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Research paper

Experimental study to examine the independent roles of lime and cement on the stabilization of a mountain soil: A comparative study

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ABSTRACT

The durability, efficiency and the integrity of structures built within or over mountain soils are mainly controlled by the geotechnical properties. It is therefore imperative to analyse these properties before the commencement of such projects, and upgrade them when and where required. The current study focusses on the addressing the problems associated with soil failure that occur during the construction and widening of roads and highways in the area of interest. The soil samples, which were collected from the study area, were stabilized using two types of readily-available additives, namely, lime and cement. The outcomes of the study indicate the dependence of the geotechnical and microstructural properties on the type of additive used. The comparative analysis suggests that the cement has a relatively higher influence on the mechanical behaviour of soil when compared to that of lime. Additionally, the compressive strength of the samples that had been cured for 28 days increased nearly four to six times than that of the untreated specimen, thereby suggesting the influence of curing time on the strength parameters. The increase in compressive strength can be attributed to the chemical transformations that occur in the soil on the addition of additives. The cation exchange and pozzolanic reactions resulted in the formation of cementitious compounds within the soil matrix, which was observed by performing X-ray diffraction (XRD), scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) analysis. The present study suggests that satisfactory strength can be achieved with the addition of 5% additives to the soil mixture, which will save the cost of stabilization subsequently.

1. Introduction

The process of soil stabilization is widely used to improve the physical and geotechnical properties of soils. The usual and long-standing method of soil stabilization is to replace the ill-suited soil with stronger materials such as gravely soil, concrete, geogrids and geotextiles. However, such techniques incur a higher cost, and generally take longer to implement since they involve removal and replacement of weak soil. In recent decades, researchers have introduced a new technique for the stabilization of soils, designated as the chemical stabilization (Bell, 1993; Rogers et al., 1997). In this technique, the soils having poor engineering properties are blended with the stabilizers in order to initiate a suite of chemical reactions such as cation exchange, flocculation, carbonation and pozzolanic activity which consequently enhance the geotechnical properties of the soil. Thereafter, the geotechnical properties of the treated soils were evaluated to optimize the amount of additives to be used in the stabilization process. The enhancement in soil properties depends on several factors such as mineralogical composition and the water content of soil, the quantity and type of additives, curing time and temperature (Kassim and Chern, 2004).

Mountain soils, which act as important raw material during the construction of roads in hilly terrains, are primarily found at the toe and top of hills. A variety of mountain soils exist as their genesis depends on the type of parent rock, degree of weathering and climatic conditions of the area. In India, mountain soils are mainly located in the Himalayan regions and in the states of Sikkim, Assam, Arunachal Pradesh, Uttarakhand and Kashmir. In addition to these regions, the Peninsula, Eastern Ghats and the summits of the Western Ghats, which are also known as Sahyadri, possess large quantities of mountain soils. Since transportation of men and material via roadways is the sole means of access in most of these hilly areas, the construction of durable and damage-resistant roads is imperative for a faster economic growth and social inclusion. A network of such roadways can also help in the smooth transportation of heavy defence machinery, which would thereby reduce the total time, cost and energy associated with such operations. However, the studies conducted on naturally available soil suggest that soil is not appropriate for construction owing to its poor

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mechanical properties, which are a result of long-term weathering and complex geological conditions. A structure built with only soil would result in serious damage to the foundations and embankments. Therefore, it becomes all the more imperative to enhance the geotechnical properties of such mountain soils before the commencement of any construction project. Addition of easily-available additives to the soil is a viable option for the enhancement of geotechnical properties.

Bell (1996) reported that the optimum addition of lime (normally between 1 and 3% lime by weight) to clayey soils improves their engineering properties, thereby transforming them into a better construction materials. However, the study reported that further addition of lime does not bring any significant change to the consistency limits but improves the strength of soil. Basma and Tuncer (1991) reported the optimum amount of hydrated lime used for soil stabilization varies between 2 and 8%. Du et al. (1999) reported that the fabric of the lime-stabilized soil is denser when compared to that of the untreated compacted expansive soil. Al-Rawas et al. (2005) used lime, cement and Sarooj (an artificial pozzolan) to reduce the swelling potential of expansive soil. Seco et al. (2011) studied the stabilization of grey marl from the region of Pamplona, Northern Spain using a combination of additives that included lime, magnesium oxide (obtained from a commercial by-product called PC-7), rice husk fly ash (RHFA), coal fly ash (CFA) and aluminate filler (AF). Additionally, the soil samples were also treated with a non-standard stabilizer called Consolid System (CS) having both liquid and solid phases. The result of the analysis suggested that the addition of lime improved the mechanical capacities of the soil, which was determined by the California Bearing Ratio (CBR) and the unconfined compression tests. Additionally, the addition of RHFA to the soil-lime mixture produced better results when compared to CFA and AF. Furthermore, the use of RHFA with lime/PC-7 is environmentally and economically sustainable since it is a waste material that is produced in large volumes, especially in developing nations. They have also reported that the low doses of CS produced similar results. Kavak and Akyarlı (2007) stated that the addition of 5% of lime by mass into brown and green clay is sufficient to improve the California bearing ratio (CBR), thereby making it useful for the construction of road embankments. Eisazadeh et al. (2012) adopted the addition of phosphoric acid and laboratory-grade lime to stabilize tropical kaolin soil, and reported that the chemical stabilizers favourably attacked the alumina surface of the clay particles. Kavak and Baykal (2012) reported that the addition of 4% hydrated calcium lime by mass into kaolinite increased the unconfined compressive strength (UCS) by 21 times within a span of 10 years. Millogo et al. (2012) determined the microstructural, geotechnical and mechanical performance of the lateritic gravels that had been treated with quicklime (up to 3 wt%), and reported an increase in the mechanical properties (compressive strength, tensile strength and CBR). The increase in the magnitude of the geomechanical parameters was therefore attributed to the formation of calcium silicate hydrate (CSH (I)), calcite and/or portlandite. A similar study was performed by Lemaire et al. (2013) in order to analyse the behaviour of mechanical, microstructural and physicochemical parameters of the Hericourt silt that had been treated with both, quicklime (1%) and cement (5%) (CEM II/A-LL 42.5 R THIS CP2 NF), and reported a change in the mechanical performance of silt. Similarly, Calik and Sadoglu (2014) utilized hydrated lime and perlite to stabilize expansive clayey soil and suggested that an addition of 8% lime and > 30% perlite to the expansive soil produces the highest strength and durability. The formation of cementitious pozzolanic compounds (calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH)) on the addition of hydrated lime or Portland cement to the expansive soils was reported by Mutaz and Dafalla (2014). Kiliç et al. (2016) investigated the independent roles of lime, gypsum and a mixture of lime and gypsum on the swell percent, swell pressure and UCS of highly plastic clays, and concluded that the optimum mixture consisting of 6% of lime produces a 99.55% decrease for swell percent, 98.98% decrease for swell pressure and 191.87% increase in the UCS, when treated for 90 days.

On the basis of the available literature and the results therein, it can be concluded that addition of chemical stabilizers affects and enunciates the geotechnical properties of soils. The addition of lime and/or cement is a well-known and widely used technique for stabilizing various types of soils (Al-Rawas and Goosen, 2006). In the case of expansive soils, the addition of cement produces the best stabilization result (Al-Rawas et al., 2005). Although several studies have been performed on analysing the behaviour of the geotechnical properties of soils on the addition of additives, very few consider the effect of time interval on the degree of stabilization. Therefore, the primary objective of the present study is to evaluate the time dependent mechanical and microstructural performance of a mountain soil that had been treated with varying percentages of lime/cement. A detailed descriptions of the sample, additive and treatment procedure has been enlisted in the further sections. The mechanical behaviour was monitored by testing the treated soil for its consistency limits, compaction, UCS, modulus of elasticity and shear strength. The change in the mechanical behaviour was further analysed by studying the mineralogical and morphological features of the treated soil with the help of X-ray diffraction analysis (XRD), scanning electron microscope (SEM) and Fourier transform infrared spectroscopy (FTIR).

2. Study area

For this study, the samples of mountain soil were collected along the Orang-Kalaktang-Shergaon-Rupa-Tenga (OKSRT) road, Arunachal Pradesh, India (Fig. 1a). The OKSRT road is strategically important for the movement of defence personnel and civilians. Detailed site investigation suggests that the area is prone to both natural and engineered-slope instability (Fig. 1b). The construction and widening of road suffers various types of unforeseen problems. Additionally, the preliminary investigation revealed the occurrence of failure on the edges of the road slopes in addition to the formation of tension cracks along the road. Such phenomena are a result of swelling that occur in the soil due to the presence of phyllosilicates. Such soils, when saturated, exhibit highly expansive and unstable behaviour (Frempong, 1994). The phenomenon of swelling leads to the development of high tensile stresses, which can thereby lead to the failure of construction materials such as concrete (Lee et al., 2005; Neville and Aitcin, 1998).The study area is mostly composed of granitic gneiss, sandstone, and highly jointed and fractured quartzite. The area experiences relatively high rates of weathering due to the complex and harsh climatic conditions, heavy rainfall, variable topography and complex drainage network in the entire region. The high rate of physico-chemical weathering favours the formation of soil. The nature of the mountain soil is a function of the parent rocks, topography, rainfall and degree of weathering (Sharma et al., 2017). The soil in this area is primarily composed of stony particles that are derived from the parent rocks. These stony particles are rich in quartz since the rate of chemical weathering of quartz and mica is relatively slow when compared to that of feldspar (Frempong, 1994).

3. Research methodology

3.1. Materials

The materials used in the present work are mountain soil, commercially-available Portland cement and hydrated lime. Before collecting the soil sample, detailed ground investigations were carried out to find out the most vulnerable location for the possible occurrence of failure. Once the location has been located, the soil sample were collected from trial pits that had been excavated to depth of 1 to 1.5 m. Approximately 30 kg of disturbed soil was collected from these pits for this study. The samples were collected and stored in plastic sampling bags in order to retain the natural moisture conditions and to avoid contamination. The physical properties of the soil samples, namely,