Physical and Geotechnical Perspectives of Gypsum on Lime Stabilized Expansive Soil: A Critical Appraisal

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Abstract

The gypsum is the source of sulphate commonly found in the soils throughout the world. The expansive soils are considered as problematic as they exhibit uncertain swelling and shrinkage in presence of moisture. The expansive soils are treated with different stabilizers to suppress the swelling behaviour. Lime is most effective stabilizer used to stabilize the expansive soil. Researchers reported that expansive soil when treated with lime encounters the gypsum it regenerates the swelling. This regenerated expansion of lime treated soil in presence of sulphate may have alarming signs for sulphate bearing soils. The presence of sulphate alters the mineralogical behaviour of expansive clay. The stabilization additive used for such soils needs more attention. A comprehensive approach towards proper understanding of the effects of gypsum on lime stabilized soil is required in order to understand the future threats of expansive soils. In this paper, an attempt has been made to present a comprehensive review on the effects of (Gypsum) calcium sulphate dihydrate on the physical properties of untreated and lime treated expansive soil have.

Keywords: Expansive soil; black cotton soil; gypsum, lime; microstructure; stabilization; sulphate.

1. Introduction and Background

Expansive soils are very unpredictable due to uncertain shrinkage and swelling behaviour. The clay minerals such as montmorillonite or Kaolinite are considered to be responsible for such behaviour [4, 25, 33, 37]. For the purpose of construction the expansive soils are seldom suitable [12]. Therefore soil improvement is required to make it feasible to execute the work. Soil stabilization techniques to alter the microstructural properties of a soil are in practice which controls the engineering behaviour [5, 34]. Black Cotton soils covered more than 20% of the area in India. These soils show high shrinkage and swelling properties [7]. Gypsum is among the soluble salts present in soils that can cause adverse effects on subgrade soils and structures built on them if present in quantities exceeding the limit [29]. Several engineering problems are reported throughout the world due to the existence of gypsum in the soil and its soluble characteristics. The soil which contains gypsum is termed as Gypseous soil or gypsiferous soil [10]. The gypsum is extended to around 1/5th of land in the world [39]. In India, gypseous soil covers 0.06% of the total area of India i.e. it is extended over an area of 182.0 km2, [10, 40]. Gypseferous or gypseous soil encounters leaching & soaking and drying & wetting cycles when they are taken as subgrade material, this can cause severe damage [2, 22]. Gypseous soil has different impact of engineering properties of soil depending upon different parameters such as quantity of gypsum, type of soil, other minerals, environmental conditions, temperature, pH etc. [18]. Mitchell [22] reported the formation of heaves in the soil due to the occupancy of sulphate in the soil or the immigration along with water. When particularly calcium-based stabilizers are used to stabilize the natural expansive soil which is attacked by sulphate it results in the distress in the form of induced heaves which have high expansion extent [20, 23]. It is well known fact that Gypsum is considered as common source of sulphates causing sulphate induced heaves due to the formation of ettringite [1, 16, 27, 31]. The sulphate induced heaves causes danger to life and loss of economy. The expansive minerals responsible for sulphate induced heaves are ettringite [Ca6,(Al,OH)6]2(SO4)3.26H2O] and thaumasite [Ca6,2(Si,OH)6]2(SO4),(CO3)2.24H2O] [6, 17]. Kimuthia [19] and Jha [13] explained that ettringite is having structural tendency to hold higher no of water molecules thereby facilitating the subsequent growth, also it in non-soluble in nature. Adverse effects of sulphates on the properties of soil treated with lime can be controlled by knowing the amount of sulphate present in soil and also the types of soil [16, 41]. If the sulphate limit exceeds the suggested threshold then calcium based stabilizers must not be used for stabilization purposes. The amount of sulphates present in soil is if below 2000 ppm (or 0.2%) it has minimal risk of generation of heaves [24, 26] and if exceeded it can adversely affects the soil [28]. The behaviour of expansive soil in presence of sulphate is vital to understand. In the present study, a comprehensive review has been made to understand the behaviour of expansive soil treated with lime when it encounters the sulphates from gypsum. The effects of gypsum on physical and geotechnical properties of expansive soils are reviewed in the present study.

2. Discussion
2.1 Effects of type of soil, quantity of lime, quantity of gypsum

The results obtained from the investigations indicate that sulphate, lime and soil reactions takes place. These reactions result in the induced heaves due to the origination of ettringite/thaumasite expansive compounds. The extent of formation of heaves depends upon the many factors viz. type of soil, clay mineral, moisture content, temperature, pH, quantity & quality of lime, gypsum etc. These expansion problems of lime treated soil likely to occur in expansive soils having montmorillonite clay mineral [1, 38]. Past studies showed that researchers also used different types of soil to identify the effects and give conclusions. The black cotton soils are more prone towards generation of sulphate induced heaves. The considerable amount of lime used for stabilization varies from 2–8 % depending upon type of soil and other environmental conditions [38]. An optimum value of lime is identified for effective stabilization. Researchers used gypsum as a source of sulphate in terms of percentage, weight and mole. Different amount of gypsum is utilized inorder to study the effects to extract the most vulnerable range of sulphatic quantity. Researchers reported that if soluble sulphate concentration is under 2000 ppm then its effects are marginal [24]. Beyond 2000 ppm of sulphatic concentration the quantity of sulphate affects the lime stabilized soil with severity however other parameters also governs the impacts [28].

2.2 Effects of gypsum on plasticity characteristics of lime-stabilized soil

When Lime is added to expansive soil, the liquid limit is decreased and plasticity behaviour is improved [11]. The improvement in plasticity is due to the reduction in Diffuse Double Layer (DDL). This happens due to cation exchange process which occurs when divalent calcium ions from lime replaces the monovalent ions in the soil system [10, 30]. Researchers stated that shrinkage limit of soil is increased when lime is added due to change in fabric of soil [38]. Previous researches agreed the addition of lime as beneficial stabilization technique. Some researchers investigated that existence of gypsum in soil disturbs the stable matrix of lime stabilized soil. The gypsum creates surplus amount of calcium ions to the soil and sulphates to the soil. The sulphate comes in contact with lime stabilized soil and the liquid limit again increases, also plastic behaviour is affected. At higher sulphatic concentration gypsum interferes with the short term reactions (cation exchange process and flocculation) and long term reactions (pozzolanic reactions) [11, 19, 17].

2.3 Effects of gypsum on compaction characteristics of lime-stabilized soil

Due to substitution of monovalent ions in the soil by calcium ions dissociated from lime alters the grading of soil particle. These changes results in the development of CSH and CAH gel are followed by the ion exchange and flocculation. When gelatinous compounds are formed the aggregation takes place which causes decrease in dry density [9, 21, 35]. Increase in optimum water content is due to the increment of water holding capacity in the flocculated matrix and enhancement in the need for more water for pozzolanic reactions [9, 19]. In the presence of sulphates considerable deduction in maximum dry density and increase in optimum water content of lime treated soil are observed. Due to the increase in flocculation maximum dry density is increased. Along with flocculation/agglomeration and pozzolanic reaction, formation of ettringite are also increased the pore size which holds more water causing increase in optimum water content [10].

2.4 Effects of gypsum on strength behaviour of lime-stabilized soils

It is shown from the experimental work that presence of gypsum highly affects the strength properties of lime stabilized soil. It causes reduction in strength as long as curing period is increased. At lower gypsum content and 0-7 curing days, the strength property increases but proceeding towards the higher curing period and higher sulphatic content strength reduces thereafter [8, 15]. The immediate increase in unconfined compressive strength at low curing period is due to the cementation behaviour of lime-soil-gypsum reactions. This is due to the fact that at lower gypsum content gypsum becomes the source of additional Ca ions and supports the increase in strength and simultaneously reactivity of sulphates is observed as negligible [10]. The formation of ettringite induces considerable gain in strength initially due to the development of interlocking soil matrix with filling of voids. When curing period is increased Calcium, soil and sulphates react to form ettringite causing decrease in the strength.

2.5 Effects of gypsum on swell behaviour of lime-stabilized soils

The investigation about the swelling potential of lime stabilized is done by limited researchers. It is shown that lime treatment to expansive soil diminishes the volume expansion behavior [31]. The short term and long term
reactions are responsible for controlling such behaviour. This controlled behaviour of expansive soil with lime when turned to rapid development of expansive mineral in presence of sulphate, it becomes severe case. The study of swelling behaviour clearly helps in investigating the swelling extension as sufficient water is available to facilitate lime-soil-sulphate reaction. Few of the past studies explained the growth of ettringite and mechanism of its formation. It is reported that at higher gypsum content the reactions between soil, lime and sulphate take place therefore formation of ettringite occurs [2, 13, 27]. At lower sulphates effects of sulphate is not visible and lime stabilization technique dominates. During swell studies the more availability of water is there as compared to other tests thereby causing the fast growth of ettringite. Immediately after entering of water immediate swelling occurs.

2.6 Microstructural investigation of lime-stabilized soil with gypsum

The formation of calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrate (CAH) gel which is responsible for stabilization by lime and formation of ettringite which is responsible for sulphate induced heaves are studied by microstructural investigations. Microstructural investigations are done through X Ray Diffraction Technique, Energy Dispersive X-ray Spectroscopy (EDAX) and Field Emission Scanning Electron Microscope (FESEM,) techniques executed on the samples from experiments. The results are studied and confirmed by micro structural studies also followed by Thermo Gravimetric Analysis (TGA), Derivative Thermo-Gravimetry (DTG) and Fourier Transform Infrared Spectroscopy (FTIR). Researchers conducted microstructural investigation to confirm the behavioral change observed in geotechnical properties due to the addition of gypsum. These investigations are still need to understand in a broader perspective considering other parameters also so that clear scenario would become visible and correct stabilization technique can be selected for treatment of expansive soil.

3. Conclusions

1. The behaviour of soil highly depends upon the type of soil, clay mineral, quantity & type of lime, quantity of gypsum, temperature, water, pH etc.
2. Lime stabilization is effective technology to treat expansive soils. Lime improves the plasticity behaviour by decreasing liquid limit.
3. The quantity of gypsum plays major role in exhibiting the strength performance of lime treated soil. If soluble sulphates are below 2000 ppm, then it causes marginal impacts on soil. Exceeding this, the higher sulphatic range causes serious impacts.
4. In the presence of high sulphates considerable deduction in MDD and along with this increase in OWC of lime treated soil are observed.
5. The magnitude of sulphatic content and time period of curing significantly affects the strength properties. Unconfined compression strength is reduced at higher sulphates and larger curing period. However, immediate addition of gypsum reported increase in strength at lower sulphatic amount for lime treated soil.
6. High expansion is reported through swelling test for lime treated soil. The more availability of water helped in soil-lime-sulphates reactions as ettringite holds water molecules depicting swelling.
7. The microanalysis also confirmed the strength and swell behaviour change.
8. A detailed study covering varying parameters to present consistent result is needed to be studied.

References

[1] Abdi, M.R., Wild, S. (1993). Sulphate expansion of lime-stabilized kaolinite: I. Physical characteristics. Clay Miner. 28:555–567.
[2] Alkaoud, A., Bouasker, M., Al-Mukhtar, M. (2014). Effect of long-term soaking and leaching on the behaviour of lime-stabilised gypseous soil. Int J Pavement Eng, 16(1):11–26.
[3] Bell, P.G. and Maud, R.R. (1994). Dispersive soils and earth dams with some experiences from South Africa. Bulletin of the Association of Engineering Geologists.31(4): 433–446.
[4] Chen, F.H.(1975). Foundations on expansive soils. Elsevier.
[5] Chen, F.H. (2000) Soil engineering, testing, design, and remediation. USA : CRCPress LLC.
[6] Dermatas, D. (1995). Ettringite-induced swelling in soils: state-of-the-art. Appl Mech. Rev 48:659.
[7] IS 1498, 1970. Classification and identification of soil. Bureau of Indian Standards, New Delhi, India.
[8] Gadouri, Hamid ,Harichane, Khelifa, Ghrici, Mohamed (2017). A comparison study between CaSO4·2H2O and Na2SO4 effects on geotechnical properties of clayey soils stabilised with mineral additives to recommend adequate mixtures as materials for road pavements. International Journal of Geotechnical Engineering, 2017.https://doi.org/10.1080/19386162.2017.1320850.
Jha, A.K., & Sivapullaiah, P.V. (2014). Gypsum Induced Strength Behaviour of Fly Ash-Lime Stabilized Expansive Soil. J Geotech Geoenviron En. DOI 10.1007/s10706-014-9790-7.

Jha, A.K., & Sivapullaiah, P.V. (2015a). Susceptibility of strength development by lime in gypsiferous soil—A macro mechanistic study. Applied Clay Science, Elsevier, 115, 39-50.

Jha, A. K., & Sivapullaiah, P. V. (2015b). Mechanism of improvement in the strength and volume change behavior of lime stabilized soil. Engineering Geology, Elsevier, 198, 53-64.

Jha, A.K., & Sivapullaiah, P.V. (2016a). Role of gypsum on microstructure and strength of soil. Environmental Geotechnics, ICE, 3(2), 78-89.

Jha, A.K., & Sivapullaiah, P.V. (2016b). Volume change behavior of lime treated gypseous soil—Influence of mineralogy and microstructure. Applied Clay Science, Elsevier, 119(2), 202-212.

Jha, A.K., & Sivapullaiah, P.V. (2016c). Lime Stabilization of Soil: A Physico-Chemical and Micro-Mechanistic Perspective. Indian Geotech J.

Jha, A.K., Pandey, Mandeep, Sivapullaiah,P.V., (2016d). Geotechnical Properties of Lime Treated Gypseous Soil with Fly Ash—a Micro-Level study. Geo-Chicago GSP 271.

Jha, A.K., & Sivapullaiah, P.V. (2017a). Physical and strength development of lime treated gypseous soil with fly ash - Micro-analyses. Applied Clay Science, Elsevier, 145(1), 17-27.

Jha, A.K., & Sivapullaiah, P.V. (2017b). Unpredictable Behaviour of Gypseous/Gypseous Soil: An Overview. Indian Geotech Journal.

Kuttah, D., Sato, K. (2015). Review on the effect of gypsum content on soil behavior. Transport Geotechnics.

Kintzias, J.M.; Wild, S.; Jones, G.L. (1999). Effects of monovalent and divalent metal sulphates on consistency and compaction of lime-stabilised kaolinite. Appl. Clay Sci. 14 (1), 27-45.

Little, D.N., Nair, S., Herbert, B. (2009). Addressing sulfate-induced heave in lime treated soils. Journal of Geotechnical and Geoenvironmental Engineering, 136(1):110-118

McCarthy, M.J., Cvetceny, I.J., Sachtler, A., Dhir, R.K. (2012). Fly ash influences on sulphate—heave in lime-stabilized soils. In: Proceedings of the ICE: Ground Improvement, vol. 165(3), pp. 147-158.

Mitchell, J.K. (1986). Practical problems from surprising soil behavior. J Geotech Eng 1986,112(3):259–89.

Mitchell, J.K., Dermatas, D. (1992). Clay soil heave caused by lime sulfate reactions. Innovations and uses for lime, 41–64. oils., J. Geotech. Geoenviron. Eng., Vol. 136, No. 1, pp. 110–118.

Petry, T.M., Little, D.N. (1992). Update on sulfate induced heave in treated clays: problematic sulfate levels. Transportation Research Board, TIR 1362, Washington, DC

Phani, Kumar B, Sharma, R.S. (2004). Effect of fly ash on engineering properties of expansive soils. Journal of Geotechnical and Geoenvironmental Engineering, 130(7):764-767.

Puppala, A.J., Wattanasanticharoen, E., Punthutaecha, K. (2003). Experimental evaluations of stabilization methods for sulphate rich expansive soils. Ground Improv, 7(1):25–35.

Puppala, A.J., Intaharomrat, N., Vempati, R.K. (2005). Experimental studies on ettringite-induced heaving in soils. Journal of Geotechnical and Geoenvironmental Engineering 131(3):325–337.

Puppala, A.J., Taiburi, N., Congress S.S.C, Gaily, A. (2018). Ettringite induced heaving in stabilized high sulphate. Innovative Infrastructure Solutions soils 3:72.

Porta, J. (1998) Methodologies for the analysis and characterization of gypsum in soils: a review. Geoderma, 87: 31–46.

Raja, P S N Rami Karthick Thiagaraj, T (2019) Effect of short-term sulphate contamination on lime-stabilized expansive soil. International journal of geotechnical engineering. https://doi.org/10.1080/19386362.2019.1614665.

Rajasekaran, G., 2005. Sulphate attack and ettringite formation in the lime and cement stabilized marine clays. Ocean Eng. 32, 1133–1159.

Ramouli, S.S., Kuttah, D.K. (2006) Predicting long-term soaked CBR of gypseous subgrade soils. Proc Inst Civ Eng Transport 2006,159(3):135–40.

Sharma, R.S., Phansukumar, B.R., Rao, B.V. (2008). Engineering behaviour of a remolded expansive clay blended with lime, calcium chloride, and rice-husk ash. J Mater Civ Eng, 20(8):509–515.

Sherard, J.L., Woodward, R.J., Gizienksi, S.F., Clevenger, W.A. (1963). Earth-rock dam, engineering problems of design and construction. New York: John Wiley and Sons Inc.

Shrivasthala, A.K., Jain, A.K (2019). Swell behaviour of Lime treated Soil under Sulphate Contamination. Proceedings of the XVIII ECGMGE 2019. doi: 10.32075/17ECSGME-2019-0570.

Sivapullaiah, P. V., Sitharam, T. G., and Subba, Rao K. S. (1987) Modified free swell index for clays. ASTM Geotechnical Testing J1, 10, No. 2, 80-85.

Sivapullaiah, P.V., Jha, A.K. (2014). Gypsum Induced Strength Behaviour of Fly Ash-Lime Stabilized Expansive Soil. Geotechnical and Geological Engineering, Springer, 32(5), 1261-1273.

Sivapullaiah, P.V., Sridharan, A., Bhaskar raju K. V. (2000). Role of amount and type of clay in the lime Stabilization of soils. Ground Improvement (2000) 4, 37-45.

Solis, R., Zhang, J. (2008). Gypseous soils: an engineering problem. Sinkholes and the Engineering and Environmental Impacts of Karst, ASCE, pp. 742–749.

Watson, A. (1979). Gypsum crusts in deserts. J. Arid Environ., 2(1), 3–20.

Wijd S, Abdi MR, Leng Ward G (1993) Sulphate expansion of lime-stabilized kaolinite: II. Reaction products and expansion. Clay Miner 28(4):569-584.