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Research paper

The effect of magnesium chloride solution on the engineering properties of clay soil with expansive and dispersive characteristics

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ABSTRACT

Because expansive and dispersive soils damage engineering structures, extensive studies on using additives to ameliorate the effects of these soils have been conducted. In this study, the effect of magnesium chloride ($MgCl_2$) solution on the engineering properties of clay soils was evaluated. Previous studies on this subject have shown that $MgCl_2$ is more commonly used as an anti-icing agent on roads than as a soil stabilizer. $MgCl_2$ is also used to control dust and humidity on roads and to reduce the scattering of coarse particles from road surfaces. However, as the use of $MgCl_2$ becomes more common, its potential to improve the geotechnical properties of problematic soils will receive increasing attention.

To this end, the variation in the engineering properties of expansive and dispersive clay soil samples as functions of the added $MgCl_2$ content was investigated. First, the physical and chemical properties of the soil sample were determined. Next, the swell percentage, swell pressure, crumb, pinhole and unconsolidated undrained (UU) triaxial compression tests were performed at different curing times on samples with and without the additive by compressing the sample to achieve particular compaction characteristics. Scanning electron microscopy (SEM) analyses were performed to observe the microstructures in the sample without the additive and with the amount of additive that most strongly improved the expansive and dispersive qualities of the clay. The results show that dispersive and expansive clay soils can be effectively improved using an additive $MgCl_2$ solution.

1. Introduction

During geotechnical engineering projects, it may be found that the soils in the intended project areas are not ideal. These soils may be loose, expansive, dispersive, highly compressible or highly permeable. Dispersive and expansive soils are considered problematic, and these soil properties cause serious problems for many engineering structures. Dispersive soils are thought to be the cause of internal erosion in earthen structures (NRC, 1983), and expansive soils are thought to be the main cause of problems in light structures (Nelson and Miller, 1992).

Expansive soils are common in many parts of the world, especially in regions with arid and semi-arid climates. The structural damage caused by these soils can be reduced or prevented by determining the soil's expansive properties and the factors that affect these properties prior to construction. The swelling pressure of clays can cause significant damage to light hydraulic structures such as drinking water networks, irrigation pipes and open canal linings, as water can easily leak and penetrate the soil during the loading and unloading stages. This damage results in significant financial losses. A total of $2.3 billion worth of damage is caused annually by expansive soil problems in the United States alone (Dhowian et al., 1988). The global annual cost of this damage likely exceeds $10 billion. Similar levels of damage have also been reported in other countries (Abdullah et al., 1999; Al-Rawas et al., 2002; Basma et al., 1995; Chen, 1988; Du et al., 1999; Parker et al., 1977; Shi et al., 2002). These problems have been encountered during the construction of light water structures in Turkey and have generally occurred during the construction of the irrigation structures of the Southeastern Anatolia Project. This problem was especially common in the channel structures built in the irrigation areas of the Harran plain, and thus, they became the topic of engineering studies that have added to our understanding of these soils (Turkoz and Tosun, 2011).

The dispersive nature of clay soils is another source of problems. Dispersive soils are structurally unstable and can easily disintegrate or erode. If dispersive clay soils are being considered for use in water structures, earth fill dams and road fills, knowledge of their properties and the use of appropriate building techniques are necessary. Without these precautions, serious engineering problems, including collapse, can occur. The erosion arising from the dispersibility of the clay depends on the mineralogy and chemical structure of the clay, the presence of voids in the soil and the nature of the dissolved salt content of the

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water that causes the erosion. Many earthen dams have suffered damage or collapsed because of the piping caused by dispersive soils (NRC, 1983). Piping was the cause of the recorded damage and collapse of approximately 25% of the 214 earthen dams in existence between the years 1885 and 1951 (Sherard et al., 1963). Among the many factors that cause piping, the dispersibility of the soil is particularly important. Many studies have attempted to describe dispersive clays and study their use in embankment dams in Turkey (Tosun et al., 2007).

Because expansive and dispersive soils damage engineering structures, extensive studies on using additives to improve these soils have been performed (Murty and Praveen, 2008; Ouhadi and Goodarzi, 2006). The stabilizers of soils are categorized into two main groups as traditional and nontraditional stabilizers. Traditional stabilizers such as limestone, cement, zeolite, gypsum, industrial wastes and fly ash are commonly used, as reported in the extensive studies by Cole et al. (1977), Indraratna (1996), Bell (1996), Cokca (2001), Biggs and Mahony (2004), Bhuvaneshwari et al. (2007), Yilmaz and Civelekoglu (2009) and Turkoz and Vural (2013).

A number of nontraditional soil stabilizer products which are not calcium based are potentially effective alternatives for treating soils. These nontraditional chemical stabilizers are usually sold as concentrated liquids diluted with water on the project site and sprayed on the soil to be treated before compaction. In addition to bringing lower transportation costs, these products are a potentially attractive alternative for treating high sulfate soils (Rauch et al., 2002). Several studies have shown that calcium-based stabilizer treatments of natural expansive soils rich with sulfates may lead to a new heave distress problem instead of mitigating it (Mitchell, 1986; Mitchell and Dermatas, 1992; Puppala et al., 1999). This phenomenon is referred to as sulfate-induced heave in the literature (Dermatas, 1995; Mitchell, 1986). Sulfate-induced heave is primarily attributed to the presence of sulfates in natural expansive soils and usually occurs when lime or cement treatments are used for stabilizing these soils (Puppala et al., 2005).

Concentrated liquid products that do not contain calcium can be used on sulfate-rich soils without causing excessive expansion. Liquid chemical stabilizers may work through a variety of mechanisms, including encapsulation of clay minerals, exchange of interlayer cations, breakdown of clay mineral with the expulsion of water from the double layer, or interlayer expansion with subsequent moisture entrapment (Scholen, 1992). With some products, improved engineering properties may result from obtaining higher compacted soil densities (Randolph, 1997; Rauch et al., 2002). However, nontraditional additives comprise of many different chemical agents that are varied in their components and in the manner they react with the soil (Latifi et al., 2013). In studies by Turkoz et al. (2011) and Acaz (2011), the effects of a magnesium chloride ($MgCl_2$) solution on the swell potential, strength characteristics and dispersibility properties of clay soils were investigated.

In the developed world, chemical substances such as $MgCl_2$ solution that do not corrode vehicles, damage cement and asphalt or harm plants or living creatures have long been used to de-ice roads in regions that experience harsh winters, such as North America, Scandinavia and Europe (Environmental Canada, 2001).

The current literature indicates that $MgCl_2$ is used on roads to control dust and humidity, to minimize coarse particle scattering and to prevent ice formation (Ketcham et al., 1996; Nixon and Williams, 2001; Transportation Research Board, 1991). However, as the use of $MgCl_2$ is becoming more common, its potential to improve the geotechnical properties of problematic soils is receiving increasing attention. Unlike traditional stabilizers, attempts to define the stabilization mechanisms of nontraditional additives have been limited.

Each feature in the literature associated with the improvement of the dispersive and swell properties of clay soil with additives was separately evaluated. In this study, the effect of $MgCl_2$ additive as a solution on the characteristic of dispersibility and swelling potential of clay soils was investigated together.

To investigate this application, a clay sample was obtained from the Afyon province located in the Central Anatolia Region of Turkey, and the effects of different amounts of the $MgCl_2$ additive as a solution (0, 3, 5, 7, 9, 11 and 13% by dry weight of the soil sample) on the engineering properties of the soil were investigated. First, the physical and chemical properties of the soil sample were determined. Next, the swell percentage, swell pressure, crumb, pinhole and unconsolidated undrained (UU) triaxial compression tests were performed at different curing times on samples with and without the additive by compressing the sample to achieve particular compaction characteristics. Finally, scanning electron microscopy (SEM) analyses were performed to examine the microstructures in a sample without the additive and in the sample with the amount of additive that most strongly improved the soil properties. The standard methods of the American Society for Testing and Materials (ASTM, 1994) were followed during the sampling, preparing of samples and testing. The results of this study show that the engineering properties of dispersive and expansive clay soils can be improved by using $MgCl_2$ solution as an additive.

2. Materials and methods

2.1. Soil

The soil sample used in this study was obtained from the Afyon province in the Central Anatolia region of Turkey. Sieve analysis, hydrometer analysis (ASTM D 422-63), consistency limits (ASTM D 4318-00) and specific gravity (ASTM D 854-00) tests were performed to characterize the soil sample. ASTM (1994) standard methods were followed during the sampling, preparing of samples and testing. Based on the identification test results, the sample was classified as high-plasticity clay (CH) according to the Unified Soil Classification System (USCS) (ASTM D 2487-00). The grain-size distribution and X-ray diffraction (XRD) pattern of the soil sample are presented in Figs. 1 and 2, respectively. It can be said that the illite is the dominant clay mineral, depending on the result of the XRD analysis. The sample's index and chemical properties are summarized in Tables 1 and 2, respectively.

2.2. Magnesium chloride ($MgCl_2$)

$MgCl_2$ solution has been used to de-ice roads in areas with harsh winters for many years. In Turkey, the $MgCl_2$ solution as an additive is now produced from natural resources. The sample used in this study was obtained from Alkim Alkali Chemicals Incorporated in Istanbul. Although it can be used as a solid or in solution, the solution form is more common. The general properties of the $MgCl_2$ solution used in this study are presented in Table 3.

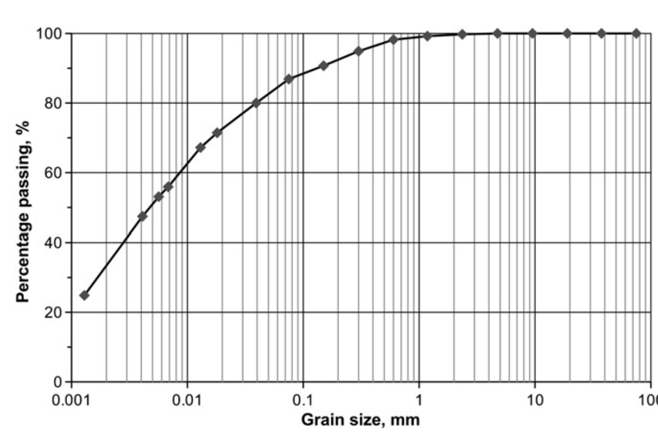

Fig. 1. Grain size distribution of the soil.