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Modification of the geotechnical properties, as influenced by freeze–thaw, of granular soils with waste additives

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Abstract

This paper evaluates the use of waste materials such as silica fume, fly ash, and red mud in the modification of granular soils in order to remove the effects of freezing–thawing cycles. In this study, two granular soils obtained from primary rock were stabilized by silica fume–lime, fly ash–lime, and red mud–cement additive mixtures. Natural and stabilized soil samples were subjected to freezing–thawing cycles after curing for 28 days. After the freezing–thawing cycles, compressive strength, California bearing ratio, freezing–thawing, ultrasonic wave, and resonant frequency tests were performed to investigate effects of additive mixtures on the freezing–thawing properties of natural and stabilized soil samples. The experimental results show that stabilized samples with silica fume–lime, fly ash–lime, and red mud–cement additive mixtures have high freezing–thawing durability as compared to unstabilized samples. These additive mixtures have also improved the dynamic behaviors of the soil samples. Consequently, we conclude that silica fume–lime, fly ash–lime, and red mud–cement additive mixtures, particularly silica fume–lime mixture, can be successfully used as an additive material to enhance the freezing–thawing durability of granular soils for road constructions and earthwork applications.

Keywords: Freezing–thawing; Silica fume; Fly ash; Red mud; Stabilization; Earthwork applications

1. Introduction

In cold regions, soils in areas with seasonal frost are exposed to at least one freezing–thawing cycle every year. In the freezing period, subsoil moisture moves towards the frozen layer because of a temperature gradient. Void spaces of soil gradually increase due to frost heave and moisture moves to the interstices of the soil and then freezes. In the thawing period, thawing of the frozen layer begins from the top and the bottom at the same time. The maximum soil moisture content appears above the frozen layer and becomes temporarily-perched water. Additionally the soil moisture content under the frozen layer is more than it was during the pre-frozen period (Zhang and Shijie, 2001).

The geotechnical properties of natural and stabilized soils change due to the effects of freezing–thawing cycles. For this reason, the strength and force of these soils are affected negatively. In cold regions, freezing–thawing damage is one of the major problems in road construction and earthwork applications. Cracking and spalling are the most common results of freezing–thawing damage in

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stabilized soils. The design and construction of earth structures influenced seasonally by subzero temperatures requires the determination of the mechanical properties of the construction materials under appropriate thermal conditions (Cruzda and Hohmann, 1997). The strength properties and the stress–strain behavior of granular soils influenced by subzero temperatures, under natural and laboratory water conditions, are well analyzed and the parameters of the strength and strain rates for many of these soil types have been investigated (Andersland, 1989; Zaman et al., 1992; Cruzda and Hohmann, 1997; Ma et al., 1999; Viklander and Eigenbrod, 2000; Grechishchev et al., 2001; Kozlowski, 2003; Talmucci, 2003; Akbulut and Saglamer, 2004; Hansson and Lundin, 2006; Wang et al., 2006).

In this study, silica fume–lime (MIXA), fly ash–lime (MIXB), and red mud–cement (MIXC) additive mixtures were used to modify the freezing–thawing properties of granular soils. Silica fume (SF) and fly ash (FA) are waste materials and they are extensively used in geotechnical engineering applications due to their pozzolanic reactivity. These materials have low unit weight, low compressibility, and high pozzolanic reactivity. The pozzolanic reactivity depends on their reactive silica, free lime, carbon and iron content, fineness flame temperature in furnace, and particle size distribution (Cabrera and Gray, 1973; Ravina, 1980; Malhotra and Carette, 1982; Aitcin et al., 1984; Ozbayoglu, 1993). Red mud (RM) also is a by-product material and many proposals for the re-use of RM have been advanced in engineering applications (San Filippo and Usai, 1988; Deng et al., 1980; Prasad and Sharma, 1986; Allaire, 1993; Kohno et al., 1993; Singh et al., 1996). The performance of stabilized samples with these additive mixtures was evaluated to develop them as alternative construction materials with high freezing–thawing durability for road constructions and earthwork applications. The compressive strength data were obtained from the compression tests, California bearing ratio from the California bearing tests, freezing–thawing from the freezing–thawing tests, ultrasonic pulse velocity from the ultrasonic wave tests, and dynamic behaviors from the resonant frequency tests under laboratory conditions.

The main objective of this experimental research was to evaluate the effects of MIXA, MIXB, and MIXC additive materials on the freezing–thawing properties of granular soils. To accomplish this objective, a series of tests were performed on the natural and stabilized samples with MIXA, MIXB, and MIXC additive mixtures. These additive mixtures were added to the soils and blended together in dry conditions prior to the preparation of stabilized samples. The additive mixture–granular soil mixtures were compacted at the optimum moisture content and then cured for 28 days before conducting tests. The experimental results indicate that MIXA, MIXB, and MIXC additive materials are acceptable materials to enhance the freezing–thawing properties of granular soils in road constructions and earthwork applications.

2. Materials

2.1. Granular materials

Two sand–gravel mixtures, produced by grinding, were selected for tests. These materials obtained from limestone and crystallized limestone primary rocks were supplied from the Stone Quarry Facility of Makimsan Company in Erzurum, Turkey. Grain size distributions of the mixtures were selected between the limits used in Turkish Highway Standards. Grain size distribution curves of soils used in the tests and the limits of the Turkish Highway Standards are given in Fig. 1. The soils had a density of 2.75 Mg/m^3.

2.2. Lime and cement

LM and CM were used as manufactured additive materials in this study. LM used in tests was supplied from Kayseri Lime Factory in Kayseri, Turkey. CM used in tests was supplied from Askale Cement Factory in Erzrum, Turkey. CM had a specific density of 0.31 Mg/m^3 and specific surface of 306 m^2/kg.

2.3. Wastes

In this study, SF, FA, and RM were used as waste additives. SF used in the tests was supplied from Ferro-

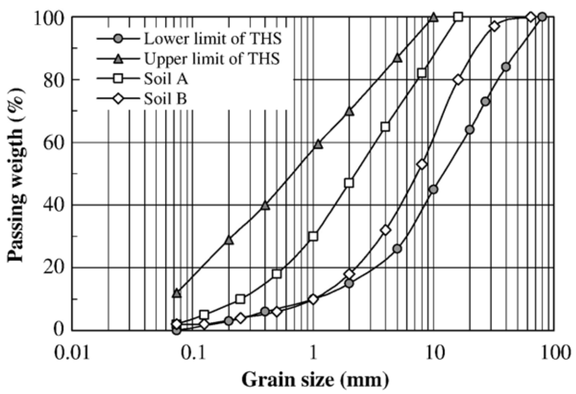

Fig. 1. Grain size distribution curves of the granular soils and Turkish Highway Standards (THS) for road construction materials.