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Research Article

Effect of Cement Fineness on the Penetrability of CEM IV/B Based Cement Grouts

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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. Four gradations from CEM IV/B (according to EN 197-1) type of cement were used having nominal maximum grain sizes of 100 μm, 40 μm, 20 μm and 10 μm. Suspension properties with water-to-cement (W/C) ratios of 1:1, 2:1 and 3:1 by weight, were determined in terms of apparent viscosity. Penetrability was evaluated by conducting one-dimensional injections into four different, clean sands using a specially constructed device. Penetrability of cement suspensions increases with increasing cement fineness and water-to-cement (W/C) ratio. Microfine cement suspensions with water-to-cement (W/C) ratios of 2:1 and 3:1 can penetrate into medium-to-fine sands.

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 [3-5] as well as permanent seismic movements of slopes [6]. Permeation grouting is commonly used in geotechnical engineering either to reduce the permeability or improve the mechanical properties of soil and rock [7]. 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 grout, research efforts in recent years have focused on the use of special cements composed of very fine particles, like fine and ultrafine cements [8-14].

Materials and Procedures

For the purposes of this investigation, a cement of type CEM IV/B, according to EN 197-1, was used. The ordinary cement (designated as F0) was pulverized in order to produce three additional cements with nominal maximum grain sizes of 40 μm, 20 μm and 10 μm, which are designated as F1, F2 and F3, respectively. Characteristic grain sizes and Blaine specific surface values for all cements are presented in Table 1. All suspensions were prepared using potable water. The water-to-cement (W/C) ratios of all suspensions used, was equal to 1:1, 2:1 and 3:1 by weight. A dosage of superplasticizer equal to 1.4% by weight of dry cement was added to F1, F2 and F3 cement suspensions. This fixed superplasticizer dosage was determined following a laboratory evaluation of the effect of various dosages on the apparent viscosity of the pulverized cement suspensions [9]. Presented in Table 2 are the apparent viscosity values of ordinary cement suspensions without superplasticizer and microfine cement suspensions with superplasticizer, obtained at t = 30 min after preparation and at viscometer rotation speed equal to 60 rpm. The grouted soils were clean, uniform sands with angular grains. Four different sand gradations were used with grain sizes limited between sieve sizes (ASTM E11) Nos. 10 and 14, 14 and 25, 25 and 50, and 50 and 100, and designated as S1, S2, S3 and S4, respectively. The sands were grouted in dense condition (mean value of relative density, Dr, 98±1%) and were dry prior to grouting. The values of other properties of sands are presented in Table 3.

Table 1: Cements gradations. [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.

Grain Sizes[a] Specific Surface	Cement Type			
	F0	F1	F2	F3
d_{max}[b] (μm)	100	40	20	10
d_{95} (μm)	48	26	12.8	9.8
d_{90} (μm)	39.5	21.2	10.7	8.5
d_{85} (μm)	33	18.5	9.2	7.8
d_{50} (μm)	14.2	9.3	4.4	3.9
d_{10} (μm)	3.0	2.2	1.3	1.2
Blaine (m^2/kg)	452	582	715	923

Table 2: Apparent viscosity (mPa.s) of cement suspensions.

Cement Type Designation	Nominal Maximum Grain Size d_{max} (μm)	W/C ratio	Apparent Viscosity (mPa.s)
F0	100	1:1	160
		2:1	23
		3:1	10
F1	40	1:1	43
		2:1	4
		3:1	2
F2	20	1:1	51
		2:1	4
		3:1	3
F3	10	1:1	168
		2:1	9
		3:1	5

Table 3: Sand properties. *Sands in dense condition.

Sand	Specific Gravity, G_s	Void Ratios		Permeability Coefficient, $*k_{20}$ (cm/sec)
		Minimum, e_{min}	Maximum, e_{max}	
S1	2.72	0.68	1.03	0.80
S2	2.72	0.69	1.07	0.22
S3	2.70	0.7	1.06	0.04
S4	2.72	0.72	1.12	0.013

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 7.5 cm and a height of 144 cm and was formed by placing at each end a 5 cm thick gravel layer, between two screens of suitable aperture, and filling the remaining length (134 cm) 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 700 kPa. 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 4 cm, 14 cm, 34 cm, 54 cm, 83 cm and 123 cm, respectively. The pressure sensors were placed in cyclical openings on the grouting columns using specially designed clamps and were connected to an automatic data acquisition system.

Experimental Results

The groutability 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 4. Penetrability was considered as: (a) "optimal" when the entire amount of suspension penetrates the sand column with low injection pressure, (b) "satisfactory" when all or almost the entire amount of suspension penetrates the sand column with increasing injection pressure, (c) "marginal" when penetration length is greater than 60 cm with maximum injection pressure and (d) "low" when penetration length is less than 60 cm with maximum injection pressure. The effect of cement fineness on suspensions penetrability is highlighted, mainly by injections carried out in the sand fractions S2 (Nos. 14-25) and S3 (Nos. 25-50). In particular, in the sand fraction S2 (Nos. 14-25) the effect of CEM IV/B cement fineness was studied for three different granulometries (d_{max} = 100, 20 and 10 μm) and for three water-to-cement (W/C) ratios (1:1, 2:1, 3:1). Impregnation difficulty of CEM IV/B common cement suspensions in sand fraction S2 (Nos. 14-25) is obvious from the data analysis in Table 4, in contrast to the suspensions of microfine cements. Evaluating the effects of injections on S2 sand columns (Nos. 14-25) with CEM IV/B cement suspensions F0, F2 and F3, it appears that microfine cement suspensions have better injectability than the common cement suspensions. This finding is supported by the observations of Table 4, which show that the penetrability of the so-called suspension IV-F0-3 is negligible (penetration length equal to 3 cm and maximum impregnation pressure equal to 840 kPa).

Figure 1: Laboratory equipment for penetrability evaluation [8-14].

On the contrary, microfine cement suspensions (nominal maximum grain size, d_{max} =20 μm and 10 μm) penetrated completely the S2 sand columns (Nos. 14-25) for all three water-to-cement (W/C) ratios. Attempting the comparison between suspensions fineness F2 and F3 of type CEM IV/B, a relative variation is observed in terms of the maximum injection pressure, which is attenuated by the increase of the water-to-cement (W/C) ratio. Analyzing the experimental findings of Table 4 regarding the injectability of microfine cement grouts (d_{max} = 20 μm and 10 μm) in columns of S3 sand fraction (Nos. 25-50), no stable trend emerges as to whether further grinding beyond 20 μm improves penetration. Specifically, the so-called suspension IV-F2-2 penetrated the entire length of the sand column with a maximum injection pressure of 476 kPa, while the so-called suspension IV-F3-2 was able to penetrate the sand column to a length of 54,5 cm with a maximum injection pressure of 600 kPa. The finding that grinding cement to a degree greater than a certain fineness does not substantially improve the permeability of cement

Table 4: Experimental results.

Sand Fraction	Cement Type Designation	Nominal Maximum Grain Sized_{max} (μm)	W/C Ratio	Suspension Designation	Penetration Length (cm)	Maximum Injection Pressure (kPa)	Injection Result
S1	F0	100	1:1	IV-F0-1	130	800	Marginal
	F0	100	2:1	IV-F0-2	>134	<50	Optimal
	F3	10	2:1	IV-F3-2	>134	36	Optimal
S2	F2	20	1:1	IV-F2-1	>134	610	Satisfactory
	F3	10	1:1	IV-F3-1	>134	144	Optimal
	F2	20	2:1	IV-F2-2	>134	55	Optimal
	F3	10	2:1	IV-F3-2	>134	<50	Optimal
	F0	100	3:1	IV-F0-3	3	840	Low
	F2	20	3:1	IV-F2-3	>134	41	Optimal
	F3	10	3:1	IV-F3-3	>134	<50	Optimal
S3	F2	20	1:1	IV-F2-1	9	700	Low
	F2	20	2:1	IV-F2-2	>134	476	Marginal
	F3	10	2:1	IV-F3-2	54,5	600	Low
	F3	10	3:1	IV-F3-3	129	812	Marginal
S4	F3	10	3:1	IV-F3-3	26	800	Low

suspensions is confirmed by other researchers [15].

Conclusion

Based on the results obtained and the observations made during this investigation, the following conclusions may be advanced:

a. Suspension grouts prepared with very fine cement are an attractive and environmentally safer alternative to chemical grouting.
b. The increase of cement fineness improves the penetrability of cement suspensions rendering them effective for grouting of medium-to-fine sands.
c. Microfine cement suspensions with water-to-cement (W/C) ratios of 2:1 and 3:1 can be injected in medium-to-fine sands.
d. Cement grinding to a degree greater than a certain fineness, does not substantially improve suspension penetrability.

The overall problem is extremely complicated, and available information from research efforts and field experiences is sparse; furthermore, each field situation presents its own unique set of circumstances. Accordingly, the results reported herein must be utilized with full awareness of their origin, and caution is urged when attempting to generalize them to other situations not explicitly addressed.

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