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Short Communication

Investigation of the Penetrability of CEM II/B-M Based Microfine Cement Grouts in Composite Sands with Different Gradation

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Abstract

Grouting is a common technical method with many applications, e.g. it is used for soil stabilization and strengthening, for reduction for water ingress to underground facilities or of the water loss through a dam foundation, etc. Grouts comprise several constituents, which are combined in many ways depending on the in-situ conditions and the outcome desired. The use of very fine cement grouts for injections into fine-to-medium sands has been proposed to circumvent problems associated with the permanence and toxicity of chemical grouts and the inability of ordinary cement grouts to permeate soil formations finer than coarse sand. A laboratory investigation was conducted in order to evaluate the penetrability of cement suspensions. Two gradations from CEM II/B-M (according to EN 197-1) type of cement were used having nominal maximum grain sizes of 100μm and 10μm. Suspension properties with water-to-cement (W/C) ratio of 2:1 by weight, were determined in terms of apparent viscosity. The experimental results reported in the present paper suggest some trend in the effect of gradation on grout penetrability, however, rather the regulatory factor is the increase in the percentage of fine components in the final composition of the mixture

Keywords: Permeation grouting; Suspensions; Microfine cements; Sand gradation

Introduction

The construction of underground structures on soft ground often requires the soil to be improved in order to ensure the safety and the stability of surrounding buildings. The improvement of the properties and mechanical behavior of the soil formations is of particular interest because it has a direct impact on bearing capacity problems [1,2], stability of slopes and embankments [3] as well as permanent seismic movements of slopes [4]. Permeation grouting is commonly used in geotechnical engineering either to reduce the permeability or improve the mechanical properties of soil and rock [5]. Success in a given grouting operation requires that the grout is capable of being injected into the soil formation and that the desired improvements in the properties of the formations are attained. Grouts are generally categorized as suspension, or particulate grouts, which are prepared with ordinary Portland or other cements, clays, or cement-clay mixtures, and fine sands in some cases, and solution, or chemical grouts which include sodium-silicate formulations, acrylamides, acrylates, lignosulfonates, phenoplasts and aminoplasts as well as other materials that have no particles in suspension. Chemical solutions can be injected in fine sands or coarse silts but some of them pose a health and environmental hazard. To improve the penetrability of cement grouts, research efforts in recent years have focused on the use of special cements composed of very fine particles, like fine and ultrafine cements [6-13].

Materials Used

For the purposes of this investigation, a cement of type CEM II/B-M, according to EN 197-1, was used. The ordinary cement (designated as F0) was pulverized in order to produce one additional cement with nominal maximum grain sizes of 10μm, which are designated as F1. Characteristic grain sizes and Blaine specific surface values for all cements are presented in Table 1.

Table 1: Cements gradations.

Grain Sizes[a] Specific Surface	Cement Type	
	F0	F1
d_{max}[b] (μm)	100	10
d_{95} (μm)	45.5	9.1
d_{90} (μm)	37.0	8.3
d_{85} (μm)	32.0	7.6
d_{50} (μm)	14.0	4.2
d_{10} (μm)	2.2	1.1
Blaine (m^2/kg)	466	942

[a]d_{95}, d_{90}, d_{85}, d_{50}, and d_{10} correspond to the particle diameter at which 95%, 90%, 85%, 50%, and 10% of the weight of the specimen is finer, respectively

[b]Nominal maximum cement grain size

All suspensions were prepared using potable water since it is considered appropriate for preparing cement-based grouts. A dosage of superplasticizer equal to 1.4% by weight of dry cement was added to F1 cement suspensions. The water-to-cement (W/C) ratio of all suspensions used, was equal to 2:1 by weight (II-F1-2). A superplasticizer at a dosage of 1.4% by weight of dry cement, was used to improve the suspension properties of the microfine cement. This fixed superplasticizer dosage was determined following a laboratory evaluation of the effect of various dosages on the apparent viscosity and the rheological characteristics of the pulverized cement suspensions [7].

Clean and uniform sands with angular grains were used as a base. Five different sand gradations were used with grain sizes limited between sieve sizes (ASTM E11) Nos. 5 and 10, 10 and 14, 14 and 25, 25 and 50, and 50 and 100, and designated as S1, S2, S3, S4 and S5, respectively. The sands were grouted in dense condition (mean value of relative density, D_r, 98±1%) and were dry prior to grouting. The values of other properties of the “base” sands are presented in Table 2.

Table 2: Sand properties.

Sand	Specific Gravity, G_s	Void Ratios		Permeability Coefficient, *k_{20} (cm/sec)
		Minimum, e_{min}	Maximum, e_{max}	
S1	2.71	0.66	1.06	2.31
S2	2.72	0.68	1.03	0.80
S3	2.72	0.69	1.07	0.22
S4	2.70	0.70	1.06	0.04
S5	2.72	0.72	1.12	0.013

The aim of this injection program was to minimize the effect of grain size as much as possible and to examine the effect of soil gradation. For this reason, soils were created with common “boundaries” in terms of grain size (sands 5-50 and 5-100) composing the individual uniform sands. The differentiation of the uniformity coefficient, C_u, was achieved by changing the percentage with which each sand participated in the new composition.

Laboratory equipment

The special apparatus shown in Figure 1 was used for injecting sand columns with cement suspensions. It allows for adequate laboratory simulation of the injection process and investigation of the influence of the distance from injection point on the properties of grouted sand. The grouting column was made of thick PVC tube with an internal diameter of 7.5cm and a height of 144cm and was formed by placing at each end a 5cm thick gravel layer, between two screens of suitable aperture, and filling the remaining length (134cm) with dry sand in a dense or loose condition. The sand was saturated, when required by the testing program, by upward flow of water pumped from the grout tank. The rate of discharge of the pump was regulated to be constant and equal to 60 L/h. Injection was stopped when either the volume of the injected grout was equal to two void volumes of the sand in the column or when the injection pressure became equal to 700kPa. The grout pressure was continuously recorded during the injections, by installing one pressure sensor at the inflow pipe of the grouting column and six pressure sensors on the grouting column, at distances from the injection point equal to 4cm, 14cm, 34cm, 54cm, 83cm and 123cm, respectively. The pressure sensors (PWF-PA pressure transducers of Tokyo Sokki Kenkyujo) were placed in cyclical openings on the grouting columns using specially designed clamps and were connected to an automatic data acquisition system.

Figure 1: Laboratory equipment [6-13].

Experimental Results and Discussion

The grout ability of a suspension grout can be evaluated in terms of: (a) the ability of the grout to enter into the voids of a given soil and (b) the permeation distance that can be achieved under a predetermined maximum injection pressure. The terms "injectability" and "penetrability", respectively, were selected to describe these two conditions or criteria. Thus, the penetrability of cement grouts was the objective of the investigation reported herein. All factors relating to penetrability were evaluated experimentally by grouting sand columns with the apparatus shown in Figure 1 and the results obtained, are presented in Table 3.

Table 3: Injection results.

Sand Designation	Percentage of Participation of Sand Fractions (%)					Uniformity Coefficient, C_u	Void ratio, e	Maximum Pressure (kPa)	*Injection Result
	5-10	10-14	14-25	25-50	50-100				
5-100	20.0	20.0	20.0	20.0	20.0	6.67	0.41	>700	MP
5-25/25-100/20	26.7	26.7	26.7	10.0	10.0	5.60	0.47	>700	MP
5-25/25-100/15	28.3	28.3	28.3	7.5	7.5	4.30	0.50	>700	SP
5-25/25-100/10	30.0	30.0	30.0	5.0	5.0	2.52	0.53	60	OP
5-50	25.0	25.0	25.0	25.0	0.0	3.83	0.52	131	OP
5-25/25-50/20	26.7	26.7	26.7	20.0	0.0	3.63	0.50	583	OP
5-25/25-50/15	28.3	28.3	28.3	15.0	0.0	3.23	0.51	177	OP
5-25/25-50/10	30.0	30.0	30.0	10.0	0.0	2.51	0.55	68	OP

*MP: Marginal Penetration, SP: Satisfactory Penetration, OP: Optimal Penetration

Based on the results of the injections carried out on the composite sands 5-25 / 25-100 (Table 3), there is some escalation of the injectability, which is in line with the increase of void ratio, e, of the composite sand and the decrease of uniformity coefficient, C_u. The less uniform sands 5-100 (C_u = 6.67) and 5-25 / 25-100 / 20 (C_u = 5.60) were not injected with the suspensions, which had penetration lengths of 115.8cm and 90.2cm, respectively, application of maximum pressures exceeding the limit of 700kPa. Further escalation of the penetration with the effect of the uniformity coefficient is highlighted taking into account the experimental findings concerning the sands 5-25 / 25-100 / 15 and 5-25 / 25-100 / 10. The sand 5-25 / 25-100/10, which has the lowest coefficient of uniformity, (C_u = 2.52), was completely injected by applying a maximum pressure of 60kPa, satisfying the requirement for a suspension of volume equal to twice of the volume of voids of the soil column. Complete impregnation was also achieved for the sand column 5-25 / 25-100/15, which is less uniform (C_u = 4.30), with the difference that a maximum injection pressure greater than 700kPa was developed and no suspension volume equal to double the volume of the gaps in the soil column. The above observations indicate a trend in the effect of gradation on penetration, however, rather the regulatory factor is the increase in the percentage of sand 50-100 in the final composition of the mixture. It is found that the presence of the sand fraction 50-100 in percentages of 20% and 10% by weight of the mixture, does not allow the complete impregnation of the soil column. On the contrary, the reduction of the percentage to 7.5% by weight of the mixture contributes to the marginal penetration of the suspension, while a further reduction of the percentage to 5% by weight of the mixture makes injection possible with a low value of maximum injection pressure. Regarding the injections made in soil columns of composite sands 5-25/25-50, there was no clear escalation of the injectability and penetrability of the type CEM II/B-M cement suspensions, as the suspensions showed their optimal penetration within the soil formations, according to the above characterizations. The trend highlighted in Table 3 is the values of the maximum pressure measured during the injection procedure, which decrease with decreasing void ratio, e, indicating impregnation difficulty.

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