Stress-Strain Behaviours Of Two Stage Lime-Cement Treated Expansive Soils

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Abstract: *The aim of this research work is to examine the stress-strain behaviours of Two Stage Lime-Cement Stabilized Expansive Soil. The stress-strain of stabilized soils under different loading conditions is essential to properly understand how the material will behave when exposed to applied load. An investigation has been performed on soils stabilized in two stage lime-cement process in different combinations of binders with the purpose of demonstrating the impact of different loading conditions. The binders used were lime, cement, and a combination of lime and cement with a mellowing period between them. Strains at failure were recorded on all tested samples. The results show that while the untreated sample exhibited a ductile behavior, the lime treated samples exhibited brittle behavior but the two stage lime-cement treatment changed the brittle behaviour of lime treated soils to more ductile ones. This abrupt change from brittle to ductility is strongly linked to the influence that the two stage lime-cement treatment has on the deformation behaviour of treated soils.*

Keywords: *Two-stage stabilization, unconfined compressive tests, and stress-strain behaviour.*

I. Introduction

Treated expansive soils behave differently with different loads resulting in varying degrees of initial strength gains and final strength development to support foundations for building purposes. The strength gain and stability in treated soils are due to complex chemical reactions which take place between the soil, water and admixtures. The immediate initial strength gains in expansive soils are a result of cation exchange and flocculation of clay particles in the presence of lime. The final strength development depends on admixtures content, soil water content, soil type, curing duration, temperature and stress state. The final strength generally refers to the soil's ability to support the loads imposed by buildings or structure preferably without failure.

Information about the material's behaviour under load is well captured by monitoring the relationship between stress and strain for a material. When a material is loaded with the applied load, it produces a stress, which then causes a material to deform. The degree of soil deformation is governed not only by the interplay between the magnitude of stress levels (loading) applied to the soil and the rigidity of the soil in controlling these external stresses but also by internal stresses. The internal resistance of the material to counteract the applied load is called internally induced stress, and the arising deformation is known as strain. The internal stresses arise from physico-chemical mechanisms and microstructural behavior of soils. The applied stress is contained as long as the strength of the soil arising from its physico-chemical mechanisms and microstructural behavior remains above the stresses required to maintain equilibrium. It is unfortunate that expansive soils that shrink and swell because of changes in moisture content always have their stress equilibrium constantly disturbed. Expansive soil which has been treated with appropriate binders, will have higher internal effective stress and has little tendency to deform.

Typical expansive soils often display linear relationship between stress and strain over a short range of load, followed by non-linearity small-strain stiffness over the rest range of loading. When the soil is treated with cement, lime or a combination of the two, the failures stress increases and the ultimate strain required to reach the maximum principal stress difference decreases. It is postulated that the addition of lime alone, decreases the rate of strength gain and the addition of cement significantly increases the initial rate of strength in treated soils (Indraratna et al., 1995 and Madhyannapu et al., 2009). Therefore, the addition of either lime or cement results in brittle behaviour associated with low strain and high strength than those of non-treated soils. For both treated and untreated soils, the maximum peak shear strength is taken as the peak stress of the soil stress-strain curve or the shear strength at critical state when the stress-strain relationship levels off. If the stress-strain curve does reach the peak before the end of shear strength test, the shear strength at a strain of 15% to 20% is considered to be the shear resistance (Salgado et al., 2000)

The stress stain behaviour of lime treated expansive soils has been extensively investigated (Tuncer and Basma, 1991, Nalbantoglu, 2006, Khattab et al., 2007, Sharma et al., 2008, and Yin and Tong, 2011). Likewise, the stress stain behaviour of cement treated expansive soils has received the attention of nuerous researchers (Anagnostopoulos, 2006, Al-Zoubi, 2008 and Kamruzzaman, 2009). Cautiously, the stress-strain behaviours of lime and cement treated soils has been examined by a number of researchers (Kennedy and Tahmovessi, 1987, Jacobson, 2002 and Puppala et al., 2005). Nevertheless, each of the treatment studied behaves in a different way depending on the binder systems used. Although many researchers have studied the stress-strain behaviours of soils with cementing agent like lime and cement and a combination of the two, not many of these researchers have explored the stress-strain behaviours of two stage lime-cement stabilization mixtures with mellowing period between them. This paper therefore presents experimental results in stress-strain plot obtained from tests conducted on remolded expansive soil specimens stabilized with lime, cement, and lime-cement with the mellowing period between them.

II. Materials and Experimental Methodology

Description of the Area

The site from where the samples were taken is found in Kibaha Township in Tanzania. Kibaha Township is located in eastern Tanzania, about 40 km west of Dar es Salaam (the commercial capital city of Tanzania), along the Dar Es Salaam-Morogoro highway. It's positioned at an altitude of about 155 m above sea level and located approximately by geographic latitude and longitude of 06º46'S and 38º55'E respectively. It is within the coastal belt where expansive clay soils are predominant (Lucian, 2009 & 2011).

III. Soil Samples

The soil samples used in this study were taken in their natural expansive conditions from a depth of 1.3 m to 1.5 m below the ground level in a 3.5 m deep test pit. The samples were carefully wrapped in cling-films and aluminium foil and transported to the soil laboratory at the College of Engineering and Technology (CoET) at the University of Dar es Salaam in Tanzania. In the laboratory, the basic soil properties were determined and they are shown in Table 1. The soil is classified as a very stiff active clayey SAND of high plasticity (SCH) with expansive behaviour. Furthermore, the other soil samples were stabilized using lime, cement as a whole and in combinations of the two (with the mellowing period between them) at different proportions for Unconfined Compressive Strength (UCS).

Table 1: Basic Properties of Native Expansive Soil

PROPERTY	VALUE	PROPERTY	VALUE
Liquid limit (%)	60.2	Sand (%)	55
Plastic limit (%)	23.5	Silt (%)	11
Plasticity index (%)	36.7	Clay (%)	29
Swell potential, (S) (%)	19.2	Bulk density (ρ), kg/m^3	2120
Swell pressure (P_s), kPa	560	Dry density (ρ_d), kg/m^3	1910
Gravel (%)	5	Density of solids(ρ_s), kg/m^3	2650

IV. Binders Used

Two stabilizer materials, Lime and Cement, were used in this study. The cement used in this research was an Ordinary Portland Cement, Twiga brand from Tanzania Portland Cement at Wazo Hill, Tegeta, Dar es Salaam which was purchased from a local supplier. The hydrated lime used in this study was also obtained locally in Tanzania. To obtaining a higher level of fineness of the binder, the hydrated lime was sieved through No. 40 sieve before mixing.

V. Specimens Preparation

Soil samples were dried, ground and sieved through No. 40 sieve and oven dried at 50°C for 24 hours. Based on the Initial Consumption of Lime which was established to be 5.3%, lime was added at the rate of 4%, 6%, 8% and 10% by weight of dry soil. Also, some of lime-modified soil samples were allowed to mellow for 4 hours in a sealed container before treating with different ranges of cement contents of 2%, 4% and 6%. All treated soils were compacted using a modified Proctor effort (BSI, 1990), extruded from the compaction mold, and sealed in a plastic bag, cured at room temperature for a period of 7, 14 or 28 days, trimmed to appropriate 110 mm high and 52.4 mm diameter sizes and their stress-strain behaviours measured by running Unconfined Compressive Strength (UCS) test.

VI. Laboratory Testing Procedures

To assess the stress-strain behaviour of treated specimens, unconfined compression strength (UCS) tests were conducted in accordance with TMHI–1986, Method A14 (NITTRI, 1986). In the unconfined compression test, the prior compacted, cured soil samples and trimmed specimens were placed in the loading machine between the lower and upper plates. Before starting the loading, the upper compression plate was just brought barely into contact with the specimen and the deformation was set to zero at the start of the test. The tests were performed at a strain rate of approximately 2% per minute. The load and deformation values were recorded and load-deformation curve drawn. The loading was continued until the load values decreased or remained constant with increasing strain, indicating specimen's failure. Prior to testing, specimens were carefully weighed and measured and soonest after specimen testing the mode of failure was recorded (Figure 1). The Unconfined Compressive Strength of a stabilized material was recorded as the load in kN/m^2 (kPa) required to crush a cylindrical specimen, at a rate of 140 kN/m^2 per second (140 kPa/s).

Figure 1: UCS Test - specimens crushed to total failure

VII. Experimental results and Discussion

In the light of this research, the stress-strain behaviour of soil specimens treated with different admixtures, proportions and curing times has been investigated based on unconfined compression tests. The stress-strain behaviours of treated expansive soil specimens cured for 7, 14 and 28 days are represented in Figures 2, 3 and 4 respectively. For comparison purposes, Figure 2 shows stress-strain behaviours of natural soil specimen compacted using the same procedure as the one used for treated samples. Strain at the onset of failure corresponding to the maximum stress was recorded on each tested sample. At its natural state, the maximum compressive strength of untreated expansive soils reached 106kPa at a strain of about 1.8%, with no true failure points observed. Indeed, the untreated specimens exhibited a ductile behavior with a continuous deformation until a steady state was reached. Upon treatment with considerable amount of lime (8% and 10%), the Unconfined Compressive Strength (UCS) increased considerably but the shear failure mode of specimens was close to brittle failure and the specimens strain is less than that of the natural soil. For lime treated specimens the shear strength increased significantly over small strain increments until the peak value was reached followed by a sudden drop in shear strength. It implies that the addition of considerable amount of lime to the expansive soils increased stiffness, peak strength, and brittleness. Unfortunately, the addition of reasonable amount of cement (2%, 4% and 6%) to expansive soils did not produce significant increase in strength. The addition of cement greater than the mention percent cannot justify the cost of further addition of pricey cement.

In contrast, the stress-strain curves of mellowed lime-cement treated soils exhibited gradual pronounced peaks, depending on the lime-cement proportions and curing time (Figures 2, 3 & 4). All strain-stress behaviours shown in the Figures reveal that the two-stage stabilized samples approached residual strength more gradually and maintained certain post-yield failure strength for all tested curing periods. This may be explained by the fact that addition of cement to a lime-modified sample increases the rate and extent of gradual strength development, whereas cement treatment of unmodified soil generates lower strength due to poor workability of the plastic soil that results into a non-uniform material and formation of chunks.

Furthermore, the unconfined compression strength increased with the curing period (Figures 2, 3 and 4). The figures indicate that almost all treated specimens, irrespective of the kind of admixtures, gained most of their strength within the first fourteen days of curing and no significant increase in 28 days of curing. Interestingly, lime treated specimens developed highest initial values within 7 days of curing indicating that the initial rapid hydration process took place within the first few days. At 14 and 28 days of curing, the strength values for lime treated specimens showed an increase in fracture strain and a reduction in strength due to degradation during curing. Furthermore, Figure 2 shows that during the first seven days of curing there is a linear reduction in the strain at failure that becomes stable when increasing the period of curing to 14 and 28 days as shown in Figure 3 and Figure 4 respectively. In 28 days curing period (Figure 3), USC increased from 106 kPa of untreated soil to 462 kPa and 2.65 MPa for 4% and 10% lime contents respectively. Two-stage stabilized soil with 4% lime and 2% cement increased the UCS to 1.05 MPa, 1.32 MPa and 1.55 MPa in 7, 14 and 28 days curing periods, respectively (Figures 2, 3 & 4), whereas 4% lime-and-6% cement resulted in the UCS of 2.25 MPa, 2.43 MPa and 2.51 MPa in the same curing periods. Higher percentages of lime and cement produced higher UCS values, up to 3.0 MPa in 28 curing days. For reasonably graded material, the minimum Unconfined compression Strength (UCS) of 800 kPa suggested by NAASRA (1986) can be used to base the selection of the two stage operation.

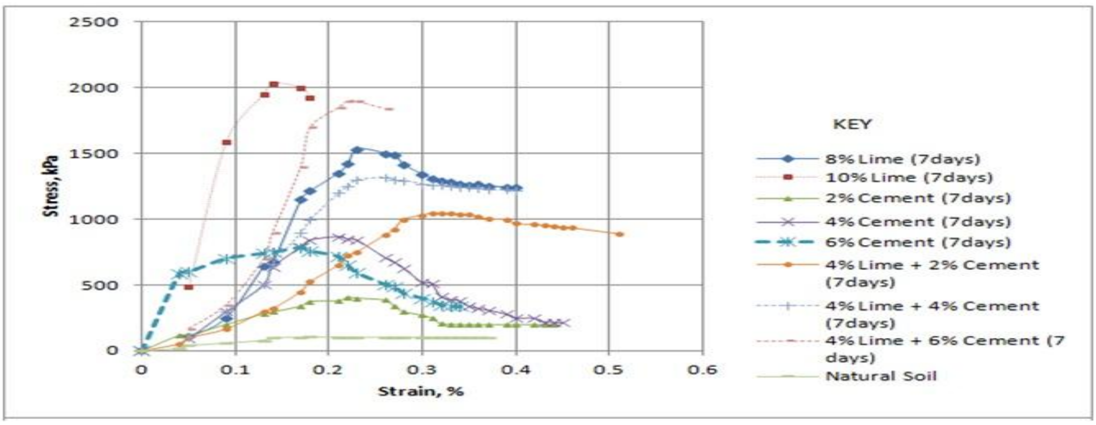

Figure 2: Stress- strain relationship of stabilized expansive soil specimens treated with different proportions of admixtures and cured for 7 days

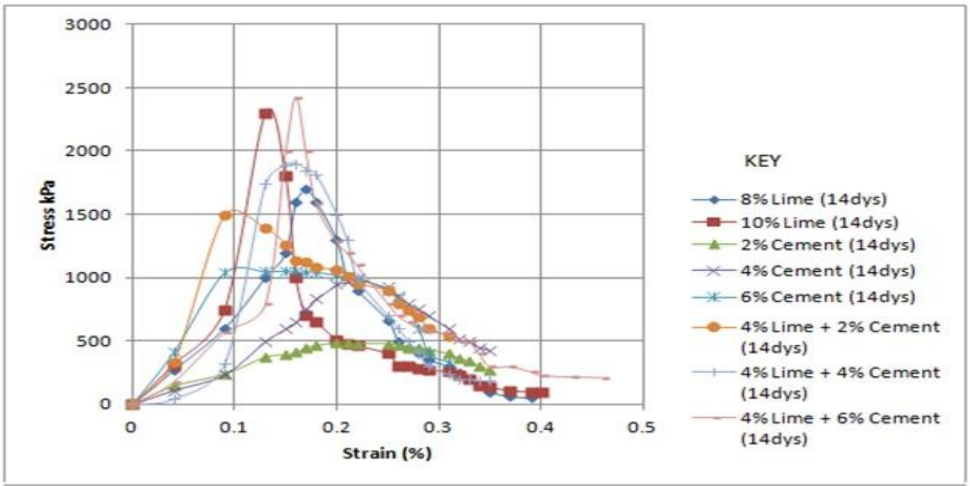

Figure 3: Stress- strain relationship of stabilized expansive soil specimens treated with different proportions of admixtures and cured for 14 days

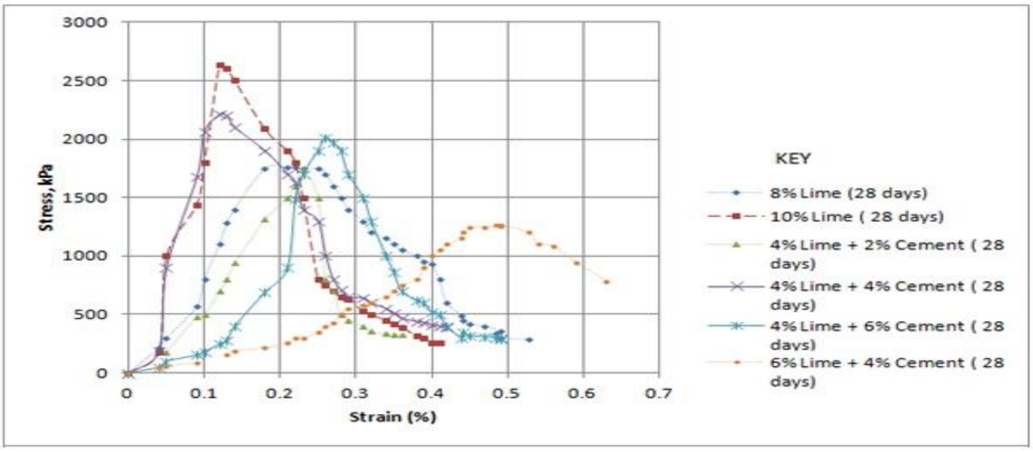

Figure 4: Stress- strain relationship of stabilized expansive soil specimens treated with different proportions of admixtures and cured for 28 days

VIII. Conclusions

This study has discussed the results of the stress-strain behaviours of lime, cement and Two Stage Lime-Cement Stabilized Expansive Soils in unconfined compressive strength (UCS) tests. In general test results indicated the strength, deformation characteristics and stress strain behaviours of treated soils depend on mix proportion and curing duration. In comparison with those of treated specimens, the untreated sample exhibited a ductile behavior associated with lower strength and higher failure strain.

The test results of treated specimens indicated that the unconfined compressive strengths increase with the increase in the quantity of stabilizer. For example, the increase in lime portion induced greater initial strength development at a lower strain to peak strength. The stress-strain curves obtained from unconfined compression strength tests showed sharp peak with an abrupt drop in peak implying that the lime treated specimens exhibited brittle behavior. The lower strain to peak strength and higher strength for lime specimens indicates that the immediate cation exchange and flocculation of expansive clay particles in the presence of lime induce apparent and more friable modified specimens.

Also, treating expansive soils with cement alone did not work well. All cement treated specimens tested were characterized by large deformation or strain but inadequate strength. Furthermore, the unconfined strength for cement treated specimens did not increase in direct proportion with cement content. Lastly, the length of curing had little effect on stress-strain behaviour of cement treated specimens.

The two stage lime-cement treatment indeed struck the right balance between lime modification and cement treatment. The two stage stabilization changed the brittle behaviour of lime treated soils where the specimens were more ductile thus required larger strain to reach ultimate failure. The strain curves of mellowed lime-cement treated soils exhibited gradual pronounced peaks, depending on the lime-cement proportions and curing time. Prolonged curing time showed more improvement in two stage lime-cement treatment than lime or cement treatment alone. It implies that cement stabilization needs pre-treatment with lime to reduce the plasticity of the soil and improve its workability before cement is added to improve the strength of clayey soils. Therefore, two-stage stabilization is strongly recommended whenever expansive soils similar to that in Kibaha region along the coast - Chalinze belt is to be improved for construction purposes. Importantly, the 4% lime and 2% cement two stage operation conform conveniently with NAASRA (1986) standard specification.

IX. Acknowledgement

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