DNIPRO UNIVERSITY
of TECHNOLOGY
1899

NAUKOVYI VISNYK

Natsionalnoho Hirnychoho Universytetu

Peer-reviewed
journal

5 2021
185

Geology

Mining

Solid State Physics, Mineral Processing

Geotechnical and Mining Mechanical Engineering,
Machine Building

Electrical Complexes and Systems

Power Supply Technologies

Environmental Safety, Labour Protection

Information Technologies,
Systems Analysis and Administration

Economy and Management

Bi-Monthly ■ Founded in September 1998

Editor-in-chief G. G. Pivnyak
Deputy editors-in-chief O. S. Beshta, O. M. Shashenko
Executive editor T. V. Barna

EDITORIAL BOARD: (Ukraine) K. A. Bezruchko, V. I. Bondarenko, A. F. Bulat, M. M. Dovbnich, R. O. Dychkovskyi, O. V. Fomin, V. I. Golinko, V. V. Hnatushenko, V. V. Lukinov, V. G. Marhasova, V. S. Nitsenko, O. P. Orliuk, I. P. Otenko, A. V. Pavlychenko, S. M. Peresada, P. I. Pilov, Yu. I. Pylypenko, G. M. Pylypenko, V. F. Prykhodchenko, V. V. Protsiv, M. V. Ruzina, V. S. Savchuk, V. I. Samusia, Ye. A. Sdvizhkova, V. V. Soboliev, I. O. Taran, I. M. Udovik, O. G. Vagonova, T. G. Shendrik, A. O. Zadoia.

FOREIGN MEMBERS OF EDITORIAL BOARD: Abderrazzak El Albani (*Université de Poitiers, France*); A. Benselhoub (*Badjhi Mokhtar University, Algeria*); Yu. Bilan (*Szczecin University, Poland*), G. Gruhler (*Heilbronn University, Federal Republic of Germany*); C. Drebenstedt (*Freiberg University of Mining and Technology, Federal Republic of Germany*); J. Dubinski (*Central Mining Institute, Republic of Poland*); Liu Baochang (*College of Construction Engineering, Jilin University, China*); T. Majcherczyk (*AGH University of Science and Technology, Republic of Poland*); V. Naumov (*Cracow University of Technology, Republic of Poland*); B. Rakishev (*Kazakh National Technical University after K. I. Satpaev, Republic of Kazakhstan*); H. Ramadan (*The University of Technology of Belfort-Montbeliard, France*); B. Ratov (*Kazakh National Research Technical University*, *Republic of Kazakhstan*); S. Simon (*The Brandenburg University of Technology Cottbus-Senftenberg, Federal Republic of Germany*); A. Smolinski (*Central Mining Institute, Republic of Poland*); Andīna Sprince (*Riga Technical University, The Republic of Latvia*); A. Stovas (*The Norwegian University of Science and Technology, Kingdom of Norway*); J. Strugul (*The University of Adelaide, Commonwealth of Australia*); A. Tajduś (*AGH University of Science and Technology, Republic of Poland*); W. Czarnetzki (*The Esslingen University of Applied Sciences, Federal Republic of Germany*); M. Schmidt (*The Brandenburg Technical University, Federal Republic of Germany*), G. Schmidt (*The Esslingen University of Applied Sciences, Federal Republic of Germany*).

The journal has been included in SciVerseSCOPUS, Index Copernicus Journal Master List, ProQuest, EBSCOhost, Ulrichsweb Global Serials Directory, ResearchBib, Ukrainika naukova, Dzherelo.

Subscription for the journal can be done in post offices of the Ukraine (subscription index in Subscription Publication Catalogue is 89166) and in the subscription agencies Ukrinformnauka (index in Subscription Publication Catalogue is 10107) and Ideia (index is 17736)

Makeup T. A. Klimenko. Proofreading M. T. Sysun.
Passed for printing under recommendation of Academic Council of Dnipro University of Technology (transaction No. 14 dated October 13, 2021).

Certified by Ministry of Justice of Ukraine. Registration number KB No. 24305-14145PR
dated December 27, 2019. Passed for printing October 25, 2021. Sheet size 60 × 90/8.
Presswork 23.3. Offset paper. Number of copies printed 200. Order No. 1.

Founder and publisher Dnipro University of Technology, Dnipro
Certificate of Publisher ДК No.1842 dated June 11, 2004

Address of publisher and editorial office: 19, D. Yavornytskoho Ave., building 3, room 24a, Dnipro, 49005
Tel.: (056) 373 08 65, e-mail: nv.ngu@ukr.net, www.nvngu.in.ua; nv.nmu.org.ua

Production PP KF “Gerda”. 60, D. Yavornytskoho Ave., Dnipro, 49000.
Certificate of Publisher ДК No.397 dated April 3, 2001

© Dnipro University of Technology, 2021

CONTENTS

UDC 699.85: 621.039.743

https://doi.org/10.33271/nvngu/2021-5/106

O. Meneylyuk[1],
orcid.org/0000-0002-1007-309X,
A. Nikiforov[1],
orcid.org/0000-0001-7002-7055,
I. Menejljuk[2],
orcid.org/0000-0001-7075-2898,
V. Russyi[1],
orcid.org/0000-0002-5884-2097

1 – Odesa State Academy of Civil Engineering and Architecture, Odesa, Ukraine, e-mail: nikiforov.aleksey@yahoo.com
2 – Kharkiv National University of Civil Engineering and Architecture, Kharkiv, Ukraine

CHOOSING INJECTABLE SOLUTION FOR AUGER TECHNOLOGY OF UNDERGROUND SPACE PROTECTION AGAINST POLLUTION

Purpose. The research is devoted to the experimental choice of injection composition for auger technology of installation of underground anti-filtration shields under the source of pollution. The auger technology for the arrangement of an anti-filtration shield consists of pilot holes made by the horizontal directional drilling, which is followed by the arrangement of a waterproof layer by replacing the soil with auger by special concrete solution.

Methodology. The main research method is experimental-statistical modeling, which includes conducting laboratory tests; correlation-regression analysis of the obtained data; qualitative, quantitative and graphical analysis of the obtained regularities of the studied indicators change from the varied factors.

Findings. The main results of the study are the following: substantiation of the relevance of the development of the auger technology for the protection of underground space; development of methods and conducting laboratory experiments in choosing the injectable solution; analysis of experimental and statistical regularities of changes in water absorption and time of plastic strength setting when varying the composition of the anti-filtration shield (concentration of fiber, bentonite, water glass); development of the concept of technology of the anti-filtration shield arrangement.

Originality. Experimental studies made it possible to establish that the minimum water absorption of the shied samples is observed at the lowest concentration of fiber (0.5 %), bentonite (1 %) and liquid glass (2 %) in the injected solution. For structures of small width (10–20 m), there are suitable compositions with a minimum time of plastic strength setting at a concentration of fiber (3 %), bentonite (5 %) and water glass (18 %). For structures with a large width (40–60 m), there are suitable compositions with a long time of plastic strength at a concentration of fiber (9 %), bentonite (5 %) and water glass (6 %).

Practical value. Experimental results made it possible to develop technological recommendations for construction of anti-filtration shields using the auger technology. Namely: to develop a concept and procedure of works, to calculate the costs of labor and machine time, to compile a list of necessary materials, machinery and equipment.

Keywords: *radiation safety, auger technology; horizontal directional drilling; anti-filtration shield; experimental statistical modeling*

Introduction. An analysis of the problems arising during the disposal of the consequences of the Chernobyl accident showed that in terms of the scale of the impact and the necessary financial and technical resources, the leading place is taken by the localization of pollution and the reduction of the emission of radioactive substances into groundwater. The arrangement of anti-filtration shields by the method of horizontal directional drilling can be used to protect groundwater from the migration of pollutants. Numerous methods have been proposed for constructing anti-filtration shields, but their analysis showed low economic and environmental efficiency. For these criteria, the use of horizontal directional drilling is preferable. In recent years, a number of technologies have been developed (injection technology by A. Petrovsky, knife technology by A. Galinsky), using horizontal directional drilling for the installation of anti-filtration shields. Exploratory studies showed that the use of auger technology can provide a more reliable shield at a lower cost for its manufacture.

Literature review. A large number of studies show that the land and groundwater in the area of 30 km around the Chernobyl accident site are contaminated with a large amount of radionuclides. Almost all radioactive elements are concentrated in the buried layer of the earth [1, 2]. Studies [3] show that groundwater is the most dangerous way of spreading radionuclides.

The arrangement of underground anti-filtration shields under sources of radioactive contamination is capable of ensuring radiation safety. Among the technologies that can provide anti-filtration protection of underground space, we should note injection of soil [4, 5], arrangement of fiber-reinforced concrete protective structures [6] and others. The most relevant for the construction of underground anti-filtration shields are technologies using horizontal directional drilling. The injection technology by A. Petrovsky [7] involves the construction of a series of pilot wells, with the help of which an injection solution is supplied, which turns the soil layer into the anti-filtration shield. However, due to the lack of a working tool, it is impossible to say with certainty that after the application of this technology the continuity of the shield is ensured, which leads to the need for excessive consumption of the injection solution. The knife technology by A. Galinsky [8] is based on the arrangement of pilot holes with the subsequent pulling of a knife along them, "cutting" the thickness of the soil. A solution is fed into the resulting cavity, which forms an anti-filtration shield. However, for the movement of the working tool in the soil, significant forces are required, which can break the already arranged sections of the shield. A possible alternative to these technologies can be a method that involves the arrangement of pilot holes and a working tool that experiences less resistance in the ground, for example, an auger.

Determination of optimal technological modes during the construction or reconstruction of engineering structures is possible with the use of experimental-statistical modeling [9, 10].

Studies on the selection of waterproof solutions show that bentonite, liquid glass, injection resins are often used for underground structures [11, 12]. In the proposed auger technology, the solutions are used to create a soil-concrete shield by mixing with the existing soil under the structure.

Unsolved aspects of the problem. It can be concluded that the problem of ensuring the radiation safety of underground space in places where radioactive elements are spread, for example, burial grounds of the remains of the Chernobyl accident, is urgent. This problem can be solved by installing underground anti-filtration shields using horizontal directional

---

drilling technologies. Similar known technologies have shown low efficiency; therefore, the development and experimental substantiation of a new effective technology that eliminates the previous disadvantages is required.

Purpose. The purpose of the study is to experimentally substantiate the efficiency of the auger technology for the construction of underground anti-filtration shields to ensure the radiation safety of facilities. This new technology can allow an economical industrial way to protect the underground space from radiation pollution. Research objectives are:

1. To substantiate the relevance and methods for developing the technology for the construction of underground anti-filtration shields to ensure the radiation safety of facilities.
2. To choose experimentally the characteristics of the recommended solution for the anti-filtration shields in terms of water absorption and time of plastic strength setting.
3. To implement the research results by developing technological recommendations for a new technology.

Methods. In this work, a technology has been developed for determining the filtration characteristics in the laboratory bench, and the analysis of the results of the studies performed on the process of creating anti-filtration shield was carried out. Analytical and graphical dependences of the indicators on the following investigated factors were determined: concentration of materials used in the solution and technological modes. It was proposed to determine the optimal composition of the supplied solution by analyzing the change in filtration characteristics depending on the components of the test solution. The study determined the optimal mode of drilling and concreting according to the cost criterion by analyzing the analytical and graphical dependences of the filtration characteristics on the technological factors under study. To implement the described tasks, a general research methodology has been developed (Fig. 1).

An underground anti-filtration shield means a structure designed to prevent flooding of polluted water, or to prevent the discharge of polluted effluents from a radiation waste containment facility. This structure consists of base soil, which acquires anti-filtration properties due to mixing of soil with solution.

The water absorption was determined by testing samples, the size and quantity of which met the requirements of the regulatory document DSTU B V.2.7-170:2008.

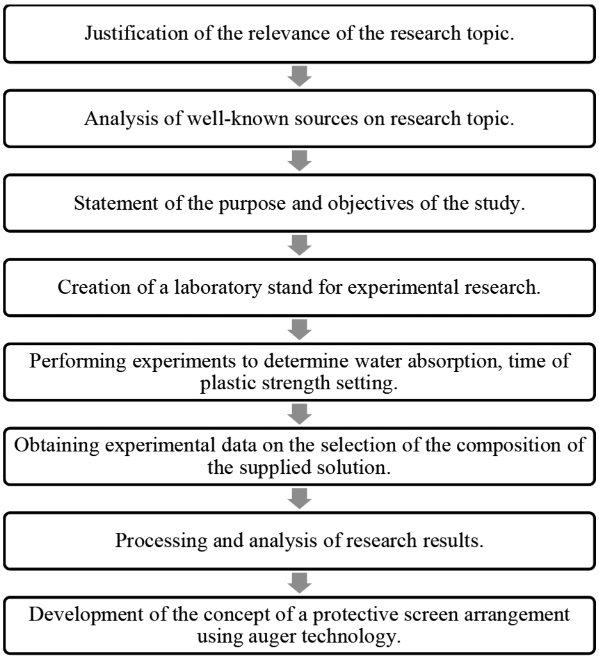


Fig. 1. General research methodology

The samples were made in the bunker of the laboratory bench using a movable auger. As a drive for rotation of the unidirectional part of the auger, a screwdriver and a hammer drill were used. The surface of the samples was cleaned of dust, dirt and traces of grease using a wire brush. Reference samples were tested dried to constant weight, after which they were placed in a vessel filled with water in such a way that the water level in it was about 50 mm higher than the upper level of the samples. The samples were placed on spacers so that their height was minimal. The water temperature in the vessel was (20 ± 2) °C. The samples were weighed every 24 hours in water on hydrostatic weighing scales. The tests were carried out until the results of two successive weighings differed by no more than 0.1 %. The water absorption of a separate sample by weight in percent is determined with an error of up to 0.1 % according to the formula

$$W_m = \frac{m_b - m_c}{m_c} \times 100,$$

where m_b is the mass of the dried sample, g; m_c is the mass of the water-saturated sample, g.

The method for determining the time of plastic strength setting consists in measuring the amount of immersion of the cone in the test material under the influence of a constant load. The cone height was 50 mm and the diameter was 70 mm. These dimensions were selected based on the conditions for the minimum influence of the walls and bottom on the value of determining the time of plastic strength setting. Plastic strength *“P_m”* (MPa) was determined through the ultimate shear stress τ by immersing a cone with a load into the studied mortar mixture to a certain depth under the action of a constant load. As a result, the contact area of the cone with the material increased, which led to a decrease in stress. Measurements were carried out every 15 min after preparation of the solution with a gradual increase in the load weight from 10 to 300 grams.

Evaluation of the plastic strength of mortar was carried out on a Rebinder plastometer, modernized by an electric drive.

The following hydrophobic and reinforcing materials were chosen for the arrangement of the anti-filtration shield:

- bentonite as a substance with the most pronounced hydrophobic properties;
- liquid glass, which penetrates into the smallest cracks and pores, strengthens concrete bases well, creates a waterproof film;
- plasticizer, which prevents stratification of the mortar mixture, and as a result, prevents the loss of hydrophobic properties of the solution;
- fiberglass fiber, which increases the binding characteristics of the solution and allows uniform reinforcement of the structure, prevents the formation of microcracks;
- hydrophobic additive that reduces water absorption, increases compressive strength and bending under torsion, increases resistance in aggressive environments.

Concrete was used with a cone draft of 16–20 cm, with a setting time of at least 2 hours, retaining mobility for 40 minutes, and a filler size of no more than 30 mm. To obtain concretes of the required technological parameters (increased mobility, cohesion and delayed setting), chemical additives were added.

The processing of the experimental results was carried out using the methods of correlation-regression analysis in the CompEx dialogue system. In the course of the analysis, the hypotheses about the equality of the present coefficients of the experimental-statistical model were tested, as well as about the adequacy of the model to the experimental data on which it was built. Student’s test (t-test) was chosen for a given level of risk ($\alpha = 0.1$) and a given number of degrees of freedom of the experiment. The model was tested for adequacy using information about the mean square error of the experiment, S_E, and the mean square error of inadequacy, S_{NA}. Fisher’s test was performed at $\beta = 0.05$. The constructed experimental-statistical models satisfied two hypotheses: all estimates of the coefficients are significant (with a given risk level α) and differ from zero. Since different factors and levels of their variation were used, own experimental plans described in the relevant sections for each experiment and experimental-statistical models were adopted, the general view of which is shown in the formula

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i=1}^{k} b_{jj} x_j^2 + \ldots + \varepsilon.$$

Results. The following factors were chosen for the study on the "water absorption" indicator: X_1 – concentration of fiber with the following values: 0.5, 1 and 1.5 %; X_2 – concentration of bentonite with the following values: 1, 2 and 3 %; X_3 – concentration of liquid glass with the following values: 2, 12 and 22 %. A series of shield samples was produced on a laboratory bench according to an optimized 15-point experiment plan. The experimental plan, the levels of variable technological factors and the results are shown in Table 1.

Based on the calculation results in the CompEx software, the following experimental-statistical model of the "water absorption" indicator was obtained. The experimental error was $S_e = 0.236$ %. Coefficients deemed as indistinguishable from zero were excluded from the model.

$$Y_1 = 17.356 + 0.590X_1 + 0.285X_1X_2 + 0.916X_2 + \\ + 0.200X_2X_3 + 3.590X_3 + 0.288X_3^2.$$

Let us consider the ranking of the degree of influence of variable factors on the indicator. According to Fig. 2, it can be seen that the degrees of influence of factors in the zone of maximum and minimum are different, although the nature of their ranking is the same.

In the zone of maximum and minimum, the factor of "concentration of liquid glass" (X_3) has the greatest influence on water absorption. At the same time, the concentrations of fiber (X_1) and bentonite (X_2) in the zone of maximum and minimum have a much smaller effect on the indicator. The influence of these factors is practically at the same level. In the minimum zone, their influence is insignificant.

Fig. 3 shows graphs of the dependence of the indicator on each of the variable factors separately.

The dependence of water absorption on the concentration of additives is directly proportional. It should be noted that within the framework of this study it is necessary to take as significant those dependencies that are obtained in the minimum zone, since the ultimate goal of the experiments is to determine the conditions under which the water absorption of the anti-filtration shield is minimal. The smallest value of the water absorption was observed with the value of the factors ($X_1 = 0.5$ %; $X_2 = 1$ %; $X_3 = 2$ %).

The patterns noted above can be observed in Fig. 4, which shows the isosurfaces of indicator changes from all variable factors in the selected factor space. An isosurface is understood as a plane on which equal values of the response function are located.

In the course of the analysis of the obtained experimental-statistical data, it was concluded that the simultaneous use of additives is inexpedient, since it is obvious that a further decrease in their amount to zero will lead to minimum water absorption (9–10 %), which corresponds to samples made of pure concrete.

The time of plastic strength setting is assumed to be the minimum time required for the plastic strength setting of the shield sample, equal to 1.5 MPa. The importance of this indicator is justified by the need to quickly solidify the shield after its installation in order to ensure continuity and, as a result, water resistance.

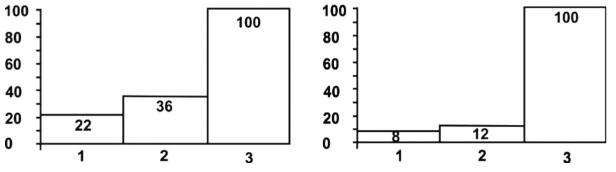
The following factors were chosen to study the "time of plastic strength setting" indicator: X_1 – concentration of fiber with the following values: 3, 6 and 9 %; X_2 – concentration of bentonite with the following values: 5, 10 and 15 %; X_3 – concentration of liquid glass with the following values: 6, 12 and 18 %. A series of prototypes was produced on a laboratory bench according to an abbreviated 15-point experiment plan. The experimental plan, the levels of variable technological factors and the results are shown in Table 2.

Based on the calculation results in the CompEx software, the following experimental-statistical model of the "time of plastic strength setting" was obtained. The experimental error

Table 1

The plan and results of the experiment to determine the effect of the injected solution composition on water absorption

#	Factor values						Water absorption Y_1, %
	Natural		Normalized				
	Concentration of fiber X_1, %	Concentration of bentonite X_2, %	Concentration of liquid glass X_3, %	X_1	X_2	X_3	
1	0.5	1	2	–1	–1	–1	12.46
2	0.5	1	22	–1	–1	1	19.24
3	0.5	2	12	–1	0	0	16.55
4	0.5	3	2	–1	1	–1	13.41
5	0.5	3	22	–1	1	1	21.23
6	1	1	12	0	–1	0	16.93
7	1	2	2	0	0	–1	13.51
8	1	2	12	0	0	0	17.28
9	1	2	22	0	0	1	20.37
10	1	3	12	0	1	0	17.81
11	1.5	1	2	1	–1	–1	12.87
12	1.5	1	22	1	–1	1	19.75
13	1.5	2	12	1	0	0	18.21
14	1.5	3	2	1	1	–1	15.20
15	1.5	3	22	1	1	1	22.65



Ranking in the maximum zone *Ranking in the minimum zone*

Fig. 2. Ranking of the degree of influence of variable factors on the water absorption rate Y_1 (the numbers show the factor indices: concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, %)

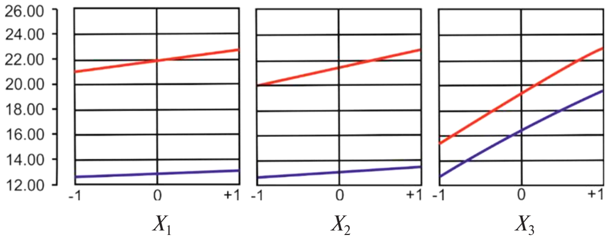


Fig. 3. Graphs of dependence of the "water absorption" indicator Y_1 on each of the factors:

concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, % (the upper line is the dependence in the maximum zone, the lower one is in the minimum zone of the indicator)

was $S_e = 5.59$ min. Coefficients deemed indistinguishable from zero were excluded from the model.

$$Y_2 = 84.971 + 5.700X_1 - 4.929X_1^2 + 2.375X_1X_2 - $$
$$- 5.125X_1X_3 - 3.100X_2 + 8.375X_2X_3 - 25.800X_3 + 15.571X_3^2.$$

Consider the ranking of the degree of influence of variable factors on the indicator. According to Fig. 5, it can be noted that the degrees of influence of factors in the maximum and minimum zones are different, although the nature of their ranking is the same.

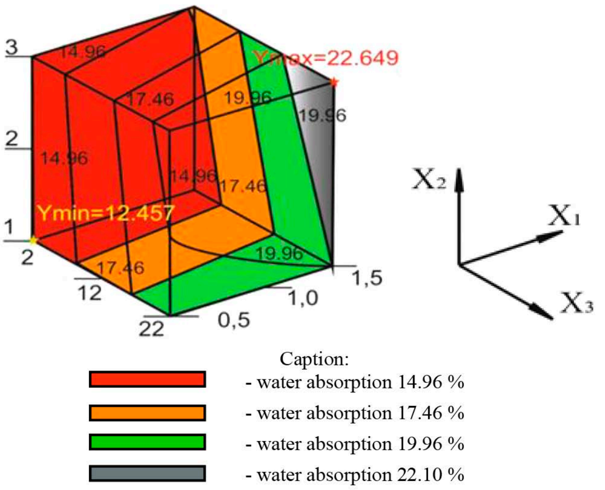
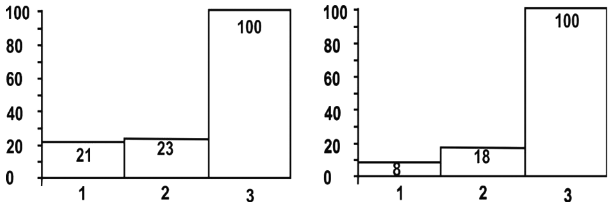


Fig. 4. Isosurfaces of water absorption values Y_1 when changing the variable factors:

concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, %



Ranking in the maximum zone *Ranking in the minimum zone*

Fig. 5. Ranking the influence of variable factors on the time of plastic strength setting Y_2 (the numbers show the factor indices: concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, %)

Table 2

The plan and results of the experiment to determine the effect of the composition of the injected solution on the time of plastic strength setting

#	Factor values						Time of plastic strength setting Y_2, min
	Natural			Normalized			
	Concentration of fiber X_1, %	Concentration of bentonite X_2, %	Concentration of liquid glass X_3, %	X_1	X_2	X_3	
1	3	5	6	–1	–1	–1	126
2	3	5	18	–1	–1	1	66
3	3	10	12	–1	0	0	80
4	3	15	6	–1	1	–1	90
5	3	15	18	–1	1	1	73
6	6	5	12	0	–1	0	81
7	6	10	6	0	0	–1	132
8	6	10	12	0	0	0	85
9	6	10	18	0	0	1	71
10	6	15	12	0	1	0	87
11	9	5	6	1	–1	–1	141
12	9	5	18	1	–1	1	69
13	9	10	12	1	0	0	82
14	9	15	6	1	1	–1	124
15	9	15	18	1	1	1	76

Approximately the same influence of factors on the studied indicator is observed in the maximum and minimum zones. The greatest influence is exerted by the concentration of liquid glass (X_3). At the same time, the concentrations of fiber and bentonite in the solution do not play a significant role in the change in the indicator.

Dependences of the time of plastic strength setting changes under the variation in the concentration of fiber X_1 and bentonite X_2 are of different nature in the maximum and minimum zones of the indicator. In view of their insignificant influence on the investigated indicator, one can restrict oneself to considering the zone of minimum, since the condition for a faster setting of strength is defined. Based on the graphs, it can be seen that at the values $X_1 = 3$ and $X_2 = 5$ %, the maximum time of plastic strength setting is achieved.

The nature of the dependence of the concentration of liquid glass X_3 on the time of plastic strength setting can be called close to parabolic. However, an inversely proportional relationship is clearly noticeable – with an increase in the concentration of liquid glass X_3, the time of plastic strength setting decreases. The fastest setting of plastic strength is observed at a concentration of liquid glass $X_3 = 18$ %.

The patterns noted above can be observed in the complex in Fig. 7, which shows the isosurfaces of changes in the indicator from variable factors in the selected factor space.

The data obtained made it possible to determine the solution for structures of different widths.

For structures of small width (10–20 m), solutions with minimum time of plastic strength setting with the following values of factors are suitable: $X_1 = 3$ %; $X_2 = 5$ %; $X_3 = 18$ %. For structures of large width (40–60 m.), solution with maximum time of plastic strength setting are suitable, in order to be able to concretize an extended section, with the following values of factors: $X_1 = 9$ %; $X_2 = 5$ %; $X_3 = 6$ %.

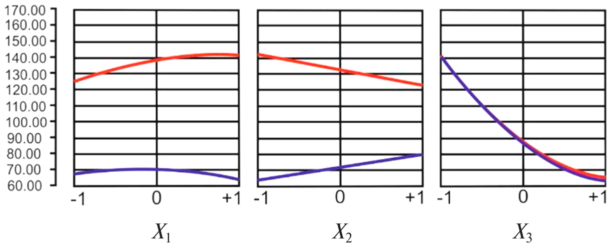


Fig. 6. Graphs of dependence of the time of plastic strength setting Y_2 on each of the factors:

concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, % (the upper line is the influence in the maximum zone, the lower one is in the minimum zone of the indicator)

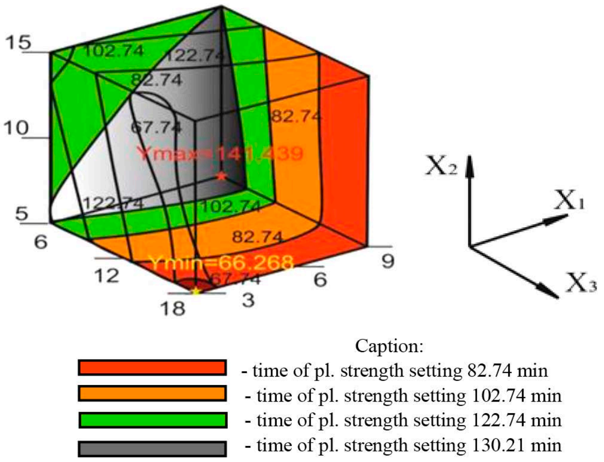


Fig. 7. Isosurfaces of time of plastic strength setting values Y_2 under changing the variable factors:

concentration of fiber X_1, %; concentration of bentonite X_2, %; concentration of liquid glass X_3, %

Application of the auger technology of the anti-filtration shield arrangement to ensure radiation safety. This conception has been developed for the use of the auger technology for the arrangement of anti-filtration shields under various structures that pose a radiation hazard: repositories of radioactive waste, sedimentation tanks, reactors and other structures. It is also possible to use the technology to protect important facilities from flooding by radiation-contaminated groundwater.

The concept of using the auger technology is as follows. Drilling of technological wells is carried out in a staggered manner and in two stages with minimal impact on the foundation of the existing building. At the first stage, wells are drilled in a curvilinear manner, authentically to the bottom of an existing building or structure. The required inclination of the wells is determined taking into account the depth of the foundation and the width of the area that is used for protective work. The step of the wells depends on the width of the structure and the geological conditions of the anti-filtration shield arrangement and varies from 1 to 2 meters. The depth of technological wells is determined taking into account the intersection of two opposite planes in the lower level of the anti-filtration shield and their mutual conjugation. The location of the wells of two planes, relative to each other, is advisable to perform with ligation to ensure their conjugation when crossing.

After reaching the drilling depth, a slot is formed when the soil drilled by the auger is washed away. At the same time, a hardening solution is supplied to the auger through the rods, which fill the slot, during the reverse penetration. The drilling rig evenly lifts the rotating auger using guide rods. The hydraulic motor drives the auger, which is attached to the drill rods.

The developed technological methods allow using the new technology to ensure radiation safety by effective protecting of buildings and structures from groundwater, and groundwater from contamination with radioactive waste.

Conclusions.

1. The data on the state of radioactive waste disposal facilities in Ukraine indicate that the development, experimental substantiation and arrangement of anti-filtration shields to prevent the spread of groundwater contaminated with radionuclides are relevant.

2. The minimum value of water absorption is observed at the lowest concentration of additives in the concrete of the anti-filtration shield (concentration of fiber 0.5 %, bentonite 1 %, liquid glass 2 %).

3. For small width structures (10–20 m), the solutions are suitable with maximum time of plastic strength setting at concentration of fiber 3 %, bentonite 5 %, liquid glass 18 %. For large width structures (40–60 m), the solutions are suitable with minimum time of plastic strength setting, in order to be able to concreting an extended section, with concentration of fiber 9 %, bentonite 5 %, liquid glass 6 %.

4. The developed concept of the auger technology for the arrangement of anti-filtration shields allows the technology to be used in industrial production.

References.

1. Bugai, D., Skalskyy, A., Dzhepo, S., Kubko, Y., Kashparov, V., Van Meir, N., & Martin-Garin, A. (2012). Radionuclide migration at experimental polygon at Red Forest waste site in Chernobyl zone. Part 2: Hydrogeological characterization and groundwater transport modeling. *Applied Geochemistry, 27*(7), 1359-1374. https://doi.org/10.1016/j.apgeochem.2011.09.028.

2. Roux, C., Le Gal La Salle, C., Simonucci, C., Van Meir, N., Keith Fifield, L., Diez, O., & Lancelot, J. (2014). High 36Cl/Cl ratios in Chernobyl groundwater. *Journal of Environmental Radioactivity, 138*, 19-32. https://doi.org/10.1016/j.jenvrad.2014.07.008.

3. Le Gal La Salle, C., Aquilina, L., Fourre, E., Jean-Baptiste, P., Michelot, J.-L., Roux, C., & Lancelot, J. (2012). Groundwater residence time downgradient of Trench No. 22 at the Chernobyl Pilot Site: Constraints on hydrogeological aquifer functioning. *Applied Geochemistry*, *27*(7), 1304-1319. https://doi.org/10.1016/j.apgeochem.2011.12.006.

4. Shui-Long Shen, Zhi-Feng Wang, Suksun Horpibulsuk, & Yong-Hyun Kim (2013). Jet grouting with a newly developed technology: The Twin-Jet method. *Engineering Geology, 152*(1), 87-95. https://doi.org/10.1016/j.enggeo.2012.10.018.

5. Makovetskiy, O., & Zuev, S. (2016). Practice Device Artificial Improvement Basis of Soil Technologies Jet Grouting. *Procedia Engineering, 165*, 504-509. https://doi.org/10.1016/j.proeng.2016.11.726.

6. Bernard, E. S., & Thomas, A. H. (2020). Fibre reinforced sprayed concrete for ground support. *Tunnelling and Underground Space Technology, 99*, 103-108. https://doi.org/10.1016/j.tust.2020.103302.

7. Meneylyuk, A., Petrovskiy, A., Borisov, A., & Nikiforov, A. (2017). Innovative technology of horizontal protective shield arrangement using injection. *Electronic Journal of the Faculty of Civil Engineering Osijek (e-GFOS), 15*, 36-49. https://doi.org/10.13167/2017.15.4.

8. Galinsky, A., Chernukhin, A., & Meneylyuk, A. (2016). Improvement of constructive and technological solutions for the localization of soil pollution sources. *Bulletin of Odesa State Academy of Construction and Architecture,* (63), 309-315.

9. Lyashenko, T., & Dovgan, A. (2017). Isoparametric analysis when studying composite materials. *Bulletin of Odesa State Academy of Civil Engineering and Architecture*, (66), 72-78.

10. Lyashenko, T., & Antoniuk, N. (2020). Multicriterial search for rational solutions when developing building composites. *Bulletin of Odesa State Academy of Civil Engineering and Architecture*, (79), 99-108.

11. Xu, L., Ye, W., Chen, B., Chen, Y., & Cui, Y. (2016). Experimental investigations on thermo-hydro-mechanical properties of compacted GMZ01 bentonite–sand mixture using as buffer materials. Engineering *Geology, 213*, 46-54. https://doi.org/10.1016/j.enggeo.2016.08.015.

12. Nowamooz, H. (2016). Resin injection in clays with high plasticity. *Comptes Rendus Mécanique, 344*(11-12), 797-806. https://doi.org/10.1016/j.crme.2016.09.001.

Вибір ін’єкційного розчину для шнекової технології захисту підземного простору від забруднення

О. І. Менейлюк[1], *О. Л. Нікіфоров*[1], *І. О. Менейлюк*[2], *В. В. Руссий*[1]

1 – Одеська державна академія будівництва та архітектури, м. Одеса, Україна, e-mail: nikiforov.aleksey@yahoo.com
2 – Харківський національний університет будівництва та архітектури, м. Харків, Україна

Мета. Дослідження присвячене експериментальному вибору ін'єкційного складу для шнекової технології влаштування підземних протифільтраційних екранів під джерелом забруднення. Шнекова технологія улаштування протифільтраційного екрану полягає в утворенні напрямних свердловин методом горизонтально направленого буріння з подальшим влаштуванням водонепроникного шару за допомогою заміни ґрунту шнеком на спеціальний бетонний розчин.

Методика. В якості основного методу дослідження вибрано експериментально-статистичне моделювання, що включає в себе: проведення лабораторних випробувань; кореляційно-регресійний аналіз отриманих даних; якісний, кількісний і графічний аналіз отриманих закономірностей зміни показників, що досліджуються, від варійованих факторів.

Результати. Основними результатами дослідження є наступні: обґрунтування актуальності розробки шнекової технології захисту підземного простору; розробка методики та проведення лабораторних експериментів з підбору ін'єкційного складу; аналіз експериментально-статистичних закономірностей зміни водопоглинання та пластичної міцності при варіюванні складом протифільтраційного екрана (концентрація фібри, бентоніту, рідкого скла); розробка концепції шнекової технології влаштування протифільтраційних екранів.

Наукова новизна. Експериментальні дослідження дозволили встановити, що вологостійкість зразків екрану спостерігається при найменшій концентрації фібри (0,5 %), бентоніту (1 %) і рідкого скла (2 %) в ін’єкційному розчині. Для споруд невеликої ширини (10–20 м) підходять розчини з мінімальним часом набору пластичної міцності при концентрації фібри (3 %), бентоніту (5 %) і рідкого скла (18 %). Для споруд великої ширини (40–60 м) підходять розчини з великим часом набору пластичної міцності при концентрації фібри (9 %), бентоніту (5 %) і рідкого скла (6 %).

Практична значимість. Експериментальні результати дозволили розробити технологічні рекомендації із влаштування протифільтраційних екранів за допомогою шнекової технології. А саме: розробити концепцію й порядок виконання робіт, розрахувати витрати праці й машинного часу, скласти перелік необхідних матеріалів, машин і обладнання.

Ключові слова: *радіаційна безпека, шнекова технологія, горизонтально направлене буріння, протифільтраційний екран, експериментально-статистичне моделювання*

Recommended for publication by V. A. Halushko, Doctor of Technical Sciences. The manuscript was submitted 31.01.21.