UDC 624.048-033.26:621.651

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THE PHASE FIELD REGIME OF A GROUTING MODEL

The sophisticated grouting model based on the convection dispersion equation is used. Its set up corresponds to the standard laboratory test. For different sets of input data, it is checked numerically that the ratio of the distance covered by the injection front to the width of the zone of the transition from the soil with the maximal value of cement concentration in the liquid phase to the one where this concentration is negligible increases with time at sufficiently high injection pressure. Besides, the numerical evidence that in situ two-dimensional model of the permeation grouting based on a problem with a free moving boundary is relevant is produced.

Keywords: Phase field model, Convection dispersion equation, Grouting, Transition zone width, In situ conditions.

Introduction. Several decades are an ordinary duration of a large construction project. Often at the start of such the undertaking there is need in constructing a tunnel in a ground that is not going to experience heavy loads subsequently. In such the case before the excavation it is worthwhile to stabilize it to make sure that the shaft will not crash by the end of the project due to additional weight trees will create. In this case, the permeation grouting should be used to reduce the cost through preserving the structure of the treated soil. In this technique, cement grout is injected in soil at pressure that does not ruin the structure of the treated ground. It is expensive and time consuming. Its regime is determined by the evolution of the cement concentration distribution in space. Hence, modeling this evolution is research that has a great value. Cement grout consists of particles. The small ones can deposit on the walls of the pores and pore throats. However, these particles can be large enough to get stuck in the pore throats [1]. Therefore, mathematical description of the cement grout propagation in the soil is not trivial. There are a lot of papers such as [2] and [3] that shed light on various issues that arise during the construction of this description through comparing the results of the model calculations with the ones of laboratory measurements. However, respective models are problems in which initial conditions do not conform to the boundary ones. It gives rise to the significant waste of computer resources that occurs during the search of numerical solutions [4]. Since they contain regions of high gradients which positions depend on time [2, 3], it is not feasible to estimate the truncation error through analysis of numerical solutions. Therefore, in the above mentioned papers there is significant uncertainty in the input data which allows neglecting the truncation error. However, it makes the above mentioned comparison to be not informative [5]. Nevertheless, in the recent research [4], the sophisticated grouting model based on the convection dispersion equation is developed. In this model initial conditions conform to the boundary ones. As for its set up, it corresponds to the standard laboratory test. In it, a cement grout is injected at a constant pumping rate in the base of a vertical tube opened at the top and filled with water saturated sand [2], [3]. In the reference [3], the injection pressure reaches 8 bars and it is assumed that at such the pressure the structure of the grouted sand is not ruined. The fact that results of numerical calculations according to the permeation grouting model [3] are in agreement with the ones of the respective laboratory measurements verifies this assumption. Moreover, if this technique is used to treat dry chalk, then the injection pressure can be as high as 12 bars [6]. M. Demchuk and N. Saiyouri performed rough estimates that indicate that at such the values of the injection pressure, permeation grouting can be modeled by a problem with a free moving boundary [7].

M. Demchuk has recently obtained numerical solutions of 2-dimensional problems of the latter class which set ups correspond to *in situ* grouting. In each of these set ups, it is assumed that either a long trench or a round bore-hole is made under injector foundation. The astringent infiltrate is injected in such the injector at the constant pressure p_0. In each case, 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. First, M. Demchuk obtained solutions choosing the initial position of the injection front as close to Γ_3 as a modern computer allows, however, according to *in situ* conditions [8]. Nevertheless, later he showed that such the choice of the initial position of the injection front gives rise to inappropriateness of adoption of the continuum approach. Moreover, as a remedial measure he offered to assume that the initial position of the injection front is the one of the free surface after 120 seconds of the evolution calculated according to the model [8]. This modification gave rise to only 3 % decrease in the injection time. As for the final injection front positions and their uncertainties, the modification does not influence them [9], [10].

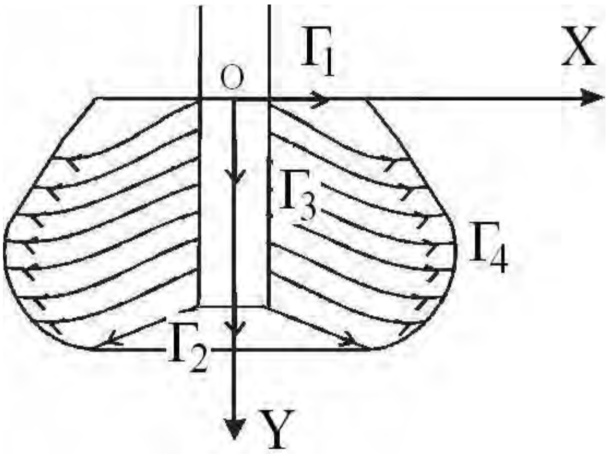

FIG. 1. The stabilized domain.

The aim of this work consists in checking numerically that starting from some moment of time one can model the evolution of the cement concentration spatial distribution during grouting using a problem with a free moving boundary. We conduct the numerical experiment in the frameworks of the calculation # 1 [9] and the sophisticated grouting model [4] based on the convection dispersion equation.

Numerical Results.

In what follows,

$$\varepsilon_1'(t_0) = \frac{\varepsilon_1(t_0+\tau)-\varepsilon_1(t_0)}{\tau} \qquad (1)$$

where $\tau << t_0$ and $\varepsilon_1(t_0)$ is uncertainty in the final injection front position obtained in the framework of the calculation #1 [9] when one assumes that the initial position of the injection front is the location of the free surface after time equal to t_0 elapses since the beginning of the evolution calculated according to the model [8]. From Table 1, it follows that there is the sharp threshold in the dependence $\varepsilon_1'(t_0)$ when $22\sec < t_0 < 44\sec$. Since in the recent research [9] $t_0 = 120\sec$, one can conclude that it is appropriate to use a problem with a free moving boundary to model the evolution of the cement concentration spatial distribution in the case of the calculation # 1 [9].

TABLE 1

The dependence of ε_1' on t_0.

t_0 *(sec)*	ε_1', %/sec
22	0.116
44	0.0175
66	0.0172
90	0.0169
104	0.0168
114	0.0166

As for the sophisticated grouting model [4], in what follows, the threshold value is the one which order of magnitude is one order of magnitude greater than the truncation error. We define the width of the transition zone as the distance between the point at which the cement concentration is equal to the difference between its maximal value and the threshold value and the point at which this concentration is equal to the threshold value. As for the position of the injection front, we assume that it corresponds to the point at which the cement concentration is two times smaller than its maximal value. The estimation of the truncation error is cumbersome because the solutions of the grouting models based on the convection dispersion equation contain regions of high gradients which positions depend upon time and not known in advance. In this work, we estimate the truncation error as described in [5]. The calculations are performed for two sets of the input parameters. In the first set, the pumping rate, the length of the tube, and the number of the grid nodes in the spatial direction equal to $1.5\cdot10^{-6}$ m^3/sec, 0,7 m, and 501 respectively [5] whereas in the second one they are equal to $1.2\cdot10^{-5}$ m^3/sec, 5 m, and 4001. As for the diameter of the tube, the injection times, and the characteristics of the treated soil, their values are taken from the reference [5]. The values of the small parameters and the large ones introduced in the model to guarantee that the initial conditions conform to the boundary ones are the same functions of the number of the grid nodes in the spatial direction that are used in the reference [5]. In both cases, the time increment is equal to 0.005 sec. The results of numerical calculations for two sets of input data are presented in Tables 2 and 3 respectively. From Tables 2 and 3, it follows that the ratio of the transition zone width to the distance covered by the injection front decreases with time and that at a fixed injection time the higher the rate is, the smaller the ratio is.

TABLE 2

The numerical results for the case of the first set of input data

Injection Time (sec)	*Ratio*	*Absolute Error*
100	2.31	0.18
250	1.65	0.19
400	1.46	0.15

TABLE 3

The numerical results for the case of the second set of input data

Injection Time (sec)	*Ratio*	*Absolute Error*
100	1.24	0.11
250	0.82	0.07
400	0.66	0.05

Conclusion. In this work, it is checked numerically that modeling cement concentration spatial distribution evolution with the help of the problem that belongs to the class of problems with free moving boundaries is appropriate in the case of one of the calculations presented in [9]. Besides, in this work we produce the numerical evidence that the sophisticated grouting model [4] of the standard laboratory test becomes the phase field one at sufficiently high injection pressure.

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АНОТАЦІЯ

Використано детальну модель нагнітання, основану на рівнянні конвективної дисперсії. У ній постановка задачі відповідає стандартному лабораторному дос-

лідженню. Для різних наборів вхідних параметрів, перевірено чисельно, що відношення відстані, пройденої фронтом нагнітання, до ширини зони переходу від області максимальної концентрації цементу в рідкій фазі до області нульової такої концентрації зростає з плином часу за достатньо великого тиску нагнітання. Крім того отримано чисельне підтвердження адекватності використання задачі з вільною рухомою межею для моделювання нагнітання, що виконується за умов, наближених до реальних.

Ключові слова: модель фазового поля, рівняння конвективної дисперсії, стабілізація ґрунту, ширина перехідної зони, узгоджена початково-крайова задача, дво-вимірна модель, одно-вимірна модель.

АННОТАЦИЯ

Использовано подробную модель нагнетания, основанную на уравнении конвективной дисперсии. В ней постановка задачи соответствует стандартному лабораторному исследованию. Для различных наборов входных параметров проверено численно, что отношение расстояния, пройденного фронтом нагнетания, к ширине зоны перехода от области максимальной концентрации цемента в жидкой фазе к области нулевой такой концентрации возрастает с течением времени при достаточно большом давлении нагнетания. Кроме того получено численное подтверждение адекватности использования задачи со свободной подвижной границей для моделирования нагнетания, которое выполняется в условиях, приближенных к реальным. А именно, рассмотрен случай ряда цилиндрических инжекторов, который в модели заменён траншеей. При этом рассматривается нагнетание цементного раствора в сухой грунт под давлением, которое не способно разрушить структуру грунта.

Ключевые слова: модель фазового поля, уравнение конвективной дисперсии, стабилизация грунта, ширина переходной зоны, согласованная начально-краевая задача, двумерная модель, одномерная модель.

УДК 628.38

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ВИКОРИСТАННЯ ВІДХОДІВ МЕТАЛУРГІЙНОГО ВИРОБНИЦТВА В ТЕХНОЛОГІЇ БЕТОНУ

Використання промислових відходів у будівельній індустрії є перспективним напрямом зниження собівартості продукції і зменшення негативного навантаження на навколишнє середовище. За результатами будівельно-технічних (досліджувались міцність при стисканні і вигині, водопоглинання, водостійкість і морозостійкість) і санітарно-хімічних (досліджувались елементний склад і рівні міграції значущих в гігієнічному відношенні металевих катіонів у водне середовище і середовище, що імітує кислотні дощі) випробувань зразків бетону, що містять осади гальваностоків металургійного виробництва, показано можливість використання осадів в якості добавок в бетон в кількості 1…2 %. Обґрунтовано рекомендації щодо використання бетонної суміші з добавками осаду для виготовлення залізобетонних плит для покриттів міських доріг.

Ключові слова: осад стічних вод; утилізація; бетонні вироби; будівельно-технічні, санітарно-хімічні дослідження

Постановка проблеми. Важливість захоронення токсичних промислових відходів, що містять важкі метали, в даний час не викликає сумніву, причому невідкладність вирішення проблеми весь час зростає. Одним з перспективних напрямків утилізації промислових відходів є включення їх у вигляді добавок до складу будівельних матеріалів. Зазначений спосіб забезпечує більшу в порівнянні з об'ємними сховищами екологічну безпеку, в тому числі і стійкість в умовах катастроф.

Аналіз основних досліджень та публікацій. Використання промислових