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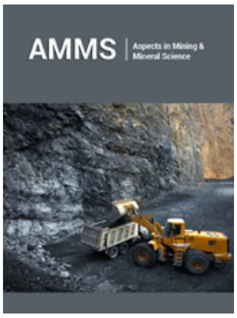
Mini Review

Review of Experimental Arrangements for Soil Grouting with Cement Suspensions

ISSN: 2578-0255



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Abstract

Improvement of the mechanical properties and behavior of soils by permeation grouting, using either suspensions or chemical solutions, is frequently required in order to assure the safe construction and operation of many structures. Suspensions have lower cost and are harmless to the environment but cannot be injected into soils with gradations finer than coarse sands. Chemical solutions can be injected in fine sands or coarse silts but are more expensive and some of them pose a health and environmental hazard. Efforts have been made to extend the injectability range of suspension grouts by developing materials with very fine gradations and, as a result, a number of "microfine" or "ultrafine" cements has been developed and marketed in the last decades. The object of the present study was the inventory and grouping of equipment used internationally for the experimental documentation of the inclusion of cement suspensions for the improvement and reinforcement of soil formations.

Keywords: Permeation grouting; Suspensions; Injectability; One-dimensional impregnation columns

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Submission: May 18, 2023
Published: May 31, 2023

Volume 11 - Issue 3

How to cite this article: Dimitrios Christodoulou. Review of Experimental Arrangements for Soil Grouting with Cement Suspensions. Aspects Min Miner Sci. 11(3). AMMS. 000765. 2023.
DOI: 10.31031/AMMS.2023.11.000765

Introduction

The use of permeation grouting is a method of improving the properties and mechanical behavior of the soil that generally has a high cost and its choice depends on the relative cost to other alternatives. The method is based on the replacement of water (or air) in soil voids or rock mass cracks by grout injected under low pressure so as not to disturb the soil formation. It is the oldest injection method and is usually applied to soil zones of relatively small volume that are located at a great distance from the ground surface. The method is used in technical projects with the aim of: (a) controlling underground flows, (b) increasing the shear strength of the soil formation, (c) reducing deformations or subsidence and (d) filling voids [1]. From the '80s onwards, a shift in technological development was observed in the direction of limiting the use of chemical solutions and the development of new non-toxic materials composed of inorganic components and less burdensome on the natural environment [2]. However, the already costly microfine cements are supplied from limited locations throughout the world, so shipping to the job site and currency exchange rate must be included in the cost. As a result, the price of microfine cements in the U.S.A. is roughly 10 times higher than that of ordinary Portland cement. The increase of availability with the development of new, cost-effective materials of this type would be a solution to this problem.

The assessment of relevance has been and continues to be the subject of thorough research. Most research efforts have focused on conducting laboratory tests to simulate the injection process in the field [3-6]. Based on laboratory and field observations, general criteria and empirical relationships have been formulated, and in recent years efforts to investigate injectability using numerical and analytical methods have been underway. The study of the literature revealed that the methods predominantly used for the assessment of injectability involve one-dimensional injections using long and short length laboratory columns. Devices involving matrices are also used, and methods have been developed for the manual preparation of specimens and injections in three dimensions or large-scale injections. The following are some details primarily related to the devices that have been used from time to time to perform impregnation injections.

One-Dimensional Impregnation Injections in Long Columns

In general, one-dimensional impregnation injections in long columns are defined as injections made in soil columns having a length/diameter ratio ≥10 and allowing the preparation of more than one specimen. This category also includes those experimental devices that follow the guidelines of the French standard NF P 18-891, now incorporated in the European standard EN-12715. They are the most popular of the methods for preparing impregnated soil samples and the reasons for this are the relatively good simulation of the conditions prevailing in real impregnation injections, the obtaining of results relating to the injectability of the suspensions, the preparation of a sufficient number of impregnated soil samples, the possibility of studying the phenomenon of filtration of the suspension, the examination of the effect of the distance from the impregnation point on the effectiveness of the injections [7] and reducing the effect of lateral flows due to the relatively large cross-section [8]. Research efforts that have relied on such experimental setups to determine the effectiveness of cement suspension impregnation injections are those of Krizek et al. [9-11].

Injection devices of this type were first used for research purposes in the ’80s [12,13] and to date there have been modifications focusing on the length (from 46cm to 200cm) and diameter (4cm to 10cm) of the impregnation column, the method of application and the value of the impregnation pressure, the way the soil is compacted and the possibility of monitoring and controlling the process (e.g. use of pressure sensors in the column, pressure gauges in the flow lines, etc.). Briefly, the injection process consists of the penetration of a quantity of suspension into the soil column - with a bottom-up flow direction - and is completed when one of the following two events occurs (a) collection of a specific quantity of suspension from the column outlet (The literature review shows that this quantity is usually chosen to be equal to 2V or 1. 2V, where V is the volume of soil voids in the column) or (b) when the impregnation pressure at the pump approaches a selected maximum value (usually this value is chosen to be equal to 0.7MPa or 1.0MPa).

Generally, the sand column is in a saturated or dry condition prior to injection, and the suspension is placed in a suitable container at the time of injection where it is under continuous agitation to avoid precipitation of solids. After maturation of the impregnated columns, the test specimens are produced either by cutting or dividing them.

Conclusion

a. The improvement of properties and the mechanical behavior of soil formations can be achieved on the spot by performing an appropriate injection program. The injection program may: (a) be performed as a part of the preliminary field work prior to the commencement of a project’s construction, (b) be a part of the construction of the main project, or (c) be designed and executed as a “treatment” when unforeseen circumstances arise during the construction of a project.

b. Injections are generally intended either to increase the shear strength, density and stiffness of the soil or to reduce compressibility and permeability.

c. The grouts used to make permeation injections are mainly suspensions and chemical solutions.

d. Methods predominantly used for the assessment of entericity involve one-dimensional injections using long and short length laboratory columns. Devices involving matrices are also used, and methods have been developed for the manual preparation of specimens and injections in three dimensions or large-scale injections.

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