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Experimental study for the mechanical characterization of Tunis soft soil reinforced by a group of sand columns

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Abstract

An experimental investigation has been conducted to study the mechanical properties of remolded Tunis soft soil reinforced by a group of sand columns. The tested soft soil, extracted from the city center of Tunis at a depth of 15 m, has poor mechanical properties, and its moisture-sensitivity is very important. Specimens were initially slurry mixed at 1.5 times their liquid limit. They were then remolded at an initial K_0 consolidation path up to a vertical stress of 140 kPa. The holes, initially made in the specimens, were afterwards filled with standard sand which simulated the reinforcing column material. All the reinforced soil specimens were then subjected to consolidated undrained triaxial shear tests with measured excess pore-pressure (CU+u). Three confining pressures of 100, 200, and 300 kPa were applied during the consolidation phase. In addition to the unreinforced control specimen, three different types of reinforced specimens were used, namely, reinforced specimens with a single column, three columns, and four columns. All the reinforced specimens had the same area replacement ratio. The test results have shown that the number of reinforcing columns has a significant effect on the mechanical characteristics of the reinforced soft soil.

Keywords: Group stone columns; Tunis soft soil; Triaxial test; Undrained shear strength; Friction angle

1. Introduction

The soil of the plateau of Tunis, Tunisia is composed of three main formations: a 7-m fill layer (from a depth of 1 to 8 m), soft soil (from a depth of 8 to 70 m), and a sandy-clay layer that is assumed as a rigid substratum (Touiti et al., 2009; Tounekti et al., 2008).

The first twenty meters of the Tunis soft soil layer is used as the foundation level for the majority of buildings in Tunis City. Tunis soft soil is considered as a problematic soil because of its low strength and high compressibility. For this reason, the design of foundations to be built on Tunis soft clay requires a thorough study of both the short-term and long-term behaviors. According to the results of classification tests performed by Klai and Bouassida (2009), Tunis soft clay is a very plastic muddy soil with a high proportion of silt and varied clay fractions. Saturated Tunis soft clay is classified as a highly plastic silt with a very low consistency (Bouassida, 2006).

Building on such a problematic soil requires the use of deep piles with lengths that can reach up to 50 m. Thus, for economic reasons, soil-improvement techniques could present a solution to problems encountered when founding on Tunis soft soil. Among the various current methods for improving in-situ soils, stone columns are considered to be a cost-effective soil-improvement technique especially for soft soils (Andreou et al., 2008; Frikha et al., 2014). The use of reinforcing techniques that apply stone or sand columns results in an increase in bearing capacity as well as a reduction and acceleration in

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Nomenclature

A	total cross-sectional reinforced area
A_C	cross-sectional area of stone columns
B	Skempton coefficient
C_u	coefficient of uniformity
c_U	$q_{max}/2$
c_s	shear strength of untreated soil (shear strength)
c_c	shear strength of stone column constitutive material
D_c	diameter of column
H	length of column
I_P	plasticity index
n	column number
M	slope of critical state line
P_c	perimeter of single column
P_t	perimeter of reinforced soil (composite cell)
$p=\sigma_1+2\sigma_3/3$	mean stress
p'	effective mean stress
$q=\sigma_1-\sigma_3$	deviator stress
q_{max}	peak deviator stress
R	radii of total cross-sectional reinforced area
R_{C_n}	radii of cross-sectional area of one stone column
S	spacing between columns
SL_C	lateral surface of single column of radius R_C
SL_{C_i}	lateral surface of one column belonging to group of n columns having same radius R_{C_n}
u	excess pore water pressure
ω	natural water content
ω_l	liquid limit
ω_p	plastic limit
σ'_3	triaxial confining pressure
σ_1	axial pressure
ε_a	axial strain
φ'	effective friction angle
η	area replacement ratio
γ_d	dry unit weight
χ	contact coefficient

consolidation settlement. Furthermore, the rapid installation process has made this technique quite competitive compared to other soil-improvement techniques (Frikha et al., 2008; Frikha and Bouassida, 2014).

Several laboratory investigations have been conducted to estimate the performance of soft soil reinforced by granular columns (Juran and Guermazi, 1988; Bouassida, 1996; Wood et al., 2000; Sivakumar et al., 2004; Black et al., 2007; Andreou et al., 2008; Frikha et al., 2013, 2014). The main objectives of these studies were to validate some theoretical results and to evaluate the effects of the main design parameters on the overall behavior of the reinforced soil, such as the applied load, the improvement area ratio, the boundary conditions, the column installation techniques, the grain size distribution of the column material, the column length, etc. (Frikha, 2010).

The group effect of stone—column reinforcement was studied using field tests (Goughnour and Bayuk, 1979; Munfakh et al., 1984, etc.) and centrifuge tests to evaluate the general failure mechanisms (Terashi et al., 1991) and the extent of the improvement (Kimura et al., 1983).

Kaffezakis (1983) performed triaxial tests on clay specimens reinforced by a group of stone columns. He reported a significant increase in the lateral stress developing within the stone columns which increased as the number of columns within the group increased.

Bachus and Barksdale (1984) concluded that there is only a slight increase in the ultimate load bearing capacity per column when the number of columns increases. However, in their tests, the effect of lateral confinement was more significant since the reinforcing columns were set close to the borders of the testing box.

Hu (1995) built a laboratory-scale model to examine the behavior of a cohesive soft soil reinforced by a group of stone columns supporting a rigid footing. He found that reinforcement by a group of columns is more effective than that by an isolated column. The interaction between the columns and the soft clay was found to efficiently contribute to the enhancement of the load bearing capacity and to provide a wider transfer of loading.

Wood et al. (2000) commented on the tests performed by Hu (1995) and confirmed that the mode of failure for each column, in the case of group-column reinforcement, depends on its location within the group, its length, and the type of loading. Their results showed that the pre-failure mechanisms and the failure modes of a stone-column group are different from those observed for a single column. They reported that the area replacement ratio affects the extent of the columns' interaction and the load transferred to the soft clay in between the columns. This research concluded that a significant improvement in the bearing capacity depends on a minimum area replacement ratio of 25%.

Black et al. (2007) found that clay specimens reinforced by a single end-bearing column (fully penetrating column over the specimen length) show a 33% increase in strength. They noted that the installation of a group of columns, with the same area replacement ratio, does not provide any particular difference in load-carrying capacity. With regard to the settlement under drained conditions, a group of columns brings about a significant difference in the stiffness of the composite material. The results, presented by Black et al. (2007), indicate that a group of columns can lead to a possible reduction in stiffness when compared to a single column with similar area replacement ratios.

Ambily and Gandhi (2007) reported that the stiffness of a single column and that of a group of six columns (spaced apart by more than 3 times the column diameter) are almost comparable. It has been noted, using the unit cell concept, that the behavior of a single column can simulate the field behavior of an interior column belonging to a group of columns.