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Effect of Curing Period on the Geotechnical Properties of Lime Treated Organic Soils

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Abstract. Organic soils are characterized by their high water holding capacity, low shear strength and large compressibility. The properties of organic soil have to be improved before using it for any construction purpose. Lime stabilization is one of the most popular methods used to enhance the properties of clayey soils. Previous studies have shown that the improving effect of lime gets deteriorated in the presence of organic matter with time. In this paper an attempt is made to study the effect of longer curing period (up to 120 days) on the geotechnical properties of lime treated organic soils. The tests were carried out on artificially prepared organic soil mixtures treated with 6% lime. Various laboratory tests like Atterberg limits test, free swell index test, unconfined compressive test and one dimensional consolidation tests were conducted on artificial organic soil treated with lime at different curing periods (0,7,30,60,90 and 120 days) to examine the effect of each parameter. The test results reveal that the effect of lime stabilization is nullified by the presence of organic matter at longer curing periods. The plasticity characteristics of lime treated organic soils varied with curing period. The unconfined compressive strength of lime treated organic soil decreased after 90 days of curing. Compression index of lime treated organic soil samples increased after 120 days curing period.

Keywords: Organic Soil, Lime Stabilization, Atterberg Limits, Unconfined Compressive Strength, Compressibility Characteristics.

1 Introduction

Organic soils are mostly composed of decayed plant matter and weathered rock material. These soils are known for their inferior engineering behavior such as very high compressibility and low shear strength. In order to improve these properties, organic soils are modified with calcium based stabilizers like lime, cement and fly ash [1]. Lime is the most common stabilizer used to improve the engineering behavior of weak soils, especially clay. Furthermore, lime is also considered as a low cost material, making it a popular choice amongst many other effective stabilizers [2]. In contrast with lime stabilisation of inorganic clay, reactions between lime and clay are not efficient when organic matter is present in clay minerals. There is evidence in the literature that, the presence of high concentrations of organic matter in clay can adversely affect the chemical reaction between lime and clay minerals and can have detrimental effects on the engineering properties of soil[3]. The factors that influence the mechanism in lime- treated organic clay is the moisture content and the insufficient dissolution of the clay minerals during the pozzolanic reaction. Organic matters possess high water retention capacity which limits the quantity of water available for the hydration process. Also, the high water content may produce more spacing between aggregates, thereby reducing the required cementation bond[4]. It has also been observed that organic matter coats the clay particles and thereby behaves as a barrier to lime and clay[5]. Previous studies have shown that the improving effect of lime gets deteriorated in the presence of organic matter with curing period. In this paper the effect of lime treatment on the engineering properties of highly organic soils for longer curing period (up to 120 days) are investigated and summarized.

2 Materials Used for the Study

2.1 Bentonite

Bentonite is naturally occurring clay with unusual properties like very high swelling capacity, high ion exchange capacity and very low water permeability[6]. For the present study, commercially available sodium bentonite was used. All the tests were conducted on samples prepared using this soil since it contains no organic matter. The physical properties of bentonite used are given in Table 1.

Table 1. Physical properties of the bentonite

Property		Test value
Moisture content	(%)	25
Liquid limit	(%)	326
Plastic limit	(%)	45
Plasticity index	(%)	281
Shrinkage limit	(%)	9
Clay size (<0.002 mm)	(%)	81
Silt size (0.002- 0.075 mm)	(%)	16
Sand size (>0.075 mm)	(%)	3
Free swell index	(cc/g)	6.25
Specific gravity		2.7

2.2 Organic matter

Vermicompost collected from College of agriculture, Vellayani, Thiruvananthapuram was used in the study to convert sodium bentonite into an organic soil. Compost has high cation exchange capacity and hence can increase the cation exchange capacity of soil when added to it. Also, the most essential nutrients in compost are in organic forms which are released slowly. Soil structure can be improved by the binding action between soil organic matter and clay particles via cation bridges and through simulation of microbial activity[6]. The physical properties of organic matter used in the study are summarized in Table 2.

Table 2. Physical properties of organic matter

Property		Test value
Moisture content	(%)	105
Liquid limit	(%)	165
Plastic limit	(%)	79
Plasticity index	(%)	86
Shrinkage limit	(%)	40
Organic content	(%)	32
Free swell index	(cc/g)	3.85
Specific gravity		2.05

2.3 Lime

Hydrated lime[$Ca(OH)_2$] was used for the treatment. Hydrated lime was prepared by sprinkling water over lime shells and the crumbled shells were then sieved through IS 425 micron sieve.

3 Experimental Investigation

In this study ,the effect of curing period on the Atterberg limits, unconfined compressive strength, compressibility and swelling of lime treated organic soil samples was investigated. In the experimental investigation, artificial organic soil was prepared by mixing bentonite with different percentages of organic matter (0%,50%,100%). The organic content in the soil was determined by loss on ignition method. By knowing the amount of organic content induced by the organic matter, the amount required to induce an organic percentage of 50% and 100% were calculated. The identified amount was mixed with bentonite and lime to obtain three different organic soil mixtures as given in Table 3. To study the effect of organic matter on lime stabilized clayey soil, the lime content was fixed from the literature as 6%.

Remoulded samples for unconfined compressive strength were prepared with the help of a metallic mould having 3.8 cm inner diameter and 7.6 cm length as per IS 2720-Part 10 [7]. Predetermined quantity of soil for the required density was filled inside the mould to make the specimen. The prepared samples were cured in labelled air tight polyethene bags. The cured samples were tested to study the effect of curing period. UCC and consolidation samples were made for different curing periods (0,7,30,60,90,120 days) and were kept for curing. All the specimens used in the study were prepared and tested using the standard procedures described by the bureau of

Indian standards. Three sets of identical samples were tested to ascertain the repeatability of the tests[8].

Table 3. Experimental program for the study

Sample description	Tests conducted	Curing period (days)
Bentonite + 6% lime	Atterberg limits tests	0 day 7days
50% bentonite + 50% organic matter + 6%lime	Free swell index test Unconfined compressive strength test	30 days 60 days 90 days 120 days
100% organic matter +6% lime	Consolidation test	

4 Results and Discussions

4.1 Atterberg limit test

Table. 4 shows the effect of curing period on liquid limit of lime treated organic soil. The liquid limit of lime treated bentonite decreased by 9.7% after 120 days curing period. On the other hand, there was an increase of 4.1% in liquid limit of soil sample containing 100% organic matter when compared to soil sample containing 50% organic matter initially and it further increased to 8% at 120 days curing period. Liquid limit is directly dependent upon the clay fraction of the soil. It is seen that water holding capacity of organic soils are more, this in turn also increases the liquid limit [9].

Table 4. Effect of curing period on liquid limit

Curing Period (days)	0	7	30	60	90	120
Sample Description	Liquid limit (%)					
Organic matter + lime	152	150	148	154	152	149
Organic matter + bentonite + lime	146	145	148	145	143	138
Bentonite + lime	310	315	305	299	282	280

The plastic limit of different soil samples at various curing period are given in the Table 5. The result shows that plastic limit increases with increase in organic content.

This may be due to the high colloidal nature of the organic matter, and also their surface area and water absorptive capacity are far in excess of those exhibited by the clays[7].

Table 5. Effect of curing period on plastic limit

Curing Period (days)	0	7	30	60	90	120
Sample Description	Plastic limit (%)					
Organic matter + lime	88	85	88	92	87	85
Organic matter +bentonite + lime	72	63	70	72	73	69
Bentonite + lime	51	48	50	52	48	49

The shrinkage limit of different soil samples at various curing period are given in the Table 6. From the test results, it is noted that shrinkage limit decreases with increase in organic content and curing period for lime treated organic soil samples. The decrease in shrinkage limit indicates the increase in the expansive nature of the soil with an increase in the percentage of organic content [9].

Table 6. Effect of curing period on shrinkage limit

Curing Period (days)	0	7	30	60	90	120
Sample Description	Shrinkage limit (%)					
Organic matter + lime	40	37	38	36	38	35
Organic matter + bentonite + lime	17	10	7	7	6	11
Bentonite + lime	9	8	5	10	4	7

4.2 Free Swell Index

Free Swell Free swell index (FSI) represents the ratio of swelled volume of the soil in water per unit weight of the soil. It is the simplest parameter to specify the swelling ability of soils[9]. Table 7 shows the variation of free swell index with curing period. For bentonite + lime soil mixture, the free swell index decreased by 20.7% at the end of 120 days curing period. The decrease in free swell index due to the addition of 6 % lime is attributed to the fact that bentonite cations are substituted by calcium, leading to the formation of calcium silicate and aluminate hydrates. The decreased affinity for water of the Ca-saturated bentonite and the formation of a cementitious matrix resists swelling and thus decreases the free swell index[10]. However, when organic matter was introduced, the free swell index increased by 7.8%.

Table 7. Effect of curing period on free swell index

Curing Period (days)	0	7	30	60	90	120
Sample Description	Free swell index (cc/g)					
Organic matter + lime	4.1	3.7	4	4	4.3	4
Organic matter +bentonite + lime	5	6.1	6.7	5.8	6.7	5.4
Bentonite + lime	10.9	9.1	9.1	9	8.7	8.7

4.3 Unconfined compressive strength

The effect of curing period on the unconfined compressive strength of different soil samples is shown in Fig. 1.

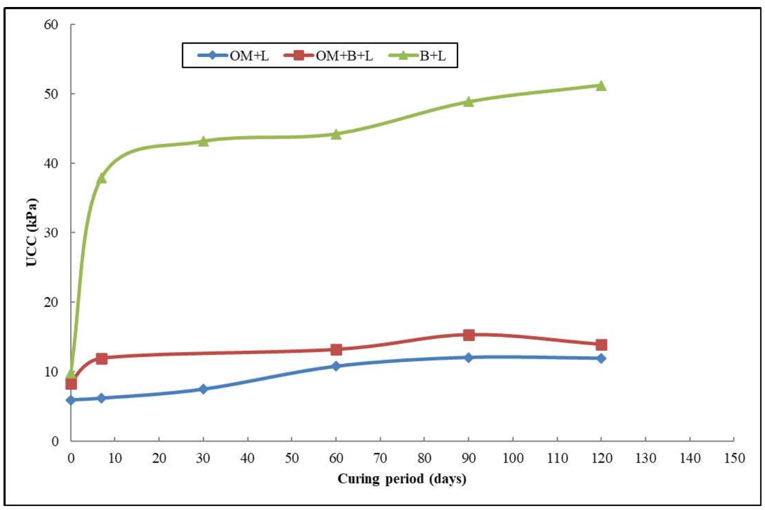

Fig. 1. Effect of curing period on unconfined compressive strength of different soil samples.

The unconfined compressive strength of soil sample containing lime and 100% organic matter was initially 5.95 kPa and it increased with curing period up to 3 months and then decreased. Same trend was observed in the case of lime treated organic soil + bentonite samples i.e. strength decreased after 3 months of curing period. For lime treated bentonite sample the strength increased with curing period. In case of organic soil the initial strength gain occurs since the effect of organic matter do not come into action. After 3 months of curing, the strength decreased because the organic matter inhibits the bond formation. Lime treated bentonite samples attained more strength even with higher water content which means the presence of organic matter is the only factor that reduced the strength of lime treated organic samples.

Percentages of strength loss increased with increasing organic matter content and with curing period. It was observed that after 120 days curing period, for lime treated organic soil + bentonite sample the unconfined compressive strength decreased by 73% when compared to lime treated bentonite sample. In the case of lime treated organic sample, the decrease was 77% when compared to lime treated bentonite sample. Similarly, when the organic matter was increased from 50% to 100%, the unconfined compressive strength reduced by 14.3% at the end of 120 days curing period. Hence it can be also concluded that, as the presence of organic matter increases, the strength of lime treated soil decreases drastically. In other words, lime treatment is ineffective in strength improvement for highly organic soils. Similar results were reported by Yunus et al [11] on lime treated organic soil.

4.4 Compressibility characteristics

The e-log p curves for different soil samples at 30 days and 120 days curing period are shown in Fig. 2 and Fig. 3 respectively. From figures 2 and 3, it can be seen that the e log p curve of lime treated soil samples have more slope i.e. the lime treated bentonite samples have more compression index and lime treated organic matter samples have the least compression index. After 120 days of curing period, it is observed that organic matter samples are more compressible than the bentonite samples. The reason for increasing compressibility of lime treated organic matter samples may be due to the aggregated structure by molecular complexion involving metallic, organic and clay molecules caused by the added organic substances[8].

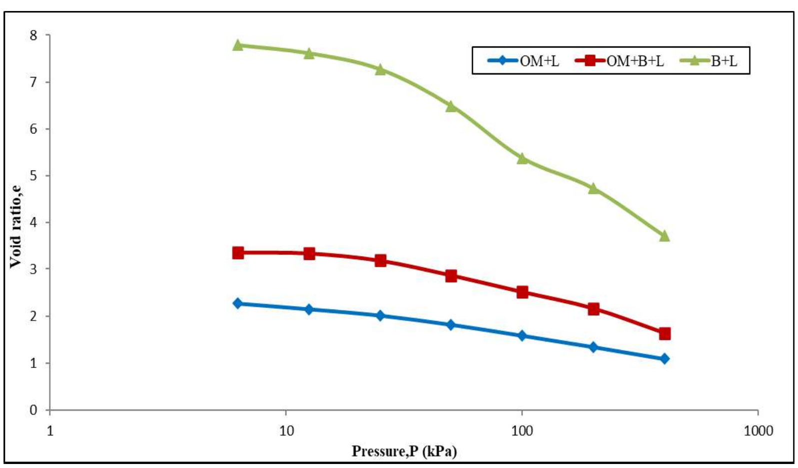

Fig. 2. e log p curve of different soil samples for 30 days curing period

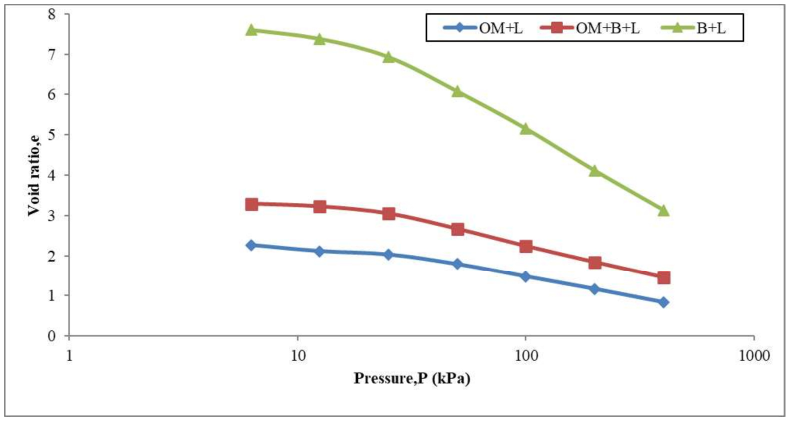

Fig. 3. e log p curve of different soil samples for 120 days curing period

Fig. 4 depicts the variation of de/d (log p) values with pressure range for different soil samples cured for 120 days. From the Fig. 4 it can be seen that the de/d(log p) value of lime treated bentonite samples increased with pressure and then decreased whereas the de/d(log p) value of lime treated organic matter samples increased with pressure.

At the end of 120 days curing period, the de/d(log p) value of lime treated organic soil increased by 6.1% when compared to lime treated organic soil + bentonite sample. We can conclude that the amount of compression undergone by the lime treated organic soil sample is significantly higher and goes on increasing with increasing organic matter content.

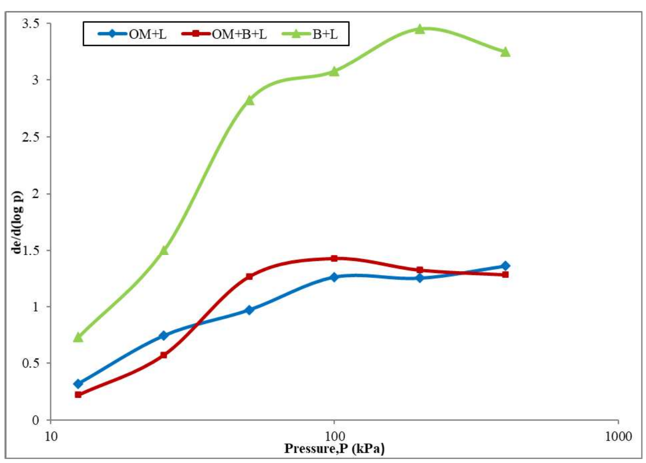

Fig. 4. Variation of de/d(log p) with pressure range for different soil samples cured for 120 days

Compression index is defined as the slope of e log p curve. The compression index is extremely useful for the determination of settlement in the field. Fig. 5 depicts the variation of compression index (Cc) values of lime treated soil samples for different curing periods.

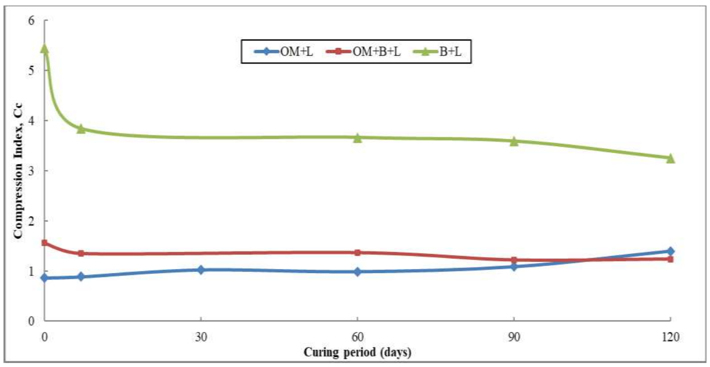

Fig. 5. Variation of compression index values with curing period of different samples for a pressure range of 200-400 kPa

From the Fig. 5 it can be seen that compression index values of lime treated bentonite samples decreases with curing period and that of lime treated organic matter samples increases with curing period.ie the lime treated bentonite samples become less compressible with curing whereas the compressibility of lime treated organic sample increases with curing period.

At the end of 120 days curing period, the compression index value of lime treated organic soil increased by 13% when compared to lime treated organic soil + bentonite sample. We can conclude that the compression index increases with increase in the organic matter content added into the soils. Therefore, the consolidation settlement increases with increase in the organic content added into the soils. The increase in the settlement may be due to the increase in the water content holding capacity of soils with an increase in the percentage of organic content[8].

4.5 Micro structural analysis

Microstructure of soil specimens was analyzed by the Fourier transform infrared spectroscopy (FTIR). Fourier transform infrared spectroscopy analysis is a powerful tool to identify the organic functional groups in soil samples. Infrared radiation is passed through a sample. Some of the infrared is absorbed by the sample and few of it is transmitted. The resulting spectrum represents a fingerprint of the sample with absorption peaks corresponding to the frequencies of vibrations between the bonds of the atoms making up the soil structure[12]. High transmittance at a frequency means there are few bonds to soak up that color light within the sample, low transmittance means there's a high population of bonds which have vibrational energies like incident light. In the present study, soil samples were characterized using Fourier transform infrared (Thermo Avtar 370 DTGS) in pressed KBr pellets. The spectral resolution was set to 4 cm−1, and 32 scans were collected for each spectrum over a range of 4000–400 cm−1. Fig. 6 shows the FTIR spectrum of soil samples at 120 days curing period. With the addition of organic matter, for the same frequency of 3430 cm^{-1} there was a reduction in transmittance from 31.5% in lime treated bentonite, to 10.12% in lime treated bentonite +organic matter soil due to aggregation[12]. For lime treated bentonite +organic matter soil, the formation of aliphatic C-H group was observed at an absorption band of 2900 cm^{-1}. For lime treated organic soil, an increase in transmittance was observed at a frequency of 3430 cm^{-1}.This can be attributed to the formation of flock which increased the particle size and pore size [12].These pores in the microstructure of this soil sample are responsible for the high compressibility and low compressive strength.

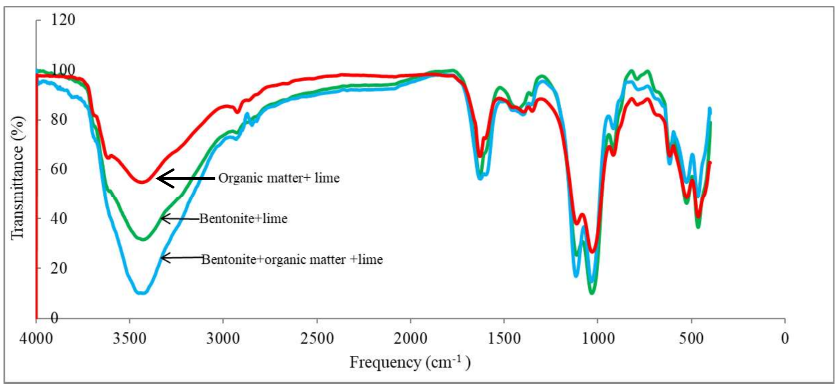

Fig. 6. FTIR spectrum of soil samples at 120 days curing period

5 Conclusions

From the results of experimental investigation conducted on lime treated organic soil samples, the following conclusions are drawn:

1. Liquid limit shows a decreasing trend with curing period. For lime treated bentonite sample liquid limit increases after one week and then decreases and for lime treated organic matter and organic matter + bentonite samples liquid limit decreases initially and then increases at two months and one month respectively and then again decreases.
2. With the addition of lime, plastic limit increases and the decreases initially for 7 days curing and then increases till certain curing period and then decreases.
3. UCS results shows that, strength of lime treated bentonite sample increased with 120 days curing whereas for lime treated organic matter samples

strength decreased after three months of curing (when the deleterious effect of organic matter came into action).

4. The compression index increases with increase in the organic matter content added into the soils. Therefore, the consolidation settlement increases with increase in the organic content added into the soils.
5. The pore size in the microstructure of lime treated organic matter samples increased after 120 days curing period.
6. The effect of lime stabilization is nullified by the presence of organic matter.

Hence, the results contribute to a better understanding of the impact of curing period on the stabilization of lime treated organic soils, which can ultimately provide a warning to the geotechnical engineers while choosing ground improvement methods for organic soils.

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