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Potential of fly ash to suppress the susceptible behavior of lime-treated gypseous soil

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Abstract

The use of lime and fly ash to improve the properties of certain types of soil is well established. However, the potential of fly ash to control the adverse effects of lime-treated gypseous/sulphatic soil has not been well investigated. In the present work, an attempt is made to quantify the fly ash content used to suppress the susceptible behavior of lime-treated gypseous soil. Series of one-dimensional swell and compressibility analyses are performed on various combinations of expansive soil with a predominance of montmorillonite mineral containing lime, gypsum (0–6%), and fly ash (0–30%). It is observed that the volume change behavior of the lime-treated gypseous soil is not controlled completely by addition of fly ash. However, the maximum improvement in the volume change behavior of the lime-treated gypseous soil is observed with a 20% fly ash content, and hence, can be taken as the Optimum Fly ash Content (OFC). Micro-analyses revealed that the relative dominance of the change in gradation and the formation of cementitious compounds of different compositions and ettringite crystals are the key factors in controlling the volume change behavior of lime-treated gypseous soil with fly ash. However, several factors, such as the types of minerals present in the soil, the types of fly ash and lime, and other physico-chemical environmental conditions (temperature, method of curing, and so on), are seen in the present study to affect the value of the obtained OFC.

Keywords: Compressibility; Ettringite; Expansive soil; Fly ash; Gypseous; Micro-analysis

1. Introduction

The bulk production of fly ash from coal-based thermal power plants throughout the world has created serious problems related to the handling and disposal of this fly ash. In India, about 160 million tons of fly ash were generated in 2010, and this amount is expected to increase to about 600 million tons/year by 2030 (http://cbrienvis.nic.in/flyashscenario.html). Pavements comprise one of the potential areas for the utilization of fly ash in bulk quantities. Saride et al. (2015) reported that about 15–30% of the generated fly ash can be employed in the base/subbase course of pavements. Furthermore, fly ash can also be used to effectively and economically stabilize problematic soil alone or in combination with lime (Consoli et al., 1998; Smith, 1993). The utilization of fly ash in soil stabilization enhances the hydration reactions by supplying additional pozzolans (siliceous and aluminous) with collections of adequate divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+}, etc.) (Indraratna et al., 1991). Fly ash has several valuable characteristics, such as low specific gravity, high volume stability, low compressibility, high rate of consolidation, water insensitivity to compaction, and pozzolanic reactivity, which lead to an improvement in the properties of soil, such as the consistency limit, compaction characteristics, and the swell potential (Cokca, 2001; Prakash and Sridharan, 2009; Sivapullaiah et al., 1996). However,

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proper precautions must be taken and extensive testing must be done before the lime and fly ash can be applied as stabilizing agents for sulphatic/gypseous soil (Mitchell, 1986).

Gypsum is the main source of sulfate in soil, and the type of soil that contains gypsum is known as gypseous soil (Abdi, 1992). About 20% of the earth's surface, particularly in the semi-arid and arid regions of the world, is covered with gypseous soil (Porta, 1998). Gypseous soil is not used in the field of construction due to its unreliable behavior caused by variations in moisture (Solis and Zhang, 2008). Several engineering problems have been encountered worldwide with gypseous soil due to its high water sensitivity (phase transformation and solubility) with variations in water (Yamamoto and Kennedy, 1969; Yilmaz, 2001).

Several calcium-based stabilizers, such as lime and cement, have been used in the past to stabilize sulfate-rich soil (Hausmann, 1990; Mitchell and Dermatas, 1992; Jha and Sivapullaiah, 2015). However, the ionic reactions among the aluminum in the soil, the calcium in the lime, and the sulfate in the gypsum have led to the formation of highly expansive crystalline minerals, called ettringite or thaumasite (depending on such environmental conditions as pH, temperature, etc.), resulting in the deterioration and failure of several pavement projects stabilized with calcium-based stabilizers (Hunter, 1988; Mitchell and Dermatas, 1992). Aldaood et al. (2014a,b,c,d) revealed the various aspects of lime-treated gypseous soil, such as (i) the adverse effects on the swell potential, (ii) the reduction in a substantial amount of strength under freeze–thaw cycles and wetting–drying cycles, and significant volume changes, and (iii) the increase in the water-holding capacity with an increase in the gypsum content. It has been mentioned that these effects are, by and large, due to the formation of ettringite and to the related changes in the mineralogy and the microstructure of the soil matrix. Hence, comprehensive research is needed to find suitable preventive measures for overcoming the adverse effects of lime-treated gypseous soil.

Attempts have previously been made to control the adverse effects of lime and cement treatment on gypseous soil by using Ground Granulated Blast Furnace Slag (GGBS), sulfate-resisting cement, barium chloride lithium salt, and double-lime methods (Gollop and Taylor, 1996; Petry and Little, 1992; Tsatsos and Dermatas, 1998; Wild et al., 1998). On the contrary, the use of these materials may deteriorate the properties of the lime-treated soil depending on the chemical environment (Rajasekaran, 2005). Despite the several valuable characteristics of fly ash, as discussed earlier, relatively few attempts have been made to explore its possible use in suppressing the adverse effects of lime-treated gypseous soil (Berger et al., 2001; Kawamura et al., 1986; McCarthy et al., 2012a,b; Talluri, 2013). However, the intrusion of alumina, which is favorable for ettringite formation, by the fly ash to lime-treated gypseous soil and its effect on the volume change behavior has not been addressed. Recently, Jha and Sivapullaiah (2016a,b) revealed that the use of 10% fly ash accelerates the swell strain of lime-treated expansive soil in the presence of 1% gypsum, although fly ash is supposed to control the sulfate-induced heave in lime-treated soil. Hence, research needs to be extended in order to find the suitable fly ash content for the optimum suppression of sulfate-induced heave in lime-treated soil and is the prime objective of the present work.

An attempt has been made in the present study to investigate the potential of fly ash for suppressing the adverse effects of lime treatment on the volume change behavior (swell and compressibility) of gypseous soil. In order to achieve the objective, detailed one-dimensional oedometer tests have been performed to determine the volume change behavior of various combinations of Soil (S), Lime (L), Fly Ash (FA), and Gypsum (G) mixtures. Furthermore, microanalyses [X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Energy Dispersive X-Ray Spectroscopy (EDAX)] have been performed in order to elucidate the mechanisms of the volume change behavior of lime-treated gypseous soil with fly ash.

2. Materials used and methodologies followed

2.1. Materials used

The geotechnical properties of the soil and fly ash used in the present study are presented in Table 1, and the particle size distribution and compaction characteristics of the soil and fly ash are shown graphically in Fig. 1(A) and (B).

The expansive soil used in the present study was collected by the open excavation method from a depth of approximately 1.5 m below the natural ground level from the Belgaum district of Karnataka, India. A particle size analysis of the soil revealed the presence of clay (<2 μm in size) as the predominating particles (Fig. 1(A)). According to the Indian Standard (IS) classification, the soil is classified as clay of high compressibility (CH) and a high degree of expansion. The XRD of the soil (Fig. 2(a)) confirmed the presence of montmorillonite, aluminum oxide,

Table 1
Geotechnical properties of soil and fly ash.

Property	Soil	Fly ash
Specific gravity	2.67	2.14
Sand (4.75–0.075 mm), %	6	26
Silt (0.075–0.002 mm), %	31	70
Clay (<0.002 mm), %	63	4
Liquid limit, %	72.1	31.3
Plastic limit, %	31.7	_
Plasticity index, %	40.4	_
Shrinkage limit, %	13.6	_
Free swell index, %	72.7	_
Modified free swell index, ml/g	1.9	_
Optimum water content, %	32.5	21
Max. dry unit weight, kN/m^3	13.4	12.6
Classification as per IS plasticity chart	CH	_
Degree of expansion	Very high	_

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