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Swell behaviour of Lime treated Soil under Sulphate Contamination

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ABSTRACT: Lime stabilization is well-established technique to improve the properties of different soils for constructions despite of several difficulties and its ineffectiveness in certain conditions. Further, a greater level of understanding is needed to know the mechanism of alteration in the properties of stabilized soil, particularly under migration of contaminated water from surrounding environment. In the present study, effects of migration of sulphate contaminated water on the physical and swell behaviour of lime stabilized soil have been examined in detail. The objective has been achieved by performing different tests. The soil sample treated with optimum lime content is subjected to sulphate contaminated water of various concentrations. The susceptible behaviour of lime stabilized soil has been observed after inundating the samples with sulphate contaminated water.

Keywords: Lime stabilization; Soil stabilization; Sulphate contamination; Swell

1 INTRODUCTION

The soil stabilization is the alteration or modifications in soil to modify the existing properties. The stabilization or, treatment of expansive soil generally refers the conversion of soil particles to rigid granular materials that can resist the internal swelling pressure of the clay, and restriction of the movement of moisture within the soil to control the seasonal variations (Al–Rawas & Goosen, 2006). Soil stabilization results in improvement of strength, permeability, compressibility and swell behaviour. The purpose of soil stabilization is to improve the soil in the natural condition for the construction of highway, ground, airway etc. (Jha and Sivapullaiah, 2016).There are many areas where expansive soil exists in the form of variable-thicknesses layers in the developed regions. Much Distress can be caused to infrastructures due to the development of heave and swelling pressure in expansive soils.

The foundation on soils which are expansive is a challenge to foundation engineers as the volume change occurs with variation in water content. The volume change can be either in the form of swell or in the form of shrinkage and often called as swell/shrink soils. Considerable understanding exists on their identification, estimation of swell pressure. Black cotton soils, are found mostly in the central and western parts and covered approximately 20% of the total area (Jha and Sivapullaiah, 2015). The expansive soils exhibit high plasticity, high compressibility, high swelling potential, reduced strength, low coefficient of internal friction, and low durability. (Chen, 2012).

There are different stabilizers like lime, cement, ash etc. used for the purpose of stabilization of soil. Lime is one of the chemical stabilizers popularly used to alter the engineering properties for different types of soils also in the cases when soils are rich in sulphate content (Hausmann, 1990; Mitchell and Dermatas, 1992; Nalbantoglu and Tuncer 2001; Petry and Little, 2002).

Lime treatment of natural soils has already been successfully used for many past years for improving strength and stiffness properties of soil. Lime is used as an effective additive to imodify various engineering properties of expansive soils. Lime treatment in cohesive soils causes a decrease in plasticity, change in volume, and an increase in particle size, permeability, strength, and also compressibility (Al-Mukhtar 2014). The interaction of the lime and soil is very complex reaction occurring rapidly as soon as they are mixed. These reactions are Cation exchange, flocculation and agglomeration (George, 1992).

Sulphatic content is extended over more than 20% of the land surface on the earth. In India 0.06% of the land is covered with Gypesous soil (Watson, 1979). If the soluble sulphate is more than 2000 ppm in a soil then that soil is termed as sulphate - rich soil or sulphate bearing soil. Gypsum is the most common sulphate minerals present in the soil because of its relatively low solubility (2.6 gm/L) level compared to Na_2SO_4 (408 gm/L) and $MgSO_4$ (260 gm/L). In most of the cases, gypsum is considered as the main source of sulphate. Gypseous soil poses several engineering problems such as settlement in dry conditions and ground subsidence with formation of pores, cracks and cavities by the dissolution of gypsum in wet conditions. During stabilization of sulphate–bearing soil through calcium based stabilizer the formations of ettringite or thaumasite by soil–lime–sulphate reactions create several distresses to structures by heaving. It is essential to study and understand the effects of sulphate on the swell behavior of lime treated soil to overcome the failures (Petry and Little, 2002).

The heaving and premature failures of structures constructed on lime and cement–treated soils containing sulphates exhibits, leading to question the validity of calcium based stabilization. The main focus of this work is to identify the free swell and other properties of lime treated expansive soil by different molar solution contain varying sulphatic content.

2 MATERIALS USED AND METHODOLOGIES FOLLOWED

2.1 Soil and its characterization

The soil which is taken for the investigation is from Shivdaspura village, near Jaipur District, Rajasthan-303903, India. The soil was collected from the depth of 1-1.5 m to the ground. The particle size analysis done as per Indian Standard (IS) – 2720 (Part 4) (1985) of soil show the presence of sand sized particle (4.75 – 0.075 mm) of 11.00%, silt sized particle (0.075 – 0.002 mm) of 13.00% and clay sized particle (<0.002mm) of 76.00%. It is observed that black cotton soil is predominated with clayey size particle. The specific gravity (IS-2720 (Part 3) (1980) of soil (i.e. 2.38) is observed. The Atterberg's limits i.e. liquid limit, plastic limit and shrinkage limit of parent material and soil-lime mixes are determined by following the standard procedure of IS-2720 (Part 3) (1985), IS-2720 (Part 5) (1980); IS-2720 Part 6 (1972), respectively. The geotechnical properties of black cotton soil are shown in Table 1.

Table1. Properties of black cotton soil

Property	Soil
Sand (4.75 – 0.075 mm), %	11.00
Silt (0.075 – 0.002 mm), %	13.00
Clay (<0.002mm), %	76.00
Specific Gravity	2.37
Liquid limit, %	49.00
Plastic limit, %	29.18
Plasticity index, %	19.81
Shrinkage Limit, %	11.65
Differential free swell index, %	70.00
Optimum water content, %	20.80
Max. dry density, gm/cm^3	1.62
CBR, %	1.62
pH value	8.07

The X-ray diffraction (XRD) spectrometer is performed to find out the mineralogical composition of the black soil by using graphite mono-chromator and Cu-Kα radiation. The scanning angle of the sample for 2θ is 3° to 90°. The data file which is developed by the Joint Committee on Powder Diffraction Standards (JCPDS, 1999) is used to identify the presence of various minerals in the sample. The XRD analysis of soil indicates the presence of montmorillonite, aluminum oxide and quartz as predominant minerals.

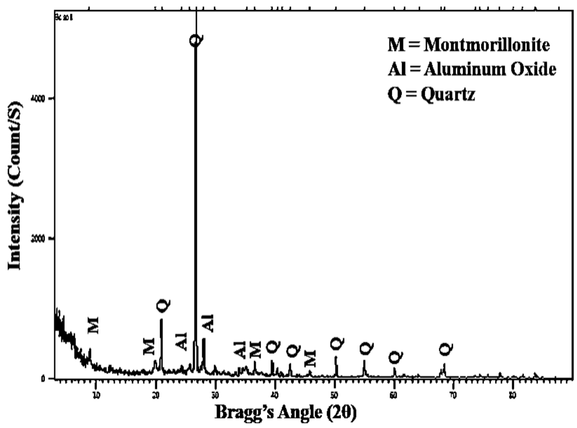

Figure 1.XRD analysis of black cotton soil

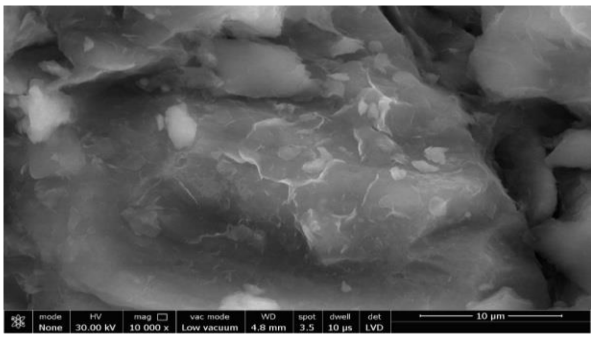

Figure2. SEM images of black cotton soil

Field Emission Scanning Electron Microscope (FESEM) coupled with Energy Dispersive X–ray Spectroscopy (EDAX) is performed to examine micro structural and chemical composition of soil. A small amount of oven dried soils are mounted on the aluminum mounting disc (also called SEM stubs) with the help of carbon tape. Prior to SEM examination, the sample was coated with 100 Å thin layer of gold palladium for 38 second using a sputter coater, polaron E5100 at 10^{-3}Torr Vacuum. Coating of gold is done to avoid charging problem during imaging.

Microscopic images of black cotton soil [Fig.2] illustrate the Microscopic images of BC soil pronounces the several voids with honeycomb networking patterns. EDAX is performed for the chemical composition to observe the element present in black cotton soil. It is found that black cotton soil is predominated with Silica (Si) and Aluminum (Al) with minor amount of magnesium (Mg) and Sodium (Na) [Table 2].

Table 2.Chemical composition analyses of black cotton soil (BCS)

Element	Atomic %
O	66.41
Si	15.38
Al	12.62
Fe	3.85
K	0.67
Mg	0.54
Na	0.53
C	0.00
Total	**100.00**

2.2 Lime and Gypsum

The Lime ($Ca(OH)_2$) and Gypsum($CaSO_4.2H_2O$), which have 4% maximum limit of impurities, are obtained from manufacturer of Jaipur, India.

3 RESULTS AND DISCUSSION

3.1 Effect of lime on the specific gravity of black cotton soil

Fig. 3 shows the effect of lime on the specific gravity of black cotton soil. The investigation shows that the specific gravity increases after the addition of optimum lime to the black cotton soil. The specific gravity may increase due to the aggregation of soil particle due to ionic exchange between soil and lime.

3.2 Effect of lime on the plasticity characteristic of black cotton soil

3.2.1 Liquid Limit

The effect of addition of lime to the black cotton soil with distilled water on the liquid limit is shown in Fig. 4.

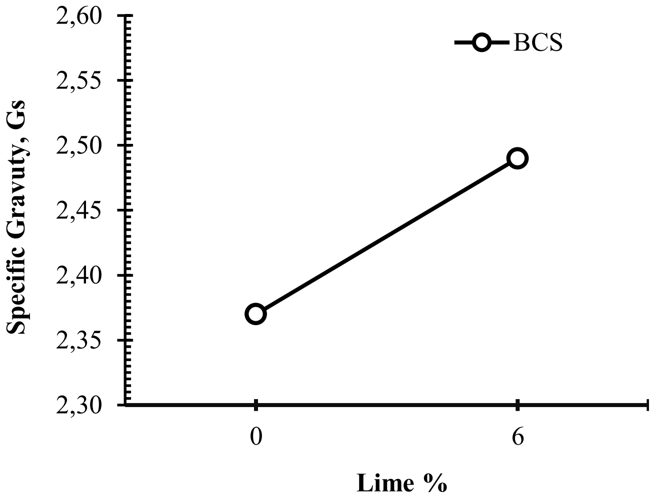

Figure 3.Variation of specific gravity of black cotton soil with addition of Lime.

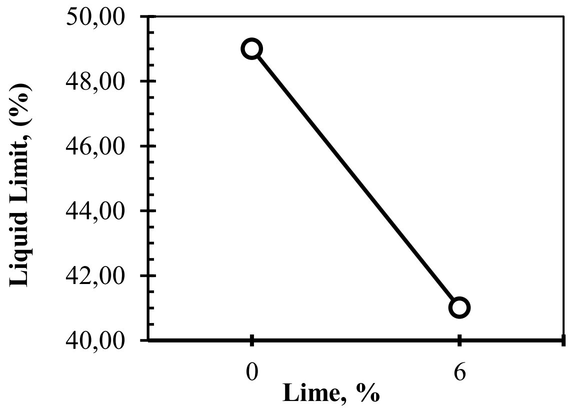

Figure 4.Variation of liquid limit of black cotton soil with addition of lime.

The results are showing the reduction in the liquid limit of black cotton soil with increase amount of lime. The changes in the liquid limit of soil is ascribed to the void water present in the floccules and between the clay particles comprising the floccules (Terzaghi and Peck, 1967).This result is attributed to a reduction in the thickness of the double layer attributable to increased electrolyte concentration in the pore fluid.

Variation of liquid limit of black cotton soil & lime in presence of sulphatic contamination is also shown in Fig.5.The liquid limit test of black cotton soil & lime is conducted with molar solution of gypsum of 500, 1000, 2000, 3000, 4000 and 5000 ppm instead of distilled water. The decrement is observed in the liquid limit when ppm of sulphatic content is increased. This may be attributed due to the ettringite is formed immediately (Wild et al., 1993).

The increase in the flow resistance may be due to the distortion of arrangement of soil particles with addition of gypsum content, it may increase the liquid limit of lime treated soil (kinuthia, 1997) but the supply of additional calcium ions and un-reacted gypsum particles, which act as a fully saturated inert filler particles and devoid the unsatisfied charges by its crystal boundary of soil caused reduction in liquid limit (Azam et al., 1998).

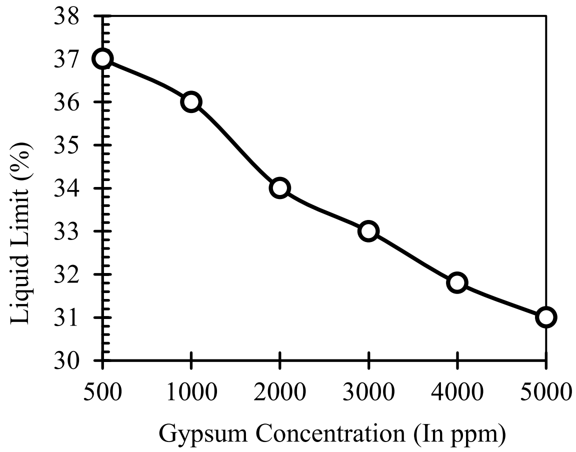

Figure 5.Variation of liquid limit of black cotton soil & lime in presence of sulphatic contamination

3.2.2 Plastic Limit

The effect of addition of lime to the black cotton soil on the plastic limit is shown in Fig. 6. The plastic limit is increasing with the addition of optimsum lime in the black cotton soil. This behaviour of the increment in the plastic limit is attributed to the cation exchange process between the cations of the soil and lime (kinuthia, 1999).

3.2.3 Plasticity Index

The variation of addition of lime to black cotton soil percentage with on the plastic index is shown in Fig. 6.The liquid limit is decreasing and plastic limit is increasing with the addition of lime resulting in decreased plasticity index.

3.2.4 Shrinkage Limit

The effect of addition of lime to black cotton soil on the shrinkage limit is shown in Fig. 7. Shrinkage limit is increasing up to the addition of optimum lime content.

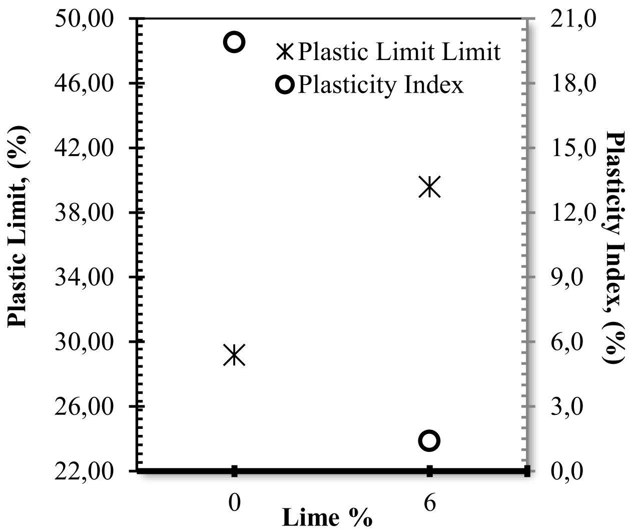

Figure 6. Variation of plastic limit and plasticity index of black cotton soil with addition of lime.

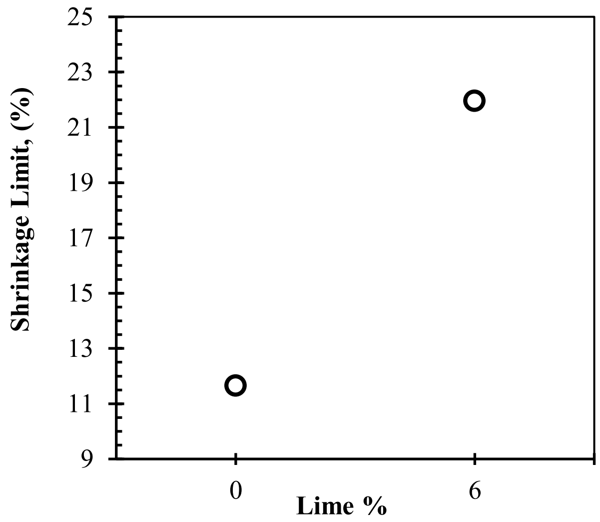

Figure 7.Variation of shrinkage limit of black cotton soil with addition of lime.

3.3 Effect of lime on the compaction characteristics (maximum dry density and optimum water content of black cotton soil)

Effects of addition of lime on the Maximum Dry Density (MDD) and Optimum Water Content (OWC) of Black soil are shown in Fig.8 & 9.

Aggregation takes place when gelatinous compounds are formed, which may cause decrease in dry density. The increase in water holding capacity within flocculated soil matrix and requirement of additional water for the pozzolanic reaction between soil–lime leads to the increase in optimum water content.

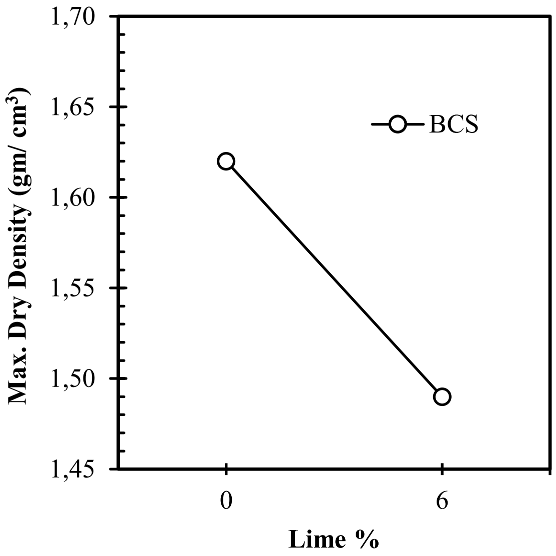

Figure 8.Variation of maximum dry density of black soil with addition of lime.

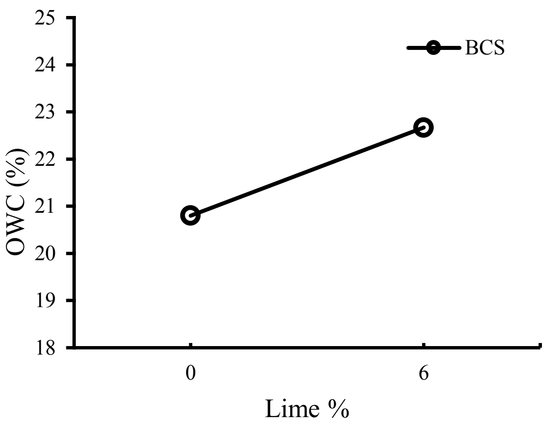

Figure 9.Variation of optimum water content of black cotton soil (BCS) with addition of lime.

3.4 Effect of lime on the free swelling index (FSI)

The Fig. 10 shows the impact on FSI with the addition of lime to the black soil. The FSI of black soil is 70%. It is increasing with the addition of optimum lime content in presence of different molar solution of sulphate.

Different molar solutions of 500, 1000, 2000, 3000, 4000 and 5000 ppm are prepared. Free swell tests are conducted for black cotton soil with and without lime in suphatic contamination.

When amount of gypsum increases it in turn supplies calcium ions, which then leads to flocculate the soil matrix system. This increases the water holding capacity within the flocculated matrix which then increases swell index of soil.

Further, the reaction among the sulphate (released from gypsum), calcium (released from lime) and aluminum (released from soil in the presence of water causes formation ettringite mineral. The formation of ettringite results in the increase in free swell of the lime treated soil contaminated with sulphatic water.

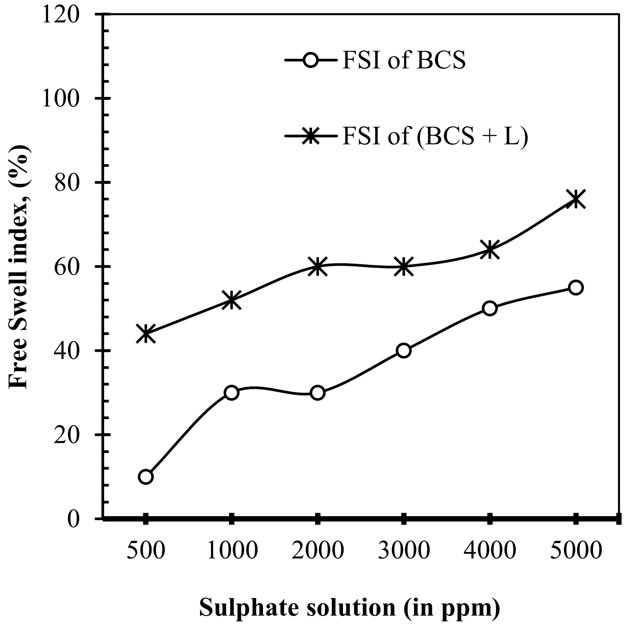

Figure 10. Free swell index of Black cotton soil with addition of lime in presence of sulphate contaminated water.

4 CONCLUSIONS

The effect of suphatic contamination on the physical and swell behaviour of lime treated black cotton soil is investigated in details. The major conclusions that can be drawn from the present study, are as follows:

1. The specific gravity increases after the addition of optimum lime (6 %) to the black cotton soil. Whereas the liquid limit is decreased and plastic limit of black cotton soil is increased, therefore plasticity index also decreased and shrinkage limit is increased. These results are attributed to the reduction in the thickness of the double layer due to increased electrolyte concentration in the pore fluid.
2. Sulphate contamination causes the reduction in liquid limit of lime treated soil. The reduction in liquid limit is due to the formation of ettringite mineral.
3. The maximum dry density decreases with an increase in Optimum Water Content of black cotton soil treated with lime. Dry density is decreased due to the formation of gelatinous compounds whereas the OWC is increased due to the increase in water holding capacity.

4. The free swell index of black cotton soil increases continuously with concentration of sulphate in water. Lime treatment of soil increases the free swell index drastically with the increasing amount of sulphate concentration. The increase in free swell index of lime treated soil in the presence of sulphate contaminated water is due to the ettringite mineral is formed.

The present study indicates that the lime is used to stabilize the soil. However, intriguing behaviour of soil treated with lime is observed in the presence of suphate contamination.

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6 REFERENCES

Al-Mukhtar, Muzahim, Lasledj, Abdelmadjid, Alcover, J.F. (2014). “Lime consumption of different clayey soils.” Applied clay science, 95, 133–145.

Al-Rawas, A. A., & Goosen, M. F. (Eds.) (2006). “Expansive soils: recent advances in characterization and treatment”. Taylor & Francis.

Azam, S., Abduljauwad, S. N., Al-Shayea, N. A. (1998).“Expansive characteristics of gypsiferous / anhydritic soil formations”. Engineering geology 51: 89-107.

Bureau of Indian standards (1985) IS 2720 (Part 4). “Methods of test for soils: grain size analysis.” New Delhi.

Bureau of Indian Standards (1980) (second revision) IS 2720, (Part 3/Set 1), Methods of test for soils: Determination of specific gravity, New Delhi, India.

Bureau of Indian Standards (1985) (second revision) IS 2720, (Part 5) Methods of test for soils: Determination of liquid limit and plastic limit, New Delhi, India.

Bureau of Indian standards (1985) IS 2720 (Part 4) Methods of test for soils: grain size analysis, New Delhi, India.

Bureau of Indian Standards (1987) (second revision) IS 2720 (Part 26) Methods of test for soils: Determination of pH value, New Delhi, India.

Chen, F. H. (2012). “Foundations on Expansive Soils (Vol. 12).” Elsevier. Chittoori, B. C. S. (2008). “Clay mineralogy effects on long-term performance.

George, S. Z., Ponniah, D. A., Little, J. A. (1992). “Effect of temperature on lime-soil stabilization.” Construction and Building Materials 6(4): 247-252.

Hausmann, M. R. (1990). “Engineering principles of ground modification.” McGraw-Hill.

JCPDS (Joint Committee on Powder Diffraction Standards) (1999) Index to the powder diffraction file, International Centre for Diffraction Data, Newtown Square, PA.

Jha, A. K., & Sivapullaiah, P. V. (2015). “Susceptibility of strength development by lime in gypsiferous soil—A micro mechanistic study.” Journal of Materials in Civil Engineering, ASCE.

Arvind Kumar Jha, P.V. Sivapullaiah (2016). "Volume change behavior of lime treated gypseous soil — influence of mineralogy and microstructure", Applied Clay Science.

Jha, A. K. & Sivapullaiah, P. V. (2016). “Gypsum induced volume change behavior of stabilized expansive soil with fly ash-lime”. Geotechnical Testing Journal, ASTM, Vol. 39, No. 3, pp. 1–16.

Arvind Kumar Jha, P.V. Sivapullaiah(2017). "Physical and strength development in lime treated gypseous soil with fly ash — Micro-analyses", Applied Clay Science.

Kinuthia, J. M. (1997). “Property changes and mechanisms in lime–stabilised Kaolinite in the presence of metal sulphates.” Doctoral dissertation, University of Glamorgan.

Kinuthia, J. M., Wild, S., and Jones, G. I. (1999). “Effects of monovalent and divalent metal sulphates on consistency and compaction of lime-stabilised kaolinite.” Applied Clay Science, 14(1): 27-45.

Nalbantoglu, Z., and Tuncer, E. R. (2001). “Compressibility and Hydraulic Conductivity of A Chemically Treated Expansive Clay.” Canadian geotechnical journal, 38(1), 154–160.

Mitchell, J. K., and Dermatas, D. (1992). “Clay soil heave caused by lime–sulphate reactions.” Innovations and uses for lime, 41–64.

Petry, T. M. & Little, D. N. (2002). “Review of stabilization of clays and expansive soils in pavements and lightly loaded structures history, practice, and future”. Journal of Materials in Civil Engineering, 14(6), 447-460

Terzaghi, K., Peck, R. B. (1967).” Soil mechanics in engineering practice”. 2nd edn., Wiley, New York. 729.

Watson, A. (1979).“Gypsum crusts in deserts.” Journal of Arid Environments 2: 3-20.