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Ensuring the functioning of engineering, transport networks thanks to the strengthening of damaged reinforced concrete columns of their structures

Забезпечення функціонування інженерних, транспортних мереж завдяки підсиленню пошкоджених залізобетонних колон їх споруд

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The reliability of the functioning of engineering and transportation networks largely depends on the technical condition of their structural facilities. For example, in many design solutions for pumping stations in water supply, sewage, and heating networks, significant attention is paid to the compact use of the internal space of technological rooms. This is due to the need to accommodate large-sized technological equipment in these rooms, as well as to install a complex pipeline system in accordance with the operational scheme of the pumping station. Therefore, the use of columns in such spaces aligns well with the requirements for the reliable operation of engineering networks because it: ensures the technological requirements for the operation of the pumping station; facilitates the relocation, repair, and replacement of large-scale technological equipment and the installation of complex pipeline systems during modernization, reconstruction, or restoration after damage, while considering changes to the system's operational scheme. In this regard, the mechanical properties of concrete made with ordinary Portland cement, microsilica, and the SP-1 superplasticizer have been studied for its potential use as a high-strength material in reinforcing the load-bearing concrete structures, specifically the columns of engineering structures within engineering and transportation networks. These include pumping stations in water supply, sewage, and heating networks; district heating plants; bridges; and pedestrian overpasses. The concrete mix was developed to construct reinforced concrete jackets for strengthening damaged column structures. This technology has significant advantages for constructing column structures in terms of their resilience during shelling, particularly in terms of *execution speed, strength, reliability, and protection from various external impacts during such events. When performing research, first, mixing water, SP-1 additive, Portland cement and microsilica (from 0 to 10 %) were sequentially introduced, later they were combined with a dosed amount of quartz sand and granite crushed stone in an ordinary concrete mixer. The compressive strength of concrete was determined according to DSTU B V.2.7-214:2009. Experimental data showed that by varying the selected factors, it is possible to increase the strength of concrete in the initial period when it is doubled in compression.*

Надійність функціонування інженерних, транспортних мереж значною мірою залежить від технічного стану їх інженерних споруд. Наприклад, у багатьох планувальних рішеннях насосних станцій мереж водопостачання, каналізації, теплопостачання значна увага зосереджується на компактному використанні внутрішнього простору технологічних приміщень. Це пов'язано з потребою розташування у таких приміщеннях технологічного обладнання великих габаритів, а також влаштування складної системи трубопроводів відповідно до принципової схеми роботи насосної станції. Тому використання колон у таких приміщеннях добре відповідає вимогам надійної експлуатації інженерних мереж, оскільки: дозволяє забезпечити технологічні вимоги до роботи насосної станції; під час модернізації, реконструкції, відновлення після руйнування насосної станції створює можливості для переміщення, ремонту, заміни технологічного обладнання великих габаритів та можливості для монтажу складних систем трубопроводів, враховуючи потреби зміни принципової схеми системи. У зв'язку з цим, досліджено механічні властивості бетону на звичайному портландцементі з добавкою мікрокремнезему та суперпластифікатора СП-1 для можливості застосування його в якості високоміцного при підсиленні залізобетонних несучих конструкцій, а саме колон інженерних споруд інженерних, транспортних мереж (насосні станції мереж водопостачання, каналізації, теплопостачання; районні котельні; мости та надземні пішохідні переходи). Склад бетону розроблявся для влаштування залізобетонних обойм для підсилення конструкцій пошкоджених колон. Така технологія має важливі переваги для влаштування конструкцій колон щодо стійкості конструкцій колон при обстрілах, зокрема – за швидкістю виконання, міцністю, надійністю, захисту від різного роду зовнішніх впливів при обстрілах. При виконанні досліджень спочатку послідовно вводили воду замішування, добавку СП-1, портландцемент та мікрокремнезем (від 0 до 10%), згодом вони поєднувалася з віддозованою кількістю кварцового піску і гранітного щебеню в ординарному бетонозмішувачі. Міцність бетону на стиск визначалася згідно ДСТУ Б В.2.7-214:2009. Експериментальні дані показали, що варіюючи обраними факторами можливо збільшити міцність бетону в початковий період на стиск удвічі.

Keywords: reconstruction, structures, column, strengthening, high-strength concrete, operation, research methodology, engineering and transport networks.

Ключові слова: реконструкція, споруди, колона, підсилення, високоміцний бетон, експлуатація, методологія досліджень, інженерні і транспортні мережі.

Problem statement. Modern operating conditions of Ukraine's critical infrastructure, including engineering structures of utility and transportation networks, have posed additional challenges for the construction industry. The destruction of critical infrastructure due to ongoing shelling necessitates urgent intervention—repairs and reconstruction with reinforcement of the load-bearing structures of these engineering facilities. Military actions result in damage or destruction of structures across various categories, including residential buildings, social infrastructure, industrial facilities, and engineering structures. Nevertheless, the swift restoration of the functionality of utility and transportation networks is a top priority, as it critically impact the country's economy, defense capabilities, and the living conditions of its population. Considering the operational characteristics of utility and transportation networks, most of their engineering structures are technically difficult or impossible to relocate or reconstruct promptly. Therefore, one of the most effective construction solutions in cases where engineering structures are damaged or partially destroyed is to ensure their rapid restoration. Maintaining the strength and reliability of these structural components is a critical requirement for the restoration technology. This challenge is often compounded by adverse weather conditions, such as heat, frost, or precipitation, which exacerbate the effects of shelling. Damage or destruction of structures may result from one or several factors of various origins, including physical-mechanical and chemical impacts, such as blows, explosions, heat and fire, chemical degradation, and dynamic loads.

Construction structures based on cement, concrete, and reinforced concrete are the most widespread in construction and at the same time one of the most resistant, in terms of strength and reliability, to external influences of various origins. This is also confirmed by the prevalence of their use in various concrete reinforcements and products. Therefore, despite certain disadvantages, the use of cement and concrete is one of the best solutions for strengthening reinforced concrete columns damaged as a result of shelling, as well as for ensuring their protection during the operation of facilities in engineering and transportation networks. Such structures of urban critical infrastructure, the structural scheme of most of which includes reinforced concrete columns, in particular, include: pumping stations of water supply, sewage, heating networks; district heating plants; bridges and bridge crossings.

Thus, since the main structures of columns of modern facilities in engineering and transportation networks are mainly made of concrete and monolithic reinforced concrete [1], and in connection with the increased requirements for their stability during shelling, special attention should be paid to their strengthening after damage or partial destruction using technologies for strengthening columns based on high-strength concrete. Therefore, the relevant research task is the development of the composition of such high-strength concrete. To determine the further possibility and feasibility of reinforcing a column, selecting appropriate methods and techniques and performing engineering calculations, it is necessary to take into account not only the physical-mechanical, chemical or other features characteristic of a specific method and process of destruction but also the actual condition of the structure and the conditions (factors) of external environmental impact during the subsequent operation of the column structure [2-4].

Analysis of literary data and problem statement. The study of methods for strengthening reinforced concrete structures, as well as the reasons that led to the need for reinforcement, has been the subject of numerous works [5-11 et al.]. The installation of a shell with an additional reinforcement layer increases the thickness of the column, provides a complex combination of strength, rigidity, and plasticity of the column structures and the framework of the facility, and creates additional loads on the foundations. In particular, shotcrete reinforcement during reconstruction with reinforcement allows for maximum preservation of existing structures and ensures their efficient operation with minimal work duration. When designing the concrete mix for shotcrete, it is necessary to consider several factors, such as the ratio of cement to fillers, granulometric composition, equipment characteristics, preparation method, etc. [12-21].

The aim of the article: to study high-strength concrete designed for strengthening reinforced concrete columns of engineering structures damaged during shelling, based on the reconstruction conditions required for the operational restoration of the functionality of engineering and transportation networks. **The main objectives**: to investigate the composition and mechanical characteristics of high-strength concrete based on ordinary Portland cement, intended for shotcreting reinforced concrete columns of engineering structures damaged during shelling, considering the reconstruction conditions necessary for the operational restoration of the functionality of engineering and transportation networks.

Materials and Methods. Portland cement was prepared by grinding clinker with gypsum stone to specific surface areas of 300, 400, and 500 m^2/kg. Microsilica (from 0 to 10 %) from the Nikopol Ferroalloy Plant was used as an active additive in the studies. The SP-1 plasticizer, in the amount of 1 % (calculated on a dry matter basis) of the binder mass, was used to plasticize the concrete mixture. Quartz sand with M = 2.2 and granite crushed stone were used as aggregates. Initially, water for mixing, SP-1 additive, Portland cement, and microsilica were sequentially introduced, and then these were mixed with a dosed amount of quartz sand and granite crushed stone in a conventional concrete mixer. Concrete compressive strength was determined according to [22].

Results. The accepted composition and strength of high-strength concrete based on ordinary Portland cement were experimentally studied for its suitability for shotcreting reinforced concrete columns of engineering structures damaged during shelling. To obtain high-strength concrete, the binder was modified with an organo-mineral additive. The following factors were used in the experiment: x_1 – the microsilica (MS) content in Portland cement (by weight) – 5±5 %; x_2 – the binder content in concrete – 450±100 kg/m³; x_3 – the specific surface area (S_s) of Portland cement – 400±100 m²/kg. The amount of SP-1 superplasticizer was set at 1 %. The results of the research on the mechanical properties of concrete at the ages of 3, 7, and 28 days are presented in Table 1. Achievement of concrete strength (up to 40 MPa) at 3 days of age with 10% microsilica content and the presence of SP-1, makes it suitable for repair, including strengthening load-bearing structures. As shown in table 1, by the 7th day, the concrete strength increases almost twice, and by the 28th day, it reaches a value of $f_{ck.cube}$ =88.4 MPa.

Table 1

Mechanical characteristics of concrete aged 3, 7 and 28 days

№	Levels of var.			MS, %	Binder consumpt., kg/m³	Spec. surf. area of cement S_s, m²/kg	Compressive strength indicators, $f_{ck.cube}$, MPa		
	x_1	x_2	x_3				3 days	7 days	28 days
1	-	-	-	0	350	300	18.6	29.5	43.6
2	+	-	-	10	350	300	23.8	42.1	52.3
3	-	+	-	0	550	300	26.9	45.1	53.9
4	+	+	-	10	550	300	29.5	54.3	69.5
5	-	-	+	0	350	500	24.8	34.8	52.7
6	+	-	+	10	350	500	27.6	40.8	64,3
7	-	+	+	0	550	500	29.1	60.9	72.8
8	+	+	+	10	550	500	37.4	69.6	88.4
9	-	0	0	0	450	400	28.6	47.3	64.9
10	+	0	0	10	450	400	36.2	60.1	81.4
11	0	-	0	5	350	400	26.9	52,5	61.6
12	0	+	0	5	550	400	32.9	62.3	75.2
13	0	0	-	5	450	300	26.9	40.7	53.9
14	0	0	+	5	450	500	30.0	48.2	58.1
15	0	0	0	5	450	400	32.2	56.6	73.4

Conclusions. In the current conditions of constant threats of shelling of critical infrastructure objects, significant attention is paid to the rapid restoration of engineering and transportation networks. In particular, the rapid restoration of reinforced concrete columns of engineering structures (pumping stations of water supply, sewage, and heating networks; district boiler houses; bridges and overpass pedestrian crossings) damaged during shelling can be carried out by strengthening their structures with shotcreting high-strength concrete. This also promotes the rapid restoration of equipment and pipelines located in damaged rooms of engineering structures in engineering networks. In this regard, the experiments have established that the main conditions for obtaining high-strength concrete are the use of highly active binders, large and fine aggregates of appropriate quality, with the use of plasticizers and micro-fillers. The addition of microsilica and SP-1 superplasticizer allows the production of heavy concrete classes C32/40...C70/85 with a binder consumption ranging from 350 to 550 kg/m³.

Further research will focus on the specifics of the shotcreting technology of reinforced concrete columns of engineering structures damaged during shelling using the concrete of the investigated composition.

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