Geotechnical Properties of Lime Treated Soil Contaminated with Sulphatic Water

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Abstract. Chemical stabilization using calcium based stabilizers such as lime and cement to improve the properties of soils is well-known technique since previous several decades. However, the longevity potential of calcium based stabilized soils with change in environmental conditions, particularly; in migration of contaminated sulphatic water is a matter of concern for the geotechnical engineer. The gypsum ($Ca_2SO_4.2H_2O$) is main source of sulphate and is abundantly available in soils throughout the world, despite of its low solubility rate. The present work is aimed to study the potential of lime stabilized soil contaminated with migration of sulphatic water. Detail experimental works to determine the plasticity, compaction characteristics and one dimensional oedometer swell percentage have been performed in expansive soil alone/and stabilized with optimum lime content with water having sulphate concentrations of 0, 3000, 5000, 10000, and 20000 ppm. The result shows that the plasticity of expansive soil contaminated with sulphatic water reduces drastically with lime treatment. Further, Optimum Water Content (OWC) of soil is observed to be less than lime treated soil contaminated with various concentration of sulphatic water, whereas Maximum Dry Density (MDD) of sulphate contaminated soil reduces with lime treatment. It is interesting to observe that lime treated soil exhibits drastic swell after inundating with sulphatic water having different concentration. The formation of highly expansive ettringite mineral by ionic reaction between calcium-aluminum-sulphate in the presence of water results the swell in lime treated soil.

Keywords: Compaction, Gypsum, Plasticity, Sulphate, Swell

Introduction

The expansive soils occur around all over the world. In India, expansive soil is also known as Black Cotton Soil (BCS) which covers an area of 0.8 million square kilometer (about 20% of total land area) of country. The major areas of their occurrence in India are states of Maharashtra, Gujarat, southern parts of Uttar Pradesh, eastern parts of Madhya Pradesh, parts of Andhra Pradesh and Karnataka. This type of soil is available up to a depth of 3.7 meters on an average in the above parts of India [1]. Expansive soils undergo volumetric changes with temporal variation. Increase in swelling and loss of strength occur in the presence of water/moisture and reduction in moisture content leads to huge crack and shrinkage. Cyclic swell-shrinkage of expansive soil causes differential settlements, resulting in severe damage to the foundations, buildings, roads, retaining structures, canal linings, etc.

Although several ground improvement techniques are adopted to stabilize and modify the expansive soils. However, chemical treatment of such soils by using lime or cement is considered as a most viable and economical method of stabilization. Since cement is costly and scarce resource, thus lime has been commonly used since past many centuries as a soil stabilizer. Generally, four reactions are attributed for modification of properties of soil lime-mixtures [2]. They are: a) Cation exchange; b) Flocculation/agglomeration; c) Carbonation; and d) Pozzolanic reaction. It improves the strength and durability of soils by ion exchange and cementitious reactions. Mehta et al. [1] reported that all lime treated fine-grained soils exhibit a reduction in plasticity, improved workability and reduced volume change characteristics. However, all soils do not exhibit improved strength characteristics. It should be emphasized that the properties of soil-lime mixtures are dependent on many variables such as soil type, lime type, lime percentage and curing conditions (time, temperature, and moisture) [3].

The application of cement and lime to improve the characteristics of soft fine grained soils is not novel [4, 5, 6]. However, recent studies reported that calcium based stabilization in presence of sulfates create more distress [7, 8]. Gypsum is the major source of sulphate present in soils, despite of its low rate of solubility [9]. Lime treated soil leads to the induced heave due to the formation of ettringite mineral at a highly alkaline environment (pH>10.5) by reaction of calcium, aluminum and sulfates the presence of water [7, 8, 10]. The formation of such minerals is due to presence of sulfates in soil, thus before the application of lime, it is important to understand the nature of sulfates in soil. The presence of sulfates either in ground or, mixing in water may affect the cation exchange and pozzolanic reactions of lime treated soil systems [11]. Serious structural damages including uplifting of tunnel floors, rock under dams, embankments and roads due to heaving and settlement during the hydrations of different calcium sulfate phases have been reported [11, 12, 13]. The ettringite formation is controlled by various factors such as clay minerals present, pH, water content, sulfate content and temperature [7, 10, 11]. Hunter [7] reported that the sulfate only affects the pozzolanic reactions i.e. the long term reaction in lime treated soil and hence, immediate formation of ettringite is discarded. However, longevity potential of lime stabilized soil needs to be validate subjected to sulphate migration through surrounding surface or, sub-surface water bodies.

In the present study, an attempt has been made to examine the physical and swell behaviour of untreated and lime treated soil subjected to migration of sulphatic water. Atterberg's limit, compaction characteristics and one dimensional oedomter swelling tests are performed in BCS and BCS treated with optimum lime content subjected to sulphatic water. Gypsum is taken to synthesize the sulphatic water in order to quantify amount of sulpahte concentration (0 to 20000 ppm) which affects the durability of lime treated soil.

Materials Used and Methodologies Followed

The Black cotton soil (BCS) used in the present study is collected from Shivdaspura village, near Jaipur District, Rajasthan-303903, India. The soil was excavated from the depth of 1-1.5 m to the ground. The physical properties of soil are presented in Table 1.The particle size analysis is done as per Indian Standard (IS) – 2720 (Part 4) [14]. The combined curve of wet sieving and hydrometer analysis (Fig. 1) shows 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 particles. The specific gravity (IS-2720 (Part 3) [15] of soil is observed to be 2.38. Atterberg's limits of untreated and lime treated soil are determined by following the standard procedure of IS-2720 (Part 3) [16], IS-2720 (Part 5) [17], respectively.
Mini compaction test procedure developed by Sridharan and Sivapullaiah [18] is used to determine the Maximum dry density and Optimum Water Content (OWC) values of untreated and treated soil. The swell percentages of all sample are carried out as per respected Indian standard code IS 2720 (Part 15) [19].

Table 1. Properties of Black Cotton Soil (BCS)

Property	BCS
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, %	45.00
Plastic limit, %	24.56
Plasticity index, %	20.44
Shrinkage Limit, %	11.65
Differential free swell index, %	70.00
Optimum water content, %	22.06
Max. dry density, gm/cm^3	1.60
CBR, %	1.62
pH value	7.50

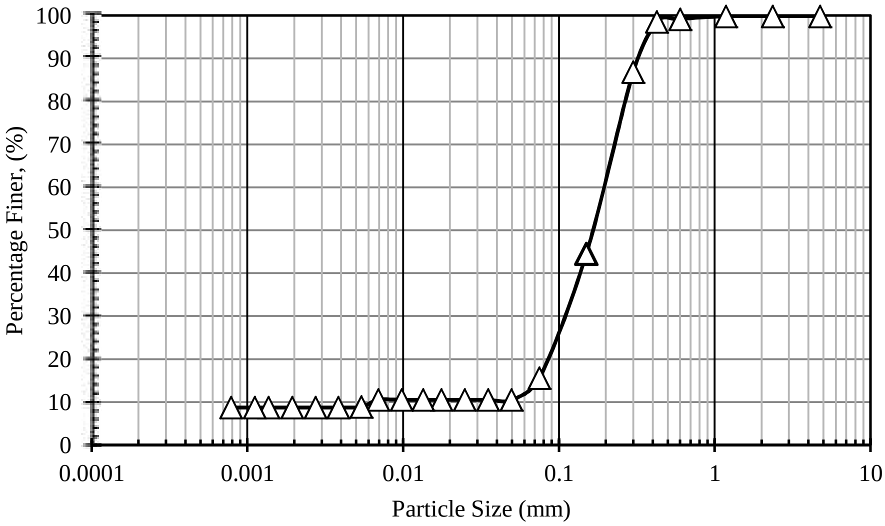

Fig. 1. Particle size analysis of Black Cotton soil

The XRD analysis of soil shows the presence of montmorillonite, aluminum oxide and quartz as predominant minerals (Fig 2). Also Field Emission Scanning Electron Microscope (FESEM) is performed to examine microstructural composition of soil. Microscopic images of black cotton soil (Fig 2) illustrates the presence of several voids with honeycomb networking patterns. Energy Dispersive X–ray Spectroscopy (EDAX) is performed to observe the chemical composition of black cotton soil. It is found that BCS is predominated with Silica (Si) and Aluminum (Al) (Table 2).

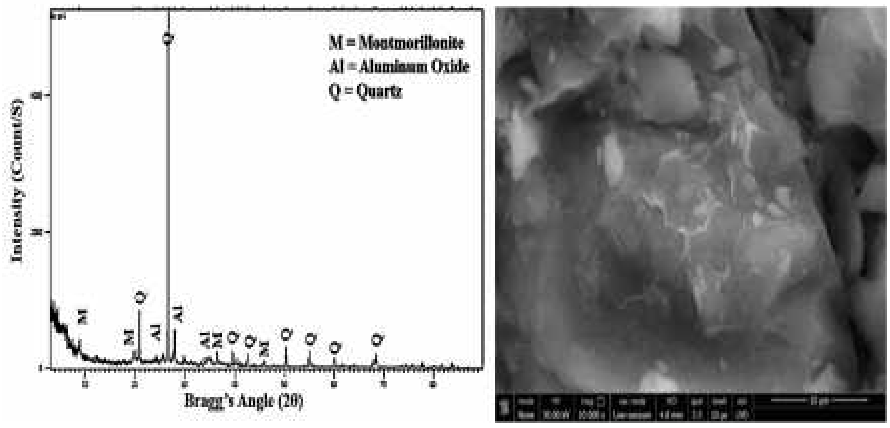

Fig. 2. XRD and SEM examination of black cotton soil

Table 2. Chemical composition of soil

Element	Atomic Weight (%)
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

Laboratory reagents hydrated lime ($Ca(OH)_2$) and Gypsum ($CaSO_4.2H_2O$) are used as chemical additives.

Results and Discussions

Determination of Optimum Lime Content (OLC)

The pH test is conducted on soil with different amount of lime to examine the optimum amount of lime to be used for the stabilization as procedure of Eades and Grim [20]. It was observed that the pH became constant after addition of 6% of lime to the soil by weight (Fig. 3). Hence, 6% lime is considered as optimum lime content and is taken to treat the soil in present study.

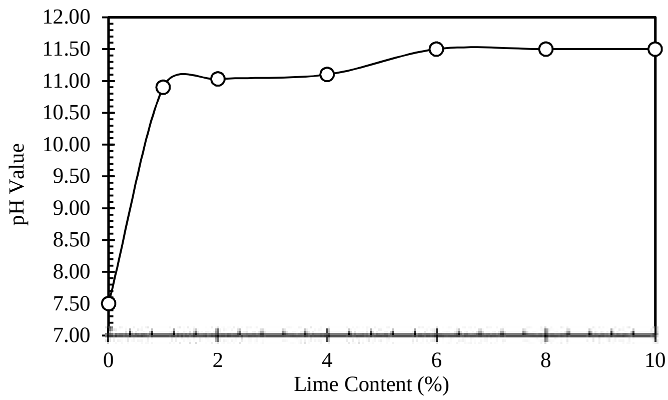

Fig. 3. pH value of soil-lime mixes

Atterberg's Limits of Lime Treated Soil

The effect of lime in the Atterberg's limits of BCS is presented in Table 3. It is observed that increase in lime content leads to decrease the liquid limit and plasticity index of soil. The improvement in plasticity of soil with lime treatment is due to the cation exchange and reduction in double diffuse layer by an increase in the electrolyte concentration of pore fluids. The plastic limit subsequently increases with lime treatment of soil.

Atterberg's Limits of Untreated Soil and Lime Treated Soil with Sulphatic Water

Effect of sulphate in Atterberg's limits of untreated and lime treated soil is presented in Table 3 and is shown in Fig. 4 and 5.

It is observed that liquid limit and plastic limit of soil increase initially with lower sulphate concentration of 3000 ppm and reduce thereafter (Fig. 4). Further, reduction in both liquid limit and plastic limit are observed for lime treated soil with increase in sulphate concentration (Fig. 5). However, reduction in liquid limit and plastic limit are observed to be minimal after 5000 ppm sulphate concentration. On contrary, the plasticity index of lime treated soil increases significantly up to 5000 ppm sulphate concentration and marginal thereafter. It is interesting to note that sulphate contamination of untreated and lime treated soil exhibits a degradation in soil plasticity index. The presence of calcium in gypsum and lime and, possible nucleation and formation of ettringite mineral are responsible for variation in Atterberg's limits.

Table 3. Atterberg's Limits for untreated and lime treated soil with sulphatic water

Sulphate Concentration (ppm)	P.L. (%)		L.L. (%)		P.I. (%)	
	Soil	Soil + 6% Lime	Soil	Soil + 6% Lime	Soil	Soil + 6% Lime
0	24.56	36.00	45.00	38.00	20.44	2.00
3000	34.70	26.60	53.00	33.00	18.30	6.40
5000	30.90	22.30	49.00	31.00	18.10	8.70
10000	30.10	21.10	48.00	30.34	17.90	9.24
20000	22.05	20.10	45.00	29.67	22.95	9.57

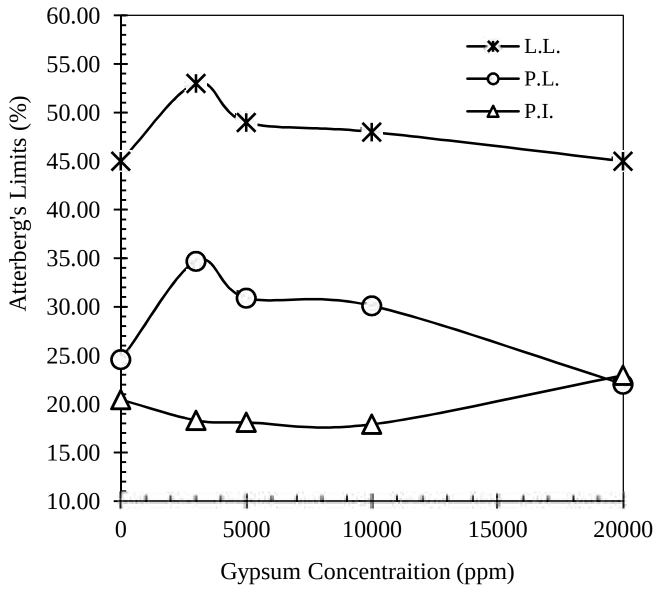

Fig. 4. Effect of sulphate on Atterberg's limits for soil

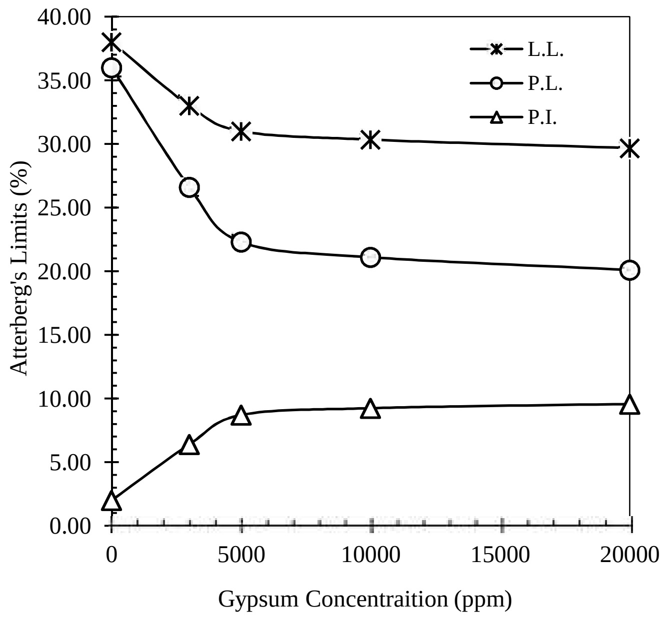

Fig. 5. Effect of sulphate on Atterberg's limits for lime treated soil

Compaction Characteristics of Untreated and Lime Treated Soil with Sulphatic Concentration

Compaction improves the strength and stability of the soil. The compaction characteristics of untreated soil and lime treated soil in the presence of varying sulphate concentration are presented in Table 3 and are shown in Fig. 6.

It is observed that marginal variation in maximum dry density and Optimum Water Content (OWC) of soil has been observed in the presence of sulphate concentrations. However, the dry density and OWC of lime treated soil reduce in the presence of lower sulphate concentration up to 3000 ppm and increase thereafter. Comparing the compaction characteristics of untreated and lime treated soil, significant reduction in dry density and increase in OWC of lime treated soil are pronounced at any sulphate concentration than that of same measured with untreated soil.

Table 3. Compaction characteristics of untreated and lime treated soil with sulphatic concentration

Sulphate Concentration (ppm)	ρ_{max} (gm/cc)		OWC (%)	
	Soil	Soil + 6% Lime	Soil	Soil + 6% Lime
0	1.60	1.46	22.06	28.23
3000	1.65	1.42	18.66	21.90
5000	1.65	1.45	23.36	23.74
10000	1.64	1.45	22.46	26.12
20000	1.64	1.47	19.84	28.10

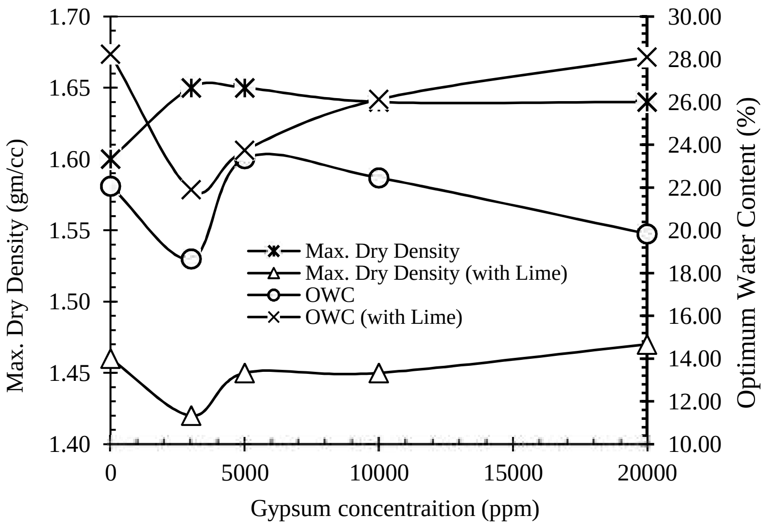

Fig. 6. Compaction characteristics of untreated and lime treated soil with sulphatic concentration

Effect of sulphate contamination on swell behavior of lime treated soil

The swelling percentage of untreated and lime treated soil is presented in Table 4 and is shown in Fig. 7.

The swell percentage of soil increases up to 5000 ppm and reduces drastically thereafter. The reduction in swell is due to the increase in percentage of calcium and thereby, formation cementitious compounds. Further, no swell is observed in soil after lime treatment. However, inundation of lime treated soil with varying concentration of sulphatic water exhibits the drastic increase in swell percentage. The formation of ettringite mineral due to the ionic reactions between aluminum, calcium and sulphate is mainly responsible for sulphate induced swell in lime treated soil. Hence, it can be concluded that migration of suplatic water leads to induced heave in the soil.

Table 4. Maximum swell percentage of untreated and lime treated soil at different sulphate concentration

Sulphate Concentration (ppm)	Swell Percentage (%)	
	Soil	Soil + 6% Lime
0	2.53	0.00
3000	2.58	0.52
5000	3.08	0.60
10000	0.96	1.40
20000	0.24	1.24

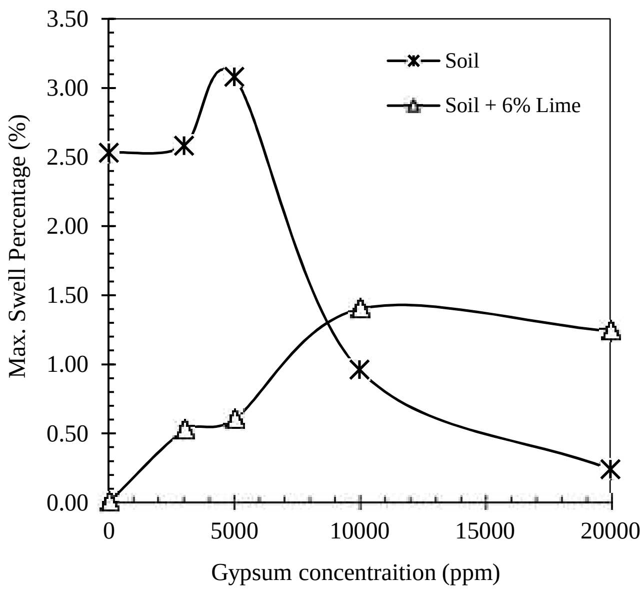

Fig. 7. Maximum swell percentage of untreated and lime treated soil at different sulphate concentration

Conclusion

The major conclusions drawn from the present study are as follows:

1. Sulphate contamination affects adversely the plasticity behaviour of soil and lime treated soil.
2. Lime treated soil at any sulphate concentration undergoes significant reduction in dry density and increase in OWC as compared to same with soil.
3. Swell percentage of untreated soil increase with lower sulphate concentration and reduces drastically with higher sulphate concentration.
4. Drastic increase in swell percentage of lime treated soil has been pronounced in the presence of sulphate concentration. Hence, migration of suplatic water leads to the cause of induced heave in the lime treated soil.

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