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The Effect of Cement Type and Granulometry on the Injectability of Suspension Grouts for Soil Improvement – A Mini Review

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Abstract

The safe construction and operation of many engineering projects often requires the improvement of the properties and mechanical behavior of the soil formations occurring in their area. Impregnation injections are one of the oldest methods of improving soil formations and present a wide range of applications. The injectability and penetrability of cement-based slurries are significantly affected by factors such as cement granulometry, water-to-cement ratio, grain size and degree of sand compaction, type and dosage of slurry admixtures, mixing process and the impregnation pressure. The object of this paper is to investigate the effect of cement suspensions type and granulometry on the injectability and penetrability within soil formations.

Keywords: Permeation grouting; Suspensions; Cement; Grain size; Injectability

Introduction

The design related on the shear behavior of a soil material is of particular interest because it has a direct impact on practical problems of bearing capacity [1,2], stability of slopes and embankments [3-5] as well as permanent seismic movements of slopes [6-8]. The safe construction and operation of many technical projects often requires the improvement of the properties and mechanical behavior of the soil formations that appear in their area. Various methods are used to improve the soils, such as: the lowering of the well horizon, the vibrational condensation, the dynamic condensation, the preloading and the injections. The category of injections includes:

a) permeation grouting

b) compensation grouting

c) condensation injections

d) high pressure vein injections

In general, permeation grouting aim at increasing the shear strength, the density and the stiffness, along with a reduction of the compressibility and the soil permeability. The grouts used to perform permeation groutings, based on their composition, can be divided into:

a) Suspensions

b) Solutions

c) Emulsions

d) Foams

In the category of suspensions belong these of clay and bentonite, the mixtures of bentonite-cement, pozzolanic-cement, Portland cement and fine-grained cements. Typical representatives of chemical solutions are sodium silicate, amino plastics, phenoplastics, acrylics and acrylamides. The most popular emulsions are asphalt, a combination of asphalt - soap - casein in water, and asphalt with a suitable filler such as clay in water, which have been applied to soil stabilization and waterproofing problems. Foams include cement or clay-cement suspensions that can undergo a physical or chemical modification that creates air bubbles within them.

Practically, the distinction has prevailed in the following types of grouts:

a) Cement grouts

b) Fine cement grouts

c) Fuel solutions

d) Resins

Cement suspensions are low cost and environmentally friendly, but have a limited scope which reaches up to the coarse sands. On the contrary, chemical solutions can penetrate fine-grained sands or coarse-grained sludges, but they are more expensive and some of them are considered harmful to the environment and humans. With the aim of replacing these chemical solutions with suspensions that are harmless to the environment, but also equally effective in terms of their penetration into soil formations, efforts have been made to develop new suspension-type materials based on fine-grained cements.

Injections in General

Injection is defined as the transmission process of a fluid material under pressure, 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 from the soil pores and coagulates or solidifies in a short time. Injections are generally intended to either increase the shear strength, density and stiffness of the soil or to reduce compressibility and permeability. The categories of injections as defined by European standards EN12715: 2000 and EN12716: 2000 are as follows:

a) Permeation Grouting

b) Compensation Grouting

c) Jet Grouting

The use of permeation grouting is a method of improving the properties and mechanical behavior of the soil. The method is generally expensive, and its choice depends on the relative cost with respect to other alternative solutions. It is based on the replacement of water (or air) of soil voids or rock mass cracks by a grout, that is pressed under low pressure, so as not to disturb the soil formation. It is the oldest method of injection and is usually applied to relatively small areas of soil that are far from the soil surface. The method is used in technical projects, aiming at controlling underground flows, increasing the shear strength of soil formation, reducing deformation or subsidence and filling gaps [9].

Injectability and Penetrability of Cement Suspensions

The term "Injectability" describes the ability of a specific suspension to impregnate a specific soil under a specified impregnation pressure. The term "Penetrability" describes the maximum length from the injection point that a specific suspension can penetrate into a specific sandy soil under a specified maximum infiltration pressure [10]. From their definition, these parameters seem to be decisive for the assessment of the feasibility of impregnation injections, the choice of the appropriate grout and, therefore, the economics of the injection program. Due to their great importance, these parameters have been the subject of a thorough investigation aimed at their quantification.

Cement Type as a Factor Influencing the Injectability of Suspensions Grouts

The type of cement is considered to be an important parameter to investigate in terms of its effect on the injectability and penetrability of cement-based slurries. Fine-grained cements are based on common Portland cements, blast furnace slag or a combination of Portland cement and pozzolan. The differentiation lies mainly in the chemical composition of the products, which also affects the effectiveness of the injection. In general, it is considered that the use of fine-grained cements based on pure Portland cement makes it difficult to inject the suspensions, since these are more reactive materials than slag cements and form aggregates faster [11-13]. Similar conclusions were reached by Warner [14], who found that slurries based on slag fine-grained cements showed better injectability behavior compared to pure Portland fine-grained cements. He even points out that the results of these tests agree with previous research projects around the world, in which the author himself participated.

Cement Particle Size as a Factor Influencing the Injectability of Suspensions Grouts

Cement is one of the most important factors affecting injectability and penetrability. It has been proven that these sizes improve when: the sizes of the cement grains are reduced, the grain size grading is improved and its specific surface area is increased. However, due to the fact that cement is characterized by many influencing parameters, it becomes difficult to isolate each of them and estimate the effect it exerts individually on injectability and penetrability. It is accepted in the international literature that injectability and penetrability of cement-based slurries improve as cement grain sizes decrease. This finding was the subject of extensive research with the aim of preparing fine-grained cements, the suspensions of which will have the ability to penetrate medium to fine sands. Several researchers focused their interest in investigating the properties of fine-grained cements and carried out laboratory impregnations using only some of these available fine-grained cements [15-17].

An important research effort to assess the effect of cement fineness and grain size on injectability was made by Perret et al. [18], who compared suspensions of a fine-grained and common type III cement at water-to-cement ratios of 0.5:1, 0.6:1, 1.2:1 and 2:1. The sand impregnated was fine Ottawa sand. The granulometric gradation of available cements is shown in figure 1.

From the penetration tests carried out, it was observed that the fine cement suspensions penetrated the test sand completely and with great ease. Grouts based on common cement and water-to-cement (W/C) ratios of 1.2:1 and 2:1 also impregnated the sand column at a very slow rate, however. This conclusion also follows from table 1 below.

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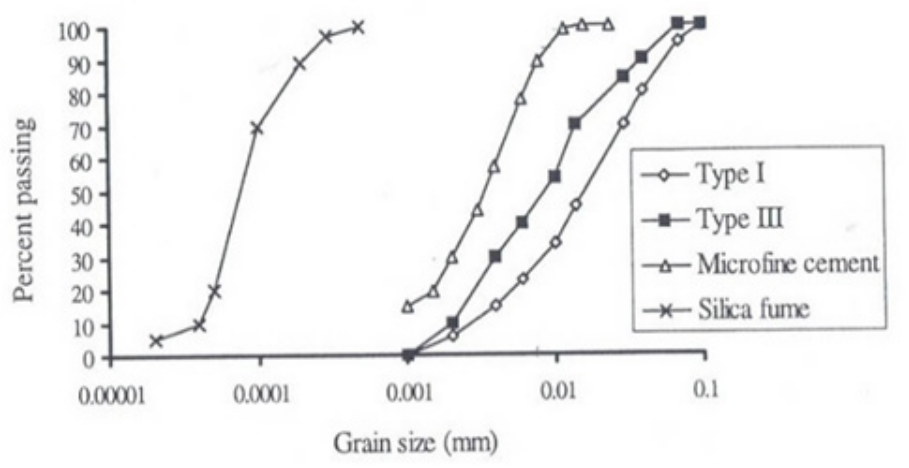

Figure 1: Grain size of available cements [18].

Table 1: Injections results for the two types of cement [18].

Cement	W/C Ratio	Penetration Length (cm)	% of Total Length	Time (s)
Fine grained	2:01	37	100	22
Fine grained	1.2:1	37	100	69
Type III	2:01	37	100	210
Type III	1.2:1	37	100	320
Fine grained	0.6:1	20	54	(36)*
Fine grained	0.5:1	5	14	(2)
Type III	0.5:1	5	14	(20)

( )*: time necessary for the suspension to saturate the column to the height given.

Mollamahmutoglu [19] investigates the relationship between cement grain size and injectability by injecting suspensions of an ordinary Portland cement (OPC) and a fine Portland cement (Microcem H900). The grain sizes of fine cement range from 2-40mm, while 80% of common grains range from 10mm to 100mm. The sand used is listed as coarse - medium and the water-to-cement ratio was 1.2:1. From the test results, it was found that the Microcem H900 slurries completely impregnated the sand at a pressure of 80 kPa in contrast to the joint Portland cement grouts, which did not penetrate the test sand. The penetration length reached 1/5 of the column height even when a pressure of 250kPa was applied.

The importance of the effect that cement grain size has on injectability is also pointed out by Tamura et al. [20], who performed field injections using three different cements: a fine grain, a colloid, and a common Portland cement. The grain sizes of the three cements are shown in table 2. The impregnated soil was a layer of fine Narita sand.

Table 2: Characteristic grain sizes of the three cements [20].

Cement Type	D_{50} (μm)	D_{95} (μm)	Specific Density
Fine-grained	4	8	2.95
Colloidal	11	30	2.96
Common Portland	18	60	3.16

From the injection results, it emerged that the suspensions of the joint and the colloidal cement did not penetrate the sand layer. Penetration into the sand layer was achieved only with fine cement slurry and a water-to-cement ratio of 0.8.

Discussion and Conclusions

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:

i. be performed as a part of the preliminary field work prior to the commencement of a project's construction.

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ii. be a part of the construction of the main project.

iii. 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) Cement is undoubtedly one of the most important factors affecting injectability and penetrability. It has been proven that these sizes improve when: the sizes of the cement grains are reduced, the grain size grading is improved and its specific surface area is increased. However, due to the fact that each cement displays many characteristics that may affect the injectability of a suspension, it becomes difficult both to isolate each of them and to assess their individual effect on injectability and permeability.

d) The use of fine-grained cements based on pure Portland cement makes it difficult to inject the suspensions, since these are more reactive materials than slag cements and form aggregates faster.

e) Injectability is improved by reducing the size of the cement grains.

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