

# The Strength Behaviour of Lime Stabilized Organic Clay Soil Modified by Catalyst Additeives

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## الخلاصة

يمكن العثور على التربة الطينية العضوية في العديد من الأراضي المستصلحة الكبيرة الحجم. هذه التربة تؤدي الى طاقة هطول عالية ومقاومة منخفضة والتي تحتاج الى تحسين بوسائل وتقنيات تحسين الارض. واحدة من التقنيات منخفضة التكلفة هو تحسين التربة مع الجير في الموقع لجعله عملي للبناء وتمكنه من زيادة في القوة من خلال ردود الفعل البوزولانية بين الجير والمعادن الطينية. ومن المعروف ان الجير هو وسيلة فعالة لتحقيق الاستقرار للتربة الطينية. ومع ذلك، قد يكون لها فعالية أقل مع الطين العضوي نتيجة لانخفاض فعالية في خصائص القوة. وبالتالي، تتناول هذه الدراسة إضافة محفزات مثل الزيولايت الذي يؤدي إلى تحسين أداء استقرار الجير لتسريع التفاعلات الطين والجير العضوية. يجري اختبار الضغط غير المحدد (UCT) على عينات أعيد تشكيلها (80 mm, 38 mm) لمدة انضاج (0, 7, 14, 28, 90) يوما. ان إضافة الزيولايت الاصطناعية يؤدي الى زيادة القوة في التربة العضوية بنسبة 185% في 90 يوما فترة في المزيج من التربة العضوية + 10% الجير + 10% الزيولايت. ان ارتفاع قيمة UCS تدل على أن الزيولايت هو حفازا فعالا لتعزيز استقرار الجير.

**الكلمات المفتاحية:** التثبيت بالجير، اضافات محفزة، الزيولايت الاصطناعية، الطين العضوية

## Abstract

The organic clay soil can be found in many large size reclaimed lands. These soils present enormously high settlement potential and low strength that needs to be improved by means of effective ground improvement techniques. One of the low cost techniques is to modify the soil with lime in-situ to make it suitable for construction and allow it to increase in strength by pozzolanic reactions between lime and clay minerals. Lime is known to be an effective stabilization material for clayey soil. Nevertheless, its effectiveness may be less with organic clay due to low effective strength properties. Thus, this study concerns the addition of catalyst i.e. zeolite which may improve the performance of lime stabilization to accelerate lime-organic clay reactions. The unconfined compressive test (UCT) is conducted on remoulded samples (38mm x 80mm) for 0, 7, 14, 28, and 90 days of curing period. The addition of synthetic zeolite in lime-organic stabilized soil has increased the soil strength by 185% at 90 days curing period at the design mix of organic clay + 10% lime +10% zeolite. The higher value of UCS indicates that zeolite is an effective catalyst to enhance lime stabilization.

**Keyword:** Lime Stabilization, Catalyst additive, Synthetic Zeolite, Organic Clay

## 1. Introduction

The most critical problem of construction on organic clay is low undrained shear strength and low bearing capacity. This result is influenced by the appearances of some organic matter which consist of humic acid more than 2%. Organic matter will act as 'masking' in which it will coat the primary source of organic or inorganic clay minerals (silica and alumina) thus will affect the pozzolanic reaction in stabilization process. Consequently, the construction over them may experience bearing capacity failure induced by its low shear strength. Therefore, these soils should be improved before any engineering works can commence (Yunus, 2007).

Various techniques are available to reduce this problem. The important of a basic decision must therefore to take into account whether to use the original site material and design to standard sufficient by its existing quality or: to replace the site material with the superior material or: to create a new site material that suites the standard requirement by altering the properties of existing material using stabilization technique (Ingles, 1972). However, replacement of this poor soil by suitable imported

fill materials is naturally very expensive especially when encountered with a thick layer. Therefore, one of alternative low cost techniques is to modify the soil with lime in-situ to make it workable for construction and allow it to increase in strength by pozzolanic reactions between lime and clay minerals(Eisazadeh, 2010).

It should be noted that many types of soils can be treated by the addition of small percentages, by weight, of lime, thereby enhancing many of the engineering properties of the soil and producing an improved construction material. However, regarding the nature of organic soil, the use of lime alone is not the most effective stabilizer although the use of lime stabilization of soil has been used extensively. This is due to low increase in strength which is attributed to the organic matters which have tendency to coat the soil particles causing the obstruction when lime is used as well as reducing the effectiveness of lime stabilization(Koslanant *et al*, 2006). Even though previous works on lime stabilization proved that some types of soil may be enriched, but some may not due to a reduction in compacted dry unit weight of clay soil (Dan Marks and Allen Haliburton,1972;Ingles,1972). Furthermore, this is due to the variation in clay fraction and soil minerals.

Reactions of lime-soil can be classified into short-term reactions and long-term, as stated by (Broms and Boman,1976). The short-term reactions (modification or flocculation) include hydration, migration of lime, pH, cation exchange reactions, and carbonation. During this phase, 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 as a result of flocculation of soil aggregates, making it easier to work and compact. These reactions influence the physical properties (i.e. Atterberg limits and particle size distribution) of the soil. This is accompanied by an increase in strength caused by both the dehydration and fundamental changes in the clay particle chemistry.

In particular, during this stage and when the lime is added to a clay soil, the divalent calcium cations present in the solution can easily exchange the unfriendly monovalent exchangeable cations that are adsorbed on the surface of clay lattice. This substitution causes alteration in the density of electrical charges around the clay particles known as the zeta potential, and it also causes a sharp reduction in the repulsive diffuse double layer forces. This would lead to the closer proximity of clay particles and their edge to face attraction. The process which is called "flocculation and agglomeration,"generally occurs in a matter of hours. The net results of cation exchange and modification that took place in this stage have many influences on the structure and behaviour of clay soils (Rogers *et. al.*,1996). These effects include; the conversion of the structure into soil aggregates or clusters of larger size, increased internal fraction between clusters, due to the flocculated structure, significant reduction in the capability of the clay changes the moisture that is caused by the sharp reduction in the thickness of the double diffuse layer, and also further improve workability due to texture changes from a plastic clay plate in a brittle material such as needle like material.

Whereas, the long-term reactions that take place after the modification phase are time dependent and they continue for a long period. It is termed soil stabilization, which indicated as a strength gain phase via a pozzolanic reaction (Glendinning *et. al.*,1998).These reactions have been studied and reported in detail by many researchers including Arman and Munfakh (1970);Eades and Grim (1960); and Diamond and Kinter (1965). This process leads to alteration in the clay's mineralogy and the results in the formation stable cementitious products calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). The pozzolanic products are obtained in the phase when they are added appropriate amounts of lime and water are added,

the soil pH increases rapidly above 10.5, which allows the particles of clay to break down. Silica and alumina are released and they react with calcium lime to form calcium silicate-hydrate (CSH) and calcium-aluminate-hydrates (CAH). Therefore, the pozzolanic reaction can continue in the presence of silica and alumina in strongly alkaline conditions, and as long as enough residual calcium ions are present in the system, CSH and CAH have been identified as the main reaction activity for good stabilization of the soil-lime according to the following (Little, 1995).



These cementitious products form the matrix that contributes to flocculation by coating and bonding adjacent soil particles together and as the hardening that reinforces the soil occurs. Also, because this matrix produces, the soil is changed from a sandy granular material to a hard, comparatively impermeable layer with a considerable bearing capacity. The process activates within hours and may continue for years in a well-designed system, to form matrix, which is stable and durable, and substantially impermeable, producing a structural layer that is both strong and flexible. However, in the early periods of the reaction, the cementitious products are often poorly crystalline and amorphous in nature.

Modification and stabilization are the processes caused by the reaction between lime and clay (Rogers & Glendinning, 1997). Modification is a short term reaction which occurs rapidly within 24 to 72 hours after the addition of lime. During the process, dehydration reaction takes place to remove water through the production of steam. In addition, metal ions associated with the clay may exchange with calcium ions released by the lime. This flocculation reaction will cause plasticity of clay decreased and increased the strength of the soil under any given normal stress condition (Rogers & Glendinning, 1997).

Three mainly reactions which give a major strength gain of lime treated clay are dehydration of soil, ion exchange and flocculation, and pozzolanic reaction. Mechanisms such as carbonation only cause minor strength increase of soil and can be neglected. The use of lime as a natural stabilizing agent for clay will produce a binder by slow chemical reactions mainly with silicates in the clay mineral.  $\text{Ca}(\text{OH})_2$  is formed due to hydration process when lime ( $\text{CaO}$ ) is added to soil (Koslanant, Onitsuka & Negami, 2006). During the hydration process, larger amount of pore water evaporates because of the heavy heat release induced by an increase of temperature

Chemical stabilizer mostly functions to modify the soil properties by means of some additives (Ingles & Metcalf, 1972). The addition of zeolite, may act as catalyzer to accelerate as well as help lime increase the strength of organic soil. To extend this finding, lime with addition of catalyst were examined for soil stabilization. Addition of catalyst such as zeolite may improve the long term performance of lime stabilization due to the enhancement in the pozzolanic reaction.

Zeolites are alumina-silicate minerals commonly used as commercial absorbents. Compositionally, zeolites are similar to clay minerals. However, they have different crystalline structure in comparison with the other clay minerals. Zeolites have a rigid, 3-dimensional crystalline structure (similar to a honeycomb) consisting of a network of interconnected tunnels and cages. Water moves freely in and out of these pores but the zeolite framework remains rigid (Perraki *et. al.*, 2003).

There are two types of zeolite which are natural zeolite and synthetic zeolite. Natural zeolites form where volcanic rocks and ash layers react with alkaline groundwater. They are rarely pure and are contaminated to variable degrees by other minerals, metals, quartz, or other zeolites. As concluded by (Kassim and chern, 2004),

using this type of zeolite tends to be ineffective stabilization with lime due to the presence of quartz, and also due to its impure composition.

The other type of zeolites is synthetic zeolite which forms by a process of slow crystallization of a silica-alumina gel in the presence of alkalis and organic templates. They are considered as the best in comparison to the natural type of zeolites. This is attributed to the fact that the synthetics can be manufactured in a uniform, phase-pure state. Thus, it can manufacture the desirable zeolite structures which do not appear in nature (Perraki *et. al.*,2003). Furthermore, a synthetic zeolite is a well-known example due to the principal raw materials used to manufacture zeolites of silica and alumina, which are among the most abundant mineral components on earth.

Zeolite additives to lime stabilization may increase the strength of mixture (Koslanant *et. al.*,2006).The addition is as pozzolans that act as catalyzer to accelerate as well as helping lime to increase the strength of soil. A pozzolan is a material which exhibits,when combined with calcium hydroxide to form calcium silicates cementitious properties when combination. However, many pozzolans available for use in construction today were previously seen as waste products, and often finish up in landfills. It should be noted that using these pozzolans can permit a decrease in the use of Portland cement when creating concrete, this is more environmentally approachable than limiting cementitious materials to Portland cement.

This research was carried out to investigate the effectiveness of lime-zeolite in stabilizing the weak soils like an organic soil. Furthermore, this study was applied to establish the optimum mix of lime and zeolite additives for effective organic soil stabilization.

## **2. Laboratory Experimental Works**

There are some tests should be conducted for soil and lime in the laboratory to ensure that the soil is suitable for stabilization and to determine the adequate amount of lime to be used. The classification test for soil involves specific gravity, Atterberg limit and particle size distribution whereas the suitability test involves initial consumption of lime. Also, a set of compaction test has been carried out on the mixture of soil-lime-zeolites to obtain the maximum dry density (MDD) and optimum moisture content (OMC).These values are important for sample preparation for Unconfined Compressive Test (UCT) that has been done after curing at 0,7,14, 28 and 90 days. 36 sets of UCT have been tested to investigate the effect of lime stabilization ranging from 5% and 10% on the strength development. To examine the influence of soil stabilization , an addition of lime with zeolite was performed by different concentration ranges from 2.5%, 5%, and 10%. It Should be noted that all the laboratory testing on lime and soil are carried out in accordance with BS1377 (1990): Part 1, Part 2, Part 3 and Part 4 and BS1924 (1990): Part 1 and Part 2.

The test specimens were prepared by varying the proportion of hydrated lime and then a known proportion of zeolite was added to soil paste. Analysis was carried out for geotechnical properties by relating the effects of 5 and 10 % lime. This latter range is more prominent for pozzolanic reactions (Kassim and Chern, 2004). Furthermore, it was taken 0,2.5%, 5% and 10 % zeolite additions, after a 7, 14, 28, and 90 days curing period.

### **2.1 The Materials**

Based on particle size distributions analysis, the soil used in this investigation consists of 6.81% sand and 77.35% of fines (55.52% of silt and 21.83% of clay). Therefore, this soil is suitable to be stabilized with lime as it is categorized as fine grained soil. Furthermore, the percentage of clay is more than 10%, thus it meets the

requirements for lime stabilization (Locat,1996).The chemical and physical properties of the untreated natural soil are presented in Table 1.

**Table 1:** The chemical and physical properties of the untreated organic clay

Engineering and Physical Properties	Values
Specific gravity	2.42
Liquid limit, L.L (%)	52.4%
Plastic limit, P.L (%)	35%
Plasticity index, P.I (%)	17.4% > 10
BS classification	MH (high silt)
ICL(%)Initial Consumption of Lime	5%
Max. dry density (Mg/m <sup>3</sup> )	1.47
Optimum moisture content (%)	25.53
Unconfined compressive strength (kpa)	36

A hydrated lime  $\text{Ca}(\text{OH})_2$  is used in this study. It works well with clayey soils, especially those with moderate to high plasticity index ( $\text{PI} > 15$ ). Inspection of the lime quality used in this investigation is essential as it determines the effectiveness of lime modification and stabilization. Standard means of specifying the content of lime should be used. Based on the test, 5.0% of hydrated lime is the minimum percentage of lime needed for soil stabilization. This value plays an important role in order to sustain the strength producing lime-soil pozzolanic reactions (Das, 1990;Maher *et. al.* 2005). Once after conducting the test for lime and soil have been done, clay that has been treated will be stabilized with different values of zeolite content at the optimum concentration of lime.

Regarding the type of zeolites that is used in this research, it is a stable synthetic zeolite processed by hydrothermal method.

## 2.2 Preparation of Specimens

In this study, all the soil samples were prepared from oven-dried soil broken into smaller sizes and sieved through a 2 mm sieve. The sieving was done to ensure that the soil was of uniform grade.

As noted, the clay in all cases was oven-dried to obtain its initial dry weight after being mixed with the required amount of water at optimum moisture content and its respective percentage of hydrated lime. Zero percentage of lime tests refers to the investigation for no longer than 1 hour after addition of water. As for fine-grained materials, specimens were prepared and compacted to predetermined density in a cylindrical steel mould of dimensions 100 mm high x 50 mm diameter having two steel plugs (BS 1924:Part 2:1990 Section4). The aim for this test is to determine the strength of the soil treated by lime as well as soil treated by lime additives. It is a special type of unconsolidated-undrained test that is commonly used for clayey specimens. Based on the UCT principle, the confining pressure is equal to zero. Clay specimen will be tested until failure when an axial load is applied rapidly to the specimen. At failure, the total minor principal stress is zero while the total major principal stress is  $\sigma_1$ .

After extrusion, the specimen were stored at room temperature and sealed with paraffin wax in PVC tubes in accordance with BS 1924: Part 2: 1990 to minimize loss of moisture content and also to prevent access carbon dioxide. For each stabilizer content, at least two specimen were tested by compression testing machine at a steady rate of axial deformation of approximately 1 mm / min after 0,7,14, 28 and 90 days of curing.

### 3. Results and Discussions

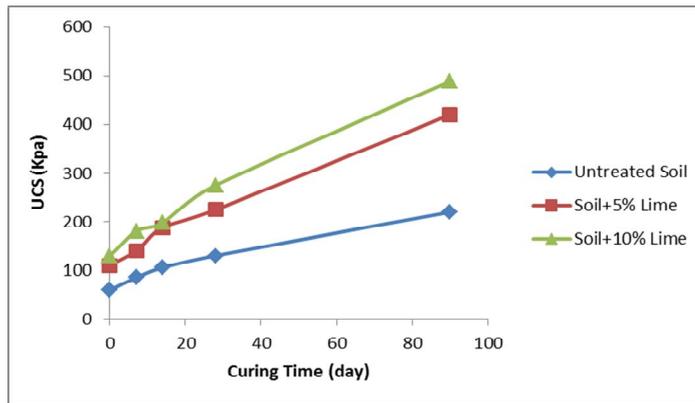
The determination of OMC and MDD also necessary to get after lime has been added to the soil. This is because adding lime will change the soil's OMC and MDD. Table (2) shows a result of compaction test performed on clay soil, lime treated clay soil, and lime treated clay with addition of zeolite at different concentration.

**Table 2:** The results of compaction test

Sample	MDD (mg/m <sup>3</sup> )	OMC(%)
Untreated	1.47	25.53
Clay + 5% Lime	1.38	29.23
Clay + 10% Lime	1.277	33.6
Clay + 10% Lime +2.5% Zeolite	1.43	25.8
Clay + 10% Lime +5% Zeolite	1.44	27
Clay + 10% Lime +10% Zeolite	1.38	29

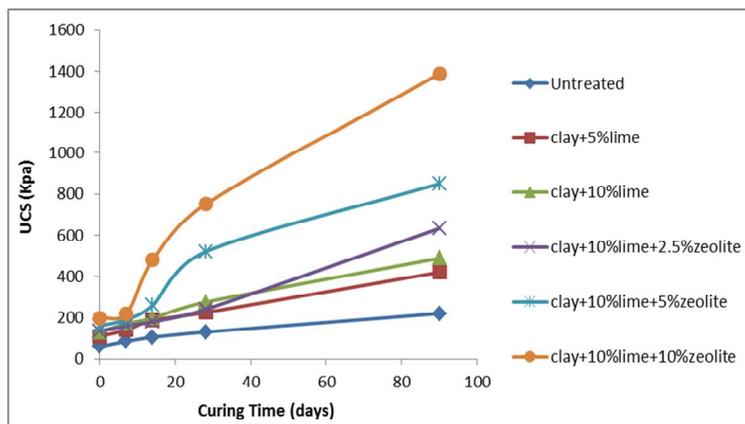
It can be noticed from the results shown in the table that there was, decrease in the dry density and increase in the moisture content with further addition of lime. These results were attributed to the ion exchange and flocculation of soil particles which make soil particle more friable for compaction as reported by (Kassim and Chern,2004).However, the addition of zeolite led to reduce the MDD due to the flocculation and agglomeration behaviour of soil particle which tend to minimize the compatibility and then the density of treated soil. On the other hand, there was an increase in the optimum moisture content with zeolite addition. This behaviour was attributed to the higher consumption of water for the reaction to take place. Furthermore,when zeolite acts as pozzolans, it reduces chloride permeability and improves workability. It reduces the weight and helps moderate water content while allowing for slower drying.

The unconfined compressive strength (UCS) of organic clay-lime at different days of curing period (0,7,14,28 and 90 days) was summarized in Figure 1. From the results, it can be noticed that the lime content and the time are the effective factors on the strength development for the organic clay–lime mixtures. Thus, it can be observed that there was an increase in the UCS values for the organic clay with the increasing the stabilizer content, and also with progressing in time. The figure shows that the strength increases with time especially after 28 days. This is due to the fact that the mixture almost reaches the stable condition after 28 days from the curing. Furthermore, this indicate a continuous pozzolanic reaction. While, before day 14, the mixture is going through modification process where the flocculation and rearrangement of soil particle provide instability of the mixture (Hussein, 2014) and (Yunus, 2007).



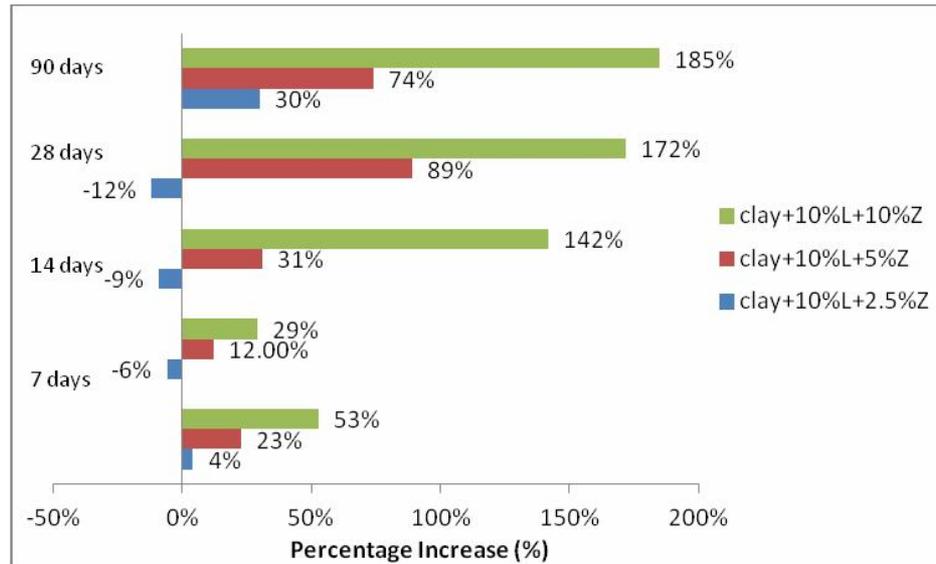
**Figure 1:** UCS of untreated organic clay and lime treated clay at different curing period

Figure(2), shows the effect of various percentages of zeolite addition at different days of curing period (0, 7,14, 28 and 90 days). Prior analysis indicates that stiffness of organic clay stabilized with lime will improve with addition of synthetic zeolite. Therefore, based on the study it is proved that the strength of lime treated clay will increase with addition zeolite. Figure 2 shows the strength of organic clay, one stabilized with 10% lime and 2.5% ,5%, and 10% of synthetic zeolite at 0,7,14,28 and 90 days.



**Figure 2:** UCS of 10% lime treated organic clay with 2.5%, 5%, and 10% zeolite at different curing time

It can be seen that the percentage of strength increases in as compared lime stabilized organic clay without additives, and with zeolite additive as shown in figure (3). From the graphs; it can be concluded that a small addition of zeolite is not effective in improving lime stabilization. This is due to the insufficient minerals needed to react and to bond the lime and zeolite minerals. However, when the percentage of zeolite increases, the strength tends to be higher and it is really effective in enhancing lime stabilization of organic clay. Cementations are required to bridge between the particles and this leads to higher strength on the mixture part (Kassim and Chern, 2004).



**Figure 3:** Strength percentage increase in soil + 10% lime + 2.5% , 5%, and 10% zeolite compared with soil + 10% lime stabilization

#### 4. Conclusion

Based on the results the conclusion are listed below

- 1- The physical and strength properties of the lime -treated organic clay soil, and of the lime-zeolite treated organic clay soils can be summarized as following below:
- 2- It should be mentioned that the compaction parameters are vital during the work and prior to the preparation of sample for strength test.
- 3- It was noticed from the standard proctor compaction test, that there is a decrease in the maximum dry density and increase in the moisture content when the lime is added to the organic clay soil. This is attributed to the nation that the ion exchange and flocculation of soil particle occurs make soil particle more friable for compaction, and also due to the higher consumption of water required for the reaction to take place. However, that the same trend is observed for the dry density and moisture content with addition the zeolite in comparison to the untreated soil.
- 4- It can be concluded from the results that the addition of synthetic zeolite shows a significant improvement in shear strength with an increase of about 185% compared to lime stabilized soil at an optimum mix of 10%lime +10% zeolite cured after 90 days.

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