Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 158 (2016) 416 – 421

Procedia Engineering

www.elsevier.com/locate/procedia

VI ITALIAN CONFERENCE OF RESEARCHERS IN GEOTECHNICAL ENGINEERING – Geotechnical Engineering in Multidisciplinary Research: from Microscale to Regional Scale, CNRIG2016

Reliable definition of the characteristic strength of jet grouted soils by Random Field Theory

Caterina Toraldo[a,*], Giuseppe Modoni[a], Paolo Croce[a]

[a]*University of Cassino and Southern Lazio, Via G. di Biasio 43, Cassino (FR) 03043, Italy*

Abstract

The jet grouted soils are very heterogeneous and thus the statistical methods normally used to define strength of artificial construction materials become extremely conservative. To quantify the mechanical effects of variability on the characteristic strength and the effects of the samples dimensions, the random and spatial variation are firstly explored interpreting field and laboratory tests with the Random Field theory. Then the variability is reproduced on a large volume of material together with the imaginary coring of samples of different sizes and with uniaxial compression testing. This calculation enables to relate the statistical parameters of strength to the size of samples, to the variability observed at small scale and to the correlation distance. The parametrical analysis carried out, has shown that the increase in the element size turns into a reduction of the variability which can be opposed by an increase of the correlation distance.

Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016

Keywords: Jet grouting; variability; random field; characteristic strength; design

1. Introduction

The traditional approach to manage variability and reduce uncertainty in geotechnical design makes use of characteristic values for the soil properties computed with safety factors traditionally more generous than those typically suggested for artificial materials. One of the most striking issues is represented by the calculation of

* Corresponding author. Tel.: +39-0776-2993738.
E-mail address: c.toraldo@unicas.it

Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016
doi:10.1016/j.proeng.2016.08.465

characteristic strength valid for elements representative of the scale of the problem under study, typically larger than the small laboratory specimens [1]. Neglecting this step, generally leads to over conservative estimates as it does not take into account the positive collaboration among contiguous elements. To consider this aspect, the Standard Codes for geotechnical design (e.g. [2]) suggest to compute the full scale response of structures assuming a mean resistance estimated over an undefined range of values. For instance Schneider [3] computes the characteristic value x_k of a soil property as the average value over an appropriate spatial domain. In his formulation the variation coefficient over the volume of characteristic length L is computed accounting the different factors of uncertainty, as:

$$COV_{total} = \sqrt{(\Gamma^2 \cdot COV_{inherent}^2} + COV_{measurement}^2 + COV_{transformation}^2 + COV_{statistical}^2) \quad (1)$$

where Γ^2 is the variance reduction function that accounts for the spatial extent of the governing failure mechanism, defined as the ratio between the standard deviations averaged over the governing failure mechanism and that measured on small samples [4]; $COV_{inherent}$ expresses the natural variation at small scale inherent to the soil layer; $COV_{measurement}$ is the epistemic uncertainty stemming from inaccurate measuring, poor testing, low quality workmanship etc.; $COV_{statistical}$ is the statistical uncertainty introduced due to limited information or small number of tests or observations; $COV_{transformation}$ is connected to the modification of measured field or laboratory results by means of empirical correlations or theoretical models, to derive soil properties suitable for design.

In spite of being logical, the above equation lacks of experimental validation and the definition of a procedure to determine the characteristic value is missing, these statements holding true for both natural and treated soils. There is the need to define the characteristic values of the resistance of geotechnical materials with more rational approaches possibly measuring the uncertainty related with the chosen values. Aim of this study is to find a criterion responding to these questions for cement treated soils.

Experimental studies (e.g. [5]) have shown that the uniaxial compressive strength of small samples of jet grouted material presents a very large variability (with coefficients of variation of 0.5 and more). Assuming the same distribution, with the same mean and standard deviation, for the strength of bigger jet grouted elements would be excessively detrimental for the latter, with the result that cemented material would be too weak to produce any effective reinforcement. Indeed larger jet grouted elements should be seen as formed by assemblies of clusters mutually cooperating each other. However, if spatial correlation is considered, the vicinity of weaker/stronger clusters increases the dimension of representative samples and thus, for a given dimension of the element, the variability of strength becomes higher. This effect has been clearly demonstrated by Namikawa and Koseki [6] who found that the strength of soil treated by Deep Soil Mixing varies greatly, even in a single column, in accordance with the variability of the in-situ soil properties. These results suggest that the spatial autocorrelation should be considered also in the choice of the design strength of the jet grouted material. The Random Field theory, already applied in different fields of mechanics (e.g.: [7,8]), blends algorithms of numerical calculation with the simulation of variability to provide a rational approach to the estimation of the mechanical behavior of structures having locally variable characteristics. The present paper adopts this approach into FEM calculation to analyze the scale effect on the characteristic strength of the jet grouted material.

2. Experimental variability

The random and spatial distribution of strength for jet grouted soil are here seen on the experimental data pertaining to a trial field foundation reinforced with jet grouting [9]. Similarly to many other cases [10], the statistical analysis of uniaxial compressive strength (Fig. 1a) reveals that a log-normal probability function can be inferred among data. This result are then combined with the distribution of the compressive wave velocity, obtained on the same material with cross-hole tests and sonic tomography, to quantify the spatial variability of the small strain stiffness (Fig. 1c). It is worth noting that stiffness and strength of jet grouted material are correlated each other [11], as they both depend on the composition or degree of cementation of the material (Fig. 1b). From sonic tomography (Fig. 1c) the experimental autocorrelation function can be calculated in both directions (vertical and horizontal), and the exponential function can be adopted to model the observed trend (Fig. 1d) according to past studies [12]: