Effectiveness Of Mellowing Time On The Properties Of Two-Stage Lime-Cement Stabilized Expansive Soils

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EXPANSIVE SOILS

ABSTRACT

The primary objective of this study is to assess the effectiveness of mellowing (free expansion reaction) on swell properties of two stage lime-cement stabilized expansive soils. Expansive soils are normally associated with shrink swell behaviour, thus causing localized stresses and non-uniform movements of the structures and the eventual defects. Lime is generally regarded to be an effective stabilization method to control the shrink swell behavior and improve the strengths of expansive soils. The modification improvements with lime are generally temporary and will not produce permanent strength in expansive soils. On the other hand, the effectiveness of cement treatment is limited in expansive soils because of the high plasticity of the clay and the inevitable high costs of cement. The highest level of stabilization is achieved through a two-stage stabilization technique whereby the soil is first modified with the minimum amount of lime followed by cement treatment with a mellowing period between them. The minimum amount of lime required for the first stage is determined based on initial consumption of lime (ICL). Apart from improving the general geotechnical properties of expansive soil, the modification with the minimum amount of lime greatly decreases the plasticity of the clayey soil and improves its workability followed by cement stabilization that greatly improves the strength of the soil. The mellowing period between the two applications allows time for expansive reactions to take place before final application of cement that greatly improve strength. In this study the duration of the mellowing period was estimated to be 4 hours based on the judgment of free swell plots against time. Generally, the mellowing period of 4 hours was observed to reduce swell potential significantly and beyond the 4 hours the mellowing period has insignificant effect on the swell potential of the mixtures. Geotechnical properties of both natural soil and treated soil were carried out to compare the two states. The unconfined compressive strength was conducted on both mellowed and unmellowed specimens with different ranges of lime, cement, and lime-cement concentrations cured for 7, 14, 21 and 28 days. Triaxial tests and free swell in oedometer were done on compacted cured specimens. The 4% lime 2% cement stabilization reduced the swell significantly and produced desired strength than the other tested mix proportions in 7 days of curing.

Keywords: Mellowing period, Initial Consumption of Lime (ICL), soil stabilization, free-swell oedometer test and unconfined compressive strength (UCS)

INTRODUCTION

The presence and abundance of expansive soils in the coast belt of Kibaha, Tanzania has been a major cause of common construction defects such as cracking and shear failure of the buildings, excessive heave and breaking up of pavements constructed on these soils (Lucian, 2011). Some builders have tried to use either lime or cement stabilization primarily to upgrade poor quality of expansive in order to meet the desired end performance criteria but the end results have been frequently of questionable quality.

The stabilization of most expansive soils has been an issue of concern because of rapid free expansion upon stabilization with lime resulting into cracking of stabilized material. The rapid high free expansion in lime stabilized expansive soils results from the growth of ettringite crystals on the clay particle surfaces due to the chemical reaction between the sulfites and aluminates present in lime, cement or soils. Unfortunately, the expansive soils in Kibaha are rich in sulfur dioxides which react with lime to form solid calcium sulfite (Lucian, 2008).

To prevent cracks from forming due to the thermally-induced volume change (a result of ettringite formation); two-stage stabilization process is a viable solution. The two-stage process is conducted by first by mixing soil with the minimum amount of lime then completing the process by mixing the mixture with cement while leaving spacetime interval between the two treatments. When the minimum amount of lime is added, the pH of the soil quickly increases to above 12, which enables the clay particles to break down and start the stabilization process by forming calcium silicate and calcium aluminate hydrates gel which coats the soil particles and subsequently crystallises them into an insoluble interlocking matrix (Oates, 2007).

The minimum amount of lime is determined by using the Initial Consumption of Lime (ICL) test suggested by Eades and Grim pH test (Eades and Grim, 1966 and ASTM D6276). To determine the Initial Consumption of Lime, the tests are repeated at a range of moisture contents and increments of 0.5% lime until such a time that there is no significant difference in pH values. For stabilization, the lime content for pretreatment should be greater than the initial consumption of lime value. It should be noted that the ICL has nothing to do with the amount of lime needed to react with soil to produce either a substantial strength increase or maximum cured compressive strengths. The pretreatment of the soil with the percent slightly higher than the initial consumption of lime is followed by an extended spacetime before stabilizing with cement. The spacetime interval between applications allows the stabilized materials to mellow sufficiently to allow the chemical reaction to break down the clay material (Bozbey and Garaisayev, 2010).

When little lime (generally from 1 to maximum 3% by weight) is added to expansive soils the binding effect induced by the cation exchange between the metallic ions from the surface of clay particles and the calcium ions of lime by means of a flocculation/agglomeration process takes place instantly to form very small aggregates. This process is commonly referred as lime fixation or soil modification since lime is fixed in the soil. Addition of lime beyond fixation point brings no further changes in plasticity and workability of the soils but increases the strength of the soils (Bell and Coulthard, 1990). The application of cement beyond fixation is successful if it is separated by the mellowing period.

ASTM D 3551 indicates that adequate mellowing time typical for soil-lime mixtures may be as little as one hour and for cement-amended soils, a mellowing time is in general not specified. A number of other authors have specified different durations of mellowing periods for stabilization of soils. ASTM D 3551 indicates that for lime treated mixtures, a mellowing time of one hour should be allowed. Osula, 1990 used mellowing period from 1 hour to 7 hours at intervals of 1 hour before the tests were carried out on laterite soils. Locat, et al., 1990 suggested 24 hours mellowing period on the lime stabilization of sensitive clays. Rahmat and Kinuthia, 2011 noted that mellowing was not beneficial in the clay they investigated. Due to the fact that the nature of the soil is not constant, this study was carried out for ascertaining as well as assessing the effectiveness of mellowing on swell properties of two stage lime-cement stabilized expansive soils. The effectiveness of mellowing period was assessed through the transformation of soil index properties and engineering parameters according to the procedures stated in BS 1377, free swell tests in oedeometer according to the criteria proposed by ASTM D4546 and Unconfined

Compressive Strength (UCS) in accordance with TMHI–1986, Method A14 (NITRR, 1986). Indeed, the Unconfined Compressive Strength (UCS) is commonly used as a key factor in evaluating the quality of stabilized soils.

METHODS AND MATERIALS USED

Expansive soil

The soil used for sub-grade is expansive soil collected from Kibaha, Tanzania. The tests carried before classified the soil as a very stiff active clayey sand of high plasticity (Lucian, 2009). The clay minerals potassium montmorillonite subordinated with sodium montmorillonite and calcium montmorillonite dominate the clay in most soils in Kibaha. Such soils with high contents of clay minerals of the expanding lattice type like montmorillonite have abilities to expand or contract in response to the increase or decrease in moisture content (Chen, 1988)

Stabilizing Agents: Lime and Cement

The stabilizer materials used in this study were Lime and Cement. The cement used was the Ordinary Portland Cement, Twiga brand from Tanzania Portland Cement at Wazo Hill, Dar es Salaam, Tanzania. The hydrated lime powder was also obtained locally in Tanzania. The required quantity of hydrated lime was sieved through No. 40 sieve before mixing

Initial Consumption of Lime (ICL)

The Initial Consumption of Lime (ICL) was determined according to Eades and Grim, 1966, Rogders, et al., 1997 and ASTM D6276 criteria. Soil samples were mixed with water and different proportions of the lime until pH measurements remained constant.

Triaxial Compression

Untreated soil and lime- and lime-cement treated samples were subjected to CU triaxial compression tests, in accordance with BS 1377-8:1990 Part 8, four hours after preparation (to allow for mellowing). By conducting a series of monotonic triaxial tests, it is possible to extract fundamental material shear parameters about the sample such as its internal angle of friction φ and cohesion c. The variation of the two parameters (internal angle of friction φ and cohesion c) after the mellowing period of different lime applications was traced.

Specimen Preparation for Unconfined Compression Strength (UCS)

Air-dried soil samples for mixing were pulverized and sieved through No. 40 sieve and oven dried at 50°C for 24 hours. The soil was then thoroughly and carefully mixed with the various amounts of the stabilizers and the required amount of water. Cylindrical specimens (whose heights were approximately twice their diameters i.e. about 110 mm high and 52.4 mm) were then prepared by compaction at OMC and corresponding maximum dry unit weight of natural soil in specimen molds. Hydrated lime and Ordinary Portland Cement were used to stabilize the samples. The initial consumption of lime (ICL) of the soil had been determined to be 3.5%, thus, 4%, 6%, 8% and 10% of lime by weight of dry soil was added to the soil and cured for 7, 14 and 28 days, after which Unconfined Compression Strength (UCS) tests were conducted in accordance with TMHI–1986, Method A14 (NITRR, 1986). Also, lime-modified soil samples were stabilized with 2%, 4% and 6% cement by dry weight of the soil, cured and subjected to the same laboratory tests as for lime-treated samples.

Free Swell Tests

The free swell tests were conducted in the oedometer. The compacted specimens at their respective OMC and MDD (determined by Proctor's test) and cured were trimmed into 63-mm diameter oedometer (consolidation) rings to a thickness of 19 mm. After applying a vertical seating pressure of about 2.4 kPa, the soil was inundated with water, which could seep into the sample through top and bottom porous stones to allow the specimens to swell freely. The deflection of the dial gauge was recorded with respect to swelling of the specimens. The applied pressure was kept constant until the specimens reached equilibrium (volume change stopped) which corresponds with maximum deflection. The free swell was calculated as $[H_1 – H_0] / H_0 \times 100\%$ where, H_o = initial height of specimen before inundation and H_1 = height of specimen after inundation.

TEST RESULTS AND ANALYSIS

Native Soil Properties

Native soil characteristics were determined using grain size analysis, Atterberg limits, specific gravity, swell, standard Proctor, Triaxial Compression and unconfined compression tests. The index properties of the native soil are presented in Table 1. The soil has a liquidity index (I_L) of -0.34, consistency index (I_C) of 1.34 and clay activity (A) of 1.27. It was therefore classified as a very stiff active clayey SAND of high plasticity (SCH). Based on the high clay activity (A>1.25), high liquid limit (LL>60) and high plasticity index (PI>35%), this soil type has a high shrink-swell potential (Chen, 1988 and Sudjinto et al., 2011). Furthermore, Table 2 indicates that the dry density of this soil was 2650 kg/m^3. According to Chen, 1988, soils with dry densities in excess of 1,760 kg/m^3 generally possess a high degree of swelling potential. The swelling pressure was 560 kPa and if the swelling pressure is greater than 50 kPa, treatment is necessary.

Table 1: Native Soil Index Properties

PROPERTY	VALUE (%)
Liquid limit	60.2
Plastic limit	23.5
Plasticity index	36.7
Gravel	5
Sand	55
Silt	11
Clay	29

Table 1: Geomechanical parameters of Kibaha expansive soil

Bulk density	Dry density	Density of solids	Swell potential	Swell pressure	Compaction (Heavy Proctor)		CBR		UCS	Triaxial test (CU)		Consolidation (Oedometer)		
ρ	ρ_d	ρ_s	S	P_s	MDD	OMC	Soaked	Unsoaked	q_f	Φ	c	E_s	E_{sr}	C_c
kg/m^3	kg/m^3	kg/m^3	%	kPa	kg/m^3	%	%	%	kN/m^2	°	kN/m^2	MN/m^2	MN/m^2	
2120	1910	2650	19.2	560	1944	11.7	18	17	106	14	17	10.3	11.7	0.04

Table 3: Particle size distribution vs. lime content after 4 hours of mellowing

Mix type	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
0% (Natural Soil)	29	11	55	5
4% Lime	4	34	60	2
6% Lime	4	34	56	6
8% Lime	4	36	54	6
10% Lime	6	26	66	2

Table 4: Three point CBR values (unsoaked) for 4% lime-modified soil cured for 4 hours

Three point CBR Values	DD (kg/m^3)	CBR (%)	Degree (%)	MDD (kg/m^3)	OMC (%)	SWELL (%)
(2.5kg hummer) 3Layers/62 blows	1.60	17	88	1.83	11.5	0.00
(4.5kg hummer) 5Layers/30 blows	1.78	30	97	1.83	11.5	0.00
(4.5kg hummer) 5Layers/62 blows	1.79	39	98	1.83	11.5	0.00

Table 5: Change in swell potential with time at 4% lime content

Curing Period	Swell Potential (%)
0 days (Natural Soil)	19.2
4 hours	8.6
7 days	0.1

Initial Consumption of Lime (ICL)

The Initial Consumption of Lime (ICL) followed the criteria of ASTM D6276 and the results are shown in Figure 1. From the Figure, the ICL of the soil was determined to be 3.5%, so lime stabilization starting from 4% lime content to 6%, 8% and 10% by weight of dry soil was added to the soil and cured for 7, 14 and 28 days, after which laboratory experiments were conducted.

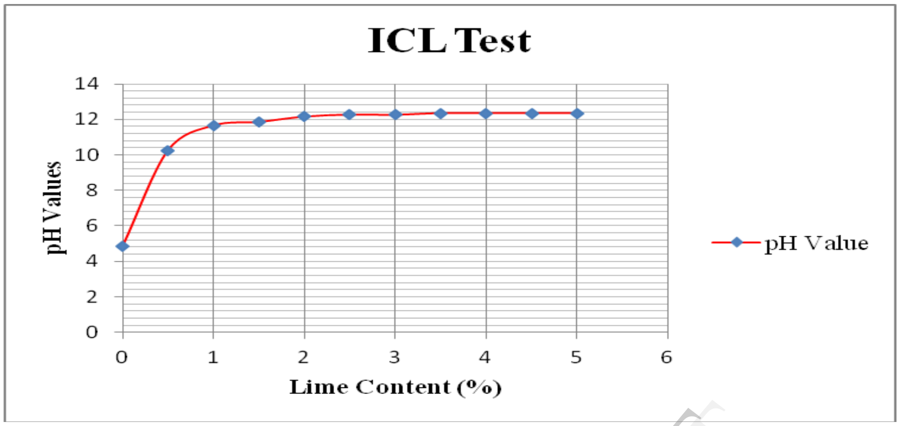

Figure 1: Initial Consumption of Lime (ICL) Test at Room temperature

Characterization of Lime-treated Samples

Figure 2 indicates the transition of Atterberg limits from untreated to treated soils. The plasticity Index reduces significantly with lime content. Similarly, Table 3 shows changes in particle size distribution after lime modification. Generally, there was a reduction in the percentage of fines (clay and silt) and a little change in the coarser sizes (sand and gravel) with increased lime content but the changes was pronouncing with mellowing the soil with 4% lime. The changes indicate that mellowing the soil with lime caused the flocculation and agglomeration of clay into pseudo sand sizes by forming larger sand sizes. Furthermore, with the modification of the expansive soil with 4% lime and 4 hours of mellowing, the maximum dry density (MDD) and optimum moisture content (OMC) changed from 1944kg/m^3 and 11.7% to 1825kg/m^3 and 11.5% respectively while the California Bearing Ratio (CBR) value increased from 17% to 39% at 98% of the MDD, heavy compaction (Tables 2 & 5). Furthermore, the treatment of expansive soils with 4% lime within the mellowing period of 4 hours reduced the plasticity index from 36.7% to 5.9% and clay fraction from 29% to 4% (activity from 1.27 to 1.48). For the lime contents of 6%, 8% and 10% the plasticity index was also reduced to 7.9%, 9.5% and 8.5% respectively (Figure 2), and clay fraction to 4% for all lime mix proportions. Lime-treatment, therefore, changed the soil from an active, highly plastic clayey SAND (SCH) to a silty SAND of intermediate plasticity (SMI) and normal activity within a period of 4 hours only. . Furthermore, with 4% lime content, the swell potential of the soil reduced significantly from 19.2% to 0.23% and swell pressure from 560 kPa to 0 kPa in a curing period of 7 days (Table 5). This suggests that lime modification can improve the workability and particle size distribution of an expansive plastic soil to a material that is more suitable for geotechnical works

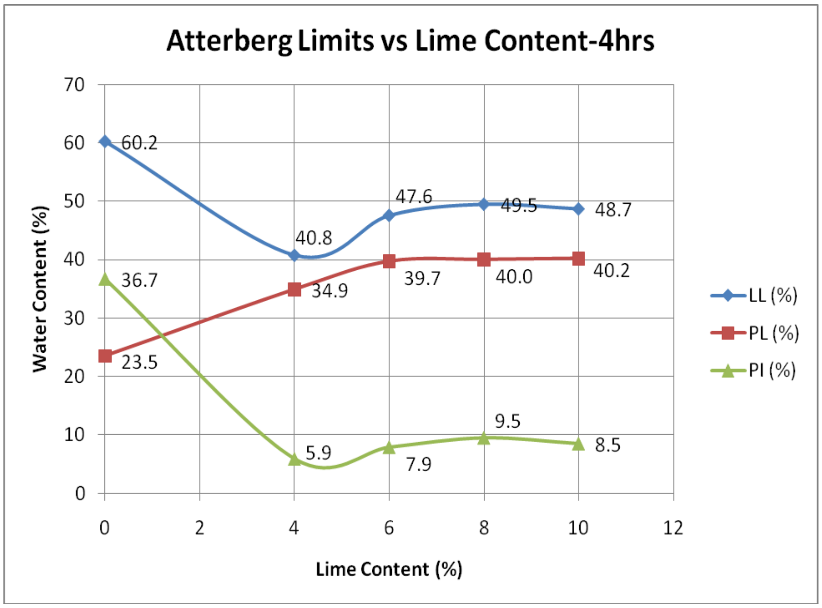

Figure 2: Variation of Atterberg limits of the soil with lime content

Table 6: Particle size distribution vs. lime content after 4 hours of mellowing

Mix type	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
0% (Natural Soil)	29	11	55	5
4% Lime	4	34	60	2
6% Lime	4	34	56	6
8% Lime	4	36	54	6
10% Lime	6	26	66	2

Triaxial Compression

Untreated soil and Lime-treated samples were subjected to CU triaxial compression tests four hours after preparation (mellowing). The results are presented in Table 7 and Figures 3 & 4.

Table 7: Triaxial strength parameters

	Untr. Soil	4% Lime	6% Lime	8% Lime
Φ′ [°]	14	31	32	33
c [kN/m^2]	17	152	300	187

Figure 3: Triaxial compression (CU) samples after test

The results of the triaxial compression tests indicate that lime-treatment greatly improves the strength of the soil, both in terms of the internal angle of friction (from 14° to 33°) and cohesion (from 17 kPa to 300 kPa) in four hours mellowing period (Table 7). Further, Table 7 and Figure 3 indicate that the samples treated with 6% lime show better strength properties than the other tested mix proportions. It is likely that higher lime content (e.g. 8% lime) creates excess lime in the mixture that makes the sample less cohesive and weaker than the lower (6%) lime-treated samples. The semi-barrelling form of failure for the 8% lime-stabilized sample supports this argument, when compared with the 6% lime-treated sample which shows a clear shear form of failure (closely similar to that of granular soils as shown in Figure 3).

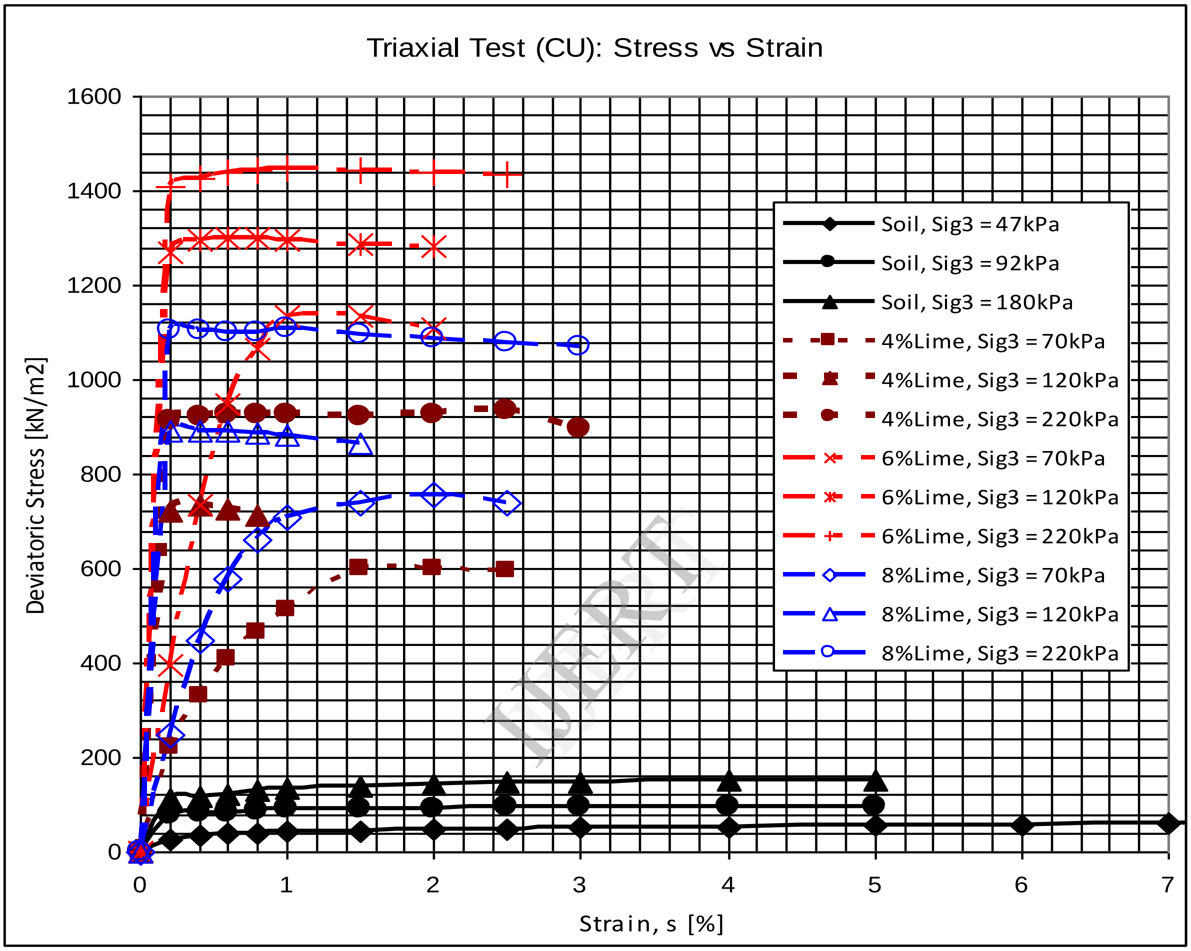

Figure 0: Results of CU triaxial compression on natural and lime-treated soil samples

Free Swelling in Oedometer

The specimens for free swell were compacted into 63-mm diameter consolidation rings to a thickness of 19 mm and then the ring was placed into the oedometer after placing dry filter papers as well as air-dry porous stone after the filter paper on top and bottom of the samples. The oedometer was mounted on the loading device and the deflection dial gauge measuring the vertical deflection was set to zero and a token load of 2.45kPa was applied. The samples were inundated by providing water through stand pipes directly from the top of the oedometer. Swelling of the sample started at the moment the sample was started to be inundated. The untreated specimens were tested immediately and they swelled to an average of 19.2% (Table 2). For treated specimens, the tests were finished when there was no change on the dial gauge. Changes in the heights of the specimen were recorded after 1 day, 3 days, 7days, 14 day and 28 days. Figure 5 indicates variation of swell percentage for two stage mixing operation with different mellowing periods to illustrate the impacts of the different mellowing conditions on the characteristics of the stabilization. For 1 hour mellowing, the equilibrium was reached within 3 days whereas 2, 3 and 4 hours mellowing, the equilibrium was reached after about 7 days. Furthermore, the Figure indicates that application of lime followed by mellowing can adequately reduce the swelling properties of expansive soil. Adding 4% lime and mellowing for 4 hours followed by application of 2% cement reduced the swell to almost zero. 2 and 3 hours mellowed systems indicated significant greater swell magnitudes relative to the equivalent 4 hours mellowed system. Likewise, 1 hour mellowed system recorded the highest swell compared with other mellowed system. Indeed, swell decreased with increasing mellowing period, until a near zero swell was reached with 4% lime pre-treatment and 4 hours mellowing followed by 2% cement application. Based on these results of the laboratory testing, it is proposed that 4 %t lime pretreatment with at least 4 hours mellowing should be followed by the addition of 2 % cement. Increasing the mellowing time beyond 4 hours for this particular soil may lead to reductions in the unsoaked strength.

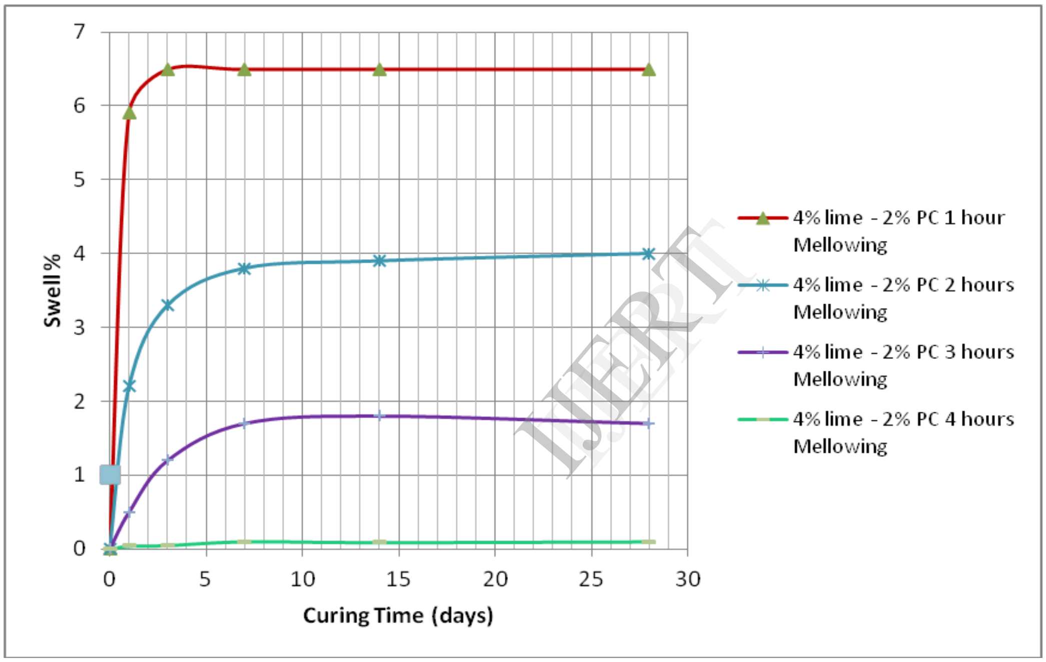

Figure 5: Swell (%) of untreated soil (US) and two stage 4% lime - 2% cement (PC) stabilized soils (SS) with 1 hour, 2, 3 and 4 hours mellowing period

Unconfined Compression Strength

The results of unconfined compression strength (UCS) as shown in Figure 6 are very interesting and provide valuable insight into the effectiveness of two stage lime-cement expansive soils stabilization. During the early 7 days of curing the unconfined compressive strength increased rapidly. Although the most notable increase in strength occurred within the first 7 days, it continued to increase with increasing length of curing. After 28 days of curing, the maximum UCS values were obtained in the sample with 8% lime and 6% cement addition. Furthermore, the specimens' unconfined compression strength increased significantly when the lime dosage was increased. The significant increase in UCS is directly associated with the level of stiffness and rigidity of lime stabilized expansive soil, which were characterized by very little plastic post-peak deformation behaviour. Other specimens treated with moderate amount of lime followed by little amount cement (e.g. 4% lime + 4% Cement) with the mellowing indicated moderate UCS but underwent greater deformation prior to failure. Because 4% lime + 2% Cement treatment with mellowing period of 4 hours reduced the swell to the minimum possible (Figure 6), it was taken as optimum value of percentage of cement and lime to be added to achieve desired strength and resilient. Moreover, the 4% lime + 2% Cement treatment improved the soil to UCS of 1048kPa after 7 days of curing which is a bit higher than 800 kPa (Unconfined Compressive Strength after 7 days moist curing) for a reasonably graded material suggested by NAASRA (1987).

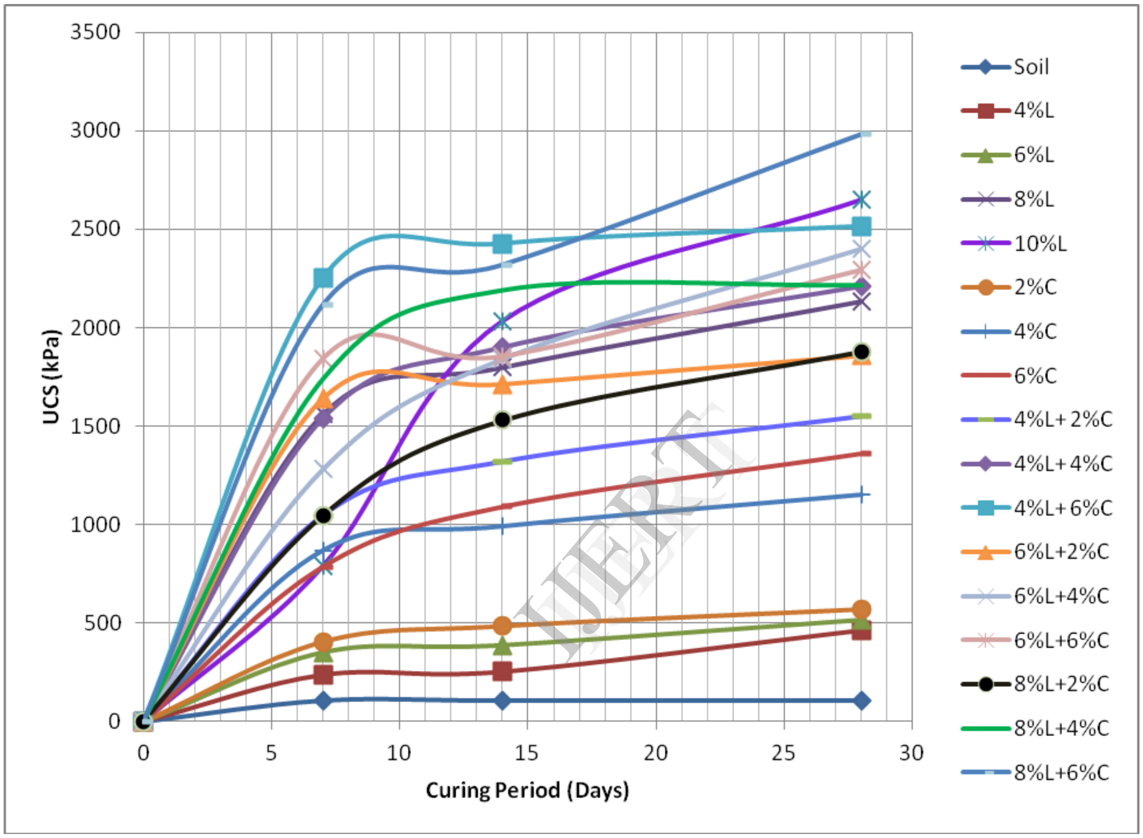

Figure 6: Relationship between the Unconfined Compressive Strength and curing of lime, cement, and two stage lime-cement-treated stabilized soils

CONCLUSION

This study has evaluated the effectiveness of a two-stage lime-cement treatment process with a mellowing period for stabilization of expansive soils. The stabilization was carried out with various amounts of either lime or ordinary Portland cement (OPC) alone as well as different combinations of the two stabilizers (lime and cement) with the mellowing period of 4 hours between them. Because, the initial consumption of lime (ICL) of the soil was determined to be 3.5%, so lime treatment started from 4% lime up to 10% contents. The modification of soil with lime followed by mellowing greatly increased the MDD, CBR and UCS and reduced the OMC and plasticity index, thus producing denser and hence stronger specimens. The modification, therefore, changed the soil from an active, highly plastic clayey SAND (SCH) to a silty SAND of intermediate plasticity (SMI) and normal activity within a period of 4 hours only.

The free swell in the Oedometer test was reduced to the minimum possible (~0%) by treatment with 4% lime and 2% cement. The results of triaxial tests indicated a slightly increasing internal friction angle and considerable increase in cohesion. However, the samples treated with 6% lime show better strength properties in triaxial test than the other lime mix proportions. Subsequent unconfined compression strength (UCS) tests showed that when a soil is treated with lime or cement or mixture of the two, the strength improves with curing period due to hydration and pozzolanic reaction between lime or cement constituents and clay constituents. The rate of increase in UCS increased at nearly identical rates with additional stabilizers. Two-stage stabilization produces much higher strength and smaller failure strain than lime stabilization. Cement stabilization alone becomes difficult in such expansive soils due to the high plasticity and poor workability of the soil. Therefore, two-stage stabilization is strongly recommended whenever the ground in the coastal belt of Kibaha is to be improved for construction purposes. Overall, the NAASRA (1987) specification and the ever raising cost of cement favours the two-stage stabilization with 4% lime and 2% cement to provide adequate performance at a reasonable cost for expansive soil treatment under same conditions of construction.

ACKNOWLEDGMENT

The author grateful acknowledges the financial support of the Swedish International Development Cooperation Agency (SIDA). High-performance laboratory supports provided by staff at the Soil laboratory at the College of Engineering and Technology (CoET), University of Dar es Salaam in Tanzania are gratefully acknowledged.

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