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Assessment of the technical condition of cave complexes

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The study of artificial caves and underground complexes, as well as their protection and preservation, remains a pressing problem of modern scientific research. Ancient dungeons, which are located not only in the territories of major cities (mainly in places where there were castle fortifications, trading rows, and monasteries), but also in small towns, cities, and villages, are in unsatisfactory condition. The work is devoted to the analysis of cave complexes and underground premises for historical purposes. Special attention should be paid to the operating conditions. The methods of surveying underground premises are given, in particular, attention is paid to the creation of 3D models. The results of the study of brick on water absorption result. The article pays attention to methods of strengthening damaged structures in operation conditions with modern composite materials based on basalt and carbon fibers

Keywords: cave, underground structure, survey, technical condition, increase

Оцінювання технічного стану печерних комплексів

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Дослідження штучних печер та підземних комплексів, а також їх захист та збереження залишається актуальною проблемою сучасних наукових досліджень. Стародавні підземелля, які розміщуються не лише на територіях великих міст (переважно в тих місцях де існували замкові укріплення, торгові ряди, монастирі), а й у малих містах, містечках та селах, знаходяться у незадовільному стані. Досить багато з них не досліджені та не виявлені, такі об’єкти стають відомими лише після часткового їх обвалення та утворення провалля на територіях. Тому окрему увагу приділено виявленню таких об’єктів неруйнівними методами. Робота присвячена аналізу печерних комплексів та підземних приміщень історичного призначення. Розглянуто як загальновідомі печерні комплекси, так і ті, які невідомі та потребують обстеження. Викладено фактори впливу на стан печерних об’єктів, зокрема перезволоження ґрунтового масиву, порушення температурно-вологісного режиму, техногенне навантаження на прилеглу територію. Розглянуто умови експлуатації печерних комплексів, порушення їх умов та вплив зовнішнього середовища. Встановлено, що окрім руйнування печерних комплексів від природніх чинників: руйнування, що викликані тиском ґрунту; підняттям та опусканням рівня підземного водоносного горизонту, тощо – існують також фактори, які напряму пов’язані з негативними діями людей, зокрема: планування території під забудову, прокладання комунікацій і хаотична забудова, яка може спричинити збільшення навантаження на підземні об’єкти, чи змінити фізико-кліматичні умови підземних комплексів. Наведені методи обстеження підземних приміщень, зокрема приділено увагу створенню 3D-моделей за допомогою 3D-сканер CR-Scan 01 на прикладі Антонієвих печер в Чернігові. Наведено результати дослідження цегли, що відібрана під час наукових досліджень, на водопоглинання. Приділено увагу способам підсилення пошкоджених конструкцій в умовах експлуатації сучасними композитними матеріалами на базі базальтових і вуглецевих волокон

Ключові слова: печера, підземна споруда, обстеження, технічний стан, підсилення

Introduction

The study of artificial caves and underground complexes, as well as their protection and preservation, remains an actual problem of modern scientific research.

Cave complexes and dungeons exist not only in the territories of large cities (mainly in places where there were castle fortifications, trade rows, monasteries, etc.), but such structures are found in small towns, towns, and villages.

Review of the research sources and publications

Certain questions concerning the problems of preservation of underground complexes are reflected in [1, 2].

Proposals on the assessment of the stability of slopes and the use of geotechnical information modeling technology, in particular, are devoted to the articles Vynnykov Yu., Kharchenko A., Yagolnik A. and Lystopad S. [3].

The analysis of the most common damage of brick, reinforced concrete, and wooden fencing structures of buildings from the impact of moisture is analyzed in the work of Semko A., Mahas N., Mishchenko A. and Mishchenko R. [4].

The consolidation of findings (catacomb) and monitoring issues in the performance of work is devoted to the work of Mytynskyi V., Chepelev V. etc. [5].

Definition of unsolved aspects of the problem

There are many and relatively few ancient dungeons, many of which have not been studied or even identified. Such objects become known only after their partial collapse and the formation of a gap in the territories. It should be noted that identifying the underground structure - is only part of the troublesome work. The main task is to explore and save the monument.

However, there are significant difficulties in maintaining such objects. Most of them are located on slopes, which are periodically exposed to landslides. Funds for their research are not provided either by state programs or local budgets. Such structures are usually left for gradual destruction. Domestic legislation does not contain materials on the study, preservation, and use of such complexes and structures.

Problem statement

Therefore, the purpose of the work is to identify and summarize information on cave complexes and underground premises of historical significance in the Chernihiv region and develop methods for their examination and preservation measures.

Basic material and results

Among the underground sacred structures are tombs (burial chambers or crypts with a ritual chapel); temples (underground structures of various shapes and large areas, large-section chambers, containing an altar and a place for believers); monasteries (housing for the servants of the cult and believers in the temple or separately from it) and complexes of sacred structures, combining these objects in a single underground space. Saint Anthony in Chernihiv are well known, and although there are many more studies to come, the results of the work are constantly published. However, in the territory of both Chernihiv and Chernihiv there are still many underground structures, little or no explored and in poor, and sometimes destroyed condition.

So about the dungeons of the Yelets Monastery in Chernihiv information is quite small, and all of them are in an emergency condition and access to them is closed. In addition to the underground structures of the Ilyinsky and Yeletsky monasteries in Chernihiv, there are many other cave complexes and underground structures: "Siveryanski" and "Onufriyevsky" caves, secret underground passages and dungeons of Chernihiv Detinets, which, unfortunately, have not yet been explored. Much is unknown about the Baturinese underground passages. There are some publications about the cave complexes of Lyubech, but archaeological research on these complexes is not completed.

Numerous sinkholes that occur in various sections of the old Sednev and some records of underground galleries and cellars also remained unexplored. After the formation of the precipice in 2002, underground tunnels and premises (some 4 m high) were discovered near the All Saints Church in Nizhin, with an area of about 200 m^2. In 2021, during the reconstruction of Gogolya Street, the basement of the former building of the noble assembly at the end of XVIII was discovered while observing the laying of a drainage well (Fig. 1).

There are no publications about the cave structures in Sribne village, and no results of cave research on the outskirts of Polonky village, on the bank of the Uday River have been printed. There is evidence of ancient underground structures in the village of Saltykova Divytsia, Kulykivsky district, an underground passage in the village of Sokoryntsi in the Sribnyanshchyna, and the underground of the former manor in the village of Petrusheno. Archaeologist V. Rudenok in his works mentions underground passages and underground structures in the central part of Sosnytsia; on the shore of the Seym river in the village of Osich, Bakhmach district; in the village of Ladan, Pryluts'kyi district; the village of Irzhavets, Ichnia district. In addition to this list, there are many other ancient dungeons, most of which are not investigated and not detected, such objects become known only after their partial collapse and the formation of a gap in the territories.

The caves are divided into those that have a natural origin and were partially modified by man for certain purposes, and those that from beginning to end were created by man for a certain purpose of their use. Underground structures, except caves, can be attributed to galleries, underground passages, premises, churches, tombs, crypts, root cellars, and cellars.

Underground complexes are located in difficult engineering and geological conditions, which are caused by: the location in landslide and landslide zones; the presence of significant masses of cover soot rocks capable of erosion; the placement of underground premises in the ground massifs with different physical and mechanical properties; the presence of aquifers above and below the layers containing the caves.

The preservation of underground complexes requires large-scale, labor-intensive, and extremely complex engineering works, usually consisting of ensuring the general stability of the slopes; observance of optimal operating conditions; regulating the humidity, both inside the premises and the soil environment; control of man-made load [6].

a

b

c

Figure 1 – Dungeons in Nizhyn:
a – failure to the underground premises https://cutt.ly/pXahO6K;
b – one of the underground premises https://cutt.ly/2XahS7v;
c- GPR control https://cutt.ly/bNmMMhv

The main factors of influence the state of cave objects can be attributed to:
- waterlogging of the soil massif;
- violation of temperature and humidity conditions;
- technogenic load on the surrounding area.

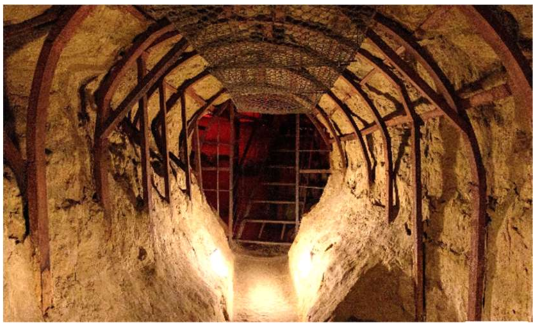
Particular attention should be paid to the operating conditions of these facilities. For example, during observations of the microclimate of the Antoniev caves, it was found that the air temperature in them ranges from 7.6 to 13.3 degrees, and the relative humidity of the air during the year varies between 75% and 100% (mainly varies from 86% to 95%).

Temporary wooden fasteners were used in various repair and restoration works, which are replaced with permanent reinforced concrete or metal fasteners, if necessary, after completion of the works.

In 1890, one of the galleries was strengthened with metal arcs, in 1950-1960 repair and conservation works were carried out with the help of bricks, in 1998-1990 an arched fastener made of metal was used, in 1992 the entrance opening was strengthened by metal-reinforced-concrete structures, in 1993 metal-brick fasteners were installed at emergency sites (fig. 2).

a

b



c

Figure 2 – Metal fasteners of Saint Anthony Caves:
a – Photo from the archive of Viktor Koshmal https://cutt.ly/LXahJ60;
b, c – https://cutt.ly/9Nm24bk

However, it is not always possible to use temporary wooden elements, sometimes when they are installed they are joined by a method of cutting, and the structures crush the walls and vault of the cave, which deforms the latter and leads to destruction.

Also, when replacing temporary elements with permanent ones, rock crumbling can occur, which sometimes causes emergency situations, and in conditions of high humidity, the wood quickly deteriorates.

Therefore, during certain restoration works, permanent metal fastenings were immediately used in the Saint Anthony caves. The measures used to strengthen metal elements need constant monitoring and updating of corrosion protection, and such elements distort the historical appearance of underground structures.

Now there are ways to strengthen damaged structures under operating conditions of modern composite materials based on basalt and carbon fibers. An example of such strengthening is the work of Belov I., Vabishchevich M. and Dedova O. on the preservation of the Church of the Nativity of Christ of the Holy Dormition Kyiv-Pechersk Lavra, where composite materials are introduced for reconstruction and restoration [2].

However, this method has been proposed to strengthen the soil environment, and how it will work if it is necessary to strengthen underground premises having brick, metal, and reinforced concrete structures - a question that still needs to be explored.

In addition to the destruction of cave complexes by natural factors: destruction caused by soil pressure; raising and lowering the level of the underground aquifer, etc. - There are also factors directly related to negative actions of people, in particular: planning of the territory for construction, laying of communications and chaotic development, which can lead to an increase of the load on underground objects, or change the physical and climatic conditions of underground complexes.

Drilling wells near or even above the facilities destroys underground structures by bringing moisture from the surface and upper horizons. Therefore, the detection of underground structures should be done in non-destructive ways of research. In modern practice, space and aerial photography materials and georadar techniques are increasingly being used. They allow you to predetermine the location and overall plan of an object.

The geological method of exploration of cave complexes is the most technologically advanced and allows not interfere with the structural elements and soil during the execution of works. A georadar is a device that can do the following functions: forming pulses emitted by an antenna, processing signals coming from the receiving antenna, and synchronizing the operation of the entire system.

To obtain data from different depths, antenna blocks operating at different frequencies are used.

A decrease in the operating frequency of the antenna increases the depth of the penetration signal but decreases the resolution of the antenna and vice versa.

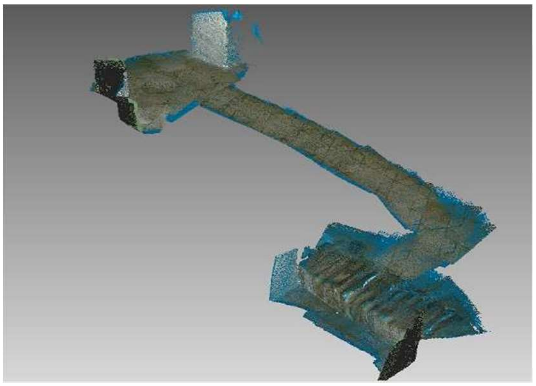
Therefore, multiple antennas can be used. For example, Leica-Geosystems AG (Switzerland) uses two antennas with frequencies of 250 MHz and 700 MHz in the DS2000 radar.

It should be borne in mind that in the presence of obstacles under the surface of the earth (construction debris, reinforcement, road clothing, etc.), the maximum depth of research can be reduced. Considering that the research is mainly conducted in the old parts of the city which are full of construction debris and layers of previous years of buildings, the depth of deciphering the data of the georadar reaches about 5 m.

Another feature is that it is almost impossible to distinguish on the profile the remains of the walls and the heat of the collectors [7].

As for the methods of the survey of underground complexes, in addition to using georadar to detect voids, currently widely used methods of scanning and creating 3D images to analyze how underground premises are located in space. Scientists of NU "Chernihiv Polytechnic" together with the National Architectural and Historical Reserve of "Ancient Chernihiv" began work on creating a 3D model of Saint Anthony Caves in Chernihiv (Fig. 3).

a



b

c

Figure 3 – Scan of Saint Anthony Caves in Chernihiv:
a – 3D- scanner CR-Scan 01;
b – fragment of the scanned corridor;
c – 3D-model of the underground church of Antoniy Pecherskyi

In addition, underground complexes can contain various structural elements: brick masonry, metal, wooden structures, etc.

Therefore, in addition to methods for determining and locating underground facilities, it is necessary to assess the technical condition and level of reliability of such structures (Fig. 4).

a

b

Figure 4 – Visual inspection of the grotto in the village Sedniv:
a – corresponding member of the Academy of Construction of Ukraine Bulat V.V. and the author of the article;
b – the author of the article and Honored Builder of Ukraine A.I. Sergeev

There are also certain difficulties, taking into account the imperfections of the existing normative documents and their absence in certain directions.

However, it should be noted that the correct use of existing regulatory documents in assessing the technical condition of underground complexes is an important factor in their preservation, and the development of special regulatory documents for such objects is a very relevant area.

Given that the structures of underground complexes are in humid conditions in most cases, special attention should be paid to the protection of such structures from excessive humidification.

To do this, it is necessary to understand how certain designs and materials that were made mainly more than half a century ago behave, and continue to be used in a moist environment, experiencing constant moisture.

For this purpose, work was started on the study of water absorption of brick materials, because the water absorption of brick is one of its most important technical characteristics. Water absorption is directly related to the strength and ability to withstand the load.

The higher the water absorption rate, the lower the strength of the structure and consequently the resistance to low temperatures.

The studies were conducted on samples of bricks selected from the brickwork of the beginning of the XX century and from a brick, which is used at present in masonry (Fig. 5).

In the course of the study, whole products were used, without damage.

The results of the water absorption of the products are presented in Table 1.

After the restoration of structures and materials underground complexes need to be adapted to use, this will help to preserve and keep them [8].

Most of the underground complexes are in an abandoned state and are not used, some buildings are adapted for museum complexes.

Figure 5 - Investigation of bricks on water absorption

An example of the concept of museum complexes, as well as the organization of engineering support, can be the museums of Europe, primarily Paris, London, and Madrid. For example, the Louvre in Paris has a multilevel underground space with a total area of about 200 thousand m2, and the Musée d'Orsay, despite its location underground, with the nearby Seine River, has dry rooms at a depth of more than 20 m.

Table 1 – The results of water absorption of bricks

Brick Name	№ sample	Weight in dry condition, g	Soak in the bath, h				Water absorption by volume, %
			1	12	24	48	
fireproof	1	375	410	421	422	423	16,8
	2	473	515	520	521	521	17,9
	3	449	474	485	486	486	17,7
	4	410	457	459	460	460	24,8
	5	407	441	445	446	446	18,4
silicate	1	4078	4424	4591	4598	4615	19,9
	2	4078	4419	4569	4569	4587	18,8
	3	4065	4386	4524	4524	4554	18,1
red Nor-mal	1	3099	3562	3584	3584	3607	26,3
	2	3211	3529	3557	3562	3585	19,0
	3	3178	3455	3482	3483	3508	16,3
the red cavity.	1	2899	3419	3453	3456	3479	30,1
	2	2980	3489	3515	3519	3537	28,1
	3	3102	3599	3632	3657	3660	26,8

The modern development of underground space in such cities as Kyiv, Kharkiv, Lviv, Odesa significantly lags behind such world cities as London, Montreal, Osaka, Beijing, Singapore, Tokyo, Shanghai, etc., and its development in Ukrainian cities is chaotic, without any plan with insufficient legislative and regulatory support.

Quite often, historic underground structures are destroyed, and in their places buildings with a maximum of one or three levels of underground parking are built. Taking into account recent events and commitments from developers to build bomb shelters during the construction of new buildings, it is necessary to develop a comprehensive program for the city with the creation of an underground environment.

Special attention should be paid to existing underground structures, including them in the general environment, and for this, it is necessary to examine and perform restoration work.

The issue of restoration should take into account the system "base-foundation - construction", and for underground complexes, the foundation is the habitat of the object, the soil not only perceives the load from the foundation but also creates auxiliary loads on the structures. The precondition for the loss of bearing capacity of structures in underground complexes can be not only cracks or displacement of structures but also the destruction of the material.

In the XI - early XX century buildings, the following types of foundations can be distinguished by design solutions: ribbon, columnar, slab, and piled.

According to the material, it is mainly - brick, stone, wood, concrete, and reinforced concrete. The solutions used clay and lime, sometimes with cemyank impurities (burnt and the ground mixture of ceramic crumbs and flour) (Fig. 6).

A characteristic feature of the construction equipment of the Kh-XIII century is the laying of artificially made ceramic bricks – plinths on lime mortar. In addition to the decorative effect, the cement solution received also hydraulic properties.

The metal was used mainly in tightening and beams of the floor.

Quite often there is no waterproofing in the monuments, as well as the mechanical properties of bulk soils, within which foundations were arranged without proper penetration [9].

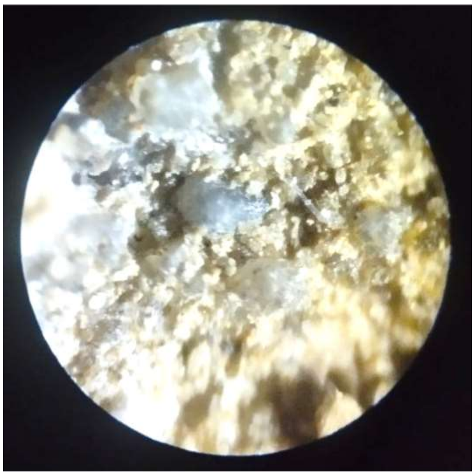
If the protection of the building from excessive moisture can be done by disconnecting the above-ground part from the underground by creating insulating barriers, then with underground complexes the difficulty lies in the fact that they border the entire area with the ground, and in addition to the use of waterproofing methods, it is also necessary to create a system for draining water from the object.

The structures should be subjected to the slightest interference and choose the methods of waterproofing, which least require the effort of their construction [10]. Such measures may include: the installation of hidden trenches along the perimeter of the structure separating the wet soil from the structures; the replacement of bulk soils, working as filters; organized drainage from structures, the use of special devices based on magnetic pulses and changing the direction of surface tension in the capillaries of the walls.

The methods of strengthening include the expansion of the sole of the foundation, cementing, silicatization, strengthening with piles, replacing part of the foundation, or relocation.

a

b



c

Figure 6 - Research of building solutions:
a – microscope MBS-10, MMU-3
and samples of solutions of the XXI-XX centuries.;
b – a sample of the solution of the house
of the manor Yatskiv, village Nove,
Chernihiv region. (1892);
c – photo of the solution under the microscope
(increase of 100 times)

However, it should be borne in mind that such elements should be considered underground elements-underground structures-above-ground elements. With mandatory modeling of the stress-strain state of both the soil environment and structural elements.

The masonry can be restored using MAPEI's designs, in particular the Eco-Pozzolan material, which can initiate the process of hardening lime much faster than in the past. Solutions based on this material gain high resistance to the effects of soluble salts a few days after application. TM MAPEI also uses materials for fixing sandy soils or soils with low permeability [11].

Conclusions

Thus, the results of the studies have established the following.

1. Cave complexes and underground premises not covered by previous works have been identified.
2. The method of scanning and creating 3D images of cave complexes has been tested.
3. A method of strengthening underground complexes based on the use of composite materials is proposed.
4. A material has been prepared for the use of composite materials in strengthening cave complexes in the Chernihiv region.
5. The necessity of development of the normative base on research, preservation, and use of historical underground complexes and constructions has been proved.

References

1. Черевко І.А. (2017). Проблеми збереження підземних сакральних пам'яток (на прикладі печерних комплексів Києво-Печерської лаври). *Сіверщина в історії України*, 10, 34-37

2. Belov I., Vabischevich M. & Dedov O. (2019). Numerical and experimental investigation of the cave passage model. *Technology Audit and Production Reserves*, 5/2(49), 31-33 https://doi.org/10.15587/2312-8372.2019.182732

3. Vynnykov, Yu., Kravchenko, M., Yaholnyk, A. & Lystopad S. (2020) Change of stress-deformed mode of the slope masses during developing and operation of excavations in it. *Industrial Machine Building, Civil Engineering*, 1(54), 73-80 https://doi.org/10.26906/znp.2020.54.2272

4. Semko O., Mahas N., Mishchenko A. & Mishchenko R. (2018). Moisture efcts on the buildings enclosing structures. *Industrial Machine Building, Civil Engineering*, 1(50), 278-284 https://doi.org/10.26906/znp.2018.50.1086

5. Mitinskiy V., Chepelev V., Vynnykov Yu., Lartseva I., Aniskin A. (2018). Overall stabilization of underground workings in limestone-shells. *Industrial Machine Building, Civil Engineering*, 2(51), 79-84 https://doi.org/10.26906/znp.2018.51.1296

6. Демчишин М.Г., Кріль Т.В. (2019). Вдосконалення інженерного захисту заповідника «Києво-Печерська лавра». *Наука та інновації*, 15(3), 37-51 https://doi.org/10.15407/scin15.03.037

7. Сєдін В.Л., Бауск Є.А., Ульянов В.Ю., Ковба В.В., Ієвлев, С.В., Фролов М.О. (2021). Досвід перших георадарних досліджень на території палацу студентів ДНУ центрального парку культури ім. Т.Г. Шевченка у м. Дніпро. *Український журнал будівництва та архітектури*, 4(004), 85-97 https://doi.org/10.30838/J.BPSACEA.2312.310821.85.793

8. Риндюк С.В., Максименко М.А. (2020). Освоєння підземного простору як вирішення проблем урбанізації міст. *Сучасні технології, матеріали і конструкції в будівництві*, 29/2, 101-107 https://doi.org/10.31649/2311-1429-2020-2-101-107

9. Kornienko M.V., Korzachenko M.M., Bolotov M.G. & Horb O.M. (2017). Constructional features of Hegumen house in Chernihiv. *Industrial Machine Building, Civil Engineering*, 2(49), 70-75 https://doi.org/10.26906/znp.2017.49.826

10. Якименко О.В. (2020)/ Ремонт і відновлення гідроізоляції будівель і споруд. *Містобудування та територіальне планування*, 75, 403–410. https://doi.org/10.32347/2076-815x.2020.75.403-410

11. *Матеріали і технічні рішення ТМ MAPEI.* Взято з https://www.mapei.com/ua

1. Cherevko I.A. (2017). Problems of preserving underground sacred monuments (on the example of the cave complexes of the Kyiv-Pechersk Lavra). *Severshchyna in the history of Ukraine*, 10, 34-37

2. Belov I., Vabischevich M. & Dedov O. (2019). Numerical and experimental investigation of the cave passage model. Technology Audit and Production Reserves, 5/2(49), 31-33 https://doi.org/10.15587/2312-8372.2019.182732

3. Vynnykov, Yu., Kravchenko, M., Yaholnyk, A. & Lystopad S. (2020) Change of stress-deformed mode of the slope masses during developing and operation of excavations in it. *Industrial Machine Building, Civil Engineering*, 1(54), 73-80 https://doi.org/10.26906/znp.2020.54.2272

4. Semko O., Mahas N., Mishchenko A. & Mishchenko R. (2018). Moisture efcts on the buildings enclosing structures. *Industrial Machine Building, Civil Engineering*, 1(50), 278-284 https://doi.org/10.26906/znp.2018.50.1086

5. Mitinskiy V., Chepelev V., Vynnykov Yu., Lartseva I., Aniskin A. (2018). Overall stabilization of underground workings in limestone-shells. *Industrial Machine Building, Civil Engineering*, 2(51), 79-84 https://doi.org/10.26906/znp.2018.51.1296

6. Demchyshyn M.G. & Kril T.V. (2019). Improvement of the Engineering Protection Systems of the Kyiv-Pechersk Lavra Reserve Territory. *Science & Innovation*, 15(3), 37-51 https://doi.org/10.15407/scin15.03.037

7. Sedin V.L., Bausk Ye.A., Ulianov V.Yu., Kovba V.V., Iievlev S.V. & Frolov M.O. (2021). Experience of the first georadar research on the territory of the DNU palace of students of the Central Park of Culture named after T.G. Shevchenko in Dnipro. *Ukrainian Journal of Construction and Architecture*, 4 (004), 85-97 https://doi.org/10.30838/J.BPSACEA.2312.310821.85.793

8. Ryndyuk S.V., Maksymenko M.A. (2020). The development of underground space as a solution to the problems of urban urbanization. *Modern technologies, materials and structures in construction*, 29/2, 101-107 https://doi.org/10.31649/2311-1429-2020-2-101-107

9. Kornienko M.V., Korzachenko M.M., Bolotov M.G. & Horb O.M. (2017). Constructional features of Hegumen house in Chernihiv. *Industrial Machine Building, Civil Engineering*, 2(49), 70-75 https://doi.org/10.26906/znp.2017.49.826

10. Yakymenko O.V. (2020). Repair and restoration of waterproofing of buildings and structures. *Urban and Regional Planning*, 75, 403–410. https://doi.org/10.32347/2076-815x.2020.75.403-410

11. TM MAPEI materials and technical solutions. Retrivered from https://www.mapei.com/ua