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Experimental Study on Clay Soil Stabilization Using Lime

Dr. K.S. Kulhar¹, Navneet Shrimal², Ritika Tiwari³, Priyam Mina⁴, Mohit sharma⁵

Professor, Department of Civil Engineering, Vivekananda Institute of Technology, Jaipur, India¹

B.Tech Student, Department of Civil Engineering, Vivekananda Institute of Technology, Jaipur, India²⁻⁵

ABSTRACT: Soil stabilization can be explained as the alteration of the soil properties by chemical or physical means in order to enhance the engineering quality of the soil. The main objectives of the soil stabilization is to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures, Therefore soil stabilization techniques are necessary to ensure the good stability of soil so that it can successfully sustain the load of the superstructure especially in case of soil which are highly active, also it saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil. This paper deals with the complete analysis of the improvement of soil properties and its stabilization using lime.

KEYWORDS: Soil Stabilization, Permeability, Lime, Cement, Water Content

I. INTRODUCTION

Improving an on site soil's engineering properties is called soil stabilization. Soils containing significant levels of silt or clay, have changing geotechnical characteristics: they swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost. Site traffic is always a delicate and difficult issue when projects are carried out on such soils. In other words, the re-use of these materials is often difficult, if not impossible. Once they have been treated with lime, such soil can be used to create embankments or subgrade of structures, thus avoiding expensive excavation works and transport. Use of lime significantly changes the characteristics of a soil to produce long-term permanent strength and stability, particularly with respect to the action of water and frost. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good candidates for stabilization. Soils containing significant amounts of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime or special construction procedures.

II. LITERATURE REVIEW

A considerable amount of research have been done in this field. Some of them are below –

Evans, P., (1998). "Lime Stabilization of Black Clay Soils in Queensland, Australia," Presentation to the National Lime Association Convention

Chaddock, B. C. J., (1996), "The Structural Performance of Stabilized Road Soil in Road Foundations," Lime stabilization.

Basma, A. A., and Tuncer, E. R., (1991), "Effect of Lime on Volume Change and Compressibility of Expansive Clays," Transportation Research

Doty, R., and Alexander, M. L., (1968) "Determination of Strength Equivalency for Design of Lime-Stabilized Roadways," Report No. FHWA-CATL-78-3

Dawson, R. F., and McDowell, C., (1961), "A Study of an Old Lime-Stabilized Gravel Base," Highway Research Board, Lime Stabilization:

III. METHODOLOGY

3.1 Lime-cement columns

In general, the soil in-situ on the construction site is mixed with dry binder that react with the water that soil already contains e.g. clays and soft soils. This is done in a way that creating vertical columns in the ground that for example improve the bearing capacity of the ground. The columns can be arranged differently depending on the application and needed function. The method can also be used in drier conditions but then water needs to be added to get proper reaction of the binder and therefore the method is divided in wet and dry depending on the conditions (Kellergrundläggning, 2017). The columns can be constructed to about 25 m depth with a diameter of 400-1000 mm and a normal centrum distance of the columns is 0,8-1,7 m (Cementa, 2017).

3.1.1 Applications

The method is normally used in different civil engineering constructions to reduce settlements and improve the stability of the ground. For example, in embankments, slopes, deep excavations and under smaller constructions like pipelines (Cementa, 2017). If the columns been arranged in lines with overlap to each other it creates a wall in the ground that is less permeable for the groundwater, which then can be useful to keep contaminated land from leaking to the environment. This wall arrangement of the columns can also work as vibration protection of buildings or be used to take up vibrations, from railways for example (SGF-LarssonS, 2017).

3.1.2 Design

Depending on the problem and requirements the design is mainly done by adjustment of installation patterns, column diameter, distance between columns and column depth. But this assumes that the soil on the site is thoroughly investigated so that design of binder can be done, which is depending on the soil properties and in-situ conditions. I.e. different soils require adjustment of the combination of lime, cement and other alternative binders (Larsson, 2006).

Conditions

For the most used type of lime-cement column with dry binder the soil needs to contain about 20 % of water, which is normal in many soft clays. Therefore, the method is most used in these conditions. Other soils where the method can be used in is organic soils, silts and lose sands that have high water content but an important condition is also that the soil is enough lose to allow proper mixing (SGFMethodblad, 2017).

3.1.3 Benefits

Use of lime-cement columns is often a cost-effective method. The installation process and variation in design is flexible, which gives the many opportunities of applications. In some ways, it is an environmentally friendly method considering low noise and vibrations from the installation but also considering the use of the in-situ soil to create the columns (SGFMethodblad, 2017). The method is also less time consuming in comparison to other ground improvement methods so the construction time can be reduced in many cases (Kellergrundläggning, 2017).

3.2 Quicklime and Portland cement

Binders that have been used for the method is mainly lime and cement, this two can be used in different proportions or separately depending on in which type of soil and application it is regarding.

Columns created of lime separately is most used in clays, combinations of lime and cement can be used in all type of soils except peat and cement separately can be used in all type of soils (Larsson, 2006).

3.2.1 Quicklime

The normal used lime is fine grind quicklime, CL90-Q. This lime is first reacting with the water in the soil and after that with the fine solid particles as clay particles. Therefore, the strength is very depending on the reactions between the lime and soil particles. The strength growth for columns created separately from lime is linear and going on under long time in compare to columns with addition of cement. A normal addition of lime is about 6-8 weight percent of the solid soil mass, which is about 70 - 90 kg/m³ (Larsson, 2006).

Quicklime is produced by heating up limestone (calcium carbonate) to temperatures about 1000 degrees. This take away carbon dioxide from the limestone, which gives that only almost pure calcium oxide been left (Entreprenörsskolan, Sveriges Byggindustrier, 2016).

3.2.2 Portlandcement

The normal used type of cement is a Portland cement, CEM II/A-LL 42.5 R. The cement is only reacting with the water in the soil and therefore strength not depends on which type of soil it is. The strength is then only depending on the amount of cement and the supply of water in the soil that can react with the cement. The strength growth for columns created separately with cement is fast in the beginning and then decreases more and more over time in compare to columns with addition of only lime. A typical addition of cement in clay soils is about 6-16 weight percent of the solid soil mass, which is about 70 - 180 kg/m³ and in peat it can be need of over 300 kg/m³ (Larsson, 2006). Portland cement is produced by heating up fine grind mix of limestone and clay minerals (Alite, Belite, Aluminate and Ferrite) to 1400 degrees. This forms what is called Portland cement clinker and the main components of this is calcium oxide and silicon dioxide. But it is also forming small quantities of many other substances and the most important ones is alkalis (K₂O, Na₂O), aluminum oxides and iron oxides (Entreprenörsskolan, Sveriges Byggindustrier, 2016).

3.3 Alternativebinders

Lime and Portland cement is usually used in different proportions to take advantage of the different characteristics that they have. In this way, also other alternative binders can be added to improve the characteristics with propose to create better columns for different conditions and applications (Åhnberg, 2006). Most of the alternative binders do not work as a separately binder that can replace both lime and Portland cement since most of them needs to be activated by the reactions between calcium oxide and water. These binders are called pozzolans (Entreprenörsskolan, Sveriges Byggindustrier, 2016).

The alternative binders that been found in this literature study was taken from the listed alternative binders in the main reference (Åhnberg, 2006). Namely Slaked lime, Alumina cement, Slag, Fly ash, Gypsum, Silica fume, Kiln dust and Water glass. Some of these binders have been described with inter alia their specific properties, content, origin/source and impacts taken from other find references. Alternatives to Portland cement was also find in one study that describe four different alternatives, which is produced in the same way as Portland cement but have a lower impact on the environment (Juenger, Winnefeld, Provis, & Ideker, 2011).

3.4 CHEMISTRY OF LIME TREATMENT

1. Drying: If quicklime is used, it immediately hydrates (i.e., chemically combines with water) and releases heat. Soils are dried, because water present in the soil participates in this reaction, and because the heat generated can evaporate additional moisture. The hydrated lime produced by these initial reactions will subsequently react with clay particles (discussed below). These subsequent reactions will slowly produce additional drying because they reduce the soil's moisture holding capacity. If hydrated lime or hydrated lime slurry is used instead of quicklime, drying occurs only through the chemical changes in the soil that reduce its capacity to hold water and increase its stability. In fig.1 water content W_n is reduced to W'_n after treatment with lime.

2. Modification: After initial mixing, the calcium ions (Ca⁺⁺) from hydrated lime migrate to the surface of the clay particles and displace water and other ions. The soil becomes friable and granular, making it easier to work and compact. At this stage the Plasticity Index of the soil as shown in fig. 1 decreases dramatically, as does its tendency to swell and shrink. The process, which is called "flocculation and agglomeration," generally occurs in a matter of hours.

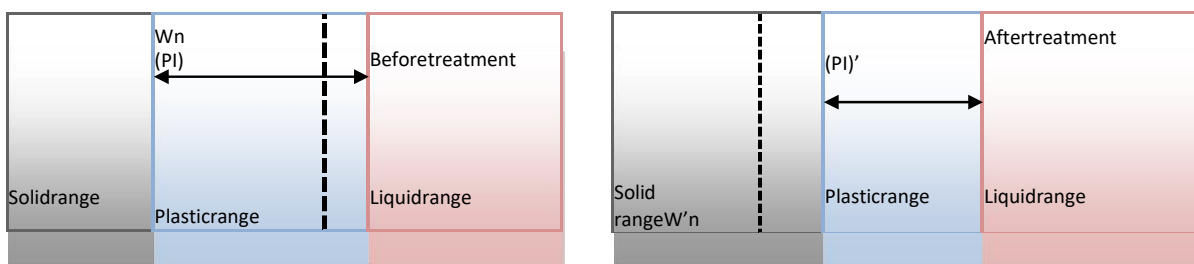


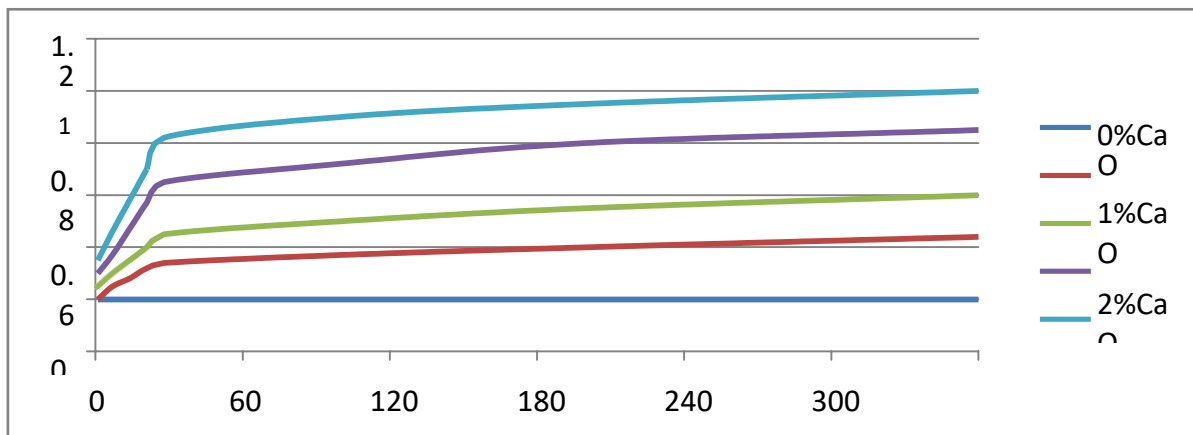
Fig.1 Effect of liming on the consistency of soil



Stabilization: When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables the clay particles to break down. Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). CSA and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of lime-stabilized soil layers. As this matrix forms, the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. The process begins within hours and can continue for years in a properly designed system. The matrix formed is permanent, durable, and significantly impermeable, producing a structural layer that is both strong and flexible.

3.4 IMMEDIATE EFFECT: SOIL IMPROVEMENT

1. A reduction in the plasticity index: The soil suddenly switches from being plastic (yielding and sticky) to being crumbly (stiff and grainy). In the latter condition it is easier to excavate, load, discharge, compact and level.
2. An improvement in the compaction properties of the soil: The maximum dry density drops, while the optimal water content rises, so that the soil moves into a humidity range that can be easily compacted. This effect is clearly advantageous when used on soils with a high water content. A treatment with quicklime therefore makes it possible to transform a sticky plastic soil, which is difficult to compact, into a stiff, easily handled material. After compacting, the soil has excellent load-bearing properties.
1. Improvement of bearing capacity: In most cases, two hours after treatment, the CBR (California Bearing Ratio) of a treated soil is between 4 and 10 times higher than that of an untreated soil. This reaction greatly relieves on-site transportation difficulties.



Graph 1

3.5 MEDIUM TERM EFFECT : SOIL STABILIZATION

When lime comes into contact with a substance containing soluble silicates and aluminates (such as clay and silt), it forms hydrated calcium aluminates and calcium silicates. As with cement, this gives rise to a true bond upon crystallization. Called a pozzolanic reaction, this bonding process brings about improved resistance to frost and a distinct increase in the soil’s compressive strength and CBR. In general, in non-winter conditions, the soil develops sufficient strength after three to six months. A slow curing process during road construction is a marked advantage, as it allows greater flexibility when working with the treated soil. The long-term hardening facilitates the design of foundations for industrial platforms. The stabilizing effect gives load-bearing qualities to the treated soil.

3.7 Soil classification

Classification of the soil has been done according to Indian standards as follows.

3.7.1 Natural water content

Representative soil, from corners to the middle is collected and put in a cup that first weighed without soil and then when wet soil is collected. After that soil is dried in an oven, 105°C for 24 hours to be weighed again. Now the water content can be calculated as the ratio between the mass of evaporated water and mass of dry soil, see equation 2.

$$W = \frac{m_w}{m_s} \times 100$$

3.7.2 Particle size distribution

Two different ways can be used to get the particle size distribution, by doing dry or wet sieving. For dry sieving, the soil needs to air dry before the sieving can start and therefore soil is spread on a plate. When clay material is dried it also needs to be grinded before it can be sieved. Now the dry and grinded material is weighed and putted in weighed sieves from 1 to 0,063 mm placed above each other. Sieves are then placed in a machine that shaking for 10 minutes to get the soil particles go through and the different sieves is afterwards weighed again. For the wet sieving it is no need of drying the material before the sieving, the water content is taken and then weighed soil is directly putted on the sieves. The soil is flushed with water through the sieves during shaking and all water with particles passing the 0,063 mm is collected in a bucket for sedimentation test. The sieves are weighed after they have been dried in an oven to get the distribution curve. After dry and wet sieving, the particle size distribution for the fine particles that have pass the 0,063-mm sieve is done by sedimentation test. This was performed both with hydrometer and pipette to compare results between them. The sedimentation is done by putting the fine material from dry or wet sieving in a 1000 ml glass tube and fill it to the 1000 ml marking. A special chemically additive that make the smallest particles to separate is also add, included to 1000 ml. Then the soil is stirred very well so it is equally distributed in the 14 water and the sedimentation starts as the stirring stops. The methods are until here the same. The difference is now how the measurement of sedimentation is done. With the hydrometer method are readings taken directly on the hydrometer when it is lowered down in the water. With the pipette method is water samples taken that is putted in a cup that after drying in oven is weighed. The calculations for both methods are based on the speed of the sedimentation according to Stokes' law.

3.8 Modified proctor test

Particle size distribution

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3.9 Liquid limit

The used method for determine the liquid limit was Falling cone test. It is performed by letting a steel cone that weighs 60 g and have a tip angle of 60° fall into the soil. Mixed soil is filled in a small cup and the surface is made plane by



pull off the material leftover. The cone is adjusted so that it tangent the soil surface without touching it. From this position cone is released and the penetration depth is then measured. The definition of the liquid limit is that the cone should penetrate the soil with 10 mm. By using a reference table, the liquid limit can be calculated depending on the soils water content and the measured penetration between 7-13 mm. Otherwise the test can be done more times with different water contents and then plotting water content against the penetration depth.

3.10 Plasticlimit

Determination of the plastic limit is simply done by taking plastic soil and try to roll it to a little strip by hand. The definition of the plastic limit is that it can be rolled to a strip that is 3 mm in diameter and 40 mm long. This is most preferably done on a water absorbing paper so that the water content of the soil is decreasing faster during the test rolls. Rolling out the strip is repeated until it brake/fall apart before getting the limits according to the definition.

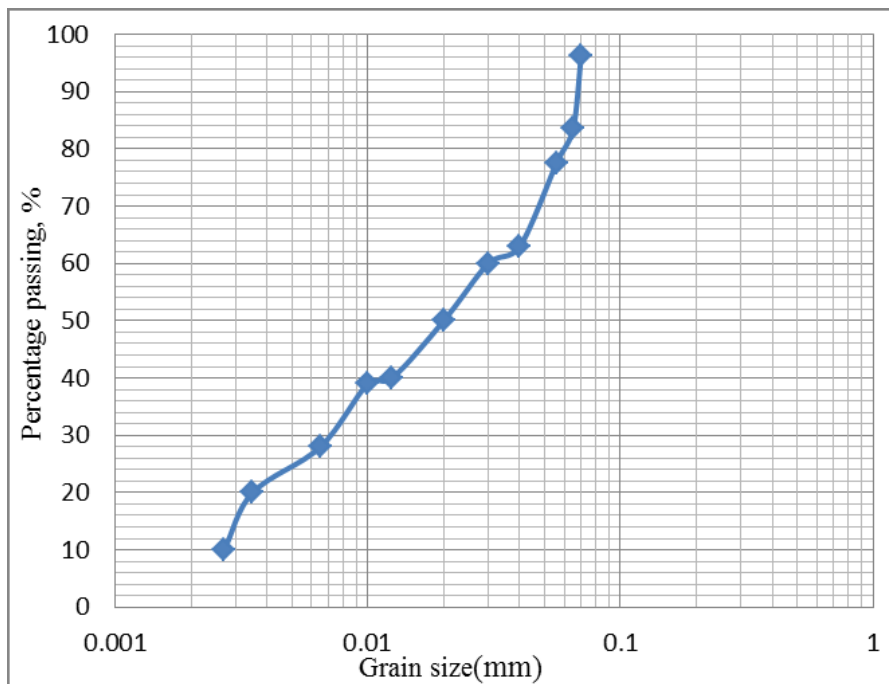
IV. RESULTS

4.1 Natural water content

Since the soil have been stored for long time without being totally sealed, water have evaporated from the soil. The measured natural water content 53 %, Table 2 therefore not correspond to the water content that the soil have in-situ before it was excavated at the site.

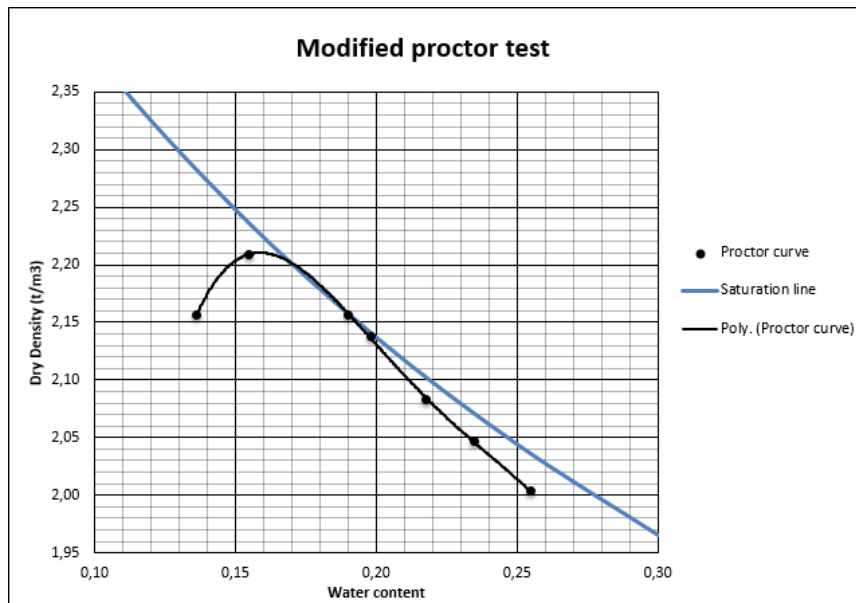
However the in-situ natural water content is 60-65 %retrieved from the geotechnical report that was made on the project where the soil comes from

4.2 Paricle size distribution curve of soil

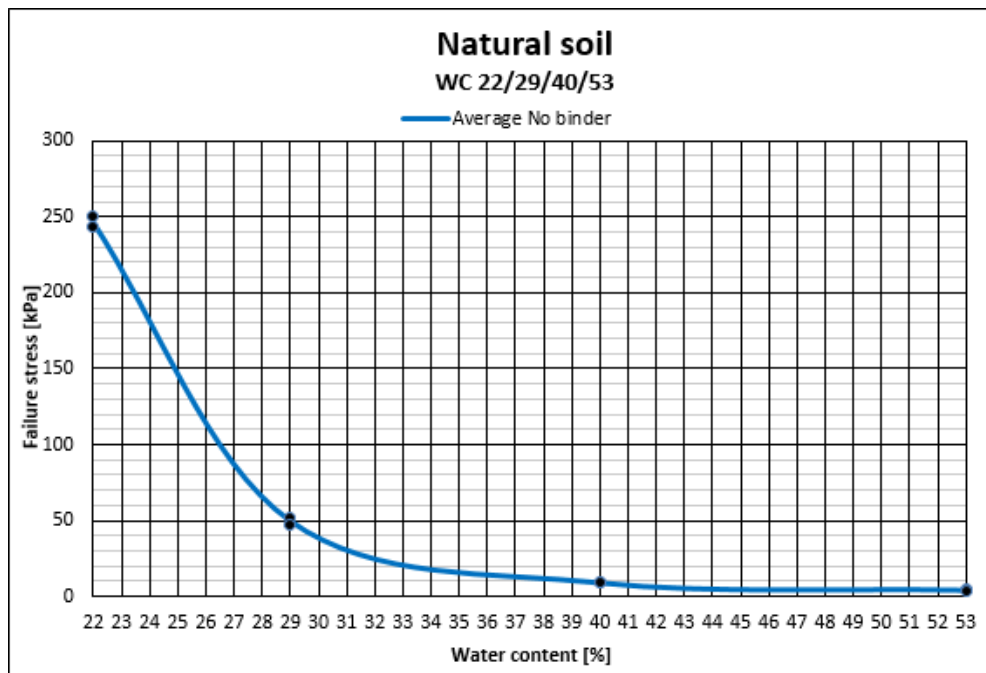


4.3 Modified proctortest

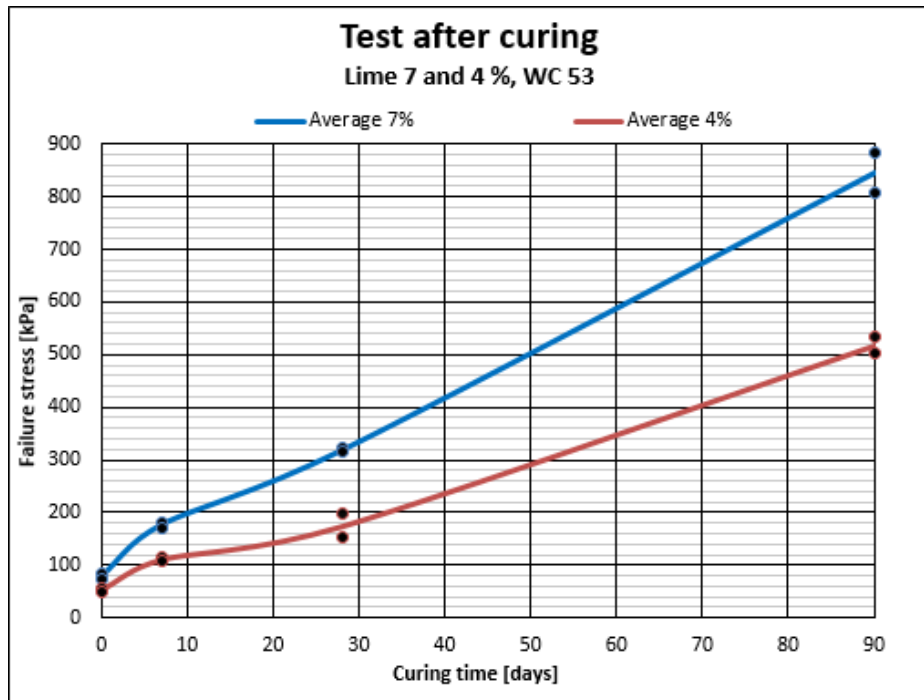
In order to perform compaction of clay in the proctor packing machine, soil was first air dried to a water content of 25,5 %. Between each compaction dried six times before the degree of compaction was decreasing and a curve that show the optimum water content with the highest degree of compaction could be obtained, see

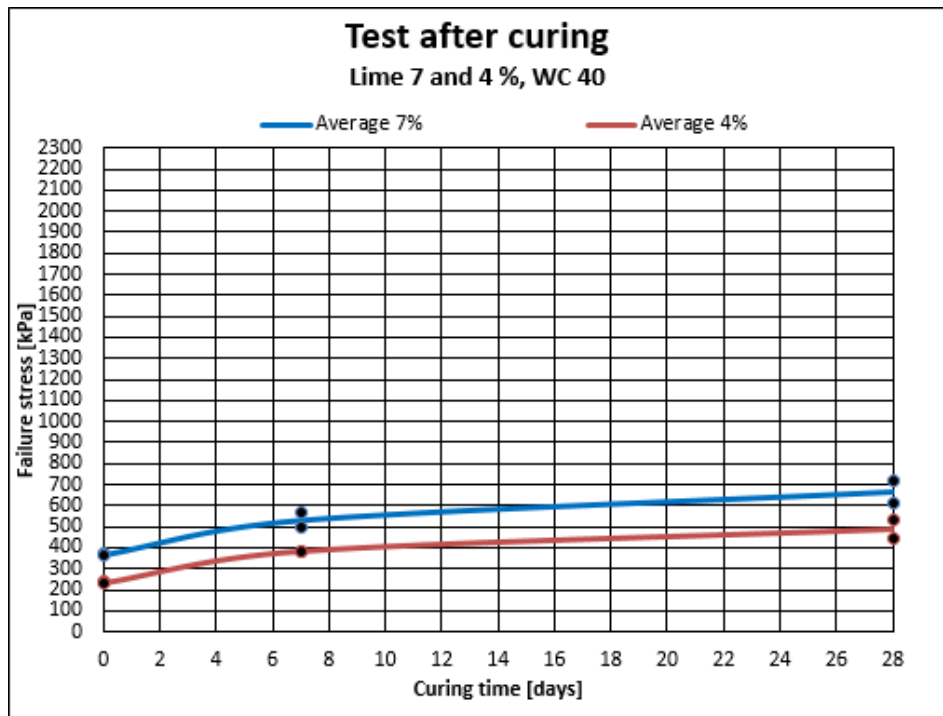


From the figure above an optimum water content is decided to be 16%, which gives a dry density of approximately 2.1 t/m³.



Test result after adding lime at 7 and 4%, and curing at different water contents





The strength increase by instead adding 7 and 4 % lime to soil with a water content of 53 % and curing it up to 90 days . This also compared to the strength of natural soil lime increase the strength from 4,2 up to 846 kPa (201 times) where about 19 times correspond to the immediately effect and 4 % lime increase the strength to 518 kPa (123 times) where the immediately effect correspond to about 13 times.

4.4 NUMEROUSADVANTAGESINBROADRANGE OFAPPLICATION

- In the time of a few hours, an unconditional soil is transformed by lime into a stabilized soil which can carry the traffic load sufficiently. An added bonus is that the soil becomes less sensitive to moisture. This immediate and spectaculareffect makes it possible to build job site roads that can be used regardless of weather condition.
- The technique makes it possible to retain high quality raw materials for quality applications. The building of embankments using moist plastic soils treated with lime can result in considerable savings on materials brought in from elsewhere, often at great cost, and the inevitably high costs of waste soil disposal.
- Lime treatment makes it possible to construct good quality capping layers and beds for roads, railway tracks, and runways. The stiffening/curing of the structure means that the slopes of the structure have greater stability.
- Because it is such a simple process, lime-stabilization of soil is easy to apply to “small” works, such as foundations for car parks, industrial platforms, and agricultural and forestry roads. The greatest benefits of this procedure, namely the savings on aggregate and disposal charges, are indeed the same as for all major earth moving works.
- Limitation of the need for embankment materials brought in from outside and the elimination of their transporting costs.
- Reduction of transport movements in the immediate vicinity of the construction site.

V. CONCLUSION

- Lime is used as an excellent soil stabilizing materials for highly active soils which undergo through frequent expansion and shrinkage.

- Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, increase in CBR value and subsequent increase in the compression resistance with the increase in time.
- The reaction is very quick and stabilization of soil starts within few hours.
- The graphs presented above give a clear idea about the improvement in the properties of soil after adding lime

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