a correlation for two projects, including various soils and various stabilizers and dosages.

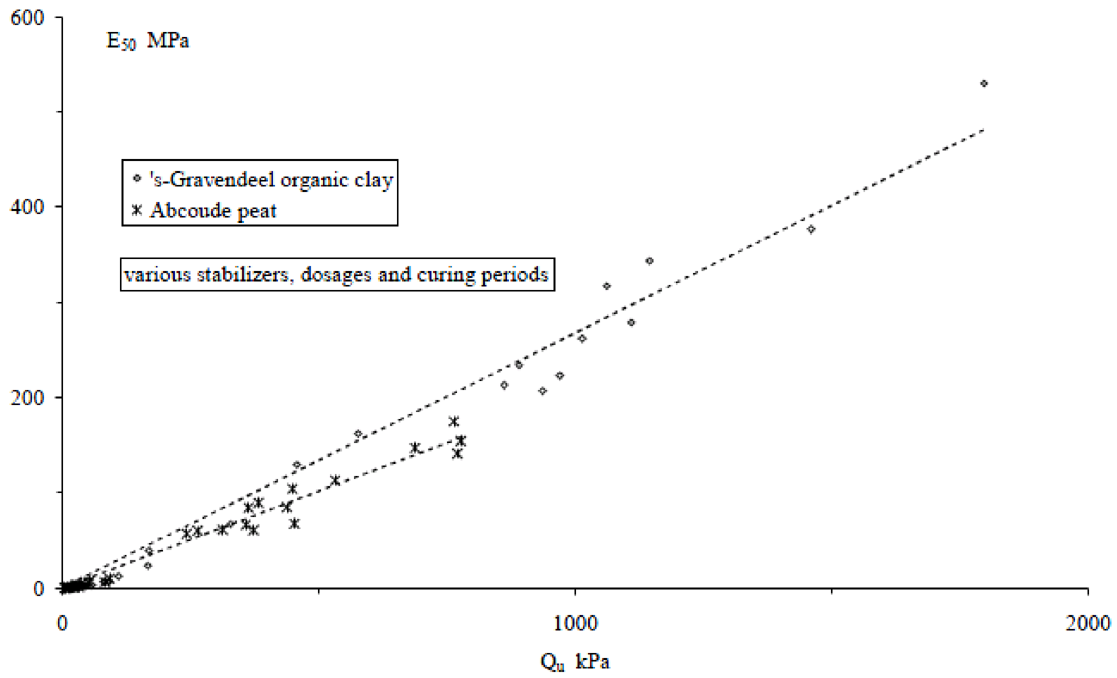


Figure 2 Correlation between E50 and unconfined compressive strength

The following figure reveals the existence of a threshold dosage below which the increase of strength is likely to be very minimal. In other words: every extra kg of stabilizer above the threshold yields a disproportionately strong increase of attainable strength. In Fig. 3 the threshold would be some 100 kg stabilizer per m3 of soil. If this is true for laboratory samples which are subjected to ideal mixing and curing conditions, then it is unlikely that lower dosages than the threshold value in the field would be very effective, although due to the variable mixing, locally in a column high strengths could still be attained.

28 day strength vs. dosage for Ductch soils, stabilizer F

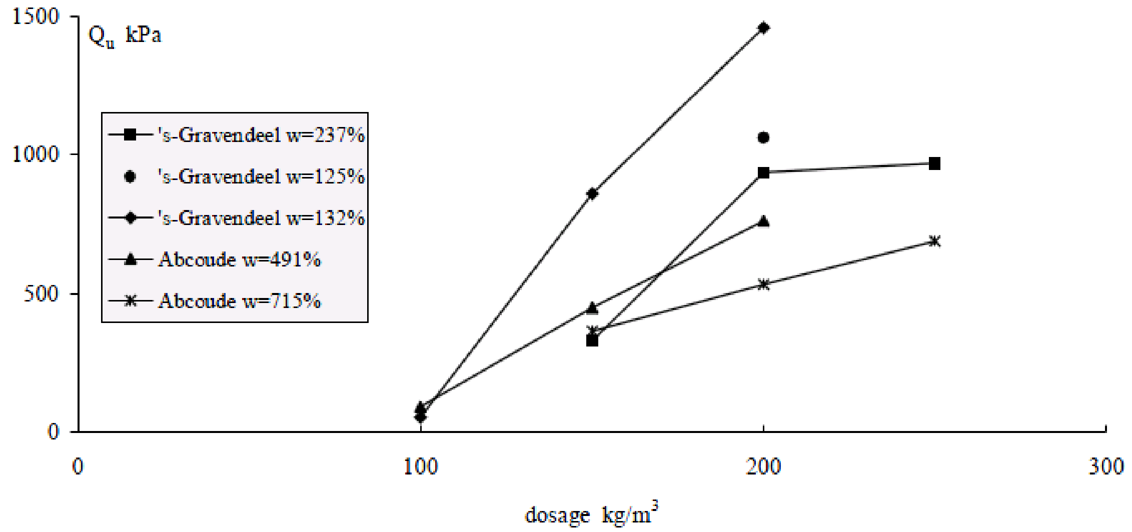


Figure 3 Correlation between E50 and unconfined compressive strength

Another example of the influence of the quantity of binder is shown in Fig. 4 giving the influence of the binder quantity at stabilization of peat with cement-slag as binder.

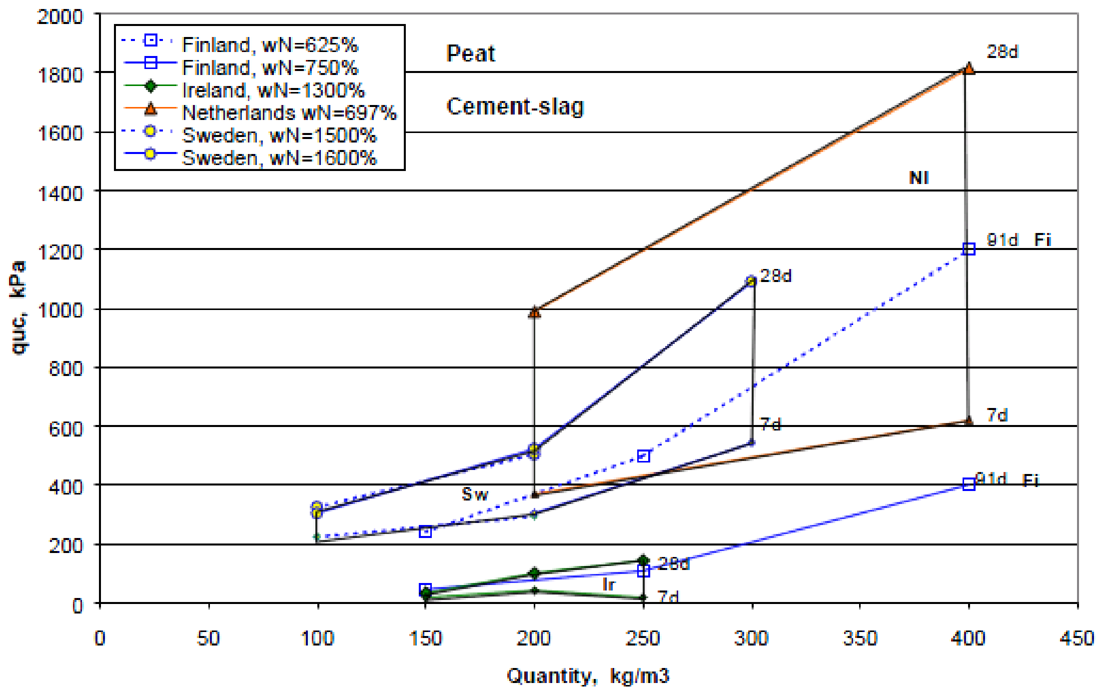


Figure 4 Influence of the quantity of binder to the unconfined compressive strength

Permeability of stabilized soil can be derived preferably from permeability tests. If derived from odometer tests in the usual manner applying Taylor's or Casagrande's interpretation of the primary part of the settlement curve, a somewhat different permeability is obtained due to a lower degree of saturation.

Consolidated drained triaxial tests on stabilized soil should be used to determine the effective strength parameters such as j¢ and c´. From undrained triaxial tests it is possible to determine the increase of column strength with depth. Often such tests show a tendency to develop excess pores pressures almost equal to the effective cell pressure (i.e. cell pressure relative to back pressure). Effective stresses then tend to be zero in the horizontal direction, and the sample usually fails. Sometimes, as shown in Fig. 5 (curve for lowest consolidation pressure), compression and hardening continue for quite a while with virtually zero horizontal effective stress. In this condition, j¢ cannot be determined from undrained tests- it would turn out at 90°! Such behavior may well reflect actual field behavior, and allowance for it would need to be made in calculating column strength.

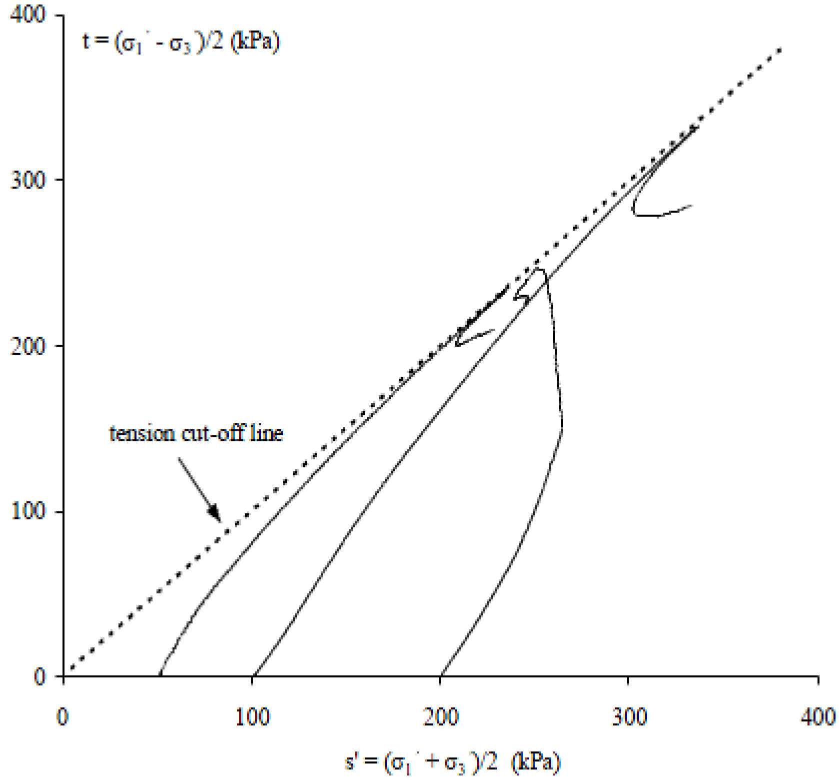


Figure 5 Triaxial test on stabilized soil

In all evaluations of the laboratory tests it must be remembered that laboratory prepared stabilized soil samples are likely to exhibit very different behavior from stabilized soil in the field. Overall strength of stabilized organic clay and peat is most often considerably less in the field than for laboratory prepared samples. This is different from the situation in inorganic soft clays where field strength sometimes surpasses laboratory values. Permeability of stabilized organic soils and peat has been found to be lower for laboratory samples than for cores obtained from columns, but otherwise relatively little is known about this relationship.

Appendix 4 Example of a risk assessment for Deep Soil Stabilization

DATE: ##/##/## **ASSESSED BY:** *Project Manager* **LOCATION:** *Any Site* **Page 1**

ACTIVITY: Deep in situ soil mixing

Operation	Hazard	Who might be harmed?	Risk Factor	Is the risk adequately controlled?	What further action is necessary?
Describe the operation(s) being assessed.	List hazards here (see note 1 and refer to Annex B).	List groups of people at risk from the hazards identified. (note 2)	Calculate the Risk Factor. (note 3)	List existing controls, or where the relevant information may be found. (note 4)	List the risks that are not adequately controlled and the action you will take where it is reasonably practicable to do so. You are entitled to take cost into account, unless the risk is high. (note 5)
Pedestrian access	Debris falling, equipment, oil or other spills, uneven ground, trailing pipes	Users, other staff, contractors	1	Instruction, wear protestive clothing.	Cone off working area to restrict access to users only
Use of vehicles,	Collision with pedestrians	Users, other staff, contractors	1	Warning signs, Instruction	Cone off working area to restrict access to users only
Manual handling	Lifting, lowering, pulling, pushing	Users	1	Instruction, users must attend manual handling course, use mechanical assistance where necessary.	None.
Working with contractors crane	Collision with suspended equipment, falling debris, Worn, faulty or wrong lifting attachments.	Users, other staff, contractors	1	Instruction, users must attend manual handling and slinging course, wear protective clothing.	None
Mixing of binders Storage and	Inhalation of dust, lifting bags of materials, lowering bags of materials, opening bags of materials	Users, other staff, contractors	1	Instruction, Manual handling course, wear protective clothing, use of mechanical assistance where possible.	Work in well ventilated areas

transfer of materials	Inhalation of dust, lifting bags of materials, lowering bags of materials, opening bags of materials, Escaping high pressure gas and gas driven particles	Users, other staff, contractors	1	Instruction, Manual handling course, wear protective clothing, use of mechanical assistance where possible.	Work in well ventilated area, Clean up contingency in place.

Appendix 5 Table of comparison: DDM with other ground improvement methods

method	injection	grouting	electro-chemical	thermal method	DDM
increase strength of the soil	+	+	+	+	++
soil types not treatable	soils with fines content of over about 25%	saturated clayey soils			boulders, logs, and hard strata can be a problem
controling ground water flow	+	-	+	-	++
harmfull environmental effect	+	-	+	+	-
treatment beneath existing structures possible	+	+	-	-	earth structures
improvement of a big areas is possible	-	-	-	+	+
large diameter drilling	-	-	-	+	+
low headroom work possible	+	+	+	-	-
selective treatment possible	+	+	+	-	-
intimate contact with structure possible	+	limited	-	-	-
treatment at very low confinement possible	+	marginal	-	+	+
without care, likely disturbance	significant ground movement; damaged pipes	significant ground movement; damaged pipes	significant ground	significant ground	significant ground movement; damaged pipes
quantity of waste produced	little	little	little	a lot	some
prevents seismic-induced subsidence	+	+	+	-	depends on design
well-defined specifications required	+	+	+	+	+
quality control during instalation required	+	+	+	+	+
other evaluations required	durability, creep, health and safety,site pilot study	site pilot study			durability, site pilot study
can be highly cost effective	+	+	-	-	+
cost	expensive	expensive	expensive	expensive	expensive

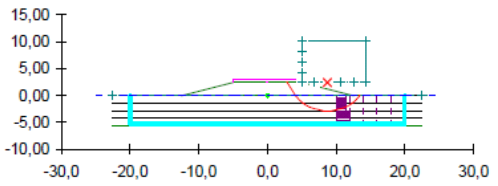
Program developed by Road management in Finland and uses in Sipooranta project. (Roman Timashkin, FCG oy)

Finnish version

D3708 SIPOONRANTA **Stabilointi, Alue I, täyttö tasoon +2.0** 20.1.2010

SYVASTABILOINNIN MITOITUS
V. 3.0 7.4.2002 (c) M. Smura
FCG Finnish Consulting Group Oy

20.1.10 15:58 Laskija: TKA



Varmuuskerroin ilman syvästabilointia		F=	0,76	
Pilarityyppi :	1	Varmuuskerroin F=	**2,88**	
Laskentakerros	2	Laskentapuoli vas/oik = 0/1	1	

	Pilari	Aktiivi	Passiivi	Savi	Välissä	Ulkop.	Ohjearv.
Cu-väh.kerr.		1,0	0,1	Cu-väh.kerr.	0,0	0,0	0,0

Puristusmurron tarkastelusyvyys 2 m

Lähtöarvot: (valkeat ruudut, harmaat tarvittaessa)				
SIPOONRANTA, k260,Torialue (I), täyttö +2,0, Lujat pilarit				
Maanpinnan kaltevuus M:10	M	0		m
Penkereen leveys	B	10		
		Vas	Oik	
Pengerkorkeus	H	2,5	2,5	m
Luiskakaltevuus 1:N	N	3	3	
Pohjavesipinnan etäisyys	hw	0,0	0,0	m
Penkereen tilavuuspaino	γ	21		kN/m3
Penkereen kitkakulma	φ	25	X1	X2
Liikennekuorma kPa	q	5	-5	5

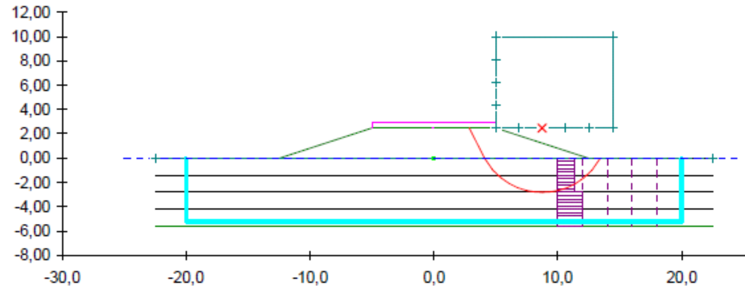
MAAKERROSRAJAT									
X	-20,0	-10,0	0,0	10,0	20,0	w	γ	Cu	M
Maanpinta Y	0,0	0,0	0,0	0,0	0,0	%	kN/m3	kPa	kPa
Kerros 1 d	1,4	1,4	1,4	1,4	1,4	60	16,4	7	490
Kerros 2 d	1,4	1,4	1,4	1,4	1,4	60	16,4	7	490
Kerros 3 d	1,4	1,4	1,4	1,4	1,4	50	17,1	10	700
Kerros 4 d	1,4	1,4	1,4	1,4	1,4	50	17,1	10	700
Ulkoinen vesipinta Y			0,0	Mitoitusarvo (pilariväli):					490

SYVASTABILOINTI					Puris-tuslu-juus	E-moduli	Massastabiloinnin painuma mm		
Massa-stabilointi	Syvyys m		Leveys m						
	Vas	Oik	Vas	Oik		kPa	Vas	KL	Oik
	0	0	11	11	200	10000	0	0	0

	Pilaristabilointi	Parametrit					Mitoituksen tulos				
	Leikkaus lujuus	Puristus-murtoluj.	Mit.-% (murto-luj.) %	Mitoitus-pur.lujuus	Pilarin E-moduli	Liikenne-kuorma	Pilariväli k/k	Pilari-jänni-tys	Pilaristabiloinnin painuma mm		
Pilarityyppi	kPa	kPa		kPa	kPa	0/1	m	tys	Vas	KL	Oik
1 Luja	200	400	50	200	40000	1	**1,32**	200	26	26	26
2 Kimmoisa	120	279	70	195	18000	1	**1,35**	195	51	51	51
3 Myötäävä	70	179	85	152	10500	1	**1,20**	152	140	146	140
Penkereen kokonaispainuma, pilarityyppi:								1	48	48	48
Penkereen kok.painuma ilman syvästabilointia:								M	428	439	428

	Pilaristabilointi	Geometria					Kallistus luiskissa N:1	
	Pilari-koko	Pilarointisyvyys m			Pilaroinnin leveys			
	mm	Vas	KL	Oik	Vas	Oik	Vas	Oik
1	800	5,2	5,2	5,2	20	20	0	0
2	800	5,2	5,2	5,2	20	20	0	0
3	800	5,2	5,2	5,2	20	20	0	0
Pilarin geotekninen kantavuus, kN:						112	F=	1,11

Huom: **Alapään geotekn. kantavuus ei riitä**



VAKAVUUSLASKENTA (STABILITEETTI) (Hila, vastapenkereen ja kevennyksen mitat)

Laskentakerros ja laskentapuoli annetaan aloitusnäytöllä

	X	Y	dx	dy
Hila 5x6	5,0	2,5	1,9	1,9

VAARALLISIN LIUKUPINTA		X	Y	R
VARMUUSKERROIN F=	**2,88**	8,8	2,5	5,3

VASTAPENGER		Vas	Oik	
Vastapenkereen korkeus	h	0	0	m
leveys	b	10	10	m
luiskakaltevuus	n	0	0	
yläpinnan kaltevuus	m	0	0	
tilavuuspaino	γ	18		kN/m3

PAINUMALASKENTA PILARITYYPPI 1

Painuma mm	vas	KL	oik	%
Kerros 1	0	0	0	**0,0**
Kerros 2	0	0	0	**0,0**
Kerros 3	0	0	0	**0,0**
Kerros 4	0	0	0	**0,0**
Yhteensä	0	0	0	

Painuman ohjearvo: alle 3 %.
Ok

KEVENNYS		Vas	Kesk	Oik	
Kevennyksen paksuus	h	0	0	0	
Kevennyksen leveys	b	0		0	m
Päällysrakenteen paksuus	k	0	0	0	m
Kevennyksen luiskakaltevuus '	n	0		0	
Kevennysmateriaalin tilav.paino	γ		0	-10	kN/m3
Kevennysmateriaalin kitkakulma	φ		0		ast

HUOM: Tarkista, että painumalaskennassa käytetyt M-moduulit on määritetty oikealta jännitysväliltä, joka riippuu pengerkorkeudesta.

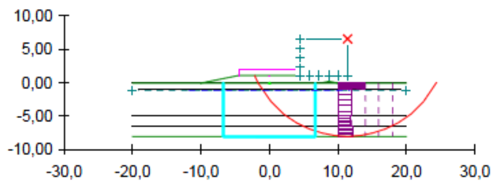
Russian version

РАСЧЕТ ГЛУБОКОИ СТАБИЛИЗАЦИИ ГРУНТОВ

V. 3.0 7.4.2002 (c) M. Smura

IP ENGINEERING FINLAND LTD.

18.3.05 15:21 Произвёл: Roman Timashkin



Коэфф. надёжности до стабилизаци			F=	1,81
Тим колонн :	**2**	Коэфф. надёжности		**2,73**
Расч.слой	4	Сторона расчёта	лев./пра	1

Колонна	Актив	Пассив	Глина	Промеж.	Наружн	Рекоменд.
cu- поправ.коэфф.	1,0	0,1	C_u- поправ.коэфф.	0,5	0,5	0,5

Глубина проверки на сжатие 2 м

Исходные дан (белые поля, серые поля по необходимости)

Дальневосточный пр-кт, РАЗРЕЗ 150-150

Естесств. уклон пов.земли М:10	M	0		m
Ширина насыпи	B	9		
		Прав.	Лев.	
Высота насыпи	H	1,1	1,1	m
Откос 1:N	N	5	5	
Глубина подз. вод	hw	1,2	1,2	m
Объёмный вес насыпи	γ	21		кН/м3
Угол внутр.трения	ϕ	35	X1	X2
Расч. нагрузка кПа	q	10	-4,5	4,5

ГРАНИЦЫ ИГЭ

X	-20,0	-10,0	0,0	10,0	20,0	w	γ	Cu	M
Пов.земли Y	0,0	0,0	0,0	0,0	0,0	%	kN/m3	кПа	кПа
Слой 1 насыпь	1,0	1,0	1,0	1,0	1,0	30	19,2	20	4000
Слой 2 гидроз	4,0	4,0	4,0	4,0	4,0	54	15,9	10	700
Слой 3 Торф,	1,5	1,5	1,5	1,5	1,5	421	10,1	9	630
Слой 4 Суглин	1,5	1,5	1,5	1,5	1,5	36	18,5	11	770
Пов.воды		Y	-1,2	Расч.значение (между колонн)					630

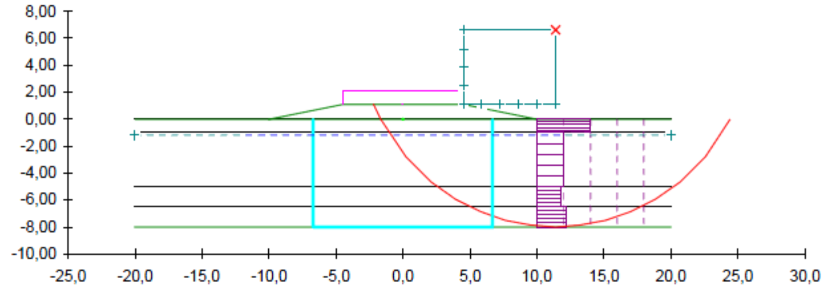
ГЛУБ.СТАБИЛИЗАЦИЯ					Сопрот. сжатию	E-модуль кПа	Осадка при массовой стаб., м		
Массовая стабилизация	Глубина,м		Ширина, м						
	Лев.	Прав.	Лев.	Прав.			Лев.	Ось	Прав
	0	0	7,7	7,7	200	10000	0	0	0

Тип колонн	Стабилизация методом кп: Параметры — Прочнос сдвиг кПа	Сопроти сжатию кПа	изм.-% (сопрот. сжат.) %	Расчётн сопр.сж кПа	Модуль де колонны кПа	Расч.наг от транс 0/1	Результат расчёта — шаг кс ц/ц м	Напряж колонн	Осадка стабилиз. грунта, мм — Лев.	Ось	Прав.
1 Жёсткая	250	500	50	250	50000	1	**1,46**	250	40	40	40
2 Эластичная	135	309	70	216	20250	1	**1,20**	150	39	39	39
3 Поддающ.п	90	219	85	186	13500	0	**1,86**	186	95	101	95
Общ.осадка насыпи, тип колонн:								**2**	**39**	**39**	**39**
Общ.осадка грунта под насыпью без стабилиз.								M	165	173	165

Стабилизация мет	Геометрия — Разме колонн мм	Глубина стабилиза м — Лев.	Ось	Прав.	Ширина стабилизаци — Лев.	Прав.	Уклон на откосах N:1 — Лев.	Прав.
1	600	8,0	8,0	8,0	6,7	6,7	0	0
2	600	8,0	8,0	8,0	6,7	6,7	0	0
3	600	8,0	8,0	8,0	6,7	6,7	0	0

нес.способность колонны, кН: Ok

Вним: **Tarkista penk. holvaantuminen, pilarityyppi 2**



РАСЧЁТУСТОЙЧИВОСТИ (СТАБИЛИТЕТ) (Hila, расчёт подпорной насыпи и облегчения грунтов

Расч.слой и расч.сторона задаётся выше

	X	Y	dx	dy
Hila 5x6	4,5	1,1	1,4	1,4
НАИБОЛЕЕ ОПАСНАЯ ПОВ.СКОЛЬЖ	X	Y	R	
КОЭФФ.НАДЕЖНОСТИ F=	**2,73**	11,4	6,6	14,6

ПОДПОР		Лев.	Прав.	
Высота подпора	h	0	0	м
ширина	b	10	10	м
уклон откоса	n	0	0	
уклон поверхности	m	0	0	
уд.вес	γ	18		kN/m3

РАСЧЕТ ОСАДОК **ТИП КОЛОНН 2**

Осадка, мм	Лев.	KL	Прав.	%
Слой 1	3	3	3	**0,3**
Слой 2	20	20	20	**0,5**
Слой 3	8	8	8	**0,5**
Слой 4	8	8	8	**0,5**
Всего:	39	39	39	

Норм.осадка: менее3 %.
Ok

ОБЛЕГЧЕНИЕ ГРУНТА		Лев.	Ось	Прав.	
Мощность облегчаемого сло	h	0	0	0	
Ширина	b	0		0	м
Толщина дор.покрытия	k	0	0	0	м
уклон откоса 1:n	n	0		0	
Уд.вес облегчённого заполнителя	γ	0		-10	kN/m3
Угол внутр.трения облегч.заполнит	ϕ	0			градус

HUOM: Tarkista, että painumalaskennassa käytetyt M-moduulit on määritetty oikealta jännitysväliltä, joka riippuu pengerkorkeudesta.

KPO – Kalkkipilarointiohje – "executives for calcium columns", a program that officially developed and used for Espoo city

kpo_painuma_1.02.xls 1/4

KPO 2000	Object	Example 2 b	Nb	Espoo city training
	Computer	TLv		
	Date	25.5.2010		

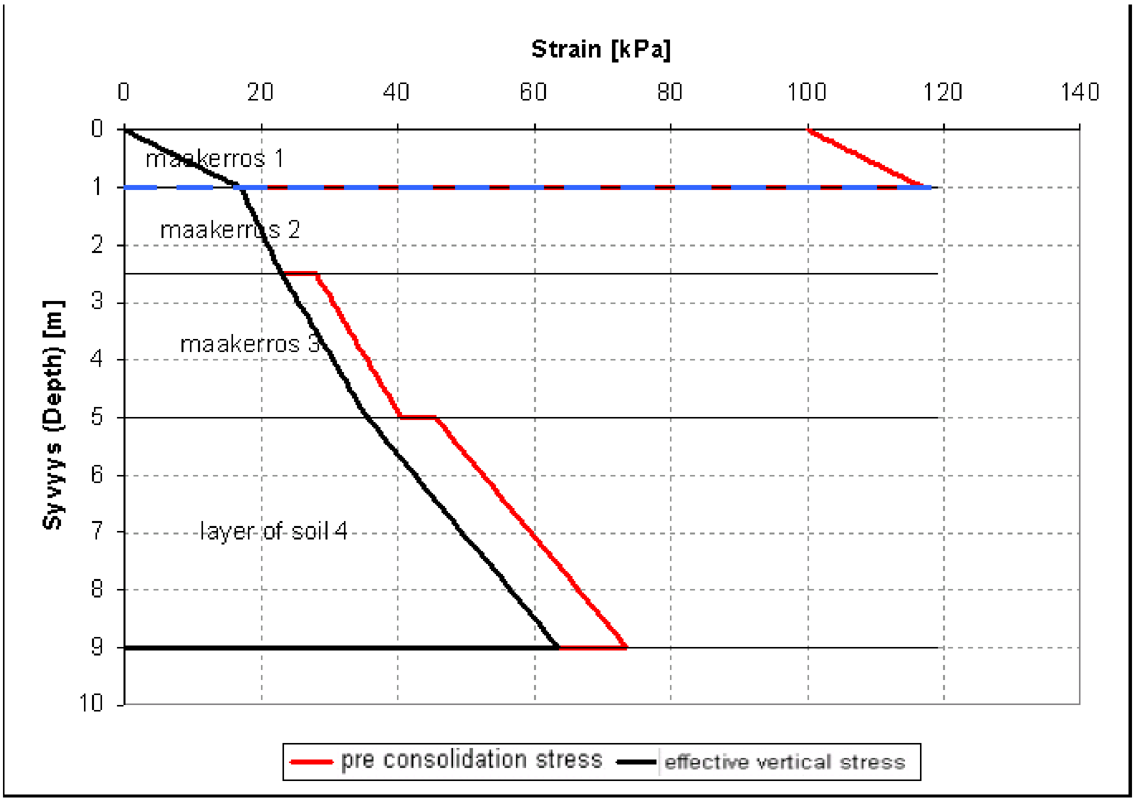
Number of soil layers	σ'_{cv} determination	Soil parameters	Module of column
4	POP	Ruotsalainen CRS moduuli	Ep = 100*tp

pvp. Distance 1 100

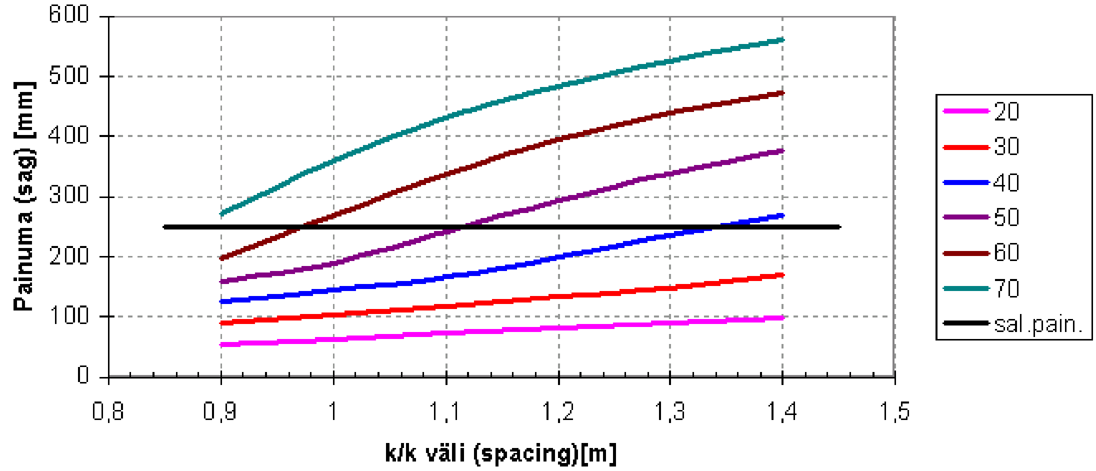
Layer of soil	z [m]	γ [kN/m³]	σ'_{cv} POP kPa	Deformation parameters of layers M0 kPa	ML kPa	x (sL-scv) kPa	M'	Columns τ_p kPa	E_p kPa
1	1	17	100	5000	500	200	10	80	8000
2	1,5	14	0	1500	300	8	13	120	12000
3	2,5	15	5	2000	400	10	12	80	8000
4	4	17	10	3000	550	0	8	80	8000

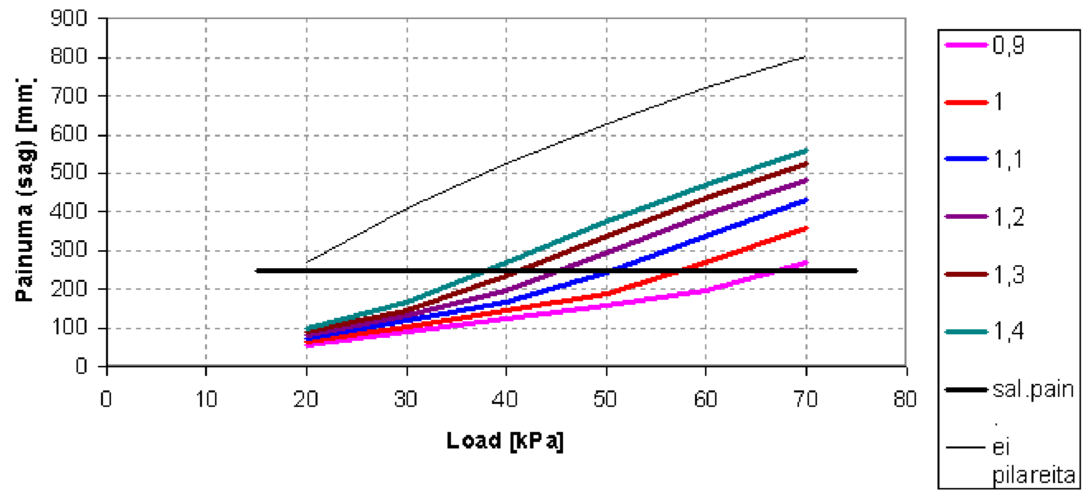
	min	step	maks
Diameter of column mm	500		
Columns length m	9		
Columns position	Neliö		
Distance between columns, m	0,9	0,1	1,4
Load, kPa	20	10	70
The load area length	101		
Load area width	101		

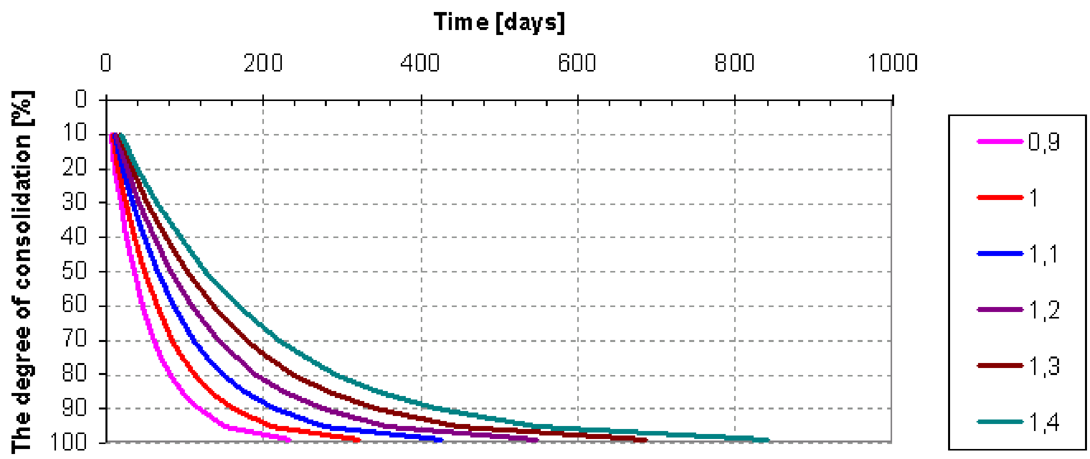
Columns myötö factor	0,7
Assurance against the collapse	Yli 1,5
Note the horizontal stress increases50 %	Kyllä / Ei
Soil consolidation coefficient c_h	0,8 m^2/a
Columns and the k-ratio values	400
Drainage	2-puolinen



KPO 2000	Object	Example 2 b	Nb	Espoo city training
	Computer	TLv		
	Date	25.5.2010		







KPO 2000	Object	Example 2 b	Nb	Espoo city training
	Computer	TLv		
	Date	25.5.2010		

Summary of the deflection of the column in stabilized area

pvp. Distance		1	σ'cv	Deformation parameters				Columns	
Maaker ros	z [m]	γ [kN/m³]	POP kPa	M0 kPa	ML kPa	x (sL-scv) kPa	M'	tp kPa	Ep kPa
1	1	17	100	5000	500	200	10	80	8000
2	1,5	14	0	1500	300	8	13	120	12000
3	2,5	15	5	2000	400	10	12	80	8000
4	4	17	10	3000	550	0	8	80	8000

Deflection calculation

(yellow) = maks. compression > 3 %
(red) = maks. compression > 5 %

Allowable deflection
250

Load kPa	Sag mm - k/k spacing, m 0,9	1	1,1	1,2	1,3	1,4	without cc	Limit k/k
20	55	64	73	81	90	98	271	over1,4
30	90	104	119	133	148	168	410	over1,4
40	124	145	166	199	236	269	528	1,34
50	159	190	243	294	339	377	631	1,11
60	198	269	337	395	438	473	721	0,97
70	272	360	432	484	526	561	803	alle 0,9
Limit kPa	67	58	51	45	41	38	alle 20	

The degree of consolidation

You can calculate time required for sag, or a sag, take place within certain period

select load: Kuorma = 50 kPa

select k/k spacing: k/k väli = 1,1 m

Sag mm	
100	
U	day
41	49
Time(days)	
200	
U	Sag
88	215

U %	Time (days) - k/k spacing, m 0,9	1	1,1	1,2	1,3	1,4
10	5	7	10	13	16	19
20	11	16	21	27	33	41
30	18	25	33	42	53	65
40	26	36	47	61	76	93
50	35	48	64	82	103	127
60	46	64	85	109	136	167
70	61	84	112	143	179	220
75	70	97	128	165	206	253
80	81	113	149	191	240	294
85	96	133	176	226	282	346
90	116	161	213	274	343	420
95	151	209	278	356	446	547
99	233	322	427	548	685	841

date	place	signature
26.5.2010		

KPO 2000	Object	Example 2 b	Nb	Espoo city training
	Computer	TLv		
	Date	25.5.2010