

INFLUENCE DEPTH OF LIME APPLICATION ON ORGANIC SOFT CLAY

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Abstract

This study is intended to investigate the depth and the degree of influence of lime application on wet soft clay soil with respect to the shear strength and moisture content. The study concerns the increase of efficiency of a soil-lime improvement. Oostvaarders Plassen (OVP) clay, which is a high plasticity, low shear strength, modulated organic matter content clay with a high natural moisture content (typical properties of Dutch clay), was used in the test with lime (CaO). The investigation's results on shear strength and moisture content indicated that the influence of the lime application causes both of them to vary with the distance and time of the lime application. A significant increase in shear strength occurs within 6 h after applying the lime. A significant decrease in moisture content immediately occurs at the contact area after applying the lime. A linear relation between the influence depth and the square root of time of the lime application exists for the influence depth of the lime application on shear strength and moisture content. Empirical equations for these relations are proposed.

Keywords: Soil improvement, lime, organic soft clay, influence depth

Introduction

Soft clay is one of the natural soils that can be found in many regions of the world. Because of its very poor civil engineering properties, it has been treated as a problematic material. In some areas the organic matter found in this clay has given more problems to be solved. Excavation results in large quantities of spoil, which can become a serious problem. Re-use of this spoil for a construction material would be a way to solve this problem.

Fill materials for roads or dike embankments are potential applications for the use of clays as a construction material. A decision must be made to improve the properties of those clays to meet the specified engineering requirements. Soil properties are most suitable for placement and densification when the soil is in its partially saturated state, but this is often found not to be the natural situation. The water content of many soils in their natural state is too high. For most

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engineering purposes, their water content must be lowered as much as feasible and practical. In the case of clay soils, chemical improvement is commonly most effective since it can be used to change the nature of the material (Cernica, 1995). Chemical means can be used to strengthen the soil and also remove water in the soil, so that for soft clays their suitability and workability can be improved. Lime has been used to improve the properties of clays since olden times (Rao and Rajasekaran, 1996). One of the effects when mixing clay with lime is the reduction of the water content, which is beneficial for the improvement of wet clay. The changes in the engineering properties of the soil attributed to the lime depend on the depth of lime migration into the soil over time. Lime is diffused into the soil due to concentration gradient between the lime and the soil (Rajasekaran and Rao, 1997).

For wet soft clays, lime is used to improve their properties, since lime has a strong affinity for water and the resulting reaction is harsh. The reaction breaks down clay lumps by drawing water from the clay, thus creating a drier material. Many factors are involved in achievement of soil-lime improvement. Mixing is one of those factors which plays an important role in the efficiency of the improvement. It is difficult to mix lime and clay into small lumps, especially with wet clays, as normally in a mixture of clay and lime in lump form the lime attaches at the surface and the size of the lumps depends on the degree of pulverization. For a high moisture content clay, breaking up into small lumps is expensive and time consuming and sometimes impossible to achieve. To determine the proper size of mixed clay lumps, the depth and degree of influence of lime application on the clay lumps has to be known. The main properties that may be required to be altered by improvement are strength, the volume stability, durability and permeability.

In this study, the influences of distance on the effects of a lime application on wet clay soil are investigated concerning the change of shear strength and moisture content. This information on the proper size of mixed clay lumps of a soil-lime improvement which could

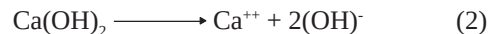
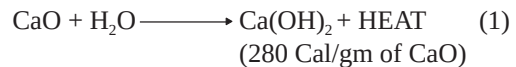
be beneficial for determining suitability and workability. Oostvaarders Plassen (OVP) clay, which is typical Dutch clay, is used as the testing material. The lime which is used in this study is calcium oxide (CaO).

Mechanism of Lime Improvement

Lime treatment has been extensively used for road construction. The primary application has traditionally been the improvement of clay subgrades using mix-in-place techniques. Lime-treated clay gains strength from three phases, namely: drying, modification and stabilization. Drying and modification occur in the short term. Stabilization occurs in the long term (Hausmann, 1990).

Drying

An immediate reduction of moisture content occurs when quicklime is mixed with clay, as water is consumed in the hydration process. Quicklime will immediately take up 32% of its own mass of water from the surrounding soil and slake to form a hydrated lime. The calcium hydroxide, Ca(OH)_2 , from the hydration of quicklime dissociates in the water, increasing the electrolytic concentration and the pH of the pore water, and dissolving the SiO_2 and Al_2O_3 from the clay particles. These processes will result in the modification and stabilization processes. The reactions in drying phase are as follows:

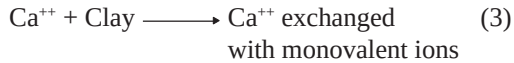


Modification

When lime is mixed with clay in the presence of water, a cation exchange takes place. This change in the cation complex affects the structural components of the clay mineral, which produce a new material. Hence, there are significant changes in the engineering properties of clays.

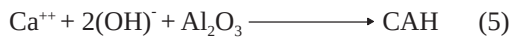
This reaction phase causes a flocculation of the clay particles and results in a modified material being produced which has a coarser

texture, is more friable and is less plastic (Holt and Freer-Hewish, 1996).



Stabilization

Clay minerals are natural pozzolanas and have the ability to react with lime added to the soil to produce cementitious products. The shear strength of the stabilized soil gradually increases over time mainly due to pozzolanic reactions. The calcium ions from calcium hydroxide in the soil water react with the silicates and aluminates to form calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH).



The gel of calcium silicates (and/or aluminate hydrates) cements the soil particles in a manner similar to the effect produced by the hydration of Portland cement, but the lime cementing process is a much slower reaction.

Experimental Investigations

The tests were performed at the laboratory of GeoDelft, The Netherlands. Influence depths of lime application on wet soft clay concerning the change of moisture content and shear strength were investigated. The tests comprised several basic tests to determine the basic properties of Oostvaarders Plassen (OVP) clay and lime application tests to determine the influence depth of lime application on OVP clay. The moisture content and shear strength at a range of depths and times were measured after applying lime.

To investigate the influence depth, the experimental procedure started by mixing OVP clay manually in a plastic mixing bowl. After mixing the clay was placed into an airtight container and sealed. It was left standing for a curing period of 24 h in a cool place to allow water to permeate through the soil mass and for the initiate aging reaction. The clay was removed from the container after maturing. It was remixed by hand for 10 min to obtain a uniform distribution of water throughout the samples. Then clay samples were placed in PVC

tubes (diameter 65 mm, height 110 mm) until clay height 100 mm was reached. The surface of clay was leveled before a layer of lime 10 mm thick was placed on the clay surface. Eighteen sample tubes were placed with the clay and lime. One sample tube was placed only with clay to determine the initial condition. All the samples were covered with a plastic sheet and placed in a constant room temperature.

After specific time intervals sample tubes, to which had been applied lime were taken to measure the shear strengths and moisture contents. The clay was extruded from the tubes. The lime was removed until the clay surface was reached where the shear strength was measured. The shear strength was measured by the vane shear test; the dimensions of the vane blade was 12.8 mm in height and 8 mm in diameter, and the torque was applied by HAAKE rotational viscometers type M 1500 as shown in Figure 1. After inserting the vane blade 5 mm deep in the clay, the vane blade was rotated at a steady rate until the clay failed while the maximum shear strength was recorded. After the blade was taken out, 5 mm of the clay was extruded into two layers (2.5 mm each) for determining the moisture content. For the next layer, the measurement of shear strength and moisture content continued with the same procedure up to 30 mm; after that the shear strength was measured every 10 mm, and 5 mm of clay at the



Figure 1. HAAKE rotational viscometers type M 1500

shear strength measurement position was taken to determine the moisture content. The positions of vane shear strength and moisture content measurements are shown in Figure 2.

For 1 h after applying the lime, a sample tube was taken every 15 min for measuring the shear strength and moisture content as in the procedure described above, the depth of examination being 20 mm. From 1 h to 3 h, a sample tube was measured every 30 min with an examination depth of 50 mm. From 3 h to 6 h, measuring was every 1 h with an examination depth of 50 mm. After that the measuring was done at 6 h, 12 h, and 1 day with an examination depth of 50 mm. At 3, 7, 14, 21, and 28 days the examination depth was 100 mm.

In the one sample tube with only clay, the shear strength and moisture content were measured at a depth 0.5 mm, 50 mm and 90 mm for determining the initial shear strength and moisture content of the clay.

Results and Discussions

The results of the tests to determine the basic properties of Oostvaarders Plassen (OVP) clay are shown in Table 1.

The average initial vane shear strength of OVP clay was 9.3 kPa and the moisture content was 204%.

Moisture Content Results

Two parts can be distinguished in all the curves shown Figure 3; the first part (0 - 10 mm) where moisture content decreases significantly and the second part (greater than 10 mm) where moisture content decreases slightly. The first part appears as an inclined straight line. From 15 min to 1 day, the slopes are constant and begin to decrease until the curve is flat in the 28 days curve. The curves in the second part show the trend to connect the moisture content in the first part with the moisture content at a greater depth. It can be seen that the behavior of the moisture decrease is not the same for those two areas.

It should be noted that after applying lime the moisture content is significantly reduced at the contact area, because pore water in the clay is sucked out by the lime (CaO) in the hydration process. The influence area of immediate suction is about 10 mm from the lime, as we can see a straight line representing the moisture content decreased by this influence. With a different gradient the moisture outside of this influence

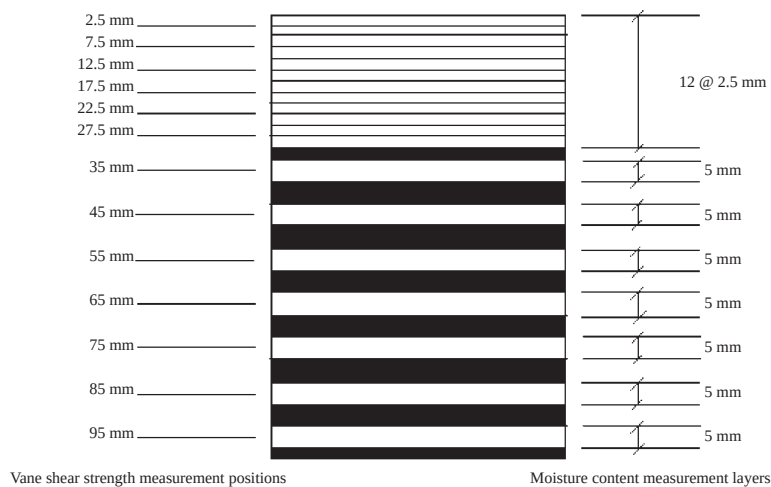
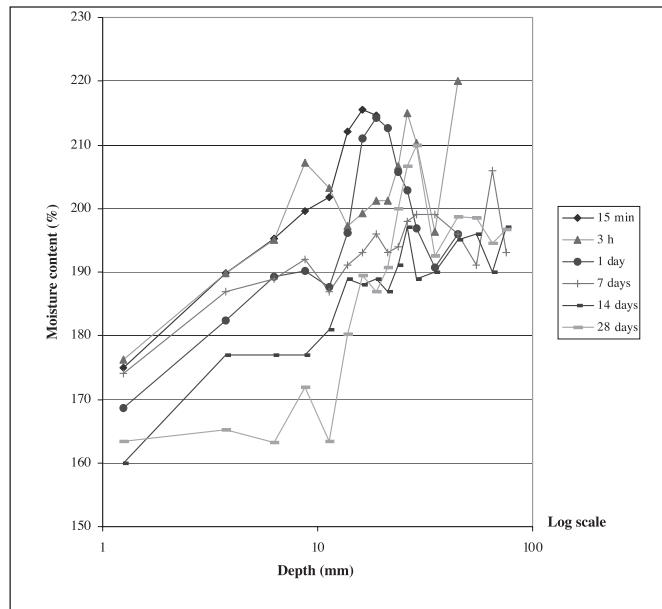


Figure 2. Measurement positions of vane shear strength and moisture content

Table 1. Physical and chemical properties of OVP clay

1.	Liquid limit (%)	232
2.	Plastic limit (%)	108
3.	Plasticity index (%)	124
4.	pH	8.1
5.	Organic content (%)	4.03
6.	Main chemical components	SiO ₂
7.	Cation exchange capacity (cmol+/kg)	21.1
8.	Specific surface area (m ² /g)	141
9.	Particle size distribution (%)	
	2 mm - 0.075 mm	3
	0.075 mm - 0.02 mm	12
	0.02 mm - 0.0075 mm	25
	0.0075 mm - 0.002 mm	20
	< 0.002 mm	40
10.	Soil classification (NEN 5104)	Ks2, h2 Clay, Moderately Silty, Moderately organic

**Figure 3. Moisture content vs depth (log scale)**

area can be drawn to the influence area. The moisture at a depth of 10 mm from the lime will be adjusted as shown by the slope tending to decrease until the curve is flat within 28 days. The strong influence occurs around the 10 mm depth as we can see from the plot of the moisture content ratio (moisture content / average initial moisture content) vs time as shown in Figure 4. The reduction of the moisture content at 28 days is 20% at a depth of 10 mm from the lime. The small size of the sample, the inhomogeneity of soil and the organic matter content are considered as the main causes of the scattering of data.

The influence depth of lime the application on the moisture content can be determined from the ratio of the measurement of moisture content and the average moisture content of the last two layers which represents

the initial moisture content value of the sample. The influence depth and square root of time in linear function is the most suitable correlation as shown in Figure 5. The influence curve can be separated into two parts. The first part (0 - 3 h) and the second part (after 3 h) have different slopes which indicate the different rates of the influence depth. The influence depth in the second part increases more slowly than in the first part due to the change in porosity and permeability of the clay after the water is sucked out by the lime. The empirical correlation equations are

$$\text{Influence depth} = (11.11 \cdot \sqrt{\text{Time}}) + 7.78 \quad (6)$$

(For 0 - 3 h)

$$\text{Influence depth} = (6.2 \cdot \sqrt{\text{Time}}) + 16 \quad (7)$$

(For 3 - 72 h)

(Influence depth in mm, Time in hour)

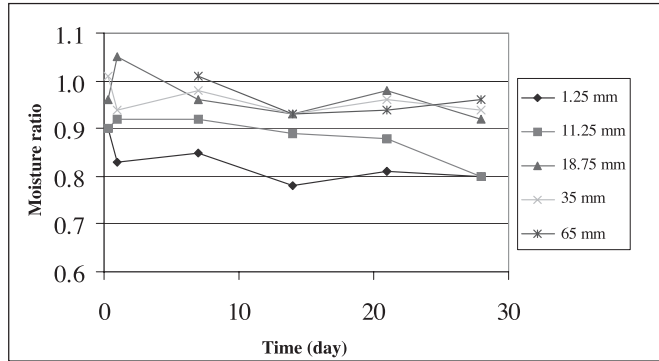


Figure 4. Variation in moisture content with time

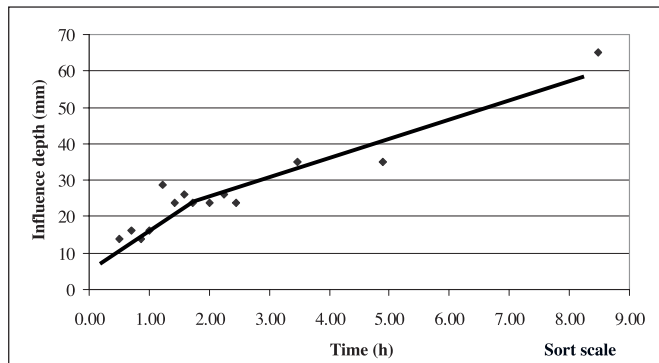


Figure 5. Relationship between $\sqrt{\text{Time}}$ and influence depth

Vane Shear Strength Results

The vane shear strength results are plotted vs depth as shown in Figure 6. It can be seen that the increase in shear strength decreases when the depth increases and also increases over time. The points on the graph have a considerable scatter, which represents the inhomogeneous condition of the soil.

The results of this investigation indicate a significant increase in shear strength of OVP clay within the first 6 h after applying lime and a slow increase over time after this period. Figures 7 and 8 show the relation of moisture content ratio and strength ratio (the ratio of the measurement of shear strength and the average shear strength of the last two layers over time at 2.5 mm depth). As can be seen from the figures

that the increase of shear strength is around 2 times the initial strength from 0 to 6 h and after 28 days (the latest investigation of this study) the increase of the shear strength is around 2.3 times the initial strength. It is seen that within the 28 days test period more than 80% of the shear strength is gained in the first 6 h.

This strength may come from a modification process related to migration of calcium ions into the clay and the pozzolanic reaction. The change of moisture content has a small effect on the change of shear strength as shown in Figures 7 and 8. The strong influence occurs within a depth of 12.5 mm as shown in Figure 9.

From the shear strength ratio, the influence depth of the lime application on shear strength can be determined. The depth of the

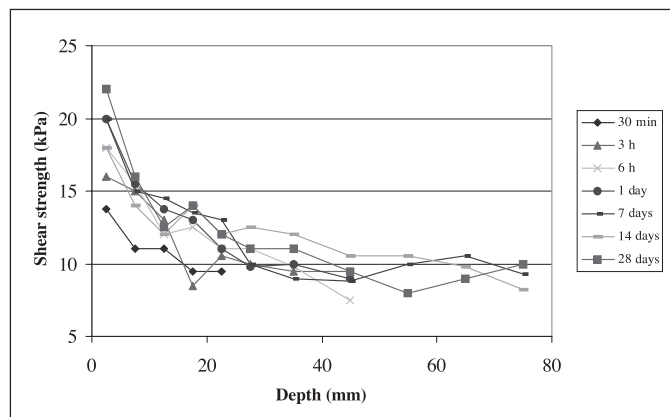


Figure 6. Shear strength vs depth

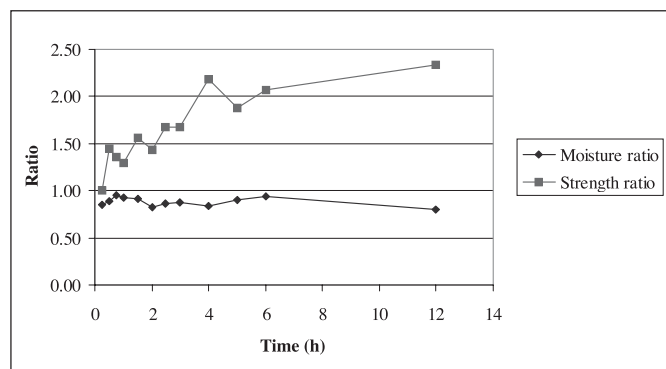


Figure 7. Variation of moisture and strength ratio with times at 2.5 mm depth (0 - 12 h)

slope of the strength ratio curve, which becomes flat at around the strength ratio of one, is determined as the influence depth. The relationship of the influence depth and time is plotted in Figure 10.

According to Figure 10, two parts can be distinguished in the influence depth curves. The first part (0 - 6 h) is a straight line with a steep slope and the second part (after 6 h) is a straight line with a gentle slope. The difference in slopes indicates that in the first 6 h the influence depth increases faster than in the second part.

It may be considered that after 6 h the soil properties such as soil structure, porosity and permeability are changed due to the drying, modification and stabilization processes. The changes cause the difference in the migration rate of Ca^{++} and OH^- into the clay between the first

and the second parts. The influence depth linearly increases as the square root of time. The empirical correlation equations are

$$\text{Influence depth} = (13.63 * \sqrt{\text{Time}}) - 1.74 \quad (8)$$

(For 0 - 6 h)

$$\text{Influence depth} = (1.15 * \sqrt{\text{Time}}) + 29 \quad (9)$$

(For 6 - 672 h)

(Influence depth in mm, Time in hour)

Discussion of Workability

Application of this study can be used to evaluate the suitability and workability of OVP clay-lime improvement. The increase in shear strength of the test results means that this clay, which is wet and soft, reacts with lime, indicating the potential to improve this clay by

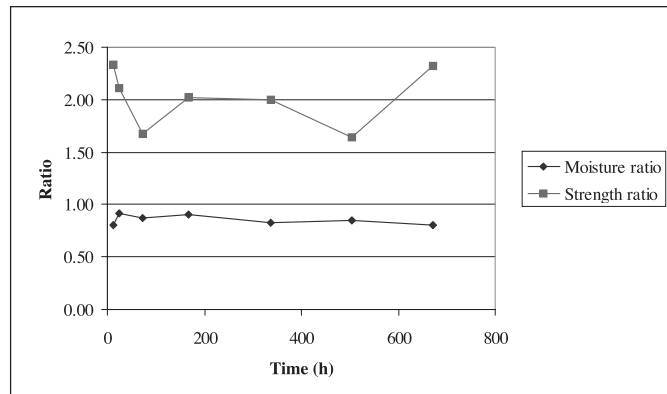


Figure 8. Variation of moisture and strength ratio with times at 2.5 mm depth (12 – 672 h)

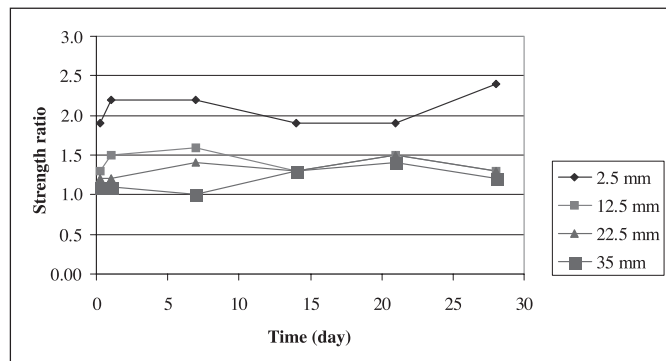


Figure 9. Variation in shear strength with time

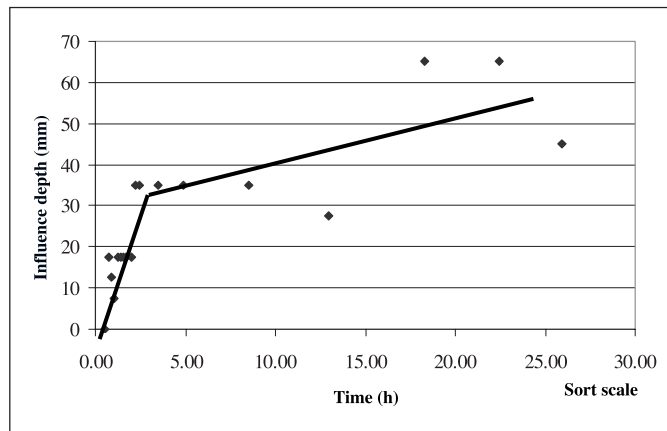


Figure 10. Influence depth on shear strength vs lime application time

the application of lime. The decrease of moisture content leads to the potential to increase workability. OVP clay has a high initial moisture content which is difficult to work and also affects its engineering properties.

The test results show that although soil lumps have low strength, the influence of lime diffusion can improve the properties of the lumps as a result of lime application in the system. The degree of lump improvement depends on time and the size of the lumps. At 28 days OVP clay increases in strength on average 48% from its initial value at a 45 mm influence depth and the decrease in moisture content on average 10% from its initial value at a 75 mm influence depth. Thus the effective size of clay lumps should be not larger than 90 mm for 28 days of improvement. If the size of the clay lump is larger, the improvement time will have to be prolonged to ensure the migration of Ca^{++} and OH^- into the entire clay lump, or re-mixing will have to be carried out. However, re-mixing after 24 h may destroy the cementitious product of the stabilization process.

Conclusions

The investigation results on shear strength and moisture content indicated that the influence of lime application causes both properties to vary

with the depth and time of the lime application. A significant increase in shear strength of OVP clay occurs within 6 h of lime diffusion and gradually increases after this period. A significant decrease in moisture content immediately occurs at the contact area after the application of lime. A linear relation between the influence depth and the square root of time of the lime application exists for the influence depth of lime application on shear strength and moisture content. The OVP clay indicates the potential to improve shear strength and workability by soil-lime improvement. The degree of lump improvement depends on time and size of the lumps. Wet soils usually facing a pulverization problem can be more effectively and economically improved with lime by indicating a maximum lump size, which could relate to the time of lime diffusion.

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