Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

INFLUENCE OF LIME STABILIZATION ON THE GEOTECHNICAL PROPERTIES OF AN EXPANSIVE SOIL

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ABSTRACT

In this research, geotechnical properties of a selected lime treated expansive soil have been investigated. For this purpose, initially, index and swelling properties of soil sample collected from Akhaura-Laksham were determined. The soil is classified as inorganic highly plastic clay as per USCS classification (Liquid Limit= 52%, Plastic Limit= 27%, Plasticity Index= 25%) and categorized as moderate to highly expansive soil according to recommended criteria given by various personals (Free Swell= 22%, Free Swell Index= 43%, Swelling Potential= 3.69%). The sample was treated with 3%, 6% and 9% lime content followed by index, swelling and engineering properties determination to examine the influence of lime stabilization on various geotechnical properties of this expansive soil. Compared with untreated soil samples, it has been seen that liquid limit of the treated samples initially decreased with the increasing lime content up to 6% but then increased with the increase in lime content Plastic limit of the treated sample increased considerably with increasing lime content. Compared with untreated sample, plasticity index and linear shrinkage of the treated samples decreased significantly with increasing lime content.

Swelling test results showed that free swell, free swell index and swelling potential decreased significantly with the increase in lime content. The experimental results on the influence of lime stabilization on swelling properties clearly demonstrate that lime can be considered as an effective and economical additive to reduce various swelling properties of expansive soil.
It has been found that with the increase in lime content, maximum dry density reduced while optimum moisture content increased.

Compared with untreated soil samples, the unconfined compressive strength of lime treated sample increased with the increase of lime content. It has been observed from the present investigation that long term curing has profound influence on the gain in strength. The effect of long term curing on the increase in unconfined compressive strength has been found to be more pronounced when samples were treated with higher lime contents.

It has also been observed that with the increase in lime content and curing age, the effective angle of friction and effective cohesion increased compared with untreated sample. It has also been seen that curing age plays a significant role in the increase of effective angle of friction and effective cohesion for a particular lime content.

Keywords: *Expansive soil, Free swell, Unconfined compressive strength.*

1. INTRODUCTION

1.1 General

Expansive soils are those which swell considerably on absorption of water and shrink on the removal of water. In many parts of the world, the possibility of damage to structures due to swelling of soils constitutes a severe problem in design and construction. 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. Improvement of its properties may be essential to meet the required soil condition for construction.

Stabilization is one of the most economical and desirable method for improving the strength, durability and resistance to deformation of in situ soil. There are several methods of soil stabilization for improving the physical and engineering properties. Undoubtedly, the most widely applied methods involve the use of inorganic cementative bonds between the particles in the soil system. 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.
Among several additives that are commonly used for the treatment of expansive clays, lime has, however, been most commonly used for the treatment of expansive clays and other clay soils as it improves the mechanical properties of expansive clays. Besides, it is economical and abundantly available in many parts of the world. Once treated with lime, soil can be used to create embankments or subgrade of structures, thus avoiding expensive excavation works and transport. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop.

1.2 Statement of The Problem

One would expect an enormous amount of damage to lightly loaded buildings on shallow foundation founded on expansive soils as the water content changes. Heavy buildings, however, may not suffer much vertical movement. Unless special precautions are taken to eliminate the effect of expansive soil, light buildings are often badly damaged by differential uplift as the volume of the soil changes.
In the recent past, damage to buildings and other structures due to swelling of soils have been reported from different parts of Bangladesh. Several instances were reported by Hossain (1983) and Khan (1995). In the region between Rajshahi and Nawabganj and the area surrounding Sreepur, especially the small structures as offices and staff quarters are severely and strangely cracked (BRTC, 1997). It is obvious that the lightweight structures that are designed and built by conventional techniques will be damaged in case of heaving (Kehew, 1995). But although highway embankments and roadways are generally insensitive to vertical movements, high maintenance costs should be overcome if constructed on expansive soils (Mowafy et al. 1985). Especially soils containing the clay mineral montmorillonite generally exhibit these properties. To understand and overcome these problems, expansive soils should be examined carefully and unsaturated soil mechanics should be taken into consideration.

1.3 Background of Lime Stabilization

The modern era of soil stabilization began during the 1960s and 70s when general shortages of aggregates and fuel resources forced engineers to consider alternatives to the conventional techniques of replacing poor soils at building sites with shipped-in aggregates that possessed more favourable engineering characteristics. Lime provides an economical as well as powerful way of chemical improvement. The standard utilization of lime stabilization is in the treatment of clay subgrade to create improved road foundation without necessity for large amounts of imported granular aggregates. In United States and Europe, lime stabilization is popular regarding improving traffic ability, loading capacity of foundations of road and embankment and also for erosion control. Contrary to lime modification, lime creates long lasting improvements in soils characteristics offering structural benefits.

1.4 Objective of Present Research

The research program has been intended to evaluate the behaviour and engineering properties (moisture-density relations, compressive strength and stiffness, durability etc.) of lime treated and untreated expansive soil collected from the Akhaura-Laksham railway zone. Objectives to be carried out in this research are as follows:

- To investigate the effect of lime stabilization on the index properties (e.g. liquid limit, plastic limit, linear shrinkage) on the selected expansive soil treated with three different percentages of lime contents (3%, 6% and 9%).
- To investigate the effect of lime stabilization on the swelling properties (e.g. free swell, free swell index and swelling potential) of the selected soil treated with three different percentages of lime contents (3%, 6% and 9%).
- To observe the effect of lime stabilization on optimum moisture content and maximum dry density of soil sample treated with 3%, 6% and 9% lime content.
- To observe the effects of lime content and curing age on unconfined compressive strength (q_u) soil sample treated with 3%, 6% and 9% lime content and cured at 7. 14 and 28 days.
- To observe the effects of lime content and curing age on effective cohesion (c') and effective angle of friction (φ') from direct shear test for soil sample treated with 3%, 6% and 9% lime content and cured at 7. 14 and 28 days.

1.5 Geology of the Project Area

Bangladesh can be divided into three major physiographic units namely, (i) The tertiary hill formations, (ii) The Pleistocene terrace and (iii) The recent flood plains. According to the study of Morgan and Mcintire (1959), there are two major areas of Pleistocene sediments, commonly known as the Modhupur tract and Barind tract and a small area in Akhaura. The Akhaura-Laksam residuum is composed of light-yellowish-grey, orange, light to brick-red and greyish-white, micaceous silty clay to sandy clay. The clay is plastic and abundantly mottled (patterned) in upper 8 m and contains small clusters of organic matter. Dominants clay minerals in this residuum are kaolinite and illite.

2. METHODOLOGY

Several equipment and instruments have been used for performing the tests required in this investigation. A detailed description of the laboratory investigations conducted on untreated and lime stabilized samples has been discussed here.

2.1 Laboratory Testing Program

The soil was collected from the Akhaura-Laksam railway zone. A comprehensive laboratory investigation program was taken to examine the physical, index, engineering and swelling properties of the soil. The sample collected from the field was disturbed sample.

2.1.1 Determination of Physical and Index Properties of Untreated Soils

The following tests were carried out to determine the index and physical properties of the sample:

- Specific gravity test (ASTM D 854)
- Grain size analysis (ASTM D 422)
- Atterberg limit test (ASTM D 4318)
- Linear shrinkage test (BS 1377)

2.1.2 Determination of Mechanical Properties of Untreated Soil Sample

The following tests were carried out on the soil samples to evaluate the mechanical properties.

- Standard Proctor compaction test (ASTM D 1577)
- Unconfined compressive strength test (ASTM D 2166)
- Consolidated drained Direct shear test (ASTM 3080)

2.1.3 Determination of Swelling Properties of Untreated Soil Sample

Swelling tests included determination of the following swelling properties:

- Free swell
- Free Swell index
- Swelling potential

2.1.4 Determination of Change in Index, Swelling and Mechanical Properties of Lime Treated Soil Sample

Based on the index and swelling properties, a suitable expansive soil to be treated with lime stabilization was selected. The following tests were carried out on the selected expansive sample:

- Index properties (e.g. Atterberg Limit, Linear Shrinkage) of the soil treated with three different lime contents (3%, 6% and 9%) were determined.
- Swelling properties (e.g. Free Swell, Free Swell Index, Swelling Potential) of the soil treated with three different lime contents (3%, 6% and 9%) were determined.

The following tests were also carried out on the selected expansive soil with three different lime contents (3%, 6% and 9%).

- Standard Proctor compaction test (ASTM D 1577)
- Unconfined compressive strength test (ASTM D 2166)
- Consolidated drained Direct shear test (ASTM 3080)

Compressive strength and direct shear test on the cured samples was carried out on curing at 7 days, 14 days and 28 days.

3. RESULTS AND DISCUSSIONS

The findings of the laboratory investigations on soil samples collected from Akhaura-Laksham are reported and discussed here. In the following sections, the physical and engineering characteristics comprising plasticity and shrinkage properties, swelling properties, moisture density relations, unconfined compression strength and direct shear strength of untreated and treated soil with 3%, 6% and 9% lime content are presented and discussed.

3.1 Index Properties of Soil

The flow curve of soil sample determined in the laboratory is shown in Figure 1. From the curve, liquid limit is found to be 52. Specific gravity and other index properties from the Atterberg limit test are shown in Table 1. For LL=52 and PI=25, it is found from Figure 2 that our soil is CH (highly plastic clay).

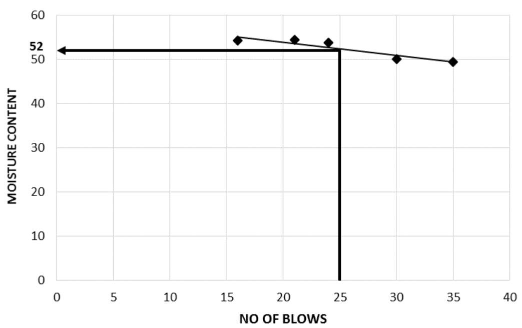

Figure 1: Flow Curve

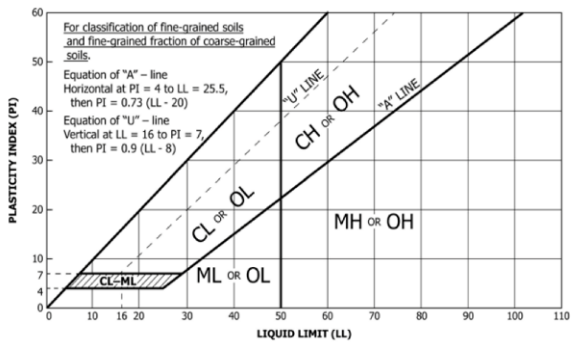

Figure 2: Cassagrande Plasticity Chart

From grain size analysis, it was found that soil sample contains Sand (larger than .06 mm) 1%, Silt (.002 to.06 mm) 45% and Clay (smaller than .002 mm) 54%. From Table 2, it can be seen that according to AASHTO classification soil sample is A-7-6 and USCS classification soil sample is CH.

Table 1: Identification of Index Properties

Specific Gravity	2.62
Liquid Limit	52%
Plastic Limit	27%
Plasticity Index	25%
Linear Shrinkage	11%

Table 2: Summary of Results Derived From Grain Size Analysis

Sand	**Silt**	**Clay**	**Soil Classification**	
			USCS	AASHTO
1%	45%	54%	CH	A-7-6

3.2 Swelling Properties of Soil

A summary of swelling properties is presented in Table 3. Assessment of degree of expansion based on different parameters proposed by various shown in Table 4.

Table 3: Identification of Swell Properties

Free Swell	**Free Swell Index**	**Swell Potential**
22%	43%	3.69%

Table 4: Assessment of Degree of Expansion

Plasticity Index and Shrinkage Limit (Holtz, 1956)	High
Liquid Limit and Plasticity Index (IS: 2911, 1980)	High
Liquid Limit and Plasticity Index (Snethen, 1959)	Marginal to High
Linear Shrinkage (Hossain, 1983)	Medium
Free Swell (IS: 1948, 1970)	Low
Free Swell Index (IS: 2911, Part III, 1980)	Medium
Swelling Potential (Seed et al., 1962)	Medium

3.3 Moisture Content- Dry Density Relationship

Standard Proctor was carried out to know the compaction energy of the soil sample. Maximum dry density and optimum moisture content were found for the compaction energy. Moisture- density curve is shown in Figure 3. From this Figure, it has been seen that the optimum moisture content was found to be 17% for Standard Proctor. The maximum dry density was found to be 16.65 kN/m^3.

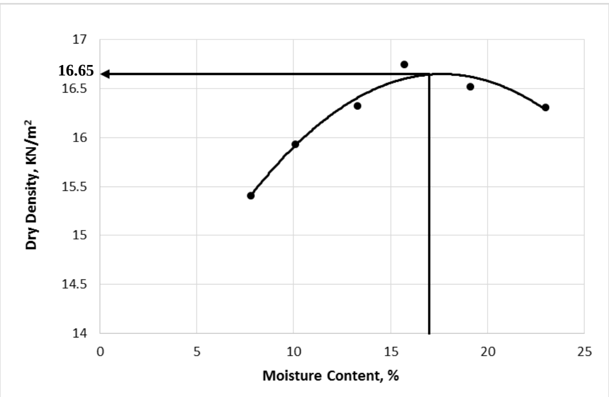

Figure 3: Moisture Content vs. Dry Density Relationship for Standard Proctor Compaction

3.4 Effect of Lime on Index Properties

The values of plasticity and shrinkage properties of untreated and lime stabilized samples of expansive soil are shown in Table 5.

- Compared with the untreated sample, the liquid limit of the lime stabilized samples initially decreased with the addition of lime content and then increased.
- Compared with the untreated sample, the plastic limit increased.
- Compared with the untreated sample, the plasticity index and linear shrinkage decreased.

Table 5: Comparison of Index Properties of Untreated and Lime Treated Expansive Soil

Index and Shrinkage Properties	**Lime Content (%)**			
	0	3	6	9
Liquid Limit (%)	52	49	45	46
Plastic Limit (%)	27	30	32	35
Plasticity Index (%)	25	19	13	10
Linear Shrinkage (%)	11	8	6	3

Figure 4 and 5 show the variation of liquid limit and plastic limit with the increase in lime content while Figure 6 shows the change in plasticity index with increasing lime content. From Figure 4, it is observed that the liquid limit initially decreases with the increase of lime content up to 6% and then slightly increases with increasing lime content. Figure 5, however, shows that the plastic limit increases remarkably with increasing lime content. Compared with the untreated samples, plastic limits of treated samples were found to increase by 11% to 30% because of stabilization of 3% to 9% lime content. Figure 6 shows that plasticity index decreases markedly by 24% to 60% with the increase of lime content from 3% to 9%. Figure 7 presents that linear shrinkage decreases significantly with the increase in lime content. Compared with the untreated samples, linear shrinkage of lime treated samples were found to be reduced by 27% to 72% due to stabilization with 3% to 9% lime content.

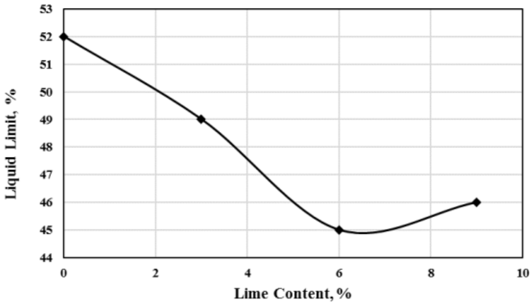

Figure 4: Effect of Lime on Liquid Limit

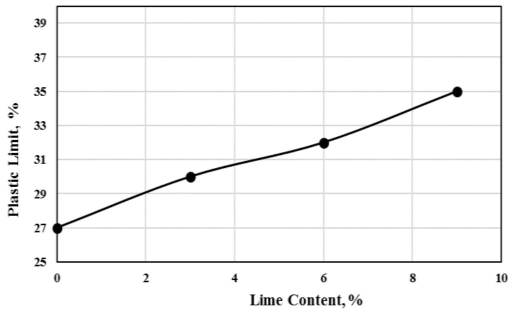

Figure 5: Effect of Lime on Plastic Limit

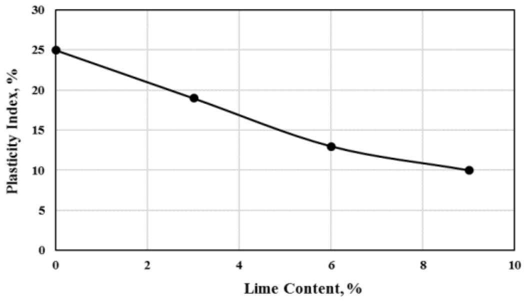

Figure 6: Effect of Lime on Plasticity Index

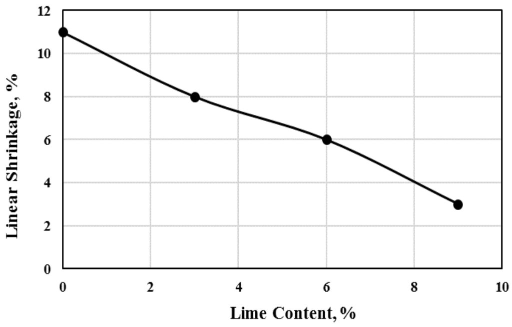

Figure 7: Effect of Lime on Linear Shrinkage

3.5 Effect of Lime on Swelling Properties of Expansive Soil

Attempts have been made to investigate the influence of lime on the swelling properties of expansive soil. Table 6 presents a comparison of the swelling properties of untreated and lime stabilized samples of the expansive soil. Table 6 shows, compared with the untreated samples, free swell, free swell index and swelling potential decreased with the increase in lime content.

The variations of free swell, free swell index and swelling potential of the treated sample with the increase of lime content are shown in Figure 8 to 10 respectively. Compared with the untreated samples, it has been seen that free swell, free swell index and swelling potential decreases by 18% to 64%, 51% to 83% and 38% to 77%, respectively, due to stabilization with 3% to 9% lime.

Table 6: Comparison of Swelling Properties of Untreated and Lime Treated Expansive Soil

Swelling Properties	**Lime Content, %**			
	0	3	6	9
Free Swell (%)	22	18	13	8
Free Swell Index (%)	43	21	12	7
Swelling Potential (%)	3.69	2.27	1.24	0.84

3.6 Effect of Lime on Optimum Moisture Content and Dry Density of Expansive Soil

Several experiments have been performed to investigate the effect of lime content on the optimum moisture content and dry density of soil. Moisture-density relations of lime treated samples of the expansive soil are shown in Figure 11. From the relations presented in Figure 11, the maximum dry density (γ_{dmax}) and optimum moisture content (w_{opt}) of samples of the expansive soil have been determined. It has been observed that with increasing lime concentration the optimum moisture content of the soil increased while dry density decreased. Table 7 illustrates the variation of optimum moisture content and dry density with increasing lime content.

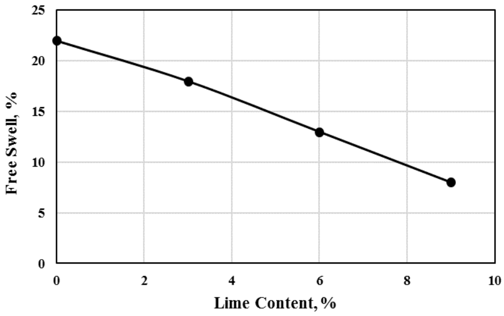

Figure 8: Effect of Lime on Free Swell

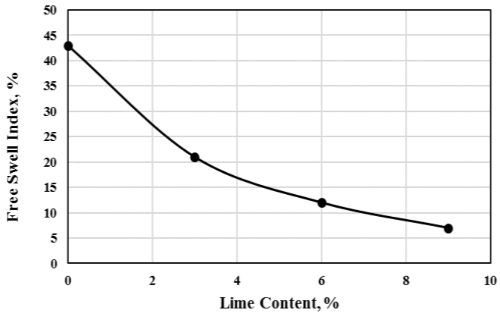

Figure 9: Effect of Lime on Free Swell Index

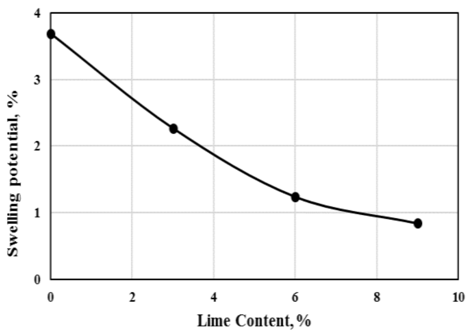

Figure 10: Effect of Lime on Swelling Potential

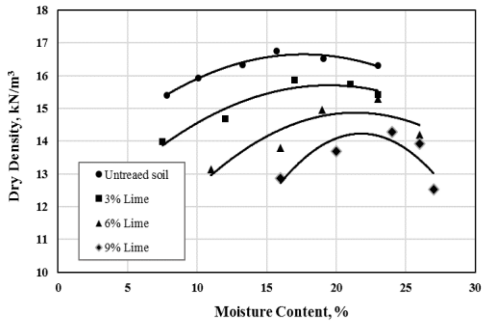

Figure 11: Moisture-Density Relationship of Soil Treated with Different Lime Content

Table 7: Comparison of optimum moisture content and dry density of untreated and lime treated soil

Compaction Properties	Lime Content (%)			
	0	3	6	9
Optimum Moisture Content (%)	17	19	22	23
Dry Density (KN/m^3)	16.65	15.78	14.89	14.23

The reduction in γ_{dmax} with the increase in lime content for the stabilized samples is shown in Figure 12 while Figure 13 shows the increase in optimum moisture content with the increase in lime content. It has been found that compared with the untreated sample, the values of γ_{dmax} decreased by 5% to 14% for an increase in lime content from 3% to 9%. The values of w_{opt} have been found to increase by 11% to 35% due to stabilization with 3% to 9% lime.

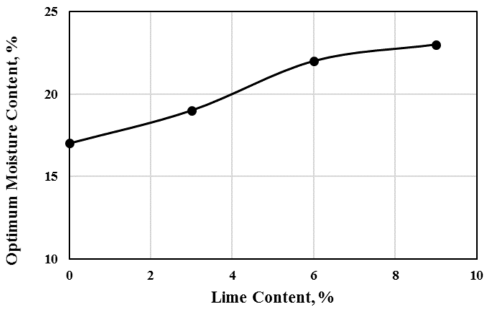

Figure 12: Effect of Lime on Optimum Moisture Content

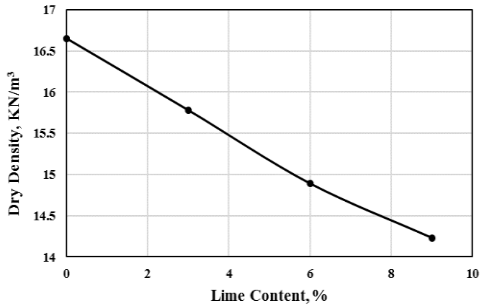

Figure 13: Effect of Lime on Maximum Dry Density

3.7 Effect of Lime Stabilization on Unconfined Compressive Strength of Expansive Soil

The values of unconfined compressive strength (q_u), drained shear strength (s_u), axial strain at failure (ε_f) for the untreated samples and samples treated with different lime contents of 3%, 6% and 9% and cured for 7 days, 14 days and 28 days are presented in Table 8.

Table 8: Summary of Unconfined Compressive Strength Test Results of Untreated and Lime Treated Expansive Soil

Lime Content (%)	Curing Age (days)	q_u (kN/m^2)	S_u (kN/m^2)	ε_f, (%)
0	-	162	82	15
3	7	184	92	13
	14	268	134	9
	28	373	186.5	6
6	7	233	116.5	10
	14	312	156	5
	28	410	205	3
9	7	294	147	7
	14	389	194.5	4
	28	455	227.5	1.5

From the above table it has been seen that with the increase in lime concentration, the unconfined compressive strength increased markedly. The relationship between q_u and different lime contents and curing ages are shown in Figure 14 and 15, respectively. Figure 14 illustrates that the unconfined compressive strength of treated samples cured at any particular age increased with increasing lime content while Figure 15 shows that values of q_u of samples treated with particular lime content increased with the increase in curing age. From our experiment, we have seen that, compared with an untreated soil sample, the unconfined compressive strength of sample cured at 28 days increased by 130%, 153% and 181% with 3%, 6% and 9% lime content respectively. The effect of curing age on the increase in qu thus is more pronounced when samples are stabilized with higher lime contents.

Table 8 also shows that compared with the untreated samples, the values of $\boldsymbol{\varepsilon_f}$ of the stabilized samples reduced. This finding indicates that the treated samples became more brittle due to lime stabilization. Figure 16 shows that with the increase in lime content for a particulate curing age axial strain decreases while Figure 17 shows that with the increase in curing age for a particulate lime content axial strain at failure decreases. However, the curing age played a significant role here.

3.8 Effect of Lime on Direct Shear Strength Parameters of Expansive Soil

Variation has been seen in cohesion and angle of friction while performing the drained direct shear tests on untreated and treated soil samples with various lime concentrations. Figure 18 shows the change in effective cohesion for different lime concentration. It has been observed that the cohesion of soil increases significantly with increasing lime content. For a certain curing age, the effective cohesion of soil increases up to 2.5 with increasing lime content. Figure 19, on the other hand, illustrates the effect of curing age on cohesion. For a fixed lime content, the effective cohesion is found to be increasing with long term curing.

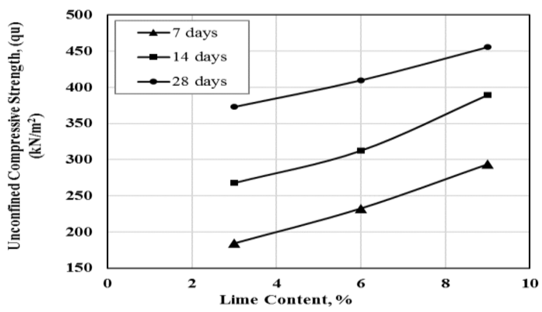

Figure 14: Effect of Lime Content on Unconfined Compression Strength

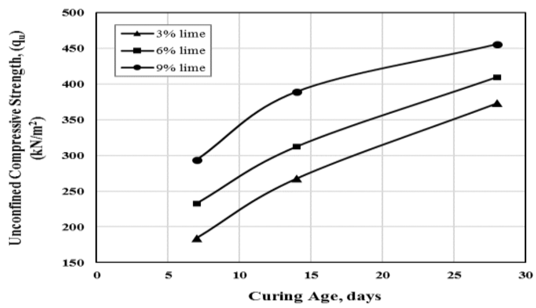

Figure 15: Effect of Curing Age on Unconfined Compression Strength

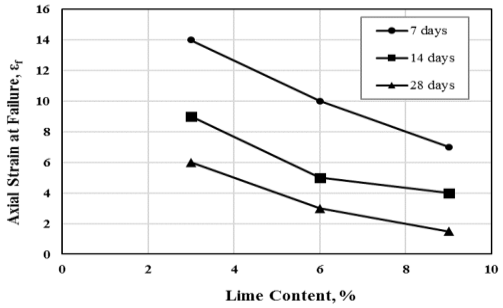

Figure 16: Effect of Lime Content on Axial Strain at Failure

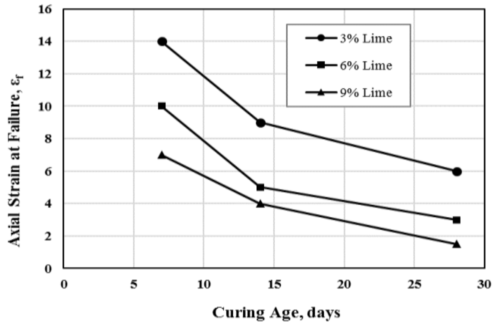

Figure 17: Effect of Curing Age on Axial Strain at Failure

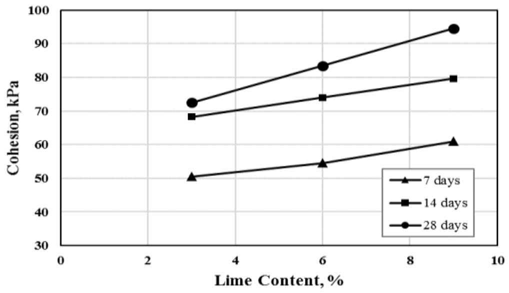

Figure 18: Effect of Lime Content on Effective Cohesion

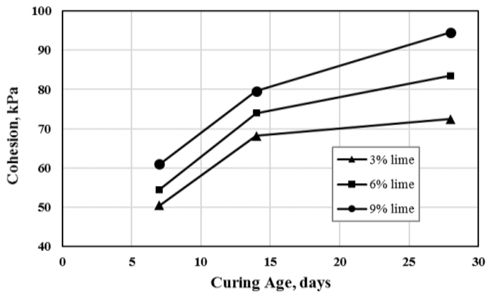

Figure 19: Effect of Curing Age on Effective Cohesion

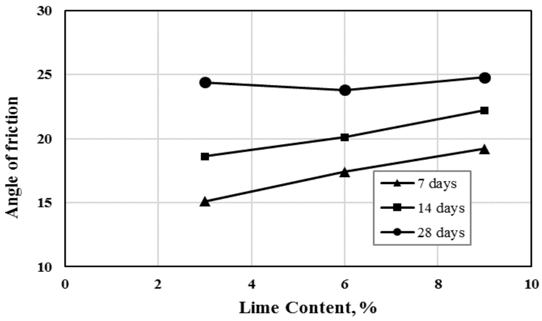

Figure 20: Effect of Lime Content on Effective Angle of Friction

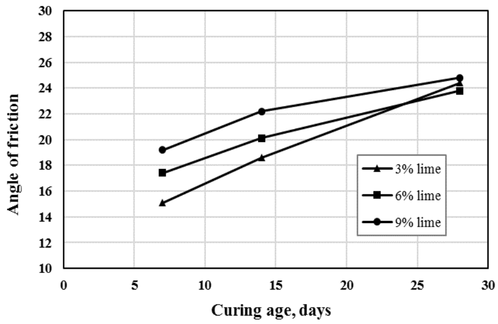

Figure 21: Effect of Curing Age on Effective Angle of Friction

Figure 20 shows the variation in effective angle of friction for different lime concentrations and curing age. It has been seen that the angle of friction of soil increases significantly with increasing lime content. For a certain curing age, the effective angle of friction of soil increases up to 95% with increasing lime content, compared with untreated soil. Figure 21, however, illustrates that the change of effective angle of friction with long term curing.

4. CONCLUSIONS

The major findings and conclusions drawn on various aspect of this study on the selected expansive soil may be summarized as follows:

- With the addition of lime, plasticity index and linear shrinkage decrease, thus reducing the shrinkage and plastic properties of soil.
- The swelling problem of expansive soil can be eliminated by introducing a small amount of lime into the soil.
- With the addition of lime, maximum dry density decreases while OMC increases. Thus, the required density can be easily achieved for a broad range of water content, thereby conserving time, effort and energy.
- With increasing lime content, the unconfined compressive strength increases though the soil becomes brittle.
- The addition of lime increases the effective cohesion and effective angle of internal friction of soil thus in turns increases the ultimate bearing capacity and skin friction of soil.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude and profound indebtedness to Dr. Abu Siddique, Professor of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. His Constant supervision, Continuous guidance, helpful criticism, suggestion and encouragement at every stage made this work possible. This dissertation would not have been possible without him. The authors are indebted to the Civil Engineering Department, BUET, Dhaka, Bangladesh for having provided then with all facilities and equipment, which enabled them to carry out the research work.

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