Utilization of industrial by-products to strengthen soft clayey and organic soils

Utilisation des sous-produits de l'industrie pour renforcer des sols tendres organiques et argileux

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ABSTRACT: Different industrial by-products have been utilized in deep stabilization works where soft clays and even peats have been reinforced. In Finland and Sweden many contracts have been carried out by using by-product based binders during the last two years.

RESUMÉ: Des sous-produits différents ont été utilisés pour renforcement profond des terres argileuses et bien marécageuses. En Finlande et en Suéde on a mené plusieurs contrats utilisant des liants des sous-produits.

1 INTRODUCTION

As a result of recent development work to create more efficient stabilizing agents, different by-products from the industry have been taken into use in deep stabilization work. The most common by-products used as a component in binders are blast furnace slag, coal fly ash, desulphuration products and gypsum.

Lohja Rudus has developed its own by-product based stabilizing agent called Lohjamix®. Under the name of Lohjamix are attached stabilizing agents, which are developed and supplied by Lohja Rudus and in which industrial by-products are utilized as components in addition to different types of cements. The Lohjamix compound consists of cement to at least 40% and the remainder consists of by-products, mainly coal fly ash and blast furnace slag.

The deep stabilization technique has been used in Sweden and Finland since the 1970's. Deep stabilization is a method in which the stabilizing agent is mixed with soft soil. The method was previously used only with clay, but nowadays also mud and even peat have been stabilized. A wider stabilization possibility is a consequence of a new block stabilization method, where a whole soil block is treated instead of only columns as before. The block stabilization method was innovated by YIT Corporation in Finland in the beginning of this decade, and has been used in several projects both in Finland and in Sweden during the last two years.

2 MATERIAL CHARACTERISTICS

In Sweden and Finland the stabilizing agents used so far are powdery materials that can be divided into three main groups: activators, like quick lime (CaO) and cement, which can be used as binders as such; latent hydraulic materials like blast furnace slag; pozzolanic materials like coal fly ash. The two latter materials need an activator to start chemical strengthening reactions.

2.1 *Activators*

Quick lime and various types of cements are activators used purely as stabilizing agents or as a 1:1 cement lime mixture.

Quick lime was only used in the early years and therefore the method was called the lime column method. Nowadays the most commonly used stabilizing agent is the 1:1 cement lime mixture.

When quick lime is added into soil it reacts with the water, and calciumhydroxide $Ca(OH)_2$ is formed. Clay minerals react with calciumhydroxide leading to a strengthening procedure. This process is called the pozzolanic reaction.

The quick lime reaction with water is described as follows:

$$100\ g\ CaO + 32\ g\ H_2O = 132\ g\ Ca(OH)_2 \quad (1)$$

When cement is added into soil it reacts with the water and, as a consequence, calcium-silica-hydrate CHS as well as calciumhydroxide $Ca(OH)_2$ are formed. CHS gel binds soil particles together which leads to increasing strength. In addition to the cementatory reactions also pozzolanic reactions occur, but only up to about 20% if compared with the same amount of pure quick lime reaction.

The cement reaction with water is described as follows:

$$100\ g\ cement + 25\ g\ H_2O = 100\ g\ CHS\ gel + 25\ g\ Ca(OH)_2 \quad (2)$$

2.2 *Latent hydraulic materials*

Blast furnace slag is a by-product of the steel manufacturing process. Its mineralogical characteristics and their reactivities vary depending on the cooling process. Quick cooling with water creates slag with latent hydraulic properties. After cooling, the slag is pulverized and is ready for use as a component in stabilizing mixtures.

Blast furnace slag must be mixed with an activator before its reactions in soil can start.

2.3 *Pozzolanic materials*

Coal fly ash is a by-product derived from burning of pulverized coal in order to generate electricity or power. Coal fly ash is removed from the flue gas stream by air pollution control devices. Coal fly ash contains mainly glass and non-combustible mineral compounds of the coal.

In Finland and Sweden the coal fly ash contains only poor amounts of CaO and therefore its function as a stabilizing agent is based on pozzolanic reactions.

Pozzolanic reactions start slowly when coal fly ash is mixed with water and $Ca(OH)_2$. When coal fly ash is mixed with cement, both cementatory and pozzolanic reactions occur. Cement is the most commonly used activator with coal fly ash in stabilizing materials.

Also other fly ashes are produced, depending on the raw material used in the plant. In Finland peat fly ash is the second common type, but it has not yet been used in binders.

2.4 *Lohjamix*

Lohja Rudus has developed its own by-product based stabilizing agent product which is called Lohjamix®. Under the name of

Lohjamix are attached stabilizing agents, which are developed and supplied by Lohja Rudus, and in which industrial by-products are utilized as components in addition to different types of cements. The Lohjamix compound contains of cement, at least 40%, the rest consisting of by-products, i.e. mainly coal fly ash and blast furnace slag.

Because of the great content of cement, the Lohjamix product can be presumed to function in the same way as a lime cement mixture. When Lohjamix is added to soil, what first happens is that cement minerals react with the water creating CSH-gel, which gives the primary strength to the stabilized soil. Then the pozzolanic or latent hydraulic by-products in Lohjamix give additional strength to the stabilized soil.

Lohjamix is a trademark for different types of stabilizing agent compounds developed, manufactured, and sold by Lohja Rudus. For now, the exact description of the content of Lohjamix, i.e. a component specification and their percentual proportions, have been kept secret but in the near future the components in Lohjamix will be made public. The proportions will, however, still remain secret.

The different Lohjamix compounds described later in the text are separated by a code after the name Lohjamix.

3 STABILIZATION TESTS AND FIELD INVESTIGATIONS

This chapter describes how stabilization tests are normally performed in practical work.

3.1 *Selecting stabilizing agent according to soil type*

The deep stabilization method has in substance been used in order to improve soft clayey soils. Recently, stabilizing of organic soils like mud and peat has also begun. The results are very promising due to new by-product based stabilizing agents and improved stabilizing technology.

On the contrary to clay, the mineral content is low in organic soils like peat and mud and therefore the strengthening often stays low when lime or lime cement is used. New stabilizing agents containing industrial by-products have proven to strengthen such organic soils extremely well. In order to find the most appropriate stabilizing agent, laboratory tests must be performed in each case.

3.2 *Stabilization test description*

Before a stabilization test is made, the soil that is meant to be stabilized must be investigated. After that some stabilizing agents are chosen (the selection is based on prior tests and on experience) as well as the amount of the binder which shall be added.

Soil and binder are mixed together properly and packed into cylinders. Ready samples are stored in a definite temperature for a definite period. Testing is accomplished by compress tests.

3.2.1 *Soil investigations*

The characterization of the soil material must include at least a definition of its water content. Furthermore grain size tests and humus content tests should be carried out. With the results from the tests mentioned above on hand, the appropriate binders can be selected for stabilization tests.

In addition to the above test results, pH and sulphate content tests are also recommended.

3.2.2 *Binder selection*

In practice, only a few binders are tested due to lack of both money and time. The binders are chosen based on previous experience. Normally conventional binders such as cement and lime cement mixtures are tested and, in addition to these, a few

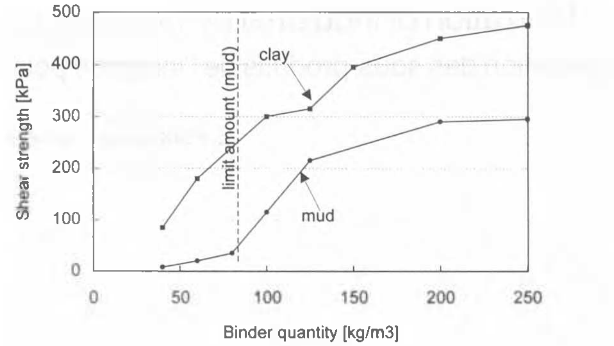

Figure 1. A typical strengthening curve for clay and mud when it agrees to the binder amount.

other compounds too.

The binder quantity added to the soil varies from 80 to 250 kg/m^3 (dry binder weight per soil volume) depending on the soil type and the designed strength degree. The bigger the binder quantity, the more organic material the soil usually contains.

Fig. 1 shows how the strength increases depending on soil type and binder quantity. It shows that organic soil needs a limit amount of binder before the strengthening process begins (in this example about 80 kg/m^3), whereas in clay, on the contrary, the strengthening curve is pretty linear with a binder amount of between 40 and 250 kg/m^3. There is also an upper limit for the binder, after which strengthening abates.

3.2.3 *Sample preparation*

When the binders and binder amount(s) have been selected, samples can be prepared.

First the soil itself must be weighed and homogenized. Then the selected proportion of the binder is added into the soil. The binder is mixed properly with the soil either by hand or with a mixer. When the material is homogenous, samples can be made.

There are different types of packing methods and various cylider sizes. Normally the samples are made manually by packing the material into cylinders in five to ten layers. The cylinder sizes vary from 43 to 68 mm in diameter and from 86 to 136 mm in height (size 1:2 in diameter and height respectively).

After packing, the stabilized clay and mud samples are stored in airproof plastic bags and kept in a temperature of +8 degrees Celsius until testing.

The stabilized peat will instead be placed in a basin in which water is added in order to prevent the samples from drying. The samples will be kept under pressure, which should correspond to the load embankment that will be built in the field after stabilization. Normally, the bank height is between 0,5 and 1,0 m. It is very important to build such a bank on the stabilized peat because in this way the superfluous water and porosity is reduced.

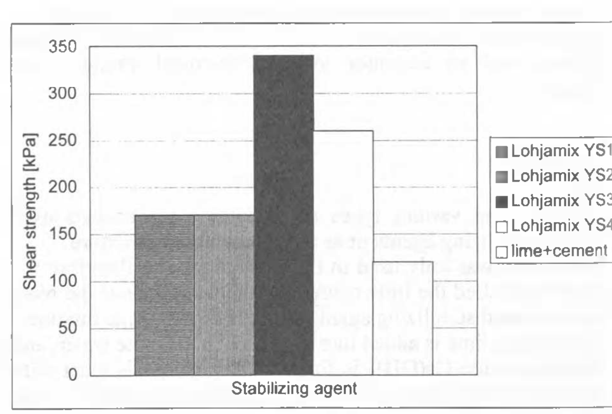

Figure 2. An example of stabilization test results. These results come from Highway 1 in Finland.

The samples are kept in the conditions described above for a certain time after which they are taken out from the cylinders. The samples are normally tested by means of a compression test through which a maximum compressive strength is received.

Fig. 2 shows results from stabilization tests, in which four Lohjamixes, coded YS1, YS2, YS3, and YS4, were compared with lime cement mixture. In this case the appropriate stabilizing agent in laboratory tests turned out to be the Lohjamix YS3.

From these tests the optimal binder is usually selected either for field tests or directly for the actual stabilization work.

3.3 *Additional tests*

Stabilization tests in laboratory conditions only do not, however, always suffice, but also field investigations must be performed. By the field tests the strengthening level of the stabilized block or column in situ is ensured. The tests are normally accomplished by column sonding.

Furthermore, the characteristics of the stabilizing agent is tested. One important thing is, that the stabilizing agent owns such a flowability, which makes the actual stabilizing work practical. Lohjamix flowabilities are confirmed by graininess tests or by specific flowability tests.

4 STABILIZATION WORKS DURING THE LAST YEARS

In Finland and in Sweden the number of stabilization contracts has clearly increased since the 70's. In Fig. 3 the accomplished stabilization amounts in both countries are shown.

The pillars of accomplished works in Finland also indicate which binder has been used. Until the year 1995 only lime and cement had been used but the results show that by-product based materials (Lohjamix) have taken their place as a stabilizing agent and their use continues to increase.

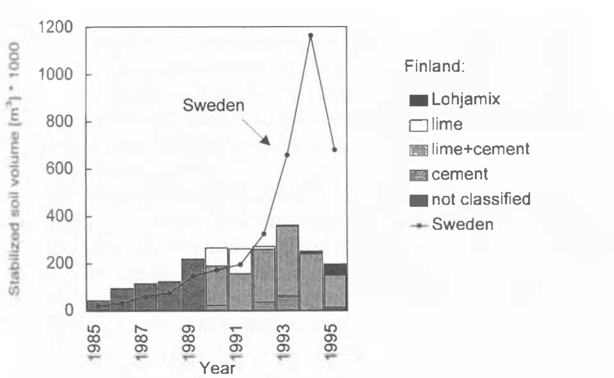

Figure 3. Column stabilization amounts in Finland and in Sweden.

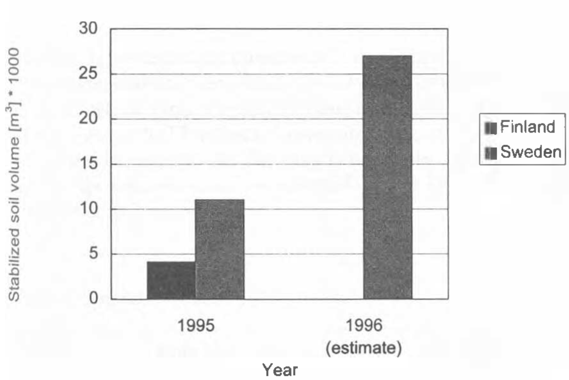

Figure 4. Block stabilization amounts in Finland and Sweden which have been carried through by using by-product based binders (Lohjamix).

year	project	Lohjamix (code and amount)
95	Highway 1, Turku	YS3, 5400 tons
95	Sundsvagen601,Ranea,Sweden	V15, 1600 tons
95	Westendway, Espoo, Finland	K2, 610 tons
95	IKEA, Espoo, Finland	KL3, 375 tons
96	Hertsby, Sipoo, Finland	V15, 1000 tons
96	Porvoo Westbeach, Finland	V15, 850 tons
96	Skyttorp, Sweden	V17, 600 tons
96	Askersund, Sweden	V17, 1600 tons
96	Skyttorp, Sweden	V17, 1100 tons
96	West pass, Espoo, Finland	K2, 600 tons
96	Enanger, Sweden	V16B, 750 tons
96	Jorn-Lidlund, Sweden	V16B, 350 tons
96	Tikkurila, Vantaa, Finland	KL1, 1800 tons

Figure 5. References of contracts where by-product based stabilizing agents (Lohjamix) have been used.

In addition to column stabilization also block stabilizations have been carried out. In Fig. 4 some projects in Finland and in Sweden are shown, which have been accomplished by using by-product based stabilizing agents (Lohjamix).

5 UTILIZING BY-PRODUCT BINDERS, CASE STUDIES

The R&D work accomplished by Lohja Rudus has led to several stabilization projects, where Lohjamix has been used successfully as a stabilizing agent. Fig. 5 shows some prominent stabilization contracts in which by-product based stabilizing agents (Lohjamix) have been utilized.

5.1 *Column stabilization along Highway 1 in western Finland*

The most remarkable contract in which Lohjamix was used in 1995 was along Highway 1 in western Finland, the stabilization work of which was going on from April to August 1995. The project included one road section which was carried out by stabilizing clayey soil with Lohjamix columns instead of conventional lime cement columns (see the stabilization test results in Fig. 2). Lohjamix made it possible to reduce the total stabilizing agent amount by 20% in comparison with the originally designed amount. The total amount of stabilizing agent in this section came up to 5'500 tons corresponding to about 138'000 column metres.

The commissioner was the Finnish National Road Administration/Highway 1 Project. The stabilization contractor was Sillanpaa and the stabilizing agent Lohjamix YS3 was delivered by Lohja Rudus.

Figure 6. Column stabilization equipment along Highway 1 in Finland.

As a whole the project met with success. The contractor was pleased with the stabilizing agent's characteristics and the commissioner with the completed stabilization work.

Fig. 6 shows the column stabilization equipment at work.

5.2 *Block stabilizations in Sweden*

Block stabilization, unlike column stabilization, strengthens the whole soil volume instead of columns only. This method and the new by-product based stabilizing agents have made it possible to stabilize organic soils and even peat into solid blocks.

5.2.1 *Sundsvagen 601 in Ranea in northern Sweden*

In addition to a few block stabilization projects made in Finland, the block stabilization method was also applied in order to strengthen peat in northern Sweden in the summer 1995. The project was part of a road construction work of Highway 601 Sundsvagen near Lulea.

The commissioner was the Swedish National Road Administration Region Norr and the block stabilization contractor was YIT Corporation.

The total length of the road under construction was 5 km, of which 700 m was located on a peat area. This section was decided to be stabilized with Lohjamix down to a depth of 2 metres.

The total stabilization volume was about 10'000 cum and it took 1'600 tons of Lohjamix V15 stabilizing agent. The supplier of Lohjamix V15 was Lohja Rudus.

The hardening reactions in the peat began directly after mixing and only some hours later the aggregates layer could be built on top of the stabilized block. The height of the preconsolidation bank was about 0,5 m, which sufficed to compress the stabilized peat block as designed.

In comparison with the traditional soil replacement method, in this case no surplus masses were produced, but they were exploited by means of stabilization instead. This was a very important benefit in Ranea where nature is very sensitive and soil replacement including transportation could have caused inconveniences.

Fig. 7 shows block stabilization under construction.

5.2.2 *Block stabilization under railway embankments*

In addition to stabilization work under road embankments also a few block stabilization projects have been carried through under railway embankments in Sweden.

These projects have successfully been accomplished and the railway in Skyttorp in eastern Sweden is already in use.

As a consequence of these projects the interest of block stabilization has increased and many projects will be under design in the near future.

Figure 7. Block stabilization in Ranea in northern Sweden.

6 CONCLUSIONS

1. Utilizing industrial by-prducts as a component in stabilizing agent compounds with activators has shown great opportunities as to stabilization of clays and organic soils.
2. When utilizing industrial by-products, the loading of landfills decreases and at the same time less energy is spent because the activator amount can be deducted.
3. By-product based stabilizing agents have proven very effective in stabilizing organic soils. Formerly these soils have been excavated and transported to landfills. The new technology has had the effect that the quantity of surplus masses have decreased immensely. And in addition to this, the need of transportation has diminished.

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