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Full Length Article

Effect of curing, capillary action, and groundwater level increment on geotechnical properties of lime concrete: Experimental and prediction studies

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A B S T R A C T

Lime concrete and lime treatment are two attractive techniques for geotechnical engineers. However, researches have rarely been carried out to study the effects of moisture and capillary action due to increasing groundwater level on geotechnical properties of lime concrete. The aim of this study is to investigate the effects of curing time and degree of saturation on some of geotechnical properties of lime concrete such as unconfined compressive strength (UCS), secant modulus (E_s), failure strain, brittleness index (I_B), and deformability index (I_D) using unconfined compression tests. First of all, geotechnical and chemical properties of used materials were determined. After curing times of 14 d, 28 d, 45 d, and 60 d in laboratory condition, the specimens were exposed to saturation levels ranging from 0 to 100%. The results showed that the moisture and curing time have significant effects on the properties of lime concrete. Based on the results of scanning electron micrograph (SEM) test, it was observed that the specimen was characterized by a rather well-structured matrix since both the filling of a large proportion of the coarse-grained soil voids by clay and the pozzolanic activity of lime led to retaining less pore water in the specimen, increasing the UCS and E_s, and consequently resisting against swelling and shrinkage of the clay soil. Moreover, due to the pozzolanic reactions and reduction of water, by increasing the curing time and decreasing the degrees of saturation, UCS, E_s, and I_B increased, and I_D decreased. Based on the experimental results, a phenomenological model was used to develop equations for predicting the properties in relation to the ratio of degree of saturation/curing time. The results showed that there was a good correlation (almost $R^2 > 90\%$) between the measured parameters and the estimated ones given by the predicted equations.

1. Introduction

Lime stabilization, lime mortar, lime-hemp concrete, and lime concrete are the main items of lime utilization in civil engineering although each item completely differs from the others in applications and materials used. Sometimes, construction of civil projects on soft and problematic deposits such as clays and peats with high swelling and settlement potentials is inevitable (Rahgozar and Saberian, 2015; Saberian et al., 2017). There are several stabilization methods. Provided greater thickness of the problematic soil, the removal and replacement method is not considered affordable, however, stabilization by chemical agents such as lime is regarded as a commendable way to reduce the swelling behavior of the soil. This trend is one of the applications of lime in civil engineering projects, in which lime and water are mixed with the soil and the mixture is compacted. This method is used for highway embankments and even airport subgrades (Wang et al., 2012; Saberian and Rahgozar, 2016; Firoozfar and Khosroshiri, 2017; Jahandari et al., 2017a). Lime is also used as lime mortar for masonry bonds (Costigan et al., 2015; Pavlík and Užáková, 2016). Moreover, lime can be used as lime-hemp concrete. In this method, hemp, lime, clay, and coarse-grained soil are applied to construction of lime blocks. Also, lime-hemp concrete is a light composite

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building material with lime as binding agents and hemp (Cannabis sativa) as a renewable raw material from agriculture. Contemporary lime-hemp concrete only uses the woody core part of the hemp shives and fibers may improve the mechanical strength, eliminating the need for a fiber separation process (de Bruijna et al., 2009; Walker et al., 2014). At last but not the least, when a soil is excavated more than an acceptable level, it should be filled with a proper material to the required level. One of the most important applications of lime is using lime concrete to achieve a strong foundation at the required level (Grist et al., 2015).

On the other hand, although lime concrete is an old material used in civil engineering, only few researches have been carried out to investigate its behavior. In addition, the potential use of lime concrete as an alternative to Portland cement concrete for structural components has been recognized, but it is acknowledged that "the science has not been developed" (Grist et al., 2015). Moreover, it is important to point out that most of the researches have just investigated the stabilization of soils with lime, which is different from lime concrete.

Lime concrete is a traditional material and technique that has been used widely in warm regions as a support layer for shallow foundations, road backfills, and even railway tracks. In some cities and provinces such as Kerman, Yazd, and Mashhad in Iran, for the sake of being located in warm regions, lime concrete is being widely used. Since the rainfall in warm regions is often low, the depth of groundwater is often very deep and it is scientific to use lime concrete. Based on the previous researches, it is shown that high temperatures and low moistures have noticeable effects on the increases in the strength of lime concrete and lime stabilized soils (Toohey et al., 2013). For the above-mentioned reasons, it is a general belief that lime concrete is important to be used as a support layer for shallow foundations in warm regions. In addition, in some warm regions such as Kerman City of Iran, there are some specific reasons leading to an increase in groundwater level. The three most important of those are the destruction of old underground aqueducts, old swage pits system, and bowl shape of the bedrock of Kerman. On one hand, although Kerman is located in a warm region, the groundwater level is increasing there. On the other hand, the soil in Kerman is mostly fine-grained to a great depth (i.e. specially clay soil) (Firoozfar and Khosroshiri, 2017). Due to capillary action in fine-grained soils, water penetration to lime concrete has negative effects on the reduction of the strengths of lime concrete, foundations, and ultimately structures, and more importantly, historical buildings. Also, there is an incorrect belief among most engineers regarding the use of lime concrete still under the foundation of buildings. From the results of the current study, some instructions may be proposed about using and/or not using lime concrete, advantages, and drawbacks of lime concrete based on the depth of the excavated soil, soil properties, natural water content due to the capillary action, and distance between the bottom of foundation and groundwater level.

In order to reach an acceptable depth for construction of foundation and make a proper base for transferring loads, provided that the construction site is located in a warm region, lime concrete is a proper material to be utilized for light buildings up to 3 stories (building A in Fig. 1). For buildings with higher stories, sometimes up to 7 stories, the use of lime concrete columns (also known as lime columns) is a practical and popular technique (building B in Fig. 1). For the rest of buildings, other techniques such as deep foundations like piles may be more acceptable and safer.

Lime is mainly used to strengthen and stabilize problematic soils (Rogers et al., 2006; Thyagaraj et al., 2012). As soon as quicklime (CaO) reacts with water in the soil, hydrated lime ($Ca(OH)_2$) is created. The released heat from the reaction accelerates the reactions and reduces water content. As a result, ion exchange reactions lead to stabilization of the soil (Saberian and Rahgozar, 2016). The use of lime to stabilize soil is a well-established construction technique, documented in the studies of Winterkorn (1955) and Lund and Ramsey (1959).

Stiffness and permanent deformation of stabilized clay soil by lime and lime/cement were studied by Rogers et al. (2006). They concluded that it is vital to allow the samples to access water. Moreover, addition of lime and cement to the soil not only improved the strength and resilient modulus of soil, but also

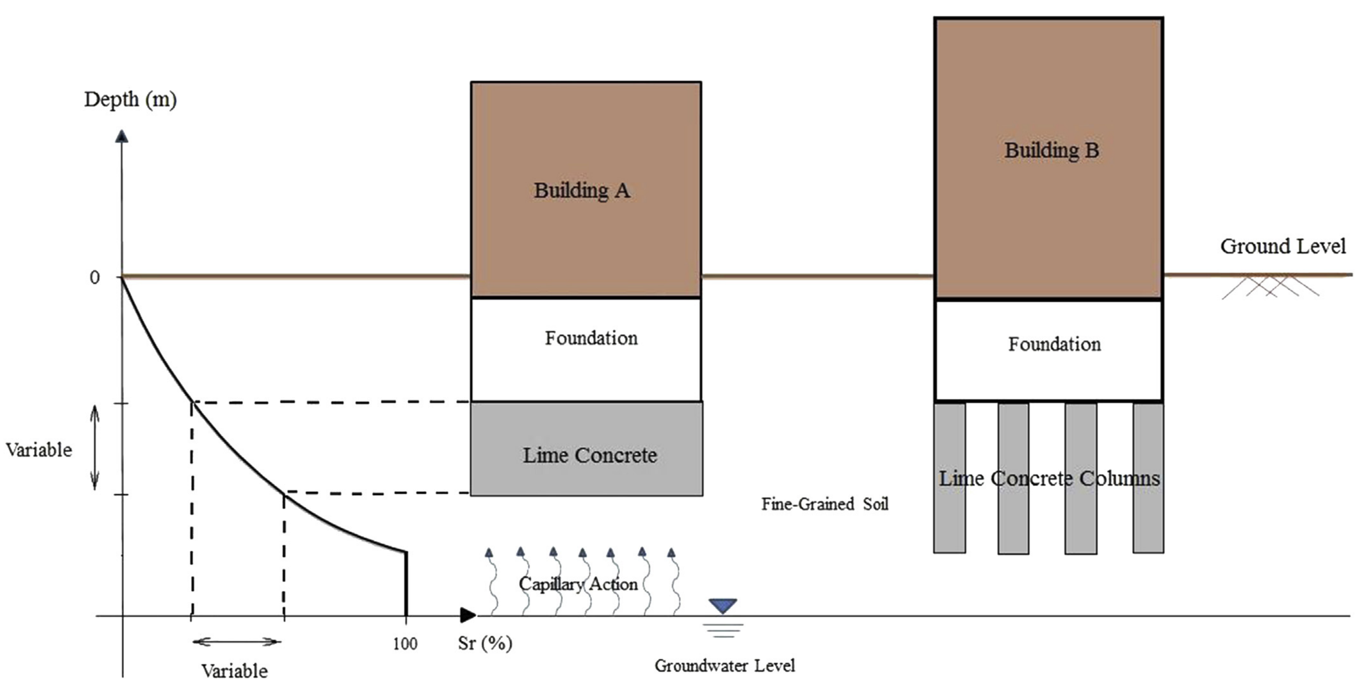

Fig. 1. A sketch of two buildings constructed over lime concrete and the effect of capillary action.