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Modeling cement distribution evolution during permeation grouting

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Abstract. *Permeation grouting is a proper technique for strengthening dry sand before a tunnel construction in it. In the fifties of the past century, N. N. Verygin modeled this technique with 1-dimensional problems formulated in domains with a free moving boundary and came up with their analytical solutions. As for the 2-dimensional set ups, respective problems are formulated in domains that have complicated shapes and contain free moving boundaries. Until recently these difficulties seemed to be insuperable and all 2-dimensional grouting models in the framework of the continuum approach were based on the convective dispersion equation. They can be classified as the ones that describe pollution propagation. Nevertheless, M. B. Demchuk has lately come up with numerical solutions of 2-dimensional problems with free moving boundaries which set ups correspond to in situ grouting. Moreover, he has shown the following: adoption of the continuum approach is relevant for the set of input parameters used, among the curvilinear grids the calculations are performed on there are the ones that have chaotic dispositions of their nodes in space on some time layers. In this work, rough estimates are performed that indicate that the use of problems with free moving boundaries in the numerical modeling in hand is relevant.*

Keywords. *Permeation grouting; Free moving boundary; 2-dimensional models; Chaotic disposition of nodes; Pollution propagation.*

1 Introduction

Strengthening dry sand must precede the tunnel construction in it to have enough time for installing temporary support. In this case, to reduce the total cost of excavation it is desirable to preserve the structure of the treated soil. Therefore, permeation grouting is a proper technique for such the soil reinforcement. It assumes injecting cement grout in a treated soil through an injector. The quality of the soil reinforcement significantly influences the overall efficiency of the construction. This technique is rather costly and time consuming. The cement concentration distribution evolution determines the regime of the grouting [1]. Therefore, its mathematical modeling is important. There are a lot of papers devoted to modeling permeation grouting. The models [1]–[3] are based on the convective dispersion equation and can be classified as the ones that describe pollution propagation [4]. In the paper [5], this technique is modeled with a 1-dimensional problem containing a free moving boundary. In the recent paper [6], the last approach is generalized for the cases of 2-dimensional set ups that correspond to *in situ* permeation grouting. Specifically, in the research [6], M. B. Demchuk performed calculations on sparse curvilinear spatial grids and estimated the truncation errors of the final injection front position calculations neglecting the uncertainty in the final injection front position due to uncertainty in the choice of the method of the injection front interpolation on every time layer. In the paper [7], M. B. Demchuk and O. G. Nakonechnyi conducted the numerical experiment that verified the validity of this assumption. Moreover, its results indicate that the curvilinear grids the calculations [7] are performed on have chaotic dispositions of their nodes in space on some time layers. The aim of this work is to show that the use of problems with free moving boundaries in the numerical modeling [6] is relevant.

2 Modeling permeation grouting with problems containing a free moving boundary

The filtration of a cement grout in a soil is an example of a creeping flow. Describing such the motion, one can neglect the inertia forces in comparison with the frictional ones. The cement grout solution becomes more homogenous when the grain concentration increases [1]. Therefore, filling partially pores with it during its injection in a dry soil can be modeled as its dissolution in a fictitious weightless fluid with zero viscosity that saturated the soil before the injection. In the paper [4], M. B. Demchuk analyzed the analytical solution of the following partial differential equation:

$$D\partial^2 c/\partial x^2 - V\,\partial c/\partial x = \partial c/\partial t \tag{1}$$

with such the initial and boundary conditions:

$$c(x,0)=0,\ c(\infty,t)=0,\ c(0,t)=\hat{c} \tag{2}$$

where D, V, and $\hat{c}$ are positive constants. He showed that the injection front is sharp only if

$$V\cdot t >> \sqrt{8\cdot D\cdot t}\ . \tag{3}$$

If V is the velocity of particles of the fluid phase, then injection implies

$$D \approx a_L \cdot V \tag{4}$$

where a_L is the coefficient of the longitudinal dispersion. From equations (1)–(4), it follows that describing injection of a cement solution in a fluid saturated soil one can neglect the peculiarities of a solute propagation in a porous medium and model the cement concentration distribution evolution with a problem containing a free moving boundary if the following holds

$$\sqrt{V\cdot t} >> \sqrt{8\cdot a_L}\ . \tag{5}$$

The phenomenon of the mechanical dispersion taking place during cement grout solution injection in a fluid saturated soil ($a_L V >> D*$ where $D*$ is the diffusion coefficient) occurs due to the gradual change of the velocity of the fluid particles from the zero value on the surface of the pore to the maximal one in some internal point of the pore and due to the fact the pores in the ground can be viewed as a chaotic system of interconnected tunnels [8]. Comparison of injection of cement grout solution in water saturated sand with the one in the dry sand when other conditions are the same suggests that in the last case the ratio of the number of grains that are situated in a zone of the transition from the soil with the maximal cement concentration to the one with the zero concentration and simultaneously are in the contact with the pore surface to the total number of grains situated in the zone is greater than such the ratio in the first case. Hence, from dimensional considerations it follows that a_L for the fictitious fluid saturated sand is smaller than a_L for the respective water saturated one. Therefore, checking the validity of the condition (5) for the dry sand, one can substitute in its right hand side a_L for the respective water saturated sand.

3 Numerical estimations

In the paper [6], four problem set ups are considered. In the cases of the set ups # 1 and # 3, it is assumed that a long trench is made under an injector foundation. Its width is $2 \cdot r_0$ and its depth is h_0. The astringent infiltrate is injected in this trench at the constant pressure p_0 (see Fig. 1). In the set ups #

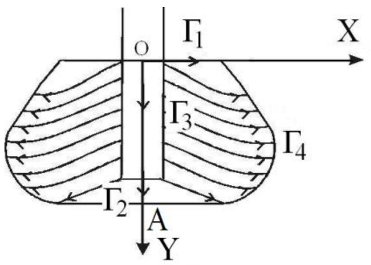

Figure 1: Problem set ups.

2 and # 4 we have the round bore-hole instead of the trench and assume that other conditions are the same. Its radius is r_0 and its depth is h_0. In the set ups # 1 and # 2, the ground skeleton is regarded as absolutely rigid whereas in the other ones it is assumed to be deformable. In each case $h_0 >> r_0$, the injection front (the curve Γ_4 on Figure 1) is a free surface, and its evolution in time and space needs to be found. In the recent research [6], the truncation error of the final injection front position calculation is so large that final free surfaces obtained for the absolute rigid ground skeleton can be compared with the respective ones obtained for the deformable ground. On Figure 2, the evolution of the injection front during permeation grouting corresponding to the case of the set up # 4 and the softest ground obtained in the numerical modeling [6] is presented. From this figure, it follows that the point of the intersection of the injection front with the vertical axis (the point A on Figure 1) moves slower than other points of the free surface. It covers the distance equal to 1.193 m. In the modeling [6], the treated soil is sand. Since for the water saturated sand $a_L = 1 \cdot 10^{-2}$ m [3], the condition (5) is fulfilled for all evolutions obtained in [6].

4 Conclusions

In this work, rough estimates are performed that indicate that problems with free moving boundaries are properly used to model the cement concentration distribution evolution during permeation grouting in the recent research [6].

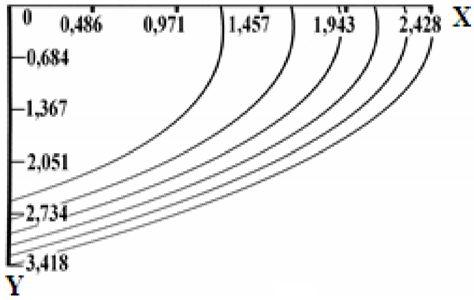

Figure 2: Injection front evolution [4].

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