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Soil Improvement with Cement Mortars and Different Water-to-Cement Ratios

Christodoulou Dimitrios[1]* and Tsiatsiava Foteini[2]

[1]Assistant Professor, Department of Environmental Sciences, University of Thessaly, Greece

[2]Environmental Engineer, Wastewater Treatment Plant Manager, Hellenic Dairies SA, Greece

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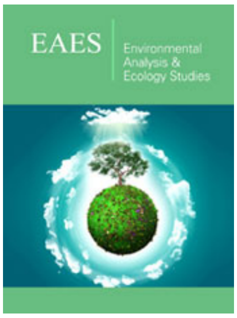

***Corresponding author:** Christodoulou Dimitrios, Assistant Professor, Department of Environmental Sciences, University of Thessaly, Greece

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Abstract

Improvement of the properties and mechanical behavior of soils can be carried out 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 ground surface. The injection material, which is either a suspension of solid granules in water or a solution of chemicals, displaces soil pore water and sets or solidifies in a short time. Injections are generally aimed either at increasing the shear strength, density and stiffness of the soil or at reducing compressibility and permeability. In this work, the effect of the water-to-cement ratio on the permeability of cement suspensions is highlighted in order to improve and strengthen soil formations.

Keywords: Permeation grouting; Cement suspension; Water-to-cement ratio; Thin grout; Dense grout

Introduction to Injections

Improvement of the properties and mechanical behavior of soils can be carried out 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 ground surface. The injection material, which is either a suspension of solid granules in water or a solution of chemicals, displaces soil pore water and sets or solidifies in a short time. 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. Injections are generally aimed either at increasing the shear strength, density and stiffness of the soil or at reducing compressibility and permeability. A suitable injection program may (a) be carried out as part of preliminary fieldwork before the start of construction of a project, (b) be part of the construction of the main project, or (c) be designed and carried out as a "remedial treatment" when unforeseen circumstances occur during the construction of a project. The selection of the optimal suspension for the needs of a technical project must be the subject of thorough investigation and documentation and is primarily determined by its properties always combined with the specialized requirements of each application [1-7]. The criteria, which advocate or not in the selection of an optimal suspension, are related to penetration, setting times, strength, stability, rheological properties, permeability, permanence, shrinkage, etc. Determining and documenting the properties of the suspensions is the first approach to choosing the best solution. However, the final choice presupposes the investigation of further influencing parameters such as reasons of economy and particular requirements of each technical project.

Categories of Injections

There are many criteria by which injection methods can be classified and relate to the type of injection, the application cases, the cannabis of the injection sites and the sequence of manufacturing steps.

The categories of injections, as defined by the European standards EN12715:2000 and EN12716:2000, are the following:

A. Permeation grouting,

B. Compensation grouting and

C. Jet grouting.

Permeation grouting

The use of impregnation injections 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: controlling underground flows, increasing the shear strength of the soil formation, reducing deformations or subsidence and filling voids [1].

Compensation grouting

They are divided into two separate categories: (a) Compaction Grouting and (b) Fracturing Grouting. In compaction injections, a very thick and durable grout is pumped into loose soils forming "bulbs" of grout that move and compact the surrounding soil, without penetrating the soil voids. The development of compaction grouting began in the mid 30's, but its systematic use began in the late '60's. It is applied only to certain types of soils and is based on the creation of a "bulb" of injection material that increases in volume as it is injected in the ground new injection material under high pressure. The injection material has a high viscosity and works like a three-dimensional "jack" displacing the soil grains with the final result of its compaction. They are mainly used in technical sedimentation restoration projects and/or for the purpose of strengthening the ground adjacent to tunnel excavations. In fracturing grouting, high-density, low-viscosity grout is pumped into the soil formation causing it to rupture and eventually move from its original location. Because of the rupture they cause, they are also characterized as uncontrolled injections. Fracture Injections are only used for sediment restoration [2].

Jet grouting

High pressure jet injection has been used in Japan since about 1970. They first appeared in Europe in the '80s and have recently begun to gain recognition as technically acceptable solutions in the U.S.A. and elsewhere. This is a technique that uses special drill heads equipped with nozzles that shoot water and injection material at high speed under high pressure. Water, in principle, erodes the soil material and then mixes with injection material. Thus, a new material (mixture of soil and injection material) is created that has the desired properties. Depending on the materials and equipment used, the following techniques are distinguished:

a. Single fluid system

b. Dual fluid-air system

c. Dual fluid-water system and

d. Triple fluid system.

Suspension Grouts

They are mixtures of water and solids with a grain size greater than 0.1μm. They are the most economical solution compared to the grouts mentioned in the other categories and can be used to reduce permeability and increase the strength of soil formations. The viscosity of the suspensions increases dramatically during curing and it takes a few hours to a few days for them to reach a satisfactory strength. In general, they exhibit Bingham-type rheological behavior. Grouts of this type are clay and bentonite suspensions, bentonite-cement mixtures, pozzolans-cement, pure Portland cement and fine-grained cements. Suspension-type grouts can even be soil-water mixtures. These grouts are the most economical solution, but at the same time they show many and important disadvantages such as the inability to rest strength and the difficulty of penetration. The most popular slurry grouts are cement-based, which have common Portland cement and water as their main ingredients. Depending on the needs of each application (high initial strength, resistance to chemical environment) it is possible to use different types of cement (aluminous, slag, etc.) instead of common cement. In addition, it is possible to add certain solids (sand, clay) to the grouts with the main aim of reducing the cost of the injections, while using admixtures such as fly ash, slag and silica fume and adding chemical improvers (super fluidizers, water reducers, coagulation accelerators etc.) aims to improve some properties [3-9].

Water-to-Cement Ratio as a Factor Influencing the Penetration of Cement Grouts

The most important variable affecting the suspension properties is the Water-to-Cement (W/C) ratio, as it determines the rate of exudation, the upcoming plasticity, fluidity, durability and final strength of the grout. Excess water causes settlement, low strength, increased shrinkage and low durability [10]. The water-to-cement ratio is expressed either by weight or by volume. In practice, for convenience, the ratio by volume to the apparent volume of cement is used [11]. In the literature, the water-to-cement ratio is mainly expressed as the weight ratio of water to dry cement. Deere [12], presented a conversion table of the W/C ratio from volume to weight ratios and vice versa using as a basis of calculation the apparent weight of cement which is calculated equal to 1.5gr/cm^3. Based on this table a suspension with a W/C ratio of 6:1 by volume has a W/C ratio of 4:1 by weight. In the following, where a value of the ratio of water to cement (W/C) is mentioned, this is expressed in proportions by weight.

The water-to-cement ratio has been and continues to be the subject of extensive research due to its importance in the design of suspensions [3-9]. In the scientific community, two main trends have been formed regarding the selection of the optimal W/C ratio for cementing. One trend supports the selection of thin (or unstable) suspensions and the second view favors the selection of dense (or stable) suspensions. Proponents of the first trend highlight as an advantage of a thin suspension the possibility of greater penetration due to its low viscosity and low consistency. They believe that with appropriate pressures and available time they can more satisfactorily fill small cracks or soil pores compared to dense suspensions [13]. The counterargument of those who applaud the use of dense suspensions concerns the advantages they present over thin suspensions. These include: satisfactory filling of soil voids, high mechanical strength, less shrinkage, resistance to chemical attack and the possibility of more accurate prediction of their application [14]. In addition, the possibility of adding chemical improvers, which can impart low viscosity and consistency to thick suspensions, is highlighted.

In international practice, there is no discernible boundary separating slurries into thin and dense based on the water-to-cement ratio. Only some guidelines are given which recommend the use of suspensions with W/C ratios of 2:1 and denser [12]. Summarizing the literature data, it can be said that dense suspensions include those with W/C ratios lower than 1.5:1, while thin suspensions include those with W/C ratios greater than 4:1. This trend is supported by the proposal of Bremen [15], who suggests the use of W/C ratios between 0.6:1 and 0.9:1 for common cements, while he sets the W/C ratio 1.6:1 as the stability limit of fine-grained cement suspensions. As far as the international practice of performing injections in the field is concerned, two application trends have also been formed. The first trend highlights the use, initially, of a base dilute suspension and its gradual thickening with suspensions that eventually reach a W/C ratio even equal to 1:1 or even thicker [12,13]. The second trend speaks of the use of an initial base suspension, which depends on the application at hand, and maintaining it until the end of the injection with the addition, if necessary, of some improvers during the execution of the injection [14].

Discussion

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

A. The most important variable affecting the suspension properties is the water-to-cement ratio, as it determines the rate of exudation, the upcoming plasticity, fluidity, durability and final strength of the grout.

B. In the scientific community, two main trends have been formed regarding the selection of the optimal W/C ratio for cementing. One trend supports the selection of thin (or unstable) suspensions and the second view favors the selection of dense (or stable) suspensions.

C. In international practice, there is no discernible boundary separating slurries into thin and dense based on the water-to-cement ratio. Only some guidelines are given which recommend the use of suspensions with W/C ratios of 2:1 and denser.

D. Summarizing the literature data, it can be said that dense suspensions include those with W/C ratios lower than 1.5:1, while thin suspensions include those with W/C ratios greater than 4:1.

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