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Enhancing mechanical behaviors of collapsible soil using two biopolymers

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ABSTRACT

This study aims to investigate the possibility of using biopolymer (environmental friendly material) to enhance the mechanical behaviors of collapsible soil. Two types of biopolymers were (xanthan gum and guar gum) used in this study due to their stable behaviors under severe conditions and their availability with reasonable prices. The experimental program focused on three major soil properties, i.e. compaction characterizations, collapsible potential and shear parameters. These three properties are essential in process of soil improvement. Different biopolymer concentrations were used in this study and the experimental program was performed at two curing periods (soon after mixing the soil with the biopolymer and after one week curing time). Shear parameters were measured for the treated specimens under both soaked and unsoaked conditions, while a collapsible potential test was performed under different mixing conditions (wet mix and dry mix). A numerical model was built to predict the behavior of the treated collapsible soil after and before water immersing. The results indicated that the ability of both xanthan gum and guar gum can be used as improvement materials for collapsible soil treatment. The collapsible potential has been reduced from 9% to 1% after mixing the soil with 2% biopolymer concentration in the wet case. After one week curing, the cohesion has been increased from 8.5 kPa to 105 kPa by increasing the xanthan gum concentration from zero to 2%, leading to an overall improvement in soil shear strength. It also proves that the guar gum is superior to the xanthan gum. The shear strength of soil can be increased by about 30% when using the guar gum in comparison with the xanthan gum at the same conditions; however, the collapsible potential of soil material will be reduced by about 20%.

1. Introduction

Problematic soils can change with the variation in environmental conditions when they are directly used for construction. Collapsible soil is one of the widespread problematic soils in arid and semi-arid areas all over the world. The collapsible soil can be recognized by its sudden volumetric reduction after increasing its humidity. The collapsible potential of the soil – the percentage of volumetric change at certain vertical stresses after and before water immersing – is a function of several factors, such as void ratio, density, soil composition and moisture content (Houston et al., 2001; Cerato et al., 2009). Most collapsible soils are naturally wind deposited silt or sand. Loess is one of the wind deposited collapsible soils which cover 15%–20% area of Europe, China and United States (Das, 1995). The collapsible soil cohesion could be attricuted to the clay particles that cover and bond the soil particles together to form what is apparently stable soil in its dry state. Some soluble materials also can be responsible for creating apparent cohesion between the soil particles, such as gypsum and calcium chloride. Collapsible soil is stable in its unsaturated status with a high apparent shear stress; however, under water immersing conditions, water can break down the cementation between the particles, causing large volumetric changes (Peck et al., 1974; Clemence and Finbarr, 1981).

Many methods are reported in literature to improve the collapsible soil behaviors, while choosing the appropriate method is more challenging in association with various factors, such as collapsibility degree, economic aspects and construction aspects. Wet compaction can be effective in improving the shallow layers of

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collapsible soil which can be suitable for light weight structures, while injection can be effectively used for deep improvement of heavy or underground structures. Chemical stabilization is widely used to treat collapsible soil by using several stabilizing materials, such as cement, sulfur, acrylate, and sodium silicate. Deep foundations such as piles can be used in collapsible soil by transferring the structures load to stable layers below the collapsible one. However, negative skin friction should be considered in that case (Houston et al., 1988; Jefferson et al., 2005; Guan et al., 2010; Rollins and Kim, 2010; Mohamed and El Gamal, 2012; Fattah et al., 2015).

Despite the great success of using chemical stabilization materials to improve the behavior of collapsible soil, they cannot be considered as environmental friendly materials as they are toxic, modify the pH level of soil, and contaminate groundwater and soils. Moreover, cement industries are responsible for 5% of global carbon dioxide emissions, where producing of 1 t cement is accompanied by releasing 1 t CO_2 (Worrell et al., 2001). Many environmental factors are associated with huge amount of energy consumed for production, gross water used, which contribute to global climate change and CO_2 emissions. Thus it is essential to find out new environmental friendly materials that can cover these negative aspects and can be sustainable as well. Biopolymer is sustainable carbon neutrality and is always classified as a renewable material because it is made from agricultural non-food crops. Therefore, the use of biopolymer in geotechnical engineering would create a sustainable industry (Stupp and Braun, 1997).

Although there are various potential applications of biopolymers to geotechnical engineering at present, the promising applications are only concentrated on bio-clogging. Bio-clogging aims to reduce the hydraulic conductivity of soils and porous rocks, which could be used to (i) reduce drainage channel erosion, (ii) form grout curtains to reduce the migration of heavy metals and organic pollutants, and (iii) prevent piping of earth dams and dikes (Ivanov and Chu, 2008). More applications were investigated by the US Army Corps of Engineers regarding the use of biopolymers to improve slope stability on berm ranges and reduce the loss of sediment in surface water runoff (Larson et al., 2012). Several recent researches show the ability to increase the shear strength of soil using biopolymer. Different types of biopolymers (such as xanthan gum, guar gum, modified starches, agar and glucan) have been used to improve the behavior of typical soils (sand, silt and clay) (Chang and Cho, 2012; Chen et al., 2013; Khatami and O'Kelly, 2013; Chang et al., 2015a, b, c; Ayeldeen et al., 2016). Biopolymer showed a remarkable success in improving the soil shear strength; however, the improvement degree differs according to biopolymer types, soil types and compositions, biopolymer doses, and curing conditions. Reducing the soil permeability by using biopolymer was also reported previously, where biopolymer showed another success (Martin et al., 1996; Khachatoorian et al., 2003; Ayeldeen et al., 2016). Despite the success of using biopolymer to improve the behavior of typical soils, using biopolymer to treat problematic soil is rarely reported. Durability of biopolymer and its economic feasibility as soil improvement material have been discussed previously (Ayeldeen et al., 2016). Regardless of the stability of xanthan gum and guar gum which have been recorded in the literature under different severe conditions and after curing time up to 750 d (Chang et al., 2015a), more researches are focusing on some durable biopolymer such as lignin sporopollenin. The decomposition of biopolymer after long time period and exposure to wet and dry cycles should be studied as well.

This paper attempts to understand and evaluate the effect of the behaviors of two types of biopolymers in terms of engineering properties applicable to collapsible soil. Different concentrations were used in the study under two mixing conditions (wet and dry). Compaction characterizations, shear parameters and collapsible potential are the target parameters. Also, a numerical model was built to estimate the load-settlement curves for treated soils with different biopolymer concentrations before and after saturation.

2. Materials and experiments

2.1. Soils properties

To understand the effect of biopolymer behavior on the mechanical properties of collapsible soil, a natural collapsible soil was sampled from New Borg-Alarab City, Egypt. The physical properties of the soil are given in Table 1, while the grain size distribution curve is illustrated in Fig. 1.

2.2. Biopolymers

Two types of biopolymers, i.e. xanthan gum and guar gum, were used in this study. These biopolymers were chosen because of their availability with reasonable prices compared to other biopolymers. Moreover, their unique functional properties include excellent cold water dissolving, pH stability, storage stability, ionic salt compatibility and pseudo plastic flow characteristics (Ayeldeen et al., 2016).

Xanthan gum is an anionic exocellular polysaccharide produced by aerobic fermentation of sugars by the bacterium *Xanthomonas campestris*. The main chain of this type consists of a linear 1, 4-linked β-D-glucose backbone substituted on every two units, with a charged tri-saccharide side chain. The latter side chain is composed of a D-glucuronic acid unit linked between two D-mannose units (Hassler and Doherty, 1990).

Guar gum is a polysaccharide composed mainly of the sugars galactose and mannose. The backbone is a linear chain of β 1,4-linked mannose residues to which galactose residues are 1, 6-linked at every second mannose, forming short side branches. Guar gum is more soluble than many other biopolymers and is a better stabilizer as it has more galactose branch points. In contact with water, it is non-ionic and hydrocolloidal (Risica et al., 2005; Lauren, 2010; Chaplin, 2012).

2.3. Specimen preparation

To prepare the treated soil specimens, the natural collapsible soil was disturbed by hand; next air dried for one week, and then sieved using US sieve size #50. The soil water content was found to be about 3% after being air-dried and before mixing the soil with the biopolymer. Two methods were used to mix the soil with biopolymer: dry mix and wet mix. The wet mix method is the main method in this study and has been used to prepare the samples for all tests. In that method, the biopolymer solution was prepared first with specific concentrations, and then mixed with the air-dried soil to obtain average water content of 8% ± 0.1%. The solution concentration was calculated as the ratio between the weight of the used biopolymer powder and the overall weight of the solution in percentage. The powder was added to the water gently to avoid clumping, and then the solution was mixed until a homogeneous solution was obtained. Biopolymer concentrations of 0.25%, 0.5%, 1%, 2%, 3% and 4% were used in this study.

Table 1
Physical properties of the collapsible soil.

Liquid limit, *LL* (%)	Plastic limit, *PL* (%)	Plasticity index, *PI* (%)	Specific gravity, G_s	Maximum dry unit weight, γ_{max} (kN/m^3)	Optimum water content, w_{op} (%)
34.6	19.2	15.4	2.64	19.15	12.4