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Experimental study of the effects of geogrids on elasticity modulus, brittleness, strength, and stress-strain behavior of lime stabilized kaolinitic clay

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ABSTRACT

Lime stabilization has been widely used in civil engineering to improve soils properties. A major shortcoming of lime is that it increases the soil brittleness. Thus, the aim of this research is to study the effect of lime along with geogrids on unconfined compressive strength (UCS) and modulus of elasticity (E_s) of the stabilized soil. Atterberg limits, XRF, and pH tests were performed to determine the optimal percentage of lime. Then, different percentages of lime were added to the soil to study strength, stress, and strain of specimens using UCS tests. Also, the effect of inclusion of geogrid on the lime stabilized soil was studied by adding four layers of geogrid in the soil at constant intervals. By increasing the percentages of lime, brittleness index, UCS, and E_s increased and deformability index decreased. Moreover, applying geogrids led to increasing deformability and failure strain. Based on SEM tests, an addition of lime caused fewer voids led to increasing UCS and E_s. A phenomenological model was used to develop equations for predicting UCS, E_s, brittleness, and deformability indexes for the stabilized soil. The results showed that there was a good correlation between the measured values and the estimated values given by the predicted equations.

1. Introduction

Soils treated with lime are used extensively as the construction materials in civil engineering such as pavement, road embankments, and retaining wall. Cebeci et al. [18] studied the strength and drying shrinkage of masonry mortars in various temperature-humidity environments. Based on their research, for the lime-cement mortars, the rise of temperature led to the enhancement of strength. In fact, quicklime (CaO) reacts with water in the soil and create hydrated (slaked) lime ($Ca(OH)_2$), in lime stabilization. In addition to chemically binding water, this reaction releases heat, which promotes faster reactions and a reduction of water content. Stabilization of the soil occurs during the reaction because of ion exchange reactions [40]. Also, high temperature increases the initial rate of drying shrinkage but reduces the ultimate shrinkage [24]. From 2007 to 2016, a lot of research works were carried out to study the formation of pozzolanic compounds (CSH and CAH) such as "Behavior and Mineralogy Changes in Lime-treated Expansive Soil at 20 °C" by Al-Mukhtar et al. [2] and "Chemical Analysis and X-Ray Diffraction Assessment of Stabilized Expansive Soil" by Mutaz and Dafalla [32].

Azadegan et al. [14] estimated the shear strength parameters of lime-cement stabilized granular soils from unconfined compressive tests. To evaluate shear strength parameters of the treated materials, they introduced a method, which used the unconfined compressive strength and estimating functions in the literature. In order to evaluate which estimation function was more accurate and appropriate for cement and lime stabilized granular soils, the estimated properties were considered in finite element simulation. It was observed that for the moderate strength of the treated soils, most of the applied functions have a good compatibility with experimental conditions. Azadegan and Li, [13] studied the lime and cement influences of stabilized platform on the behavior of circular footing constructed on soft clay. They carried out several unconfined compression tests on samples treated with different mixtures of lime and cement. Finite element simulations were conducted to determine the effects of thickness, diameter, and mix type of lime

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and cement stabilized platform on the bearing capacity and load-displacement behavior of a circular footing. It was concluded that there were two types of failure modes of flexural familiar and general shear failure. Moreover, by increasing the platform diameter, the bearing capacity of the circular footing reduced. However, the settlement at the center of footing decreased in comparison with a footing platform by smaller diameters. Azadegan et al. [15] studied the effects of adding cement and lime along with geogrid on the geotechnical properties of granular soils. It was concluded that by increasing the amount of cement or decreasing the amount of lime/cement ratio, a more brittle behavior of the stabilized soils was observed. Also, by decreasing the particle size of soils from 19 mm to 9 mm, compressive strength and modulus of elasticity also decreased substantially. Moreover, compaction resistance of geogrid layers overcame the benefits of reinforcement application in some cases and this was generally depended on the elasticity modulus, stiffness, and failure modes of untreated soil.

By centrifuge testing, Porbaha [35] found that the inclusion of geotextile reinforcement could increase the stability and ductility of lime-treated cohesive soil. Moreover, Stefanidou and Papayianni [43] showed that the addition of aggregates would improve the structure and properties of lime mortars. They concluded that when adequate compaction decreases capillary pores, coarse aggregates contribute to the volume stability of lime mortars independent from increasing of strength. In addition, both highest strength values and low porosity were observed by lime mortars of low binder ratio which contained maximum aggregates size of 0–4 mm.

Osinubi and Nwaiwu [33] investigated the compaction delay effects on properties of lime-treated soil. The results showed that compaction delays significantly influence the measured values of maximum dry density, optimum moisture content, unconfined compressive strength, and California bearing ratio. The results of their study will be helpful in controlling the compaction delay for lime-treated soils.

Hanley and Pavía [27] studied the workability of natural hydraulic lime mortars and its influence on strength through a series of laboratory tests. They found that mortars should be mixed to get the various diameters of flow for any hydraulic strength in order to optimize strength. Malekpoor and Toufigh [29] carried out a laboratory experiment to improve soft soil through lime mortar-(well graded) soil columns. In their study, more than 675 California bearing ratio (CBR) tests were conducted on cylindrical specimens made of lime mortar columns and clayey soil after different curing days. To study the effects of moisture on these columns, the specimens were tested in three different moisture contents, natural or in situ water content, soaked condition, and dry condition. The tests showed that the maximum value of strength (CBR (%)) of the stabilized clayey soil was observed in the specimen of lime mortar-(well graded) soil columns contain 25% lime and 22% clay at about 13%. Also, Consoli et al. [20] studied the variables controlling stiffness and strength of lime stabilized soils and demonstrated that the void/lime ratio is an appropriate key to determining the unconfined compressive strength and initial stiffness. Toohey et al. [44] investigated the stress-strain-strength behavior of four lime stabilized soils during accelerated curing. The specimens were cured in two different conditions: (a) at 41 °C curing for 2–8 day and (b) at 23 °C curing for 0–28 day. Based on unconfined compression tests, it was found that the compressive strength of specimens cured for 7 days at 41 °C was higher than those of the specimens normally cured for 28 days at 23 °C by 230%. Sridharan and Gurtug [42], Guney et al. [26], and Akcanca and Aytekin [1] showed that addition of lime to clayey soil reduces the clay swelling.

Yang et al. [48] studied the effects of geogrid and lime in a cohesive soil of retaining wall and examined a 6 m reinforced soil retaining wall. Based on the results, it was concluded that since lime stabilized soil carried the majority of gravity load and geogrids meet the integrity criteria of the embankment, under working stress condition, lime-treated backfill is more important than geogrid reinforcements to the stable of the retaining wall.

A review of the above studies shows that although an addition of lime to soil reduces the clay swelling and significantly improves the geotechnical properties of soils such as bearing capacity, unconfined compressive strength, and CBR, it increases soil brittleness. An increase in brittleness is highly unfavorable regarding the construction of retaining walls and slopes made by lime stabilized soils. As soon as soil and wall stability get close to failure line, there is no sign of failure and sudden fall of retaining wall, and soil slope occurs. Therefore, the objective of this research is to experimentally study the effect of HDPE (high density polyethylene) geogrid in lime stabilized clayey soil and determine the optimal percentage of lime in terms of highest unconfined compressive strength, modulus of elasticity, deformability index, brittleness index, and failure strain. It is worth adding that each test was replicated three times (on three different specimens) and a mean result was computed. Moreover, a phenomenological mathematical model for the clayey soil stabilized with lime only, and lime along with geogrid was developed to predict the compressive strength, modulus of elasticity, brittleness index, and deformability index of the stabilized soil.

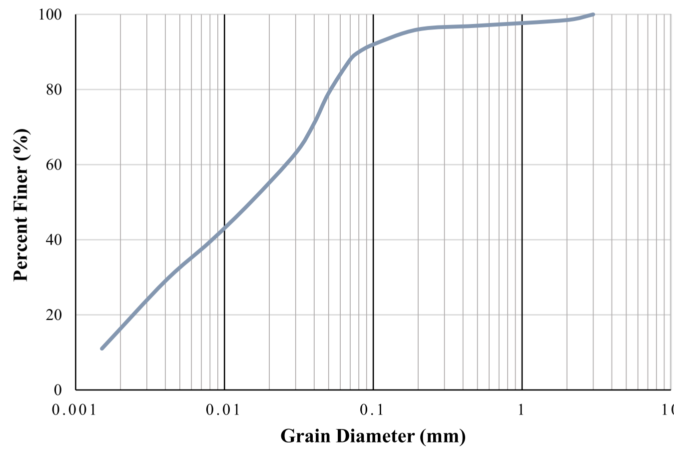

Fig. 1. Particle size distribution curve of the fine-grained clayey soil.

2. Materials

2.1. Clayey soil

The fine-grained clayey soil used in laboratory testing was sampled from Kerman, Iran. A series of laboratory tests were carried out based on the ASTM standards to determine some basic properties of the clay such as liquid limit, plastic limit, the type of mineral, activity degree, effective size, coefficient of uniformity, and coefficient of curvature of the soil. Fig. 1 shows the particle size distribution of the soil used in this study. Basic properties of the clay are summarized in Table 1.

2.2. Geogrid

The geogrid used in this study is known as CE 121 as shown in Fig. 2 (Meshiran Company [47]). Since molds of the laboratory tests are not very long and wide, a geogrid by finest meshes must be used. On the other hand, the CE 121 geogrid has finest meshes among other geogrids available in the market in Iran. Therefore, the CE 121 geogrid was used in the study. The characteristics of