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Gas permeability measurement on injected soils with cement grout

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Abstract

This paper deals with cement grout injection and its consequences in porous media from an experimental point of view. This injection with very fine cement has to reinforce the medium considered which is a sand extracted from the Loire river (in the west of France). To quantify this improvement phenomenon, measurement of the conductivity decreases after the injection operation is proposed. Injected sand columns are prepared and gas conductivity measurement is done. The aim of this paper is to show gas conductivity results and their interpretation and effects on the injected medium evolution. These demonstrate the very strong decrease between intrinsic conductivity values before and after injection. The reduction ratio is about 10^{-4}. This allows evaluation of the sample porosity reduction and then the filtration phenomenon. This is responsible for pressure and cement deposition increase in the system voids during soil injection.

Keywords: Grout injection; Gas conductivity; Intrinsic permeability; Improvement of soil; Experimental device

1. Introduction

Injection is one of the most widely used techniques of soil stabilization. Indeed, it is an inexpensive technique which can achieve several purposes: sealing, prevention and protection of the foundations as well as the improvement of the mechanical characteristics of the injected medium. This technique consists of injecting the ground under pressure with a fluid which is propagated in the medium and solidified.

The grout thus combines with the ground, thereby presenting better mechanical characteristics. The ground reinforcement process by injection has undergone an important evolution during these last years. Two aspects are studied: modeling of grout propagation and understanding of the injected soil mechanical behavior. Nevertheless, grout transport in the porous environment still remains poorly controlled because of many phenomena such as filtration [1–3]. In order to characterize the process, it is important to know how the fluid is propagated in the ground, and how the medium porosity is reduced [4]. These two parameters are the essential bases for the optimization of the technique and the success of the injection operation at a reasonable cost. In this paper, we will try to answer the second question by studying the gas permeability to have an idea of the evolution of porosity after the injection compared to the initial porosity of the sample.

To achieve this, the procedures of sand compaction in the columns which allow us to fix the desired density are first studied. Once these procedures are defined, a study of the permeability to water is made on samples of various densities. After having characterized the medium to be injected, a characterization of the grout used is also needed. This is achieved by rheological measurements which enable us to define the behavior law of the grout. The mean parameters which can be controlled by knowing the behavior law of the grout are: the setting time, the viscosity and the concentration.

The setting time is a very important parameter in the injection process. The grout has to set quickly after injection in order to be sufficiently rigid. Cements have setting times which generally range between 4 and 5 h. However, in the case of strongly diluted cements, the setting is simply delayed 10 h.

The second important parameter is the viscosity, which varies according to the cement concentration and the plasticizer (or chemical mixture) amount. Knowing the viscosity gives very good indications of the injectivity of the grout. Generally, grouts of viscosity lower than 2 mPa s can penetrate the ground without modifying its structure. Time and viscosity are strongly related for grout cements. An example of the viscosity variation according to time is given for a standard bentonite cement grout [5].

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Table 1
Procedure of sand column preparation (thickness of each layer is 10 cm)

Procedure	A	B	C	D	E
Top	No blows hammer	3	3	18	75
			3	18	
		3	4	19	
			4	19	
1m		3	5	20	
			5	20	
		3	6	21	
			6	21	
		3	7	22	
Bottom			7	22	

The ratio between the first and the last viscosity value can be about 2 (in Marsh units); between 16 and 30 h.

The third parameter is the concentration. Grout viscosity is also a function of the different component concentrations. The water-to-cement ratio (W/C) remains, however, the basic variable which influences its properties. Other authors (Einstein [6], Guth [7] and Brinkman [8]) proposed several expressions of the rheological parameters versus concentration.

Several injection tests are carried out in order to understand the propagation mechanism of the grout in the sand. The major objective of this study is to characterize the medium injected by measuring gas permeability to assess the contribution of the injection to the void reduction in the medium. Permeability will be studied according to several parameters such as the water content of the samples and the height considered in the column [9].

2. Materials and methods

2.1. Sand columns preparation

The major problem while preparing the sand columns is to obtain the desired density. Currently, there is no device which allows a precise regulation of the density except the methods which are based on compaction using hammer blows or ramming. According to Yin [10], a relation is established between the sand porosity and the densification procedure in the column. The columns used are made of transparent PVC or rigid Plexiglas of 1000 mm height and 100 mm of internal diameter. The sand used is a Loire sand, the grain size of which can vary between 0–2 mm and $\gamma_{min}=15.07$ kN/m^3, $\gamma_{max}=18.52$ kN/m^3.

In order to obtain different densities, various numbers of plastic hammer blows are applied to the column. Thus, several procedures (A to E) are developed (Table 1).

2.2. Water conductivity of sand columns

Measurements of water conductivity are achieved on Loire sand samples with different densities. The standard NFP 94-090-1 [11] is applied by using a classical constant head permeameter device. The expected results are obtained with Darcy's law.

2.3. Grout rheology

Before sand injection operations, cement grout rheology is studied. The used cement is a Spinor A12, from Origny (near Paris) with 2.94 of grain density. A coaxial cylinder rheometer (rheomat 115) is used [12]. This allows us to determine the viscosity and therefore the rheological behavior of the grout [13,14].

The grout studied is prepared by mixing the following components at 100 tr/min: water, inert load (chalk with maximum particle size of 1 μm, and 2.71 of grain density), cement, and plasticizer. The grout formulation (see Table 2) was varied to study the effects of superplasticizer content, and inert load (chalk). It is important to note here that the ratio between the dry matter and water W/(C+inert load) is mentioned for every formulation. Segregation or bleeding tests are used to verify the obtained grout stability for each formulation. The influence of time and temperature were also studied, essentially to determine the period of grout use [15,16].

2.4. Grout cement injection in the sand

The injections are made on PVC columns filled with Loire sand at different densities and water to cement ratios for the grout. The injection device (Fig. 1) consists of a variable flow pump (Milroyal B) and a mixer (Rayneri Turbotest) with a speed range between 0 and 3000 rpm. The PVC columns are of

Table 2
Grout formulations

Composition	W/C	W/C + inert load	Water	Cement (SpinorA12)	Inert load	Plasticizer	Density
Units	–		ml	g	g	ml	Kg/l
Grout 1	3.57	1.38	1350	375	600	10	–
	3.57	1.38	1350	375	600	15	1.36
	3.57	1.38	1350	375	600	20	–
	3.57	1.74	1350	375	400	15	–
	3.57	1.15	1350	375	800	15	–
Grout 2	2.38	1.16	1350	562.5	600	10	–
	2.38	1.16	1350	562.5	600	15	1.41
	2.38	1.16	1350	562.5	600	20	–
Grout 3	1.78	1.00	1350	750	600	10	–
	1.78	1.00	1350	750	600	15	1.46
	1.78	1.00	1350	750	600	20	–

Injected column composition