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Mineral complex additive for concrete

Methods of accelerating the hardening of Portland cement without heat-moisture treatment, in the presence of complex chemical additives - hardening accelerators and finely dispersed crystallization centers, were considered. The study was divided into several stages, where the effect of each accelerator additive on the cement hardening process was investigated. Based on the results, both single and complex chemical additives were selected to accelerate the hardening of cement. The effect of finely dispersed crystallization centers on the cement hardening process was also investigated. Metakaolinite (palygorskite) was used as a dispersed additive, which was synthesized by the authors using kaolin clay and insoluble magnesium compounds and sulfate aqua complexes, iron-sodium alum. The effect of complex additives in various combinations on the properties of cement dough and hardened cement is presented. The optimal composition of additives is proposed, the use of which in combination with technological methods for manufacturing concrete products can provide an energy-saving effect in the production of building structures.

Keywords: additives-cement hardening accelerators, crystallization seeds, cement structuring, sulfate alums

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Introduction

The experience of using concrete and reinforced concrete products in all branches of construction confirms that the main condition for the efficiency of its work and reliability is not only the quality indicators of the material, but the features of work in structures and buildings. The main component of any concrete is a binder, the characteristics of which determine its properties, by the type of which concretes are distinguished: cement, silicate, gypsum, slag-alkali, polymer concrete, polymer-cement concrete. [1], [3].

Concrete is subject to a number of requirements, which are often impossible to fulfill without the use of so-called modifiers and plasticizers, i.e. chemical additives that allow adding properties to the concrete mixture that meet the requirements of both designers and contractors. It is obvious that the use of concrete modifiers is beneficial both technologically and economically. The use of additives allows you to reduce energy costs for laying concrete, reduce cement consumption, maintain the necessary mobility of the mixture, ensure the necessary durability of structures, and achieve excellent indicators of early and final strength of concrete [2], [23].

In the practice of manufacturing concrete and reinforced concrete products, heat-moist treatment has proven itself well to accelerate their hardening. However, this method is associated with significant energy consumption for obtaining steam. The modern energy crisis requires a radical revision of the production technology of the specified products, the search for energy-saving ways of accelerating their hardening [9].

The following methods of increasing the rate of hardening and increasing the strength of concrete are known [2, 17, 30]:

– use of chemical additives-hardening accelerators;
– introduction of crystallization seeds and intensification of nucleation processes due to reduction of activation energy;
– regulation of the pH environment of the hardening system;
– repeated vibration after the first stage of structure formation;
– provision of internal energy reserves and heat storage of exothermic processes.

The use of additives is the most effective way to improve the quality of concrete and does not require large capital expenditures. The competent use of targeted complex additives allows you to solve problems associated with obtaining concrete with specified properties [8], [11], [25].

As a rule, additives are two- or multi-component. Thanks to certain combinations of additives, concrete plants are able to obtain high-strength concrete with the required properties. After all, the same additives, depending on their quantity and the mineralogical composition of the cement, act differently. The hardening process of cement can be increased by introducing a small amount of mineral additives - highly dispersed substances, the so-called crystallization centers. [4], [10].

Chlorides, nitrates, nitrites, soluble sulfates and carbonates are widely used, have a positive effect, but their effect depends on the concentration, mineral composition of the cement, and the hardening period of the cement. The most famous is calcium chloride. It helps increase strength at all stages of hardening, but chloride ions are aggressive towards reinforced concrete reinforcement. [5, 13]. Nitrates are inhibitors of reinforcement corrosion, but they reduce the rate of hydration of dicalcium silicate [6, 29].

To increase the rate of cement hardening, it is necessary to increase the solubility of clinker minerals in silica and lime, and a complex additive of sulfates and chlorides provides this solubility.

The introduction of a complex of salts of calcium chloride and sodium nitrite allows eliminating reinforcement corrosion and increasing the effect of increasing strength achieved by the introduction of calcium chloride. Therefore, it may be advisable to use a complex additive of calcium chloride, sodium sulfate and sodium nitrite [22].

Setting objectives. The listed methods are usually used separately from each other. In the technical literature there is little information on the effect of several methods of increasing the rate of hardening of cement and concrete at once, except for the use of complex additives, therefore the purpose of the work is to develop a complex method of influencing the hardening processes of Portland cement, which combines the effect of chemical additives, centers of crystallization and repeated vibration after the first stage of structure formation.

Characteristics of input materials

The following materials were used for the experiments:

1. Portland cement brand PC I-500-N, with a compressive strength of 58 MPa at the age of 28 days, hardening time beginning 2 h end 8 h, specific surface area, 2500 cm2⁄g

2. Tap water was used for the samples.

3. For the manufacture of chemical additives were used: calcium chloride CaCI2, sodium nitrate (pure for analysis) - NaNO2, sodium sulfate crystallization (sodium sulfate) - Na2SO4, concentrated perchloric acid HCl with a density of 1.19 g/cm3, ferric chloride FeCl3, potassium carbonate K_2CO_3 [20], [28].

Methods

The work is divided into several stages:

I - selection of the type and optimal amount of chemical additives-hardening accelerators;
II – development of a method of preparation of highly dispersed mineral substances - centers of crystallization;
III – development of technological modes of manufacturing and hardening of concrete products.

At the first stage, well-known chemical additives were used: calcium chloride ($CaCl_2$), iron chloride ($FeCl_3$), sodium nitrite ($NaNO_2$), potassium carbonate (K_2CO_3), sodium sulfate (Na_2SO_4), C-3 superplasticizer, specially prepared and processed hydrated cement (SRN).

Single, double and those containing three or four chemical substances were studied. All samples in the form of cubes measuring 3×3×3 cm were formed from pure cement dough with a normal water demand of 25.4%. Portland cement of the PC 42.5 brand of Eurocement-Ukraine was used.

About 120 experiments were performed, the results of which were processed using the computer system, [18], [19].

Result and discussions

Table 1 shows the terms of hardening and strength characteristics of cements containing the most promising combinations of additives, after processing by a computer program.

It is possible to describe the following observations of single additives, which were introduced for 1.5% of the cement mass.

Calcium chloride, according to the literature, increases the solubility of clinker minerals, so there is an increase in strength at all times of hardening. At the same time, it is an accelerator of the setting process.

Iron chloride helps to obtain higher strength at 7-day age, but in the initial period, it does not give the effect of acceleration of hardening. It requires 9-11% more mixing water than cement without additives. Not compatible with sodium nitrite, so it was excluded from further studies [14], [16].

Sodium nitrite plays the role of an accelerator to some extent during the first and second days, without particularly shortening the period of setting, but further inhibition of the rate of hydration is found.

Potassium carbonate causes very rapid structure formation in the first period, hardening times are sharply reduced, but there is no effect on the acceleration of cement hardening.

Sodium sulfate, according to the literature, has no equal in terms of increasing the strength of cement immediately after steaming. Sulfates increase the solubility of Portland cement clinker minerals in silica, better conditions are created for the hydration of minerals, but under normal conditions, the accelerating effect of hardening is not detected.

Superplasticizer C-3 is widely used in concrete technology, especially in monolithic construction. Its use helps to increase the mobility of the concrete mixture without reducing the amount of water, or reducing the water-cement ratio, which helps to increase the strength of concrete.

It is interesting to note the role of the mineral additive - the center of crystallization (CPH). Without any other chemical additives, the strength of Portland cement increased during the first day by 1.3 times, during two days by 1.8 times, and after 7 days - by 1.09 times. The effect of CPH on the rate of cement hardening in the initial stages can be compared with the effect of $CaCl_2$ in the amount of 1.5%. As noted earlier, CPH is pre-hydrated Portland cement using a special technology. In it, hydro silicates are in a gel-like state, but more crystallized compared to a cement block of ordinary concrete. These particles of hydro silicates form a spatial structure in "compressed conditions" and can be centers of crystallization.

In the theory of structure formation and hardening of binder systems, the presence of an induction period is noted, when the rate of hydration decreases by 15 times. Some researchers associate the end of the induction period with the crystallization of $Ca(OH)_2$ [5]. Calcium hydroxide in crystallized form is definitely present in the highly dispersed mineral additive of hydrated cement, which obviously affects the shortening of the induction period.

Complex additives for concrete are distinguished by the multifunctionality of their action. They affect simultaneously several characteristics of concrete. The use of complex additives enhances the effect achieved when a single-component additive is introduced (increase in strength), or eliminates a negative side effect (corrosion of fittings, shrinkage, etc.) [15].

In our studies, the concentration of chemicals in complex supplements was maintained at 1% each.

Hydrated Portland cement contained 31.2% $Ca(OH)_2$, which was determined by titration with hydrochloric acid. Such a large amount of calcium hydroxide is artificially introduced into the experimental cement before the start of hydration, so it will definitely affect the kinetics of the structure formation process. To reduce the amount of introduced $Ca(OH)_2$, a hydrochloric acid solution was added to the aqueous seed suspension at the rate of neutralization of 30, 60 and 90% calcium hydroxide, thereby increasing the content of CaCl2 in the system, which was formed during neutralization [27].

When combining single additives into complex ones, the following is sharply distinguished: CaCl2 + $NaNO_2$; $CaCl_2$ + CPH; $NaNO_2$ + Na_2SO_4, which give a significant increase in strength during all test periods; $NaNO_2$ + CPH; Na_2SO_4 + CPH without any special effect in the first day increase the strength of

At 7 days of age, and this, of course, is due to the presence of CPH [15].

Potassium carbonate in any combination, and even together with C-3 superplasticizer, dramatically shortens hardening times (up to 15-25 min), which makes its practical use impossible [21], [26].

Among the triple complex supplements, the following deserve attention:

$CaCl_2$ + $NaNO_2$ + C-3; $CaCl_2$ + $NaNO_2$ + CPH; $CaCl_2$ + Na_2SO_4 + CPH; $CaCl_2$ + $NaNO_2$ + C-3 + CPH. These additives already in the first day increase the strength of cement stone by 1.5 times while maintaining a higher rate of hardening during other terms. The research results show that in almost all cases with the best strength indicators, complex additives contain calcium chloride, which is recognized worldwide as an effective accelerator of cement and concrete hardening.

Unfortunately, chloride ions cause intense cor-rosion of reinforcement, especially when their con-tent is more than 1%.

There is information in the literature that the negative effect of calcium chloride on reinforced concrete reinforcement is almost completely elimi-nated by sodium nitrite. Moreover, NaNO¬2 at 20˚C in the amount of 2% shortens the induction period of hydration of tricalcium silicate from 7 hours to 20 minutes. The effect of NaNO2 on the kinetics of hydration of 3CaO·SiO2 in the initial stages is simi-lar to the effect of heat-moist treatment, which accelerates the hydration of mineral alit only after the formation of hydro silicate nuclei. The results of our experiments confirm these judgments in the case of using NaNO2 in combination with a mineral additive as a crystallization center.

In order to reduce the negative effect of CaCl2 on reinforcement, but to use its positive effect on the rate of cement hydration, a complex composi-tion additive is proposed: CaCl2 - 0.5%; NaNO2 – 0.5%; Na_2SO_4 – 0.5%; CPH - 1.5%. In it, each of the chemical substances enhances the effect of the other, as a result, Portland cement in the presence of such an additive shows a stable increase in strength during all periods of hardening, and in the first day, the increase in strength is 61% of cement without additives.

Table 1. - The effect of chemical additives on the hardening time and strength of hardened cement

№	Type and combination of additives	Hardening terms h/min		Compressive strength, MPa, per day		
		Beginning	End	1	2	7
1	Cement without additives	3^{15}	4^{30}	33,7	57,8	76,6
2	$CaCl_2$	1^{30}	2^{15}	45,7	69,1	86,6
3	$FeCl_3$	1^{25}	2^{40}	30,5	50,6	100,6
4	$NaNO_2$	2^{30}	4^{20}	42,4	66,4	62,9
5	K_2CO_3	0^{50}	1^{25}	19,7	41,3	60,9
6	Na_2SO_4	1^{30}	1^{55}	33,7	56,3	74,5
7	C-3	5^{30}	8^{15}	34,1	59,6	72,1
8	CPH	2^{00}	2^{50}	43,7	68,1	83,0
9	CPH+C-3	4^{35}	4^{40}	43,5	53,4	88,7
10	$CaCl_2$+$NaNO_2$	2^{00}	2^{45}	51,7	69,0	82,4
11	$CaCl_2$+ K_2CO_3	2^{05}	4^{35}	42,5	72,9	99,3
12	$CaCl_2$+ Na_2SO_4	2^{10}	4^{25}	42,2	58,4	78,4
13	$CaCl_2$+ C-3	3^{05}	5^{50}	44,1	61,2	97,1
14	$CaCl_2$+ CPH	1^{20}	2^{00}	44,6	71,7	119,9
15	$NaNO_2$+ K_2CO_3	0^{15}	0^{25}	19,1	38,5	46,1
16	$NaNO_2$+ Na_2SO_4	3^{25}	4^{25}	44,5	74,9	100,9
17	$NaNO_2$+ C-3	4^{00}	5^{00}	28,9	59,1	63,3
18	$NaNO_2$+ CPH	2^{35}	3^{45}	36,6	73,4	95,2
19	K_2CO_3+ Na_2SO_4	0^{05}	0^{10}	25,4	31,1	56,3
20	K_2CO_3+ C-3	1^{30}	2^{00}	29,0	39,0	69,7
21	K_2CO_3+ CPH	0^{05}	0^{15}	26,5	39,6	62,3
22	Na_2SO_4+ C-3	4^{30}	7^{25}	37,2	44,3	57,1
23	Na_2SO_4+CPH	3^{00}	4^{05}	36,2	42,1	91,0
24	$CaCl_2$+ CPH+ C-3	3^{00}	3^{30}	40,0	53,9	80,2
25	$CaCl_2$+ Na_2SO_4+ CPH	1^{40}	2^{15}	43,0	65,4	77,7
26	$NaNO_2$+ K_2CO_3+ C-3	1^{25}	1^{35}	31,5	59,5	89,4
27	$NaNO_2$+ Na_2SO_4+ C-3	0^{40}	4^{55}	26,5	64,3	75,9
28	$NaNO_2$+ K_2CO_3+ CPH	0^{05}	0^{15}	34,9	49,3	51,4
29	$NaNO_2$+ Na_2SO_4+ CPH	4^{15}	5^{15}	39,0	39,8	79,5
30	K_2CO_3+ C-3+ CPH	1^{10}	1^{20}	23,3	48,5	74,3
31	Na_2SO_4+ C-3+ CPH	5^{55}	6^{10}	39,8	64,2	75,0
32	$CaCl_2$+ $NaNO_2$+ C-3+ CPH	1^{55}	2^{45}	51,8	61,3	96,3
33	$CaCl_2$+ K_2CO_3+ C-3+ CPH	0^{20}	0^{40}	38,2	56,6	70,0
34	$CaCl_2$+ Na_2SO_4+ C-3+ CPH	2^{35}	4^{20}	43,7	62,7	79,0
35	$NaNO_2$+Na_2SO_4+C-3+CPH	2^{20}	4^{40}	38,1	49,9	82,9
36	$CaCl_2$+ $NaNO_2$+ Na_2SO_4	2^{40}	3^{50}	38,5	62,3	65,7
37	$CaCl_2$(0,5)+Na_2SO_4(0,5)+ $NaNO_2$(0,5)+ CPH	2^{20}	3^{35}	54,4	68,0	79,3

II method of preparation of mineral seed - center of crystallization during hardening of Portland cement.

The previous part shows the positive role of a highly dispersed mineral substance - the center of crystallization in combination with the proposed complex chemical additive composition: $CaCl_2$ - 0.5%; $NaNO_2$ – 0.25%; Na_2SO_4 - 0.5%. Although this composition of the additive has a positive effect on aluminate cement PC 42,5, and no clear effect was found for composite cement PC II B-Sh-32,5, obviously the hydrated cement primer is suitable for cements with a sufficiently high content of calcium aluminates.

Literary sources testify to the effectiveness of aluminosilicate crystallization centers, especially palygorskite [1], or natural alum stone - alunite [6]. Such breeds are very rare in nature.

Kaolin from the deposit of the Kirovohrad region was used to artificially obtain the aluminosilicate center of crystallization. In order to bring its properties closer to palygorskite or alunite, modifiers (insoluble magnesium salts and sulfate aqua complexes, iron-sodium alum) were added to kaolin. The content of magnesium cations Mg^{2+} corresponded to their content in palygorskite, and SO_4^{2-} anions corresponded to their content in alunite. The specified components were mixed with kaolin; the resulting mass was subjected to heat treatment at 800 ^{0}C.

After cooling, the product was ground in a laboratory ball mill to a specific surface area of 1500 cm^2/g.

Portland cement PC SH – 32,5 was used to test the efficiency of the new MKM crystallization center (metakaolin modified).

Dosing of additives was carried out in such a way that the cement contained 3% metakaolin and 1.3% SO_3. Based on the data in Table 1, in some experiments, potassium carbonate (potash K_2CO_3) in the amount of 0.25% or C-3 superplasticizer (0.15%) was additionally introduced into the cement. The strength characteristics of the obtained samples are shown in Table 2, they show that the use of complex additives plays a significant role in the processes of cement hydration and hardening. Cement without additives shows sufficiently low strength (13.98 MPa) per day. The addition of only metakaolin increases the strength, but very slightly (19.3 MPa). At the same time, modified metakaolin increased the strength in the first day to 24.9 MPa, i.e. 43.8% more than without additives.

It is very effective to introduce 0.25% potash along with modified metakaolin. In this case, the increase in strength was 70% on the first day, and 74% after 2 days. Compared with the data in Table 1, the overall strength index corresponds to the data in Table 2, although in the first case, high-quality PC 42,5 cement was used, and in the second - PC Sh-32,5, i.e. cements of different quality [31].

The addition of K_2CO_3 thickens the cement dough; therefore, superplasticizer C–3 (0.15%) was additionally added. The mobility of the cement paste increases sharply, but the rate of hardening slows down. The increase in strength in the first day is only 59%, although in 2 days the strength is equalized. The effectiveness of MKM action was tested on concrete samples. The samples measuring 10×10×10 cm were made from a concrete mixture of the following composition: PC Sh-32,5 – 350 kg/m^3; crushed stone fraction 5-10 – 1200 kg/m^3; quartz sand (Size module = 1.17) – 800 kg/m^3; MKM - 3%; W/C = 0.55. The test results are shown in Table 3.

Even concrete samples show the high efficiency of the proposed complex additive, especially in combination with potash K_2CO_3 and C-3 superplasticizer. The increase in strength is 65%, with the total strength in 2 days of hardening, giving reason to judge the possibility of early use of products, as well as a reduction in cement consumption per $1m^3$, since the additive contributes to the full use of the potential of cement.

Table 2. - The effect of chemical additives and mineral aluminosilicate seed on the rate of cement hydration

№	Consumption of materials					Compressive strength, МПа	
	Cement, g	MK, %	MKM, %	K_2CO_3, %	W/C	1 day	2 days
1	350				0,32	13,98	14,74
2	350	3			0,32	19,3	23,8
3	350		3		0,32	24,9 + 43,2%	30,23 + 51%
4	350		3	0,25	0,32	47,8 + 70%	57,9 + 74%
5*	350		3	0,25	0,32	34 + 59%	53,4 + 72%

MK – metakaolin; MKM - modified metakaolin

* – C-3 superplasticizer is additionally added to the mixing water.

Table 3. - The effect of a complex additive on the strength of concrete

№ з/п	The presence of an additive	Compressive strength, MPa	
		1 day	2 days
1	No additives	5,59	8,09
2	MKM 3% + K_2CO_3(0,25%)+C3 (0,15%)	12,36	23,1

Conclusions.

Three experiments were carried out during the research work. In order to study the effect of complex chemical additives on the hardening rate of Portland cement, more than 120 experiments were carried out. It has been established that the combination of single additives into double or triple is not always justified, but there are combinations when one additive enhances the effect of another with a positive effect on accelerating the hardening of cement.The expediency of using mineral seeds - cement crystallization centers - is shown. Pre-hydrated Portland cement or aluminosilicates prepared in a certain way can act as a primer.

The combination of complex chemical additives with a mineral seed increases the strength of the cement stone compared to the one without additives already in the first day by 1.6-1.8 times.

Recommended composition of additives for aluminate cement PC – 42,5: $CaCl_2$ - 0.5%, $NaNO_2$ - 0.25 - 0.5%; Na_2SO_4 - 0.5 - 1.0%; mineral seed (hydrated cement) - 1.5 - 3.0%. For composite cement type PC-Sh -32,5 the center of crystallization is more suitable.

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Мінеральна комплексна добавка для бетону

Розглянуто способи прискорення тверднення портландцементу без застосування тепловологісної обробки, з використанням комплексних хімічних добавок–прискорювачів тверднення та тонкодисперсних центрів кристалізації. Встановлено доцільність поєднання кількох технологічних прийомів, зокрема хімічного впливу, введення попередньо гідратованого цементу як активного мінерального наповнювача, а також використання повторного вібрування після першої стадії структурування. Дослідження поділено на кілька стадій, у межах яких проведено понад 120 експериментів з різними варіантами добавок та їх поєднань. Вивчено дію одно- та багатокомпонентних комплексних добавок, до складу яких входили хлориди, нітрити, сульфати, залізо-, калій- та натрійвмісні сполуки, а також надпластифікатор С-3. Виявлено оптимальні комбінації компонентів, які забезпечують прискорене тверднення цементного тіста без погіршення фізико-механічних характеристик. Окремо досліджено вплив тонкодисперсних центрів кристалізації, зокрема попередньо гідратованого портландцементу, який виконує функцію структурного ініціатора в період індукційного сповільнення гідратації. Показано, що поєднання мінеральних центрів кристалізації з комплексними хімічними добавками забезпечує приріст міцності цементного каменю вже на першу добу в 1,6–1,8 рази порівняно з контрольними зразками без добавок. Запропоновано рекомендовані склади добавок для цементів різних типів (ПЦ 42,5; ПЦ-Ш 32,5), які дозволяють скоротити тривалість технологічного циклу тверднення та досягти енергозберігаючого ефекту у виробництві бетонних та залізобетонних конструкцій.

Ключові слова: добавки–прискорювачі тверділня цементу, затравки кристалізації, структуроутворення цементу, квасці сульфатні

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Diagnostics of load-bearing building structures of construction industry enterprises operating under the influence of technological fluids

Diagnosing load-bearing structures in construction industry enterprises exposed to technological fluids presents a unique set of challenges. These fluids, ranging from corrosive chemicals to abrasive slurries, can significantly accelerate the deterioration of concrete, steel, and other building materials. Effective diagnostics require a multi-faceted approach that considers the specific fluids involved, their concentration, temperature, and exposure duration. Visual inspections, supplemented by non-destructive testing (NDT) methods like ultrasonic testing, ground-penetrating radar, and impact-echo, are crucial for identifying hidden damage such as corrosion, cracking, and delamination. Furthermore, material sampling and laboratory analysis provide a definitive assessment of the extent of chemical attack and its impact on the structural integrity. Ultimately, a comprehensive diagnostic program enables informed decisions regarding repair, rehabilitation, or even replacement of affected structures, ensuring the safety and operational continuity of the enterprise.

Keywords: building structures, technical condition, reinforcement.

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Introduction

Operation of building structures in an industrial environment, especially at construction industry enterprises, is often accompanied by the influence of aggressive technological fluids. These fluids, depending on their chemical composition, can initiate corrosion processes of metal elements, destruction of concrete, and other materials, which leads to a decrease in the load-bearing capacity and durability of structures. Therefore, timely and accurate diagnostics of the technical condition of load-bearing structures operating in such conditions is extremely important for ensuring safe and uninterrupted operation of enterprises.

Review of the research sources and publications

The results and methods of diagnostics of load-bearing building structures of construction industry enterprises operating under the influence of technological fluids are presented in the works of leading scientists [1-11].

Definition of unsolved aspects of the problem

The problem of diagnostics of load-bearing building structures operated in aggressive environments remains relevant and multifaceted, despite significant progress in this field. One of the key unresolved aspects is the insufficient accuracy and reliability of existing diagnostic methods, especially in the early stages of damage. Traditional methods, such as visual inspection or measurement of geometric parameters, are often unable to detect hidden defects or microcracks, which are precursors of more serious damage. In addition, the influence of combinations of various aggressive factors (chemicals, temperature fluctuations, humidity, biological corrosion) on the durability of structural materials has not been sufficiently studied. This makes it difficult to predict their residual strength and safety.

Another important aspect is the need to develop more effective and cost-effective methods for monitoring the condition of structures in real time. Existing methods are often labor-intensive, require specialized equipment and qualified personnel, which makes their application limited. Diagnostics of structures located in hard-to-reach places or those that are already in a state of emergency is also a significant challenge. For such cases, innovative approaches are needed, such as the use of unmanned aerial vehicles, remote sensing sensors and intelligent data analysis systems.

Finally, the lack of comprehensive models for predicting the durability of structures that would take into account the specifics of aggressive environments and the behavior of various materials is a significant problem. It is necessary to develop models that would be based on a deep understanding of the mechanisms of destruction and would take into account the uncertainty and variability of aggressive factors. Only by addressing these unresolved aspects will it be possible to ensure reliable and safe operation of building structures in difficult conditions.

Problem statement

The aim of the work is a comprehensive diagnostics of load-bearing building structures of construction industry enterprises operated under conditions of exposure to technological fluids. This involves the detection and assessment of defects, damage and changes in the physical and mechanical properties of materials caused by an aggressive environment. The results of the diagnostics will serve as the basis for the development of substantiated decisions on ensuring the reliability and durability of buildings and structures, as well as optimizing strategies for their repair and strengthening.

Basic material and results

To ensure reliable and safe operation of buildings and structures, especially those in contact with aggressive process fluids, it is critically important to have a high-quality diagnosis of the condition of their load-bearing structures. The impact of these fluids can cause corrosion, erosion, cracking and other types of damage, which over time weaken structures and can lead to emergency situations. Therefore, there are various diagnostic methods that allow you to identify potential problems at an early stage and take the necessary measures to prevent their development.

These diagnostic methods can be conditionally divided into several categories, depending on the principle of their action. The first includes visual methods, such as inspection of structures, measurement of cracks, fixation of deformations, which allows to detect obvious damage. This is followed by non-destructive inspection methods, which include ultrasonic inspection, radiography, acoustic emission and others, which allow to assess the internal structure of the material and detect hidden defects without damaging the structure. Finally, destructive methods, which include the selection of material samples for laboratory research (analysis of chemical composition, mechanical tests), allow to obtain detailed information about the properties of the material and the degree of its damage.

The combination of various diagnostic methods, depending on the specific conditions and types of structures, provides a comprehensive assessment of the condition of load-bearing elements. The choice of methods, their sequence and scope of research are determined individually, taking into account the type of technological fluid, structural materials, as well as the requirements of regulatory documents. Regular and comprehensive diagnostics is a necessary condition for maintaining the durability and safety of structures operated under the influence of technological fluids.

One of the types of construction industry enterprises operating under the influence of technological fluids is water treatment buildings in the water supply system.

If we consider the Poltava region, namely the Kremenchuk district, the source of the water supply system is the Kremenchuk reservoir on the Dnipro River. The Vlasivka water intake, which is located in the village of Vlasivka, takes in Dnipro water from the reservoir (Fig. 1), which then enters the microfiltration on drum microfilters. Water is taken from the reservoir by two siphon pipelines with a diameter of 1200 mm, which pass through the body of the earthen dam. The water intake head is placed in the reservoir at a distance of 320 m from the dam. The head is located at a depth of 14 m from the water surface.

After passing through the microfilters, the Dnieper water enters the 1st lifting pumping station, which supplies it through 3 parallel pipelines to the distribution chamber on the territory of the water treatment facilities (WTP). In the distribution chamber, water is divided into 2 directions. In the first direction, water is supplied to the water treatment facilities for the production of drinking water. Then, drinking water is supplied by the 2nd lifting pumping station to the water supply network of the city of Kremenchuk. In the second direction, the Dnieper water is supplied through separate water mains to the enterprises of the Northern Industrial Complex as technical water.

If we consider the general characteristics of the technological process of drinking water preparation, we can distinguish two technological lines:

The main stages of the first stage of wastewater treatment:

1. Mixing reagents with water:
- "Amopol" - ammonization;
- liquid chlorine - primary chlorination;
- coagulant - coagulation.
2. Clarification of water in horizontal clarifiers (HV).
3. Filtration of settled water on rapid filters (RF).
4. Secondary chlorination in the clean water tank (RCV) of the 1st stage.

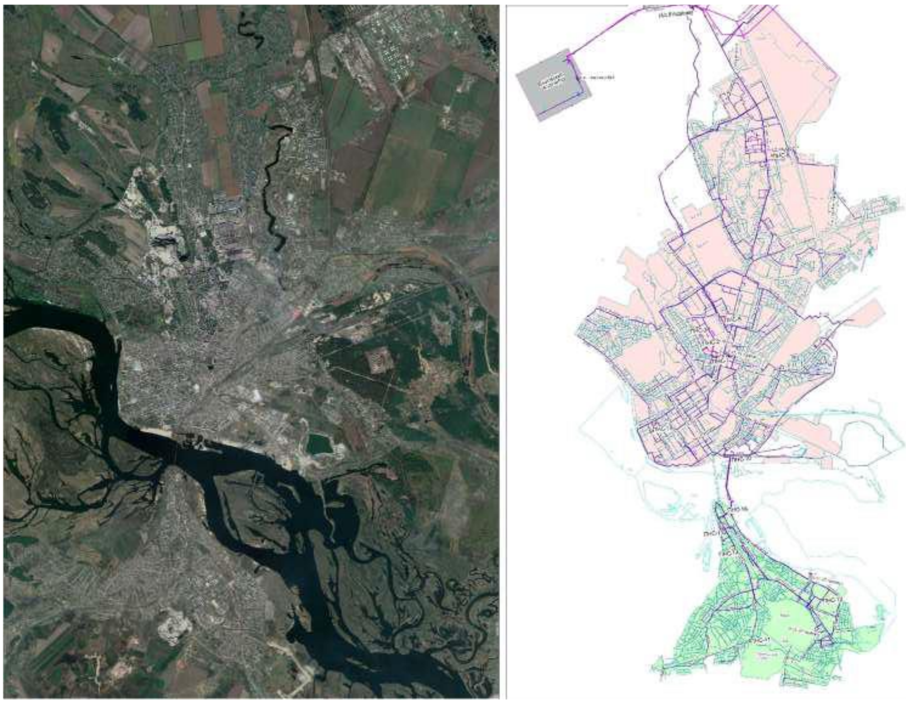

Figure 1 – Plan of water supply networks of buildings and structures of the city of Kremenchuk

The main stages of the second stage of wastewater treatment:

1. Feeding "Amopol" before microfilters.
2. Filtration through microfilters (MF).
3. Mixing reagents with water:
- liquid chlorine - primary chlorination;
- coagulant - coagulation.
4. Contact lighting.
5. Secondary chlorination in the clean water tank (PWT) of the second stage.

The water treated with reagents is supplied through a pipeline to the filtration hall of contact clarifiers (CL), where the water purification process by contact clarifier method takes place in the intergranular space of the filter material.

The regeneration of the filtering load is carried out in accordance with generally accepted requirements. The supply of washing drinking water is carried out through a drainage tubular system from bottom to top. The washing water is discharged into the industrial sewage system with subsequent discharge into the Sukhyi Kagamlyk River without preliminary treatment.

The CL filtrate enters the collecting collector, where a chlorine water solution is supplied (secondary chlorination), and then into clean water tanks, from where it is supplied to the city's water supply networks by pumps of the 2nd lifting pumping station (No. 6 on the plan).

The authors conducted a technical condition survey and developed recommendations for further reconstruction of the building structures of the block of contact illuminants of the water treatment plant section of the water supply system of the Kremenchukvodokanal enterprise of the Kremenchuk City Council of the Kremenchuk district of the Poltava region.

The load-bearing and enclosing structures of the building were subject to inspection.

The building of the contact lighting unit of the water treatment plant section is a frame structure with overall dimensions of 36×66.5 m, consisting of two longitudinal runs and a transverse run. The runs in the axes G-Zh (1-10) and Zh-K (1-10) are 18 m wide, the transverse run in the axes 11-13 (G-K) is 12 m wide.

The step of the extreme and middle columns is 6 m. The general view of the building is shown in Fig. 2.

In the spans in the axes G-Zh (1-10) and Zh-K (1-10), contact illuminators are located, in the axes E-Z, a technological platform was covered at the mark +3.900 for the hall of contact illuminators (Fig. 2), under which a pipeline gallery is located.

After a thorough analysis of defects and damage to building structures, the following categories were separated:

The first is load-bearing reinforced concrete structures.

The reinforced concrete columns of the middle and outer rows have longitudinal cracks in the protective concrete layer, local spalling of the protective concrete layer, significant areas of destruction of the protective concrete layer, and corrosion damage to the working longitudinal reinforcement (Figs. 3 -5), which requires reinforcement.

The general condition of the reinforced concrete columns is condition 3 - "unsuitable for normal operation." The second is metal elements and structures.

Metal half-timbered columns made of two channels No. 20 are significantly corroded, in the lower part of the column in the space between the channels, debris and remains of corroded metal have accumulated (Fig. 6), which requires reinforcement, cleaning from traces of corrosion, and restoration of the paint and varnish protective coating.

The general condition of the metal half-timbered columns is condition 3 - "unsuitable for normal operation."

Figure 2 – General view of the building

Figure 3 – Damage to reinforced concrete columns of the middle row

Figure 4 – Damage to reinforced concrete columns of the outer rows

Figure 5 – Damage to reinforced concrete columns of the outer rows

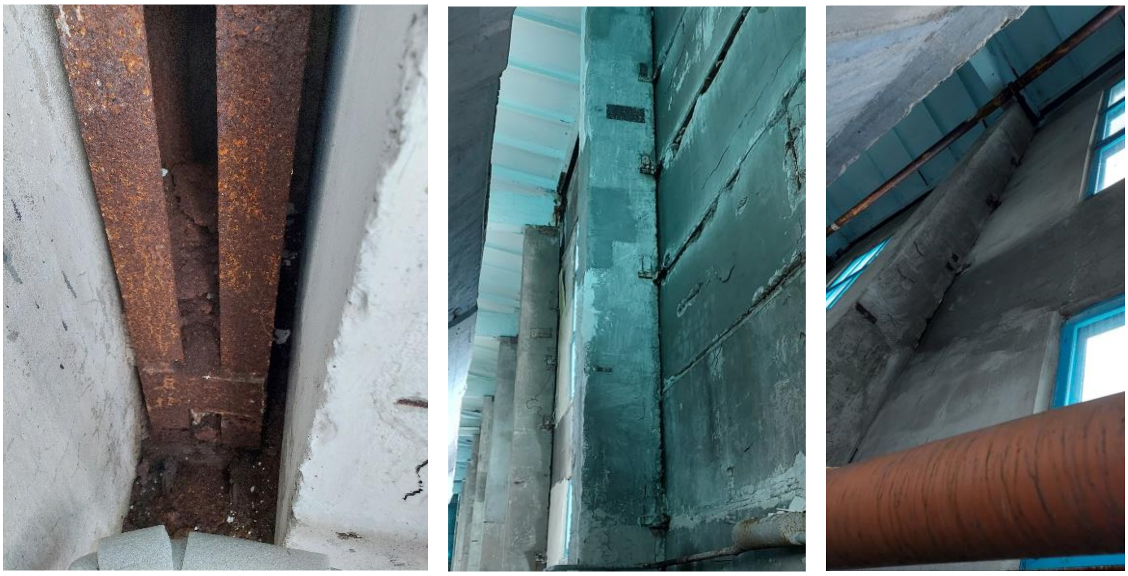

Figure 6 – Damage to half-timbered columns and metal embedded parts

The third is wall enclosing structures.

Wall enclosing structures – wall panels and window partitions made of aerated concrete masonry – were exposed to moisture both from the outside and from the inside of the building due to waterlogging from overflows through the parapet of precipitation due to freezing of pipes and drains of the drainage system and due to moisture condensation inside the room. The result is the destruction and delamination of the plaster layer on the masonry and on the panels, frost damage to the aerated concrete masonry, destruction of the protective layer of concrete on the panels with exposed reinforcement, corrosion of the reinforcement up to 2 mm, the formation of through holes in the panels, masonry and, especially, at their edges (Fig. 7). It is recommended to restore the protective plastering of the building's enclosing wall structures (internal and external), to restore the protective paint coating.

The general condition of the wall enclosing structures is condition 3 - "unsuitable for normal operation."

Conclusions

There are several effective methods for strengthening reinforced concrete columns, each with its own advantages and used depending on the specific situation. Among the most common are a metal angle and strip cage, increasing the cross-section with concrete with additional reinforcement, and the use of composite materials such as carbon fiber.

The choice of a specific strengthening method depends on many factors, including the degree of damage to the column, the amount of required increase in load-bearing capacity, space constraints, and economic feasibility.

Reinforcement of steel columns is an important process in ensuring the durability and reliability of building structures. Over time, steel columns can lose their load-bearing capacity due to corrosion, mechanical damage, or increased loads on the building. Reinforcement allows you to restore or even exceed the original characteristics of the column, extending its service life and preventing emergency situations.

There are several methods for strengthening steel columns, each of which is selected depending on the specific conditions and requirements of the project. The most common are the addition of steel overlays (plates or angles), the use of composite materials (for example, carbon fiber), and increasing the column cross-section by welding or bolting.

Figure 7 – Damage to wall panels

Effective reinforcement of wall structures not only ensures the safety and durability of the building, but can also significantly extend its service life, avoiding the costly dismantling and construction of new walls.

In general, the choice of the optimal method depends on the existing condition of both the structural elements and the building as a whole, the required degree of reinforcement, economic feasibility and impact on the functioning of the building during the work.

An important condition for successful reinforcement is a thorough diagnosis of the existing condition, identification of the causes of damage and correct calculation of the necessary reinforcement parameters.

Also, it is critical to adhere to the technology of work execution and use of quality materials to ensure the durability and reliability of the reinforced structure.

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Діагностика несучих будівельних конструкцій підприємств будівельної індустрії, що працюють під впливом технологічних рідин

Діагностування несучих конструкцій на підприємствах будівельної галузі, які піддаються впливу технологічних рідин, представляє унікальний комплекс завдань. Ці рідини, від корозійних хімікатів до абразивних суспензій, можуть значно прискорити руйнування бетону, сталі та інших будівельних матеріалів. Ефективна діагностика вимагає багатостороннього підходу, який враховує конкретні рідини, їх концентрацію, температуру та тривалість впливу. Візуальні перевірки, доповнені такими методами неруйнівного контролю, як ультразвуковий контроль, георадар і ехо-сигнал, мають вирішальне значення для виявлення прихованих пошкоджень, таких як корозія, розтріскування та розшарування. Крім того, відбір проб матеріалу та лабораторний аналіз забезпечують остаточну оцінку ступеня хімічного впливу та його впливу на цілісність конструкції. Зрештою, комплексна програма діагностики дозволяє приймати обґрунтовані рішення щодо ремонту, відновлення або навіть заміни пошкоджених конструкцій, забезпечуючи безпеку та безперервність роботи підприємства.

Ключові слова: будівельні конструкції, технічний стан, підсилення.

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Features of designing evacuation exits in the reconstruction of civil protection shelters for public buildings

In the context of the war in Ukraine, the issue of public safety has become acute. Civil protection measures include designing shelters or reconstructing existing basements. A component of the basement reconstruction is the redevelopment of evacuation exits from the shelters. The relevant current regulatory framework is analyzed. The object of the study is the building of an educational institution in the city of Poltava, built in the 19th century. A project for reconstructing the basement into a dual-purpose room with a separate emergency exit outside the building collapse zone has been developed.

Keywords: basement, civil defense. evacuation, shelter, exit.

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Introduction

Public buildings require measures to improve the level of civil protection. A way to improve security is to reconstruct basements into dual-purpose rooms (shelters). Dual-purpose premises can be used for their primary functional purposes and public protection.

Review of the research sources and publications

The world experience and expertise in planning emergency shelters are analysed in [1]. Increasing the level of passive safety of citizens in wartime is described in [2]. The development of planning solutions is studied in [3-4]. According to [5], the movement of human flow in the event of an emergency is analysed. The developed principles of universal design of shelters in the example of the United States are studied in [6]. Foreign design solutions for emergency shelters are analysed in [7]. Global design principles for evacuation centres were analysed [8].

Definition of unsolved aspects of the problem

Following current legislation and building regulations, all buildings must have shelters. In recent pre-war times, there was no need for civil protection measures. In the context of dense existing buildings, the construction of new civil protection facilities is not possible (Fig. 1). Therefore, a resource for increasing the number of relevant facilities is the conversion and reconstruction of basements of existing buildings.

The regulatory literature does not specify a design scheme for the collapse of a building when designing evacuation exits.

Figure 1 – Situation diagram

Problem statement

The work aims to clarify the design solutions for civil protection shelter elements, using the example of a historical building of an educational institution.

Basic material and results

A survey of the historic building of the educational institution was carried out. The basement of the academic institution measures 21.22×66.57 m in plan along the axes. The height of the premises is 2.1 m. The walls are brick, without a waterproofing layer along the outer contour. The blind area is deteriorated in some places. There is high humidity in the basement. The walls are affected by fungus and mould. The protective layer of concrete (exposed reinforcement) in the reinforced concrete floor beams was destroyed (Fig. 2).

During the reconstruction of the facility, it became necessary to convert the basement into a dual-purpose room with the possibility of making a radiation shelter in the future. To this end, a geological survey was conducted to determine the ground conditions and groundwater level. It was decided to lower the floor by 300 mm to comply with the requirements [9] regarding the minimum height of the storage facilities and the need to place ventilation equipment on the ceiling. The project envisages antiseptic treatment of the inner surface of the walls, replacement of the finishes, and restoration of the waterproofing layer and insulation of structures bordering the ground.

A dual-purpose emergency exit shaft was designed. The emergency exit shaft should be designed to withstand the impact of load combinations under steady-state (basic) and emergency design situations. In the calculation for emergency load combinations, the quasi-static load from the airborne shock wave is taken into account in accordance with the class of the protective structure, according to [9].

The storage capacity is 300 people. There is an emergency exit through a vertical shaft with a protective cap. The plan dimensions are 12.26×2.26 m. The internal dimensions of the tunnel and shaft in the lumen are 1.6×1.5 m. The head of the emergency shaft exit, 1.2 m above the ground surface, is equipped with four louvred grilles. The louvres are 0.9×0.9 m in size and open into the shaft. The exit from the shelter to the tunnel is equipped with protective and airtight shutters (hatches) installed on the outer and inner sides of the wall, respectively (Fig. 3).

A calculation was made for the effect of a quasi-static load from the impact of an air shock wave $q_{ex,eqv}$, on the emergency exit structures. The value was 288 kPa.

The calculation methodology is taken from the current regulatory literature [9].

Dual-purpose storage class **– (A-IV)**. Excessive air shock wave pressure $\Delta P_{ex} = 100\ kPa$**.**

When calculating the head of an emergency exit that falls within the zone of possible rubble and is elevated above the ground, the load from the ruins of the destroyed building or structure is considered.

Figure 2 – Detachment of the protective layer of concrete in the reinforced concrete floor beams of the basement.

The emergency exit head, elevated above the ground, is designed for horizontal quasi-static loading $q_{ex,eqv}$, $125\ kPa$.

Water supply, heating and sewerage networks of a building that run in an adjacent room are laid in special collectors (concrete or reinforced concrete channels), accessible for inspection and repair work during the operation of these networks in peacetime. The collectors have a slope of 2-3% towards the drain.

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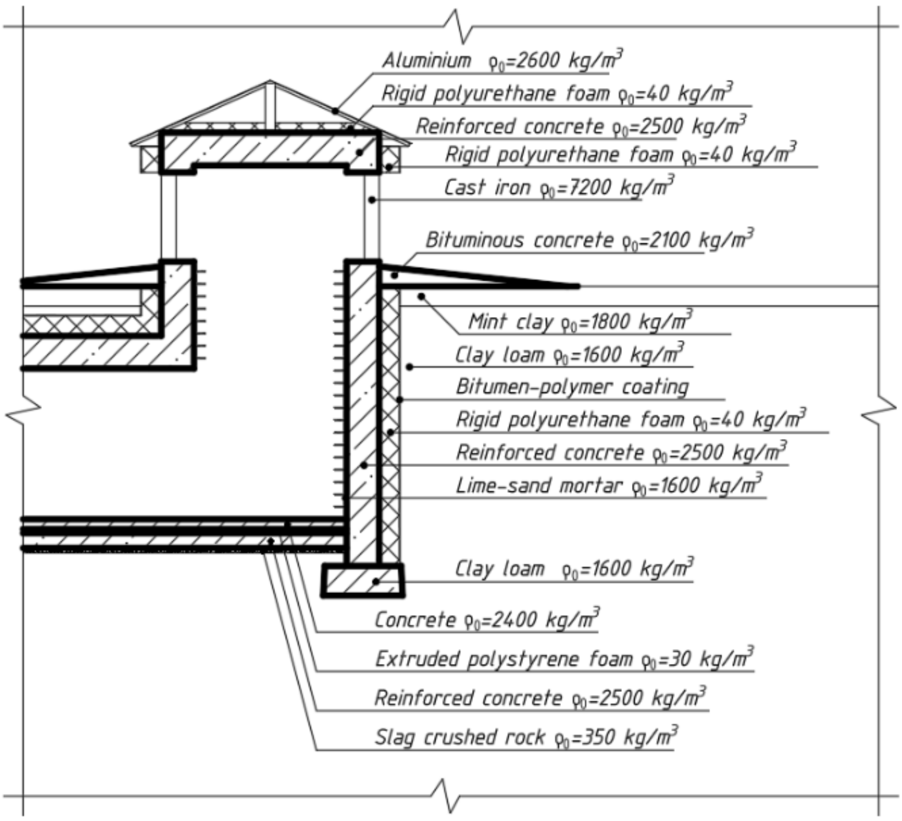


Figure 3 – Section of the head of the emergency shaft (design solution)

The embedded parts for cable entries, air ducts, water and heat supply pipes and sewage outlets are arranged in metal pipes with flanges welded in their middle part. The embedded parts will be installed in the enclosing structures before concrete concreting.

The regulatory framework does not specify which part of the building is included in the collapse volume. Taking into account the scenario of collapse of a part of the building, two types of collapse are provided for the emergency exit cover combined with the ventilation shaft

- collapse of the external load-bearing brick wall with half of the inter-floor floor and the covering above the 1st floor (inclusive);
- the collapse of the outer and inner load-bearing brick wall with half of the inter-floor ceiling of the common corridor, and the collapse of classrooms above the 1st floor (inclusive) and the building's roof.

The vertical static load on the bearing structures of the roof of an emergency mine is the dead weight of these structures and the weight of the roof structures. The weight of the supporting structures and the elements of the roof and lining is a constant value. The load per 1 m2 of the emergency shaft cover structures was calculated to be 33.11 kPa.

To consider the dynamic impact of vertical loads during the building collapse process, we introduce a dynamism coefficient equal to 1.1 by [10].

$$q_{overall.} = q \times 1{,}1 = 33{,}11 \times 1{,}1 = 36{,}42\ kPa.$$

The emergency exit design includes reinforced concrete structures with a thickness of 330 mm (concrete class C25/30). To prevent concrete particles from exfoliating from the inside of the wall, the project provides for installation of additional anti-chipping reinforcement on the inside of the protective layer of concrete at a depth of no more than 25 mm from the inner surface of the reinforced concrete structure with steel mesh with a rod diameter of at least Ø 2 mm, with a mesh spacing of no more than 40 mm, attached to the primary reinforcement of the structure (fastening should be performed with at least three turns of knitting wire at each point, with a spacing of at least 500 mm in both directions).

The roof was designed using metal profiles and embedded parts. The embedded parts are 100×100 and 100×200 mm in size. Metal profiles with a square cross-section are welded to the embedded parts with dimensions of 100×100 mm rafters and 30×30 mm.

The effectiveness of the facility's insulation was verified by finite element modelling according to the design scheme (Fig. 3). The reconstruction project provides for external insulation of the buried part of the basement to the floor level with extruded polystyrene foam 150 mm thick with a PVC membrane.

The study was conducted using Poltava's initial data. Initial conditions: outdoor air temperature -22°C; indoor air temperature +5°C according to the calculation scheme in Fig. 4.

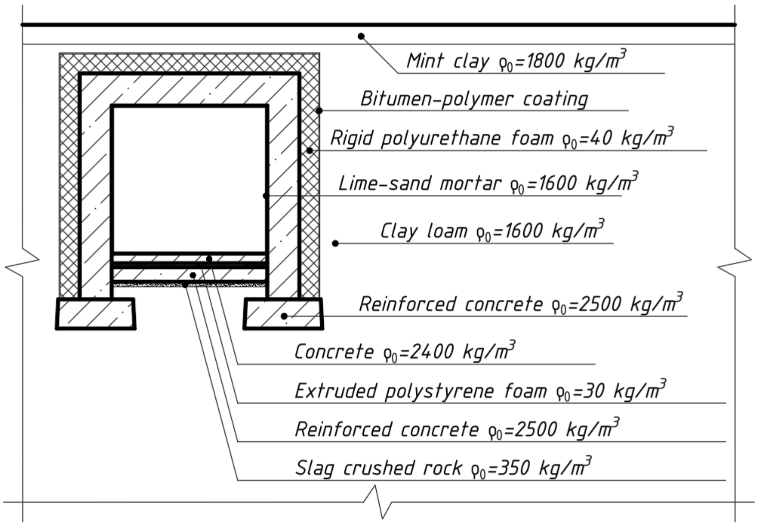
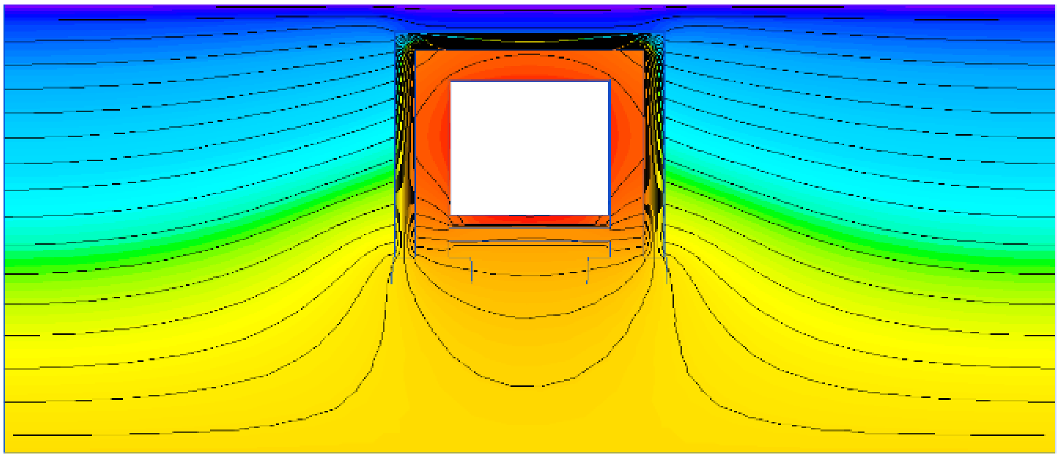
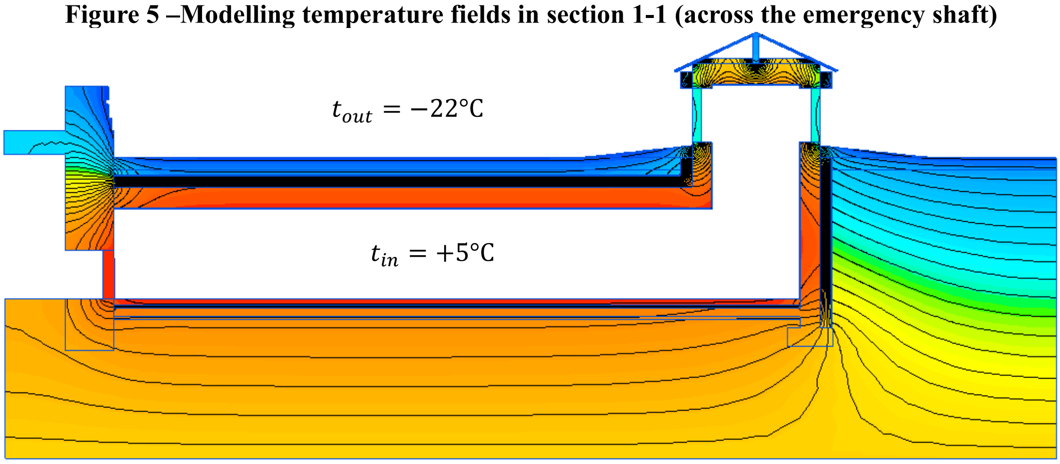


Figure 4 – Computational scheme for modelling temperature fields



Average internal surface temperature: + 4.185 °C; Heat flux: 43.209 W.

Figure 5 –Modelling temperature fields in section 1-1 (across the emergency shaft)



Average internal surface temperature: + 2.861 °C; Heat flux: 585.96 W.

Figure 6 –Modelling temperature fields in section 2-2 (along the emergency shaft)

Conclusions.

A design of an emergency exit from a dual-purpose room of an educational building in Poltava was developed. The influence of quasi-static load on the exit structure was analysed. Thermal insulation materials were selected. Calculation schemes for determining the dynamic loads on the emergency exit are proposed. When calculating the loads, the loads from the complete collapse of the following were considered: brick wall, roof structures and rafter system; attic and inter-floor floors to the ground level. The 1st-floor ceiling structures in the form of a brick vault were not considered, as the collapse of such structures has a vertical motion vector.

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Дослідження тепловологісного режиму холодних горищ інструмента

В умовах збройного конфлікту на території України питання забезпечення безпеки цивільного населення набуло особливої актуальності. Відповідно до сучасних вимог нормативно-правової бази у сфері цивільного захисту, всі громадські будівлі мають бути обладнані відповідними захисними спорудами, зокрема сховищами та укриттями. В умовах щільної забудови та обмежених ресурсів на нове будівництво одним з ефективних рішень є реконструкція підвальних приміщень існуючих будівель у приміщення подвійного призначення. У таких приміщеннях поєднуються функції звичайної експлуатації в мирний час із можливістю використання як захисних споруд у надзвичайних ситуаціях. Основною метою реконструкції є забезпечення відповідності технічного стану приміщення чинним вимогам до укриттів класу А-IV, включаючи вимоги до мінімальної висоти приміщень, вентиляції, гідроізоляції, протигрибкової обробки та конструктивної надійності в умовах впливу надлишкового тиску повітряної ударної хвилі. Проєктом передбачено перепланування з улаштуванням аварійного евакуаційного виходу через вертикальний шахтний канал, винесений за межі зони можливого обвалу основної будівлі. У межах роботи виконано обстеження існуючих конструкцій. метою забезпечення належного теплозахисту захисної споруди виконано моделювання теплофізичних процесів із застосуванням скінченно-елементного аналізу, що дозволило обґрунтувати вибір теплоізоляційних матеріалів та конструктивних рішень.

Ключові слова: евакуація, сховище, вихід, підвал, цивільний захист.

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Experimental and theoretical studies of reinforced concrete structures using fine aggregates from iron ore beneficiation waste

Beneficiation waste from mining and processing plants possesses the characteristics of strong and inexpensive aggregates suitable for structural reinforced concrete. This enables the practical use of such waste in the production of precast reinforced concrete. Practice has demonstrated the feasibility of using iron ore beneficiation waste as fine aggregate in concrete. The authors conducted studies on the behavior of concrete structures incorporating fine aggregates derived from iron ore beneficiation waste. This article presents the results of research on concrete, elements, and structures with fine aggregates from iron ore beneficiation waste under low-cycle loading.

Keywords: beneficiation waste, fine aggregates, reinforced concrete structures, low-cycle loading, prestressing reinforcement.

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Introduction

Improving the economy, reliability, and durability of structures is a key area of advancement in construction engineering both in Ukraine and internationally. Equally important is the reduction of concrete and reinforced concrete costs. One way to achieve this is through the development of construction materials utilizing waste from the mining industry

Iron ore basins hold significant reserves of aggregates from beneficiation waste, which can be used in the production of concrete and reinforced concrete structures. Utilizing such waste can help address the shortage of non-metallic construction materials and provide a supply of strong and affordable aggregates for structural reinforced concrete. Reclaiming land occupied by waste also addresses environmental protection concerns and promotes zero-waste processes in the mining industry.

Practice has confirmed the feasibility of using iron ore beneficiation waste as fine aggregate in concrete. At Kryvyi Rih National University, studies were conducted on the performance of concrete and reinforced concrete structures with concrete made using fine aggregates from iron ore beneficiation waste. The waste from all mining and processing plants has similar properties, making it viable for practical application in precast reinforced concrete production.

Review of the latest research sources and publications

A review was conducted of domestic and international research dedicated to the theoretical and experimental study of the performance of concrete and reinforced concrete elements under low-cycle loading, as well as the reinforcement of the compressed concrete zone. The nature and physical essence of low-cycle repeated loading were also analyzed.

Researchers such as Soleimani, S. M., Boyd, A. J., Komar, A. J. K., & Roudsari, S. S. Han, B., Gao, H., Zhang, L. Li, J., Liu, H., Guo, Q., Dai, G., Zhou, J., & Xie, P. and others have contributed to the study of concrete and reinforced concrete elements under low-cycle loading.

The above studies confirm that low-cycle loading causes changes in the strength and deformation characteristics of both concrete and reinforcement.

The specific behavior of concrete and reinforced concrete structures made using beneficiation waste has been studied by researchers such as Valovoi, O. I., Eremenko, O. Yu., Valovoi, M. O., & Volkov, S. O., Arbili, M. M., Alqurashi, M., Majdi, A., Ahmad, J., & Deifalla, A. F. Evangelista, L., de Brito, J. Krishna, Y.M., Dhevasenaa, P.R., Srinivasan, G and others.

Definition of unsolved aspects of the problem

Improving the economy of reinforced concrete structures requires the development of concrete with higher strength properties and the creation of reliable methods for predicting their behavior under load.

This aligns with the economically efficient use of mineral resources in production. The current technical level of industry enables the complete processing of by-product minerals and production waste, 85% of which can be used in construction. Therefore, saving and optimizing the use of resources in precast reinforced concrete production can be viewed through the lens of comprehensive utilization of raw materials and mineral processing waste.

Currently, iron ore beneficiation waste is used as a substitute for sand in construction mortars and concrete. Studies have shown high efficiency and stable physical and mechanical properties in such concrete, along with good workability in construction.

The use of concrete and reinforced concrete has expanded significantly, and the average strength of materials used has increased. High-strength materials in structures often allow for the reduction of cross-sectional areas without compromising design load capacity.

The behavior of concrete and reinforced concrete under single static loads is well studied. However, a wide range of modern structures in real operating conditions are subjected to high-intensity. repetitive low-cycle loads (such as seismic or temperature effects). Operating modes of structures are becoming more demanding and complex. Therefore, studying the resistance of reinforced concrete elements to repeated high-intensity loading is a crucial issue both in reinforced concrete theory and in solving practical engineering problems for creating reliable and efficient structures.

Problem statement

The physical nature of the stress-strain state of concrete under repeated cyclic loading remains largely unexplored, and current views on the phenomenon are often contradictory. Despite extensive experimental and theoretical research aimed at studying the physical and mechanical properties of concrete under cyclic loading, there is still no unified modern physical theory that adequately explains the deformation process and changes in strength characteristics of concrete under such conditions.

Progress in the analysis of concrete and reinforced concrete structures under variable and cyclic loading should focus not so much on refining mathematical calculations, but rather on the experimental investigation and consideration of concrete and structural behavior. It is therefore essential to develop a comprehensive understanding of the behavior of such concretes to effectively integrate this knowledge into design practices.

In conclusion, scientifically accounting for the aforementioned factors in the design of reinforced concrete structures for strength, stiffness, and crack resistance will help avoid inefficient use of concrete and steel by refining safety factors.

Basic material and results

The research of concretes elements and constructions with fine aggregate from the ore-dressing waste products was carried out in the collation of analogical samples of heavy concrete with traditional fine aggregate – quartz sands.

Physical-mechanical properties of the concretes have been explored using cubes of 10 cm ribs and prisms of 10×10×40 cm size made of concrete of 400 projected make of 1:2.22:0.89 composition, with the addition of 1% plasticizer of cement mass and B/Z = 0.32.

In both concrete mixtures were used the portland cement of M 500 and granite rubble with a 10–20 mm fraction.

At axial compression, the concrete cubes made from waste products collapsed similar to the cubes produced from conventional concretes. The prisms collapsed along the longitudinal crecks or ruptures. Comparing the character of collopse (breaking) of waste products produced concrete with the conventional concrete, it was noticed that the first type is more brittle and breaks almost immediately. Besides, the strength of concrete produced from ore-dressing waste, after 28 days, practically doesn`t increase.

Waste produced concrete has 15–20% better grip on average. For estimation of waste produced concrete grip between concrete and steel we propose the following dependence [1]:

$$N_{\max} = K_1 K_2 K_3 U I R_{gr} \tag{1}$$

where R_{gr} – average conventional value of grip; I – length of reinforcement (steel) embedding, cm; U – bar perimeter, cm; K_1 – coefficient regarding the steel (reinforcement) type: for smooth bars $K_1 = 1$, for periodical profiled bars $K_1 = 1.32$, for ropes K-7 of Ø 12-15 mm $K_1 = 1.2$; K_2 - coefficient regarding type of concrete: for conventional concretes $K_2 = 1$, for waste produced concrete $K_2 = 1.15$; K_3 –

coefficient regarding bar diameter: for Ø ≤10 mm – $K_3 = 1.1$, for Ø12-16 mm – $K_3 = 1$, for Ø18 mm – $K_3 = 0.9$.

The average discordance between test and theoretical out stresses (force) results for waste produced concrete, calculated on formula (1) doesn't exceed 7%.

The average values of waste (produced concrete limited deformations constituted 1.286 mm/m, and 1.683 mm/m for the conventional concrete). Waste produced concrete can be considered to be practically elastic material up to $0.8R_{np}$ tension (stress) (Fig. 1).

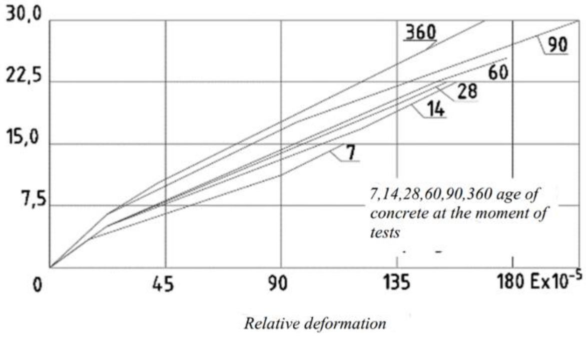

Figure 1 - Prestressed constructions produced from concrete made of fine aggregate – ore-dressing waste.

We propose to determine the waste produced concrete theoretical elastic modulus using the formula:

$$E_б = C\frac{5500\bar{R}}{27+\bar{R}} \tag{2}$$

where C – coefficient obtained from experience, $C = 1.16$.

The values of waste produced concrete shrinking deformation don't exceed the shrinkage of conventional concrete.

Waste produced concrete creep characteristic is for 16% less than that of the conventional concrete. At the age of 300 days the values of the creep of concrete characteristic at 0.5 and $0.6R_{np}$ are corresponding l_y – 1.49 and 2.02. The theoretical values of the said deformations on time are determined by the known formulas [2]:

$$\alpha_y(t) = \alpha_y\left(1-e^{-\alpha t}\right); \tag{3}$$

$$\varphi_t = \varphi_\infty\left(1-e^{-\beta t}\right), \tag{4}$$

where α – relative shrinkage deformation to arbitrary moment of time, t; α_y – limited relative shrinkage deformation the moment of its damping; φ_∞ – limited value of creep characteristic related to the moment of time $t=\infty$; α and β experimental parameters.

The average values of limited shrinkage and creep of concretes values and also the recommended coefficients α and β are given in Table 1.

Table 1- Coefficients value for the concrete under test in formula (3) and (4)

Types of concrete	φ_∞	$\alpha_y \times 10^{-5}$	α	β
Level of loading $0.5\bar{R}_{np}$				
On waste Conventional	1.27 1.66	28.5 24	0.0123 0.0132	0.0145 0.016
Level of loading $0.6R_{np}$				
On waste Conventional	1.49 2.02	28.5 24	0.0123 0.0132	0.0145 0.016

To determine the low cyclic concrete fatique (Table 2) 9 series of prisms of old age were tested in the regime of soft loading with max level of stresses within the limits of 0.75-1.

The carried out tests showed that the less the level of loading (at low cycled loading) the higher the max deformations of concrete ε_R.

For determination of the low cycled fatique of waste produced concrete the following dependence is proposed:

$$N = \frac{\bar{R}_{np}\delta(1+\alpha)\alpha}{2E_0\varepsilon_R^{\alpha}}\sigma_a^{-\frac{1}{\delta}}, \tag{5}$$

where R_{np} – concrete prism strength when subjected to monotonous by increasing loading: $\delta = \frac{\alpha}{1+\alpha}$; $\alpha = \frac{E_\delta \varepsilon_R}{\bar{R}_{np}} = \frac{1}{\upsilon}$; E_0 – modules of non-linearial concrete deformations; E_R – concrete maximum deformations; σ_α – amplitude of stresses.

Table 2- Results of low-cycle fatigue testing of waste-based concrete

№ of series	Stresses Mₐ	Level of stresses	Max. deforma-tions of concrete $\varepsilon_R \times 10^{-5}$	Cycle test number till break, N	Theoretical value, N
1	25.3	1	114	0	0
2	24.8	0.98	119	4	2
3	24.3	0.97	123	5	3
4	22.8	0.9	131	11	8
5	20.7	0.82	137	18	18
6	20.2	0.8	138.5	21	22
7	19.7	0.78	140	30	28
8	19.5	0.77	141	33	32
9	19.0	0.75	141.5	*	∞
* the prism didn`t collapse after 120 cycles					

Experimental and theoretical results of low cycled fatique of waste produced concrete are quite similar.

Prestressed T-beams were tested in laboratory conditions. The T-beams were treated with concrete simultaneously with cubes and prisms.

The steel initial stresses were specified in accordance with specifications and were transferred from the rests to concrete being 7 days of age (age of concrete). At the moment of the reinforcement tempering there were no cracks in the upper zone. The zone of clear bending free from lateral reinforcement was tested.

By monotonously increasing loading test process were checked and measured the concrete compressed zone edge deformations, as well as the deformation. At the stressed steel level deflections in the middle of the span and the width of the cracks opening.

The test results analysis of the stress distribution on high of the concrete compressed zone (Fig. 2) showed, that the strength analysis of the normal section beams made from waste produced concrete should be done regarding the triangular epure of stresses by formula:

$$M = 0,5R_{np}bx\left(h_0 - \frac{1}{3}x\right) \qquad (6)$$

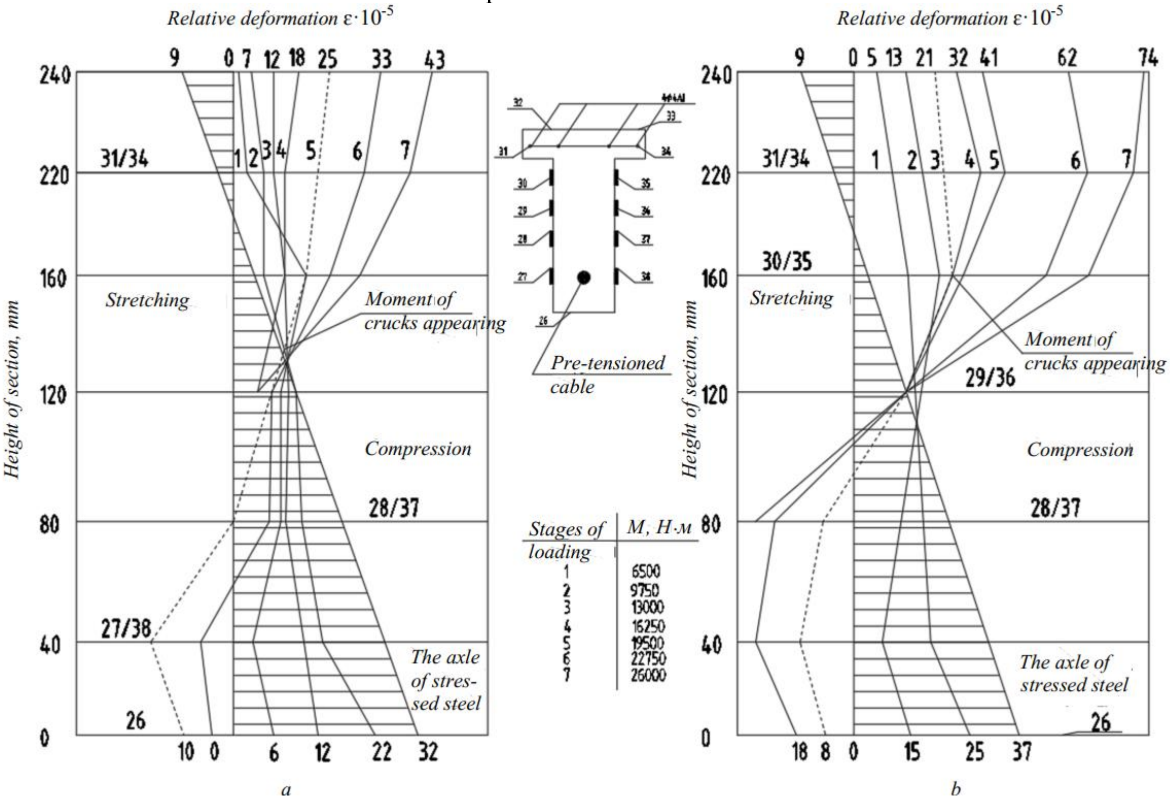

Figure 2 - Epure of longitudinal deformation of concrete on middle section height beams in dependance of the bending moment value.

According to analysis the coefficient of elasticity ν in the collapse stage for waste produced beams can be taken as 0.8.

Crack resistance of the bending elements produced from waste can be determined regarding replacement of elastic-plastic moment of resistance WT by formula:

$$W_m = b(h-x)\left(\frac{h}{2}+\frac{x}{6}\right)+\frac{2F_{св}(x+\alpha_{св})}{h-x}\times$$
$$\times\left(\frac{x}{3}-\alpha_{св}\right)+F_н\left(2n+\frac{\sigma_0}{R_p}\right)\left(h_0-\frac{x}{3}\right), \qquad (5)$$

where all indices taken according to [4].

The values of crack formation moments regarding (7), determined from the premises of triangular epure of stresses, for experimental beams are shown in Table 3.

Table 3- Values of test and theoretical index of M_t,Н·м

Concretes	σ0, Мпа	$M_m^{оп}$	$M_m^{теор.}$ with W_m (7)	% difference
Produced from waste	8361	19500	20016	2.6
Conven-tional	8072	16250	19126	17.7

The test values of crack opening in the beams of waste produced concrete with M≅0.6M are 27% less than in beams produced from conventional concrete.

Theoretical values of crack width opening of the beams made from waste produced concrete is necessary to determine by the known formula:

$$\alpha_m = KC_д\frac{\sigma_a}{E_a}\cdot 20(3,5-100\mu)\sqrt[3]{d}, \qquad (8)$$

where $K = 0.8$ – coefficient obtained experimentally, the rest of values taken from [4].

The beams deflections of beams produced from waste are on average 20% less than that in the beams produced from concrete based on quartz.

That's why the flexure of these beams series beams, with $M \le M_m$ is recommended to determine by formula:

$$\frac{1}{p} = \frac{\bar{M}C}{K_n E_б J_n}, \qquad (9)$$

where coefficient $K_n = 0.95$ is obtained experimentally.

Experimental values of dressing waste produced concrete beams shrinkage deformation aging 480 days is lesser for 31-32%, and loss stress value for 35% lesser than, that in the analogical beams made of the conventional concrete. These stresses for the reinforced armored concrete elements are expedient to determine using the recommendations [2] according to formula:

$$\sigma_{ny} = \frac{\varepsilon_{\delta y}(t)}{\frac{1}{E_н} - F_н\left(\frac{1}{F_\delta} + \frac{Y_н^2}{J_\delta}\right)\frac{\gamma}{E_0}}, \qquad (10)$$

where $E_н$ and $F_н$ – module of elasticity and sectional area of stressing steel; F_δ – sectional area of concrete; J_δ – moment of beam inertia; $Y_н$ – distance from stressed steel to the centre of gravity of the beam section; $E_0 = E_\delta(\tau)$; τ – time of application of loading; γ – is determined by the formula:

$$\gamma = \frac{\varphi_t}{1 - \exp\left(-\frac{\varphi_t}{1-\varphi_0}\right)}, \qquad (11)$$

where φ_t - the characteristic of concrete creep; φ_0 – the value of the characteristic of the concrete creep charged in old age.

The value of $\varepsilon_{\delta y}(t)$ while calculating σ_{ny}, is taken from the test data. Supposing $\varepsilon_{\delta y}(t) = \alpha_y(t)$ determined by formula (3), α_y and α are known it is possible to calculate the stress losses at any moment of time.

The max. value of steel stress losses caused by the concrete creep in the BP-1 beams in average is for 18% less, than that in the analogical (similar) beams produced of conventional concrete. The prestressed losses in the beams, reinforced by single stressed steel is recommended to determine by the formula:

$$\sigma_{nn} = \frac{n\sigma_{бн}(1-\varphi_t) - \sigma_н}{1 - n\left(\frac{1}{F_\delta} + \frac{Y^2}{J_\delta}\right)F_н\gamma}, \qquad (12)$$

where $\sigma_{бн}$ – concrete initial stress; $\sigma_н$ – steel initial stress; $n = \frac{E_н}{E_\delta}$; the rest of the values are deciphered in formula (10). The formula (12) answers rather satisfactorily to the results of the experiment.

The applied calculation formulas and methods effectively approximate the experimental data, allowing for an assessment of the impact of fine aggregates derived from iron ore beneficiation waste on the performance characteristics of concrete and its structures. Further research will focus on evaluating the convergence between the obtained experimental data and theoretical calculations based on the deformation methodology.

To inculcate in industry the results of the research a series of tests on reinforced concrete constructions made from waste were carried out. There were tested eleven constructions altogether-floor slabs, roof truss, crane beams, cross-bar and foundation beam.

The constructions were produced from the materials, the physical mechanical properties of which had been described above.

The general geometrical size and reinforcing of the construction were taken from manuals.

Testing the hollow boards made from waste produced concrete the maximum permissible deflection $l/200$, or accordingly 2.75 and 3 cm, was reached with load on average of 20-30% higher than that with the boards made from conventional concrete.

At that the deformations of concrete compressed zone and the level of stressed concrete reinforcement is 30-40% lesser than the corresponding deformations in the conventional concrete made boards (than in the boards made from conventional concrete).

The boards made from waste produced concrete have exceeded the calculated index: on strength for 20-30% on harshness for 40-45% and deformation ability for 37-40 and 33-34%.

According to shop drawings demands the truss is to take up the test joint load of 297.3 kH (factum of calculated load of 178 kH and coefficient 1.67). At normative joint load of 148 kH the deflection of the truss is to be 9 mm, in case of calculated load of 178 kH – the deflection of the truss is 12 mm.

The test results showed that the truss deflection with testing load of 150 kH was 8.9 mm and with 180 kH load – 12 mm. The truss lost its carrying capacity at joint load of 440 kH.

The crane beam loaded with single concentrated force in the middle section took up load of P=633 kH, wich created stresses of M=934.5 кHм; Q=467 kH. The second beam, loaded with concentrated forces in the one third of the span, took up the load of P=920 kH which created stresses of M=920 kHm and Q=460 kH (the project demands are M_{max}=549 kHм, Q_{max}=419 kH).

The test of collar-beam was carried-out in accordance with working drawings demands. The actual load on the collar-beam was 840 kH (calculated breaking load 653 kH).

The collar-beam deflection at normal load of 528 kH has proved to be 8.5 mm. The standardized deflection for this load equals 13.3 mm.

The breaking load of the foundation beam proved to be 350 kH with calculated load of 128.6 kH.

The described here research is a striking evidence of the possibility of wide scale usage of ore-dressing waste for conventional and prestressed reinforced constructions production.

The effectiveness of reinforced constructions production made from the waste based concrete results from the profit gained by the ore-dressing plant, building companies and railway management.

Conclusions

Successful resolution of the issues discussed above will allow for the creation of reliable and cost-effective structures, preservation of land resources and the environment, and supply of strong and inexpensive fine concrete aggregates to precast concrete plants.

This study investigates concrete and flexural reinforced concrete elements and structures using fine aggregates from iron ore beneficiation waste under constant, variable, and alternating loads of varying intensity.

As a result of the research, a number of specific physical and mechanical properties were identified in concrete made from beneficiation waste (e.g. increased strength, reduced deformability), which must be taken into account when developing structural design approaches for such materials.

A comparison of experimental and theoretical results for the strength and deformation characteristics of reinforced concrete structures (e.g., strength, stiffness, cracking moment) demonstrates the feasibility of using standard design principles, provided the unique properties of the concrete in question are considered.

Laboratory testing of elements and field tests of typical reinforced concrete structures made with this concrete confirm the potential for wide application and high effectiveness of the recommended material.

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Експериментальні та теоретичні дослідження залізобетонних конструкцій із використанням дрібного заповнювача з відходів збагачення залізної руди

Відходи збагачення гірничо-збагачувальних комбінатів характеризуються високою міцністю, однорідністю та низькою вартістю, що робить їх перспективними для використання як дрібного заповнювача у конструкційному залізобетоні. Це відкриває широкі можливості для практичного застосування таких техногенних матеріалів у виробництві збірного залізобетону, зокрема у регіонах з обмеженими запасами природних нерудних ресурсів. Практичний досвід і дослідження підтверджують доцільність заміни традиційних заповнювачів на відходи збагачення залізної руди. У дослідженні, виконаному на базі Криворізького національного університету, розглянуто особливості роботи бетону та залізобетонних конструкцій, що містять як дрібний заповнювач відходи збагачення залізної руди. Наведено результати фізико-механічних випробувань, проведених як у лабораторних умовах, так і у вигляді натурних експериментів на типових елементах конструкцій. Доведено, що бетон з техногенними заповнювачами характеризується підвищеною міцністю, зменшеною деформативністю та підвищеною тріщиностійкістю. Розглянуто поведінку таких конструкцій під дією постійного, змінного та малоциклового навантаження різної інтенсивності. На основі експериментальних даних проведено порівняння з теоретичними моделями, що дозволило підтвердити можливість використання діючих нормативних методик розрахунку за умови урахування особливих властивостей бетонної суміші. Зроблено висновки щодо ефективності використання відходів збагачення як альтернативного джерела заповнювачів, що одночасно сприяє підвищенню економічності, довговічності та екологічної безпечності будівельного виробництва.

Ключові слова: відходи збагачення, дрібний заповнювач, залізобетонні конструкції, малоциклове навантаження, попереднє напруження арматури.

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Precast flat plate frame of buildings for renewal of the housing stock of Ukraine

The suggested precast flat slab system is composed of columns and flat plates that connect to the columns without the use of consoles or capitals. This structural system is intentionally designed in such a way that lines of arrangement of plastic hinges between precast plates are artificially created. Consequently, an analysis of precast flat plate floor systems is proposed based on the yield line method. The utilization of the yield line method facilitates the development of straightforward engineering design schemes, potential fracture scenarios, and the determination of the load at which destructive failure occurs for all types of precast flat plates. By employing the yield line method within the ultimate equilibrium state, utilizing a nonlinear deformation model with an extreme criterion, design equations to address the bearing capacity of flat plate of the frame structural system are derived. These formulas are well-suited for practical engineering use and account for the plate's installation conditions as part of a precast flat floor.

Keywords: bearing capacity, building frame, flat plate, reinforced concrete, slab

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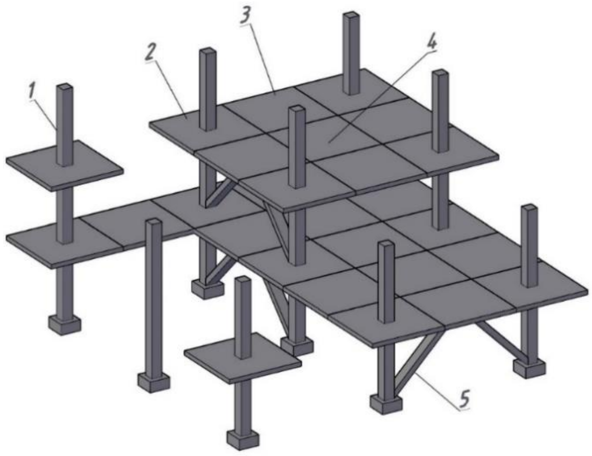
Introduction. The restoration of the housing stock for today and in the future is one of the urgent problems of construction in Ukraine. In Poltava, the solution to this problem is implemented by constructing residential buildings and infrastructure facilities based on the flat plate frame structural system [1 – 3], which ensures a fast pace of their construction with minimal labour costs for builders. The flat plate frame structural system of buildings consists of prefabricated precast reinforced concrete elements that are mounted directly on the construction site. This system demonstrates versatility, which allows it to be used for buildings of various types: from multi-storey buildings up to 16 floors high to cottages 2-3 floors high in any climatic conditions of Ukraine. It has found successful application in the construction of above-ground multi-storey parking lots, residential and public buildings. In Poltava, a precast the flat plate frame structural system is being widely introduced into residential construction. On its basis, multi-storey buildings were built in the Sadovyi microdistrict, Family Park residential complex, Baronivskyi residential complex, Yevropeiskyi kvartal residential complex, and construction is being completed in the Peliustkovyi residential complex (Fig. 1, *a*, *b*). Interest in the flat plate frame is due to a number of its advantages when used in construction: freedom of architectural and planning solutions; wide possibilities for redevelopment of premises; use of energy-efficient materials in enclosing structures; rapid resumption of industrialization of construction, etc. By its design, the frame consists of a minimum number of standard sizes of precast elements, namely: vertical multi-storeyed columns without consoles and floor slabs [2 – 3]. The slabs are divided into over-columned, inter-columned and middle (Fig. 1, *c*). The operation of each slab depends on the method of its connection with other slabs and columns.

As shown in [7 – 9], for calculating the strength of two-way slabs, it is quite convenient to use the yield line method, which allows taking into account the actual conditions of fastening, reinforcement and the nature of the destruction of elements. In this case, one should take into account the prerequisites of the calculation using the nonlinear deformation model [10], which is regulated by current regulatory documents in the field of designing reinforced concrete structures.

a)



b) *c)*

Figure 1 – Precast flat plate frame structural system of buildings:
***a*) – new building in the residential complex "Pelyustkovy" (Poltava); b) – building under construction;**
c) – general view of the structural system: 1 – column; 2 – over-columned slab;
3 – inter-columned slab; 4 – middle slab; 5 – linear brace

Problem statement. In this article, based on the yield line method using a nonlinear deformation model with an extreme strength criterion, calculation dependencies for solving the problems of the strength of slabs of the flat plate structural system of buildings are obtained.

Main material and results. As a result of the analysis of the ultimate limit state of the flat plate floor, as a system of kinematically interconnected individual disks, it was established that the load on the columns is transferred in the following sequence (Fig. 2): the middle slab transfers the load to four adjacent inter-columned slabs; inter-columned slabs transfer the load to the over-columned slab; the over-columned slab transfer the load to the column. This load distribution scheme is due to the floor failure scheme, on the basis of which the calculation of its bearing capacity is implemented.

The established load distribution scheme allows to consider each floor element separately from each other in the calculations, but taking into account their interaction. The connection of the slabs with each other in practice is carried out by arranging a loop joint, which is an elastic-plastic joint capable of perceiving a fixed value of the bending moment [2]. The bending bearing capacity of the joint of the slabs 6 m long is 51 kN·m [1].

In the calculations of slabs using the yield line method, the following assumptions are made:

– it is assumed that the slab breaks into flat disks that are interconnected along the yield lines by plastic hinges;

– the smallest possible displacement for a given fracture pattern and slab loading pattern is arbitrarily set;

– an equation is drawn up that expresses the equality of the work of external and internal forces on the specified displacement;

– the value of the external load that satisfies the obtained equation is the bearing capacity of the slab.

The fracture scheme of the slab must comply with the conditions of its support and the loading scheme, and also ensure a single kinematic variability of the system. In order to determine the degree of kinematic variability, it is convenient to use the analogy of the fracture scheme with a truss: the degree of kinematic variability of the fracture scheme of the slab is equal to the kinematic variability scheme of the truss, composed of all (positive and negative) yield lines and support hinges of the slab.

For each slab, a set of fracture schemes is accepted that meets the specified requirements and is confirmed experimentally. The acceptable (with a certain degree of idealization) will be the one for which the bearing capacity of the slab has the smallest value.

The equilibrium equation, which expresses the equality between the virtual works of external W_{Ed} and internal W_{Rd} forces on the corresponding possible movements of the slab in the direction of action of the forces, is generally presented as follows:

$$W_{Ed} = W_{Rd} \tag{1}$$

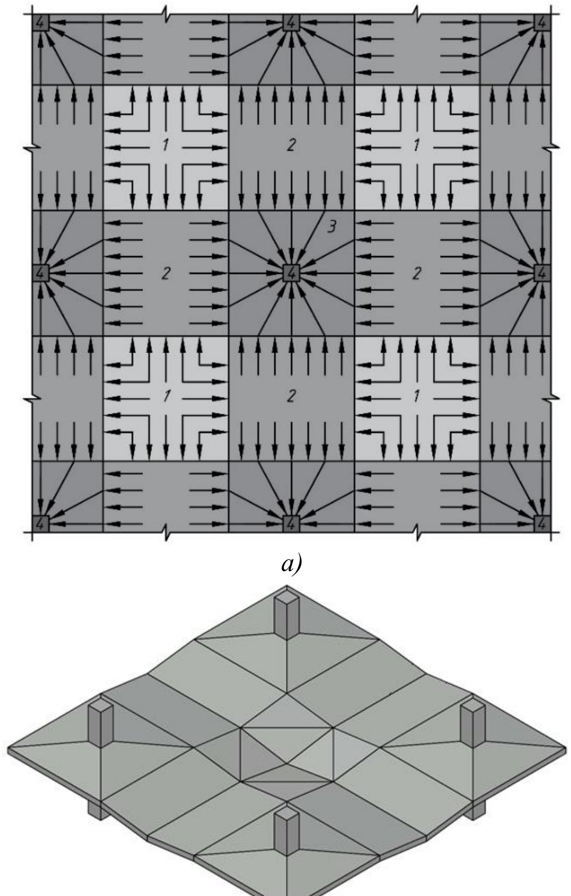


Figure 2 – Load distribution between slabs of a precast flat plate floor (a) and yield line model of floor deformation in the limit state (b): 1 – middle slab; 2 – inter-columned slab; 3 – over-columned slab; 4 – column

The equation of virtual work (1) for the case of calculating slabs loaded with loads distributed over the area and along the yield lines is presented as follows:

$$\int_A q y_q dA + \int_l p(y) y_p dl = \sum_{i=1}^{n} M_i \varphi_i l_i \,, \tag{2}$$

where q is the design limit value of the load uniformly distributed over the area A; y_q is the virtual displacement of the slab in the direction of the load q; A is the area of the part of the slab on which the load q acts; $p(y)$ is the design limit value of the load distributed along a line of length l; y_p is the virtual displacement of the slab in the direction of the load $p(y)$; l is the length of the plate line along which the load $p(y)$ acts; M_i is the ultimate value of the bending moment perceived by the i-th plastic hinge (yield line) per unit of its length; φ_i is the mutual angle of rotation of the disks in the i-th plastic hinge of the design section; l_i is the length of the i-th plastic hinge, n is the number of linear plastic hinges.

The application of the kinematic method is considered for the over-columned slab of the flat plate floor. The over-columned slabs perceive the following loads: q uniformly distributed over the entire floor, as well as the load p from the reaction of the inter-columned slab supports uniformly distributed over all faces of the slab. Since each inter-columned slab rests on two sides on the over-columned slabs, one over-columned slab is subjected to a load from 1/2 of the area of the inter-columned slab on each side. This area is rectangular in shape, so the resulting linear load on the over-columned slab will be uniformly distributed with a maximum ordinate value of $0.75ql$. The over-columned slab is rigidly fixed in the middle part within the opening and works as a cantilever in four directions (Fig. 3).

According to the applied kinematic scheme (Fig. 3), the destruction of the over-column slab occurs as a result of its division into four disks by diagonal linear hinges with the formation of linear plastic hinges at the attachment points along the perimeter of the opening.

The work of external forces in the over-columned slab in (1) is determined by the formula

$$W_{Ed} = \int_A q y_q dA + \int_l p y_p dl = \frac{qf\left(2l^2 - lb - b^2\right)}{3} + 3qfl^2 \,. \tag{3}$$

The work of internal forces (moments) at the corresponding angles of rotation is determined by the expression

$$W_{Rd} = \sum_{i=1}^{n} M_i \varphi_i l_i = 4M_{12}\varphi_{12}\left(l - b\right)\cos 45^0 + 4M_1\varphi b + 4M_{\sup}\varphi l \,, \tag{4}$$

where M_{12} is the internal bending moment that occurs when the plate breaks into adjacent disks 1 and 2 per unit length of the plastic hinge between these disks;

φ_{12} is the mutual angle of rotation of adjacent disks 1 and 2;

M_1 is the internal bending moment that occurs when disk 1 breaks off from the support along the face of the opening per unit length of the plastic hinge formed along the break-off line;

M_{sup} = 8.5 kN·m/m is the internal bending moment that occurs at the loop joint;

φ is the angle of rotation of the slab disks about the design position.

In formula (4), the angles of rotation of the disks can be expressed as follows:

$$\varphi \approx \mathrm{tg}\varphi = \frac{2f}{l - b} \,, \tag{5}$$

$$\varphi_{12} \approx \operatorname{tg}\varphi_{12} = \frac{2f}{(l-b)\cos 45^0}. \qquad (6)$$

After substituting expressions (5) – (6) into equation (4), it is obtained that

$$W_{Rd} = 8M_{12}f + 8M_1 f\frac{b}{l-b} + 8M_{\sup} f\frac{l}{l-b}. \qquad (7)$$

Equation (7) contains the unknown bending moment M_{12}, the value of which per unit length of the plastic hinge depends on the cross-sectional area of the principal reinforcement intersected by this hinge. The hinge under consideration intersects the principal reinforcement of both directions, while the over-columned slab is uniformly reinforced, i.e. the amount of reinforcement in both directions is the same, and therefore the bending moments perceived by the slab in these directions are also the same.

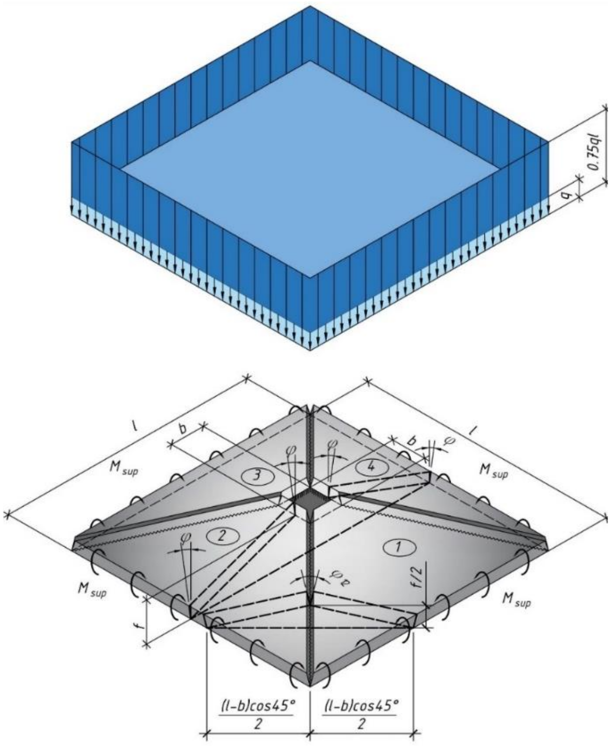


Figure 3 – Design diagram of the fracture (yield lines formation) of the over-columned slab

The bending moments perceived by the reinforcement in one direction will be $M_{Rd}\sin45°$, and in the other - $M_{Rd}\cos45°$. The value of the bending moment M_{12} is the geometric sum of the moments acting in the two directions:

$$M_{12} = \sqrt{M_{Rd}\sin 45° + M_{Rd}\cos 45°} = M_{Rd}, \qquad (8)$$

where M_{Rd} is the bending moment experienced by the slab in one direction.

The bending moment experienced by the slab in one direction is calculated by the formula:

$$M_{Rd} = f_{yd}A_s z_s, \qquad (9)$$

Taking into account (8) and (9) equation (1) takes the form

$$\frac{q\left(11l^2 - lb - b^2\right)}{3} = 8\frac{l}{l-b}\left(M_{Rd} + M_{\sup}\right). \qquad (10)$$

The ultimate load that the over-columned slab can withstand according to the failure scheme (Fig. 3) with a given reinforcement can be determined from equation (10) by the formula:

$$q = \frac{24l\left(M_{Rd} + M_{\sup}\right)}{11l^3 - 12l^2b + b^3}, \qquad (11)$$

in which

$$M_{Rd} = \frac{f_{yd}A_s}{l-b}\left(d - \chi\frac{f_{yd}A_s}{f_{cd}(l-b)}\right), \qquad (12)$$

where M_{Rd} is the value of the internal bending moment per unit length of the slab;

f_{cd} is the design value of the concrete compressive strength;

d is the effective depth of the slab section;

$\chi = 0.52 \dots 0.59$ is a parameter that depends on the concrete grade [10].

The problem of selecting the cross-sectional area of the principal reinforcement per unit length in one of the directions of the slab at a given load is solved based on the condition of equality of the internal and external bending moments by the formula

$$A_s = \frac{f_{cd}}{f_{yd}}\left(\frac{1-\sqrt{1-4\chi\bar{\alpha}_m}}{2\chi}\right)d, \qquad (13)$$

in which

$$\bar{\alpha}_m = \frac{q\left(11l^3 - 12l^2b + b^3\right) - 24lM_{\sup}}{24f_{cd}l^2d^2}. \qquad (14)$$

The inter-columned slabs of the flat plate floor perceive the following loads: uniformly distributed q over the entire floor, as well as the load $p(y)$ from the reaction of the supports of the middle slab distributed in the form of triangles on the opposite faces of the slab. This distributed load on the slab is transmitted from two neighbouring middle slabs. Since each middle slab rests along 4 sides on the inter-columned slabs, a load from 0.25 of the area of the middle slab on each side is transmitted to one inter-columned slab. This area is triangular in shape, therefore the reduced linear load on the inter-columned slab will be triangular with the maximum ordinate value $ql/2$ in the middle of the span. The intercolumn slab is actually a crossbar by the nature of its work and support schemes.

The ultimate load that the inter-columned slab with a given reinforcement can perceive is determined based on the yield line method by the formula:

$$q = \frac{24\left(M_{Rd} + M_{\sup}\right)}{5l^2}, \qquad (15)$$

in which M_{Rd} is the value of the internal bending moment per unit length of the slab is calculated by formula (12) under the condition $b = 0$.

The problem of selecting the cross-sectional area of the principal reinforcement per unit length in one of the directions of the inter-columned slab at a given load is solved based on the condition of equality of the internal and external bending moments by formula (13), in which

$$\bar{\alpha}_m = \frac{5ql^2 - 24M_{\sup}}{24 f_{cd} l d^2}. \quad (16)$$

The middle slab in the limit state from the action of a uniformly distributed load q over its area takes the shape of a pyramid with the apex at the bottom and a height equal to the deflection f. In the calculation of the bearing capacity, the middle slab is considered as hingedly supported. At the same time, in the linear hinges formed at the joints with the inter-columned plates, a uniformly distributed bending moment M_{sup} acts, which arises at the loop joint.

The ultimate load that the middle plate can perceive with a given reinforcement can be determined based on the yield line method by the formula:

$$q = \frac{24\left(M_{Rd} + M_{\sup}\right)}{l^2}, \quad (17)$$

in which M_{Rd} is the value of the internal bending moment per unit length of the slab is calculated by formula (12) under the condition $b = 0$.

The problem of selecting the cross-sectional area of the principal reinforcement per unit length in one of the directions of the middle slab at a given load is solved based on the condition of equality of the internal and external bending moments using dependence (10) by formula (13), in which

$$\bar{\alpha}_m = \frac{ql^2 - 24M_{\sup}}{24 f_{cd} l d^2}. \quad (18)$$

Interpretation of results and their approval. Based on the developed methodology, the bearing capacity of full-scale samples of the flat plate floor slabs [2] was calculated. The characteristic values of the strength of materials were used in the calculation. The results of comparisons of the values of the destructive load without taking into account the self-weight are given in Table 1.

Table 1 – Comparison of experimental and theoretical values of the destructive load for the precast flat floor slabs

Slab type	Experimental destructive load, kN	Design destructive load, kN
Over-columned	266,70	240,07
Inter-columned	156,90	122,92
Middle	211,82	109,91

Conclusions. Based on the analysis, it was found that the flat plate floor of the precast frame combines separate elements connected by linear joints, which can perceive a certain value of the bending moment. Based on this, the possibility of calculating the bearing capacity of each slab in the floor composition based on the yield line method has been established. As a result, it is possible to consider the calculation of each slab separately, taking into account the nature of the load distribution on it, the support scheme and the interaction between the slabs in the floor composition. The developed methodology for calculating the bearing capacity of a slab of a precast flat plate floor has a clear algorithm and a substantiated experimentally physical content, which allows the desired solution to be obtained in the form of analytical dependencies, and therefore does not require the use of iterative or other approximate methods in calculations. All this will contribute to improving the design process of buildings with a precast flat plate frame, increasing the accuracy of calculating the bearing capacity, and will contribute to a faster implementation of such frames in the renovation of the housing stock of Ukraine.

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Збірний безбалковий каркас будівель для поновлення житлового фонду України

У сучасному будівництві широко застосовуються каркасні конструктивні системи будівель з плоскими безбалковими перекриттями. Реалізація таких систем у збірному варіанті з мінімальною кількістю елементів створює широкі можливості для прискорення термінів будівництва. Запропонована до використання безбалкова каркасна конструктивна система будівель складається з колон і плоских плит, які з'єднуються з колонами без використання консолей або капітелей.
Розрахунок несучої здатності перекриття безбалкової конструктивної системи пропонується здійснювати на основі кінематичного способу методу граничної рівноваги. Розглядається граничний стан перекриття, котрий характеризується появою пластичних шарнірів. При цьому в збірному перекритті утворення лінійних пластичних шарнірів наперед запрогнозовано вздовж ліній стиків збірних плит. Це дає змогу розглядати в розрахунку кожну плиту окремо з урахуванням умов її завантаження та закріплення у складі перекриття. У граничному стані плита внаслідок утворення пластичних шарнірів перетворюється в механізм з подальшим зростанням деформацій без збільшення навантаження. Навантаження, що відповідає такому станові плити, є несучою здатністю плити.
Використання кінематичного методу спрощує розроблення розрахункових схем для ймовірних випадків руйнування та визначення руйнівного навантаження для всіх типів збірних плоских плит безбалкового перекриття. Цей підхід характеризується чітко визначеним алгоритмом і підтверджується експериментальними даними.
На основі кінематичного способу виведені аналітичні залежності для визначення несучої здатності надколонної, міжколонної та середньої плит збірного перекриття, а також формули для розрахунку необхідної площі арматури цих плит. Ці рівняння зручні для інженерного застосування і усувають потребу в ітераційних або наближених методах розрахунку. Отримані залежності базуються на нелінійній деформаційній моделі залізобетонних елементів та враховують передумови розрахунку за діючими нормативними документами.

Ключові слова: залізобетон, каркас, безбалкове перекриття, плита, несуча здатність.

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Review of multilayer reinforced concrete beams with rectangular cross section experimental-theoretical studies

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One of the options for reducing cement consumption for the preparation of concrete for bent reinforced concrete structures is the use of two-layer beams with higher strength concrete in the compressed zone and lower strength concrete in the tensile zone, which saves cement without losing structural strength. Experimental tests and theoretical calculations of concrete deformations in the compressed zone of five series of concrete beams with cross-sectional dimensions of b×h = 100×160 mm and a total length of 1500 mm were compared; compressed zone concrete of class C20/25; tensile zone concrete of class C12/15; reinforcement in the tensile zone - 2Ø12 mm of class A400C. The beams differed in the thickness of the concrete layers in the compressed and tensile zones. As a result of the comparison, it was found that the average value of the ratio of theoretical to experimental results was 15.1%; the mathematical expectation of this ratio was 0.856; the coefficient of variation of the ratio was 9.3%, which indicates a fairly high correlation of results.

Keywords: test, experiment, theoretical research, reinforced concrete, bending, two-layer.

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Introduction

The development of the range of building structures involves both the search for fundamentally new types of elements made of one material or in combination of several materials for their joint mutually beneficial operation and the improvement of existing building products, namely, reducing their weight while ensuring the same load-bearing capacity, increasing the manufacturability of production, etc. This issue is even more acute in bending reinforced concrete structures, as stretched concrete is not taken into account in the calculation of the overall bearing capacity of the structure, but only increases its weight and, consequently, the cost of manufacturing. *That is why replacing stretched concrete in such structures with a cheaper material, such as concrete of a lower strength class or with porous aggregates, is an urgent problem.*

Review of the research sources and publications

In their works, the researchers propose using ash, ground slag, metallurgical waste, slag-alkali concrete, chemical additives (potash, liquid glass, plasticisers), aggregates and void fillers, as well as improving the composition of concrete mixtures and their heat treatment to reduce concrete and cement consumption.

Publication [1] describes a method for the production of precast concrete floor slabs with oval cavities, which is aimed at reducing the consumption of concrete and cement during their manufacture. However, this method has not gained popularity in mass production due to the destruction of the walls of the oval holes when the punches are removed from the newly formed slab.

Work [2], led by V.S. Shmukler, indicates that for a nominal span of 6 m, the most economical in terms of concrete consumption are slabs with oval cavities, the thickness of the concrete layer of which is 92 mm, compared to 120 mm for slabs with round cavities. At the same time, the production of such panels is accompanied by technological difficulties: after the removal of the cavity fillers, the channel walls in newly formed products sometimes collapse. For this reason, boards with round cavities were adopted as the standard. Further development of technologies will allow us to move to more economical designs.

Demchyna B.G., Litviniak O.Y. and Davydiuk O.V. [3-4] were the first to scientifically substantiate the use of foam concrete in precast concrete slabs.

Current regulations [5] define cement consumption rates for the manufacture of concrete and reinforced concrete products. The regulated amount of cement per 1 m³ of concrete must ensure the design properties, such as compressive strength class, density grade, frost resistance and water resistance.

An interesting method of reducing concrete consumption in the production of floor slabs is the use of non-removable plastic voiding agents of various shapes (washer, spherical, box) [6-7], as well as stone materials [8]. This method can reduce concrete consumption by up to 30 % compared to solid slabs.

Definition of unsolved aspects of the problem

Definition of unsolved aspects of the problem

Thus, the creation of resource-saving building structures involves the search for new types of them made of one material or in combination of several materials for their mutually beneficial operation, reducing their cost while ensuring the same load-bearing capacity, increasing the manufacturability of production, etc. It should be noted that in calculations of the total bearing capacity of a structure, stretched concrete is not taken into account [9], but only increases its weight and, consequently, the cost of manufacturing. However, a systematic review of the results of both experimental and theoretical studies of the possibility of replacing stretched concrete in such structures with a cheaper material, such as concrete of a lower strength class or with porous aggregates, has not been performed.

Problem statement

The aim of this paper is to review the results of experimental and theoretical studies of concrete reinforced beams of rectangular cross-section and to compare them.

Basic material and results

To obtain experimental data on the performance of concrete reinforced beams of rectangular cross-section [10-11], the following specimens were made (see Table 1 and Figure 1):

1. concrete beam: concrete of compressed zone of class C20/25 - 80 mm, concrete of tensile zone of class C12/15 - 80 mm (sample B-1 - 3 pieces);
2. concrete beam: concrete of compressed zone of class C20/25 - 40 mm, concrete of tensile zone of class C12/15 - 120 mm (sample B-2 - 3 pieces);
3. concrete beam: concrete of the compressed zone of class C20/25 - 120 mm, concrete of the tensile zone of class C12/15 - 40 mm (sample B-3 - 3 pieces);
4. concrete beam: concrete of compressed zone of class C20/25 - 55 mm, concrete of tensile zone of class C12/15 - 105 mm (sample B-4 - 3 pieces);
5. concrete beam: concrete of compressed zone of class C20/25 - 105 mm, concrete of tensile zone of class C12/15 - 55 mm (sample B-5 - 3 pieces);
6. beam made of solid concrete of class C20/25 (sample B-6 - 3 pieces);
7. beam made of solid concrete of class C12/15 (sample B-7 - 3 pieces);
8. concrete prisms and cubes for determination of physical and mechanical properties of concrete;
9. reinforcing bars for determination of physical and mechanical characteristics of reinforcement.

Table 1 - Ratio of concrete heights of concrete reinforced beams of rectangular cross-section

Grade of beams	B-1	B-2	B-3	B-4	B-5
Ratio of height (mm) of concrete classes C20/25 to C12/15	80/80 $h_{C20/25}/h_{C12/15}=1$	40/120 $h_{C20/25}/h_{C12/15}=0{,}33$	120/40 $h_{C20/25}/h_{C12/15}=3$	55/105 $h_{C20/25}/h_{C12/15}=0{,}5$	105/55 $h_{C20/25}/h_{C12/15}=2$

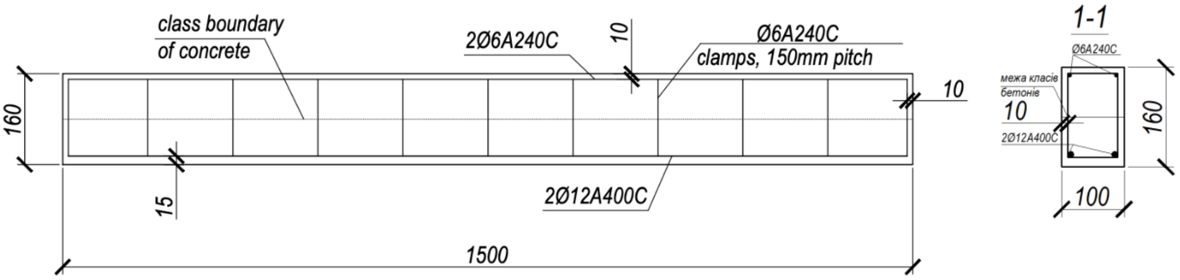

Figure 1 – Formwork drawing of experimental beams

The concrete mix was made using M500 cement from Balakleya Cement and Slate Plant, 10-20 mm granite crushed stone from Kremenchuk quarry and quartz sand with a particle size distribution of 1.0. The composition of the lightweight concrete was as follows: cement - 400 kg, sand - 655 kg, crushed stone - 1130 kg, water-cement ratio (w/c) was 0.55. The concrete mixture was mixed in a 50-litre electrically driven concrete mixer.

To measure the relative deformations of the beams in the zone of maximum bending moments, wire strain gauges 2PKB-20-200KhB with a base of 20 mm on the reinforcing bars and a base of 50 mm on the concrete surface were used (see Fig. 2). To measure the deflections, we used clock-type indicators (division price of 0.1 mm).

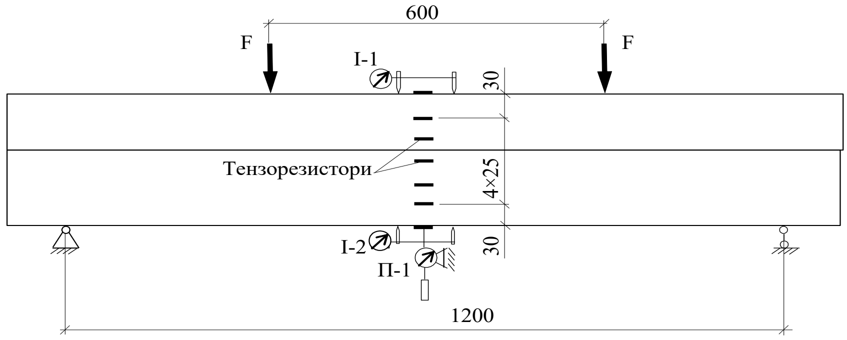

Figure 2 – Scheme of loading during experimental testing of concrete beams and placement of measuring instruments

In the study of the stress-strain state of bending elements with normal cross-sections, the deformations in the fibres furthest from the neutral layer (the most stretched and the most compressed) are of decisive importance, since they can be used to judge the bearing capacity of the structure under study. As a result of measuring the deformations in the outermost fibres of the cross-section of the studied bi-concrete reinforced beams of rectangular cross-section, measured using electrotensor resistors, graphs of the dependence of deformations on the bending moment of the samples of five series were obtained.

The theoretical determination of the strength of sections normal to the longitudinal axis of reinforced concrete beams can be carried out similarly to the calculation of the strength of conventional reinforced concrete beams [12]. In addition, in the practice of building structures construction, it is rarely necessary to accurately describe the stress-strain state of an element. Usually, it is sufficient to determine the bearing capacity of the element and the maximum deflection with the required accuracy. the assessment of the strength of the normal section of reinforced concrete beams is presented on the basis of a joint solution of the equilibrium equation of longitudinal forces in accordance with the scheme of internal forces arising in the cross section.

The hypotheses underlying the theoretical calculations of strength and deformability of concrete reinforced beams are as follows:

• concrete reinforced beams operate reliably under various loading patterns and conditions;

• at all stages of loading, the joint operation of two layers of concrete and the working reinforcement of the complex beam is ensured;

• when composite beams operate in the elastic stage, the hypothesis of flat sections is valid, and the horizontal layers do not press on each other, i.e. there are no compression deformations and they do not affect the stress-strain state of the structure.

Figure 3 shows a comparison of the development of deformations in the most compressed (upper) fibre of five series of concrete beams in the middle of the span, obtained as a result of experimental tests and calculated theoretically on the basis of a joint solution of the equilibrium equation of longitudinal forces arising in the cross-section of the beams. The graphs in Figure 3 show that all specimens, regardless of the value of the ratio of the height of the higher class concrete to the lower class, were elastic at the initial stages of loading in both the compressed and tensile zones of the bending element cross-section. The appearance of plastic deformations was observed at loads of 60-65% of the destructive load; the bending moment was 5.7-6.3 kNm.

The calculated deviations of the theoretical from the experimental results of determining the deformations of the compressed zone of concrete are recorded on the graphs in Figure 3 for each degree of loading of each series of tested specimens in percent. Table 2 shows the average values of these deviations for each series of beams. A graphical comparison of the deviations presented in Table 2 is shown in Figure 4. The average value of the deviation of theoretical from experimental results for beams of all series is 15.1%.

In order to assess how well the theoretical model for determining deformations based on the joint solution of the equilibrium equation of longitudinal forces arising in the cross-section of beams agrees with the reality represented by experimental data, statistical processing of the results was performed: the mathematical expectation and the coefficient of variation of the ratio of theoretical results to experimental ones were calculated (see Figure 5).

Statistical processing is essentially a test of the reliability of the theoretical model and the identification of potential deviations. The tasks of statistical processing are as follows:

– *assessment of the accuracy of the theoretical model:* the mathematical expectation (mean) of the ratios can show whether the theoretical values overestimate or underestimate the experimental values. The calculated mean value of the mathematical expectation of the ratio is 0.856, which indicates that the theoretical model slightly underestimates the experimental values;

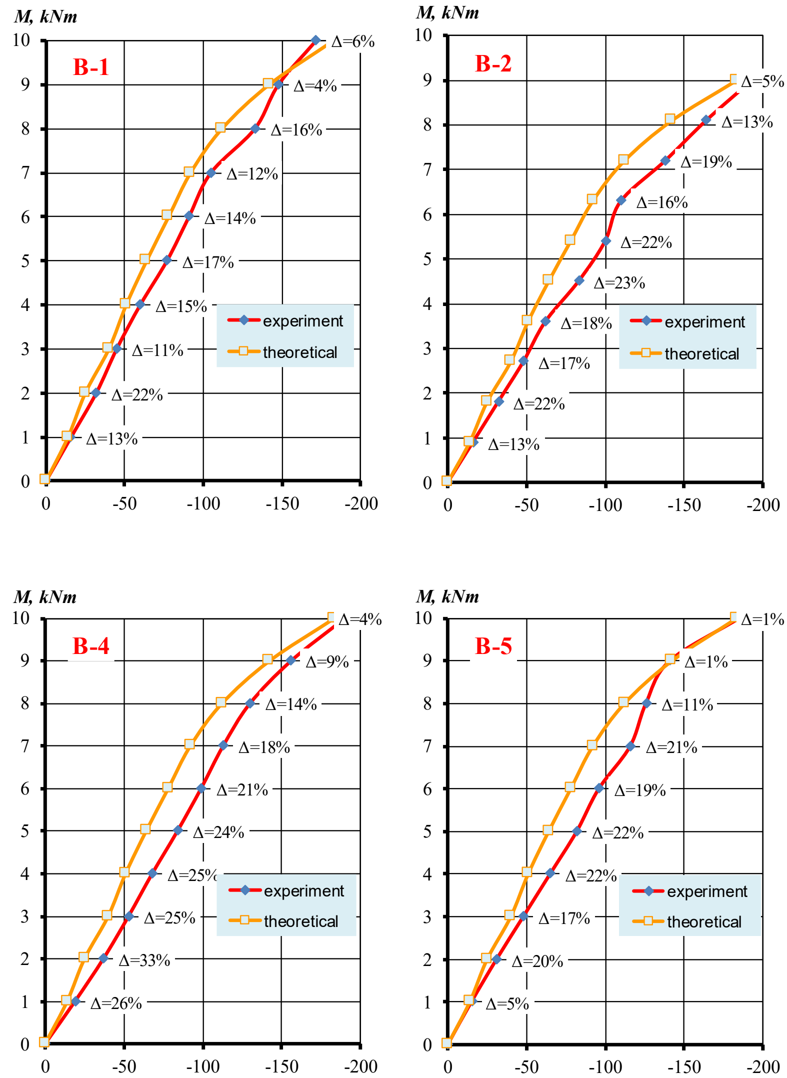

Table 2

Average deviations of theoretical calculations from experimental test data

Series number	Δ, %
B-1	13,0
B-2	16,7
B-3	12,0
B-4	19,8
B-5	13,9

Figure 3 – Comparison of the development of deformations in the most compressed (upper) fibre of five series of concrete beams obtained as a result of experimental tests and calculated theoretically on the basis of a joint solution of the equilibrium equation of longitudinal forces

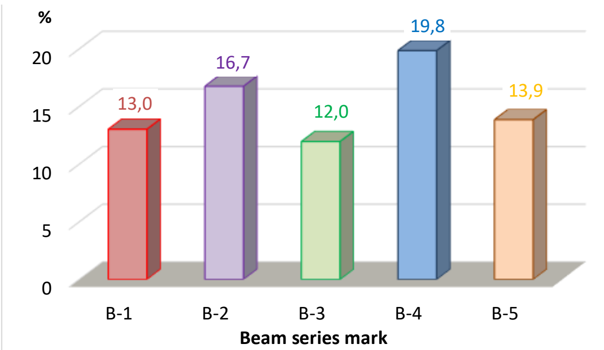

Figure 4 – Comparison of deviations of theoretical calculations from experimental tests

– *detection of systematic deviations:* if the mathematical expectation of the ratio differs from 1.0, this indicates a systematic error in the theoretical model. The applied theoretical model consistently underestimates the experimental data, as described above;

– *to determine whether the theoretical model is too simple*: if the mathematical expectation of the ratios differs significantly from 1.0, this may indicate that the model does not take into account important factors that affect the experimental data. In our case, there were no significant deviations, which indicates that all important factors of the experimental tests are taken into account in the theoretical model;

– *determining whether the theoretical model is too complex:* in some cases, an overly complex model can be 'overtrained' on experimental data, leading to poor predictions on new data. In our case, no overly complex aspects were found in the theoretical model;

– *selection of model parameters:* mathematical expectation calculations can be used to select the parameters of a theoretical model that give the best fit to experimental data;

– *model improvement:* analysis of deviations from mathematical expectation can help identify the causes of deviations and improve the theoretical model.

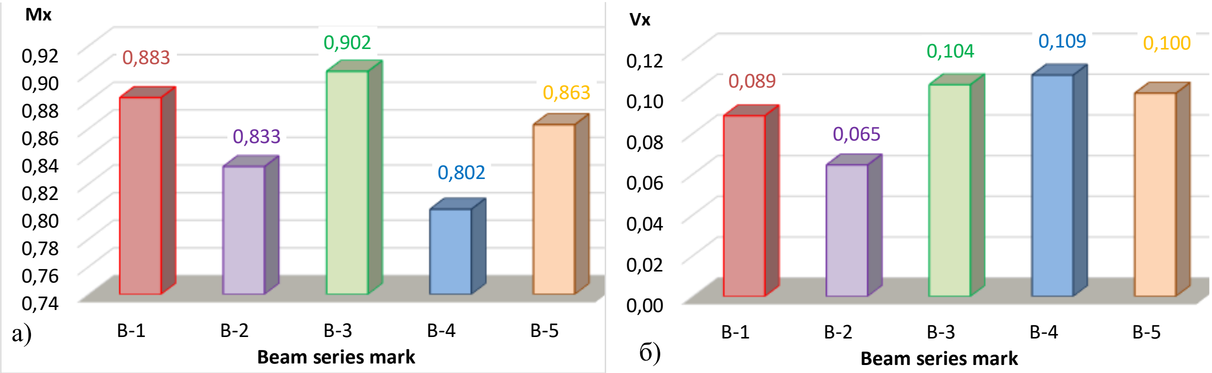

Figure 5 – Comparison of mathematical expectation (a) and coefficient of variation (b) ratio of theoretical results to experimental ones

Conclusions

The results of experimental studies confirm the feasibility of using bi-concrete beams in construction practice to ensure the economic and technical efficiency of load-bearing structures. The effective ratio of layers with different concrete characteristics reduces cement consumption for the preparation of the concrete mix. The efficiency of bi-concrete beams is based on the rational distribution of materials: concrete with higher strength is used in the compressed zone, while less durable concrete is used in the tensile zone, which saves resources without losing structural strength.

The average value of the deviation of the theoretical deviation of the longitudinal forces arising in the cross-section of the beams from the experimental results of determining the deformations of the compressed zone of concrete calculated for all five series of beams based on a joint solution of the equilibrium equation of the longitudinal forces arising in the cross-section of the beams is 15.1%. The average value of the mathematical expectation of the ratio of theoretical to experimental results of all five series of beams is 0.856; the average value of the coefficient of variation of this ratio is 9.3%.

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Порівняння експериментально-теоретичних досліджень згинаних бібетонних армованих балок прямокутного поперечного перерізу

Одним з варіантів зменшення витрат цементу для приготування бетону згинаних залізобетонних конструкцій є застосування двошарових балок із раціональним розподілом матеріалів: бетон з вищою міцністю застосовують в стиснутій зоні, тоді як менш міцний бетон використовується в розтягнутій зоні, що й забезпечує економію цементу без втрати міцності конструкції. У статті наведено конструкцію та методику виготовлення експериментально досліджених п'яти серій зразків бібетонних балок загальною кількістю 15 штук із розмірами поперечного перерізу – $b\times h$ = 100×160 мм; загальна довжина балок – 1500 мм; відстань між опорами L = 1200 мм; бетон стиснутої зони класу C20/25; бетон розтягнутої зони класу C12/15; армування в розтягнутій зоні – 2Ø12мм класу А400С. Балки відрізнялися товщиною шарів бетону стиснутої та розтягнутої зон. У результаті порівняння експериментальних випробувань та теоретичних розрахунків деформацій бетону стиснутої зони встановлено, що середнє значення відхилення теоретичних від експериментальних результатів рівне 15,1%; математичне сподівання відношення теоретичних від експериментальних результатів становить 0,856; коефіцієнт варіації відношення – 9,3%, що свідчить про достатньо високу кореляцію результатів експериментальних випробувань та теоретичних розрахунків.

Ключові слова: випробування, експеримент, теоретичні розрахунки, залізобетон, згинання, двошаровість.

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Investigation of the thermal and moisture regime of cold attics using an instrumental method

The article presents the results of an experimental study of the thermal and humidity regime of a cold attic using modern measuring instruments. The relevance of studying the microclimatic parameters of the attic space is substantiated in view of their critical role in ensuring the durability and safe operation of buildings. The dynamics of temperature and humidity changes in a cold attic in different periods of time is analyzed. Based on the results of the study, practical recommendations for optimizing the microclimate in the attic space aimed at preventing the formation of condensation, mold, and structural deformations are formulated.

Keywords: thermal and humidity conditions, cold attic, microclimate, logger, moisture meter.

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Introduction

To experimentally investigate the thermal and humidity conditions of a cold attic of a public building using an instrumental method, to analyze the dynamics of temperature and humidity changes in different periods of the year, to identify the main factors influencing the formation of a microclimate, and to develop scientifically based recommendations for the efficient and safe further operation of the attic space, taking into account the requirements of energy efficiency, durability of building structures and prevention of condensation and mold.

Task statement

Determine the humidity of materials in different areas of the attic space during different periods of time. Analyze the impact of external climatic conditions on the internal thermal and humidity regime of the attic. Identify critical areas with an increased risk of condensation and mold growth. Analyze the results of the study in accordance with current building codes and standards [7]. Based on this analysis, provide practical recommendations for improving microclimatic conditions in a cold attic in order to prevent damage to building structures and maintain the proper technical condition of the building. Conduct a study of the thermal and humidity conditions of a cold attic and formulate reasonable recommendations for its optimization in accordance with the approaches given in [3, 4] Improving the thermal insulationof cold roof structures by improving the thermal performance of attic floors with heat-conducting inclusions is the main objective of this work, and we have the same goal.

Main material

The object of the study is a public building located in the city of Poltava, built in 1880. The walls are brick, 550 mm thick. The building is one-story with a basement. The attic is cold and unused. The floor structure is made of wooden beams and insulated with a 100 mm layer of mineral wool, which is insufficient to meet modern energy efficiency standards [5,17]. In addition, prior to the installation of the insulation layer, no preliminary survey of the structures was carried out to identify the need for repair and restoration work. The existing loose insulation was not removed, nor were the remains of the outdated stove heating system, which negatively affects the thermal insulation characteristics of the structure and complicates the assessment of its technical condition [6].

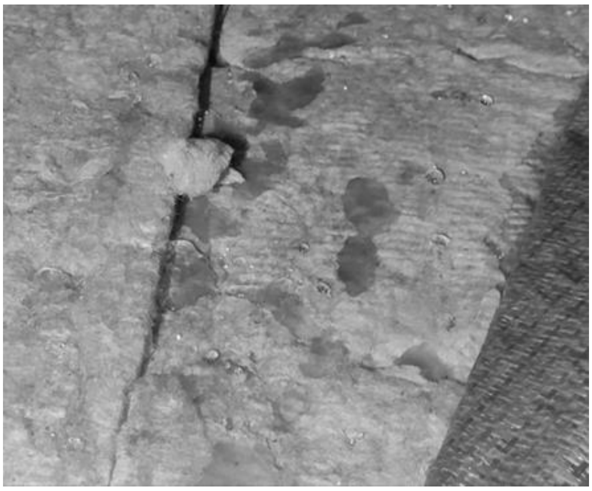

Figure 1 - Numerous traces of damage to wood due to water exposure

Figure 2 - A waterproofing film membrane is installed above the rafters

The roof is gabled and covered with metal tiles. Despite the fact that the building has only one above-ground floor, it is equipped with organized drainage systems. The rafter system is made of wood, and a waterproofing film membrane is installed above the rafters (Fig. 2). However, there are no vents in the eaves and ridge board in the attic, which significantly complicates natural ventilation (air circulation) [1]. During previous repairs, the dormer windows were replaced with airtight metal-plastic ones, which further reduces the ventilation of the attic space (Fig. 4). During the inspection to assess the humidity level, significant traces of water damage were found on the surface of the insulation (Fig. 1) [2,18].

Most elements of the attic rafter system show signs of mold damage, indicating an unfavorable microclimate in the roof structure and a violation of the moisture regime [8,9,10,11,14]. To obtain more detailed information and a more accurate understanding of the conditions, it was decided to install specialized devices to conduct instrumental experiment[12,13,15]. The experimental studies were conducted between February 7 and 15, 2025. A Testo 174H logger—a temperature and humidity recorder—was used to measure the temperature and relative humidity in the cold attic space (Fig. 3). The device is designed for autonomous periodic measurement of microclimate parameters, recording and storing the obtained data in a built-in non-volatile memory for a long time. This made it possible to obtain continuous dynamics of changes in the temperature and humidity regime in real time, which is a necessary condition for a qualitative analysis of the thermal condition of the attic space [9,19,20].

Figure 3 - Temperature measurement results using the Testo 174H recorder.

To measure the moisture content of wooden rafters and insulation, we used the Testo 606-1 moisture meter, a device for measuring the moisture content of gases, liquids, and solids (Fig. 5). The Testo 606-1 wood moisture meter measures moisture levels using a contact method. The wood moisture meter is equipped with two needle electrodes that are inserted into the material being measured.

Figure 4 - Hermetic metal-plastic windows in attic openings, which negatively affect the ventilation of the attic space

Figure 5 - The results of the moisture measurement of wooden rafters were performed using a Testo 606-1 moisture meter.

Two loggers were used for the experiment. Logger № 1 was fixed under the ridge board (Fig. 7), and logger № 2 was placed on mineral wool in the attic floor (Fig. 6).

Figure 6- Location of logger №1 on mineral wool attic insulation

Using a moisture meter, readings were taken from most of the rafter structures (Fig. 5) and from mineral wool in particularly damp areas (Fig.8).

The results of the moisture meter survey confirmed that the moisture content of some elements of the rafter system is 39.9%. This is conclusively proven by the Testo 606-1 readings shown in Fig. 5.

Throughout the experiment, average humidity and outdoor air temperature were measured. These indicators in the city of Poltava ranged from 67% to 80% during the entire study (Fig. 9, Fig. 10).

In order to ensure optimal thermal and humidity conditions in the cold attic, as well as to reduce heat loss from the building, the required thickness of the thermal insulation layer was calculated [7].

Calculated thermal conductivity coefficients of the enclosure structure materials:

wooden boards – $\lambda_1 = 0{,}14 \frac{W}{(m \times K)}$;

mineral wool – $\lambda_2 = 0{,}050 \frac{W}{(m \times K)}$;

membrane – $\lambda_3 = 0{,}3 \frac{W}{(m \times K)}$;

α_{int} – heat transfer coefficient of the inner surface of the enclosing structure;

$$\alpha_{\text{int}} = 10 \frac{W}{(m^2 \times K)};$$

α_{ext} – heat transfer coefficient of the outer surface of the enclosing structure;

Figure 7 - Location of logger №2 under the ridge board of the roof system

Figure 8 - Increased humidity of mineral wool at attic level

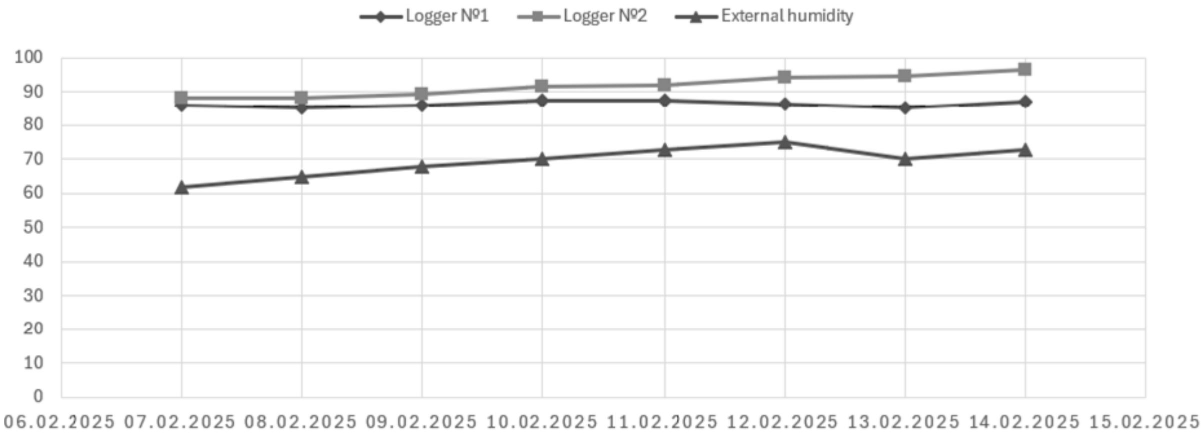

Figure 9 - Air humidity chart

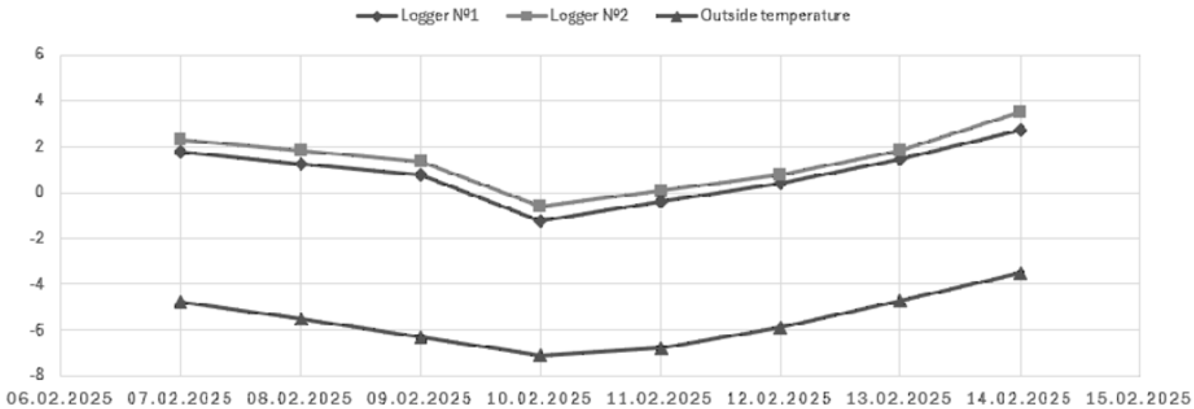

Figure 10 - Air temperature chart

Table 1 - Air humidity

Date	Logger №1, %	Logger №2, %	External humidity, %
07.02.2025	85,91	88,45	62
08.02.2025	85,31	88,3	65
09.02.2025	86,11	89,34	68
10.02.2025	87,57	91,76	60
11.02.2025	87,69	92,06	63
12.02.2025	86,43	94,51	65
13.02.2025	85,1	94,83	60
14.02.2025	87,27	96,76	63

$$\alpha_{ext} = 23\frac{W}{(m^2 \times K)};$$

We determine the transmission resistance of the enclosing structure:

$$R_{\Sigma tr} = \frac{1}{\alpha_{int}} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{1}{\alpha_{ext}};$$

$$R_{\Sigma tr} = \frac{1}{10} + \frac{0,02}{0,14} + \frac{0,300}{0,050} + \frac{0,002}{0,300} + \frac{1}{23} = 6,29\ m^2 \times \frac{K}{W};$$

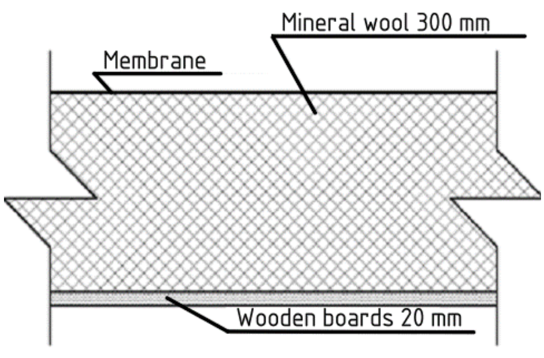

Figure 11 - Insulation diagram

Conclusion: As a result of the instrumental study of the thermal and moisture regime, it was established that the attic structure in its current state does not provide an adequate level of ventilation. This leads to excessive moisture accumulation (up to 90%) within the attic space, as confirmed by data from Testo 174 H loggers. Due to the lack of effective ventilation in the attic, condensation appears on the surface of the insulation and mold damage to wooden structures is observed. An additional unfavorable factor was the use of a moisture-impermeable film that covered the existing layer of mineral wool insulation. This led to moisture accumulation in the insulation, a decrease in its thermal insulation parameters, and an increase in weight. It is recommended that this membrane be completely dismantled. Based on thermal calculations, it has been determined that the required insulation thickness should be at least 300 mm of mineral wool with a density of 15–20 kg/m³ [3]. When installing new insulation, it is necessary to provide for the use of a protective wind or waterproof membrane that is permeable to water vapor, which will ensure free "breathing" of the structure and prevent moisture accumulation in the insulation [7]. In addition, local repairs and reinforcement of wooden floor elements affected by mold or damage should be carried out. To stabilize the thermal and moisture regime of the attic, it is also necessary to: install vents in the eaves and ridge parts of the roof; replace sealed attic windows with ventilation grilles; dismantle the existing loose insulation [4].

The implementation of these measures will significantly improve the microclimate of the attic space, extend the service life of the structures, and prevent further destruction of the roof elements [19,20].

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Дослідження тепловологісного режиму холодних горищ інструментальним методом

Стабільний тепловологісний режим у горищному просторі є запорукою збереження конструктивних елементів покрівлі та внутрішнього мікроклімату житлових приміщень. Особливу увагу під час дослідження приділено аналізу температурних коливань у зимовий та перехідний періоди року, коли ризик утворення конденсату є найвищим. Інструментальні спостереження виявили типові проблеми: надмірне зволоження дерев'яних елементів перекриття та даху, утеплювача горища, накопичення вологості в горищному просторі. Проведено оцінку ефективності існуючих рішень та розроблено практичні рекомендації щодо вдосконалення вентиляційної системи горища, і регламентів сезонного моніторингу. Результати можуть бути корисними для проектувальників, експлуатаційних організацій та власників приватних будинків, що прагнуть підвищити енергоефективність і довговічність будівель.

Ключові слова: тепловологісний режим, холодне горище, мікроклімат, логер , вологомір

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Investigation of the dependence of the amplitude of vertical vibration displacements of the working element of a vibrating platform on its inertial and stiffness parameters using a three-factor experiment

During preliminary experimental studies, it was established that the amplitude of vibration displacements of the moving frame points of the vibration platform is most significantly influenced by such characteristics as the stiffness of vibration-isolating supports, the distance from the centre of oscillation, and the mass of the moving part. These factors were selected as independent factors in the research using a three-factor experiment. As a result of mathematical and statistical processing of the experimental data, a second-order multiple regression equation was obtained. The calculated values of the variance at the zero point, the variance of adequacy, and Fisher's criterion confirm the possibility of using the obtained equation to describe the studied process. Based on the research results, three three-dimensional response surfaces were constructed, describing the dependence of the amplitude of vibration displacements of selected points on the surface of the working body of the vibration platform on two variable input factors at a fixed value of the third factor at the base level. The results obtained allow for optimal regulation of vibration-isolating supports with variable stiffness, which, in turn, allows for improving the quality of concrete product compaction.

Keywords: amplitude of vibration displacements, vibration platform, vibration support, stiffness, three-factor experiment

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Introduction

Vibrating platforms with a load capacity of up to 300 kg, primarily used for volumetric or surface compaction of concrete mixtures, are employed in the manufacturing of small-sized and precast concrete elements. Typically, they belong to the class of single-mass vibrating machines operating in a harmonic, super-resonant mode [1]. Their moving frames or plates are mounted on resilient vibration-isolating supports and set into oscillatory motion by external unbalanced vibratory exciters.

The nature of oscillations in vibrating machines used for concrete compaction largely depends on their design features, the physical and mechanical properties of the compacted medium, the synchronization principles of the vibration exciters, and the presence of additional loading [1].

The most common systems are vibrating platforms with vertically directed oscillations, operating at forced vibration frequencies ranging from 25 to 50 Hz, with displacement amplitudes of the working element between 0.3 and 0.6 mm [2–4]. It is also known that as the mass of the compacted medium increases, the amplitude of the forced oscillations of the working element decreases.

Determining the amplitude of the forced vertical displacements of the working elements of vibrating platforms used in the production of small concrete elements, depending on their oscillating mass and the stiffness of the vibration isolation supports, requires a series of tests to build a reliable mathematical model of the process.

Analysis of Recent Research and Publications

Scientific literature provides numerous examples of the use of multifactorial experiments for investigating various technological processes. For instance, in [6], a two-factor experimental design is discussed, where peak impact acceleration and cement consumption are the main influencing factors determining the strength of lightweight aggregate concrete products.

Study [7] investigates the compaction modes of lightweight concrete mixtures using an impact-vibration setup based on the method of mathematical experiment design. A three-factor experiment was used to study the influence of structural parameters of the vibrating system on the strength of the formed concrete products.

Identification of Unresolved Aspects of the General Problem

Analysis of the available literature confirms the relevance of research in the field of vibration compaction of construction mixtures. Existing works address the influence of vibration parameters on concrete strength, compaction modes, and equipment design features. It has been established that amplitude, frequency, and oscillation type significantly affect compaction quality and energy efficiency [8, 9].

However, issues related to the optimization of the stiffness characteristics of vibration-isolating supports, particularly under resonance conditions, remain insufficiently explored. There is a need to develop designs with adjustable parameters to adapt the dynamic behavior of the system to changing operating conditions.

The problem of systematically optimizing the relationship between support stiffness, moving mass, and the spatial position of the point relative to the oscillation center—factors that determine the amplitude of vertical vibration displacements—remains unresolved. Addressing this issue requires targeted experimental studies and the development of a mathematical model capable of quantitatively describing the effect of key parameters on the efficiency of concrete mixture compaction.

Problem Statement

The aim of this article is to present the results of determining the optimal stiffness of vibration-isolating supports for a vibrating platform operating in a harmonic super-resonant mode with a given oscillating mass, using the method of mathematical experiment planning.

Main Material and Results

The amplitude of forced oscillations of the vibrating platform's working element is influenced by various external independent factors: frequency of forced oscillations, mass of the working element, mass and rheological characteristics of the concrete mixture, stiffness of the vibration-isolating supports, static moment of imbalance, excitation force, presence and mass of additional loading, compaction time, and others.

Based on preliminary tests, it was found that the most significant factors affecting the amplitude of surface point displacements of the vibrating platform's working element are: stiffness of the vibration support, distance from the oscillation center, and mass of the moving part of the platform. These factors are controllable, independent, and measurable at three levels.

To establish the functional relationship between the amplitude of forced oscillations and the selected factors, a three-factor experimental design was chosen [10].

Ranges and variation intervals of these input variables were determined based on the technical specifications of the test equipment. Their numerical values are presented in Table 1.

During the experiments, according to the chosen design, each factor was varied at three levels—low (-1), base (0), and high (+1). Experimental studies were carried out following a standard experimental matrix within the defined ranges of factor variation.

The numerical values of the amplitudes of forced vertical vibrations were measured using a GM-63A digital vibrometer at fifteen predefined points on the surface of the vibrating plate.

Table 1 – Input factors, their levels and variation intervals

Levels of the studied factors	Researched factors					
	Vibration isolation mount stiffness c, H/m		Distance from the center of oscillation l, m		Mass of the moving part of the vibrating platform m, kg	
	X_1	x_1	X_2	x_2	X_3	x_3
Top level $X_{i\max}$	200 000	+1	0	+1	220	+1
Main level X_{0i}	400 000	0	0,25375	0	164	0
Bottom level $X_{i\min}$	600 000	-1	0,5075	-1	108	-1
Variation interval ΔX_i	- 200 000	1	- 0,25375	1	56	1

Since the input factors are heterogeneous, differing in dimension and influence on the vibration amplitude, they were converted into a unified computational system by transforming actual values into coded ones. The coding of input factors, which represents a linear transformation of the factor space, was performed using the formula (Eq. 1):

$$x_1 = \frac{X_1 - X_{0i}}{\Delta X_i} \qquad (1)$$

where x_i – coded value of the *i*-th factor;

X_i – actual (natural) value of the *i*-th factor;

X_{0i} – actual value of the i-th factor at the base level;

ΔX_i – variation interval of the i-th factor.

To obtain the functional relationship between the amplitude of forced vibrations and the selected input variables, a statistical analysis was carried out in the form of multiple regression based on a second-order central composite design.

As a result of the mathematical and statistical processing of the data from the three-factor experiment, a second-order regression equation was obtained. This equation describes the dependence of the amplitude of forced vertical displacements at the surface points of the vibrating plate on the selected input factors expressed in coded form:

$$\begin{aligned} y_i &= 0,220840 + 0,022x_1 + 0,0401x_2 - 0,019x_3 + \\ &+ 0,047628x_1^2 - 0,023872x_2^2 - 0,008872x_3^2 - \\ &- 0,000875x_1x_2 + 0,12125x_1x_3 + 0,013625x_2x_3 \end{aligned} \qquad (2)$$

where y_i – the response function representing the amplitude of vertical vibrations at selected points on the vibrating plate surface;

x_1, x_2, x_3 – input variables (factors) in coded form.

The accuracy of the measurements and the adequacy of the obtained mathematical model were evaluated using methods of mathematical statistics. Dispersion estimates and the model's adequacy were assessed through statistical analysis. The results of the adequacy check for the mathematical model of the experiment are presented in Table 2.

Table 2 – The value of the Fisher criterion for obtaining a mathematical model of the experiment

Evaluation criteria	Designation of the criterion	Response function y_i
Zero-point variance	$S_0{}^2$	0,000024333
Adequacy variance	$S_{ad}{}^2$	0,000232354
Calculated Fisher exact value	F_p	9,549
Fisher exact critical value for 5% significance level	$[F_p]$	19,30

To determine the critical values of the influencing factors (in coded form), first-order partial derivatives of the regression (Eq. 2) with respect to the independent variables x_1, x_2, x_3 were calculated and set to zero:

$$\left\{ \begin{aligned} &0,095256x_1 - 0,000875x_2 + 0,012125x_3 + 0,022 = 0; \\ &-0,047744x_2 - 0,000875x_1 + 0,013625x_3 + 0,0401 = 0; \\ &-0,017744x_3 + 0,012125x_1 + 0,013625x_2 - 0,0019 = 0. \end{aligned} \right\} \quad (2)$$

The resulting system of linear algebraic equations (Eq. 3) was solved using Cramer's method [11]. Its approximate solution (with an accuracy of up to 0.001) is:

$$(x_1, x_2, x_3) \approx (-0,279; 0,973; 0,448)$$

By means of mathematical analysis, it can be shown that the identified critical point of the response function, approximated by a second-order polynomial in three variables, is not an extremum.

To determine the optimal values of the influencing factors on the amplitude of forced vibrations of the vibrating platform, we decode the critical values from coded to natural units:

$X_1 = 2,64 \cdot 10^5$ Н/м = 1,08 X_{01};
$X_2 = 0,06166$ м = 0,243 X_{02};
$X_3 = 104$ кг = 1,08 X_{03};

By expressing the input factor values in their natural scale, we obtain the response function (Eq. 3), which describes the dependence of the amplitude of forced vibrations on the investigated input variables:

$$\begin{aligned} y &= 0,44078 - 8,81 \cdot 10^{-7} X_1 + 0,19391X_2 - 0,00029 \times \\ &\times X_3 + 1,19 \cdot 10^{-12} X_1^2 - 0,37068X_2^2 + 2,82 \cdot 10^{-6} X_3^2 - \\ &- 1,72 \cdot 10^{-8} X_1X_2 - 1,08 \times 10^{-9} X_1X_3 - 0,00096X_2X_3 \end{aligned} \qquad (4)$$

Thus, the influence of the selected input factors on the amplitude of forced vibrations is nonlinear in nature, which is explained by the existence of optimal values of the influencing parameters—beyond which the response function increases only insignificantly.

To visualize the experimental results, we construct three-dimensional response surfaces. For this purpose, in the mathematical model of the experiment (Eq. 4), one of the factors is fixed at its base level, while the other two vary within their respective measurement ranges. The response surfaces, plotted in natural coordinates of the input variables, are presented in Fig. 1–3.

The surfaces were generated using the engineering computational software PTC Mathcad Prime 10.

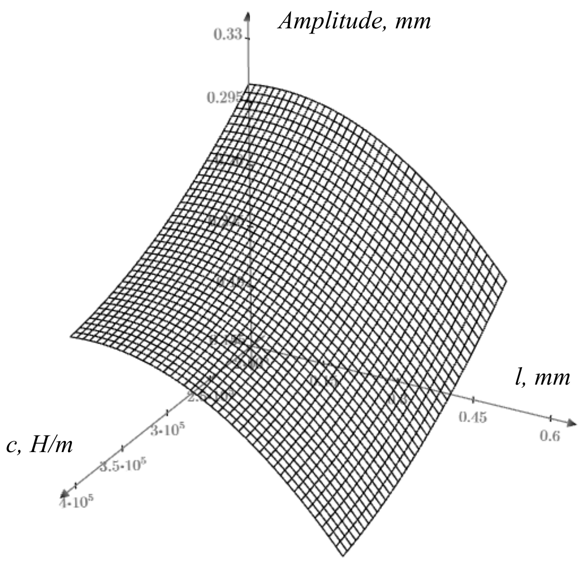

Figure 1 - Response surface of the amplitude of vertical vibrations on stiffness and distance from the center of vibrations with a fixed mass of the moving part

The signs of the response function coefficients for X_1 and X_3 are negative, indicating a decrease in the amplitude of forced vibrations with increasing stiffness of the vibration isolation support and the mass of the vibrating platform's moving part.

Analysis of Figures 1 and 2 confirms that as the distance from the center of oscillation increases, the amplitude of forced vibrations of the platform consistently decreases.

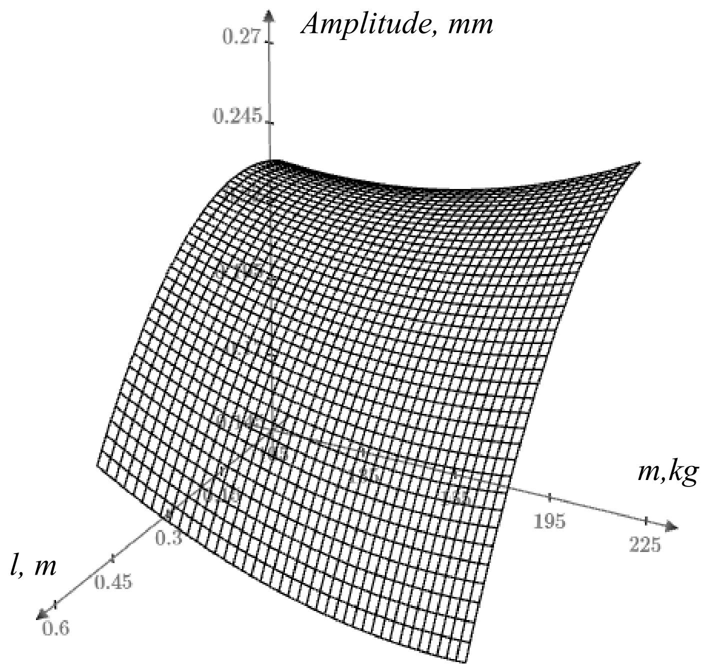

Figure 2 - Response surface of the amplitude of vertical vibrations from the mass of the moving part and the distance from the center of vibrations at a fixed stiffness of the vibration mounts

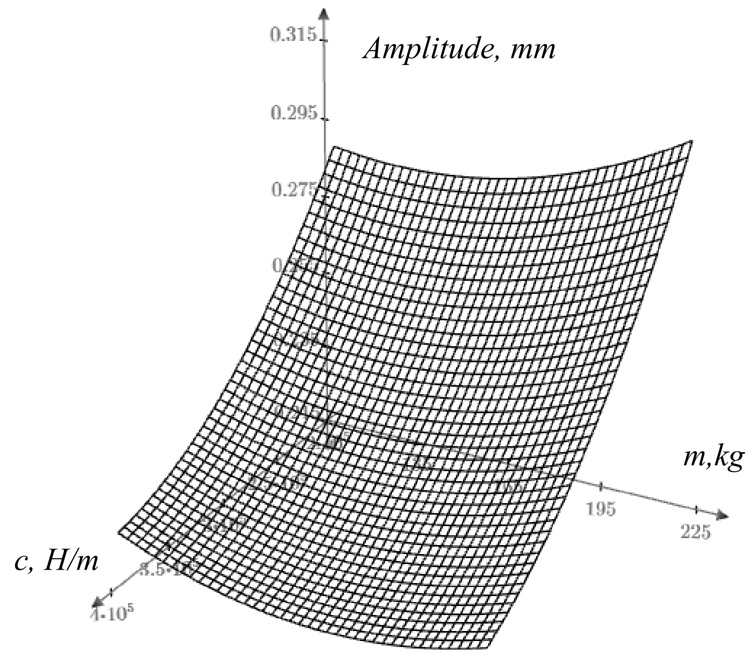

Figure 3 - Response surface of the amplitude of vertical vibrations from the stiffness and mass of the moving part at a fixed distance from the center of oscillations

In terms of comparative influence, the mass of the moving part of the platform (varying in the range from 108 kg to 220 kg) has the least effect on the amplitude of forced vibrations.

The factors X_1 and X_2 exert different influences on the response function. At a fixed value of the moving mass, the amplitude of vibrational displacements of the surface points of the working body increases with the stiffness of the vibration isolation support and decreases with increasing distance from the oscillation center.

Conclusions.

To investigate the amplitude of forced vibrational displacements of the vibrating platform's working body, a three-factor experimental design was developed and implemented. The primary independent input factors were selected as the stiffness of the vibration isolation support, the distance from the oscillation center, and the mass of the moving part of the vibrating platform.

As a result of statistical processing of the experimental data, regression models describing the relationship between the amplitude of forced vibrational displacements and the main input factors were obtained. The most influential factors affecting the amplitude of vibrational displacements of the working body surface points were identified as the stiffness of the vibration isolation support and the distance from the oscillation center. To visualize the nature of these effects, three-dimensional response surfaces were constructed based on the obtained mathematical model.

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Дослідження залежності амплітуди вертикальних віброзміщень робочого органу віброплощадки від її інерційних та жорсткісних параметрів за допомогою трифакторного експерименту

Під час проведення пробних експериментальних досліджень було встановлено, що на амплітуду віброзміщень точок рухомої рами віброплощадки найсуттєвіший вплив створюють такі її параметри, як жорсткість віброізоляційних опор, відстань від центра коливань та маса рухомої частини. Саме ці чинники були обрані як незалежні фактори проведенні досліджень за допомогою трифакторного експерименту. Серед зазначених факторів особливу увагу слід приділити жорсткості віброізоляційних опор, оскільки їхнє завдання полягає у зниженні рівня передавання вібрацій від робочого органу на опорні конструкції. Ефективна ізоляція дозволяє запобігти виникненню небажаних резонансних коливань, зменшити втрати енергії, підвищити стабільність вібраційного процесу та забезпечити більш якісне ущільнення бетонної суміші. Ізоляційні характеристики конструкції віброплощадки безпосередньо впливають на точність процесу формування виробів, а також на зменшення зносу елементів конструкції. Розраховані значення дисперсії в нульовій точці, дисперсії адекватності та критерію Фішера підтверджують можливість використання отриманого рівняння для опису досліджуваного процесу. На основі моделі побудовано три тривимірні поверхні відгуку, які відображають залежність амплітуди віброзміщень вибраних точок поверхні робочого органа віброплощадки від зміни двох незалежних факторів при фіксованому значенні третього фактору на основному рівні. Графічне представлення результатів дозволяє наочно оцінити вплив кожного параметра та вибрати оптимальні умови для роботи віброплощадки. Отримані результати дають змогу здійснювати оптимальні регулювання віброізоляційних опор зі змінною жорсткістю, що, в свою чергу, сприяє підвищенню ефективності ущільнення бетонних виробів, зниженню енерговитрат та підвищенню технологічної надійності обладнання.

Ключові слова: амплітуда віброзміщень, віброплощадка, вібраційна опора, жорсткість, трифакторний експеримент

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Research on the prospects for obtaining iodine from carbohydrate fields in Ukraine

The article describes that industrial waters are limited to deep parts of heavy hydraulic structures, mainly in zones of slow and very slow water exchange. It has been established that the production of iodine from reservoir waters is profitable under the condition that its concentration in the water is 18 mg/l. It is described that the concentration of iodine in formation waters of the Poltava region is 15-115 mg/l. Based on the results of water sample analysis, it was determined that the waters of the Andriyashiv gas condensate field have an iodine content of 15 mg/l or more. Water with an abnormally high iodine content of up to 115 mg/l was found among the samples of the Chizhivka field, the Rudivka gas field, the Lyman, and the Reshetnyaky oil and gas fields. It was determined that the specific gravity of the waters of the gas fields is usually low - from 1.071 to 1.085 g/cm3, and the water of the Reshetnyaky field is high - from 1.132 to 1.167 g/cm3. Formation waters of the following deposits were studied: Mashivka; Chutove; Raspashnivka; Novoukrainske; Lanna; Western Khrestyshche; Chervonoyarske; Western Starovirivske; Vedmedivka; Efremivka; Western Efremivske; Western Sosnivka; Kegichivka; Shebelinka from the intervals from 2520 to 5560 m. It was found that the mineralization of formation water was from 33.0 to 337.01 g/kg, the iodine content from 13.5 to 54.74 mg/l. It can be argued that the formation of groundwater with a high iodine content was significantly influenced by the considerable thickness of the sedimentary strata and the corresponding thermobaric conditions.

Keywords: reservoir water, iodine, deposit, raw materials

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Introduction.

Iodine is of great importance for human life and economic activity. Its global production is 15,000 to 20,000 tons per year. Iodine is one of the components traditionally obtained from hydromineral raw materials, including groundwater. It is widely used in medicine and the food industry, in the production of various chemicals. Its consumption and demand for it in the world are constantly growing. World reserves of iodine are estimated at approximately 15 million tons. According to various data, the deficit in demand for iodine is 900-1,500 tons per year. Prices for iodine on the world market, depending on its purity and characteristics, range from 16.0 to 30.0 dollars for 1 kg. Ukraine has reserves of associated and formation waters with industrial concentrations of valuable components, which the domestic industry feels an urgent need for [1].

The efficiency of toll water processing enterprises is quite high, especially taking into account the possibilities of their organization on the basis of oil, gas and gas condensate deposits. All this necessitates the development of new hydromineral resources, the development of new technologies for obtaining valuable components, in particular iodine, from hydromineral raw materials.

Ukraine's annual need for iodine for table salt iodization reaches 10 - 15 tons, the needs of the medical industry - 20 tons, for other branches of Ukraine's developed economy - 30 tons. The beginning of the history of oil production in Poltava region was the introduction of an oil well at the Radchenky field into industrial operation in September 1951 year. Commissioning was preceded by almost 20 years of intensive search and reconnaissance work in the eastern regions of Ukraine. Over the following years, dozens of oil and gas deposits were explored and put into operation in the region, including those that today constitute the raw material base of the Poltavanaftogaz oil and gas production management.

As a result of long-term exploitation, the oil deposits were significantly watered. Therefore, the main production volume is the associated formation waters. They are valuable hydro-mineral raw materials, in particular, they are characterized by industrial iodine content. Today, such valuable raw materials are irretrievably lost as a result of returning to the corresponding geological horizons to maintain reservoir pressure.

Review of the research sources and publications. Iodine in the underground waters of oil-bearing basins was discovered as early as the second half of the 19th century. Later, significant concentrations of iodine were found in groundwater in almost all oil fields of the world. There is no doubt that during the decomposition of dispersed organic matter contained in silts and sedimentary rocks, iodine is released from them and passes first into the silt and then into groundwater. [1].

According to O. Vinogradov, the accumulation of iodine in the underground waters of oil fields is connected with the history of oil formation. The formation of groundwater with a high iodine content is significantly influenced by the large thickness of sedimentary strata and elevated and high temperatures and pressures. According to the research of Y. M. Svoren (2006), the lower temperature limit for the release of iodine from the organo-mineral complex of sedimentary rocks and its accumulation in groundwater is 35–50 °C. However, the most intensive processes of destruction of iodine-containing organic substances occur at temperatures above 125–150 °C. [2].

The problem of extracting iodine from reservoir waters is considered in the works of Azerbaijani, American, and Japanese scientists [1, 3].

The results of the research highlight the main methods and directions for the modernization of the production of iodine, bromine and their compounds from reservoir waters. Iodine production in world practice is carried out on the basis of the following raw materials: formation waters, accompanying waters, seaweed (China), water from the production of saltpeter (Chile). According to regulatory documents, technical iodine of the 1st and 2nd grades contains, respectively: at least 99.0 and 97.5% of iodine; no more than 0.010 and 0.015% of chlorine and bromine; 0.1 and 0.2% of organic substances; 0.05 and 0.15% of ash [4].

Definition of unsolved aspects of the problem.

Today, there is no iodine production in Ukraine, and its extraction from formation waters of oil and gas fields of Ukraine is quite relevant.

Problem statement. The purpose of the research is to analyze the results of reservoir water samples from deposits of Ukraine since 2011.

Basic material and results. Industrial waters are natural underground waters that contain useful components in solution or their compounds in quantities that ensure their profitable extraction and processing. Iodine, bromine, Glauber salt, and soda are removed from industrial waters. Waters with high concentrations of boron, lithium, rubidium, germanium, uranium, tungsten and other substances are of industrial interest. In many countries of the world, industrial groundwater is the main source of iodine. More than 70% of bromine production is provided by industrial waters.

Industrial waters are confined most often to deep parts of heavy hydraulic structures, mainly in zones of slow and very slow water exchange. Structurally and tectonically, such systems correspond to syneclises and depressions of ancient platforms, as well as foothill depressions and intermountain depressions. Industrial waters are found in rocks of the most different geological age, composition and origin.

The depth of industrial waters varies widely from the first tens of meters to 4-5 km or more, the most common depths of their occurrence are 1000-3000 m. They are also characterized by very high pressures. In some areas, their piezometric levels in wells are set close to the surface and even higher (they spill over to the day surface).

Therefore, the existence of a genetic connection between the accumulation of iodine in underground waters and oil formation is not in doubt among researchers. Geologists use the increased content of iodine in groundwater and sedimentary layers of rocks to predict prospects for oil and gas potential [1,5].

The concentration of iodine in the waters of oil fields can vary widely. Reservoir water is under high pressure and has a high solubility. Groundwater is rich in various complexes of ionic, molecular and colloidal impurities, often saturated with gases. The degree of mineralization of groundwater usually depends on its chemical composition. In brines of medium concentration (100 - 150 g/l), sodium chloride most often prevails. In the USA and Italy, in addition to iodine and bromine, boric acid, tungsten, lithium, germanium are obtained from underground reservoir waters. A significant advantage of underground water as a raw material source of rare elements is the low cost of the product, because underground water is a complete raw material, some of its geochemical types have relatively high manufacturability, exploitation of water deposits of rare elements does not require significant capital investments. Therefore, in most countries (the USA, Italy, Israel, Japan, New Zealand, Iceland, Australia), technological research is constantly and systematically conducted to develop methods of extracting these elements from specific geochemical types of natural waters.

Within Ukraine, the Volyn-Podilsky, Dnipro-Donetsk, Black Sea artesian basins, fractured water basins of the Ukrainian shield, Donetsk, Crimean and Carpathian hydrogeological folded areas with small intermountain artesian basins are distinguished.

In the greater part of the territory, the layers of sedimentary deposits contain horizons of salty waters and brines with mineralization of 3 - 83 g/l and more and with the content of bromine and iodine ions from 20 mg/l [6].

When comparing the mineralization of surface and underground waters of the countries of the world (Fig. 1.), it was found that the highest mineralization was found in the waters of the United States, about 430 g/l.

Since mineralization depends on the chemical composition, it is possible to extract a larger amount of valuable raw materials from these waters.

The production of iodine from reservoir waters is profitable under the condition that its concentration in the water is 18 mg/l. In formation waters of the Poltava region, the concentration of iodine reaches 15-115 mg/l. Based on the results of water analyzes since 2011, a table of waters with high water content (15 mg/l and more) has been compiled.

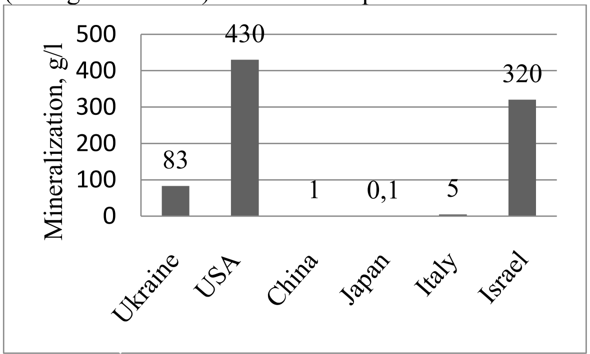

Figure 1 – Mineralization of waters of surface and underground sources [7].

Mineral iodine, bromine, and iodo-bromine waters accompany gas, oil, and gas condensate deposits, so they are most often brought to the surface by exploratory and exploitation wells for hydrocarbon minerals. But also beyond the boundaries of hydrocarbon deposits in the territories of the Dnipro-Donetsk, Black Sea, Lviv-Volyn depressions, the Pre-Kapatsky and Transcarpathian depressions, the Crimea and the folded region of the Carpathians, at depths of hundreds and thousands of meters, wells can encounter waters of increased mineralization, enriched in iodine and bromine to the level of which provides balneological conditions.

There is enough evidence of the distribution of iodine-bromine waters in the North Black Sea and Azov regions. In particular, in the area of the city of Berdyansk, Zaporizhzhia region, water with a bromine content of 38–138 mg/dm^3 and iodine content of 4–11 mg/dm^3 with a sodium chloride composition and mineralization of 11–60 g/dm^3 was found in Upper Cretaceous sands. In Koblevo (Mykolaiv Oblast), waters of the same composition were found in Miocene sediments. Water mineralization is 24.4 g/dm^3, bromine content is 48.8–56.6 mg/dm3. Bromine waters are widely distributed in the Azov region and are found in the areas of Melekino and Sedove (Donetsk region). In the Odesa region, bromine waters were found at a depth of 550 m in Upper Paleogene sands. Water mineralization is 23 g/dm^3, the bromine content is 52 mg/dm^3. Besides, sodium chloride waters with mineralization of 90–105 g/dm^3 and bromine concentration of 170 mg/dm3 and water temperature at the outlet of 35–45 ºC were discovered near Odesa by well No. 1–OT in Archaean–Proterozoic granites.

Crimea is very rich in mineral waters of this type, where unique springs are known. Well No. 905 near the city of Feodosia, which at a depth of 71 m in Lower Paleogene limestones, discovered an aquifer of sodium chloride waters with a mineralization of 7.8 g/dm^3 and an extremely high iodine content of 239 mg/dm^3. and bromine - only 57 mg/dm^3. The waters of the Sarta-Su spring, which flows from the Chokrat limestones near Lenino, also have a significant bromine content. The water of this source is poorly mineralized (3.2 g/dm^3), and the bromine content in it is 79 mg/dm^3.

The most famous resort where iodine-bromine mineral waters are used is Berdyansk (Zaporizhia region).

According to the results of the water sample analysis, it was determined that 6 water samples with an iodine content of 15 mg/l or more were taken from the wells of the Andriyashivka gas condensate field, 11 from the Chizhivka gas field, 9 from the Rudivka gas field, and 15 from the Lyman gas field. 9 samples of water with abnormally high iodine content - up to 115 mg/l were taken from the Reshetnyaky oil and gas field.

The specific gravity of gas field waters is usually low - from 1.071 to 1.085 g/cm^3, and the water of the Reshetnyaky field is high - from 1.132 to 1.167 g/cm^3.

Also, iodine and bromine are products of a single organic transformation process that takes place under conditions of high temperatures and pressures. Further, hydrocarbons and their accompanying deep chloride-sodium solutions with iodine and bromine move along zones of major tectonic disturbances to higher zones of the earth's crust. At these depths, the lithological and structural conditions are favorable for the formation of accumulations of oil, gas and accompanying iodobromine waters. The latter are localized in artesian basins associated with large tectonic structures.

The formation of groundwater with a high iodine content was significantly influenced by the considerable thickness of the sedimentary strata and the corresponding thermobaric conditions. It was established that the lower temperature limit for the release of iodine from the organo-mineral complex of sedimentary rocks and its accumulation in underground waters is 35-50°C. However, the most intensive processes of destruction of iodine-containing organic substances occur at temperatures above 125-150 °C.

The water extracted simultaneously with the oil of the NGDU "Poltavanaftogaz" is enough to extract approximately 1 ton of iodine per year [8]. Therefore, in the case of organizing production, it is necessary to use conserved water wells with their appropriate commissioning or drill new wells and develop aquifers of deposits.

An example of such a field is the Reshetnyaky mineralized water gas and oil field in the Novosanzhar district of the Poltava region, which is characterized by a high content of iodine and bromine in formation waters (Table 1).

Table 1 - Analyzes of water with high iodine content

№	Date of selection samples	Name of the field, wells	Well number	Iodine content, mg/l
1	2	3	4	6
2	28.12.2011	Andriyashivka	55	21,15
3	13.05.2014	Andriyashivka	51	29,61
4	31.01.2011	Chizhivka	37	34,90
5	22.05.2013	Chizhivka	58	25,38
6	16.05.2011	Rudivka	17	57,11
7	08.07.2014	Rudivka	1	39,13
8	24.05.2013	Lyman	17	34,90
9	03.06.2014	Lyman	52	37,01
10	18.06.2014	Lyman	16	29,61
11	04.03.2013	Holubivka	103	30,67
12	16.07.2014	Chervonozavodske	5	72,97
13	18.05.2013	Reshetnyaky	55	101,52
14	18.05.2013	Reshetnyaky	55	112,10

According to preliminary data (unpressurized water sampling, long-term storage of samples for analysis, etc.), the iodine content in the field water ranges from 15 to 50 mg/l. With an average content (30 mg/l), iodine reserves will amount to 7128 tons.

The highest concentrations of iodine and bromine are confined to chloride-sodium waters of increased mineralization. Iodine-bromine mineral waters gravitate to the zones of large ruptured landslides, which are channels for deep underground water.

Reservoir water for research was sampled at fields of the Mashiv-Shebelinka gas-bearing district [9-13]. It belongs to the Eastern oil and gas region of Ukraine. It is located on the continuation of Glynsko-Solokha, and covers the most submerged part of the axial zone of the Dnieper-Donets Trough. It is on the territory of this district that such well-known deposits as Shebelinka, Western Khrestyshche, Efremivka, etc. are located. Industrial productivity has been established by exploratory and exploratory drilling in Lower Permian and Upper Carboniferous deposits. Most of the deposits of the area, which are represented by massive stratified deposits, sometimes limited by salt diapirs and disjunctive disturbances, are confined to two long structural zones, which are simultaneously gas accumulation zones with double structural control — Raspashnivsko-Melykhivska and Sosnivsko-Belyaevska [10].

The development of a thick layer of rock salt deposits of the Lower Permian age and active salt tectonics of Devonian rock salt on the territory of the region led to the formation of unique mushroom-like salt bodies. Under their visors there are industrial accumulations of natural gas in the above-mentioned two gas accumulation zones. The main volume of explored hydrocarbon reserves is located in sandy reservoirs, but a part is concentrated in chemogenic cavernous layers (mainly anhydrites) of the Lower Permian. The data obtained during the drilling of the deepest wells indicate a higher position of the upper limit of active catagenesis than in the neighboring Glynsko-Solokha region. In addition to those listed, there are oil and gas storage zones with one and a half structural control: Shebelinska, Kopylivsko-Skhidno-Poltavska, Mashivsko-Yelizavetivska, Maryanivsko-Lanivska and Yefremivska. Formation waters of the following deposits were studied: Mashivka; Chutove; Raspashnivka; Novoukrainske; Lanna; Western Khrestyshche; Chervonoyarske; Western Starovirivske; Vedmedivka; Efremivka; Western Efremivske; Western Sosnivka; Kegichivka; Shebelinka from the intervals from 2520 to 5560 m. It was found that the mineralization of formation water was from 33.0 to 337.01 g/kg, the iodine content from 13.5 to 54.74 mg/l.

After the analysis of formation water samples from the fields, the highest iodine content was found at the Kegichivka field - 54.74 mg/l, and the mineralization of the formation water was 256.14 g/kg [9].

Conclusions. It is necessary to investigate a number of promising deposits of reservoir waters containing iodine for industrial extraction. Next, approve their reserves at the level of the state commission on reserves. The development of new deposits will provide a full-scale approach to the comprehensive development of iodine-bromide water reserves. Further, it is necessary to take measures to expand the production capacity of iodine production and obtain various chemical products from it. Groundwater is a valuable source because it contains not only iodine and bromine, but also chlorides of sodium, calcium, magnesium and other chemical elements. Their effective use is largely determined at the current stage by their availability on the market. Therefore, in parallel with the restoration of wells and the increase of production capacity, it is necessary to conduct work on the study of the domestic and foreign markets of iron bromide, ozokerite, technical carbon and other commodity products of the chemical industry.

Table 2 - Characteristics of reservoir waters of productive horizons

The name of the field	Horizon index	Mineralization, mg/l	Iodine content, mg/l
Mashivka	G-13	68,17	10,55
Chutove	A-2	307	13,7
	A-5	299	36,1
	A-6-8	333	42,0
Raspashnivka	G-9-12	337,01	45,75
Novoukrainske	A-3	263,2	48,09
Lanna;	A-8	321,46	36,50
Western Khrestyshche	G-11	315	25,1
	K-1	313	24,7
Chervonoyarske	G-13	289	15,25
Western Starovirivske	G-10н	201,359	21,0
Vedmedivka	G-10-G-13	332,2	18,61 45,68
Efremivka	A-6-8, G-3-4	220 330	40,6
Western Efremivske	G-8-13	260 270	13,5 26,2
Western Sosnivka	A-7-A-8	178,3 318,2	13,55 46,55
Kegichivka	A-6-7	256,14	54,74
Shebelinka	A-5	33,0 318,9	36,0

Therefore, the deep formation waters of the deposits of Ukraine are a promising raw material for profitable iodine extraction, which can be carried out in three directions:

1) use of available waters associated with oil production;2) use of conserved and liquidated water wells of oil deposits;

3) drilling new wells into aquifers.

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Дослідження перспектив вилучення йоду з родовищ вуглеводнів України

При значному обводнені нафтової продукції головний об'єм видобутку становлять супутні пластові води, які є цінною гідромінеральною сировиною, зокрема характеризуються промисловим умістом йоду. Значні концентрації йоду знайдено у підземних водах майже в усіх нафтових родовищах світу. Промислові води приурочені як найчастіше до глибоких частин важких гідравлічних структур, переважно у зонах сповільненого та дуже сповільненого водообміну. У стрктурно-тектонічному відношенні такі системи відповідають синеклізам та западинам стародавніх платформ, а також передгірським прогинам і міжгірським западинам. Описано існування генетичного зв'язку між накопиченням йоду в підземних водах і нафтоутворенням. На більшій частині території світу в товщі осадових відкладень містяться горизонти солоних вод і розсолів з мінералізацією 3 − 83 г/л і більше та з вмістом іонів брому, йоду від 20 мг/л. виявлено, що найбільшу мінералізацію виявлено у водах США близько 430 г/л. Мінералізація залежить від хімічного складу, то більшу кількість цінної сировини можливо вилучити саме з високомінералізованих вод. Встановлено, що виробництво йоду з пластових вод рентабельне за умови його концентрації у воді 18 мг/л. У пластових водах Полтавського регіону концентрація йоду сягає 15 – 115 мг/л. За результатами аналізів проб води встановлено, що води Андріяшівського газоконденсатного родовища мають уміст йоду 15 мг/л і більше. Серед проб Чижівського родовища, Рудівського газового родовища, Лиманського, Решетняківського нафтогазового родовища виявлено води з аномально високим умістом йоду – до 115 мг/л. Встановлено, що питома вага вод газових родовищ зазвичай низька – від 1,071 до 1,085 г/см^3, а вод Решетняківського родовища висока – від 1,132 до 1,167 г/см^3. Досліджено пластові води таких родовищ: Машівське; Чутівське; Розпашнівське; Новоукраїнське; Ланнівське; Західно-Хрестищинське; Червоноярське; Західно-Старовірівське; Ведмедівське; Єфремівське; Західно-Єфремівське; Західно-Соснівське; Кегичівське; Шебелинське з інтервалів від 2520 до 5560 м. Виявлено, що мінералізація пластової води склала від 33,0 – 337,01 г/кг, вміст йоду від 13,5 до 54,74 мг/л. На формування підземних вод з високим умістом йоду значно вплинули значна потужність осадових товщ та відповідні термобаричні умови. Підтверджено, що нижня температурна межа виділення йоду з органо-мінерального комплексу осадових порід і накопичення його в підземних водах становить 35 – 50°С. При організації виробництва потрібно використовувати законсервовані обводнені свердловини з відповідним їхнім уведенням в експлуатацію або бурити нові свердловини і розробляти водоносні горизонти родовищ.

Ключові слова: пластова вода, йод, родовище, сировина

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Sorting lines as an element of household waste management at the regional level

The article identifies the problems of household waste recycling, summarizes the data on the planned waste management infrastructure facilities, and substantiates the feasibility of building waste treatment facilities in Poltava region. The absence of a recycling system (including a separate collection system) for household waste results in Ukraine losing millions of tons of resource materials contained in waste that could potentially be put back into economic circulation. It has been established that sorting mixed household waste will enable its further reuse and recovery and reduce the load on landfills. It is determined that the stage of sorting (separation) of household waste is an integral part of integrated waste management solutions and, accordingly, is a mandatory stage before further application of waste treatment technologies

Keywords: household waste, sorting lines, secondary raw materials, territorial communities

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Introduction

Over the past decade, Ukraine has been experiencing a progressive accumulation of waste, and Poltava region is no exception. Human activity produces different types of waste: industrial, household, agricultural, etc. Household waste is mixed and/or separately collected waste from households, including paper, cardboard, glass, plastic, wood, textile, metal, packaging, bio-waste, electrical and electronic equipment waste, battery and accumulator waste, hazardous waste in household waste, bulky and repair waste, as well as mixed and/or separately collected waste from other sources if this waste is similar in composition to household waste [1].

The amount of waste increases with the growth of the settlement and the income of the population. Measures taken to prevent waste generation are insufficient, which threatens not only to deepen the environmental crisis but also to aggravate the socio-economic situation in general. Hence the need for further improvement and development of the entire legal, regulatory, methodological and economic waste management system, taking into account domestic and international experience.

Review of the research sources and publications

The absence of a recycling system (including a separate collection system) for municipal waste (hereinafter referred to as MSW) leads to the loss of millions of tons of resource-rich materials contained in waste that could potentially be put into economic circulation in a processed or recycled form. The development of separate waste collection and recycling is an integral part of increasing the efficiency of natural resources use and the transition to a sustainable green economy [2]. The theoretical and practical aspects of this issue are covered in the works of such domestic and foreign scientists as O. Bent, S. Harichkov, 3. Broide, I. Drozd, V. Kolomiiets, O. Hubanova, V. Vynnychenko, I. Korinko, G. Dawson, E. Mykhailova, G. Pancheva [3, 4]. Paying tribute to the achievements of scientists, it should be emphasized that it is necessary to continue research on this issue, given the need for immediate steps by Ukraine to implement European standards in the relevant field.

Definition of unsolved aspects of the problem

The high level of waste generation and low rates of its utilization as secondary raw materials have led to the accumulation of significant amounts of solid waste in Ukraine's industry and municipal sector every year, of which only a small part is used as secondary material resources, while the rest ends up in landfills.

The system of household waste management in Poltava Oblast's settlements is reaching the level of an environmental disaster. The absence of waste processing plants, sorting lines or stations leads to the accumulation of waste in open areas, burning, and dumping into streams, rivers and open water bodies.

Government and public institutions are aware of the problem of environmental pollution by waste in settlements and are developing regulations, holding public hearings, and implementing various campaigns. However, this environmental problem is becoming more and more significant due to the increase in waste from year to year, and the public's awareness of waste sorting does not change and remains at the level of «a common waste collection container».

Problem statement

The purpose of this paper is to determine the feasibility of using sorting lines in the territorial communities of Poltava region as an element of household waste management at the regional level.

Basic material and results

A significant increase in household waste in Ukraine has led to an extremely tense environmental situation in settlements. The National Waste Management Strategy for Ukraine until 2030 was introduced to address the problems of household waste and develop effective mechanisms for its disposal. The strategy defines the main directions of state regulation in the field of waste management in the coming decades, taking into account European approaches to waste management, with considerable attention paid to waste management at the local and regional levels [5].

According to [5], regional waste management plans should cover all activities that fall within the powers of local executive authorities in the field of waste management and provide for:

- analyzing the current situation in the field of waste management in the region, defining current and strategic goals and necessary measures;
- selection of the optimal waste management system (infrastructure for collection, separate collection, transportation, treatment or disposal) and the practical measures required for its implementation;
- determining the geographical boundaries of joint service areas (territories) for which the plan has been developed and which should jointly use the services of a landfill or waste treatment facility;
- determining the obligations of various institutions and organizations that will be involved in the implementation of measures and actions, the amount of costs and possible sources of funding.

According to V. Strutynska [6], the situation with waste recycling in Ukraine is significantly different from that in the European Union. In the EU, more than 60% of waste is recycled, with Sweden being the leader, where 99% of waste is recycled and used as a source of energy for heating homes and generating electricity. Some countries, such as Germany, Switzerland, and Austria, also have a high level of waste recycling, where 97% of waste is recycled and recycling companies use it as a source of energy, which brings economic and environmental benefits [6]. This saves billions of liters of oil products. In addition to saving budget funds, such enterprises create jobs and solve environmental problems. However, not all European countries have a similar level of waste recycling. For example, Italy, Bulgaria, Romania, and the Baltic States [7] face problems in waste management and have giant landfills, but not all waste is recycled [8, 9]. Some of these countries even export their waste to countries with high recycling rates [5].

The absence of a recycling system [10] (including a separate collection system) for household waste leads to the loss of millions of tons of resource materials contained in waste that could potentially be put into economic circulation every year. The development of separate waste collection and recovery is an integral part of increasing the efficiency of natural resource use and the transition to a sustainable economy [5].

Sorting mixed household waste will allow for its further reuse and recovery, reducing the load on landfills.

Primary recovery (processing) is the second step after sorting. Its essence is to radically reduce the volume of waste disposal. These issues require active government involvement to stimulate investment in this area at the level of local communities, using modern technologies. The third stage involves the use of waste as secondary resources.

Household waste is consumer waste generated in the course of human activity in residential buildings, social and cultural institutions, public, educational, medical, commercial and other facilities (food waste, waste paper, glass, metals, plastics, polymeric materials, etc.).

The peculiarity of municipal waste is that it is mixed, i.e. a mixture of components. The division of household waste components into separate constituent parts is called morphological composition. Mixing of household waste occurs at the stage of its generation, storage, transportation and disposal. This leads to the formation of harmful chemical compounds that pollute the air and groundwater.

Problems in the field of household waste management need to be addressed urgently, provided that measures are funded at the local and state levels.

The practical experience of household waste management in European countries shows that it is necessary to implement a comprehensive household waste management system that ensures the use of waste as a secondary raw material in accordance with environmental safety requirements. This will allow for less waste disposal to landfills and landfills and the development of waste treatment facilities using secondary resources, involving them in production.

According to [11], the main waste management infrastructure facilities that are focused on servicing the entire territory within a cluster/subcluster (subregion) are planned:

- regional landfills;
- sorting and processing complexes, which are based on mechanical and biological waste processing facilities or thermal neutralization facilities;
- sorting and transshipment stations or reloading stations;
- sorting stations / lines are stationary or mobile [11].

The organization of a system for the separation and separate collection of these wastes as part of household waste is planned to be carried out at the expense of [11]:

1) creation of specialized stationary collection points for recyclables, hazardous waste from household waste, and specific waste;
2) creation of communal points (bases or sites) for the integrated acceptance of various types of waste from the population;
3) organization of hazardous waste acceptance at «mobile facilities/acceptance points»;
4) organizing containerized collection in specialized labeled containers;
5) organizing centralized sorting of household waste as an additional or main element of the separate collection system (sorting stations/lines).

The choice of one or another option for organizing separate collection of individual components of household waste should be consistent with the chosen scenario for waste treatment, the planned infrastructure in a particular cluster.

The basis for organizing a system for the collection and subsequent management of household waste within each of the territorial communities and the organization of separate collection of household waste are indicators of material flows of these wastes [11, Annexes 3.2.1 - 3.2.4].

Taking into account the results of studies of the morphological composition of municipal waste conducted in Poltava region in 2017-2023, as well as the results of the export assessment of the morphological composition of municipal waste by GIZ project experts (2015-2016) [12], indicative strategic indicators for the selection of individual resource-rich components of municipal solid waste at the stage of generators (primarily the population) were determined:

▪ the urban population selects about 14.5% of recyclable components (plastic, glass, paper and cardboard, metals) from the volume of these wastes generated in municipal solid waste;

▪ the rural population selects about 14% of recyclable components (plastic, glass, metals) from the volume of these wastes generated as part of solid household waste, in addition: about 90% of paper and cardboard is used for incineration in individual energy installations (stoves) and about 65% of organics is used for home composting and other personal needs, which is approximately 9-9.5% of the total volume of solid household waste.

In order to reduce the volume of waste disposal at the landfill, increase the life of the landfill, and ensure the selection and reuse of resource-rich waste [13] (wood, metal, paper, plastic, glass, etc.), it is advisable to use sorting lines that will allow waste to be sorted throughout the year.

After the sorting line, only the residual waste that cannot be treated is sent to a municipal landfill.

According to the generalized data on planned waste management infrastructure facilities [11, Table 3.5.2], the feasibility of building 35 waste treatment facilities in Poltava Oblast is substantiated, including: sorting lines/stations – 13; sorting and reloading facilities – 8; reloading stations – 11; sorting and processing complexes – 3.

Thus, the stage of sorting (separation) of household waste is an integral part of integrated waste management solutions and, accordingly, is a mandatory stage before further application of waste treatment technologies.

Thus, for the Poltava region, the need for sorting stations with a capacity of 10,000 tons per year (operating in two shifts) is 11 units, and for 50,000 tons per year (operating in two shifts) – 2 units.

A significant advantage of the Poltava region is the presence of a manufacturer of such facilities, Consort [14], which creates equipment for production and logistics automation: conveyors, lines for transportation, sorting, processing, etc.

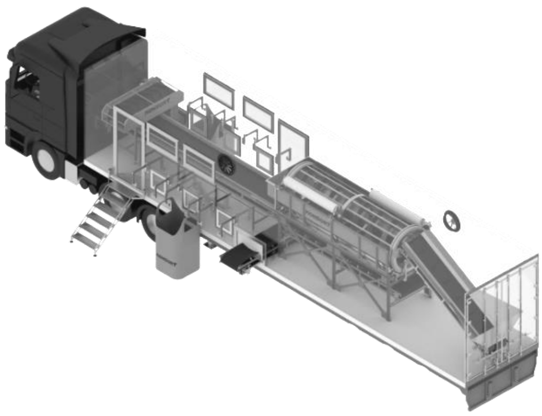

Figure 1 – Mobile line for sorting household waste [15]

Mobile sorting line - designed for manual sorting of household waste with the separation of resource-intensive components in household waste (ferrous and non-ferrous metals, glass, polymer, wood and paper). The main advantage of this line is that it is not tied to the place of accumulation of household waste and can be moved quickly and conveniently from place to place. The mobile solid waste sorting line is equipped on the basis of a cargo trailer with wheels for transportation. Transportation is possible with a tractor or a tractor with a rolling trolley. The trailer is equipped in accordance with all ergonomic labor standards. The trailer is equipped with the following: windows, doors and ventilation system, lighting, electrical panel with control panel, sorting holes with fasteners for big-bag bags, bactericidal lamps. The useful fraction is collected in big bags. The line is powered by 380 volts (panel or generator) [15].

For manual sorting with the separation of resource-intensive components in municipal solid waste (ferrous and non-ferrous metals, glass, polymer, wood and paper).

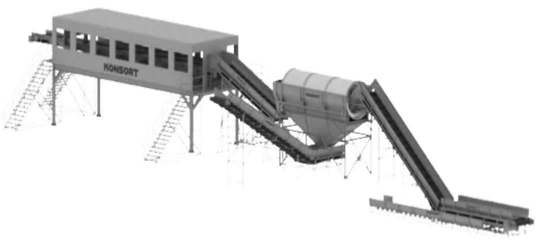

Figure 2 – Line for sorting household waste up to 50,000 tons per year [16]

The solid waste sorting complex involves the selection of valuable recyclable materials from garbage and subsequent shipment to the final processing points. Household waste is delivered to the receiving department in a specially designated pit, in which there is an L-type receiving conveyor, then the conveyor delivers the waste to the drum separator (screen). After the inlet conveyor, the garbage enters the screen, where the fine fraction (organic matter, earth, etc.) is separated. The screen is made of a mesh drum and has a bag tearing system. Under the screen is a conveyor designed to discharge the fine fraction into a special container. From the screen, the selected raw material is fed to the beneficiation room through an inclined conveyor. In the room there is a sorting department with an inspection (sorting) conveyor for manual sorting of useful secondary raw materials [16]. An automatic iron separator is installed at the end of the sorting conveyor, which separates metal products into a container. Special containers for collecting household waste are installed under the room for selecting the useful fraction.

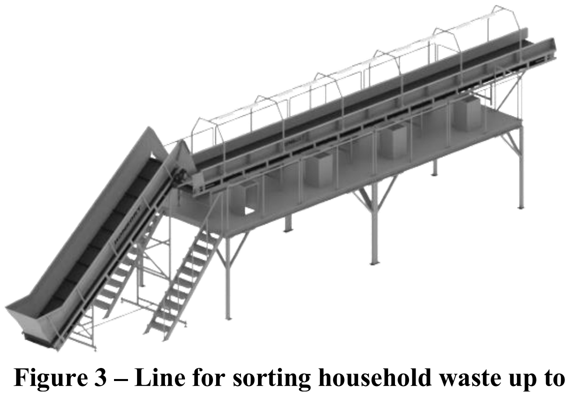

Figure 3 – Line for sorting household waste up to 10,000 tons per year [17]

The line is used at landfills or separately constructed plants for shredding and sorting various waste materials: household waste, mixed waste, construction waste, organic and inorganic waste, waste paper and polymers, for their further reuse and recovery.

The sorting complex for household waste involves the selection of valuable recyclable materials from the garbage, with subsequent shipment to the final processing points. Household waste is delivered to the receiving department, into a specially designated pit, which contains an L-type receiving conveyor. Then the raw material is shaken on the inspection (sorting) conveyor for manual sorting of useful secondary raw materials, goes through an inclined conveyor along the inspection (sorting) conveyor for manual sorting of useful secondary raw materials. Special containers for collecting household waste are installed under the inspection table [17].

The line is used at landfills or separately constructed plants for shredding and sorting various waste materials: household waste, mixed waste, construction waste, organic and inorganic waste, waste paper and polymers, for their further reuse and recycling.

Conclusions

The potential of using household waste as a secondary raw material can become a powerful factor in the development of a sustainable economy in Ukraine, provided that the institutional, organizational, and economic framework for its involvement in production and consumption is formed. To achieve this goal, it is necessary to ensure the adoption of regulations aimed at implementing economic instruments, in particular: stimulating the recovery of household waste; full cost recovery by including all costs associated with the provision of such services in the household waste management tariff; introduction of a mechanism for full financing of the waste management system, taking into account the principles of «polluter pays», «extended producer responsibility» and «pay for what you throw away»; reforming the system of holding tenders for the provision of household waste removal services; improving the procedure for setting tariffs for household waste management services.

At the same time, local state administrations and local self-government bodies should intensify their activities in the following areas: developing and approving local waste management plans, attracting investments in the development of proper infrastructure for separate collection, sorting and recovery of household waste, creating specialized municipal waste collection points and accepting certain types of household waste, conducting an information and awareness campaign, eveloping a system of indicators to monitor the level of household waste management at the local and regional levels.

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Сортувальні лінії як елемент управління побутовими відходами на регіональному рівні

У статті визначено проблеми перероблення побутових відходів, узагальнено дані щодо запланованих об'єктів інфраструктури управління відходами, обгрунтована доцільність будівництва на території Полтавської області об'єктів оброблення відходів. Основними проблемами у сфері поводження з побутовими відходами залишаються значні обсяги відходів, що утворюються, площі сміттєзвалищ і полігонів, застарілі методи управління у цій сфері, відсутність можливостей та небажання сортувати відходи, відсутність можливостей для роздільного збору та переробки різних видів відходів. Кількість відходів збільшується з ростом населеного пункту та доходом населення. Відсутність системи перероблення (у тому числі системи роздільного збирання) побутових відходів призводить до втрати Україною щороку мільйонів тонн ресурсоцінних матеріалів, що містяться у відходах, які потенційно можуть бути введені у господарський обіг. Розвиток роздільного збирання та відновлення відходів є важливою частиною підвищення ефективності використання природних ресурсів і переходу до сталої економіки. Встановлено, що сортування змішаних побутових відходів дасть можливість їх подальшого вторинного використання та відновлення зменшить рівень навантаження на сміттєзвалища побутових відходів. Для зменшення об'ємів видалення відходів на звалищі (полігоні), збільшення терміну експлуатації полігону, забезпечення відбору та повторного використання ресурсоцінних відходів (деревини, металу, паперу, пластику та скла тощо) доцільним є застосування сортувальних ліній, що надасть можливість сортувати відходи впродовж року. Визначено, що етап сортування (відокремлення) побутових відходів є невід'ємною складовою комплексних рішень в сфері управління відходами й відповідно є обов'язковим етапом перед подальшим застосуванням технологій оброблення відходів

Ключові слова: побутові відходи, сортувальні лінії, вторинна сировина, територіальні громади

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Applied aspects of using the identified regularities of the joint behavior of structural components in water-salt systems of cesium, strontium and neodymum nitrates

[1] The carried out complex study gives a reliable idea of the trends in the joint behavior of structural components in water-salt systems of nitrate precursors of neodymium, cesium, strontium in the preparatory stages of technological regulations for both concentration and immobilization of liquid radioactive waste of the nuclear energy industrial complex ^{137}Cs, ^{90}Sr and thermal activation. The stages of such transformations have been revealed; the patterns of complex and phase formation in systems and the factors influencing them have been clarified. It has been studied a number of physicochemical properties of the resulting intermediate phases (coordination neodymium nitrates: their composition, types of compounds, atomic crystal structure, shapes of Ln coordination polyhedra, types of ligand coordination, features and patterns of behavior in heat treatment processes. It has been established that, under the conditions of the existence of solutions, the system $CsNO_3 – Nd(NO_3)_3 – H_2O$ is characterized by the formation of 2 anionic complex compounds Ln^{3+}, the system $Sr(NO3)_2 – Nd(NO_3)_3 – H_2O$ – is of the eutonic type. The ongoing competing reactions are a powerful technological factor that has a significant impact on changes in the activity of structural forms of Ln^{3+}. Systematized information enables to elucidate the mechanisms and kinetics of transformations of structural components in similar objects. Also, it enables to transfer the resulting system of knowledge to the promising technological solutions for the solidification of liquid radioactive wastes.

Keywords: neodymium; cesium; strontium; nitrates; water-salt systems; complex formation; properties.

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Introduction

Develop knowledge about the interaction of structural components in water-salt systems of nitrates of rare earth elements and IA, IIA elements of the periodic table in full concentration ratios and a wide range of temperatures, phases formed in them, conditions of their existence and properties; thermal transformations; available information about the state and possible ways of improving the technologies of formation of complex oxide materials of transition elements, methods of activation of processes, existing requirements for their reproducibility and stability initiated this study and open up new areas of their practical use in the creation of framework materials for immobilization of liquid radioactive waste of the nuclear power industry complex (porous and layered types), as well as in the processes of modeling and experimental substantiation of the possibility of using certain engineering forms of sorbents and mineral-like technogenic phases-fixers of radionuclides ^{137}Cs, ^{90}Sr.

Problem statement and solution methods

Due to the diversity of sources of origin, radioactive waste has a wide variety of compositions and physicochemical properties. The greatest danger to the biosphere is represented by liquid high-level waste containing radionuclides ^{137}Cs and ^{90}Sr with high heat release, often in combination with long-lived ($T_{1/2} \geq 10^5$ years) α-emitting actinides. High-level waste of complex composition includes a number of categories of liquid radioactive waste with a wide radioisotope and chemical composition, such as emergency waste from nuclear power plants, the lanthanide-actinide fraction of high-level waste from processing in nuclear fuel cycles, unfractionated high-level waste from temporary storage tanks that contain rare earth and transuranium metals, radionuclides of cesium and strontium, transition metals, and often against the background of high concentrations of salts and increased acidity.

The multicomponent composition of liquid high-level waste and the joint presence in their composition of transuranium elements and fission products with a high content of ^{137}Cs and ^{90}Sr complicate their further processing, therefore, with the development of extraction separation methods, further fractionation of high-level waste is carried out with the separation of different groups of radionuclides in accordance with their chemical properties and half-life [1-7].

In his study, scientist Milyutin, V.V. et al., investigated the content of actinides and lanthanides in the actinide-lanthanide fraction of high-level waste that became waste after a 5-year soaking of spent nuclear fuel, which shows that the bulk of this fraction is represented by lanthanides, and the content of uranium and transuranic elements is about 4% by weight of lanthanides. The absolute majority among the lanthanides is represented by elements of the cerium subgroup (Ce-Sm), with the highest neodymium content (36.5%). It should also be noted that, despite the progress achieved in the fractionation of high-level waste by extraction processing, the concentrate of rare earth and transplutonium elements may contain several percent of cesium and strontium radionuclides. This available information has determined both object and directions of the research.

The international strategy for the safe management of all types of radioactive waste is waste minimization and aims to reduce the amount of waste by concentrating and retaining radionuclides within stable solid materials. In this case, the most dangerous components of high-level waste are supposed to be included in mineral-like matrices with their subsequent safe multi-barrier burial in stable geological formations of the Earth's crust.

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One of the promising technological solutions for solidifying liquid radioactive waste is the use of inorganic sorbents, which, after being saturated with radionuclides in the form of nitrate soluble structural components, are actually precursors of the final form of radioactive waste. Further structural rearrangement of the precursor with the inclusion of radionuclides in the target phases is carried out in the process of solid-phase crystallization upon heating.

Today, the optimal strategy for the immobilization of such waste within the framework of the sorption-mineralogical approach may be the use of a sorbent, the composition of which is focused on the extraction of a wide range of elements and the formation of polyphase ceramics based on compositions of phase concentrators of alkali and alkaline earth elements (^{137}Cs, ^{90}Sr), on the one hand , and the lanthanide-actinide fraction in combination with other metals, on the other hand.

When choosing a matrix material for the immobilization of actinides, one of the determining properties is the radiation resistance of their crystal structure to the effects of β-radiation.

The group of such radiation-stable phases – potential matrix materials – includes REE framework zirconomolybdates of the composition $Ln_2Zr_3(MoO_4)_9$, Ln – La ÷ Tb, (for example, neodymium, see Fig. 1) [8].

To implement the above projects for the development and improvement of the above-described composite sorption-active systems and technologies for the purification and immobilization of high-salt radioactive waste of complex composition based on them, it is concerned data on the processes of chemical interaction of structural components, phase formation in water-salt systems of neodymium and cesium nitrates and strontium in the range 25 - 100 °C, along with properties of the phases they form.

Setting objectives

For a systematic study of cooperative processes in the technological objects under consideration and to determine the possibility to control them, it is necessary to use a complex of physical and chemical methods:

a) to study the chemical interaction nature and mechanisms, phase equilibria in model water-salt systems $CsNO_3$ – $Nd(NO_3)_3$ – H_2O, $Sr(NO_3)_2$ – $Nd(NO_3)_3$ – H_2O at a temperature 25 – 100°C;

b) to construct polythermal solubility diagrams of systems; to determine both the concentration and temperature limits of crystallization of the starting substances and detected new phases;

c) to find out the optimal growth conditions and to carry out the synthesis of neodymium coordination nitrates (as a representative of the natural series of rare

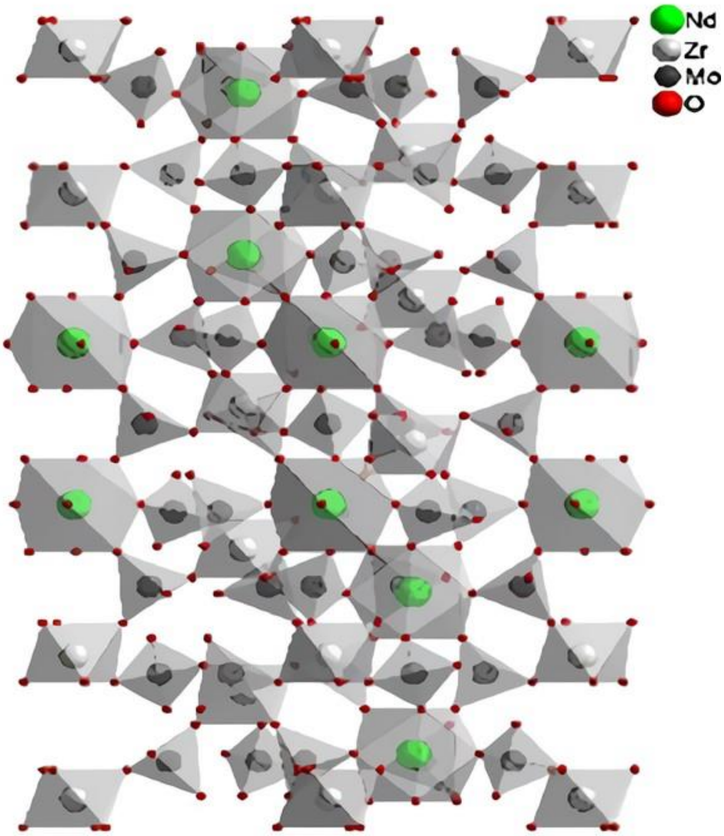

Figure 1 - Frame structure $Nd_2Zr_3(MoO_4)_9$ (trigonal space group R3c, Z=6), [13]

earth elements, where changes both in the composition and structure of compounds occur with the highest probability); to study their properties and confirm their individuality;

d) to establish patterns of dependence of the number, composition, properties of coordination nitrates formed in the systems, on the nature of the Ln^{3+} complex-forming ion, and conditions of formation.

The experimental methods

The solubility method and the technique described in [9, 10] were used to clarify the nature of the chemical behavior of structural components and phase equilibria in the studied water-salt systems isothermally, in the temperature range of existence of solutions in full concentration ratios. Phase equilibrium was achieved within 1–2 days. Hydrated and anhydrous nitrates of the indicated grade elements were used as the starting reagents «pro analys».

Chemical analysis of liquid and solid phases and "residues" was carried out for the content of Nd^{3+}, Sr^{2+} ions. The Ln^{3+} content was determined trilonometrically; Sr^{2+} was determined by complexometric titration of the substituent in the filtrate, where Ln^{3+} was expelled with ammonia buffer. The experimental data obtained from the studied systems for individual ions were listed for salt content, summarized in Tables 1, 2 and, according to the principle of correspondence, plotted on polythermal solubility diagrams of the systems (Fig. 2, 3). Graphic display of the composition of hard phases formed in systems was carried out according to the Schreinemaker` method [9, 10]. Chemical analysis of double nitrates isolated in single crystal form confirms element mass ratio in the above formulas. Their individuality was also confirmed by crystal optical, X-ray diffraction, X-ray structural, thermographic, IR spectrometric and other methods of analysis.

Crystal optical determinations of compounds were performed by the immersion method using a МИН-8 microscope. Phase analysis was performed on a DRON–3M diffractometer (Cu K_α radiation, Ni filter) using the "powder" method. The diffraction patterns were interpreted using the JCPDS PDF file. Determination of symmetry, parameters of unit cells and measurement of the intensity of diffraction reflections from single crystals was carried out on an automatic X-ray single-crystal diffractometer CAD - 4F "Enraf - Nonius" (Mo K_α- radiation, graphite monochromator; ω / 2θ - method). To determine and refine atomic structures, all calculations were carried out using the crystallographic software packages SHELX, XTL–SM, AREN. IR absorption spectra of the synthesized compounds in the range 400 – 4000 cm-1 were recorded on a spectrophotometer UR-20, using the standard method of suspension in petroleum jelly. Thermograviometric analysis was carried out on a Q1500 D derivatograph at temperatures from 293 K to 1273 K in the air with a heating rate of 10 degrees. / min and the developed device for DTA.

Results and discussion

The experimental data of the features and patterns of interaction of structural components, heterogeneous equilibria (25–100 °C) in water-salt systems of neodymium, cesium, and strontium nitrates have been obtained. They are summarized in Tables 1, 2 and generalized in the form of spatial polythermal solubility diagrams (see Fig. .2, 3). On their basis, it has been established the presence of chemical interaction between the constituent elements in the research objects; quantity, composition, nature of solubility, temperature and concentration limits for the formation of initial substances and new phases, and composition of eutonic and transition points. The optimal conditions for the formation have been determined and the synthesis of cesium double neodymium nitrates has been carried out. The growth forms of their crystals and a number of their inherent properties have been studied.

The choice of the proposed tabular and diagrammatic forms for presenting the results obtained is the most visual, informative and useful in the development of effective technological regulations for the solidification of liquid radioactive waste. It enables to predict the behavior of structural components, correctly select modes, stages, methods of forming and obtaining target products with given reproducible characteristics in similar multicomponent production processes using liquid nitrate precursors.

The studied cesium system under solution conditions is characterized by the formation of 2 new coordination nitrate compounds Nd^{3+} $Cs_2[Nd(NO_3)_5(H_2O)_2]$ and $Cs[Nd(NO_3)_4(H_2O)_3]$. The concentration boundaries of saturated solutions from which complex nitrates are released correspond to the compositions of invariant points of the corresponding solubility isotherms. The strontium system is of the eutonic type; no new solid phases have been found in it.

The obtained data obtained enable to identify phases and make quantitative calculations in the processes of evaporation and crystallization for similar objects. All detected phases were synthesized in single crystalline form (Fig. 4). Most of them have an isometric shape, size 4 – 30 mm. Chemical analysis of the isolated compounds confirms the mass ratio of the elements in the proposed formulas. Clarification of the composition of the synthesized compounds and their recording in coordination form was carried out according to the data of a comprehensive study using the above methods (see Tables 3, 4) and by conducting a low-temperature X-ray experiment in the process of studying their atomic-crystalline structure.

Using X-ray diffraction analysis methods, the authors studied the atomic structure of single crystals Nd^{3+} $Cs_2[Nd(NO_3)_5(H_2O)_2]$, $Cs[Nd(NO_3)_4(H_2O)_3]$ (see [16, 17]), types of coordination of ligands, shapes of coordination polyhedra Ln, the possible variants of the coordination environment of Nd atoms, the spatial arrangement of polyhedra (Fig. 5) in the construction of compounds with aqua-containing complex anions, and the general crystallochemical regularities of the structure of this type of compound were clarified. (More detailed information and analysis of the construction features of this class of compounds are given in the above-mentioned original publications of the authors).

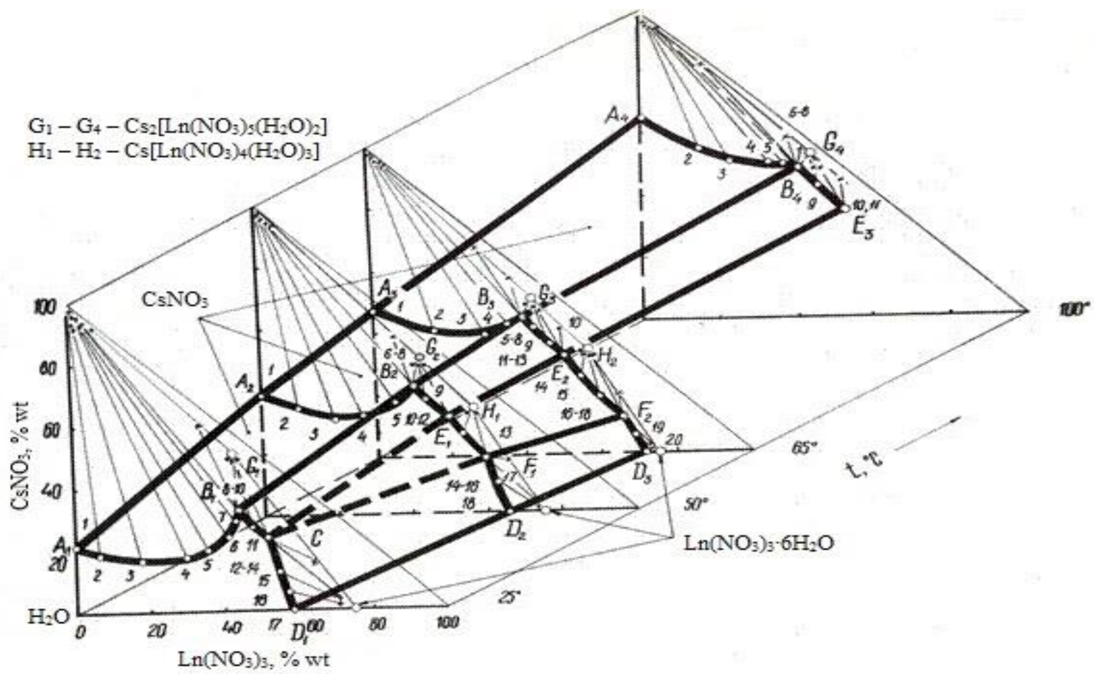

Figure 2 - Solubility polytherm of system $CsNO_3 – Ln(NO_3)_3 – H_2O$ (Ln – Nd)

Table 1 - Data on the study of phase equilibria in the system $CsNO_3$ – $Nd(NO_3)_3$ – H_2O at 25-100°C

t, °C	Composition points	Saturated solution composition, wt. %: $CsNO_3$	Saturated solution composition, wt. %: $Nd(NO_3)_3$	«Residue» composition, wt.%: $CsNO_3$	«Residue» composition, wt.%: $Nd(NO_3)_3$	Solid phases*
1	2	3	4	5	6	7
25	1 A_1	20,96	0,00	99,64	0,00	K
	2	18,59	5,91	99,58	0,00	Same
	3	16,58	18,51	99,14	0,67	-||-
	4	17,95	30,07	97,84	1,43	-||-
	5	20,67	35,68	97,76	1,60	-||-
	6	23,92	41,17	96,90	2,34	-||-
	7			95,45	3,10	-||-
	8 B_1	31,82	43,88	60,03	34,62	K+M
	9			51,08	42,15	M
	10	27,02	48,08	50,00	43,09	Same
	11			4992	43,16	-||-
	12 C	23,07	52,04	15,28	65,36	M+L
	13			2,67	72,66	L
	14	12,47	55,04	1,98	72,79	Same
	15	6,00	57,67	1,60	72,88	-||-
	16D_1	0,00	58,49	0,00	75,25	-||-
50	1 A_2	39,17	0,00	99,72	0,00	K
	2	34,72	9,93	98,63	0,57	Same
	3	31,10	20,53	98,37	1,08	-||-
	4	32,71	27,63	97,82	1,52	-||-
	5	36,99	36,68	96,54	2,47	-||-
	6			94,47	3,86	-||-
	7 B_2	40,98	40,84	59,34	35,74	K+L
	8			50,90	43,03	L
	9	36,54	44,23	49,48	43,12	Same
	10			49,64	43,26	-||-
	11 E_1	30,94	50,38	39,06	52,20	M+O
	12			33,64	56,35	O
	13	25,84	53,72	32,87	56,43	Same
	14	17,52	59,98	32,86	56,97	-||-
	15 F_1			17,54	64,69	O+L
	16			4,61	71,90	L
	17	9,77	62,91	2,81	72,12	Same
	18D_2	0,00	66,16	0,00	75,28	-||-

t, °C	Composition points	Saturated solution composition, wt. %: $CsNO_3$	Saturated solution composition, wt. %: $Nd(NO_3)_3$	«Residue» composition, wt.%: $CsNO_3$	«Residue» composition, wt.%: $Nd(NO_3)_3$	Solid phases*
1	2	3	4	5	6	7
65	1 A_3	47,16	0,00	99,69	0,00	K
	2	40,50	16,72	98,77	0,71	Same
	3	39,32	29,61	97,58	1,69	-||-
	4	43,24	35,86	95,48	3,12	-||-
	5			94,61	4,08	-||-
	6	44,92	40,11	67,95	27,47	K+M
	7 B_3			57,37	36,91	Same
	8			51,89	42,34	M
	9	42,61	41,13	50,96	43,23	Same
	10	37,02	47,33	49,67	42,89	-||-
	11			48,63	43,81	-||-
	12 E_2	32,11	50,75	42,12	49,50	M+O
	13			34,64	56,10	O
	14	24,51	54,79	33,76	56,77	Same
	15	18,25	59,84	33,32	56,69	-||-
	16			30,92	57,81	-||-
	17 F_2	11,99	66,26	15,77	66,42	O+L
	18			4,44	72,70	L
	19	6,25	68,91	1,86	73,23	Same
	20D_3	0,00	71,58	0,00	75,26	-||-
100	1 A_4	64,36	0,00	99,87	0,00	K
	2	54,44	14,95	98,76	0,83	Same
	3	50,32	22,89	97,71	0,95	-||-
	4	49,51	33,23	96,69	2,16	-||-
	5	49,05	36,69	94,72	3,86	-||-
	6			81,74	16,14	K+N
	7 B_4	47,56	41,28	57,48	37,98	Same
	8			52,89	41,93	-||-
	9	41,62	46,07	50,34	43,30	N
	10 E_3	33,80	52,92	51,71	44,41	Same

*K – $CsNO_3$, L – $Nd(NO_3)_3 \cdot 6H_2O$, M - $2CsNO_3 \cdot Nd(NO_3)_3 \cdot 3H_2O$, N – $2CsNO_3 \cdot Nd(NO_3)_3 \cdot 2H_2O$, O – $CsNO_3 \cdot Nd(NO_3)_3 \cdot 3H_2O$

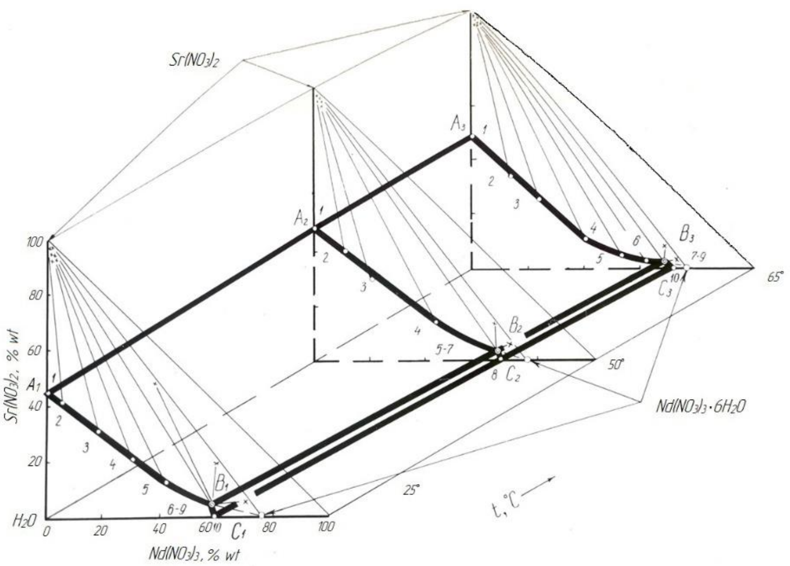

Figure 3 - Polytherm solubility of the system $Sr(NO_3)_2$ – $Nd(NO_3)_3$ – H_2O at 25 – 65 °C

Table 2 - Data on the study of phase equilibria in the system $Sr(NO_3)_2 – Nd(NO_3)_3 – H_2O$ at 25 – 65 °C

t,°C	Composition points	Saturated solution				Composition „remainder”, wt, %		Solid phase*
		Composition,wt, %		Properties				
		$Sr(NO_3)_2$	$Nd(NO_3)_3$	d x 10^3,кг/м^3	*n*	$Sr(NO_3)_2$	$Nd(NO_3)_3$	
1	2	3	4	5	6	7	8	9
25	1 A_1	44,60	0,00	1,539	1,4068	99,87	0,00	K
	2	41,66	5,12	1,541	1,4084	99,32	0,00	“-”
	3	30,71	17,66	1,547	1,4129	97,56	0,79	“-”
	4	20,86	29,99	1,550	1,4164	95,87	1,52	“-”
	5	12,58	41,84	1,569	1,4299	95,60	1,69	“-”
	6 B_1					95,72	2,80	“-”
	7 B_1	5,94	56,97	1,873	1,4548	52,50	34,84	K+L
	8 B_1					19,05	59,51	“-”
	9 B_1					2,89	70,62	“-”
	10 C_1	0,00	58,49	1,887	1,4551	0,00	75,25	L
50	1 A_2	48,03	0,00	1,487	1,4055	99,91	0,00	K
	2	39,75	10,75	1,544	1,4079	99,23	0,57	“-”
	3	29,35	20,28	1,589	1,4184	97,57	1,39	“-”
	4	14,38	43,08	1,623	1,4298	96,45	1,.87	“-”
	5 B_2					94,90	3,40	“-”
	6 B_2	3,88	65,34	1,850	1,4691	13,73	64,75	“-”
	7 B_2					7,26	9,76	“-”
	8 C_2	0,00	66,16	1,974	1,4667	0,00	75,28	L
65	1 A_3	48,60	0,00	–	–	99,92	0,00	K
	2	33,85	13,40	–	–	98,23	0,69	“-”
	3	25,84	23,91	–	–	98,11	0,85	“-”
	4	10,93	40,17	–	–	97,50	1,38	“-”
	5	4,.97	53,11	–	–	95,85	1,69	“-”
	6	2,35	61,72	–	–	95,30	2,18	“-”
	7 B_3					94,89	2,23	“-”
	8 B_3	2,52	68,39	–	–	10,39	67,78	K+L
	9 B_3					3,64	72,88	“-”
	10 C_3	0,00	71,58	–	–	0,00	72,26	L

* K – $Sr(NO_3)_2$; L – $Nd(NO_3)_3·6H_2O$

$Cs_2[Nd(NO_3)_5(H_2O)_2]$

$Cs[Nd(NO_3)_4(H_2O)_3]$

Figure 4 - Microphotos of coordination nitrates crystals Nd

Features of the processes of complex formation and crystal-chemical structure of cesium coordination nitrates of neodymium indicate that:

- the structure of complex compounds is based on rare-earth coordination polyhedra, one way or another connected in space;
- processes of exchange interaction between structural components (their binding) in the studied water-salt systems occur already under normal conditions (at 25 °C, see Table 1, Fig. 2);
- the central atoms of the Nd complexing agent under the studied conditions exhibit a mono- and bidentate nature of the connection with nitrato groups having a coordination number of 10 and the possibility of coordination formations with different compositions ([Nd(NO3)5(H2O)2]2- i [Nd(NO3)4(H2O)3]-) reveal

Table 3 - Influence of the type of symmetry on the possibility of occurrence of physical properties in crystals of coordination nitrates of rare earth elements

Connections	Sononia	Point group	Spatial group	Properties	Temperature range of formation, °C	The nature of solubility	References
$Cs_2[Nd(NO_3)_5(H_2O)_2]$	monocl.	2/m	C2/c	* ↓ ψ	25–100	incongr.	[18]
$Cs[Nd(NO_3)_4(H_2O)_3]$	tricl.	$\bar{1}$	$P\bar{1}$	* ψ	50–65	incongr.	[19]

Table 4 - X-ray data of cesium coordination neodymium nitrates

$Cs_2[Nd(NO_3)_5(H_2O)_2]$				$Cs[Nd(NO_3)_4(H_2O)_3]$	
d, Å	I/I_0, %	d, Å	I/I_0, %	d, Å	I/I_0, %
6,799	11,5	2,2191	11	6,667	80,8
5,9375	15,5	2,1923	28,5	5,4070	19,6
5,0980	55	2,1841	26	5,2727	36,5
4,8385	51,5	2,1681	16,5	4,4489	61,9
4,3708	49,5	2,0597	16	4,2467	29,2
4,2148	10	2,03162	23	4,1409	11,9
3,6775	100	1,84121	32,5	3,9241	8,8
3,4241	18,5	–	–	3,7231	14,2
3,3334	60	–	–	3,5700	13,1
3,2995	54,5	–	–	3,4035	8,8
3,0639	27	–	–	3,3384	49,6
2,9760	8,5	–	–	3,2781	52,3
2,9024	36,5	–	–	3,2314	13,5
2,8013	11,5	–	–	2,7152	8,8
2,7427	23	–	–	2,6727	100
2,7041	10,5	–	–	2,5829	11,5
2,6573	41	–	–	2,3528	16,5
2,6048	26	–	–	2,2739	5,8
2,5758	17	–	–	2,2307	9,6
2,5293	18,5	–	–	2,1882	14,2
2,4149	16	–	–	1,91250	28,8
2,4012	16	–	–	1,62366	20,8
2,3671	22,5	–	–	1,61946	10
2,3375	27,5	–	–	–	–
2,2939	15	–	–	–	–
2,2728	56,5	–	–	–	–

Note: d, Å - interplanar distances; I/I_0,% - are relative intensities of reflexes

an identically organized coordination sphere, clearly illustrating the dominant role of the Ln^{3+} ion in the structure formation of alkali rare earth nitrates.

- complex formations have the ability to preserve a layered motif of spatial construction (see Fig. 5, [12]) from rows of alternating rows of Nd and Cs atoms along the z axis. These rows are the ends of the layers of the corresponding coordination polyhedra. The planes of the layers are approximately perpendicular to the plane of the drawing. It is possible to distinguish packets consisting of four Nd – Cs – Cs – Nd layers, within which coordination polyhedra are in contact with each other due to common edges and hydrogen bonds. Every fourth layer and the next one do not have common vertices and edges, and the interaction of packages in the structure is carried out through only hydrogen bonds.

In the studied water-salt systems, the mechanism of complex formation can be explained from the standpoint of competing replacements of water molecules in the immediate environment of Ln^{3+} with NO_3^- groups. The degree of completeness of substitution depends on the nature of Ln^{3+}, the influence on these processes of the disordering effect on the structure of solutions of the existing singly and doubly charged cations Cs^+, Sr^{2+}, the nature of the thermal movement of structural components, the properties of electron-donating oxygen atoms and the spatial structure of solvents. A significant influence of the thermal factor on these processes and their staging have been revealed. The presence of certain temperatures at the beginning of the release of complex compounds into the solid phase indicates the existence of an energy barrier and the need to provide the system with some additional energy to carry out such transformations.

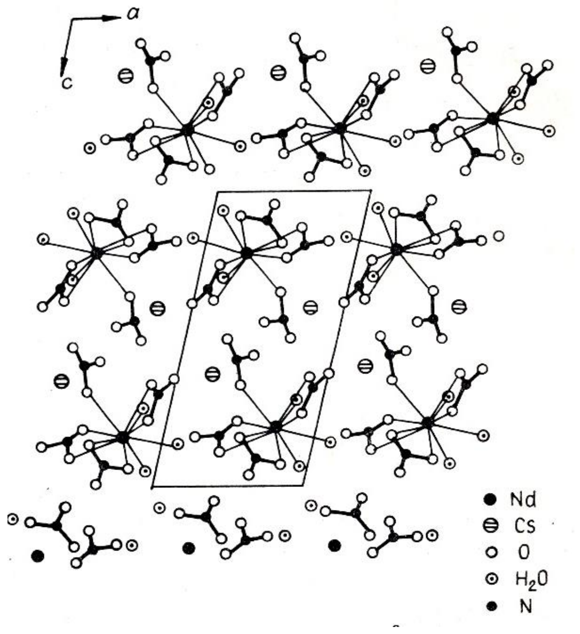

Figure 5 - Projection of the $Cs[Nd(NO_3)_4(H_2O)_3]$ structure onto the xy plane, [12]

All this makes the objects under study a promising group of nitrate precursors when developing formulations for liquid technological systems based on them and implementing processing schemes with impregnation, adsorption on radiation-resistant substrates with the possibility of thermal activation and solid-phase reactions. They have a complex of technologically valuable inherent properties: a) high solubility and compatibility with most components; b) a fairly wide temperature range for the existence of complex nitrates; c) detection of high activity by their reacting particles obtained by thermolysis of the solvent, and also nanosized and uniform in size and morphology [13]; d) the availability of a wide range of methods, methods, and technical means for activating such processes. It should also be noted that at present, combined methods of transformation with special requirements and fast-flowing syntheses with combined methods of system activation and mass production are becoming more widespread [14, 15].
With the use of thermoanalytical, chemical, and X-ray phase methods, an analysis of the nature and stages of dehydration processes, the nature and temperature intervals transformed into $Cs_2[Nd(NO_3)_5(H_2O)_2]$, $Cs[Nd(NO_3)_4(H_2O)_3]$ (20 – 1000 ºC).

On the $Cs_2[Nd(NO_3)_5(H_2O)_2]$ derivatogram, the endoeffects of 95, 122, 156 ºC correspond to the stepwise process of dehydration. The decrease in mass at 95 ºC corresponds to the loss of one water molecule. At 156°C, the incongruent melting of the sample in the water of crystallization occurs, followed by the formation of an anhydrous double salt, the melting point of which is 236°C.
For $Cs[Nd(NO_3)_4(H_2O)_3]$, the dehydration process is also three-stage (endoeffects 62, 90, 162 ºC). The loss of one water molecule according to the TG curve corresponds to a temperature of 139 ºC. An increase in temperature to 162 °C entails incogruent melting of the double nitrate dihydrate; subsequent heat treatment – formation of $CsNO_3 \cdot Nd(NO_3)_3$ from temperature 355 ºC. The thermal decomposition products of both coordination salts at t > 920 °C contain neodymium oxide.

Conclusions

The conducted comprehensive study provides a reliable idea of the trends in the general behavior of structural components in water-salt systems of nitrate precursors of neodymium, cesium, strontium in the preparatory stages of technological regulations for the concentration and immobilization of liquid radioactive waste of the nuclear power industry complex according to the schemes using porous and layered matrix fixators of radionuclides ^{137}Cs, ^{90}Sr and thermal activation. The stages of such transformations have been revealed; the patterns of complex and phase formation in systems and the factors influencing them were clarified; a number of physicochemical properties of the resulting intermediate phases - coordination neodymium nitrates - have been studied: their composition, types of compounds, atomic crystal structure, shapes of Ln coordination polyhedra, types of coordination of ligands, features and patterns of behavior in heat treatment processes. It has been established that, under the conditions of the existence of solutions, the system $CsNO_3 – Nd(NO_3)_3 – H_2O$ is characterized by the formation of 2 anionic complex compounds Ln^{3+}, the system $Sr(NO_3)_2 – Nd(NO_3)_3 – H_2O$ is of the eutonic type. The ongoing competing reactions are a powerful technological factor that has a significant impact on changes in the activity of structural forms of Ln^{3+}. Systematized information enables to elucidate the mechanisms and kinetics of transformations of structural components in similar objects and allows us to transfer the resulting system of knowledge to the plane of promising technological solutions for the solidification of liquid radioactive waste.

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Прикладні аспекти використання виявлених закономірностей сумісної поведінка структурних компонентів у водно-сольових системах нітратів цезію, стронцію і неодиму

Проведене комплексне дослідження дає достовірне уявлення про тенденції у спільній поведінці структурних компонентів у водно-сольових системах нітратних прекурсорів неодиму, цезію, стронцію у підготовчих стадіях технологічних регламентів концентрування й іммобілізації рідких радіоактивних відходів ядерного енергопромислового комплексу за схемами з використанням пористих і шаруватих матричних фіксаторів радіонуклідів ^{137}Cs, ^{90}Sr і тепловою активацією. Виявлено стадійність таких перетворень; з'ясовано закономірності комплексо- і фазоутворення в системах та фактори впливу на них; вивчений ряд фізико-хімічних властивостей утворюваних проміжних фаз – координаційних нітратів неодиму: їхній склад, види сполук, атомно-кристалічну будову, форми координаційних поліедрів Ln, типи координації лігандів, особливості і закономірності поведінки в процесах термооброблення. Встановлено, що в умовах існування розчинів система $CsNO_3 – Nd(NO_3)_3 – H_2O$ характеризується утворенням 2 аніонних комплексних сполук Ln^{3+}, система $Sr(NO_3)_2 – Nd(NO_3)_3 – H_2O$ – евтонічного типу. Протікаючі конкуруючі реакції є сильнодіючим технологічним фактором суттєво впливаючим на зміну активності структурних форм Ln^{3+}. Систематизовані відомості дозволяють з'ясовувати механізми, кінетику перетворень структурних компонентів в аналогічних об'єктах та дають можливість перенести одержану систему знань у площину перспективних технологічних рішень отверднення рідких радіоактивних відходів.

Ключові слова: неодим, цезій, стронцій, нітрати; водно-сольові системи, комплексоутворення, властивості.

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Technological equipment package for preparing polystyrene concrete mixture

The study of the production process for polystyrene concrete mixture products is driven by the need to ensure high material quality while meeting modern construction standards. To achieve this goal, an analytical method was used for reviewing literature sources, along with a design-calculation approach in the development of a new type of equipment.
The main findings highlight the shortcomings of conventional concrete mixers, including extended mixing time, mixture non-uniformity, and material sticking to working surfaces. A novel design of a gravity-compelled cascade-type concrete mixer is proposed, featuring a horizontal ribbon-paddle shaft and a rotating drum. A key innovation is the ability to adjust the rotation modes depending on the mixture composition and the presence of sand. A compact equipment package was developed, comprising a mixer, fiber cutter, belt and screw feeders, all mounted on a single frame. The use of a belt feeder with synchronized component feeding and an automated fiber cutter ensures even distribution of reinforcing elements within the mixture. A methodology for determining the productivity of the unit has been developed, considering the mixer filling volume, the geometric parameters of working elements, and mixing process characteristics. Formulas were derived for selecting key parameters of the cutter and roller feed for the fiber bundle.The proposed equipment contributes to improved quality of polystyrene concrete, reduced energy consumption, and shorter production time. Future research will focus on optimizing operating modes of the equipment for different types of polystyrene concrete mixtures using fiber reinforcement.

Keywords: polystyrene concrete, mixing, fiber, reinforcement, concrete mixer, feeder, design, quality

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Introduction

The analysis of issues in the production of polystyrene concrete products requires consideration of several aspects related to raw material properties, the manufacturing process, and compliance with construction standards. The main challenges in polystyrene concrete production often arise from the difficulty in achieving optimal strength, thermal and sound insulation characteristics, as well as meeting environmental requirements.

Review of the research sources and publications

Polystyrene concrete consists of a cement-based mixture and expanded polystyrene, which is added to enhance thermal insulation properties. However, this combination can result in structural inhomogeneity, leading to unstable physical and mechanical properties. As noted in studies, the density and strength of polystyrene concrete can vary significantly depending on the quality of raw materials and the production technology [1].

Polystyrene concrete is prone to shrinkage, which may cause surface cracking in the final products. This issue becomes particularly critical when the material has high moisture content during curing. Some researchers have suggested that shrinkage can be reduced through the use of specialized additives [2].

Polystyrene concrete is characterized by high hydrophobicity, but in the presence of microcracks, water may penetrate the material's pores. This reduces its strength and durability, especially under fluctuating moisture conditions. Studies have shown that water resistance can be improved by adding specific admixtures, though this increases production costs [3].

Ensuring consistent quality of polystyrene concrete products is a complex task. In practice, it is crucial to control not only the quality of polystyrene and cement but also to maintain precise proportions of components, as well as temperature and humidity conditions during mixing and curing. Failure to adhere to technological standards may compromise the mechanical performance of the material [4].

The analysis of these issues suggests that while polystyrene concrete has significant potential in construction, its effective application depends on overcoming technological, environmental, and economic challenges.

International research on polystyrene concrete actively addresses its thermal insulation properties, strength, durability, and environmental impact. Scientists from various countries focus on improving production technology and applications of polystyrene concrete, particularly in the context of reducing energy consumption and enhancing environmental performance in construction.

Researchers from Europe and the USA are investigating ways to improve the thermal insulation properties of polystyrene concrete without significantly compromising its strength. For instance, studies by Türker and Ali [5] in Turkey have shown that optimizing the microstructure of polystyrene concrete—particularly by adjusting the size of polystyrene granules—can enhance thermal insulation without reducing the load-bearing capacity of the material.

Researchers in Germany and Japan are exploring technologies involving special admixtures that improve the hydrophobic properties of polystyrene concrete. In an article by Schulz and Lee [6], it was reported that using silicone-based admixtures and other water-repellent agents reduced water absorption by 20–30%, positively affecting the material's durability in high-humidity environments.

Research in Italy, particularly by Ricci and D'Angelo [7], demonstrated that adding polypropylene fibers to the polystyrene concrete mix enhances crack resistance and mechanical stability. Fiber reinforcement reduces the risk of microcrack formation and deformation, especially in low-temperature conditions.

International studies highlight strong interest in polystyrene concrete as a promising construction material. However, for its effective application, challenges related to environmental safety, hydrophobicity, strength, and quality control must be addressed. Therefore, the production of polystyrene concrete requires continuous improvement to ensure reliability and compliance with current environmental and technical standards.

Definition of unsolved aspects of the problem

Analyzing the various types of mixers used for the preparation of polystyrene concrete mixtures, it can be concluded that the most common are gravity and forced-action mixers (either single-shaft or twin-shaft). In gravity mixers, the mixing process occurs through the free-fall of the material. In forced-action mixers, mixing is achieved using mechanical elements that directly act on the components of the mixture. The simplest type of equipment for preparing the mixture is a gravity batch concrete mixer.

The company *"Energy Efficient Concretes"* recommends using the *Politherm-Machine MP1000* for feeding and preparing polystyrene concrete [8]. Foam, prepared in a dedicated unit called a foam generator, is added to the cement-sand mixture. After thorough mixing, the resulting cellular-structure mixture is ready for molding into various construction products. The hardening of foam concrete typically requires steam curing in chambers under atmospheric pressure.

The *MP1V3 unit* is designed for the preparation and pumping of high-quality monolithic polystyrene concrete that contains no sand, with a density ranging from 200 to 600 kg/m³ [9].

Problem statement

Drawing on decades of accumulated experience, it is necessary to develop equipment that integrates all the essential features for producing high-quality polystyrene concrete, with the capability to incorporate reinforcing elements.

Basic material and results

When analyzing existing mixer designs used for the preparation of polystyrene concrete mixtures, several aspects must be taken into account:

- the complexity of the mixer's structural design;
- the uncertainty in achieving mixture homogeneity;
- the adhesion of the prepared mixture to the mixer's internal surfaces;
- the long time required for the mixing process.

Due to these shortcomings, it is proposed to use a gravity-forced concrete mixer operating in cascade mode for the preparation of such mixtures [10, 11, 12]. Existing designs of such mixers are typically intended for low-mobility and stiff concrete mixtures.

The gravity-forced concrete mixer features a cylindrical body with a horizontal shaft inside, onto which blades are mounted helically. Both the mixer body and the blade shaft rotate in opposite directions. Depending on the composition of the mixture, if it contains sand, the mixer body rotates; if the mixture is sand-free, the body remains static while only the ribbon-blade shaft rotates. The improved mixer design meets the requirements for producing polystyrene concrete mixtures reinforced with fiber elements.

The mixer is part of a compact equipment set, as shown in Figure 1 [13].

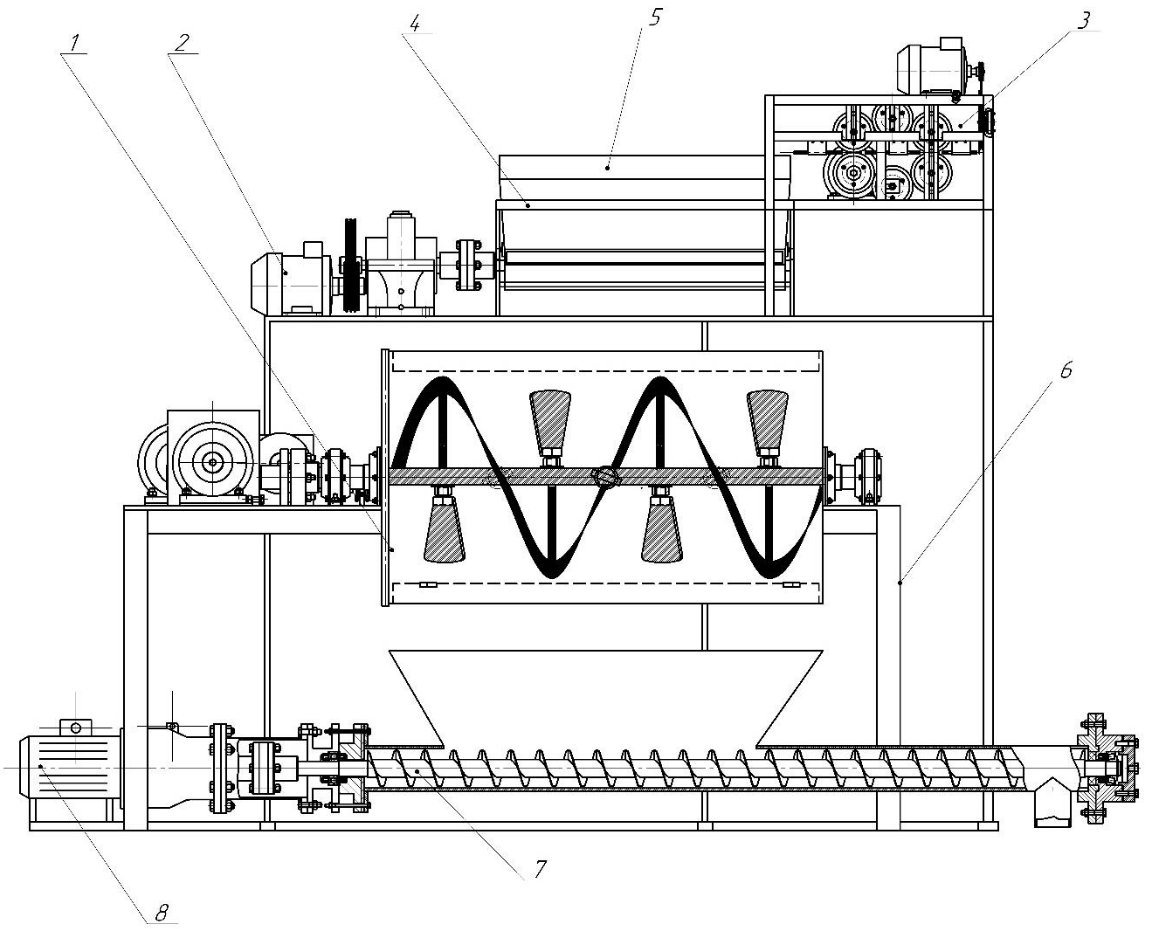

Figure 1 – Equipment set for the preparation of polystyrene concrete mixture:
1 – gravity-forced mixer; 2 – belt feeder drive; 3 – fiber cutter; 4 – belt feeder; 5 – component storage hopper; 6 – frame; 7 – screw feeder; 8 – screw feeder drive

The equipment set includes a base machine – a forced-action mixer, a fiber cutter, a belt feeder for component delivery, and a screw feeder for transporting the prepared mixture. The entire system is mounted on a single frame and operates in a synchronized manner (depending on the mixer's output capacity), allowing for reduced time in feeding components.

The operating process of the equipment set is as follows: pre-measured mixture components are stored in hopper 5 and delivered to the mixer's loading port (1) using belt feeder 4. Simultaneously, fiber strands are cut by fiber cutter 3 and evenly distributed onto the feeder belt 4 [14]. The ready polystyrene concrete mix is discharged from mixer 1 into the intake hopper of screw feeder 8, from where it is conveyed to the forming station for product fabrication.

To ensure synchronized operation of the equipment set, it is necessary to feed the material components evenly and to cut the fibrous elements. All these stages are interrelated and depend on the performance of the main equipment — the concrete mixer.

To determine the main performance indicators of the machine, a calculation method is proposed that takes into account the machine's structural parameters and the specifics of the working process:

$$\Pi_{tech.mix} = V_{total} \cdot К_z \cdot Z_c, \text{ m}^3/\text{h} ;$$

where:

V_{total} – total volume of the mix in the mixer body, m^3;

$К_z$ = 0,5; – volume filling coefficient of the mixer;

$Z_c = 3600/t_c$ – number of cycles per hour;

$(t_c = t_1 + t_2 + t_3)$ – duration of one cycle (including loading t_1, mixing t_2, and unloading t_3), s.

Загальний обсяг суміші визначається як, m^3:

$$V_{total} = V_{\text{body}} - V_{\text{shaft}} - V_{\text{blade } leg} - V_{\text{blade}} - V_{\text{screw}} - V_{\text{support}},$$

where:

$V_{\text{body}} = \frac{1}{2} \cdot \pi \cdot R^2_{body.in} \cdot L_{body}$; – volume of the mixer body, m^3;

$V_{\text{shaft}} = \frac{1}{2} \cdot \pi \cdot r^2_{\text{shaft}} \cdot L_{\text{shaft}}$; – shaft volume, m^3;

$V_{\text{blade } leg} = \frac{1}{2} \cdot \pi \cdot r^2_{leg.in} \cdot z_{leg} \cdot C_{leg}$; – volume of blade legs, m^3;

$V_{\text{blade}} = \frac{1}{2} \cdot Z_{\text{blade}} \cdot b_{\text{blade}} \cdot h_{\text{blade}} \cdot C_{\text{blade}}$; – blade volume, m^3;

$V_{\text{screw}} = \frac{1}{2} \cdot \pi \cdot (L_{\text{screw}}) \cdot (R^2_{\text{screw}} \cdot r^2_{\text{screw}}) \cdot C_{\text{screw}}$; – screw volume, m^3;

$V_{\text{support}} = \frac{1}{2} \cdot \pi \cdot R^2_{\text{support}} \cdot C_{\text{support}} \cdot Z_{\text{support}};$ – volume of shaft supports, m³;

$R_{body.in}$. – inner radius of the mixer body, m;

L_{body} – body length, m;

r_{shaft} – shaft radius, m;

L_{shaft} – shaft length, m;

$r_{leg.in}$ – inner radius of blade leg, m;

z_{leg}, C_{leg} – number of blade legs and thickness, m;

$Z_{\text{blade}}, b_{\text{blade}}, h_{\text{blade}}, C_{\text{blade}}$ – blade width, height, number of blades and thickness, m;

$L_{\text{screw}} = \sqrt{S^2 + (\pi \cdot D_{ш})^2};$ – developed length of screw, m;

$R_{\text{screw}}, r_{\text{screw}}$. – outer and inner screw radius, m;

$C_{\text{support}}, Z_{\text{support}}$ – number and thickness of screw supports, m.

The cutting machine's productivity can be determined by two approaches [14]:

1. Based on the concrete mixer's productivity:

$$П_{tech.cut.1} = П_{tech.mix} \cdot К_{max.fiber},$$

where:

$К_{max.fiber} = \frac{\pi \cdot d_{fiber}{}^2 \cdot f}{4 \cdot h \cdot l_f};$ – maximum volumetric reinforcement coefficient;

d_{fiber} – fiber diameter, m;

f – friction coefficient;

$h = 0{,}8 \cdot H$ – where H is the mixer height, m;

l_f – length of the cut fibers, m.

2. Based on knife head design parameters:

$$П_{tech.cut.2} = \frac{47{,}1 \cdot n_{н.г.} \cdot D^2_{\text{bundle}} \cdot l_f}{4 \cdot Z_{kh}},$$

where:

n_{kh} – knife head rotation speed, rpm;

D_{bundle} – diameter of synthetic fiber bundle, m;

Z_{kh} – number of knives on the head.

From this, the required number of knives can be derived:

$$Z_{kh} = \frac{П_{tech.mix} \cdot К_{max.fiber}}{188{,}4 \cdot n_{kh} \cdot D^2_{\text{bundle}} \cdot l_f}.$$

3. Productivity based on feed rollers:

$$П_{tech.cut.3} = 60 \cdot n_{roller} \cdot \pi \cdot D_{roller} \cdot d_f \cdot l_f,$$

thus:

$$n_{roller} = \frac{П_{tech.mix} \cdot К_{max.fiber}}{60 \cdot \pi \cdot D_{roller} \cdot d_f \cdot l_f},$$

where:

D_{roller} – roller diameter, m;

d_f diameter of synthetic thread, m.

Therefore, depending on the mixer performance and fiber geometry, the necessary rotation speed of the knife head and feed rollers can be determined.

Based on these dependencies, a study was conducted on the effect of fiber length on the strength of the test samples. The results are shown in Figure 2.

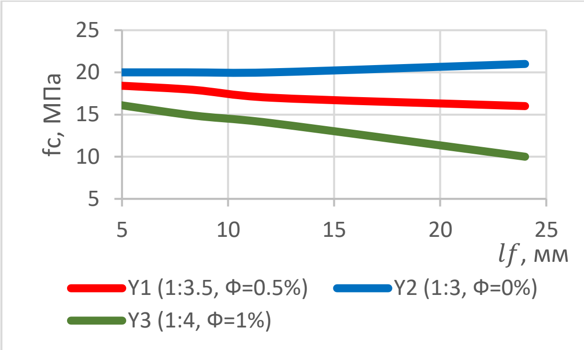

Figure 2 – Strength of test samples depending on the length of fiber elements:
Y1 – Cement-to-sand ratio 1:3.5, fiber content F = 0.5%;
Y2 – Ratio 1:3, no fibers (F = 0%);
Y3 – Ratio 1:4, fiber content F = 1%.

The study showed that the addition of reinforcing fibers improves the microstructure of the mixture, reduces porosity, and enhances the strength of finished products. The optimal fiber length is 6–12 mm.

Conclusions

The proposed set of compact equipment enables the preparation of polystyrene concrete mix with the addition of reinforcing fibers, which enhances the strength of the final product. The equipment included in the set operates asynchronously and allows for adjustable output based on the characteristics of the mixture and the requirements for the fibrous elements.

The addition of fibrous reinforcement to the polystyrene concrete mix significantly improves its mechanical properties and microstructure. Optimal selection of the fiber type, length, and quantity allows for achieving the desired material characteristics for specific construction applications.

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Комплект обладнання для приготування полістиролбетонної суміші

Дослідження процесу виробництва виробів із полістиролбетонної суміші обумовлене необхідністю забезпечення високої якості матеріалу за умов дотримання сучасних будівельних стандартів. Для досягнення поставленої мети було застосовано аналітичний метод аналізу літературних джерел, а також конструктивно-розрахунковий підхід при розробці нового типу обладнання. Основні результати дослідження вказують на недоліки традиційних бетонозмішувачів, що проявляються у тривалому часі приготування суміші, її неоднорідності та налипанні матеріалу на робочі поверхні. Запропоновано конструкцію бетонозмішувача гравітаційно-примусової дії каскадного режиму роботи з горизонтальним стрічково-лопатевим валом і обертовим корпусом. Особливістю є можливість змінювати режими обертання залежно від складу суміші та наявності піску. Створено малогабаритний комплект обладнання, що включає змішувач, різчик фібри, стрічковий і шнековий живильники, змонтовані на єдиній рамі. Використання стрічкового живильника із синхронною подачею компонентів і автоматизованого різчика фібри дозволяє рівномірно розподіляти армуючі елементи в суміші. Розроблена методика визначення продуктивності установки враховує об'єм заповнення змішувача, геометричні параметри робочих органів та особливості процесу перемішування. Визначені залежності для підбору основних параметрів різчика і роликової подачі джгута. Запропоноване обладнання сприяє підвищенню якості полістиролбетону, зменшенню енергоспоживання і часу виробництва. Перспективою подальших досліджень є оптимізація режимів роботи обладнання для різних типів полістиролбетонних сумішей із використанням фібрового армування.

Ключові слова: полістиролбетон, змішування, фібра, армування, бетонозмішувач, живильник, конструкція, якість.

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