Lime stabilization of fine-grained sediments in western Greenland

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ABSTRACT
Thick deposits of fine-grained marine sediments exist in large areas of western Greenland. Many places these sediments are located above sea-level, and now complicate construction projects in urban areas. The mineralogy of the fine-grained sediments is very different from European sediments, mainly due to the cold climate, and it is therefore of great interest to study possible methods to improve the stability and strength properties. This project includes laboratory studies of lime stabilization on fine-grained marine sediments from Kangerlussuaq, western Greenland. The results have included tests to determine the optimum lime content and the strength development in relation to both reaction time and curing temperature. Hopefully the results from this project will lead to a future use of lime stabilization and make it possible to use/reuse materials of poor quality at construction sites in Greenland.

RÉSUMÉ
Des dépôts épais de sédiments marins fins existent dans des vastes régions du Groenland de l'Ouest. A beaucoup d'endroits ces sédiments se trouvent au-dessus du niveau de la mer et compliquent maintenant les projets de construction dans les zones urbaines. La minéralogie des sédiments fins est très différente des sédiments européens, principalement à cause du climat froid, et il est donc de grande importance d'étudier les méthodes possibles pour améliorer les propriétés de stabilité et de résistance. Ce projet comprend des études de laboratoire de stabilisation de la chaux sur les sédiments marins fin de Kangerlussuaq dans l'ouest du Groenland. Les résultats ont compris des tests pour déterminer le contenu optimal de chaux et le développement de la résistance par rapport aux temps de réaction et la température de durcissement. Espérons que les résultats de ce projet mèneront à une utilisation future de stabilisation de la chaux et permettent d'utiliser / réutiliser des matériaux de mauvaise qualité sur les chantiers du Groenland.

1 INTRODUCTION

Thick deposits of fine-grained marine sediments exist in large areas of western Greenland. The sediments have through time been transported with melt-water from the Greenlandic ice-sheet to the sea, where it was deposited, and later uplifted due to a combination of iso- and eustatic processes. Today, therefore, many of these fine-grained sediments are located above sea-level, and now complicate construction projects in urban areas.

Fine-grained materials may contain large amounts of water, which during the construction phase of a civil engineering project can cause difficulties in the accessibility of the heavy vehicles and equipment used on a construction site. Subsidence in the underlying sediments result in cracks in the asphalt layer on newly paved roads. These problems are enhanced in areas with permafrost, especially where the deposits are ice-rich. It is therefore of great economic interest to develop methods to improve the stability of fine-grained sediments in Greenland.

Soil stabilization with burned lime (CaO) is a well known method used in building and construction projects in most of Europe. This is mainly because of the economic advantages of being able to use/reuse materials of poor quality at the construction sites.

The use of lime stabilization can also lead to a significant reduction in the use of sand and gravel materials in roads projects. The thickness of the road embankment can be reduced when the bearing capacity of the sub-base is increased.

The mineralogy of the fine-grained Greenlandic marine sediments is very different from that of European sediments, mainly due to the cold climate, which slows (or prevents) the chemical weathering of the sediments considerably. It is therefore of great interest to study, whether the stabilization process occurs and is feasible under Greenlandic conditions.

This paper includes results from laboratory tests carried out on fine-grained marine sediments from Kangerlussuaq, western Greenland (Figure 1). The laboratory tests include determination of the materials physical properties, as well as optimum lime content and long term strength development measurements under different curing temperatures.

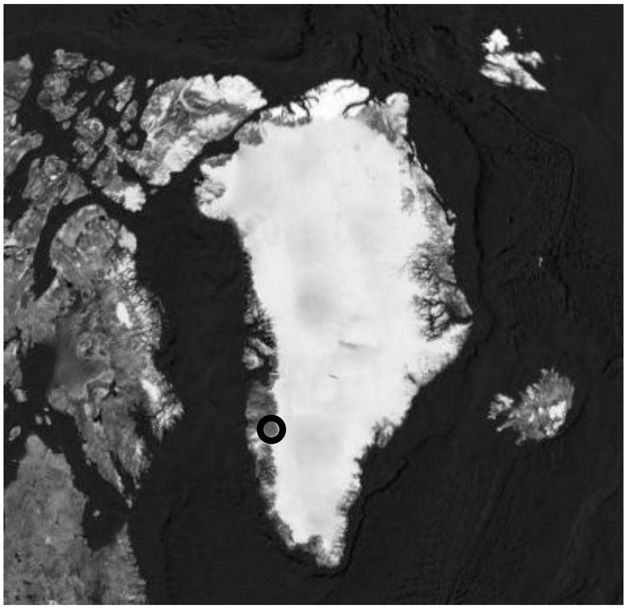

Figure 1. Location of Kangerlussuaq, western Greenland (circle) (Google Earth, 2010)

2 SITE DESCRIPTION

The village of Kangerlussuaq is built on a river terrace (altitude 30-50 m) at the head of the 170 km long fjord, Kangerlussuaq (Søndre Strømfjord), located just north of the Polar Circle at 67°00' N and 50°42' W. The sediments investigated are from the plain located just outside the village (Figure 2). The plain is made up of fine-grained glaciomarine sediments partly covered with fluvial deposits of sand and gravel.

Figure 2. Ortho-photo of Kangerlussuaq. The sediments investigated are from the plain to the left (circle)

The climatic conditions in Kangerlussuaq are arctic continental, determined by its northern location and its position in a 2-3 km wide valley surrounded by mountains (plateau altitude 400-600 m). To the east the Greenlandic ice sheet, with altitudes up to 3 km, has a dominant influence on precipitation and winds. These conditions result in a dry sub-arctic climate with winter temperatures down to -40°C (-40°F) and summer temperatures up to 20°C (68°F). In the period 1977-99 the mean annual temperature was -5.7°C and the mean annual precipitation was 151 mm (Danish Meteorological Institute, 2011).

Since the middle of the 1990s the temperature in Kangerlussuaq has increased and the mean annual temperature has been around -4.0°C, except for 2010 where the temperature was -0.2°C, which is the highest mean annual temperature ever recorded (Danish Meteorological Institute, 2011). Despite the increase in temperature, Kangerlussuaq is still in the zone of continuous permafrost, estimated to a thickness between 100-150 m (Tatenhove and Olesen, 1994). The entire active layer is frozen during the winter, but in late summer the depth to the frost table is up to 3.0 m in the open terrain (Ingeman-Nielsen et al., 2007).

3 METHODOLOGY

When burned lime is added to a clay soil it has an immediate effect on the properties of the soil. An exchange of cations will take place between the metallic ions associated with the surfaces of the clay particles and the calcium ions of the lime. The clay particles, which have a highly negative-charged surface, will attract free cations and water dipoles. This will alters the density and bring the clay particles closer to each other to cause flocculation (Bell, 1996). This will lead to an increase in the optimum moisture content and a reduction in the maximum dry density. The decrease in density is dependent not only upon the lime percentage, but also the amount of clay minerals present. Furthermore at higher water contents, lime stabilized soils tend to show a greater compactibility than an untreated soil (Bell, 1989).

Another important reaction is the pozzolanic reaction. This reaction is time and temperature dependent and is the key to effective and durable stabilization (Fang, 1991). Since the lime is fixed in the soil and not available for other reactions an optimum addition of lime can be obtained. To achieve the maximum modification of the soil it is normal to add between 1-3 % lime of the total weight. Additional lime will not bring further changes in the plastic limit or increases to the strength of the soil after reaching the maximum point.

4 RESULTS

4.1 Geotechnical soil properties

The results of the soil characterization tests are shown in table 1 and the grain-size distribution is illustrated in figure 3. This soil is classified as silty clay (CL), according to the Unified Soil Classification System. Dry quicklime (CaO) was used in the soil stabilization. The specific gravity of the lime grains is 3.11 and the grain size is between 0.0-0.2 mm (Faxe Kalk, 2011).

Table 1. Geotechnical soil properties

Consistency limits	Salinity 10 ‰	Salinity 0 ‰
Liquid limit	40.63 %	25.08 %
Plastic limit	26.50 %	20.90 %
Plasticity index	14.13 %	4.18 %
Grain-size		
Sand (> 63 μm)		0.2 %
Silt (2-63 μm)		42.8 %
Clay (< 63 μm)		57.0 %

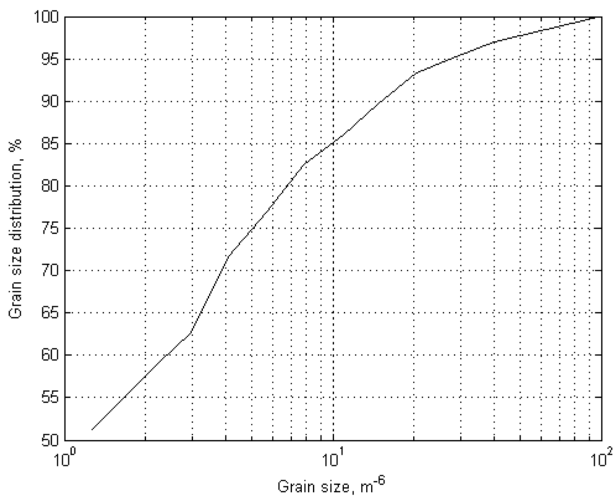

Figure 3. Grain-size distribution of the natural soil

The salinity of the soil was determined in the field, when the soil was excavated in 2002 (Jacobsen et al., 2002). The average salinity was at that time determined to be 10‰. Laboratory tests have shown that the excavated material now contains salinity on 0‰, which is probably caused by rainfall and snowfall, since the soil has been stored outside. To re-obtain the natural salinity properties, NaCl was added to a portion of the soil, so the field consistency limits could be determined.

4.2 Compaction and strength of natural soil

The dry density of the natural soil from Kangerlussuaq was determined by caring out standard proctor compaction tests in accordance to European Standard, EN 13286-2. Results from the compaction tests are illustrated in figure 4. The maximum dry density was found to be 1.71 kg/m^3 with the optimum water content at approximately 21%. Whereas, previously field investigations in Kangerlussuaq have shown that the natural water content for the material is approximately 24% (Jacobsen et al., 2002). Water content on 24% gives a dry density on 1.59 kg/m^3.

Accordingly to the results from the compaction tests, the strength of the soil at the natural water content was determined by California Bearing Ratio (CBR) tests in accordance to European Standard, EN 13286-47. The strength tests resulted in a CBR-value for the natural soil on 7%, which will be our reference point in the following tests for improving the strength of the soil by addition of lime (CaO).

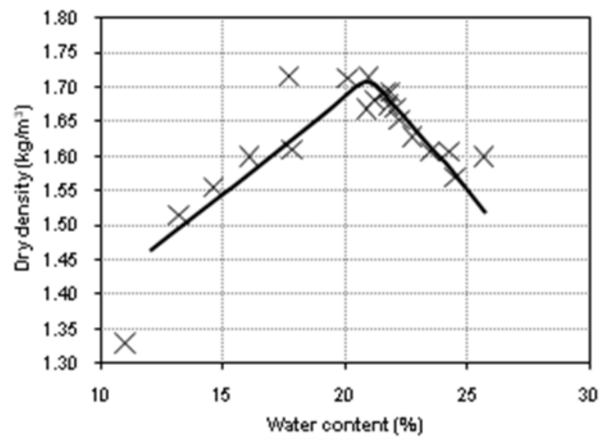

Figure 4. Soil compaction (proctor) curve for natural soil

4.3 Optimum lime content

The optimum lime content was determined by caring out standard proctor compaction tests. Since it is normally time consuming to make proctor curves for many different soil-lime mixtures, a new method of determining the optimum lime content was used. If the water content is assumed to be constant (the average natural water content in the field), then the dry density can be plotted against the corresponding lime (CaO) content.

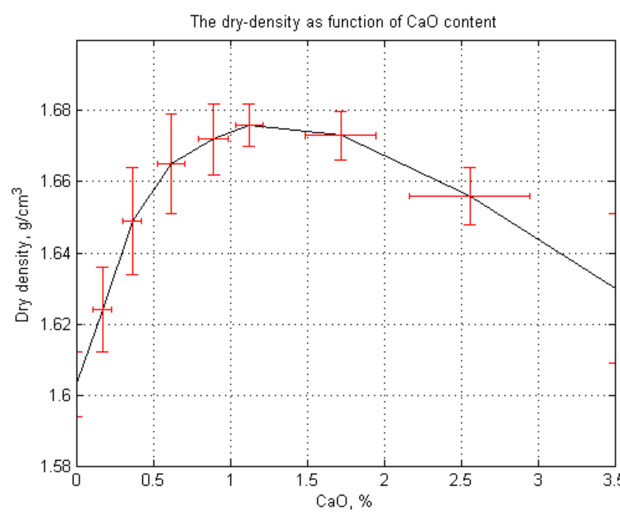

Figure 5. Dry density as function of lime (CaO) content at natural water content, w=24%

Figure 5 illustrates the results from determining the optimum lime content at the natural water content, w=24%. Based on the laboratory results, the optimum lime content was determined to 1.2%.

4.4 Strength development, time and temperature

Long term measurements have been carried out to measure the strength development of the lime-treated soil through time and under different curing temperatures.

For each time step a moulded soil sample (standard proctor test were carried out before the curing period) and a raw soil sample (standard proctor test were carried out after the curing period) were studied. The strength of each sample was determined by California Bearing Ratio (CBR).

The measurements were carried out with curing temperatures at 1˚C and 10˚C with time steps at 0 days, 7 days, 14 days, 28 days and 56 days.

At the moment we are caring out measurements at 4˚C, 7˚C, 13˚C and 20˚C. These measurements should help us to get more knowledge about the temperatures effect on the strength development in the soil. Results from these measurements will be included in the presentation at the conference.

4.4.1 Strength development at curing temperature 1˚C

The soil samples were stored at a constant curing temperature on 1˚C. Measurements were carried out over a period of 28 days. The results are illustrated in figure 6. It is seen that the CBR-values for the moulded samples are still increasing, when the tests were finished, which implied that we for the following measurements increased the measuring period to 56 days.

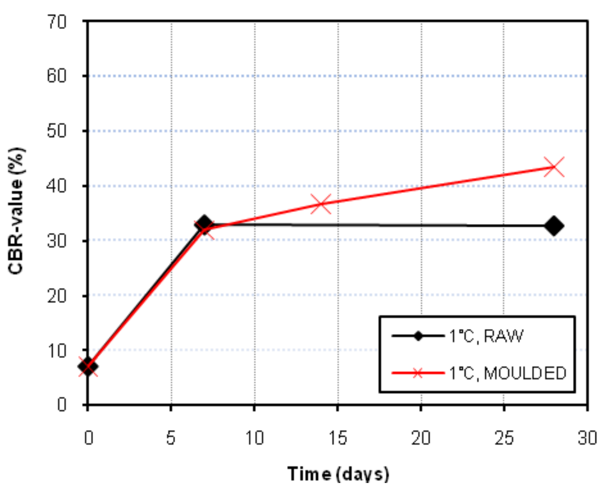

Figure 6. CBR-values as function of time (curing temperature at 1˚C)

After 7 days of curing there is no difference between the measured CBR-values for the raw and moulded samples. Both samples have increased from the starting value at 7.16% to a CBR-value at approximately 32%. After 28 days the CBR-value for the moulded samples has increased to 43.53%, whereas no further strength development has been measured for the raw samples.

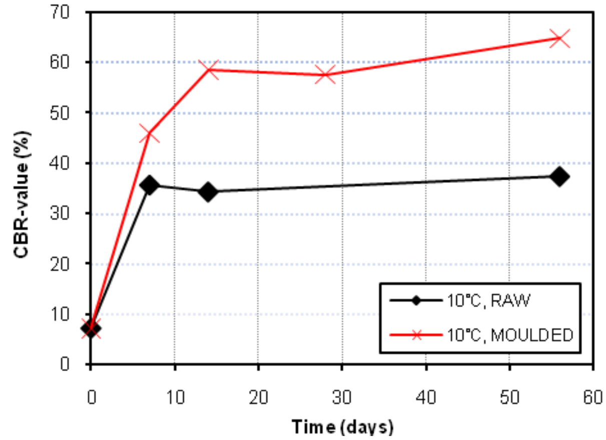

Figure 7. CBR-values as function of time (curing temperature at 10˚C)

4.4.2 Strength development at curing temperature 10˚C

The soil samples were stored at a constant curing temperature on 10˚C. Measurements were in this case carried out over a period of 56 days. The measured CBR-values are illustrated in figure 7. It is seen that the CBR-values for the moulded samples are significantly higher than CBR-values for the raw samples. After 56 days the CBR-value has increased to 64.73% for the moulded samples and 37.38% for the raw samples. It seems like the strength properties for the moulded samples are still increasing, even beyond the test period on 56 days.

Comparing the measured CBR-values from curing temperature at 10˚C and 1˚C, it is seen that there is a considerable difference in the strength development after 28 days. At that time the moulded samples at 10˚C has a CBR-value on 57.55% compared to 43.53% for the moulded samples at 1˚C, whereas the CBR-values for the raw samples are almost the same for both curing temperatures.

5 DISCUSSION AND CONCLUSION

Our preliminary laboratory tests of the fine-grained marine sediments from Kangerlussuaq have shown that it should be possible to use lime stabilization of soils under Greenlandic conditions.

The optimum lime content for the investigated soil has been determined to be 1.2%. This amount of lime has been used in the following strength development tests of the soil, which were carried out at two different curing temperatures, 1˚C and 10˚C. The results from the strength development test have shown a reduced increase in strength over time at lower curing temperature, but still a significant increase compared to the strength of the natural soil.

To gather further knowledge about the curing temperatures influence on strength development, more tests are planned to be completed during the spring 2011. Results from these tests will be included in the final conference presentation.

Furthermore, we will make strength development tests with shorter curing time intervals to get a better indication of what happens in the first days after adding lime to the soil. These tests should help us see when the strength development starts in the moulded samples and how fast the raw samples reach their stable CBR-values.

The results from this project will hopefully lead to a future use of lime stabilization and make it possible to use/reuse materials of poor quality at construction sites in Greenland.

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