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Effect of compaction method on the undrained strength of fiber-reinforced clay

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Abstract

The use of discrete fibers in reinforcing soils is of interest to the geotechnical engineering community. Two limitations exist in experimental studies involving fiber-reinforced clays. First, fiber-reinforced clay specimens are generally prepared in the lab using conventional ‘‘impact” compaction, whereas the compaction of clay systems in the field typically involves ‘‘kneading” action. Second, the majority of tests reported in the literature use synthetic fibers to the exclusion of other types. This paper addresses these limitations through an experimental triaxial testing program that: (1) supplements the scarce data available in the literature on the undrained load response of clays reinforced with ‘‘natural” fibers and that are compacted by ‘‘kneading”, and (2) assesses the capacity of the experimental procedures that involve ‘‘impact” compaction to produce responses that are relevant to actual field conditions. Results from 73 unconsolidated undrained triaxial tests indicate that the percent improvement in the undrained strength of the fiber-reinforced clay is highly dependent on the compaction method, with specimens that are prepared using impact compaction yielding improvements up to three times larger than identical specimens prepared by kneading. This discrepancy in the behavior can be traced back to differences in the fiber orientation distributions between specimens that were compacted by impact and kneading.

Keywords: Ground improvement; Fiber-reinforced clays; Compaction; Hemp fiber; Shear strength; Unconsolidated-undrained test

International Geotechnical Classification Numbers: D06; D10; K14

1. Introduction and background

The potential use of discrete fibers in applications involving the reinforcement of soils in earth retaining systems, pavement systems, earth slopes, and compacted clay liners and cover systems is garnering more attention and acceptance in the geotechnical community (Najjar et al., 2013; Hejazi et al., 2012; Sadek et al., 2010, among others). Fiber-reinforced soils were used successfully on more than 50 embankment slopes in the United States between the year 1990 and 2006 (Gregory, 2006).

The fibers traditionally investigated in research settings consist primarily of synthetic fibers. In the past decade, sustainability concerns have significantly impacted the fields of construction engineering and materials. The current drive to use renewable resources in construction is significant

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Nomenclature

L_F	length of the fiber
w	water content, in percentage
η_F	aspect ratio, defined as the ratio of the length to the diameter of the fiber (L_F/d_F)
$\chi_{F,w}$	gravimetric fiber content defined as the ratio of the weight of fibers to the dry weight of soil, in percentage
σ_3	confining pressure, in kPa
γ_d	dry unit weight of the soil, in KN/m^3
σ_d	deviatoric stress, in kPa
$\rho(\theta)$	generalized fiber orientation distribution function
$\bar{\rho}$	average volumetric concentration of the fibers
θ	fiber orientation angle with the horizontal
P	ratio of the volume of fibers having orientations within an angle $\pm\beta$ from the horizontal to the total volume of fibers
N_V	number of fibers crossing vertical planes
N_H	number of fibers crossing horizontal planes

(Hejazi et al., 2012; Mitchell and Kelly, 2013). Several studies have explored the use of natural fibers such as coconut, palm, straw, bamboo, and cane fibers to reinforce soils. Results indicate that natural fibers could provide soils with added shear strength and ductility.

Gregory (2006) reports that clayey soils constitute the real potential for the practical and extensive use of fibers in geotechnical applications. To date, several experimental studies investigated the response of clays reinforced with discrete fibers (e.g. Maher and Ho, 1994; Nataraj and McManis, 1997; Prabakar and Sridhar, 2002; Li and Zornberg, 2005; Gregory, 2006; Punthutaecha et al., 2006; Tang et al., 2007; Akbulut et al., 2007; Ozkul and Baykal, 2007; Abdi et al., 2008; Chandra et al., 2008; Attom et al., 2009; Viswanadham et al., 2009; Al-Mhaidib, 2010; Jiang et al., 2010; Babu and Chouksey, 2010; Maheshwari et al., 2011; Amir-Faryar and Aggour, 2012; Plé and Lê, 2012; Pradhan et al., 2012; Jamei et al., 2013; Maliakal and Thiyyakkandi, 2013; Mirzababaei et al., 2013; Qu et al., 2013; Anagnostopoulos et al., 2014; Najjar et al., 2014; Wu et al., 2014).

Output from published studies points to common findings in some aspects of behavior. Most studies conclude that the inclusion of fibers generally leads to an increase in the shear strength of the composite. For a given aspect ratio (fiber length/diameter), the strength increases with fiber content up to certain point, beyond which the improvement in strength reaches an upper limit, and in some cases starts to decrease. Decay in strength gain at high fiber contents is believed to be due to the presence of increasing numbers of fiber-to-fiber contact, rather than fiber-to-soil contacts. For a given fiber content, an increase in the fiber aspect ratio leads to higher strengths up to certain values of aspect ratio beyond which loss of strength, or stability in strength, is observed.

An investigation of the scope and findings of previous studies leads to two possible shortcomings and/or limitations. The first limitation is that fiber-reinforced clay specimens are prepared in the laboratory using conventional "impact" compaction methods (Proctor), although compacted clay systems in the field are typically constructed using equipment that produces high shear strains/"kneading" action (e.g. sheep's-foot rollers). A question could be raised as to whether fiber-reinforced clay samples prepared using "impact" compaction will produce reliable representations of actual field conditions.

The second limitation is that the majority of the tests reported in the literature involve synthetic fibers. From the above-referenced 27 experimental studies, only 8 involved natural fibers. It could be argued that additional emphasis and further studies on clays reinforced with "natural" fibers are needed.

The work presented in this paper aims at addressing the above two limitations by designing and implementing a comprehensive experimental program that investigates the load response of natural clay reinforced with natural fibers (hemp in our case) and prepared using "kneading" and "impact" compaction techniques. The testing program consists of a series of unconsolidated globally-undrained (UU) triaxial tests, where various parameters (fiber length, fiber content, compaction water content and confining pressure) are varied aside from the compaction method.

The UU test setup allows for an effective quantification of the degree of improvement in the undrained shear strength of the compacted clay for applications involving short-term stability (foundations, slopes, landfill covers, etc.). The UU triaxial test has been utilized for decades to investigate the strength of compacted clays (Olson and Parola, 1967; Daniel and Olson, 1974; Liang and Lovell, 1983; Mun et al., 2016, among others). The UU test setup allows for examination of the roles of the initial hydraulic conditions (the initial matric suction and degree of saturation) and compaction effects (potential changes in soil structure when a soil is compacted wet or dry of optimum) on the undrained shear strength (Mun et al., 2016). To this end, the scope of this paper was limited to short term stability.

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