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Research Article

Review of Analytical Methods for Evaluating the Injectability and Penetrability of Cement Suspensions in Soil Formations

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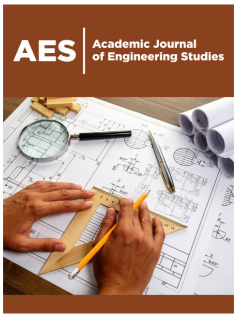

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Abstract

By the term improvement or reinforcement of a material, we mean the treatment of this material aimed at improving its geotechnical properties (strength, corrosion, permeability, compressibility, porosity, physical characteristics, mechanical properties, etc.). The basic strategy of all these techniques is to find the most suitable, effective and economical method to improve the soil so that its mechanical properties become similar to those of soft rocks, increasing the safety of geotechnical works. Improvement of the properties and mechanical behavior of soils can be carried out in-situ by carrying out an appropriate injection program. There are several criteria by which injection methods can be classified and they relate to the type of injection, the application cases, the cannula of injection sites and the sequence of manufacturing steps. Significant research efforts aimed at predicting injectability have been made in recent years using analytical and numerical methods to approximate the phenomenon. The aim is to simulate the injection process and to develop equations governing the process.

Keywords: Permeation grouting; Cement suspension; Simulation models; Diffusion; Dispersion; Filtration

Introduction to Injections

Improving the properties and mechanical behavior of soils can be achieved in situ by carrying out an appropriate injection program. Injection is defined as the process of injecting, under pressure, a fluid material to the required depth from the soil surface. The injection material, which is either a suspension of solid granules in water or a solution of chemicals, displaces the water in the soil pores and coagulates or solidifies within a short period of time. Injections are generally used either to increase the shear strength, density and stiffness of the soil or to reduce its compressibility and permeability. An appropriate injection program may (a) be performed as part of preliminary field work prior to the start of construction of a project, (b) be part of the construction of the main project, or (c) be designed and performed as a “cure” when unforeseen conditions occur during construction of a project. Many researchers have been experimentally involved in assessing the injectability of cement suspensions in order to improve the mechanical properties of soil formations [1-8].

Permeation Grouting

The use of permeation grouting is a method of improving the properties and mechanical behavior of soil that is generally costly and its selection depends on its relative cost to other alternatives. The method is based on the replacement of water (or air) in soil voids or rock mass cracks by a grout injected under low pressure to avoid disturbing the soil formation. It is the oldest method of injection and is usually applied to soil zones of relatively small volume located at a great distance from the ground surface. The method is used in engineering works to: Control subsurface flows, increase the shear strength of the soil formation, reduce deformation or subsidence and fill voids [2].

Methods for Assessing Injectability and Penetrability

The assessment of injectability continues to be the subject of thorough research, as no method has been adopted to date that ensures its reliable determination. Most research efforts have focused on conducting laboratory tests to simulate the injection process in the field. Based on laboratory and field observations, general criteria and empirical relationships for preliminary estimation of the injection result have been formulated, which take into account the relationship between the size of the voids in a soil formation and the grain size of the suspension. In recent years, efforts have been underway to investigate injectability and by developing models.

Development of Phenomenon Simulation Models

Significant research efforts aimed at predicting injectability have been made in recent years using analytical and numerical methods to approximate the phenomenon. The aim is to simulate the injection process and to develop equations governing the process. Bouchelaghem [9] presented a model that allows the simulation of the injection process with cement suspensions in porous media. The flow of cement suspension granules was simulated using a stochastic process, while the porous medium was simulated using network models. The drawback of this investigation, according to Saada [3], is that the results obtained from the simulation were not compared and therefore not verified by experimental findings. Another attempt to model the process of cement suspension injection into rock fractures was made by Eriksson et al. [10], who used network models. The grouts investigated exhibited rheological characteristics of Bingham-type fluids. The researchers proposed two characteristic parameters: $b_{critical}$ and b_{min}. They argue that when the crack width is larger than the value of the $b_{critical}$ parameter, then it is considered that no filtration effect takes place, while when the crack width is smaller than the value of the b_{min} parameter, then the grout cannot penetrate. The filtering effect occurs, according to the researchers, when the crack width is between $b_{critical}$ and b_{min} and is simulated by equations describing the flow of the suspension within the cavities, provided, however, that it exhibits Bingham-type rheological behavior. The investigations were initially carried out on simple pipe networks in order to establish the validity of the assumptions and to determine the model parameters. Extending the existing knowledge, an attempt was made by several researchers [11-13] to simulate the injection process by assuming that a suspension during its flow through a saturated porous medium undergoes (a) diffusion, (b) dispersion and (c) filtration. According to the researchers, the suspension undergoes (a) diffusion when mixed with the amount of water used to saturate the soil, (b) dispersion due to its percolation within the soil voids, and (c) filtration due to the retention of its solids at the contact points between the soil grains. For each of these three processes an attempt was made to describe them mathematically, using appropriate constitutive laws governing them (Fick's law for diffusion, use of the hydrodynamic operator for dispersion and a generalized form of the Kozeny-Carman relation to determine filtration). The finite element method was used to describe the boundary conditions governing the porous medium. The result of the above procedures was the development of a model through which the concentration of solids within the porous medium can be calculated as a function of distance and the suspension pressure along the column during injection. Later, Saada et al. [14] showed that the processes of diffusion and dispersion do not interfere as significantly as filtering in the injection process, simplifying the problem. The theoretical results obtained from the efforts of the aforementioned researchers are in very good agreement with experimental results obtained by performing laboratory injections. A theoretical model to simulate the movement of cement suspensions in saturated porous media is proposed by Chupin et al. [15].

More specifically, the proposed model is based on Bear's transport equation and simulates the movement of suspension within a column of saturated sand. With this model, the evolution in space and time of the grout concentration and applied pressure during impregnation can be predicted. It is based on the formulation of the pressure and transport equation. The discretization of the problem was performed using finite differences. The final formulation of the problem leads to a nonlinear system of equations with which an attempt is made to simulate the dependence between the fluid properties and the spray concentration. In order to assess the reliability of the model, laboratory injection tests were carried out on sand columns 0.75m long and 0.08m in diameter, which were filled with Loire sand. The object of the experimental investigation was to determine the concentration and pressure of the suspension within the soil pores during impregnation. It turned out that the pressure evolution, as estimated by the model of Chupin et al. [15], is in very good agreement with the experimental results.

Discussion

Based on the available literature, the following conclusions can be advanced:

a. The use of permeation grouting is a method of improving the properties and mechanical behavior of soil that is generally costly and its selection depends on its relative cost to other alternatives.

b. A suspension during its flow through a saturated porous medium undergoes (a) diffusion, (b) dispersion and (c) filtration.

c. The suspension undergoes (a) diffusion when mixed with the amount of water used to saturate the soil, (b) dispersion due to its percolation within the soil voids, and (c) filtration due to the retention of its solids at the contact points between the soil grains.

d. The concentration of solids within the porous medium can be calculated as a function of distance and the suspension pressure along the column during injection.

e. The processes of diffusion and dispersion do not interfere as significantly as filtering in the injection process.

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