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GROUND WATERS DISPOSAL MODELING DURING THE INFRASTRUCTURAL GEOTECHNICAL SYSTEMS DEVELOPMENT

МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ОТВЕДЕНИЯ ГРУНТОВЫХ ВОД ПРИ РАЗВИТИИ ИНФРАСТРУКТУРНЫХ ГЕОТЕХНИЧЕСКИХ СИСТЕМ

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Abstract. *As a rule, the technologies for the development of infrastructural geotechnical systems are associated with the processes of nearby territories flooding and the formation of appropriate technological conditions, which determine the main sources of groundwater supply. The article discusses options for modeling the processes of groundwater abstraction in the development of infrastructure projects, taking into account sound methods and tools for predicting and managing flooding. The considered methods and means are supposed to be used in the development and planning of water management processes in order to improve the environmental safety of urban areas experiencing groundwater flooding. It is proposed to use the mechanism of impact of the jets as methods of groundwater abstraction, the influence and effect of an additional "control" jet on the outflow of the main stream is studied. The dependences obtained in the article make it possible to evaluate the efficiency of regulating fluid flow rates using a control jet, as well as to draw qualitative conclusions about the influence of various parameters on the process of jet outflow.*

Key words: *infrastructural geotechnical systems, jets collision, groundwater, outflow, modeling, fluid flow regulation*

Introduction. The mining engineering activities related to the development of mineral deposits always bring significant changes to the functioning of geosystems. The restoration of fractured grounds during the development of infrastructural geotechnical systems in the process of mining is one of the main agenda for the rational use of land resources. During the development of mineral deposits, the significant change happens in the physicomechanical and mining-geological features of rocks, which affects the filtration properties of soils and leads to pollution of both the upper layers and groundwater. The filtering process of the upper layers of soils is particularly influenced by such factors as temperature, porosity, viscosity, soil composition and climat conditions. To clearly esmimate this effect on violations of the existing and the formation of a new hydrodynamic and hydro-geochemical regime of soils and groundwater near existing mineral deposits, it is necessary to constantly conduct research on the main characteristics of infrastructural geotechnical systems [1].

The technologies of the development of infrastructural geotechnical systems are connected with the processes of flooding of nearby territories and the formation of appropriate technological conditions, which determine the main sources of groundwater supply. The development of mineral deposits consists of the following main operations: the planning of mining and geological works, laying roads, arranging various water basins, forming and laying temporary water utilities, opening pits and tranches, which leads to the inevitable violation of the existing topography, and also affects the change in surface runoff conditions. With the development of infrastructural geotechnical systems, the extraction and processing of minerals is usually accompanied by the laying of permanent underground utilities and their testing with the simultaneous operation of temporary networks, the construction of foundations, backfilling of foundation ditches and trenches of loosened soil, the laying of storm drains, and the operation of technological equipment and facilities, which leads to an increase in violations of the existing hydrogeological conditions [2]. Depending on the estimates of the soils' conditions in the areas near the functioning of the infrastructural geotechnical systems, the measures are taken to reduce man-made distortions of developing or already developed flooding and environmental pressure.

The process of reduction of groundwater level during the development of infrastructure geotechnical systems is carried out by engineering methods: part of the surface runoff is discharged into storm sewers; operation of urban water intakes for the use of pumped water in various technological processes; operation of special pumps; reduction of infiltration due to shielding of the earth's surface by buildings, concrete and other types of surficial.

Ensuring the stability of technological processes tied to groundwater abstraction during the development and operation of infrastructural geotechnical systems depends on determining rational parameters in the problems related to fluid flow with various boundary, geometric conditions and physicochemical properties. As a rule, while diverting the groundwater, an extensive network of canals, tranches and drains is used in which the coordination of fluid flows is possible by controlling the interacting currents in the process of their collision.

Main text. Modeling and analyzing the processes of collision of currents during mining and engineering work in the framework of the development of infrastructural geotechnical systems is a scientifically sound way of finding the parameters of fluid motion. The flow of fluid through the aperture is determined by a number of geometric, kinematic and dynamic parameters. The latter include the Froude and Reynolds numbers. The specificity is conditioned by the free-boundary problem, the shape of which is not known in advance and can vary unlimitedly depending on the problem settings. The presence of free boundaries makes the problem substantially nonlinear, which greatly complicates or even casts doubt on the possibility of applying the well-known methods of computational hydromechanics. Therefore, while examining the problem for an ideal and incompressible fluid without modeling it according to the Froude and Reynolds numbers, we can eventually obtain exact analytical solutions and formulate the main laws of the outflow depending on geometric and kinematic parameters.

This article discusses the problem of currents' collision, the influence and impact of an additional "controlling" currents on the expiration of the main one. The application of a "controlling" current is considered as one of the possibilities to manage the flow rate of the main fluid flowing through the aperture. Due to the interaction of the currents, an increased pressure is created in the outflow zone, which to a large extent determines the required flow rate.

It should be mentioned that the solution of the problem of the interaction of two currents, in the case when the fluid densities and Bernoulli constants are different for both of them, encounters serious computational difficulties in the framework of the ideal fluid model. In this respect, special cases of the organization of the controlling current are to be considered: the liquid of the controlling current has the same density as the liquid flowing through the aperture; the main and outflowing liquids to the place of their meeting move in parallel from two sides of the flat border; Bernoulli constants are the same for both currents. These assumptions enable us to solve a number of problems on the interaction of the outflowing and controlling currents in a precise analytical way.

In the case of the influence of an additional "controlling" current on the outflow of the main one, the study of the problem is carried out in the framework of the model of stationary flows of an ideal incompressible weightless liquid in a flat formulation. The solution of this problem (when solid boundaries make an arbitrary polygon), as it is known, can be obtained on the basis of the apparatus of the theory of analytic functions. The main tool for solving these problems is the Zhukovsky method and the Schwarz-Christoffel integral.

Let us consider the problem of the outflow of an infinite fluid resting at infinity through an aperture with a step into a resting medium with reduced pressure. The results of calculating the flow coefficient and other characteristics make it possible to draw qualitative conclusions about the influence of various parameters on the current expiration process and evaluate the efficiency of flow control using the controlling current. We assume that the outflow of an unlimited fluid occupying the entire upper half-space flows through a gap located in the lower wall. The outflow occurs in the lower half-space, which is filled with a liquid at rest with a lower pressure than in the fluid flowing out. In this case, we take into consideration the outflow of liquid, which is located, at an infinite distance, at rest under pressure. The scheme of this outflow is shown in Figure 1. We assume that the liquid has a density ρ and fills the entire upper half-space. At perpetuity (point H), the liquid is at rest and at the same time has pressure P_0 (stagnation pressure). In the area where the fluid flows into, pressure amounts to $P_{\grave{a}} < P_0$. We denote the boundaries of the current as AD and BD, where D is the infinitely distant point of the current.

The coordinate origin is located at point A, the axis x is directed along the side HA. The angle of inclination of the velocity vector to the axis x is denoted as θ. The gap is characterized by the mutual arrangement of points A and B, thus:

$$Z_B = l_1 + l_2, \tag{1}$$

Where l_1 and l_2 are the horizontal and vertical projections of the aperture, respectively (the variables l_1 и l_2 can be both positive or negative).

To solve this problem, we apply the Chaplygin's singular point method [3-5]. Let us consider two characteristic functions: $\omega(z) = \varphi + i\psi$ for complex flow potential and $\tilde{N}_1 = (dw/dz)/V_c$ for the conjugate flow velocity referred to the velocity at the current boundary V_c, which is determined from the Bernoulli integral:

$$V_c = \sqrt{\frac{2(P_0 - P_a)}{\rho}} \tag{2}$$

According to the Chaplygin's method, it is rational to choose the semicircle of the unit radius in the upper half-plane as the region of the parametric variable t (Fig. 1 (d)), then the conformal mapping of the variable region onto the variable region t will be "trivial":

$$\tilde{N}_1 = (dw/dz)/V_c \equiv t \tag{3}$$

Let us than find the mapping of the domain of the variable w (strip) to the domain of the variable t. The fluid flowing from an infinitely distant point H (intensity source q_c) flows out through the cross section of the current at the point D (intensity sink $-q_c$).

Thus, the function $w(t)$ has logarithmic singularities at the point H$(t=0)$ and at the point $D\ t = e^{i\beta}$. Since the boundaries on the subspace w are rectilinear, the function $w(t)$ can be continued first into the lower semicircle (in this case, at a point $D'\ t = e^{-i\beta}$ symmetrical with D an intensity sink appears $-q_c$) and then onto the entire plane (in this case, a source with intensity also appears at an infinitely distant point q_c).

The function $w(t)$ is reconstructed as:

$$w(t) = \frac{q_c}{\pi}\left[\ln t - \ln\left(t - e^{i\beta}\right) - \ln\left(t - e^{-i\beta}\right)\right] + \omega_0 \tag{4}$$

The argument count rule $t = |t|e^{i\theta}$, $\left(t - e^{i\beta}\right)$ and $\left(t - e^{-i\beta}\right)$ is shown on Figure 1(d). With this choice of angles, the invariable $w_0 = 2iq_c$.

The solution to the problem is completely determined by formulas (3) and (4) if parameters q_c and β included in (4) are specified. To determine these parameters, we establish the relation between the physical plane z and the variable plane t. From (4) we get:

$$dz = \frac{1}{V_c t}\frac{dw}{dt}dt = \frac{q_c}{\pi V_c}\frac{1}{t}\left(\frac{1}{t} - \frac{1}{t - e^{i\beta}} - \frac{1}{t - e^{-i\beta}}\right)dt$$

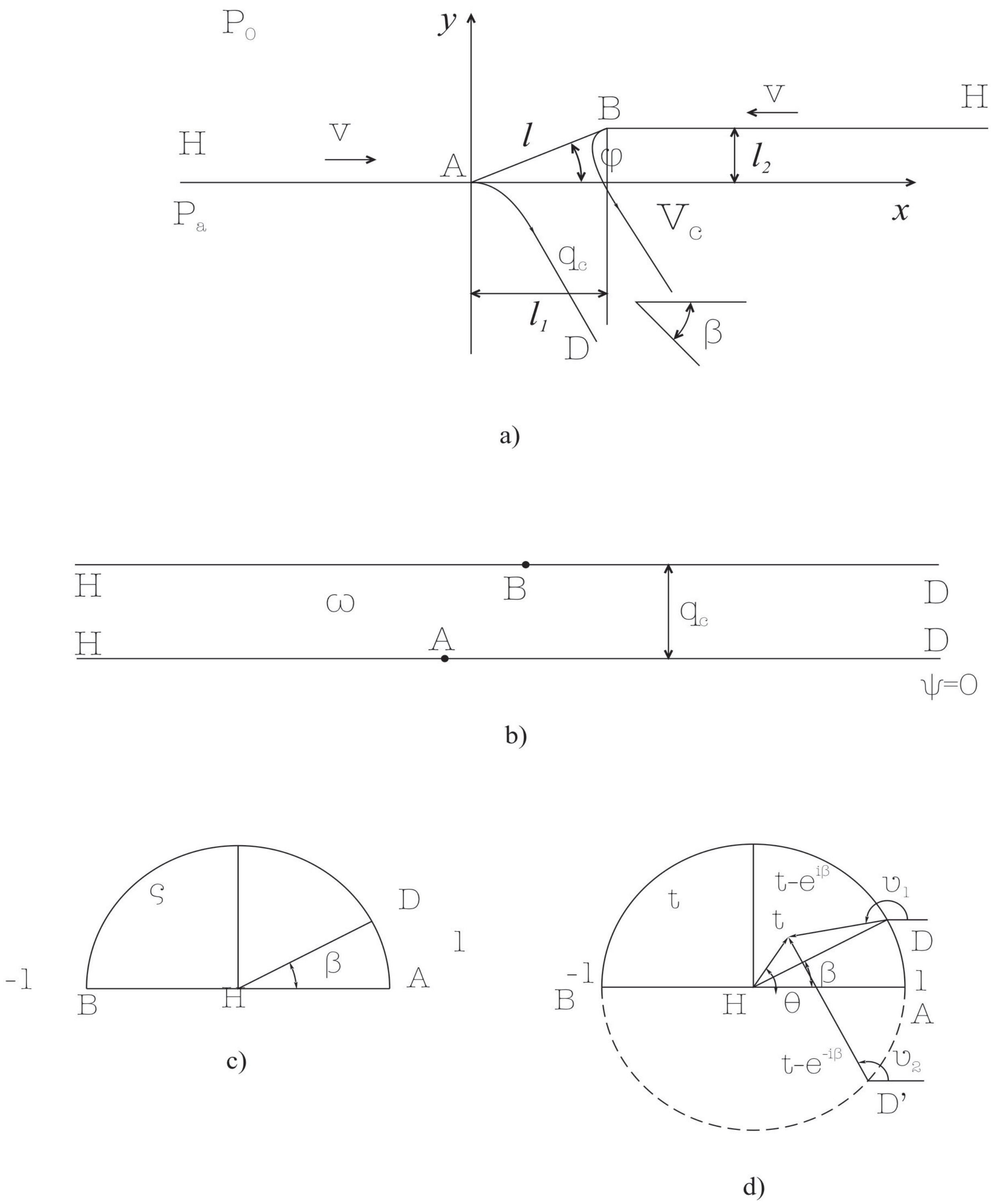

Fig.1 - Scheme of the outflow of unlimited fluid through the aperture with a ledge

a) physical plane;
b) aria of variable φ;
c) area of variable ς;
d) area of parametric variable *t*.

If we decompose this formula into common factors:

$$dz = \frac{q_c}{\pi V_c}\left(\frac{2\cos\beta}{t} + \frac{1}{t^2} - \frac{e^{-i\beta}}{t - e^{i\beta}} - \frac{e^{i\beta}}{t - e^{-i\beta}}\right)dt \tag{5}$$

And then integrate it from A $(t=1)$ to B $(t=-1)$. The integration can be carried out in any way in the field; if you use the path along the boundary AHB, then the integrals should be calculated in the sense of Cauchy number.

The result of integration provides the following:

$$z_B - z_A = l_1 + il_2 = \frac{q_c}{\pi V_c} + \left(2 + 2\cos\beta\ln\frac{\beta}{2} + \pi\sin\beta + i\pi 2\cos\beta\right) \tag{6}$$

If we assuming, using the formula (6), that the dimensions of the aperture l_1 and l_2 are given, we obtain two conditions for determining the invariables q_c and β:

$$\left.\begin{aligned} l_1 &= \frac{q_c}{\pi V_c}\left(2 + 2\cos\beta\ln tg\frac{\beta}{2} + \pi\sin\beta\right) \\ l_2 &= 2\frac{q_c}{V_c}\cos\beta \end{aligned}\right\} \tag{7}$$

Let us denote the thickness of the current at perpetuity δ_c, so $q_c = V_c\delta_c$ and formula (7) will be represented as following:

$$l_1/\delta_c = \frac{1}{\pi}\left(2 + 2\cos\beta\ln tg\frac{\beta}{2} + \pi\sin\beta\right), \quad l_2/\delta_c = 2\cos\beta \tag{8}$$

The variables $K_1 = \delta_c/l_1$ and $K_2 = \delta_c/l_2$ are commonly referred to as flow coefficients or flow coefficients, and they are the main characteristics of the flow process. In further research, instead of two flow coefficients along the slit projections, we can use a flow coefficient related to the maximum width of the passage section of the aperture. The obtained dependences make it possible to evaluate the efficiency of flow control using a controlling current and the other characteristics, as well as to draw qualitative conclusions about the influence of various parameters on the current flow process. This research is aimed at determining the rational parameters of groundwater abstraction processes to justify methods of combating waterlogging in the development of geotechnical infrastructural systems in the face of uncertainty in the initial data in order to make timely management decisions.

For the European Union countries, the priority is given to the tasks associated with the prevention of flooding, since from the point of view of economically justified costs, the elimination of the consequences of flooding is ten times more expensive than measures taken to prevent technological disasters. At the same time, the socio-economic results from concerted actions to prevent flooding are more effective for functioning infrastructural geotechnical systems despite the significant financial costs of maintaining the sustainable operation of equipment for the management of water disposal technologies.

Landscape and engineering-geological conditions of occurrence of soils determine the best option for creating projects of engineering means of combating flooding, taking into account the socio-environmental aspects of the impact on the population and the environment.

Currently, the lack of tools and modern mathematical modeling devices for decision makers is one of the main factors in identifying priority tasks, as well as in allocating funds to solve problems with flooding as part of the development of infrastructure projects, taking into account environmental activities [6, 7].

The priority management measures related to the prevention of technological situations with flooding should include:

- changing the order of repair and replacement of water pipelines in favor of areas suffering from flooding;
- attracting external financing for projects in the areas of water supply and sanitation, construction of irrigation and drainage facilities, water resources management of river basins, as well as in other sectors related to the use of water resources;
- when designing new infrastructure projects, taking into account the negative experience of the development of flooding in this territory, and taking adequate measures to prevent flooding while agreeing on the appropriate rules for the operation of the water supply, sewage and heating networks;
- in the development of infrastructural geotechnical systems, taking into account the features of the landscape-functional zones of the territories adjacent to industrial enterprises and mineral deposits.

Conclusion and results.

To justify the important management decisions, it is necessary to obtain a clear picture of the development of flooding using a network of observation points based on specially equipped technological wells and hydrogeological models of industrial areas. In this case, the main methodological approaches are used in the development of protective measures in areas of groundwater flooding, namely: natural hydrogeological approach; technogenic hydrogeological approach; urban planning approach; probabilistic statistical approach [6]. We have considered the possible modeling options for groundwater abstraction processes during the development of infrastructural geotechnical systems due to the scientific substantiation of methods and tools for predicting and controlling the flooding. These methods can be eventually used in the development and planning of water management processes in order to increase the environmental safety of urban areas prone to groundwater flooding.

References

1. Абрамов И.Б. Оценка воздействия на подземные воды промышленно-городских агломераций /И.Б.Абрамов – Харьков, 2007. – 285с.

2. N. Osadcha Methodological bases for the sustainable development of underground infrastructure facilities in Ukraine: problems and prospects / N. Osadcha, S. Dziuba, O. Haliasovskaia, M. Kybkalo // «Економіка та держава» № 6, 2019 р. – С. 16-20

3. Гуревич И.И. Теория струй идеальной жидкости / И.И. Гуревич // – М.: Наука, 1979. – 536 с.

4. Рубцов М.В. О соударении плоских многослойных струй вязкой жидкости / М.В. Рубцов// ПМТФ. – 1984. – Вып. №2. – С. 34-44

5. Кузьмин С.В. Соударение двух струй идеальной жидкости с различными константами Бернулли / С.В. Кузьмин // Механика жидкости и газа. –М.: 1987. - №2- С. 38-42

6. Размєтаєв С. В., Чебанов О. Ю. Про стратегію та головні завдання вирішення проблеми підтоплення населених територій в Україні. Екологія довкілля та безпека життєдіяльності. 2003. № 6. С. 5–11.

7. Серикова Е. Н., Стрельникова Е. А. Изучение особенностей изменения уровня грунтовых вод с помощью математического моделирования. Восточно-европейский журнал передовых технологий. 2013. № 3/4. С. 31–35.

Аннотация. *Как правило, технологии развития инфраструктурных геотехнических систем связаны с процессами подтопления близлежащих территорий и формированием соответствующих техногенных условий, которые и определяют основные источники питания подземных вод. В статье рассмотрены варианты моделирования процессов отведения грунтовых вод при развитии инфраструктурных проектов с учетом обоснованных методов и средств прогнозирования и управления подтоплением. Рассмотренные методы и средства предполагаться использовать при разработке и планировании процессов управления водными ресурсами с целью повышения экологической безопасности урбанизированных территорий, испытывающих подтопление грунтовыми водами. В качестве методов отведения грунтовых вод предложено использовать механизм соударения струй, изучено влияние и воздействие дополнительной «управляющей» струи на истечение основной струи. Полученные в статье зависимости позволяют оценить эффективность регулирования расходов жидкости при помощи управляющей струи, а также сделать качественные выводы о влиянии различных параметров на процесс истечения струй.*

Ключевые слова: *инфраструктурные геотехнические системы, соударение струй, грунтовые воды, истечение, моделирование, регулирование расходов жидкости*

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