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Experimental studies on the physico-mechanical properties of jet-grout columns in sandy and silty soils

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A R T I C L E I N F O

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A B S T R A C T

The term of ground improvement states to the modification of the engineering properties of soils. Jet-grouting is one of the grouting methods among various ground improvement techniques. During jet-grouting, different textures of columns can be obtained depending on the characteristics of surrounding subsoil as well as the adopted jet-grouting system for each site is variable. In addition to textural properties, strength and index parameters of jet-grout columns are highly affected by the adjacent soil. In this study, the physical and mechanical properties of jet-grout columns constructed at two different sites in silty and sandy soil conditions were determined by laboratory tests. A number of statistical relationships between physical and mechanical properties of soilcrete were established in this study in order to investigate the dependency of numerous variables. The relationship between q_u and γ_d is more reliable for sandy soilcrete than that of silty columns considering the determination coefficients. Positive linear relationships between Vp and γ_d with significantly high determination coefficients were obtained for the jet-grout columns in silt and sand. The regression analyses indicate that the P-wave velocity is a very dominant parameter for the estimation of physical and mechanical properties of jet-grout columns and should be involved during the quality control of soilcrete material despite the intensive use of uniaxial compressive strength test. Besides, it is concluded that the dry unit weight of jet-grout column is a good indicator of the efficiency of employed operational parameters during jet-grouting.

1. Introduction

A number of soil improvement methods have been developed in engineering practice to overcome various geotechnical problems. Jet-grouting or high pressure grouting is remarkably highlighted primarily for both its efficiency and cost-effectiveness. The basic concept of jet-grouting is to inject controlled quantities of cement grout through very small diameter nozzles on a rotating drill rod with significantly high pressures (300–600 bar). The injected water–cement grout creates cemented geometries of so-called soilcrete with improved physico-mechanical properties. The range of jet-grout column diameter may vary between 40 and 140 cm depending on the soil type and employed operational parameters (Lunardi, 1997). Furthermore, the physical and mechanical properties of the high-modulus columns are considerably variable due to two variables namely the effectiveness of replacing soil with cement and the composition of the foundation soil (Croce et al., 2014). Besides, the water–cement ratio is the major factor controlling the physico-mechanical parameters of the soilcrete. Although a water/cement ratio of 1.0 is mostly considered in jet-grout applications, a lower water/cement ratio should be preferred in which there is substantial groundwater flow as well as in order to get columns with high elasticity modulus (Lunardi, 1997; Kashevarova et al., 2013; Croce et al., 2014; Akan et al., 2015).

Several studies concerning the physico-mechanical properties of the jet-grout columns constructed in different soil types were conducted (Xanthakos et al., 1994; Croce and Flora, 1998; Van der Stoel, 2001; Fang et al., 2004; Correia et al., 2009; Bzowka, 2012; Lambert et al., 2012; Akan et al., 2015). However, the significance of the empirical correlations are reasonably crucial since an unknown parameter can be estimated using the identified factor (Correia et al., 2009). In addition, the behavior of soil-cement mixtures can be well-understood and the quality control process can be improved by empirical relations of various parameters (Tinoco et al., 2011). In this study, physico-mechanical properties of jet-grouted material were investigated by means of laboratory testing on core samples drilled from jet-grout columns constructed

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in sandy and silty soils. Accordingly, unit weight, porosity, P wave velocity in dry and saturated conditions and uniaxial compressive strength of sandy and silty soilcrete material were distinguished respectively. Additionally, several statistical relations were developed to reveal the relationship between physical and mechanical properties of high modulus columns. The results were also compared with the existing formulations. The jet-grout core samples tested in this study were extracted from in-situ columns erected in foundation soils during soil stabilization applications.

2. Physico-mechanical properties of jet-grouted material in silty and sandy deposits

2.1. Unit weight of jet-grout columns

Different textures of soilcrete obtained during jet-grouting due to the fact that the characteristics of surrounding subsoil and the adopted jet-grouting system for the specific site are variable. Moreover, the texture of jet-grout column is typically heterogeneous involving coarse soil particles or untreated fragments (Croce et al., 2014). Two different jet-grouted materials in this study also reveal inhomogeneous textural properties as shown in Fig. 1.

The NX-size (54.7 mm) jet-grout cores were collected from columns of 0.8 m in diameter by coring with a drilling rig from two different construction sites. The operational parameters employed during jet-grouting are very similar at both sites and summarized in Table 1. Additionally, the classification and physical properties of the foundation soils at two specific sites are presented in Table 2. And also it should be noted that the groundwater level at the sampling sites is shallow being around 3–5 m.

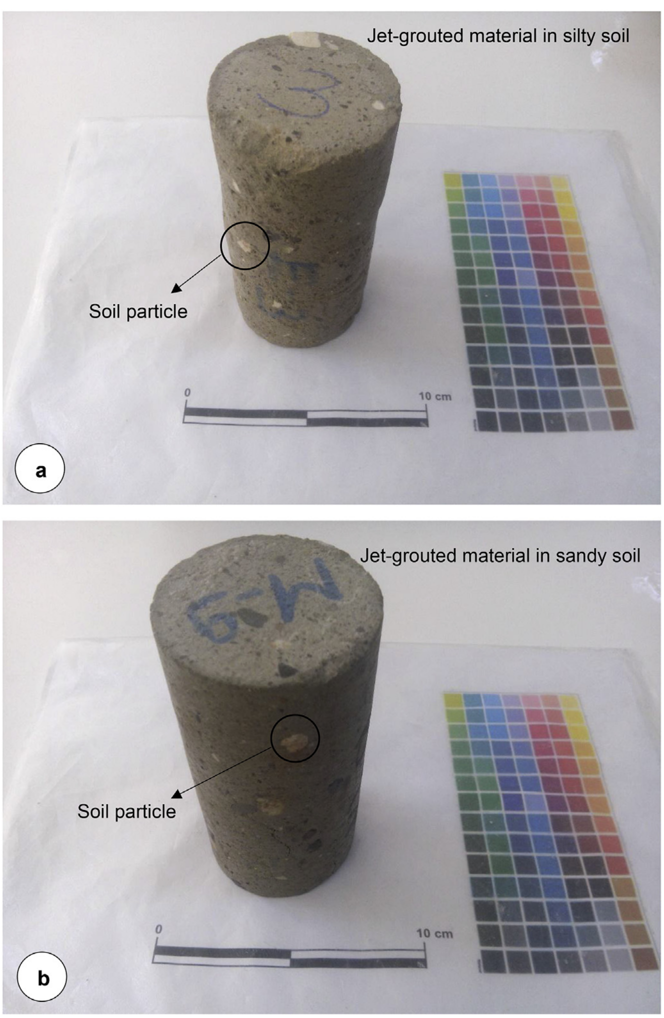

Fig. 1. Close-up views of test materials: jet-grouted materials in silty soil (a) and sandy soil (b).

Although the mechanical properties of the jet-grouted materials have been studied in detail, comparatively little attention has been paid to the unit weight of soilcrete in the literature. However, the unit weight of the jet-grout columns is very significant for the geotechnical designs such as sealing plugs or earth-retaining walls where the self-weight of the jet-grout column plays a substantial role (Croce and Modoni, 2007; Rollins et al., 2008; Eramo et al., 2012; Croce et al., 2014). Moreover, the unit weight of the column should be assessed as an indicator of the efficiency of the employed operational parameters (Croce et al., 2014). The average dry unit weight values for various soil types presented in the literature are summarized in Table 3.

A gradual increase of dry unit weight with the escalating grain size is obvious in Table 3 except pyroclastic sand. In general, the dry unit weight of columns erected in fine grained soils (clay, silt) varies between 16.0 and 17.5 kN/m^3, whereas a minimum dry unit weight of 18 kN/m^3 is reasonable in coarse grained soils. However, it should be kept in mind that different threshold values are also presented in the literature for various soils (Croce et al., 1994; Croce and Flora, 1998; Fang et al., 2004). Furthermore, despite the effect of operational parameters applied during high pressure grouting, it is reported in the literature that the jet-grouted material reveals similar unit weight values with the surrounding soil (Croce et al., 2014).

Variation of dry and saturated unit weight values of jet grout columns in sandy and silty soils is presented in Table 4. As a particular note, all jet-grout core specimens tested in this study are older than 60 days and completed their curing process. As seen in Table 4, the average dry unit weight of jet-grout columns in silty (ML) and sandy soils (SM-SW) are 15.86 and 16.95 kN/m^3, respectively. Slightly lower values were obtained for both sample groups than the literature when compared to the results presented in Table 3. However, the average dry unit weight of soilcrete in sand is still higher than that of silt. A maximum of 19.05 kN/m^3 dry unit weight was found for silty soils and it can be as low as 12.40 kN/m^3 as well. Oppositely, sandy soils reveal very similar minimum and maximum threshold values to silty layers which can be attributed to the silt content of sandy deposits. Besides dry unit weight, saturated unit weight may sometimes be essential when jet-grout columns are constructed under groundwater as sealing plugs. The same trend with the dry unit weight was obtained for saturated unit weight of tested core specimens. The average saturated unit weight of columns in silty and sandy soils are found to be 19.06 and 19.93 kN/m^3, which are noticeably higher than the average dry unit weight values.

Table 1
Several operational parameters used for jet-gouting at two sampling sites.

	Site 1 (silty soil)	Site 2 (sandy soil)
Jet-grout column diameter	0.8 m	0.8 m
Jet-grout method	Jet-1 (single fluid)	Jet-1 (single fluid)
Water/cement ratio	1.0	1.0
Injection pressure	450 bar	400 bar
Dosage	450 kg/m^3	430 kg/m^3
Uplift speed	7.5–10 s/4 cm	7–8 s/5 cm
Nozzle diameter	2.2 mm	2.2 mm