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THE USE OF DIFFERENT ADDITIVES IN DEEP STABILIZATION OF SOFT SOILS

L'USAGE DE DIFFERENTS ADDITIFS POUR LA STABILISATION PROFONDE DES SOLS MOLLES

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SYNOPSIS: The use of deep stabilization with the lime column method has increased substantially during recent years. The method is mainly used in infrastructure projects on soft clay deposits, but there is a growing use also in other applications.

Several research projects have been carried out in order to extend the range of soils that can be stabilized and to improve the properties of the columns. In these projects, the effect of quick lime, cement and also mixtures of lime and cement have been studied. The soils studied range from peat and gyttja to different types of soft clays and clayey silt. The testing programme mainly consists of laboratory tests over a period of up to one year after mixing, but field tests have also been performed.

The paper briefly describes the use of deep stabilization in Sweden, and results from a current research project concerning the effects of the various additives in different types of soft soils are presented.

INTRODUCTION

Deep stabilization with the lime column method, mainly of soft clays, has been increasingly used in Sweden for almost twenty years. The demand for the method has brought about an expanding market for contractors and a further development in machinery and installation techniques, especially during the last 5-year period. Fig. 1 shows the increase in production in Sweden, as well as the tendency for an increasing use of columns with larger diameters than the preceding standard 0.5 m.

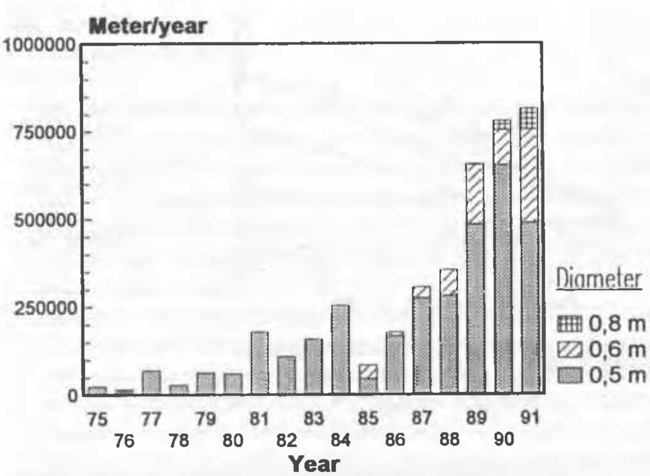

Fig. 1. Deep stabilization in Sweden 1975 - 1991.

The method has to a large extent been used for reduction of settlements and improvement of stability in connection with construction of new roads and railroads. This has especially been the case at the beginning of the 90s, when there has been a considerable increase in infrastructure investments in Sweden. Other areas of increasing application are improvement of soils under grounds and streets that are to be filled up to higher levels and for foundations of lighter buildings and bridges. The method is also used for stabilization of trenches for pipes and other excavations, stabilization of natural slopes and reduction of vibrations. Fig. 2.

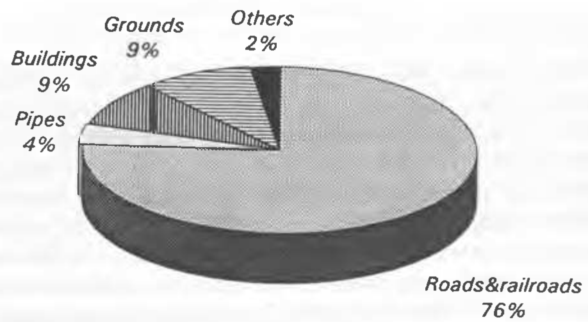

Fig. 2. Mean distribution of deep stabilization applications in Sweden during 1990 - 1991.

During the first ten years, the only stabilizing agent used was lime. Only quick lime and not slaked lime has been used, since the slaking entails a dryer product and an increased temperature in the columns which will help to speed up the hardening process. Later experience shows, however, that cement can have about the same improving effect in many clays and in silty soils. Especially in organic soils, it is essential to use a large proportion of cement. As a result, there has been an increasing use of cement alone or, as is now the dominating method, in combination with quick lime. Fig. 3.

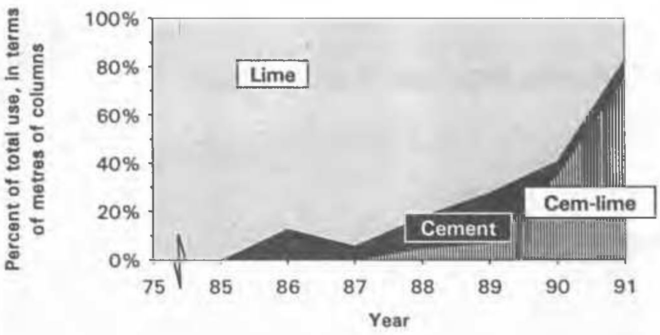

Fig. 3. Distribution of stabilizing agents used for deep stabilization in Sweden.

Present research and development activities in Sweden comprise several different subjects, such as properties of columns, installation equipment, diameter of the columns, application of the method, control and design methods. The use of cement instead of, or in combination with, lime has made it necessary to use an improved mixing technique and obtain a more homogeneous material. The ability to make use of columns with considerably higher strength than before has also emphasized the need for more diversified design methods, allowing for varying degrees of soil-column interaction in different applications. At the Swedish Geotechnical Institute (SGI), research projects include investigations of the effect of different stabilizing agents, as well as monitoring and extensive field tests to improve the method of settlement calculation. Research is also in progress concerning methods of testing and determining the properties of the columns.

CURRENT RESEARCH PROJECT CONCERNING THE USE OF CEMENT AND CEMENT-LIME

General Scope

In 1990, a research project was started to study the effect of different stabilizing agents in different types of soft soils. The stabilizing agents used were four different types of cement, four different mixes of cement and quick lime and also quick lime alone. Mixing of the stabilizing agent and the soil as well as testing, were performed in the laboratory. Different curing temperatures were used. Furthermore, the adiabatic temperature rise in samples due to the chemical reactions was measured for each stabilizing agent and soil. Testing has been performed at time intervals up to 270 days after mixing. The samples have been tested in regard to unconfined compression strength, undrained and drained shear strength by direct simple shear tests and triaxial tests, compression modulus and permeability. Theoretical and experimental studies of the chemical reactions are also included in the project.

The soils studied range from clayey silt through different types of clay, organic clay, clayey gyttja, gyttja and peat. The soils are normally consolidated and soft, with an undrained shear strength of 5-30 kPa.

Field tests are being performed at two test sites, where columns have been installed in clay and in clayey gyttja. The tests comprise measurements of temperature, permeability and shear strength.

The project is being performed in co-operation between Lime Column Markteknik AB, Cementa AB and the Swedish Geotechnical Institute. A research grant has also been provided by the Swedish Council for Building Research.

Test Results

Type of cement

Four types of Portland cement were used, Standard cement (Std), a more rapidly hardening cement (SH cement), a sulphate resistant cement (Anläggningscement) and a cement without gypsum (Klinkercement) which has a shorter setting time.

The strength increase when using Anläggningscement and Klinkercement was somewhat less in the first three studied soils than that of Standard cement and SH cement. Also because of their higher price, Anläggningscement and Klinkercement were considered generally less suitable for soil stabilization. The SH cement gave a more rapid and in most cases higher shear strength than Standard cement. In consequence, SH cement was used for the later part of the laboratory tests and also for the field tests.

Proportions of cement and quick lime

For Standard cement different proportions of cement and quick lime were studied in three soils. The proportions of cement/lime in per cent by weight were 90/10, 75/25, 50/50 and 25/75. Pure cement and pure quick lime were also used. The total amount corresponded to 6 - 16 % of the dry weight of soil. The results are shown in Fig. 4.

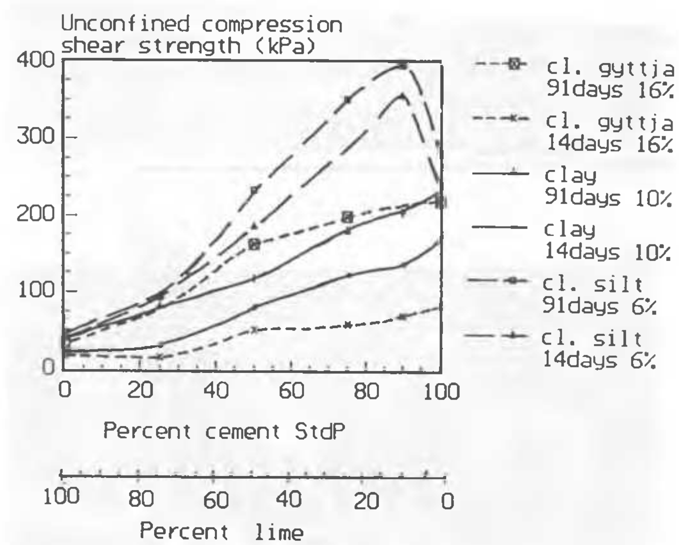

Fig. 4. The effect of different proportions of lime and cement on shear strength of three soils, 14 days and 91 days after mixing.

The compressive shear strength increases with an increasing proportion of cement in the stabilizing agent. This is valid for all three soils studied, but to different degrees. There is also a tendency to obtain lower or about the same strengths with 100 per cent cement than with a cement-lime mixture having a small proportion, 10 - 25 per cent, of lime. This effect seems to increase with time after mixing, due to the more sustained strength increase obtained with a stabilizing agent containing lime.

Type of soil

The laboratory results showed that all the studied types of soil could be improved, provided that the right combination and amount of cement and lime was used. Fig. 5 shows the effect of cement (SH), cement-lime and lime respectively in the ten different soils. The diagram shows the improved shear strength 14 days after stabilization with an amount of additive corresponding to 100 kg/m^3. This is about 7 % of the dry weight in the silty soils, 10 - 12 % in the clay soils, 18 - 40 % in the gyttja-bearing soils and 100 % in the amorphous peat. Later tests show that there is a further increase in unconfined compressive strength with time in all the stabilized soils, but the extent is highly dependent on type and total amount of stabilizing agent added to the soil.

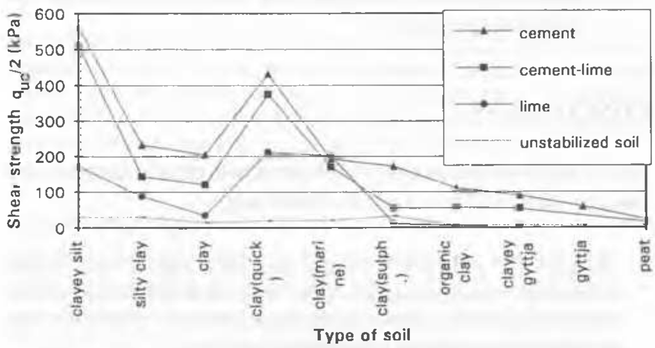

Fig. 5. Examples of the effect of cement, cement-lime (75:25) and lime 14 days after stabilization of different types of soils in the laboratory.

Total amount of additive

Tests with four different amounts of additives were performed on three types of soils; clayey silt, clay and clayey gyttja. The results indicate that, especially at shorter times after mixing, there is a significant increase in unconfined compressive strength with added amount of all three kinds of stabilizing agents. After longer curing times, however, it appears that large amounts of lime alone will slow up the rate of improvement. Larger amounts of cement, on the other hand, will provide an increase in strength for a longer period of time. Cement in combination with lime seems to be able to provide about the same or even better improvement as cement alone after a certain curing time, if the total amount of additive is not too large. Fig. 6 shows results from unconfined compression tests 14 days and 91 days after mixing in the laboratory. The amount of stabilizing agents added corresponds to 4 - 13 % of the dry weight in the clayey silt, 6 - 16 % in the clay and 16 - 40 % in the clayey gyttja.

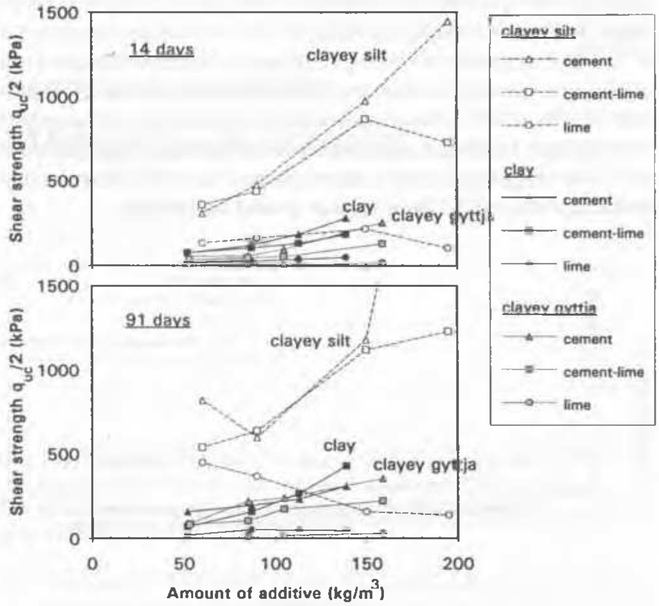

Fig. 6. Examples of the effects on shear strength of different amounts of additive on three soils stabilized in the laboratory.

Triaxial shear strength

The effects of different types and amounts of additives on the shear strength of stabilized soils were studied in a large number of unconfined compression tests. In order to understand better the behaviour of the stabilized materials and to estimate the effects of the horizontal stresses in situ, a few series of triaxial tests were also performed.

The results show an increase in drained shear strength with confining consolidation pressure. A certain increase in undrained shear strength with increasing confining consolidation pressure was also detected at relatively low shear strength levels early in the hardening process, although this effect will probably diminish as the strength increases with time, at least for what can be considered realistic horizontal stresses in situ. The results will be further analysed regarding maximum strengths, yield and residual strength, since these are factors that should be taken into account in designing deep stabilization.

Temperature effects

Stabilization with lime and to a smaller extent also cement always results in a temperature increase in the columns and soils in situ (Åhnberg et al, 1989). This affects the hardening processes in such a way that an increase in temperature results in a faster strength gain. One aim of the project was therefore to study what temperature levels could be reached in the stabilized soil and what the prevailing temperature would be after reaching a "steady" state when the columns and the surrounding soil have attained the same temperature.

Laboratory tests have been made with registration of adiabatic temperatures in isolated boxes. In situ measurements were made of temperatures in test columns just after installation, Fig. 7. The columns had a diameter of 0.6 m and an amount of lime, cement-lime and cement respectively, corresponding to 90 kg/m^3 (10 % of the dry weight of the soil). The temperature rise in lime stabilized soil is immediate due to the slaking process. An hour after mixing, the lime columns had a temperature of almost 50 ^{0}C. The cement reactions do not create the same high temperatures, but there is a generation of heat during a longer period of time. The temperature in the cement columns was 14 ^{0}C after one day, entailing a rise of 8 ^{0}C from original ground temperature.

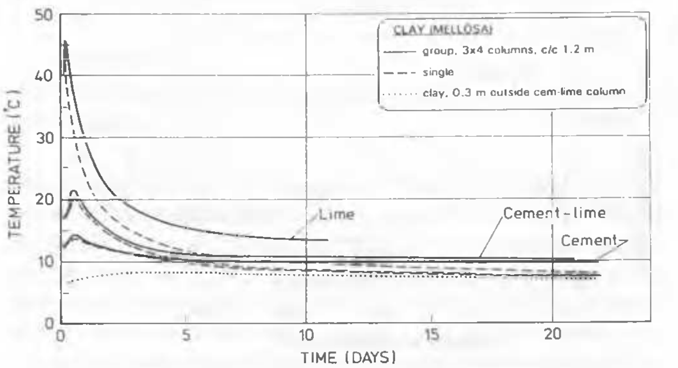

Fig. 7. Temperatures measured in test columns and in surrounding clay just outside a cement-lime column.

Permeability

The permeability of the stabilized soils is of importance when the columns are used for reduction of settlements since a certain drainage effect will help to speed up the rate of consolidation of the whole soil mass. The permeability is also taken into account when designing liners in highly permeable soils.

Lime columns have appeared to be relatively permeable in comparison with unstabilized clay. Since laboratory prepared samples have indicated only a slight increase in permeability, this has been assumed to be due to possible drainage through a weakened zone left by the installation rod at the centre of the columns, together with drainage on the outside of the columns and in fissures and cracks created by inhomogeneities/local overdosage of stabilization agents in the columns.

Since cement could be presumed to give a less permeable material than lime, permeability tests were run on samples prepared in the laboratory and also on full size test columns in situ.

In the laboratory tests, lime gave the largest increase in permeability, about 1.5 to 5 times that of unstabilized soil, whereas cement-lime gave about the same or only slightly higher permeability and cement gave slightly lower permeability. The field tests were performed by falling head tests (Tremblay & Eriksson, 1987) in piezometers installed in the columns. The filter lengths of the selected type of piezometers were 0.5 m in order to be affected by possible drainage channels in the columns. The results from the field tests show about the same effects as those from the laboratory tests. Fig 8 shows the results from field tests in clayey gyttja stabilized with an amount of additive corresponding to 90 kg/m^3 (16 % of dry weight).

The results are somewhat contradictory to earlier beliefs. Further studies should therefore be made to clarify in what way the permeability really changes.

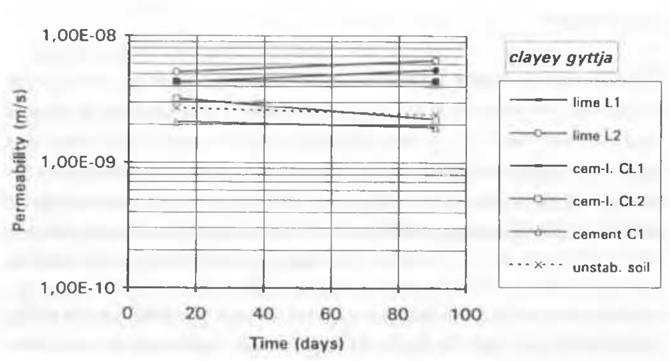

Fig. 8. Results of permeability tests in test columns in clayey gyttja at different times after mixing. Tests made with the falling-head method in piezometers.

CONCLUSIONS

The results in the research project obtained with mainly laboratory tests but also some field tests show the following:

- The soils that were tested range from clayey silt through different types of clays to clayey gyttja, gyttja and peat. All these types of soils can be stabilized by cement and/or quick lime, provided that the right amount and combination of additives are used.

- By using cement in the additive, a more rapid and higher strength increase is obtained than when using only quick lime. The stabilizing effect is increased with an increased amount of additive and an increased proportion of cement in the additive. The test results and also the theoretical studies of chemical reactions indicate that the optimal proportion of quick lime would probably be 10 to 25 per cent of the additive.

- The SH-cement will probably give a better stabilizing effect than the Std-cement.

The project comprises investigations of a large number of aspects of deep stabilization with different additives. The results will lead to an increased understanding of the behaviour of stabilized soil, and can be used as guidelines in design. The final report on the project will be presented in 1994.

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