International Journal of Applied Science and Engineering Research
Vol. 5 No. 1 (January-June, 2020)

Received: 25th August 2019 *Revised: 19th December 2019* *Accepted: 29th December 2019*

Effectiveness of Two Sequential Mixing of Lime -Portland Cement in Stabilizing Expansive Soils

Charles Lucian
Ardhi University (ARU),
P.O. Box 35176, Dar es Salaam, Tanzania

Abstract: The existence of expansive soils in the study area that undergo swelling and shrinkage when subjected to moisture variations has caused major deterioration and distresses on lightweight construction such as shallowly founded structures ad roads founded on them. Unfortunately, the treatment of these highly plastic clay soils has attracted minimal attention despite the damages they are able to induce. Stabilization of highly plastic clay soils with lime or cement alone is generally not satisfactory. While significant increase in workability and adequate strength can be achieved by lime treatment, the process is characterised by brittleness. On the other hand, soil treatment with cement alone can somehow increase strength but with the danger of leaving pockets of uncemented material in the modified mass. Therefore, substantial increase in both unconfined compressive strength (UCS) and tensile-split strength can be achieved through a two sequential mixing operation whereby soil brittleness is reduced by providing smaller loss of post-peak strength. The operation is carried out by firstly treating the soil with lime, leaving it to mellow for some hours to ensure adequate workability and then secondly treating it with cement to obtain lime-cement treated soil with adequate strength and durability. The analysis of test results of the two sequential lime-cement treated soils showed markedly improvement in the unconfined compressive strength at a large strain when highly plastic soils were first treated with lime followed with cement treatment. This indicates that the use of two-sequential lime-cement soil stabilization is the cost effective techniques that effectively improves the engineering properties of expansive problematic soils.

Keywords: Expansive soil, unconfined compressive strength, mellowing period and initial consumption of lime (ICL).

1. Introduction

Expansive soils contain amounts of active clay minerals that shrink and swell with fluctuation in moisture content (Bell and Culshaw, 1998 and Meisina, 2004). The repeated cycles of swelling or shrinkage of soil cause deteriorations and distresses on the structures especially lightweight structures supported on the expansive soils. The way forward is either to remove or treat the expansive soils before the structures are found on them. In most cases the replacement turns out to be more expensive than treatment, especially when a suitable ground improvement or treatment is technically carried out. Although different methods have been used to improve and treat the geotechnical properties of the expansive soils, the presence of active clay minerals in expansive soils makes it difficult to treat it with one stabilizer alone. Treatment with lime alone increases both workability and short term strength at small strain. On the other hand, cement stabilization is rarely suitable for highly plastic clay but ideally suited for well-graded soils with low plasticity index to result in a mix with high dry density and stability value. Cement is most effective in treating soils with a plasticity index (PI) of less than 20% and a minimum of 45% passing the 0.425 mm (No. 40) sieve (Beeghly, 2003). Therefore, to stabilize highly plastic clays with cement calls for

*Corresponding author (e-mail: lucian@aru.ac.tz)

pre-treatment with lime to reduce the plasticity of the soil and improve its workability for the lime-treated soil to react with cement to produce a substantial strength increase and adequate durability (Sivapullaiah, 2006 and Bozbey, and Garaisayev, 2010).

In two sequential treatments, lime is used to condition a heavy clay soil ready for stabilization with cement. When lime is mixed with clay, two pozzolanic chemical reactions namely cation exchange and flocculation-agglomeration occur (Daita et al., 2006 and Natheer and Thafer, 2008). In the cation exchange reaction, calcium ions are combined initially with the adsorbed cations attached to the montmorillonite surfaces while the flocculation-agglomeration reaction causes the clay particles to flocculate and agglomerate into large clumps which leads to an improvement in soil workability by generally increasing the plastic limit and decreasing the liquid limit without generating sufficient compressive strength in a reasonably practicable period of time (Boardman et al. 2007 and Mtallib and Bankole, 2011). Cement on the other hand lowers the water content and increases the strength and stiffness of the soil significantly but needs pre-treatment with lime in order to decrease the plasticity of the clayey soil and improve its workability. Moreover, many expansive soils contain high soluble sulphates that react with lime to form ettringite, which leads to a large increase in solid volume, referred to as heave. Treatment with cement helps mitigate sulfate-induced heave (Petry and Little, 1996 and Jung and Santagata, 2009). The addition of cement was also found to increase optimum moisture content (OMC), decrease the maximum dry density (MDD) and improved compactability (Oyediran and Kalejaiye, 2011). Based on the above ground the two sequential stabilization process is investigated.

The main objective of this study, therefore, is to evaluate the effectiveness of two sequential lime-cement stabilized expansive soils based on improved physical strength characteristics. Lime and cement were used starting with mixture of lime clay layer followed by cement treatment, allowing for intervening 4 hour mellowing period. Because the initial consumption of lime was found to be 3.5%, both chemical and mechanical properties of two sequential stabilisation were investigated by adding 4%, 6%, 8% and 10% of lime by weight of dry soil and curing for 7, 14 and 28 days ready for laboratory experiments. Cement contents of 2%, 4% and 6% were used for the lime-cement-treated soil. To evaluate the effectiveness of two sequential mixing of lime-cement stabilization of highly plastic soils, laboratory investigation on strength gain of stabilized cured samples was conducted.

2. Materials and Sources

2.1 Native Soils

Expansive soils used in this study was sampled from a depth of from a depth of 1.3 m to 1.5 m in a 3.5 deep open test pit dug in Kibaha township in April 2010. The samples were cautiously logged and carefully transported to the laboratory at College of Engineering and technology (CoET) in Tanzania for geotechnical testing. Previous studies (Lucian, 2008 & 2009) conducted in the area classified the soils as highly plastic (expansive) soils. The index properties of the expansive soil in consideration are found in Table 1.

2.2 Stabilizing Agents

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 powder hydrated lime was also obtained locally in Tanzania. The required quantity of hydrated lime was sieved through No. 40 sieve before mixing.

3. Experimental Methodology

3.1 Labarotary Experiments

A wide variety of geotechnical laboratory tests were conducted at the Soils laboratory, College of Engineering and Technology (CoET), University of Dar es Salaam, to measure the properties of both untreated and treated expansive soil. The tests included grain size distribution, Atterberg limits and moisture content to assess the geotechnical properties of untreated soils, and the unconfined compression strength (UCS) tests to assess the shear strength of stabilized expansive soils with lime and cement. The index properties and geomechanical parameters of the expansive soil in consideration are found in Table 1 and Table 2 respectively. The results of the granulometric analysis indicate that the sampled soil is constituted of 29% clay fraction (< 2 μm), 11% silt fraction (2-63 μm), 55% sand fraction (0.063-2.0 mm) and 5% gravel fraction (2.0-63 mm). The soil had a natural moisture content of 11.1%, liquid limit (LL) of 60.2% and plastic limit (PL) of 23.5%, resulting in the plasticity index (PI) of 36.7%, liquidity index (I_L) of -0.34, consistency index (I_C) of 1.34 and clay activity (A) of 1.27. The soil was therefore classified as a very stiff active clayey SAND of high plasticity (SCH). The activity of the clay fraction suggests a presence of potassium montmorillonite, possibly subordinated with sodium montmorillonite (A = 7) and calcium montmorillonite (A = 1.5). The high plasticity index (PI>35%) indicates presence of clay of very high swelling potential (Chen, 1975)

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 2: 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

3.2 Specimen preparation

For unconfined compression strength (UCS) a total of 30 specimens were prepared for evaluating the development of strength at different curing period of 7, 14 and 28 days. These specimens included those which were treated with cement alone, lime alone and a combination of lime and cement with the intermittent mellowing period of 4 hours.

The amount of each stabilizer or a combination of the two was added to the soil based on the dry weight of the soil, and then manually mixed to reach uniformity. After the blending process, water was added during mixing to bring the mixture to the optimum moisture content (OMC). The mixture was then compacted in a mold having a diameter 52.4 mm and a height of 110 mm to reach a dry density of between 95%-100% of the maximum dry unit weight (MUW).

After compaction, specimens were cured at a temperature of 23.0 ± 1.7ºC and a relative humidity of approximately 96% for 7, 14 and 28 days of curing. A total of three replicates were prepared for each additive type and tested for unconfined compressive strength after 7, 14 and 28 days in accordance with TMH1–1986, Method A14 (NITRRI, 1986).

4. Analysis of Test Results and Discussion

Figures 1, 2 and 3 indicate the laboratory result graph of stress versus axial strain from unconfined compression strength (UCS) test for expansive soils stabilized with lime contents of 4%, 6%, 8% and 10 %, cement contents of 2%, 4% and 6% and a combination of both lime and cement all cured for 7, 14 and 28 days. It is clearly indicated from Figure 1 that lime treatment alone and cement treatment alone do not work well in highly plastic soils. Addition of 2 to 6% cement content can produce a soil that acts just as a semi rigid slab (Nelson and Miller, 1997).

It is therefore not surprising that after 7 curing days the sample with 4% cement has higher compressive strength (kPa) than that with 6% cement (kPa) indicating favourable rate of pozzolanic reaction in 4% cement and small pozzolanic reaction in 6% cement with highly plastic soil. It implies that treatment of highly plastic soils using a low dosage rate of lime produced somewhat higher strength than treatment with a low dosage of cement.

Furthermore, the figure shows that the compressive strength of the 8% lime and 10% stabilized samples (1533 kPa and 2033 kPa respectively) cured for 7 days were higher than that of the soil samples treated with cement or a combination of lime and cement signifying that lime reacts better with plastic soils than cement. However, the stress-strain curves for 10% and 8% lime treated soil samples signify more brittle splitting type of failure with low values of strain at failure indicated by a rapid drop-off in resistance after reaching peak strength, which caused the treated specimens to crack and fail suddenly due to the breaking of inter-particle bonds.

Therefore, while increase in strength can be achieved by lime modification alone, high percentages of lime in expansive soils should be used with extreme caution. Luckily enough, the 4% lime and 2% cement as well as 4% lime and 4% cement changed the specimens from brittle to a more ductile behaviour fracturing at higher strains with more gradual and limited drop-off in shearing resistance. Figure 2 shows the relationship between unconfined compressive stress and vertical strain of unconfined stabilized expansive soil specimens at different binder dosage cured for 14 days.

Unfortunately, the 10% and 8% lime treated soil samples did not show remarkable improvement in unconfined compressive strength. However, the two sequential mixing of the 4% lime and 2% cement as well as 4% lime and 4% cement showed only significant improvement in unconfined compressive strength but reached residual strength more gradually and maintained a certain post-yield failure strength. The analysis indicates markedly improvement in the peak strength and a gradual strength decrease in the post-failure region when highly plastic soils are first treated with lime followed by cement treatment with the mellowing period between them.

Curing time had some impact on the physicochemical and engineering behaviour of stabilized expansive soils. Irrespective of the types of additives, the strength increases with curing time. For example, the strength for 4% lime and 2% cement treated samples varied from 1047 kPa, to 1505 kPa and 1740 kPa for 7, 14 and 28 days of curing respectively.

That of 4% lime and 4% cement treated samples varied from 1320 kPa, to 1500m kPa and 1900 kPa for 7, 14 and 28 days of curing respectively. Furthermore, for lime modified soils, curing time changed the brittle behaviour of lime treated soils to more ductile due to the stabilization process. For example, a brittle manner failure observed after 7 days curing did not recur in specimens cured for 14 and 28 days.

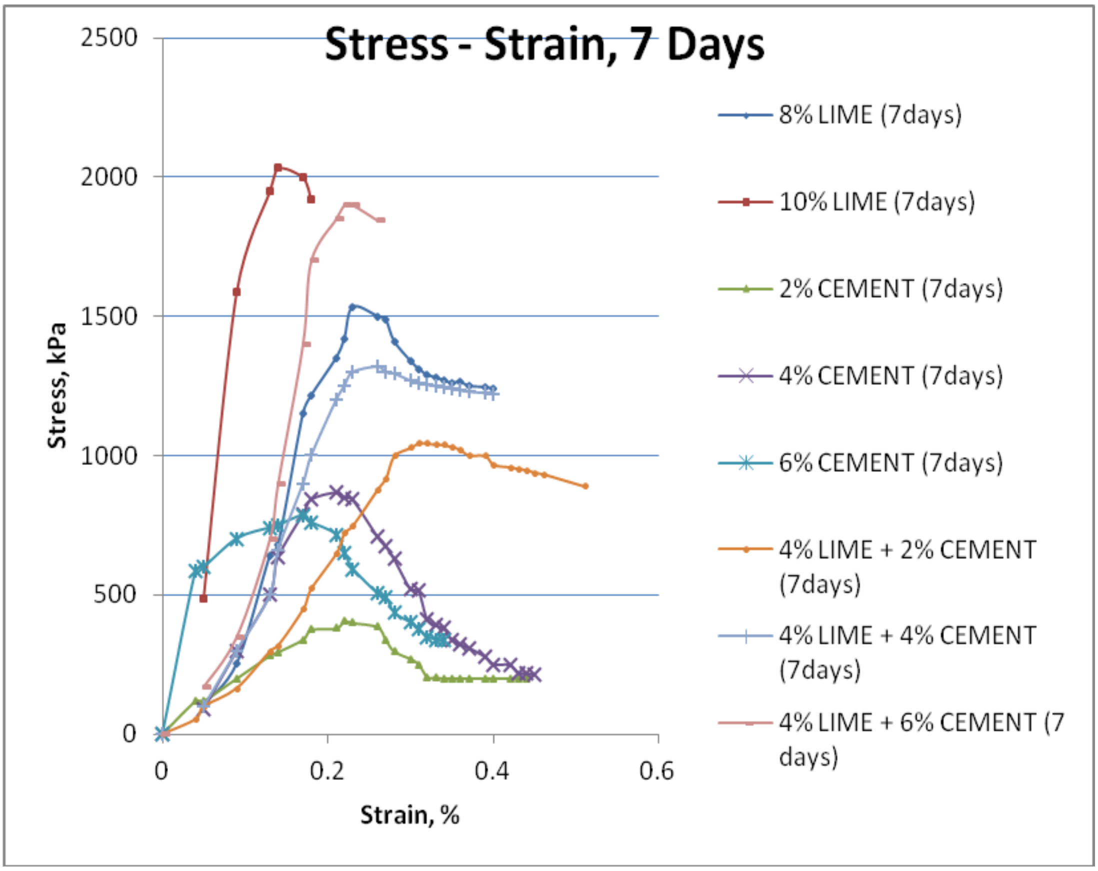

Figure 1: Unconfined compressive stress- strain relationship of stabilized expansive soil specimens at different binder dosage cured for 7 days

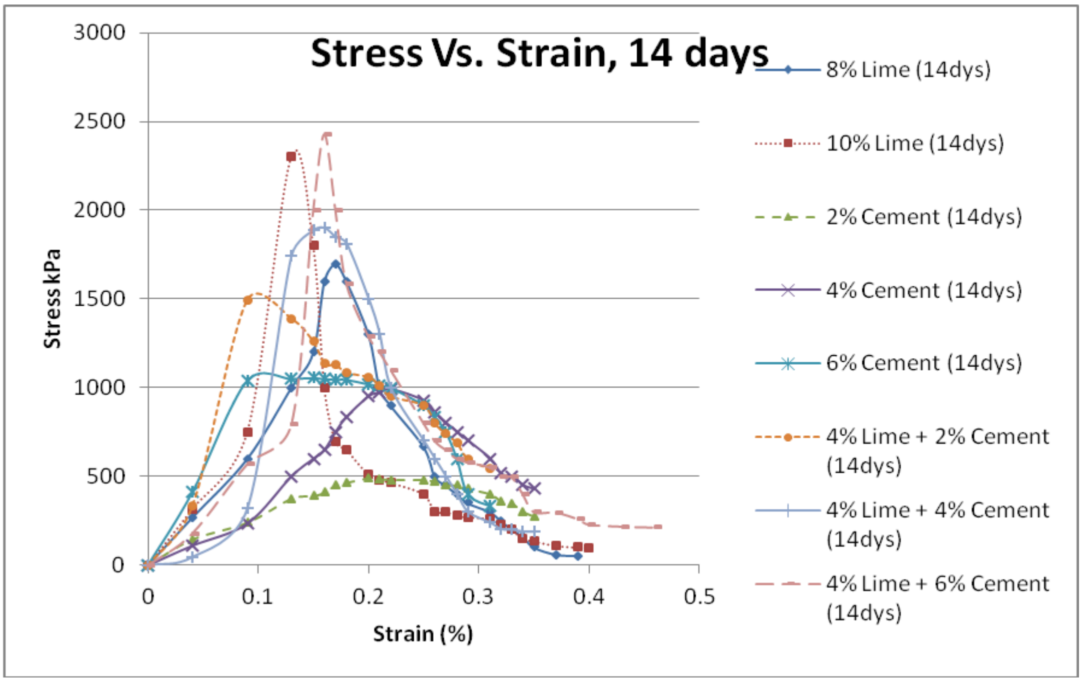

Figure 2: Unconfined compressive stress- strain relationship of stabilized expansive soil specimens at different binder dosage cured for 14 days

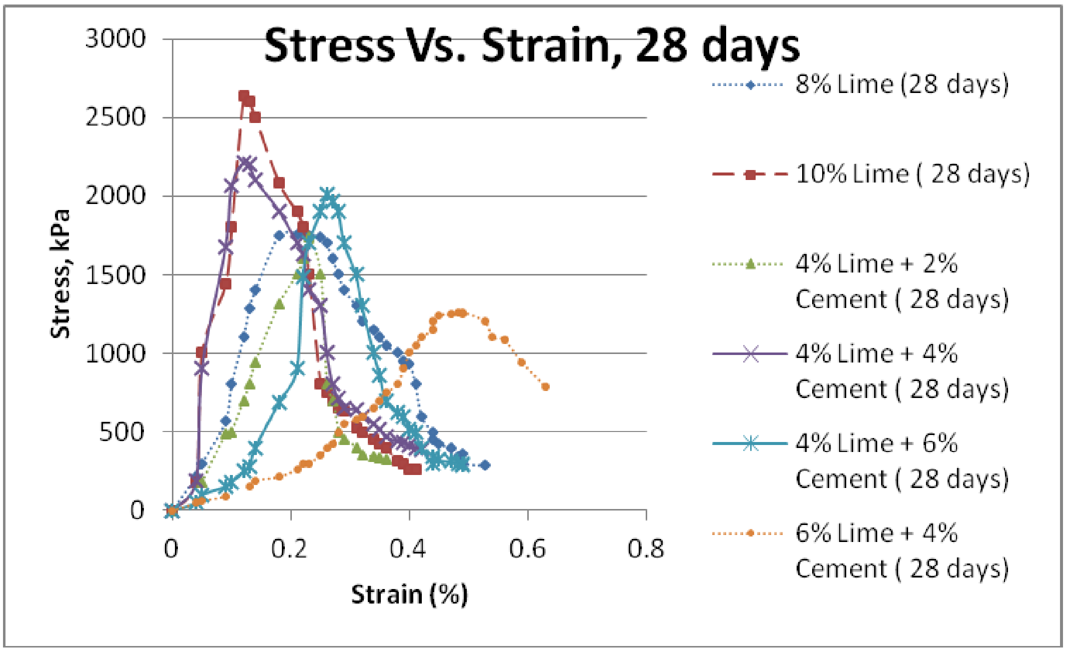

Figure 3: Unconfined compressive stress- strain relationship of stabilized expansive soil specimens at different binder dosage cured for 28 days

5. Conclusions

Lime stabilization or modification improves the workability of expansive soils with adequate development of strength but inadequate stability. In this study, hydrated lime exhibited rapid hydration characteristic by reacting with clay particles and permanently transforming into a strong but brittle and fragile cementitious matrix within 7 days. Cement on the other hand somehow improves the strength of the expansive soil but finds itself difficult to mix efficiently with highly plastic soil, thus the resulting matrix has chunks (bulbs) of unstabilized clay surrounded by cement-bound clay on the outer shell. A two sequential mixing operation whereby lime is applied first followed by cement immediately after mellowing period is best effective system for treating swelling/shrinkage soils. The first treatment with lime causes formation of clods that resemble coarse sand particles. The second treatment with cement simply binds the clods together to form a very stable mass with enhanced strength.

Acknowledgement

The most sincere gratitude is expressed to the Swedish International Development Cooperation Agency (SIDA) for funding this research. Also, special thanks ***go to my employer Ardhi University (ARU)*** for moral and material support throughout my research. Lastly, I would like to express my heart-felt thanks for the great job and dedication of the entire soil laboratory staff at College of engineering and Technology (CoET), University of Dar es Salaam, Tanzania

References

1. Beeghly, J. H. (2003) Recent Experiences With Lime – Fly Ash Stabilization Of Pavement Subgrade Soils, Base, and Recycled Asphalt, Paper Presented at the 2003 International Ash Utilization Symposium, Univ. of Kentucky, Center for Applied Energy Research, Lexington, KY.
2. Bell, G. and Culshaw, M. G. (1998). Some geohazards caused by soil mineralogy, chemistry and microfabric: a review, Geological Society, London, Engineering Geology Special Publications, 15, 427-441
3. Boardman, D. I, Glendinning, S., C. D. F. Rogers, C. D. F. and Holt, C. C. (2007).In Situ Monitoring of Lime-Stabilized Road Subgrade, Journal of the Transportation Research Board, 1757 / 2001, 3-13
4. Bozbey, I. and Garaisayev, S. (2010). Effects of soil pulverization quality on lime stabilization of an expansive clay, Journal of Environmental Earth Sciences, 60(6), 1137-1151
5. Daita, R. K., Drnevich, V. P., Kim, D. and Chen, R. (2006). Assessing the quality of Soils Modified with Lime Kiln Dust, Journal of the transportation Research Board, (1952), 101-109
6. Jung, S., and Santagata, M. C. (2009). Mitigating the Expansive Behavior of Chemically Treated Soils. Publication FHWA/IN/JTRP-2009/02. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.
7. Lucian, C. (2009). Spatial Variability of Expansive Soil Properties at Different Scale within Kibaha, Tanzania, The Global Journal of Agricultural Sciences, 8(1), 95-100
8. Lucian, C., (2008). Development of models to predict swell potential based on soil index properties, Journal of Building and Land Management, 14(2), 59-66.
9. Meisina, C. (2004). Swelling-shrinking properties of weathered clayey soils associated with shallow landslides, Quarterly Journal of Engineering Geology & Hydrogeology, 37(2), 77-94
10. Mtallib, M. O. A. and Bankole, G. M. (2011). , Improvement of the Index Properties and Compaction Characteristics of Lime Stabilized Tropical Lateritic clays with Rice Husk Ash (RHA) Admixture, The Electronic Journal of Geotechnical Engineering (EJGE), 16, 983 – 995

11. Natheer, A. M. and Thafer, A. M. (2008). Stabilization of Expansive Clayey Soil Modified by Lime with an Emulsified Asphalt Addition, Journal of Engineering & Technology, 26(10).
12. Nelson, J. D. and Miller, D. J. (1997). “Expansive Soils: Problems and Practice in Foundation and Pavement Engineering”, Wiley Publications, February 1997.
13. Oyediran, I. A. Kalejaiye, M. (2011). Effect of Increasing Cement Content on Strength and Compaction Parameters of some Lateritic Soils from Southwestern Nigeria, The Electronic Journal of Geotechnical Engineering (EJGE), 16, 1501 – 1514
14. Petry, T. M. and Little, D. N. (1996). Update on Sulfate-Induced Heave in Treated Clays; Problematic Sulfate Levels, Journal of the Transportation Research Board, (1362), 51 – 55.
15. Sivapullaiah, P.V. (2006). Pozzolanic stabilization of Expansive Soil, Chapter 29 in the Expansive Soils, Recent Advance in Characterization and Treatment. Edited by Al-Rawas, A. A. and Goosen, M. F. A., Tayloer & Francis group, London, UK.
16. TMH1 - Technical Methods for Highways (1986). Standard Methods of Testing Road Construction Materials, National Institute for Transportation and Road Research (CSIR), Pretoria.