REVIEW ON THE LIME-SOIL STABILIZATION AS ONE OF THE SUCCESSFUL TECHNOLOGIES USED IN THE IMPROVEMENT OF ROAD-SOIL-PAVEMENT LAYERS STRENGTH

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ABSTRACT

In general terms, transport infrastructure by definition describes the framework that supports our transport system. This includes, railways, sea-ports, airports and, in particular road pavements. In South Africa, the South African National Roads Agency's (SANRAL) prime mandate is to finance, improve, manage and maintain the national road networks, with other roads maintained and managed by provincial or local authorities. But due to increasing traffic and heavy-duty transport loads in many parts of the country, road pavement layers are having difficulty in coping with increasingly heavy tonnages and most now exhibit damage in their lower layers. It is for this reason that the engineering properties of soil layers underneath the pavement surfaces need to be improved using a variety of techniques. One such technique entails the improvement of soil strength through chemical stabilisation through the use of lime as the stabilising agent.

The term lime soil stabilisation applies primarily when lime is introduced to soil that is reactive to create strength development in the long run through pozzolanic reaction. In South Africa, lime is utilised extensively in the construction of roads.

In this paper, a review on literature based on the practices of lime soil stabilisation with the object of improving the engineering properties of soil is presented, with emphasis on the production of lime, nature of soils suitable for lime-soil stabilisation, the behaviour of lime-stabilised materials and the chemistry related to lime-soil stabilisation.

Key words: Lime-soil stabilisation, soil engineering properties, lime-soil chemistry.

1. INTRODUCTION

Soil as defined on the pavement engineering manual by the South African National Roads Agency (SANRAL) (2013) is a material consisting of rock particles, sand, silt and clay and is formed by the gradual disintegration or decomposition of rocks due to natural process. This (soil) is one of nature's most abundant materials available for use for construction purposes and other. Almost all construction takes place using and upon soil. For many years it has been common practice that, when unsuitable construction conditions are encountered, to use procedures that have been developed to overcome the impact of unstable soil. These include – but are not limited to - the following: finding of new construction sites; redesigning of structures by specialist design engineers so that they can be constructed on poor soil; removal of poor soil to be replaced with good soil and improving of the engineering properties of the soil.

According to Vitton (2006), there are several challenges associated with finding new construction sites and redesigning structures so that they can be constructed on poor soil, hence more advances and improvements in technology are being implemented in most parts of the world. Removal of top soil and replacement with good soil is the most commonly adopted modern strategy. In order to capacitate soil to withstand negative conditions, these techniques – particularly chemical soil stabilisation by lime - are utilised to improve the soils' engineering properties.

In South Africa, the stabilisation of highways and other pavement layers using natural occurring soils is very widely an adopted process. Diverse recommendations and standards for highway series particularly the TRH13: Cementitious Stabilisers in Road Construction (Department of Transport: TRH13, 1986) ,the TRH14: Guidelines for Road Construction Materials (Department of Transport:TRH14, 1996), with its application of them in the catalogue designs listed in the TRH4: Structural Design of flexible Pavements for interurban and Rural Roads (Bennett *et al.*, 2002) are reference documents used broadly for this.

In a journal article presented by Aldaood, et al (2014) the chemical soil stabilisation technique by lime is presented as a tried and tested technique for strength development of the soil. This is evident enough when examining several experiments and review studies documented by various different authors (Little, 1995; Jung and Bobet, 2008; Liu, Pemberton and Indraratna, 2010; Celauro *et al.*, 2012; Khattab and Hussein, 2012; Aldaood, Bouasker and Mukhtar, 2014a). They all report that lime has been widely and successfully utilised with the prime objective of increasing the bearing capacity of the soils, with other features being its resistance to the weathering process, assisting with the soils' permeability and others (Negi *et al.,* 2013).

In many parts of the world, several technological practises of increasing the carrying capacity of the soils are being used depending on the nature, behaviour and the intended final used of soils. These include mechanical soil stabilisation, electrical soil stabilisation, thermal soil stabilisation and chemical soil stabilisation as already mentioned above (Kestler, 2009). However these (above mentioned) practices may prove to function differently from region to region largely and primarily because of the nature of the soil being treated, the behaviour of soil when stabilised and probably due to the intended final use of the soil being stabilised to mention a few. Take for instance the case of South Africa where majority of soils are acidic because of the rainfall the country receives annually. Electrical stabilisation of soils for an example may prove to be impractical where chemical stabilisation using of lime becomes a practical practice, because of its benefits, which includes that of increasing the pH range of acidic soil in order to promote effective soil stabilisation.

When lime and water are mixed with soil, particularly soil with a clay both physical and chemical properties changes, resulting in beneficial alterations of its engineering behaviour. This document initially examines the study objectives and goes on to look at the processes being studied and relevant literature. This includes the production of lime, a summary that looks at the nature of the soils that are suitable for lime stabilisation and ultimately the mechanisms of lime-soil stabilisation entailing lime-soil modification or stabilisation as well as the chemistry thereof

2. STUDY OBJECTIVES

A critical, constructive analysis of the literature review covering the utilisation of lime as the stabilising agent for different soil (particularly soil with clay content) is applied in this document. The following sub-objectives apply to this analysis:

- Organisation of literature entailing present data, important findings, as well as theoretical and methodological contributions to topics relating to lime-soil stabilisation with the intention of providing a paper which may provide literature review sources to researchers.
- Evaluation of the literature in terms of accuracy, currency, coverage and the points of views by different authors relating to lime-soil stabilisation.
- Synthesis of the literature by drawing conclusions concerning the findings in the literature so as to identify how the literature addresses the topic in question.
- Identification of the gaps in the previous reviewed literature by identifying research questions not only unanswered, but whose thorough examination can meaningfully contribute to current theory and or practices dealing with lime-soil stabilisation.

3. CHEMICAL SOIL STABILISATION: LIME-SOIL STABILISATION

One method of improving the engineering properties of soil is the addition of chemicals or other materials to improve existing soil. The incapacity of the soil requiring improvements may be brought about by the inability of in-situ subgrades, sub-base or base soil layers to support traffic loading and environmental demands. The South African committee of land officials (COLTO) (Department of Transport (COLTO), 1998); a sub section of the national Department of Transport in South Africa specifies lime as one of the contentious binders that is used to treat materials used in the construction of roadbed, fill or pavement layers. This is apart from other cementitious binders (such as Portland cement) or bituminous binders (such as polymers) which may also be used not only for stabilisation, but for dust or erosion control as well.

Chemical stabilisation specifically through the use of lime is achieved by mixing lime itself with soil to form a stronger composite material (Kestler, 2009). This process is more effective to almost all soils that are fine grained with more sudden development occurring in soils with clay content and high plasticity in the presence of desired moist in the soils treated. The reactive soils mentioned above relates to soil with enough clay content (National Lime Association, 2004; Yong and Ouhadi, 2007; Khattab and Hussein, 2012; Aldaood, Bouasker and Mukhtar, 2014b; Khemissa and Mohamedi, 2014).

This document constantly refers to lime as the preferred method of improving the engineering properties in most parts of the world including South Africa not only in relation its performance benefits when mixed with moist soils but also in relation to that it is a material that can perform so many functions at so reasonable cost since it is substantially less expensive than potential substitutes (Kalidas, 2014; PPC :South Africa 2016).

Over and the above mentioned if one considers to treat an in-place soil (chemical stabilisation) using lime, the cost associated with that is much lesser compared to costs associated with importing quality soils.

However, it should be mentioned that in as much as chemical soil stabilisation viewed as the preferred treatment method of unsuitable soil , the process is generally a dependant process to mechanical soil stabilisation, which is not limited to the blending of material of different particle size in order to improve the grading or decrease the plasticity of the material (Green, 2006) but also the use of heavy machinery after application of the binder (lime) with intention of pre-consolidating soils, thus increasing density and decreasing permeability of the soils.

3.1 Production of lime

The common final product(s) emanating from the production of lime are hydrated lime, quicklime or lime slurry (Calcium hydroxide).The derivation of many final forms of lime - including the aforementioned variations - is obtained by burning limestone or dolomite, thus converting the carbonate to the oxide known as slaked (Department of Transport:TRH14, 1996). This process of transforming limestone to lime follows a carefully planned and well controlled process which follows four basic sub minimum processes, namely quarrying and mining, stone preparation, calcining and hydration (Little, 1995). During the manufacturing process heating limestone at elevated temperatures produces quicklime. The latter is illustrated by the below chemical equation (Equation 1) specifying that, limestone is heated to produce quicklime with carbon dioxide produced as a by-product.

$CaCO_3$+ Heat→CaO + CO_2……………………………………………………………1

With hydrated lime primarily and extensively used for road construction (Milburn and Parsons 2004), its formation follows a hydration process which transforms quicklime to hydrated lime. The above indicates when water is added to quicklime, hydrated lime is produced with the creation of heat as a by-product (Equation 2).

CaO+ H_2O→Ca $(OH)_2$ + Heat…………………………………………………………...2

Companies such as Idwala Lime, PPC South Africa, and PBD Lime in South Africa are among other companies responsible for lime production operations entailing mining, crushing, screening, burning, and milling.

3.2 Nature of the soils suitable for lime soil stabilisation and the performance of lime-stabilised materials

Several documentented methods of classifying soils across the globe exists. The Department of Transport: TRH13 (1986) specifies that lime is most effective when there is enough amount of clay content in the soil. This implies that lime is more suitable for treating soil materials with a plasticity index (PI) higher than 10. The American Association of State Highway and Transportation Officials (ASSTHO) is used as a guide for the selection of soils and soil-aggregate mixtures in the construction of roads (South African National Roads Agency (SANRAL), 2013). The Unified Soils Classification System (USCS) by ASTM International (2006) classifies the below mentioned group of soils, as soils suitable for lime treatment - described in this paper as lime-soils stabilisation. These are, but not limited to: Inorganic clay soils of high plasticity, fat clay soils (CH), Inorganic silts, micaceceous or diatomaceous fine sandy or silty soils (MH), Inorganic silts and very fine sand (ML), Organic clay soils of medium to high plasticity, organic silts (OH), Clayey sands, sand clay mixtures (SC) or a combination of well-graded gravel with clayey gravels (GW-GC).

3.3 Lime-soils modification and lime-soils stabilisation

For short term purposes, lime becomes the perfect alternative for the modification of the physical properties of the soil, with short term benefits achieved through compaction. This aids drying out of wet areas, bridging across underlying spongy sub soil and the provision of working platforms for the subsequent construction or conditioning of the soil for further stabilisation with traditional soil stabilisers such as lime (Little, 1995). Although the lime modification process is primarily aimed at construction expediency, additional effects such as long-term improvement of stiffness or strengthening by pozzolanic and carbonation cementation reactions may be expected (Jung and Bobet 2008).

According to Holt (2010), chemical soil stabilisation which entails both soil modification and stabilisation has been utilised for many centuries. Rome became one of the first capital cities to utilise a chemical soil stabilisation technique. During this time, soil associated with weak properties were mixed with pozzolana (volcanic ash containing alumina and silica) and lime to increase the carrying capacity. Following from the above, the current day treatment of soil became known and implemented in the late 1950s in the United States of America where weak clays were treated with hydrated lime. The United States of America, France, Australia, New Zealand, South Africa, the United Kingdom, Germany and Sweden are among the countries which have utilised and developed the technique.

3.4 Chemistry of lime-soil stabilisation

The technique of soil stabilisation utilising lime - particularly hydrated lime - can be summarised into four different processes. These are referred to as lime soil stabilisation reactions or chemistry (Fang, 1991; Negi *et al.*, 2013). Lime-soils reactions are complex and entail primarily, secondary and tertiary process. These reactions are:

- Cation exchange: The process where soil particle change positive bases with the environment in which the particles interacts (Aprile and Lorandi 2012).
- Flocculation and agglomeration: Prompted by the increased electrolyte content of the pore water due to ion exchange by the clay to the calcium during lime soils stabilisation process (Mallela, Quintus and Smith, 2004).
- Lime carbonation: The reaction of lime, soil, water with carbon dioxide to form calcium carbonate. (Mallela, Quintus and Smith, 2004) and,
- Pozzolanic reaction :The reaction between soils silica and or alumina and lime to form various types of cementing agents (University of illinois at urbana-champaign, 2007).

According to Aldaood, Bouasker and Mukhtar (2014a), the principal chemical reactions that take place during lime-soil stabilisation can be summarised by the following chemical reaction equation:

$CaO + H_2O \rightarrow Ca(OH)_2$……………………………………………………………..3

$Ca(OH)_2 \rightarrow Ca^{++} + 2(OH)^{-}$…………………………………………………………...4

$Ca^{++} + 2(OH)^{-} + SiO2 \rightarrow$ CSH silica gel………………………………………………...5

$Ca^{++} + 2(OH)^{-} + Al2O3 \rightarrow$ CAH alumina gel……………………………………………6

The aforementioned implies that the altered soil structure - particularly soil with clay content - as a result of flocculation of clay particles due to cation exchange and short-term pozzolanic reactions, results in larger particle agglomerates and more friable and workable soil (Little and Nair, 2009). All the four processes briefly mentioned above are described further in detailed as below.

3.4.1 Cation exchange

Cation exchange entails an immediate reaction of soil with lime within a few minutes of mixing, resulting in soil with improved texture. Virtually, majority of fine grained soil show cation exchange reaction when treated with lime stabilising additive in the presence of moisture or water. The reaction takes place quite quickly when the soil and lime are mixed in the presence of water (Mallela, 2004).

According to Aldaood, Bouasker and Mukhtar (2014a), one of the attributes of the aforementioned process relies upon the immediate interaction between the ions associated with the clay particles and the calcium ions of the lime. However, the latter proposal is opposite to the findings of the laboratory experimental study conducted by Akbulut and Arasan (2010) aiming at studying the effects of four diverse soil stabilising additives on the effects of cation exchange capacity, pH zeta potential and other. These additives were lime, fly ash, cement and silica fume. Upon completion of the study, the results pointed out among other, a reduction in cation exchange capacity of the soils tested.

3.4.2 Flocculation and agglomeration

The process termed flocculation and agglomeration generally takes place in a matter of hours after cation exchange reaction (Negi, 2013). This is the modification stage during the lime-soil stabilisation. Upon mixing of the soil with lime and water, the calcium ions from lime stabilising additive move to the surface of the clay particles and displace water and other ions. During this stage, the soil becomes easily crumbled friable and granular, making it easier to work and consolidate.

The addition of lime to fine-grained soil causes flocculation and agglomeration of the clay fraction. These reactions result in a clearly visible change in texture, thus promoting the clay particles to closely bond together into larger sized aggregates (Roohbakhshan and Kalantari, 2014).

3.4.3 Lime carbonation

A number of problems relating loss of cementitious content in stabilised soils were reported in South Africa (Netterberg and Green, 1984; Green, Netterberg and Sampson, 1990b; Gourley and Greening, 1999; Green, 2008). It must however be noted that this (carbonation) is a global problem. The process one of the chemical reaction taking place when lime is mixed with moist soil.

As reported by Jung and Bobet (2008), the formation of calcium carbonate when lime treated soils are in the open air is promoted by the phenomenon of carbonation. The carbonation reaction entails the marked change in nature of calcium hydroxide into calcium carbonate which results from the reaction between calcium hydroxide and atmospheric carbon dioxide gas (Cizer *et al.*, 2006).

There has been however some initiatives in trying to curb the effects of carbonation. Paige-Green and Frank Netterberg have published extensively on carbonation in relation to South African soils. These include keeping of stabilised materials as moist as possible, preventing CO_2 by minimising the exposure of stabilised materials, improvement in construction practices (e.g. compact sooner with appropriate equipment to get higher density and lower permeability and improving of curing procedures and operations (Green, Netterberg and Sampson, 1990a).

Besides the above mentioned, some of the initiatives adopted in relation to the use of lime for effective soil stabilisation include reviewing of designs and construction procedures to suit intended results (Bennett *et al.*, 2002).

3.4.4 Pozzolanic reactions

Pozzolanic reaction is one among many of the reactions that takes place when lime is added to soil thus promoting the production of new minerals such as calcium aluminate hydrates (Al-Mukhtar, Lasledj and Alcover, 2010). The reactions between lime, water, soils silica and alumina that form diverse cementing-type materials are termed as pozzolanic reactions (The National Lime Association, 2004). Little (1995); (Aldaood, Bouasker and Mukhtar, 2014a) all state that lime-soil stabilisation is associated with the long term effect of the soil and are time and curing temperature dependant. This implies that the strength of the lime stabilised soil develops either positively or negatively gradually over a long period.

As long as there is enough content of lime in the soil, the process of pozzolanic reaction can continue for quite long durations-even decades. This is attributed by functions such as the temperature, quantity of calcium, pH and the content of silica and alumina (Jawad *et al.*, 2014).

The stage of lime soil stabilisation that long-term strength is achieved is when lime is added to reactive soil to generate this long-term strength gain. The long-term behaviour of samples as experimentally evaluated by Kavak and Baykal (2012) also supports the validity of the reaction. This study investigates the changes in the micro-fabric of long-term cured lime-stabilised kaolinite clay soil. The unconfined compressive strength of lime-stabilised kaolinite increases continuously when compared to that of the natural kaolinite clay samples.

4. CONCLUSION

The chemical method of stabilising soil, through adding additives such as lime, was reviewed broadly in the literature. Several field and laboratory studies involving lime-soil stabilisation with the intention of evaluating the improvement of geotechnical properties by lime were reviewed. This included:

- A review of the section on the production of lime and the production of hydrated lime or quicklime or lime slurry derived from the limestone.
- The nature of the soils that are practically suitable for lime-soil stabilisation.
- The mechanism of soil treatment associated with: lime-soil modification and lime-soil stabilisation; cation exchange; flocculation & agglomeration; lime carbonation and pozzolanic reactions and other.

One of the things that is still a challenging issue when soils are lime treated is lime is carbonation. There is still a need to conduct more broad studies to validate it since it has constantly become a significant problem in the Southern region of Africa and other parts of the world. In a much as the causes and the impacts of it (carbonation) are broadly known, no proper, guaranteed mechanism(s) (besides keeping of stabilised materials as moist as possible, preventing carbon dioxide exposure of stabilised materials, improvement in construction practices and improving of curing procedures and operations) has been but in place to fully understand it for proper prevention. However and equally so, a lot can be said and appreciated about lime as a soils binding agent. These may include the following but not limited to:

- Lime as being one of the time tested stabilising chemical as has been used many years back in building and road construction.
- Lime as being one of the modern stabilising chemicals.
- Lime as being the versatile chemical which can be employed by a wide range of industries for a number of uses.
- Lime as being the construction chemical, with its todays construction dominant in soil stabilisation, particularly for roads.
- Lime as an affordable chemical since it proves to be substantially less expensive than potential substitutes used in road soils stabilisation.

5. REFERENCES

Akbulut, S. and Arasan, S. 2010. The variations of cation exchange capacity, ph, and zeta potential in expansive soils treated by additives. International journal of civil and structural engineering 1(2): 139-154.

Al-Mukhtar, M., Lasledj, A. and Alcover, J.-F. 2010. Behaviour and mineralogy changes in lime-treated expansive soil at 20 °C. Applied Clay Science, 50 (2): 191-198.

Aldaood, A., Bouasker, M. and Mukhtar, M. A. 2014a. Free swell potential of lime-treated gypseous soil, . Applied clay science, 102: 93-103.

Aldaood, A., Bouasker, M. and Mukhtar, M. A. 2014b. Geotechnical properties of lime treated gypseous soils, . Elsevier, 88-89: 39-48.

Aprile, F. and Lorandi , R. 2012. Evaluation of cation exchange capacity (cec) in tropical soils using four different analytical methods, . Journal of Agricultural Science, 4 (6): 278-289.

ASTM International. 2006. Standard practice forclassification of soils for engineering purposes (unified soil classification system), D 2487 – 06. United States of America: ASTM International.

Bennett, H., Ducasse, K., Payne, G. and Sewlal, S. 2002. Innovative initiatives in road design and construction, in the province of Kwazulu-Natal, South Africa. Paper presented at the 21st Annual South African Transport Conference South Africa 1-22.

Celauro, B., Bevi;acqua, A., Bosco, D. L. and Celauro, C. 2012. Design procedures for soil-lime stabilization for road and railway embankments: Part 1, Review of design methods, . Elsevier, 53: 755-764.

Cizer, O., Balen, K., Gemert, D. and Elsen, J. 2006. Carbonation reaction of lime hydrate and hydraulic binders at 20ºC. Paper presented at the First international conference on accelerated carbonation for environmental and materials engineering, the royal society, london, 12-14 june 2006. London

Department of Transport (COLTO). 1998. Standard specifications for road and bridge works for state road authorities South frica South African Institution of Civil Engineering (SAICE).

Department of Transport: TRH13. 1986. TRH13: Cementitious stabilizers in road construction. Pretoria, South Africa Department of Transport, South Africa.

Department of Transport:TRH14. 1996. TRH14: Guidelines for road conctruction materials Pretoria, South Africa Department of Transport, South Africa

Fang, H. U. 1991. Foundation engineering handbook. New York: Van Nostrand reinhold.

Gourley, C. and Greening, P. 1999. Performance of chemically stabilised roadbases: Results and recommendations from studies in Southern Africa. Department for International Development

Green, P. 2006. Appropiate roads for rural access. Paper presented at the Third Gulf conference on roads. 1-10.

Green, P. 2008. A reassessment of some raod material stabilisation problems. Paper presented at the South African Transport Conference (SATC). Pretoria, South Africa 1-10.

Green, P., Netterberg, F. and Sampson, L. 1990a. The carbonation of chemically stabilised roa construction materials: Guide to its identification and treatment Pretoria, South Africa CSIR: Roads and Transport Technology.

Green, P., Netterberg, F. and Sampson, L. 1990b. The carbonation of chemically stabilised road construction materials: Guide to its identification and treatment. Pretoria, South Africa Division of Roads and Transport Technology: CSIR.

Holt, C. 2010. Chemical Stabilization of Inherently Weak Subgrade Soils for Road Construction:Applicability in Canada, . Paper presented at the Development of New Technologies for Classification of Materials Session of the 2010 Annual Conference of the Transportation Association of Canada, . 1-21.

Jawad, I. T., Taha, M. R., Majeed, Z. H. and Khan, T. A. 2014. Soil stabilization using lime: Advantages, disadvantages and proposing a potential alternative, . Research Journal of Applied Sciences, Engineering and Technology, 8 (4): 510-520.

Jung, C. and Bobet, A. 2008. Post-Construction Evaluation of Lime-Treated Soils, . Indiana Department of Transportation State Office, .

Kalidas, N. S. 2014. Strength characterstics of stabilized embankment using fly ash. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11 (4): 1-34.

Kavak, A. and Baykal, G. 2012. Long-term behavior of lime-stabilized kaolinite clay. Environ Earth Science: 1944-1955.

Kestler, M. A. 2009. Stabilization selection guide for aggregateand native-surfaced low-volume roads, . USA:

Khattab, S. A. A. and Hussein, Y. A. 2012. The durability of fine grained soils stabilized with lime, . Al-Rafidain Engineering 20 (1): 85-92.

Khemissa, M. and Mohamedi, A. 2014. Cement and lime mixture stabilization of an expansive overconsolidated clay, . Applied clay science 95: 104-110.

Little, D. N. 1995. Handbook for stabilisation of pvement sugrades and base course with lime. United States of America Lime association of Texas.

Little, D. N. and Nair, S. 2009. Recommended practice for stabilization of subgrade soils and base materials. National cooperative highway research program: Transportation research board of the national academics.

Liu, M. D., Pemberton, S. and Indraratna, B. 2010. A study of the strength of lime treated soft clays, .

Mallela, J., Quintus, H. V. and Smith, K. L. 2004. Consideration of lime-stabilized layers in mechanistic-empirical pavement design, . Arlington, Virginia: The National Lime Association.

National Lime Association. 2004. Lime stabilisation & lime modification, .

Negi, A. S., Faizan, M., Siddharth, D. P. and Singh, R. 2013. Soil stabilization using lime, . International Journal of Innovative Research in Science, Engineering and Technology, 2 (3): 448-453.

Netterberg, F. and Green, P. 1984. Carbonation of lime cement stbilized layers in road construction. Pretoria, South Africa National Institute for Transport and Road Research: CSIR.

PPC :South Africa 2016. PPC poducts

Roohbakhshan, A. and Kalantari, B. 2014. Effect of lime andwaste stone powdervariation on the ph values, moisture content and dry density of clayey soil. International Journal of Advances in Applied Sciences (IJAAS), 3 (1): 41-46.

South African National Roads Agency (SANRAL). 2013. South african pavement engineering manual South Africa South aAfrican national roads agency.

The National Lime Association. 2004. Consideration of lime-stabilized layers in mechanistic-empirical pavement design, . Arlington, Virginia: The National Lime Association.

University of illinois at urbana-champaign. 2007. Factors influencing the plasticity and strenght of limesoil mixtures, . United State

Vitton, S. 2006. Introduction to soil stabilization, . Michigan Technological University.

Yong, R. N. and Ouhadi, V. R. 2007. Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils, . Applied clay science 35: 238-249.