Stabilization of sulphide soil with lime-cement columns by the river Keräsjoki

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ABSTRACT

Stabilization with lime-cement mixtures in loose fine sediments has long been an accepted and well-used method in southern and central Sweden. Along the coast by the Gulf of Bothnia the soil consists largely of fine sediments by sulphide soil. Lime-cement stabilization of sulphide soil has a reputation in Sweden to be fraught with risks due to the sulphide soil material properties. The rumour was created in part by a landslide, in the late 90’s, in lime-cement stabilized sulphide soil during the construction of the road E4 in the southern parts of the coastal area along the Gulf of Bothnia. The sulphide soil is in some cases considered as hazardous waste, according to Swedish environmental rules, which makes the commonly occurring soil reinforcement method excavation and refill economically unreasonable because of the disposal costs of hazardous waste. The result of both the mixing experiment and the field studies show a clear increasing of the shear strength in the sulphide soil. Detailed design is ongoing and the construction work is planned to the summer of 2017. The preconditions for a successful project are big which gives the already well-known technique is great potential even in sulphide soil in the future. The technique can be very useful in case of any major infrastructure projects along the major parts of the coastal area along the Gulf of Bothnia where up to 20 meters thick sediments with sulphide are common.

1 INTRODUCTION

Commissioned by the Swedish Transport Administration has Tyrens AB been working with risk reduction actions for the road 729 in the village Keräsjoki by the river Keräsjoki in the municipality of Haparanda. Parallel with the risk reduction project a research and development project financed by Swedish transport Administration on the same site performed by Tyrens AB. The target for the R & D project is to obtain a substantial increase in knowledge in deep stabilization with lime-cement mixtures in sulphide soil and in the extension design a solution for the road section in the risk reductions project.

1.1 Background

Soil stabilization with lime-cement mixtures in loose fine sediment has long been a well-used method in southern and central of Sweden. Along the coast by the Gulf of Bothnia, from Gävle in the south up to Haparanda by the Finnish border, does the soil consists of loose fine sediments by sulphide and sulphide-bearing soil. In some places the sulphide is varved. It should also be clarified that the sulphide soils material characteristics and layering varies along its long coastline. Stabilization with lime-cement columns in sulphide soil has a rumor to be fraught with risks due to the sulphide soil material properties. The rumor was created in part by a landslide, in the late 90’s, in lime-cement stabilized sulphide soil during the construction of the road E4 in
the southern parts of the coastal area along the Gulf of Bothnia (Andersson & Norrman, 2004).

The sulphide soil is in some cases considered as hazardous waste, according to Swedish environmental rules, which makes the commonly occurring soil reinforcement method excavation and refill economically unreasonable because of the disposal costs of hazardous waste.

Lime-Cement reinforcement would be a good complement and also very likely to be price competitive compared with the traditional use, along the Gulf of Bothnia, of the grandfathered soil reinforcement method with settlement reduction wooden piles. The wooden piles are often used in sulphide soil with a thickness of 3 to 10 meters.

2 KERÄSJOKI

The area around the location has during several years been having stability problems. The soil in the area consists of a sulphide soil and to ensure the safety of the road has an idea with deep stabilization has been drawn up. To gain knowledge and prove that the method is possible, in those soil conditions, has a test field been established in the summer of 2014 for studies of the stabilization effects.

2.1 Orientation

In the northern most parts of the Gulf of Bothnia about 10 kilometres from the Finnish border flows the river Keräsjoki out in the sea, see (Figure 1). The river Keräsjoki, which has its main catchment area of wetland areas in the Municipality of Haparanda, flows through the village by the same name and extends parallel with the road 729 in southbound direction by the problem location.

2.2 History

The Swedish Transport Administration let Tyréns AB carry out a stability investigation as early as 2011 in the area. The object in question consists of a 400 meter long straight stretch which is wedged between some houses and the river. During the stability investigation in 2011 did the landslide activity increase in the river embankment along a limited distance of the straight stretch. It resulted in a landslide in the slope separating the river and the road where the edge of the landslide ended up close to the road. The threatened part of the road were secured due to a 70 meter long permanent tied back sheet pile wall to maintain stability against successively backward moving landslides, see (Figure 2). For the other parts of the road the Swedish Transport Administration decided to keep these under surveillance.

A stretch in area was identified to have clear signs of landslide activity in the roadside down toward the river during late autumn 2013. The investigation took at the back and further stability calculations showed a poor stability along the current route. To secure the stretch so were several proposals discussed to find an economic and technical feasible solution. As the extent of this phase was over 300 meters long and the more, from a northernmost part of Sweden perspective, "ordinary" slope stabilization actions were considered unreasonable within the economic and technical framework so suggested Tyréns to deep stabilize the route with an L/C-column solution. Initially was a type design performed to see the approximate reinforcement distribution and to ensure stability problems were manageable. Different binder
variants and mixing amounts were first studied in the laboratory and later on in a test field in Keräsjoki.

2.3 Geotechnical conditions

The soil in the area consists of a thin layer of humus soil above most nearly 0.5 meter sand. The sand is stored under the 0.5 to 1.5 meter thick silt which in turn is stored under a 9.0 to 12.0 meter thick layer of clayey sulphide silt and silty sulphide clay which is resting on a silty sand till.

The sulphide soil along the stretch is relatively homogeneous when no clearly deviant layer is observed, however the clay content increases with depth. Superficial is the sulphide soil a clayey sulphide silt which then merges with the depth in a silty sulphide clay.

![Undrained shear strength Keräsjoki](image)

**Figure 3.** Undrained shear strength Keräsjoki

In the geotechnical field investigations has the undrained shear strength in the soil been determined by the in-situ methods, vane test and cone penetration test. In addition to soil characteristics has the geohydrological characteristics also been studied through several pore pressure sensors that are installed along the stretch and where the pressure levels have been observed for a long time. Soil laboratory work has consisted of routine testing, CRS trials, direct shear test, as well as a more detailed analysis of the water content at a point. In addition to soil the laboratory work has chemical analyzes also been performed to investigate the iron and sulfur contents and total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC).

The chemical analysis primary purpose has been to create the possibility to retroactively together with any future similar projects been able to compare and see if the levels affecting the stabilization effect. Soil laboratory work together with the in-situ methods has given a broad picture of the soil properties, especially for the undrained shear strength of the soil as seen (Figure 3).

3 TEST FIELD

A test field was established to investigate the soil stabilization project but to be able to build that some laboratory testing had to been done for some different mixtures.

3.1 Unconfined compression test

To find suitable mixing variants for the test field were mixing tests and unconfined compression test on the different mixtures during the spring of 2014. The goal, to find one or several mixtures that worked in laboratory environment, contributed to several varieties tested. At the mixing experiments has both mixing amount and proportion of cement been varied. In addition to the lime-cement mixtures has some mixtures with merit-cement also been performed and tested. Merit is a residual product of ground freshwater granulated blast furnace slag. Previous studies in the stabilization of sulphide soil have shown that increased mixing amount and a higher percentage of cement, compared to more conventional fine sediment soils, can give a good strength increase (Andersson & Norrman, 2004).

The sulphide soil was divided in three different soil types to capture the variations that the soil has by depth. The soil on which the mixing experiments are performed on is taken up by using a screw sampler in two different bore holes. To avoid oxidation were the soil packed, in 0.2 meter interval down to the till, with dual sampling bags were the inner was diffusion tight.

Soil type 1 is soil from only one bore hole on the depth between 1.5 meters to 2.7 meters beneath ground level. This soil was partly a sulphate soil which is an oxidized sulphide soil and made the interval differed from the other parts. For the remaining parts of the sulphide soil has the soil from the two bore holes been merged and divided in two soil types, soil type 2 and soil type 3. Soil type 2 is the soil between 2.7 meters and 6.0 meters beneath the surface while soil type 3 is oriented between 6.0 meters to 11.0 meters under the ground level.
In total, nine different mixes have been performed where the blending amount varied between 110 kg/m$^3$ to 190 kg/m$^3$. The proportion of cement has been varied between 85% and 70%, and as mentioned earlier, also has mixtures with merit been performed to complement the lime.

All of the different mixtures have been performed as duplicate samples to capture variations in the mixing. On the mixed samples have then uniaxial compression tests been performed at four different time points, excluding soil type 1 that only have been tested three times due to lack of amount of soil, to see the strength growth with time. The mixing samples are tested at 7, 14, 28 and 91 days of hardening were the 14 day test isn’t performed for soil type 1. The result from the unconfined compression test could be seen in (Figure 4).

![Figure 4. Unconfined compression test result](image)

### 3.2 Test columns

With support from the unconfined compression tests the test field were established in the summer of 2014. The test field is located in direct connection to the planned reinforcement straight stretch on a surface situated between the threatened road and the river. A total amount of 44 test columns were installed in four rows of eleven columns in each row. Three of the rows consist of recipes from the mixing experiments and the fourth row wasn’t tested in the laboratory before installation. All variants are lime-cement mixtures, the variants are:

- 30/70 L/C 110 kg/m$^3$
- 30/70 L/C 150 kg/m$^3$
- 15/85 L/C 110 kg/m$^3$
- 15/85 L/C 150 kg/m$^3$

The test column area is a relative flat surface. From the outer row, seen from the road, is land sloping slightly down towards the river. The columns are installed in natural land without any work bed. Before the installation of the columns begun was four stations with inclinometers and three stations with pore pressure gauges, two pore pressure measurement levels in each section, that have been monitored automatically. The station was installed in a section between the test field and the river. The monitoring devices were installed to show if the installation in the current could result in increased landslide activity in the slope and, if possible, determine whether any measurable mass displacement occurred.

### 3.3 Traditional penetration testing

To investigate the growth of strength in the field have 40 columns of the test columns been control sounded with a pre-drilled traditional penetration test with a cone penetration test probe inside, see Figure 5. Two different widths of the traditional penetration probe have been used, named small and big wing, with widths of 250 mm and 500 mm. The choice of wing size is done based on the pre-drilling. The pre-drilling is performed with a regular soil/rock probe.

![Figure 5. Large traditional penetration testing probe, 500 mm](image)

Control sounding is done at three time steps were 20 columns is controlled at each time. The first 20
pieces are tested at seven day and the remaining 20 pieces has been tested at 28 days. The last time step was done at 91 days that are performed in the same point as the seven day test. To ensure that the seven days and 91 days test would affect each other as little as possible was soundings performed across each other over the cross section.

Based on the field tests in each time step and mixing type has a chosen strength profile been produced, it could be seen in (Figure 6). The shear strength is generally lower towards the surface. Some of the profiles show a reduced strength growth with depth. This may partly be due to a poorer hardening of the deep layers of the soil but is also a chance that it is that the penetration testing probe that drifted out the column to depths because of the high resistance.

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3.4 Core sampling

In connection with the control sounding at 28 days was a test made to try to take core samples from three of the columns. The columns that were selected had different recipes for the mixture 30/70 L/C and 110 kg/m$^3$ was no sampling performed. Sampling was performed with the ambition to bring up samples of such quality that triaxial test could be performed. The triaxial tests would be helpful to get another input on the shear strength in the columns and to calibrate traditional penetration testing.

Unfortunately no samples with sufficient quality were able to take up. The core sampling was performed with a system with three tubes in which the innermost was dividable. Photo documentation and material evaluation of sampling is performed on the core samples that were able to get up. The soil has a clear mixing and is very granular and porous. It lacks bitwise completely cohesive. Obvious oxidation of the soil seen superficially in the sample, the core still has a clear sulphide soil colour, see (Figure 7). Bitwise were even bigger intact parts of a core able to distinguish. The soil and the L/C-mix have been mixed up well within certain depth intervals.

3.5 Excavation of test columns

To further verify whether it really had been created columns in sulphide soil so was a column forward of each recipe excavated in connection with the 91-day control probing. Excavation was performed approximately to 4.0 m below surface where the excavator capacity was limiting. All cross-sections that were excavated out showed a clear pillar structure with altered characteristics, see (Figure 8).

4 RESULT AND DISCUSSION

The primary goal of the risk reduction project, slope stabilization with lime-cement panels, has been the basis for the assessment of the tests and evaluations performed. When design of slope stabilization is performed using ground improvement with so-called soft columns. Soft columns characteristic shear strength at design should be 100 kPa according to the demand of the Swedish Transport administration. The calculation model in design is based on the rein-
forced soil interacts with the surrounding soil. Interaction between the columns and the surrounding soil can be adopted at soft and semi-hard columns (Larsson, 2006). Since it requires a greater proportion of cement and a higher amount of mixture than in ordinary clay soils to obtain a strength development, there is also the risk that the column becomes very rigid once it hardens and therefore interacts less with the surrounding soil.

All the mixing experiments show on shear strengths that exceed 100 kPa. The spread in results between of the duplicate samples indicates a good mixing in the lab and that soil volumes had similar characteristics. The decision to proceed with three of the recipes and supplement with an unproven variant and set up a test field was basically a necessity in order to be able to move forward with the design and detailed design of the slope stabilization of the stretch.

The field tests all point to that this proven soil improvement method also seriously will be able to use in sulphide soils similar to the one that is found in the area. The shear strengths in the control soundings measured between 400 and 600 kPa indicating good strength development. It should however be cautious on these numbers when the control method is relatively rough compared with other field methods for the evaluation of shear strength.

The penetration test shows, as it been mentioned before, on a poorer strength development by depth. The soil intervals were the shear strength decreases is in the same range as the deepest soil type, soil type 3, from the mixing experiments. Soil type 3 compared to soil type 2 shows the same trend that the shear strength decreases with depth as in the field measurements. The reason for this is not easy to tell but more work is needed on the sulphide soils properties impact on the strength development.

The requirement of 100 kPa should nevertheless be regarded as fulfilled. However, they demonstrate relatively rigid columns which would mean that it is difficult to count on the interaction between the columns and the surrounding soil. The major challenge in the selection of recipes in slope stability project is to choose a recipe that you can say with certainty that it hardens while creating columns that are within the scope of soft and semi-hard column.

Both core sampling and the excavation confirm that the stabilization of the soil worked. Lime and cement mixture with the sulphide soil has created a material without cohesive properties.

For the upcoming sharp stabilization project in Keräsjoki the hope is great that the result will successful. A successful result for actions with like in this case L/C-panels would be at door opener for deep stabilization at future large infrastructure projects e.g. North Bothnia Line. The solution would be a welcome addition at stretches with settlement problems.

With more ways to build on the sulphide soil, a larger object and project specific optimization could be done. Freedom of choice will involve more technical feasible and in some cases even more economically advantageous solutions.

REFERENCES