Variation of the parameters of injection for the ground in different regimes

La variation des paramètres d'injection pour le terrain en régimes différents

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ABSTRACT
One of the basic characteristics in design and execution of a suitable grouting is the grouting fluid pressure. This paper will present the relations between injection pressure, injection debit and periphery advance fluid velocity for one-dimensional penetration, plan axial symmetric penetration and spatial symmetric penetration. However, the most important part of the paper will be the presentation of an experimental model for grouting, on natural scale.

RÉSUMÉ
La caractéristique principale de la conception et de l'exécution des injections appropriée c'est la pression du fluide d'injection. Cet article présentera les relations entre la pression d'injection, le débit d'injection et la vitesse périphérique d'avance du fluide pour la pénétration unidimensionnelle, la pénétration axiale symétrique et la pénétration spatiale symétrique. Cependant, la partie la plus importante du papier sera la présentation d'un modèle expérimental pour l'injection, à l'échelle naturelle.

Keywords : grouting, injection, experimental model, natural scale

1 INTRODUCTION

A large number of grouting technologies, found in the technical literature, are developed on practical projects. They are executed in special or difficult situations and they give a lot of manners to combine simple technologies.

In the geotechnical literature is not presented a model for the ground grouting in natural scale. This model should seize upon the real occurrence of the grouting and to demonstrate constitutive laws for liquid flow trough the ground or fracture grouting.

This paper presents a spatial physical – mathematical model, to describe the injection fluid progression in unsaturated non-cohesive ground, particularly for the permeation grouting.

The model proposed refers to the permeation grouting, on constant pressure. Ground permeability decrease, due to fluid adherence to mineral particles that are part of the ground (phenomenon known as doping) it is not taken into consideration. The injection grout's viscosity is considered to be constant. It is not taken into consideration: ground porosity decrease in time and grout fluid viscosity decrease in time, fluid effective advance velocity decrease (Bingham fluid), etc.

The following parameters characterize the soil: n`– volume of pores full of fluid in the unit volume of soil; n – soil porosity; k_{fl} – medium permeability for the injection fluid; k_w – medium permeability for 20°C water.

Other hypothesis taken into consideration are: considering filling injection case, the soil is saturated, we use Darcy's law for the equations of fluid flow, in case of advancement spherical surface we assume that injection is making through spherical surface with r_0 radius; area of this surface is equal with lateral surface of packer; the soil permeability is constantly in time.

Forward, this paper will present the relations between injection pressure, injection debit and periphery advance fluid velocity for one-dimensional penetration, plan axial symmetric penetration and spatial symmetric penetration. However, the most important part of the paper will be the presentation of an experimental model for grouting, on natural scale.

2 GROUTING ANALYTICAL MODEL

This experimental model builds using the model of spatial injection by spherical surface. We consider q'_t to be the debit on packer length, r_0 sphere radius with lateral surface equals with packer surface, r_t distance from the sphere centre to the place where is the injection fluid at time t. The centre of sphere is in the middle of the packer.

For constant pressure injection, we have equation (1) to formulate time – distance relation (Bally, 1984):

$$\frac{h_0 k_w}{n`} t = \frac{1}{3}\left[\left(\frac{\alpha}{r_0} - \frac{1}{r_{\lim}}\right)(r_t^3 + r_0^3) - \frac{\alpha - 1}{2}(r_t^2 + r_0^2)\right] \quad (1)$$

Analyzing numerical examples for one dimension grouting, radial plane grouting and spatial grouting by spherical surface, spatial method offered the closer results to reality.

3 NUMERICAL MODEL

It is utilized a variant of the mathematical procedure known as collocation. The method consists in applying iterative spatial analytical model to calculate injection front advance on permeation grouting. For either iteration ground permeability is modified, but during either iteration it is considered constant.

It can determine maximum advance radius $r^m_{t\ max}$, for either iteration (m) and the process is terminate when the difference between the radius calculated on iteration (m) is higher than radius determined on iteration (m+1):

$$\frac{r^m_{t\max}}{r^{m+1}_{t\max}} < 1{,}30 \quad (2)$$

This mathematical model has been developed using C^{++} into friendly software. For practical use this developed software,

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called Geo Test v1.0 have a convenient graphic interface and it is very easy to utilize, like shown into Fig. 1.

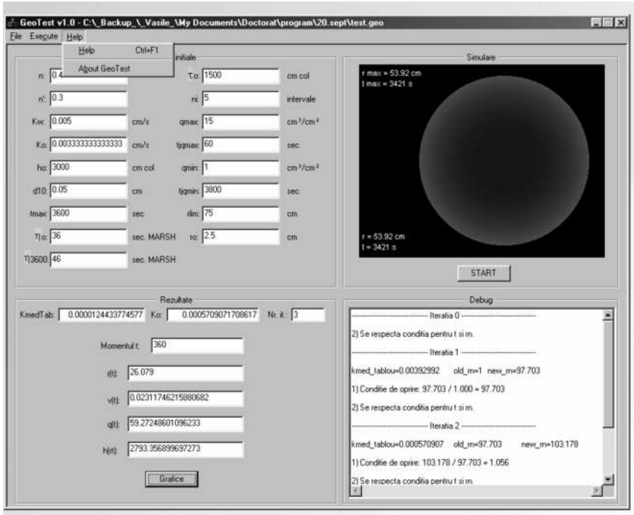

Figure 1. Geo Test v.1.0.

This software allows saving in separate files entering data. The results are presented in graphic mode and also in numeric mode, Fig. 2.

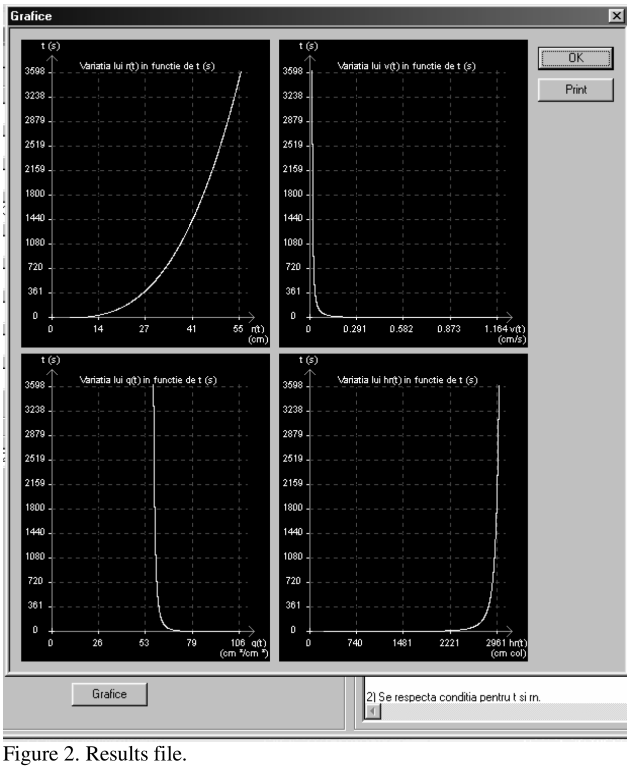

Figure 2. Results file.

It is presented in a graphic mode: injection advance radius evolution in time, injection debit, advance velocity of injection front and the pressure in fluid on the fluid – water separation line.

The increase of the injection grout's viscosity – aging – is implemented by means of a linear law and any other fluctuation may be introduced.

The doping phenomenon is describes as follows: it is taken into consideration a linear law of the permeability decrease due to doping for different discharges. The intermediate values are collating. It is possible to introduce any other law or any other parameter that leads to the modification of the permeability of the medium: for example, the difference in temperature between medium and the injection grout, etc.

In order to introduce the modification of permeability due to the above mentioned factors, we use the collocation procedure. Two imbricate iterations are used. The first step is to roll the analytical method and the certainty of a value of the injection grout's advance radius – the radial spatial method developed by the author is used.

Further, it could be determined relations for advance surfaces closer to reality: ellipsoidal, etc.

Afterwards based of laboratory experiments it could be made estimations of variation of k in time and distance trough the injector, and introducing k and the distance as function of (t, r) in afore mentioned relations.

4 EXPERIMENTAL MODEL

The experimental results, on a natural scale model, confirm the mathematical model results. In the experimental model, grouted material is loose sand and grouting fluid contains Portland cement and admixtures.

Void ratio of the sample corresponds to real void ratio of the ground in Cluj Napoca area, grain size distribution curve being presented into Figure 3.

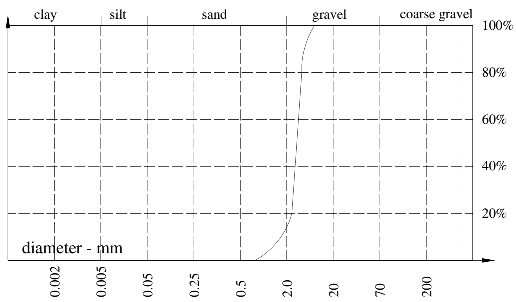

Figure 3. Grain size distribution curve.

To have a real image on of the process, ground to be injected it is sited into a cylindrical container, made of wood, having: 1.30m height and 1,50m diameter, Figure 4.

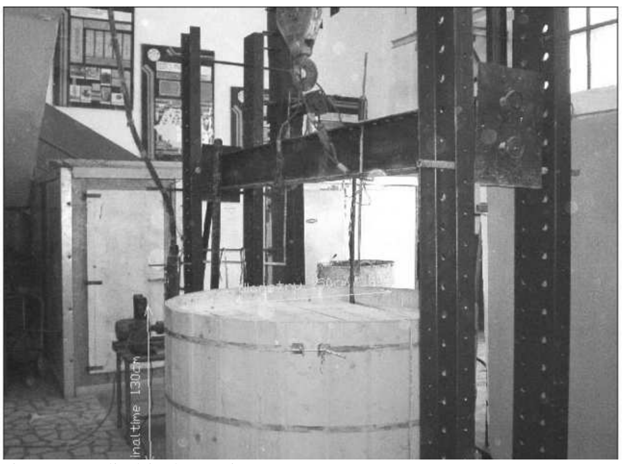

Figure 4. Cylindrical container.

With the purpose of register the advance of the injection grout it was conceived a network of sensors supplied by current. In the moment that injection grout reach the sensor, the resistance between the two electrodes decreases and the advance of the injection grout is pointed out.

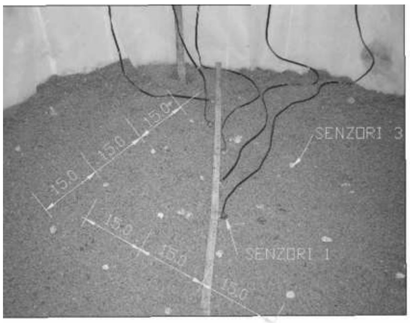

Figure 5. Sensor 1 and 3 – location.

There are four types of sensors: first type located in the horizontal median plane of the cylinder, a second type is a sensor registering neutral pressure along the injection, a third type on the central part of the sample, on 5 planes having different depth to register potential movements of the sand matrix and the fourth type to register vertical movement of the sample. The vertical movement simulates a layer of soil having 3.00m height, corresponding to a pressure of 0,6daN/cm^2.

The grouting installation was composed by a screw pump with an electric engine.

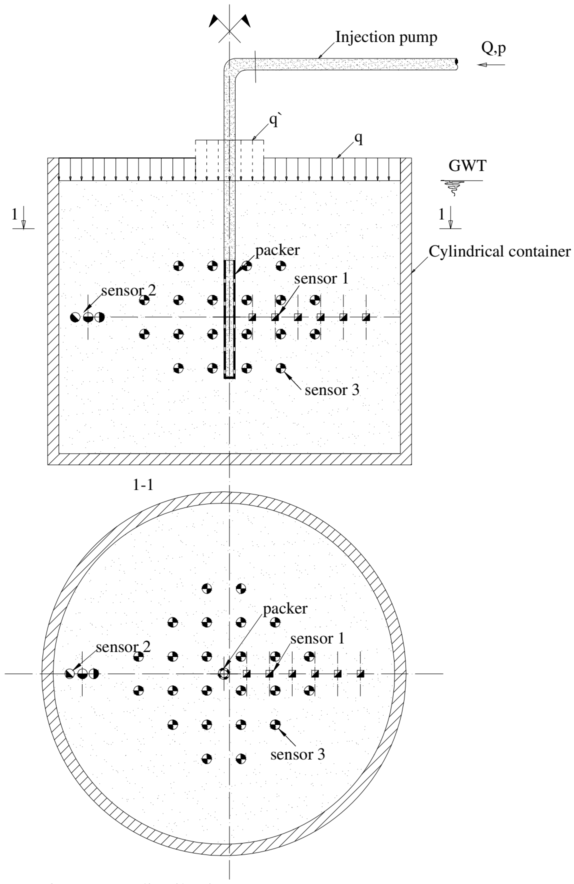

Figure 6. Sensors distribution.

To determine advance rate of the fluid in the porous medium, resistivity of the sensors have been measured each minute. In the Figure 7 is presented the variation of electrical resistivity in time for sensor 3.

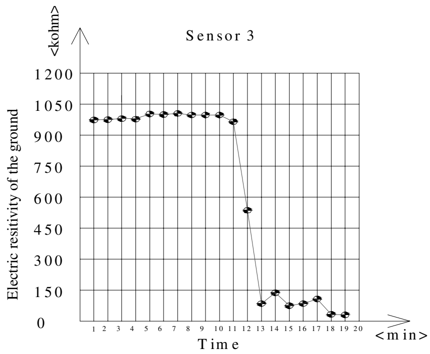

Figure 7. Electrical resistivity variation for sensor 3.

In order to determinate injection discharge, have been made measurements every one minute. In the Figure 8 is presented the fluid progression, as it looked in the cylinder.

Figure 8. Real fluid progression.

Comparing all the results: r_t – the injection advance radius, v_t – the advance front velocity and q_t – the injection debit, it is proven that numerical method have given more appropriate results, compared to experimental method, as shown in Figure 9, Figure 10 and Figure 11.

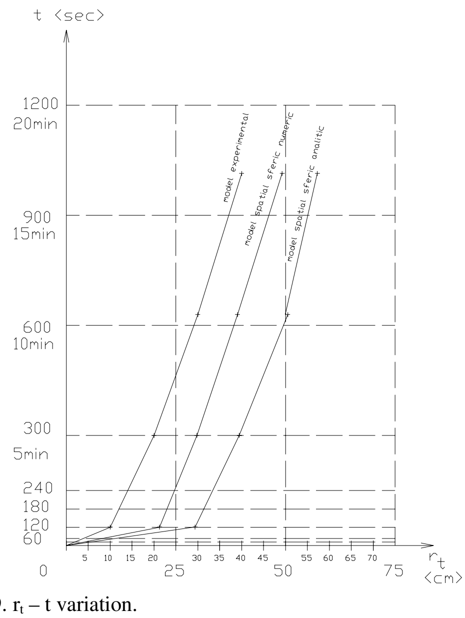

Figure 9. r_t – t variation.

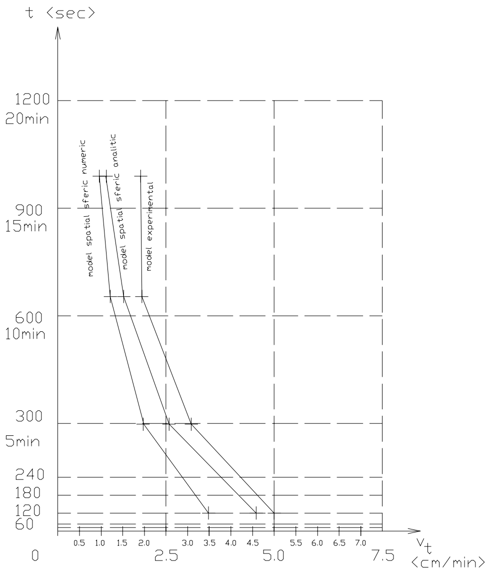

Figure 10. v_t – t variation.

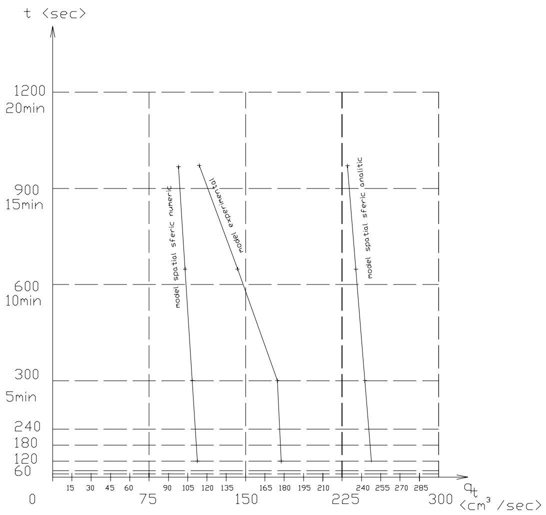

Figure 11. q_t – t variation.

For ground permeability k_w=0.25cm/s and k_0=0.017cm/s, in the following Tables are presented different parameters variation, for each model

Table 1. Experimental model.

Time <min>	Experimental model		
	r_t <cm>	v_t<cm/min>	q_t<cm^3/s>
2	10	5.0	173.33
5	20	3.33	170
11	30	1.67	146.67
17	40	1.67	108.33

Table 2. Numerical model.

Time <min>	Numerical model		
	r_t <cm>	v_t<cm/min>	q_t<cm^3/s>
2	22.31	3.48	109
5	29.81	1.896	106.11
11	38.38	1.122	104.05
17	44.17	0.840	103.14

Table 3. Analytical model.

Time <min>	Analytical model		
	r_t <cm>	v_t<cm/min>	q_t<cm^3/s>
2	29.02	4.62	244.99
5	38.93	2.52	239.40
11	50.25	1.5	235.85
17	57.91	1.14	234.27

Analytical method, because of not considering doping and increasing viscosity in time is not giving a perfect grouting model. All the simulations are accurate as long as doping can be express into entering dates.

5 CONCLUSIONS

This paper has proposed a spatial model of calculation procedure for the permeation grouting at constant pressure.

The analytical model starts from the identification of the discharge of the injection grout and of water discharge from the ground's pores.

By writing Darcy's law for the fluid that enters into the ground and the water that gets out of the ground and the identification between the discharges, we obtain the fluid's advance distance according to time and then the rest of the grouting parameters: pumping rate, advance velocity.

The linear and radial plane case was developed by Prof. R. Bally, the case of spherical radial spatial and ellipsoid case is developed by the authors.

Different grouting simulations are presented here, with believable results. In this model, ground's permeability to water, respectively to injection grouts, is considered to be constant.

The phenomenon of the injection grout's adherence to the mineral particles that are part of the ground's composition – doping – is not taken into consideration. The injection grout's viscosity is considered to be constant.

The program is limited by the constraints of grouting the medium with a certain injection grout.

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