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RESEARCH OF TECHNOLOGY FOR CREATING EXTERNAL WATERPROOFING BY INJECTION OF UNDERGROUND STRUCTURE

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In case of damage or lack of waterproofing, structures will lose their operational properties and collapse. In addition, high humidity has a negative effect on people who are there. It is appropriate to study the effectiveness of the waterproofing creating technology by injecting the material outside the structure. To this end, a number of experimental laboratory studies were performed. The waterproofing properties of the material were tested. Based on the obtained results, practical recommendations were formed for the use of improved technology of external waterproofing of underground structures.

Keywords: waterproofing, underground structures, injection, polyurethane material, research technologies, reconstruction, restoration

Introduction

Ukraine has been subjected to military aggression by the armed forces of the Russian Federation for more than 11 years, of which military operations have been taking place on the vast majority of the country's territory for more than three years. During the announcement of numerous air alert, the people, in order to protect itself from the possible impact of an explosion, shrapnel and the action of an explosive wave, hides in the nearest underground structures or premises, such as special purpose structures, underground passages, or basements or parking lots of buildings.

In accordance with Order № 579 dated 07/09/2018 On approval of requirements for the use and accounting of the fund of protective structures of civil protection [1] and Resolution of the Cabinet of Ministers of Ukraine dated March 10, 2017 № 138 on the Procedure for the creation, maintenance of the fund of protective structures of civil protection and keeping its records [2], certain requirements are put forward for means of collective protection namely, to protective structures of civil protection (storage and anti-radiation shelters), dual-purpose structures and the simplest shelters.

These include the following requirements:

- the structures of the fund of protective structures must be protected from flooding by groundwater;
- the tightness of the storage is achieved by ensuring the integrity of the enclosing protective structures (coverings, ceilings, walls, partitions, floors, foundations), the places of connections between them, waterproofing, the serviceability of the protective devices of the openings of entrances and exits, embedded parts in the places where communications are entered (water supply, heating, sewage, cables and other equipment), anti-explosive devices of ventilation systems, as well as compliance of the normal temperature and humidity regime in the premises of the protective structure;
- waterproofing, drainage and paving around the perimeter of the protective structure, as well as drainage pipes must be kept in good condition and protect the underground structure from the negative effects of atmospheric precipitation and groundwater;

- in case of detection of soaking of building structures, or flooding individual parts of the protective structure, it is necessary to take measures to restore the waterproofing properties of the underground structure;

- if possible, ongoing repair of the outer waterproofing layer is carried out. Premises that are exposed to moisture or an aggressive environment require urgent repairs.

Taking into account these recommendations, it is necessary to keep special purpose buildings in proper condition. However, if the premises or structure is not included in the list of special protective structures, these requirements are often not fully observed.

In accordance with the goals of sustainable development, the repair of buildings and structures, including underground ones, for the purpose of creating or restoring a waterproofing layer is a more sustainable option than the demolition and construction of new structures. To ensure sustainable development, when choosing repair work, it is necessary to focus on various aspects, such as reducing the negative impact on the environment, creating comfortable conditions for people, ensuring the durability of the use of building structures, etc.

Experience in surveys of a large number of construction sites indicates that a large part of underground premises and structures have damage in the form of impregnation and infiltration of water inside of the premises. Since such damage is often repaired out of time, this leads to the appearance of significant areas of wetting of structures; damage and peeling of facing; corrosion of reinforcement, embedded parts and the body of the structure; biological corrosion – presence of mold, mold, fungi, etc. (Fig. 1.). Over time, this leads to the loss of operational properties by structures and can cause their premature destruction. That is, such buildings require immediate repair and restoration works within the framework of reconstruction, restoration or major repairs. And the long-term stay of people in rooms with high humidity and existing biological corrosion have a significant negative impact on the human body. Also, increased humidity in the premises helps to accelerate damage to the technological equipment located in it.

In general, the absence or damage of waterproofing leads to deterioration of the physical and mechanical properties of the materials of structural elements, sanitary and hygienic conditions, and the safety and quality of people's stay indoors. This issue becomes especially relevant during martial law. Therefore, waterproofing of structures is an important component of the building, which requires timely repair. Thus, the research and development of effective technologies for creating waterproofing of existing underground structures is an important direction that will contribute to increasing their operational stability and durability.

Analysis of scientific and technical literature shows [3-10] that the most common places where underground parts of a building or structure are blocked are places where structural elements of the ceiling, walls and floor adjoin each other. At the same time, the main factors of external influence include the – high level of groundwater and, as a result, their infiltration through the body of the structure, technological holes or adjacencies, capillary absorption of structures with material, the absence of a drainage system, the absence of paving, etc. Internal sources of soaking include condensation of water vapor, hygroscopic moisture intake by wall and floor materials, insufficient ventilation of premises, etc.

DSTU 9253:2023 [10] regulates the requirements for the installation of waterproofing of underground structures. At the same time, depending on the level of ensuring the requirements of durability and reliability of waterproofing, three degrees of waterproofing protection of structures of buildings and structures have been established:

- first stage – protection of the structure by surface or bulk waterproofing;
- second stage – first stage waterproofing protection and additional arrangement of bulk or floor waterproofing;
- third stage – waterproofing protection of the second stage and additional installation of a waterproofing barrier outside the insulated surface of the structure.

It is important to note that during the construction of a new building, waterproofing protection is arranged on the outer surface of buried structural elements. And if it is necessary to repair the waterproofing of existing buildings or structures, a number of problems arise related to accessibility to the outside of the structures.

In general, three main methods are used to restore waterproofing of buried parts of buildings and structures:

1) excavation of soil with exposure of the outer surface of structures followed by application of waterproofing materials using traditional techniques;

2) arranging waterproofing on the inside of the room, by applying waterproofing materials working at negative pressure on the inside of the building;

3) injecting waterproofing materials into the body of the structure or into the contact zone between the soil and the structure.

(a) (b)

(c) (d)

(e) (f)

Fig. 1. Damage to structural elements of underground structures due to the action of moisture: (a), (b) – infiltration of water through the seams of structures; (c) – mold; (d) – corrosion of reinforcement; (e) – corrosion of engineering networks; (f) – damage to equipment and mold

The use of the first method is advisable if there is free space around the building or structure, because the process of excavating the soil often requires the use of special construction equipment. However, in the city, in the vast majority of cases, such work will be performed in compacted conditions. Therefore, it is necessary to take into account their possible impact on the adjacent buildings and the surrounding area, on the transport infrastructure of the city, the quality and comfort of people who will be near the area of operation of repair works. Accordingly, the use of this method can be long-term, expensive and require significant labor costs. At the same time, such technology disrupts the sustainable environment and does not allow the use of such structures as shelters at the stage of repair work.

The use of the 2nd method is appropriate, provided that it is impossible to use the first. The second method of installing waterproofing includes painting, plastering, pasting, penetrating and other types of waterproofing. However, this method has a number of significant disadvantages, namely:

- only the inner surface of the structures is protected from the influence of water, and the body of the structures continues to be under the influence of an aggressive environment and, as a result, is subject to destruction;
- often the installation of internal waterproofing has a short-term effect, which can be related both to the external influence (pressure) of the water and to the quality of the work;
- sometimes the arrangement of internal waterproofing helps to reduce the internal space, affects the aesthetic appearance of the premises, etc.;
- when installing waterproofing, it is necessary to vacate the room for a certain time and limit people's access to it, etc.

An actively developing direction is the installation of waterproofing by injection. Wherein the waterproofing material is introduced to the body of the structure or beyond it into the soil contact zone [11] by means of injectors arranging holes drilled in the design locations.

When performing research in this area, the following scientific works were analyzed [12-15].

Research Methodology

The construction market offers a wide range of injectable materials that can be divided into: polyureton resins; acrylate gels and microcements.

By injection, it is possible to achieve the creation of an external waterproofing layer and the sealing of junctions and damages in the form of cracks, cavities, etc. However, the effectiveness of injection technology depends on a number of factors, including: the type of material of the structure, injection pressure, hydro-geological conditions in which the structure or building is located, etc. In this regard, the need to investigate the technology of injecting waterproofing materials to improve the efficiency of their use is relevant. Therefore, a number of experimental studies aimed at improving the existing technology of injection of polyurethane resins were carried out, taking into account the most common factors that can affect the quality of work.

The experimental research program consisted of five phases:

- study of the effect of soil moisture on the rate of polymerization of the injectable material;
- study of the spread nature of polyurethane resin in sand with different degrees of humidity (6%, 12%, 20%);
- dependence of the geometric parameters of the formed polymer-sand structure on the volume of the injected mixture;
- study of the adhesion strength of the formed polymer-sand structure to the structure;
- study of waterproofing properties of the material.

A one-component polyurethane injection resin DE NEEF® HA Flex LV AF (GCP Applied Technologies [16]) was selected as the test material. The injectable mixture was prepared immediately prior to injection according to the manufacturer's recommendations.

Results and Discussion

At the first stage of research, the influence of water content in the soil on the rate of polymerization of the selected material was established. Sand with its preliminary moisture was used as a soil model (the determination of soil moisture parameters was performed in accordance with DSTU B V.2.1-17:2009): dry – relative humidity 6 %, wet – 12 % and 20%. The choice of soil type is based on the analysis of the results of reports the of buildings and structures inspection, which indicates the emergence of problems in the form of soaking when structures are located in sandy soils.

To perform the study, a small amount of material was added to the sand of the appropriate humidity, and the start of the reaction with time was observed. The results of the study are given in the table 1.

Table 1

Dependence of the duration of material polymerization on soil moisture

Time, min	Dry sand (humidity 6%)	Wet sand (humidity 12%)	Wet sand (humidity 20%)
	Description of changes		
0	Without structural changes	Without structural changes	Without structural changes
2	-	The beginning of foam formation	-
2.2	The beginning of foam formation	-	-
2.4	-	-	The beginning of foam formation
7	-	Completed polymerization	-
10	Completed polymerization	-	-
15	-	-	Completed polymerization

According to the results of the study, it was established that the moisture content is one of the key factors that determines the effectiveness of the use of the investigated polyurethane foam resin when creating waterproofing from it. At the same time, optimal conditions are achieved with an average level of moisture in the sand. The results obtained could serve as a basis for the development of practical recommendations in this area.

To carry out the second experimental study, experimental stands were made, which were rectangular containers, which were filled with sand of medium size of the appropriate humidity with layer-by-layer tamping (Fig. 2). A hole was drilled in the lower part of the stand, imitating a horizontal structure, through which the injection of waterproofing material was subsequently performed. After the polymerization of the material, the excavation of polymer-sand massifs was performed to establish the nature of the distribution of the material (Fig. 3).

The sample volume measurements were performed and the expansion coefficient was established (Table 2).

The analysis of the obtained data allows us to state the presence of a pronounced dependence between the degree of soil moisture and the nature of the formation of the polymer structure. Thus, in dry sand, the expansion of the material was the smallest, the percentage of expansion was 153%, in wet sand (humidity 12 %) the expansion was 320%, and in wet sand (humidity 20 %) it was 438%. Dependence can be tracked on a graph (Fig. 4).

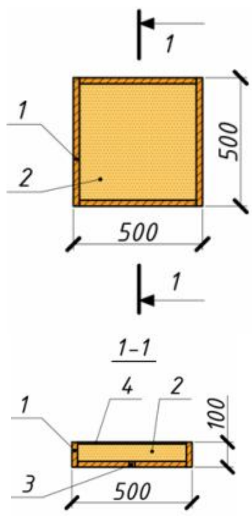
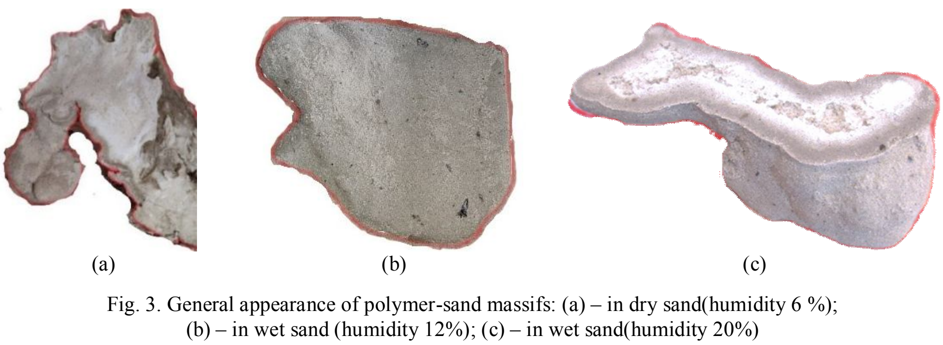


Fig. 2. Scheme of the experimental stand: 1 – wooden formwork; 2 – sand; 3 – injection hole; 4 – cover

The spread pattern of the material in dry (humidity 6%) and wet sand (humidity 20%) was similar – in the vertical direction, while in wet sand (humidity 12%) the material spread most horizontally.



(a) (b) (c)

Fig. 3. General appearance of polymer-sand massifs: (a) – in dry sand(humidity 6 %); (b) – in wet sand (humidity 12%); (c) – in wet sand(humidity 20%)

Table 2

Change in material volume depending on soil moisture

Relativesand moisture	Volume of injected material (l)	Volumeformed material (cm^3)	Expansion factor
Dry sand (humidity 6 %)	0.4	611	1.53
Wet sand (humidity 12%)	0.4	1281	3.2
Wet sand (humidity 20%)	0.4	1750	4.38

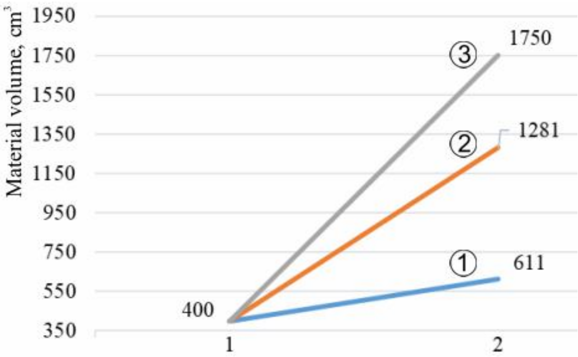


Fig. 4. Dependence of material volume change on soil moisture: blue line (1)– dry sand (humidity 6%); orange line (2) – wet sand (humidity 12%); grey line (3) – wet sand (humidity 20%)

In the third stage, the maximum possible horizontal spread of polyurethane foam resin in the soil environment was investigated and the size dependences of the formed polymer-sand structures on the mass of the injected material were constructed, namely 400 g, 1600 g and 5000 g. For this study, taking into account the obtained data of previous studies, wet sand (humidity 12%) was used. Injection was performed at low pressure with a special pump to distribute the material evenly over the horizontal plane. The results of the study are given in the Table 3.

After the study, polymer-sand massifs were excavated and their visual inspection was performed (Fig. 5).

Table 3

Dependence of distribution of polyurethane foam resin in wet sand depending on its mass

Resin mass, g	Length, cm	Width, cm	Square, cm^2	Height, cm	Injection time, s
400	26	23	451	2	60 sec
1600	45	34	986	6	3 min 45 sec
5000	36	36	757	10	11 min 40 sec

It is worth noting that the study was aimed at determining the spreading range of the material depending on the injected volume, and the increase in volume was not investigated. Therefore, the analysis of the results indicates the following. In all cases, the material has a uniform horizontal spread to form smooth, well-defined edges, indicating high fluidity of the material under given conditions. The formed arrays are homogeneous in appearance, dense, without visible structural defects.

(a) (b) (c)

Fig. 5. General appearance of polymer-sand massifs: (a) – 400 g; (b) – 1600 g; (c) – 5000 g

The material was found to spread well during the first two minutes. Thereafter, active foaming and increasing of the material in volume begins without substantially increasing the spread area. Complete hardening of the material is observed 7 min from the start of injection (Fig. 6). That is, the waterproofing injection material has a spreading limit, which is due to the properties of the material and the conditions of its injection. This can be clearly traced by superimposing the areas of spreading of materials one on top of the other (Fig. 7).

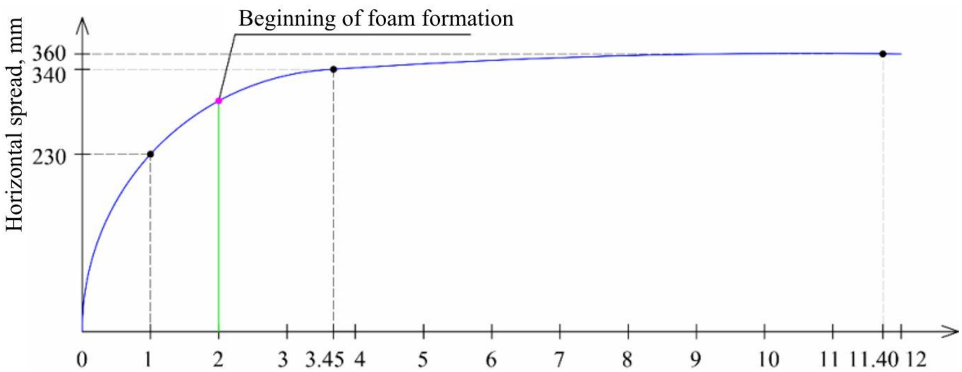


Fig. 6. Dependence of horizontal spread of material on duration of injection

The analysis of the obtained results made it possible to determine the area of overlap of the spreading boundaries, which forms the area of guaranteed filling of the environment with the injected material. The diameter of this area is 260 mm, which corresponds to a radius of guaranteed spread of 130 mm.

In the fourth step, the adhesion of the material to the structure was tested. To do this, the material was applied to the concrete structure, and then, with the help of an adhesion meter, the adhesive strength of the adhesion was determined with the fixation of values. It has been established that the type of connection – is adhesion-cohesion, that is, the destruction occurs partly in the body of the material and partly at the border of contact with the concrete structure. The values of adhesion strength are on average 0.08 MPa, which is sufficient and ensures reliable fixation of the material on the structure.

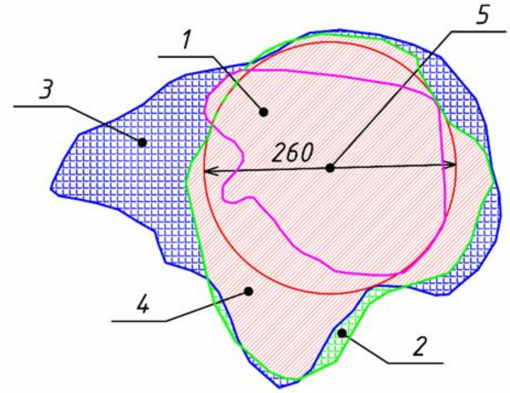


Fig. 7. The radius of the guaranteed horizontal distribution of the material, provided it is injected on a horizontal plane, where: 1 – 400 g of material; 2 – 1600 g of material; 3 – 5000 g of material; 4 – material overlap area (common zone for injection zones); 5 – injection point

In the last step of the experimental studies, the waterproofing properties of the formed polymer-sand arrays were tested [17]. For this purpose, a special stand was designed consisting of a container of water located at a height of 2.2 m above the test piece, a rubber tube combined with the container and the test piece. Fixation of the tube to the sample was performed through a cylindrical metal mold using epoxy glue to avoid water leakage through the contact zone (Fig. 8).

The water column level produced a hydrostatic pressure of 21.6 kPa (0.2 atm). The specified pressure was maintained for 100 days, during which a constant visual inspection of the surface of the sample was performed to establish possible leaks and water absorption. The results indicate that the material is an excellent waterproofing, since no changes in structure, locks, etc. were recorded.

Based on the results of laboratory experimental studies, practical recommendations were formed for the use of improved technology of external waterproofing of horizontal underground structures (at the boundary of the structure and the soil), which consisted of the following. At the initial stage, if necessary, repair structural elements. In the project places, holes are drilled to the entire thickness of the structure. At the same time, the holes should be arranged in a checkerboard pattern, and their pitch should be 200 mm (Fig. 9).

Fig. 8. Study of waterproofing properties of polymer-sand massif

The optimal level of soil moisture is 12%. Provided that the soil is excessively dry, it must be pre-moistened by water injection before injection. In this case, it is worth leaving the holes in the structure open for a few days to allow excess water to drain.

Install injection nozzles in the cleaned holes and perform material injection using special equipment. The volume of injection material should be 1.6-2.0 kg/nozzle. The duration of injection of one opening is no more than 4 minutes. After injection, the packers must be dismantled and the surface is finished.

The advantage of this technology is the possibility of its application in separate areas (occupations) without the need to completely free the premises from, for example, technological equipment, interior items, or without restricting access for people.

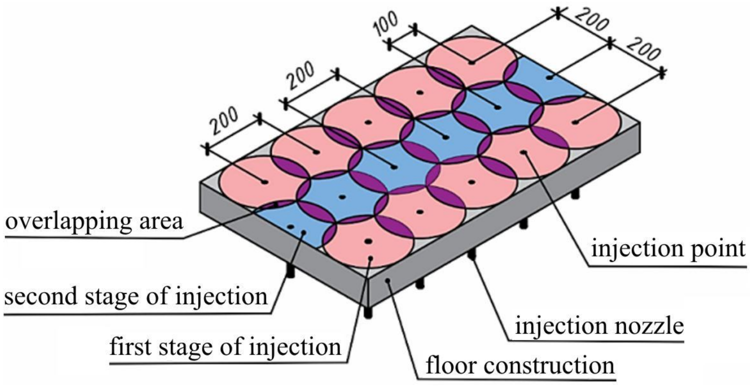


Fig. 9. Scheme of installation of waterproofing above horizontal structures

Conclusion

In the conditions of military operations taking place almost throughout the territory of Ukraine, the creation of comfortable and safe conditions in the underground premises of buildings or structures for the stay of people in them during the threat of shelling by the russian armed forces is an urgent issue.

A frequent problem of such rooms is high humidity and water leakage through seams, joints, cracks, cavities of structural elements of the building, especially through the celling. These damages have a negative impact on structures, people and equipment, so there is a need to eliminate them.

One way of arranging waterproofing is to inject polymeric materials outside the structures to create an outer waterproofing shell. However, such technology requires additional research depending on the conditions of work, the choice of injection material, etc. In connection with the above, a number of experimental studies were developed and performed to establish the possibility of using polyurethane material using injection technology to create a waterproofing layer over horizontal structures of the type of celling plates. Studies have established that the chosen injection material is most effective for creating a waterproofing shell, provided it is used in wet soils (sands) (12 %). Provided there is dry or excessively wet soil, the use of the material is not advisable. Material propagation pattern (at 12 % soil moisture) – uniform disc-shaped barrier with a propagation radius of up to 130 mm provided 1.6 to 2.0 kg is injected. The adhesion strength to the base is 0.08 MPa, which is sufficient for the installation of waterproofing. The material has high waterproofing properties (no leakage at a pressure of 21.6 kPa for 100 days).

The obtained results made it possible to develop practical recommendations for the installation of injection waterproofing, which will allow the formation of a waterproof barrier and prevent further moisture and damage to structures, will provide comfortable conditions for people. However, despite the obtained results, the technology of installing external horizontal waterproofing of reinforced concrete structures requires further research to improve it and expand the scope of application.

REFERENCES

1. Nakaz № 579 vid 09.07.2018 Pro zatverdzhennia vymoh z pytan vykorystannia ta obliku fondu zakhysnykh sporud tsyvilnoho zakhystu (Order № 579 dated 07/09/2018 On approval of requirements for the use and accounting of the fund of protective structures of civil protection)
2. Postanova Kabinetu Ministriv Ukrainy vid 10 bereznia 2017 r. № 138 pro Poriadok stvorennia, utrymannia fondu zakhysnykh sporud tsyvilnoho zakhystu ta vedennia yoho obliku (Resolution of the Cabinet of Ministers of Ukraine dated March 10, 2017 № 138 on the Procedure for creating, maintaining a fund of protective structures of civil protection and keeping its records).
3. Obstezhennia doshkilnoho navchalnoho zakladu № 435 dytiachyi sadok kompensuiuchoho typu (spetsialnyi) dlia ditei z porushenniamy movy za adresoiu m. Kyiv, Podilskyi raion, vul. Mezhova, 22a (Examination of a preschool educational institution № 435 kindergarten of compensatory type (special) for children with language disorders at the address of. Kyiv, Podilsky district, str. Mezhova, 22a) /KNUBA, Center for Engineering and Expertise. - Kyiv: KNUBA, 2024. - 41 p.
4. Obstezhennia Andrushivskoho litseiu № 1 z pochatkovoiu shkoloiu Berdychivskoho raionu Zhytomyrskoi oblasti za adresoiu m. Andrushivka, vul. Sadova, 1 (Examination of the Andrushiv Lyceum № 1 with an elementary school in the Berdychiv district of the Zhytomyr region at the address of. Andrushivka, str. Sadova, 1) /KNUBA, Center for Engineering and Expertise. - Kyiv: KNUBA, 2023. - 22 p.
5. Obstezhennia pidzemnoi chastyny budivel dlia vstanovlennia prychyn zamokan ta nadannia rekomendatsii z yikh likvidatsii po vul. Svitla, 3D v Darnytskomu r-ni m. Kyieva (Inspection of the underground part of the buildings to establish the causes of lockings and provide recommendations for their liquidation on the street. Svitla, 3D in Darnytskyi district,. Kyiv) /KNUBA, Center for Engineering and Expertise. - Kyiv: KNUBA, 2023. - 47 p.
6. Obstezhennia tekhnichnoho stanu dilianky steli u prymishchenni mahazynu v pidzemnomu perekhodi st. m. Dorohozhychi po vul. Oleny Telihy, 14A u m. Kyievi (Examination of the technical condition of the ceiling area in the store premises in the underground passage of Art. m. Dorohozhichi on the street. Olena Teliga, 14A in. Kyiv) /KNUBA, Center for Engineering and Expertise. - Kyiv: KNUBA, 2022. - 47 p.
7. Molodid O., Kovalchuk O., Skochko V., Plokhuta R., Molodid O., Musiiaka I. Inspection of war-damaged buildings and structures by the example of urban settlement Borodianka /Strength of Materials and Theory of Structures. 2023. № 110 – C. 328-343
8. O. Molodid, V. Skochko, R. Plokhuta, O. Molodid, I. Musiiaka, S. Benderskyi, S. Bogdan. Modern Restoration Methods for Damaged Historical Buildings As A Result of Military Aggression. Case of Educational Institutions, International Journal of Conservation Science, 15(1), 2024, pp. 205-220. DOI: 10.36868/IJCS.2024.si.17.
9. Nazarevich B. L. Tekhnolohiia vlashtuvannia horyzontalnoi hidroizoliatsii v budivliakh staroi zabudovy (The technology is arranged by horizontal waterproofing in buildings of old buildings) /B. L. Nazarevich, Y. Y. Luchko //Modern technologists, materials and constructives in the building - 2009. - Vol. 6, № 1. - P. 77 – 89
10. DSTU 9253:2023 Nastanova z proiektuvannia hidroizoliatsii pidzemnykh budivelnykh konstruktsii (Guidelines for the design of waterproofing of underground building structures). [Valid from 01.05.2024]. Kyiv: State Enterprise "UkrNDNTs", 2023 () (in Ukrainian)
11. Rishennia dlia hidroizoliatsii hidrotekhnichnykh sporud: budivnytstvo, remont, ekspluatatsiia (Solutions for waterproofing hydraulic structures: construction, repair, operation) [Electronic resource] / Sika Ukraine. - Kyiv, 2021. - 28 p. Access mode: https://ukr.sika.com/dam/dms/ua01/q/sikai_dams.pdf. - Date of access: 05/13/2025 () (in Ukrainian)
12. Kovalchuk, O., Grabovchak, V., Govdun, Y. (2018) Alkali activated cements mix design for concretes application in high corrosive conditions. MATEC Web of Conferences, 230,03007. DOI. 10.1051/matecconf/201823003007.
13. Provis, J.L., Muntingh, Y., Lloyd, R.R., (...), Krivenko, P.V., Van Deventer, J.S.J. (2008) Will geopolymers stand the test of time?. Ceramic Engineering and Science Proceedings, 28(9), c. 235-248.
14. Priadko, I.N., Mushchanov, V.P., Bartolo, H., Vatin, N.I., Rudnieva, I.N. (2016). Improved numerical methods in reliability analysis of suspension roof joints. Magazine of Civil Engineering, 65(5), 27–41.
15. Bushuyev, S., Murzabekova, A., Murzabekova, S., Khusainova, M. (2017) Develop breakthrough competence of project managers based on entrepreneurship energy. Proceedings of the 12th International Scientific and Technical Conference on Computer Sciences and Information Technologies, CSIT 2017. 2,8099420, c. 11-16. DOI 10.1109/STC-CSIT.2017.8099420.
16. De Neef HA Flex LV AF [Electronic resource] / GCPAT. - 2023. Access mode:https://gcpat.uk/en-gb/solutions/products/de-neef-waterproofing-injectionsolutions/de-neef-ha-flex-lv-af. Дата звернення: 30.04.2025.
17. O. Molodid, R. Plokhuta, I. Musiiaka, I. Reznichenko. Sealing joints between concrete elements with polyurethane material. AIP Conf. Proc. 31 May 2023; 2684 (1): 040017.
18. P.K. Saxena, K.G. Raut, S.R. Srinivasan, S. Sivaram, R.S. Rawat, R.K. Jain,*Polyurethane waterproofing coating for building applications*,Construction and Building Materials,Volume 5, Issue 4,1991,Pages 208-210,ISSN 0950-0618, https://doi.org/10.1016/0950-0618(91)90052-M.

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Молодід О.С., Плохута Р.О., Мусіяка І.В., Омельченко М.С., Новак Є.В.
ДОСЛІДЖЕННЯ ТЕХНОЛОГІЇ ВЛАШТУВАННЯ ЗОВНІШНЬОЇ ГІДРОІЗОЛЯЦІЙНОЇ ОБОЛОНКИ З СЕРЕДИНИ ПІДЗЕМНИХ СПОРУД

Враховуючи безпекову ситуацію в Україні частина підземних споруд та приміщень використовуються як найпростіші укриття для захисту населення від впливу вибухів та осколків. До таких споруд висуваються певні вимоги по їх утриманню, а саме: споруда повинна бути захищена від впливу ґрунтових, поверхневих та технічних вод шляхом влаштування гідроізоляції. У разі пошкодження чи відсутності гідроізоляції конструкції втрачають експлуатаційні властивості та руйнуються. Окрім того підвищена вологість негативно впливає на людей, що там перебувають. Для ремонту або влаштування гідроізоляції, зазвичай можна використовувати три способи: розкопування споруди та нанесення гідроізоляції зовні, влаштування гідроізоляції з середини, влаштування зовнішньої гідроізоляції методом ін'єктування. Для забезпечення сталого розвитку з метою зменшення впливу на довкілля та здоров'я людей найбільш прийнятним є третій спосіб влаштування гідроізоляції. Враховуючи широкий вибір матеріалів та їх властивостей доцільним є дослідження ефективності технології влаштування гідроізоляції шляхом ін'єктування матеріалу за межі конструкції (зовні). З цією метою було виконано низку експериментальних лабораторних досліджень в результаті яких виявлено вплив вологості ґрунту на здатність матеріалу до збільшення в об'ємі, розтікання та адгезії до конструкції. Також було перевірено гідроізоляційні властивості матеріалу. На основі отриманих результатів сформовано практичні рекомендації щодо використання удосконаленої технології зовнішньої гідроізоляції підземних конструкцій. Встановлено оптимальний рівень вологості грунту при влаштуванні гідроізоляції. Намічені подальші напрями досліджень щодо влаштування зовнішньої горизонтальної гідроізоляції залізобетонних конструкцій.

Ключові слова: гідроізоляція, підземні споруди, ін'єктування, поліуретановий матеріал, дослідження технології, реконструкція, реставрація, відновлення.

Molodid O.S., Plokhuta R.O., Musiiaka I.V., Omelchenko M.S., Novak .Y.V.
RESEARCH ON THE TECHNOLOGY OF INSTALLING AN EXTERNAL WATERPROOFING SHELL FROM THE INSIDE OF UNDERGROUND STRUCTURES

Given the security situation in Ukraine, some underground structures and premises are used as simple shelters to protect the population from explosions and shrapnel. Certain requirements are imposed on the maintenance of such structures, namely: the structure must be protected from the effects of ground, surface and technical water by means of waterproofing. If the waterproofing is damaged or missing, the structures lose their operational properties and collapse. In addition, high humidity has a negative impact on the people inside. There are three common methods for repairing or installing waterproofing: excavating the structure and applying waterproofing from the outside, installing waterproofing from the inside, or installing external waterproofing using the injection method. To ensure sustainable development with the aim of reducing the impact on the environment and human health, the third method of waterproofing is the most acceptable. Given the wide choice of materials and their properties, it is advisable to study the effectiveness of the technology of waterproofing by injecting material outside the structure (externally). To this end, a series of experimental laboratory studies were carried out, which revealed the influence of soil moisture on the material's ability to increase in volume, spread and adhere to the structure. The waterproofing properties of the material were also tested. Based on the results obtained, practical recommendations were formulated for the use of improved technology for external waterproofing of underground structures. The optimal level of soil moisture for waterproofing was established. Further research directions were outlined for the installation of external horizontal waterproofing of reinforced concrete structures.

Keywords: waterproofing, underground structures, injection, polyurethane material, technology research, reconstruction, restoration, renovation.

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Молодід О.С., Плохута Р.О., Мусіяка І.В., Омельченко М.С., Новак Є.В. **Дослідження технології влаштування зовнішньої гідроізоляційної оболонки з середини підземних споруд** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – Київ: КНУБА, 2026. – Вип. 116. – С. 109-119.
Досліджено технології влаштування зовнішньої гідроізоляційної оболонки з середини підземних споруд. На основі результатів лабораторних експериментальних досліджень було сформовано практичні рекомендації щодо використання удосконаленої технології зовнішньої гідроізоляції горизонтальних підземних конструкцій (на межі конструкції та ґрунту).
Табл. 3. Іл. 9. Бібліогра. 18 назв.

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Molodid O.S., Plokhuta R.O., Musiiaka I.V., Omelchenko M.S., Novak Y.V. **Research of technology for creating external waterproofing by injection of underground structure** // Strength of Materials and Theory of Structures: Scientific and Technical Collection. – Kyiv: KNUBA, 2026. – Issue 116. – P. 109-119.
The technology of installing an external waterproofing shell from the inside of underground structures has been studied. Based on the results of laboratory experimental studies, practical recommendations were formulated for the use of improved technology for external waterproofing of horizontal underground structures (at the boundary between the structure and the soil).
Table 3. Fig. 9. Refs. 18.

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