REUSE OF EXCAVATED LIME AND CEMENT STABILIZED SOFT AND QUICK CLAY

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ABSTRACT

Lime and cement stabilization is a widely used technique for stabilizing sensitive clay. By mixing binder with clay, the soil shall increase its strength and stability. Upon excavation, lime-cement columns are mixed with the surrounding non-stabilized materials that, after being disturbed, have weak strength and low stability. Such mixed materials are often disposed in landfills as inert waste.

The possibility of reuse produces a valorization of these materials and reduces the need of disposal areas. This research is part of the project "GEOreCIRC – Georesources in a circular economy" at the Norwegian Geotechnical Institute. The project, financed by the Research Council of Norway, aims to facilitate reuse and utilization of various residual resources in an environmentally satisfactory way.

A number of laboratory tests were carried out to determine the geotechnical parameters of the mixed materials of clay and lime-cement stabilized clay. Both soft and quick clay were included, as these are the most commonly soil materials stabilized with lime and cement.

The laboratory tests results show that mixed materials achieve good values in terms of strength, plasticity, compressibility and hydraulic conductivity.

The tests results show that the mixed materials changes from soft and weak remoulded clay to a material with increased shear strength. The resulting material is compactable and it is possible to spread it out in constructive layers. The material shows good potential for being used in road embankments and landscaping, if it is well blended and processed. It can also serve as a geological barrier and as an impermeable layer in landfills for inert wastes.

The use of the mixed materials as the impermeable layer in landfills for ordinary or hazardous waste is also possible. However, this requires a hydraulic conductivity lower than 10^{-9} m/s. Test results from this study show uneven hydraulic conductivity values in the order of magnitude of 10^{-9} m/s, being not conclusive.

Higher hydraulic conductivity values than those in this study were obtained on samples from a test site with earthworks on similar mixed materials of clay and lime-cement stabilized clay. This suggests that construction techniques play an important part to reach the hydraulic conductivity required.

KEYWORDS

Soils stabilization; lime-cement stabilization; stabilized clay; ground improvement; lime-cement columns; stabilized ground

INTRODUCTION

Many construction projects in Norway face major challenges as soils composed by quick clay or soft clay can be very challenging to build in. Structural stability must be ensured adopting good solutions. Lime and cement stabilization of clay is an effective method implemented in Norway and other countries since the mid-1970's. In this process, piles are formed mixing small quantities of binder in the soil. The chemical reaction that occurs

between clay and binder leads to an increase in the strength of the soil, improving stability and bearing capacity. The material firmness to attain depends on several parameters, being the type of binder, amount of admixture and curing time among the most significant (Larsson et al., 2005). Therefore, it is necessary to characterize the geotechnical properties of the mass to stabilize. Water content (*w*) is particularly important, as the firmness will often decrease if *w* is too high.
In the case of cut & cover tunnels or excavations, parts of the stabilized masses are excavated and driven to landfills for inert masses, involving important costs. These masses, considered as surplus masses, can often behave as low viscous liquids and have not specific uses.
The possibility of reuse, producing a valorization of these materials and reducing the need of disposal areas, is the aim of this study. The focus is the reuse of the stabilized masses in landfills, while considering other possible uses. This research is part of the project "GEOreCIRC – Georesources in a circular economy" at the NGI (Norwegian Geotechnical Institute). The project, financed by the Research Council of Norway, aims to facilitate reuse and utilization of various residual resources in an environmentally satisfactory way.
This paper present a laboratory test program performed on two types of clay, soft clay and quick clay. Clays were stabilized with equal parts of lime and cement. Laboratory results of tests performed on the cured mixtures are presented and compared.
The following sections summarized the testing program and some obtained results. A brief discussion and preliminary conclusions follow, and some comments on future work close.

1. TESTING PROGRAM

1.1. Materials

The primary materials used on the project were clay and binder.
The types of clay were soft clay and quick clay. The soft clay is from the New National Museum construction in Oslo, Norway. The quick clay is from a quick clay slide near route 171; about 35 km Nord-East of Oslo, Norway.
The types of binder used were lime and cement. The type of lime used was CKD (Cement Kiln Dust). CKD consists primarily of reactive minerals, i.e. calcium carbonate and silicon dioxide. This binder is somewhat similar to lime and it proposed use is for stabilizing grounds and clay-stabilizing columns. The type of cement used was commercial Portland cement.
Tested materials were obtained by adding binder (lime and cement in equal parts) to quick clay for the "K" mixture and to soft clay for the "B" mixture. The weight proportion for both mixtures was about 3% of lime and 3% of cement on the natural weight of clay. After one (1) month of curing time, an amount of quick clay was added to the K mixture in two different proportions typically observed in practice, high (35%) and low (25%) coverage. An amount of soft clay was added to the B mixture. The new mixtures were cured for two (2) additional months. Table 1 resume the prepared mixtures and time of curing for the materials to be tested.

Table 1. Description of tested materials.

Name	week 0	week 4	week 12
K-35	Mix of lime and cement with quick clay in test columns	Columns of week 0 mixed with quick clay Curing time 1 month	Mix of column of week 4 **35%** with quick clay 65% Curing time 3 months
K-25	Mix of lime and cement with quick clay in test columns	Columns of week 0 mixed with quick clay Curing time 1 month	Mix of column of week 4 **25%** with quick clay 75% Curing time 3 months
B-35	Mix of lime and cement with soft clay in test columns	Columns of week 0 mixed with soft clay Curing time 1 month	Mix of column of week 4 **35%** with quick clay 65% Curing time 3 months

The obtained materials after 3 months have a proportion of binder of about 2% for K-35 and B-35, and a proportion of about 1.5% of binder for K-25, compared with the proportion of about 6% of binder for the initial mixtures (being cured 1 month).

1.2. Laboratory testing program

Extensive laboratory work was carried out to investigate the properties of the prepared mixture materials as well as the starting mix materials. Laboratory tests have taken place at different laboratories: NTNU (Norwegian University of Science and Technology), NGI (Norwegian Geotechnical Institute), NGU (Geological Survey of Norway) and NOAH (environmental company).
As part of the testing program of the project, some of the laboratory tests and analyses performed were water content, plasticity index, fall cone test, grain size distribution, unconfined compression test, standard Proctor compaction test, hydraulic conductivity, titration, XRF (X-Ray Fluorescence) spectrometry, XRD (X-Ray Diffraction) analysis and SEM (Scanning Electron Microscopy).

2. LABORATORY TEST RESULTS

In this section, an overview of the most relevant laboratory test results is presented together with a summary interpretation. Detailed information of these test results can be found in Kristensen (2017).
All plasticity tests results have shown I_p values from 17.5 to 23.4 being in a range of medium plasticity. The corresponding water contents measured were w_p (%) from 33.2 to 39.1 and w_L (%) from 54.1 to 58.1.
Grain size distribution through hydrometer analyses shows that initial mixtures with binder (after 4 weeks) have a higher proportion of coarse particles than the pure clay and the final mixtures. This is due to the binder effect, producing particle agglomeration (Åhnberg, 2006). These mixtures tend to classify more like silts than like clays.
Peak shear strength (S_u) from unconfined compression tests were obtained on mixtures cured 4 weeks and 12 weeks (see Table 1). K-35 shows the highest shear strength of the three materials both before (S_u = 181 kPa) and after (S_u = 76 kPa) being mixed with pure clay. The difference in strength is about 2 times higher for K-35 compared to B-35 after three months of curing time. After mixing with pure clay, K-25 (S_u = 52 kPa) shows a greater S_u than B-35 (S_u = 34 kPa), although lower than K-35. K-25 shows axial strains (ε = 18%) about 15% larger than in the other mixtures. B-35 shows the lowest shear strength of the tested materials.
Hydraulic conductivity tests were done on two of the materials into analysis K-35 and B-35 (see Table 1). Dry crust clay and the clay in provenance from the New National Museum used on the B mixtures were also tested.
Figure 1 shows the hydraulic conductivity values (k) for the test results obtained at different vertical pressures (p).

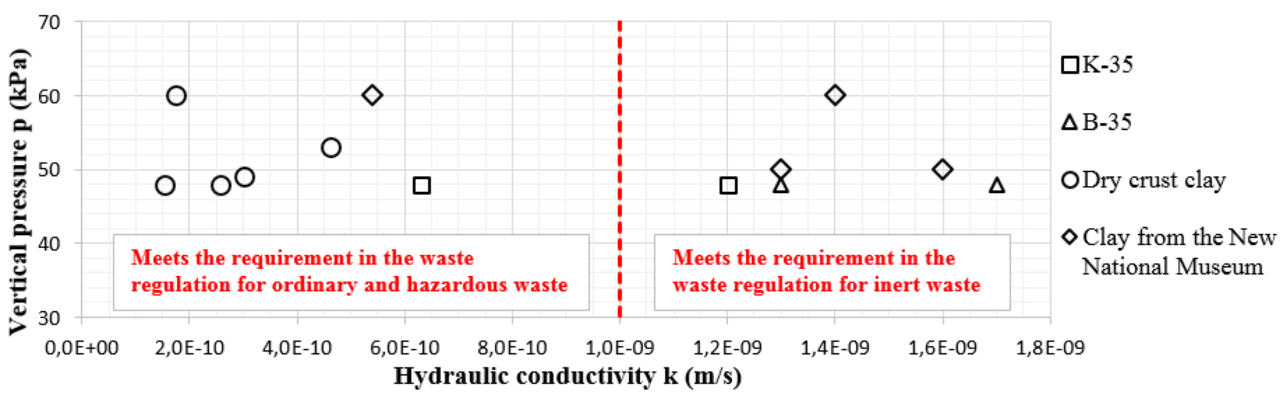

Figure 1. Hydraulic conductivity (k) test results for materials tested at different vertical pressures (p).

The vertical pressure adopted represents about 2 to 3 meters of toping materials in a landfill cover. In Figure 1, the vertical red dotted line denotes the highest k accepted for a material that meets the requirement in the waste regulation to confine ordinary and hazardous waste. The tested dry crust clay with values of $k < 5 \cdot 10^{-10}$ m/s meets this requirement. One specimen from the New National Museum and other of K-35 also meets the requirements. The other specimens tested have values of k varying from $1.2 \cdot 10^{-9}$ m/s to $1.7 \cdot 10^{-9}$ m/s, not meeting this requirement. However, they meet the requirement of the waste regulation for inert waste.

3. DISCUSSION

Table 2 shows an overview of some of the requirements for a material to be used as top sealant in landfill for hazardous waste and whether the materials on the actual study meet it. The criteria are based on NGI experience on the necessary density and clay content to achieve low hydraulic conductivity (Baardvik et al., 2014).

Table 2. Some requirements and assessment of compliance for mineral barriers in landfills for hazardous waste.

Parameter	Criteria	Material		
		K-35	B-35	K-25
Clay content	> 30%	No	Yes	Yes
Soil density γ	> 2000 kg/m^3	No	Not tested	No
Hydraulic conductivity *k*	$\leq 1 \cdot 10^{-9}$ m/s	Yes	No	Not tested

The materials tested can serve as a geological barrier and as an impermeable layer in landfills for inert wastes. For the use on landfill of ordinary and hazardous waste it requires *k* lower than 10^{-9} m/s. The test results show uneven *k* with values varying from $1.7 \cdot 10^{-9}$ m/s to $6.3 \cdot 10^{-10}$ m/s.

A previous study (Okkenhaug and Pabst, 2016) also shows tests results on similar materials of low clay content and *k* values above and below 10^{-9} m/s, the required minimum value in the waste regulation. This restrains the use of the material as landfills top seal. However, the materials of this previous study are likely to be used as bottom seal in landfills for ordinary and inert waste, as test results show good workability, low hydraulic conductivity and compressibility. At bottom seal in landfills, the material shall not be exposed to dry-wet cycles and freeze-thaw cycles, lowering the risk of shrinkage. This previous study also suggests that construction work have to be well planned and controlled to reach required *k* values.

In the present study, the strength parameters from test results show an improvement in the material from being natural clay with low strength (S_u < 20 to 25 kPa) to a material with potential use in construction (S_u > 40 to 50 kPa). This increases the ability to use the admixed materials in road fills, noise barriers, or other applications.

Quick clay is a material not exposed to oxygen in natural conditions, remaining in a chemically reduce condition. In contact with air, quick clay oxidize and the properties of the material change (Løken, 1968; Lessard and Mitchell, 1985). Quick clay can be in contact with air in the process of mixing with binder. The oxidizing process in the quick clay can also be affected by the presence of the binder itself (Løken, 1968).

4. CONCLUSIONS

Based on the test results obtained, it can be concluded that the materials show a clear potential for reuse on landfill covers or bottom seal in landfills and other applications. The geotechnical properties of tested mixtures show all over, good strength parameters with two of the mixture materials achieving S_u values of more than 50 kPa, workability with I_p values from 17.5 to 23.4 and w_p (%) values from 33.2 to 39.1, and low hydraulic conductivity (*k*) with values in the order of magnitude of 10^{-9} m/s.

The materials tested can serve as a geological barrier and as an impermeable layer in landfills for inert wastes. The test results show irregular *k* values varying from $1.7 \cdot 10^{-9}$ m/s to $6.3 \cdot 10^{-10}$ m/s and then mixtures need to improve *k* for being used for landfill of ordinary and hazardous waste as this requires *k* lower than 10^{-9} m/s.

In order to improve the hydraulic conductivity, quality mechanical compaction during construction has been particularly identified as important. This aspect has also being pointed out in previous studies (Larsson et al., 2005; Okkenhaug and Pabst, 2016). There is an interest in evaluating the long-term behaviour of materials in terms of structural resistance and reduction of hydraulic conductivity related with consolidation and curing. Tests with small quantities of other types of additives (Li et al., 2015) and adjusting binder quantities admixed (Åhnberg, 2006) is a necessity for each clay material to be reused, taking into account the application.

Large-scale field tests should be done to investigate how the materials behave during construction and compaction of waste covers, as well as, for other possible applications (e.g. stabilized columns, roads fill, etc.)

5. FUTURE WORK

"GEOreCIRC – Georesources in a circular economy" project of the NGI (Norwegian Geotechnical Institute), financed by the Research Council of Norway, and having as a main objective to facilitate reuse and utilization of various residual resources in an environmentally satisfactory way is ongoing.

A detailed testing program in preparation takes into account test results and preliminary conclusions of the actual study. The testing program includes freeze/thaw and dry/wet cycles tests on similar mixture materials than those presented in this paper. Consolidation tests and large-scale field tests should also be included.

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