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Mini Review

Predictive Effectiveness Investigation of "Grout Ability Ratios" for Soil Improvement Using Cement Suspensions - A 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 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. The object of this paper is to assess the possibility of impregnation injections based on acceptable "Grout ability Ratios".

Keywords: Permeation grouting; Cement suspension; Soil improvement; Grout ability ratios; Effectiveness

Introduction

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. 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. Impregnation injections are one of the oldest methods of improving soil formations and present a wide range of applications. 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. The preliminary investigation of the injectability of cement suspensions by applying empirical relations has been the subject of study by several research groups [1-6].

Empirical relationships

The size relationship between the voids of a soil formation and the grain of the suspension largely determines the radius of penetration of the suspension into the soil and consequently the applicability of the method. Based on laboratory and on-site observations, general criteria based on the characteristic grain sizes of soil and suspension have been formulated. For the easy and quick assessment of the injectability of suspensions, empirical relationships called "Grout ability ratios" have been developed. The best known of these is [7]:

$$\frac{(D_{15})soil}{(D_{85})suspension} \succ 25 \quad (1)$$

where $(D_{15})soil$ is the grain size of the soil that is greater than 15% of its total grains by weight and $(D_{85})suspension$ is the grain size of the suspension that is greater than 85% of its total grains by weight. When this criterion is met, the suspension is considered to be able to penetrate the specific soil. A different form of criterion (1) is [8]:

$$\frac{(D_{15})soil}{(D_{85})suspension} \succ 20 \quad (2)$$

$$\frac{(D_{15})soil}{(D_{85})suspension} \geq 50 \quad (3)$$

The satisfaction of the criterion (2) is the minimum condition for injectability, while in order to have a satisfactory penetration length the criterion (3) must be verified. The following criteria also follow the same philosophy [9]:

$$\frac{(D_{15})soil}{(D_{85})suspension} \succ 24 \quad (4)$$

$$\frac{(D_{15})soil}{(D_{85})suspension} \prec 11 \quad (5)$$

$$\frac{(D_{10})soil}{(D_{95})suspension} \succ 11 \quad (6)$$

$$\frac{(D_{10})soil}{(D_{95})suspension} \prec 6 \quad (7)$$

where $(D_{10})soil$ is the grain size of the soil that is greater than 10% of its total grains by weight and $(D_{95})suspension$ is the grain size of the suspension that is greater than 95% of its total grains by weight.

Satisfying criteria (4) and (6) means that injection is feasible, while if criteria (5) and (7) hold, injection is not possible. Furthermore, Incecik and Ceren suggest the following [10]:

$$\frac{(D_{10})soil}{(D_{90})suspension} \succ 10 \quad (8)$$

$$\frac{(D_{m})soil}{(D_{90})suspension} \succ 3 \quad (9)$$

where $(D_m)soil$ corresponds to the mean grain size of the soil and $(D_{90})suspension$ is the grain size of the suspension that is larger than 85% of its total grains by weight. Verification of inequalities (8) and (9) reveals that the injection is strong.

Although grout ability ratios are an important approach to assess injectability, many researchers today question their adequacy [10-13]. Their disadvantage lies in the fact that they are based exclusively on characteristic sizes of suspension and soil grains and do not consider all those factors that affect injectability (water-to-cement ratio, additives - chemical property improvers, particle size composition and sand density).

It is obvious that adopting these criteria focuses the determination of injectability entirely on the geometrical characteristics of the soil and suspension, which later research has shown to be not entirely accurate. It is accepted that thin slurries show improved penetrability compared to dense slurries, which proves that the water-to-cement ratio has a significant effect on this characteristic of slurries [13-15]. However, this improvement is not directly attributable to the water-to-cement ratio, but to the reduction in viscosity due to the excess water in the slurry [13]. Indeed, dilute suspensions have been shown to be susceptible to the phenomenon of filtration under the influence of high impregnation pressures, which brought to light the indirect effect of impregnation pressure on injectability [13,16,17]. It was also observed that a better improvement in injectability is achieved when the fine-grained cements are slag - instead of pure Portland - because they are less active, show higher setting times and their grains do not form aggregates as easily and quickly during the injection process [18,19]. Fine-grained cement suspensions show a higher viscosity, but research has shown that the use of superplasticizers achieves a satisfactory viscosity reduction and therefore a significant improvement in injectability [20,21]. The conclusion drawn from the data obtained to date is that the injectability and penetrability of suspensions must be tested experimentally and the "Grout ability ratios" should only be used for preliminary estimates of injectability.

A new approach to predict injectability and penetrability was carried out by Akbulut S and Saglamer A [10]. The result of this investigation was the formulation of an empirical relationship, which was based on laboratory findings. The proposed empirical relationship is as follows:

$$N = \frac{(D_{10})soil}{(D_{90})suspension} + k_1 \frac{w/c}{FC} + k_2 \frac{P}{D_r} \quad (10)$$

where N is the injectability, W/C is the water-to-cement ratio, FC is the percentage of soil that passes the #30 ASTM sieve, with an opening of 0.6 mm, P is the impregnation pressure in kP_a, Dr is the relative density of the soil and k_1, k_2 constants based on laboratory observations and taking the values: k_1=0.5 and k_2=0.01 ($1/kP_a$) respectively.

The value 28 has been taken as the injectability limit for this relationship. For N>28 the soil can be satisfactorily impregnated by cement suspensions, while for N<28 it cannot be impregnated. The equation can be used as long as the following conditions are met 0%<FC<6%, 0.8<w/c<2 and 50<P<200. If FC>0.6% applies, the soil cannot be saturated satisfactorily. If the water-to-cement ratio is less than 0.8:1, satisfactory soil impregnation is not possible, even if the impregnation pressure is increased above 200 kP_a. On the contrary, in cases where the ratio of water to cement of the suspension is greater than 2:1, the injectability N can be greater than 28 (satisfactory injectability), although the suspension undergoes filtration (so not satisfactory penetration) especially in cases where the impregnation pressure has increased significantly. Also, even if the impregnation pressure and water-to-cement ratio of a grout are increased, it does not follow that it will penetrate the soil as long as the fines content is greater than 6%.

Finally, Saada Z, et al. [22] reports an injectability criterion proposed by Bortal-Nafaa (2002) which includes a characteristic grain size of the suspension cement, a characteristic grain size of the soil formation and the void index of the soil. This criterion is given by the relation:

$$d_{95}\left(cement\right) \leq \frac{1}{1.55}\cdot\left(1.18\cdot e^{2}-1.13\cdot e+0.43\right)\cdot D_{15}\left(soil\right) \qquad (11)$$

Discussion

Based on the available literature, the following conclusions can be advanced: The predictions of the "Grout ability ratios" which consider the characteristic grain size, d_{15}, of the soil and the characteristic grain size, d_{85}, of the slurry cement are considered satisfactory in general. In contrast, the predictions of the "Grout ability ratios" that consider the characteristic grain size, d_{10}, of the soil and the characteristic grain size, d_{95}, of the slurry cement, deviate significantly from the experimental results.

The disadvantages presented by the "Grout ability ratios" are attributed to the fact that they only relate specific granulometric characteristics of the soil formation and the cement that forms the basis for the preparation of the suspensions. The inability to correctly predict can be attributed to the fact that they do not consider factors that significantly affect injectability, such as the apparent viscosity of the suspensions as well as the grain size composition and relative density of the sand.

The empirical injectability prediction relationship of Akbulut and Saglamer [10] offers more satisfactory results compared to the classical "Groutability ratios", which is attributed to the fact that it considers the ratio of water to cement of the suspension and the impregnation pressure, with which the injection. However, this relationship has the disadvantage that it overestimates the injectability of suspensions when they penetrate medium to fine sands.

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Conflict of Interest

No conflict of interest.

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