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ON THE TASKS OF OPERATIONAL CONTROL OF THE CONDITION OF REINFORCED CONCRETE STRUCTURES OF MUNICIPAL WASTEWATER DISPOSAL SYSTEMS

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Abstract

Operational monitoring of the technical condition of reinforced concrete structures (wells, collectors, tanks) in wastewater disposal systems is a set of periodic measures aimed at the timely detection of defects and the prevention of accidents. Its particular importance arises from the structures' operation in an aggressive environment exposed to moisture, temperature fluctuations, stray currents, and mechanical loads. The objectives of operational monitoring include the identification of visible and hidden defects (cracks, chips, delamination of the protective concrete layer, exposed and corroded reinforcement, leaks in joints, and mutual displacement of precast elements), an assessment of the strength and deformation properties of materials (concrete and reinforcement), the degree of corrosion, checking the tightness of the structures, and verifying the compliance of actual parameters with design specifications. Monitoring is implemented using visual and instrumental non-destructive methods, ensuring rapid results. Based on the monitoring results, a report is prepared with measurement protocols, defect diagrams, and recommendations for repair or reinforcement of the structure. Operational monitoring is planned and preventative in nature. According to current regulations, the recommended frequency is at least once a year, and more frequently for facilities showing signs of deformation or in a state of emergency. One of the modern innovative approaches that is beginning to be adopted globally is the digitalization of processes related to the operational monitoring of the technical condition of wastewater disposal systems. However, the implementation of digitalization requires both the development of new regulations and the development of an information infrastructure (systems and specialized equipment for diagnostics in difficult operating conditions, specialized software, etc.).

Therefore, systematic operational monitoring using an integrated approach based on both visual and instrumental methods, including the use of digital systems, is a prerequisite for maintaining the operability of wastewater disposal systems. This will enable a transition from repairs following an accident to preventive technical condition management, significantly increasing the reliability and extending the service life of utility networks.

Keywords: operational control, wastewater disposal systems, waste water, reinforced concrete structures, regulatory documents, technical condition assessment, forecasting.

О ЗАДАЧАХ ОПЕРАТИВНОГО КОНТРОЛЯ СОСТОЯНИЯ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ КОММУНАЛЬНЫХ СИСТЕМ ВОДООТВЕДЕНИЯ

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Реферат

Оперативный контроль технического состояния железобетонных конструкций (колодцев, коллекторов, резервуаров) в системах водоотведения – это комплекс периодических мероприятий, направленных на своевременное выявление дефектов и предотвращение аварий. Его особая важность обусловлена работой конструкций в агрессивной среде под воздействием влаги, температурных перепадов, блуждающих токов и механических нагрузок. В задачи оперативного контроля входит выявление видимых и скрытых дефектов (трещин, сколов, отслоения защитного слоя бетона, оголение и коррозия арматуры, протечки в швах, взаимных смещений сборных элементов), оценка прочностных и деформационных характеристик материалов (бетона и арматуры), степени их коррозии, проверку герметичности конструкций и соответствие фактических параметров проектным решениям. Контроль реализуется с помощью визуальных и инструментальных неразрушающих методов, обеспечивающих быстрое получение результатов. По результатам контроля составляется заключение с протоколами измерений, схемами дефектов и рекомендациями по ремонту или усилению конструкций. Оперативный контроль носит планово-профилактический характер. Согласно действующим нормативным документам, рекомендуемая периодичность – не реже одного раза в год, а для объектов с признаками деформаций или в аварийном состоянии – чаще. Одним из современных инновационных подходов, которые начинают применяться в мировой практике, является цифровизация процессов, связанных с оперативным контролем технического состояния систем водоотведения. Однако внедрение цифровизации требует как разработки новых нормативных документов, так и формирование информационной инфраструктуры (систем и специального оборудования для диагностики в сложных условиях эксплуатации, специализированного программного обеспечения и т. д.).

Таким образом, систематический оперативный контроль с применением комплексного подхода, основанного как на визуальных, так и инструментальных методах с использованием, в том числе цифровых систем, является необходимым условием для поддержания работоспособности конструкций систем водоотведения. Он позволит перейти от ремонтов по факту аварии к превентивному управлению техническим состоянием, значительно повышая надежность и продлевая срок службы инженерных сетей.

Ключевые слова: оперативный контроль, системы водоотведения, сточные воды, железобетонные конструкции, нормативные документы, оценка технического состояния, прогнозирование.

Introduction

According to general technical practice, a municipal wastewater disposal system (WDS) can be classified as a complex of interconnected engineering structures designed to collect, transport polluted wastewater (WW) outside settlements, and purify and neutralize it before discharging it into reservoirs. About 2,700 wastewater treatment plants (TP) operate in the Republic of Belarus to organize wastewater discharge into the environment, of which about 300 are undergoing artificial biological treatment with release into surface water bodies. At the same time, today the service life of the main part of the existing water management networks ranges from 20 to 55 years. At the same time, about 30 % of them are in dilapidated or disrepair, and a significant part of pumping stations require modernization (reconstruction). The situation is complicated by the fact that industrial enterprises, as a result of the lack of local effective technologies for industrial wastewater treatment and disposal of their precipitation, discharge highly concentrated wastewater into centralized sewerage systems, the harmful substances of which violate the technological regulations for wastewater treatment and are not removed during biological treatment. At the same time, at the stage of WW transportation, such pollutants with significant redox properties destroy WDS structures – the release of corrosive gases from wastewater, for example, hydrogen sulfide, has a particularly negative effect. As a result of this extremely negative impact, material and energy costs increase, which leads to an increase in electric energy costs for transportation and wastewater treatment, and, consequently, an increase in the cost of services, and the key is unacceptably reduced reliability, especially of reinforced concrete structures, up to the occurrence of emergency situations [1].

At the same time, wastewater disposal systems of water supply and sewerage companies (CWW) de facto belong to critical infrastructure (most of which are concrete elements), since as a result of possible emergencies, conditions are created for man-made pollution of territories, the development of diseases and epidemics with potential catastrophic effects on people and the environment. In accordance with the internal regulatory documents of water utilities organizations CWW, the following strict time intervals are allowed during their work: no more than 8 hours (in total) during one month, 4 hours at a time (including in case of an accident) [1, 2].

Thus, the scientific and practical task of operational control of the condition of reinforced concrete structures of the WDS is relevant and of national importance.

Setting the task. Substantiation of approaches to operational control of the condition of concrete structures of municipal wastewater disposal systems, primarily collectors, using modern automated tools and mathematical modeling in order to reduce the risks of abnormal (catastrophic) technological situations and increase the ecological safety of sanitation in populated areas.

Analysis of the existing regulatory framework in the Republic of Belarus and research by other authors on the issue of monitoring the condition of reinforced concrete structures of WDS

To monitor the normal functioning water drainage network (WN) WDS constant monitoring should be carried out on it, including [3]: external inspection of the network; technical inspection of the network; technical inspection of the main highways, storm drains, duckers and emergency outlets; inspection of the internal cavities of drainage pipes; inspection of tunnel collectors.

At the same time, the Resolution of the Council of Ministers of the Republic of Belarus dated September 4, 2019 № 594 "On Approval of the Rules for the Technical Operation of drinking water supply and sanitation (sewerage) systems in settlements" [3] defines that "the operation of sanitation (sewerage) systems in settlements includes organizational and technical measures for inspection, technical inspection, technological and technical control, maintenance, maintenance and repair carried out according to the schedule of scheduled preventive maintenance and elimination of accidents and malfunctions, approved by the chief engineer of the water supply company. The procedure for carrying out scheduled preventive maintenance on centralized drinking water supply and sanitation (sewerage) systems is determined by the Ministry of Housing and Communal Services". This regulatory document (paragraph 158 [3]) also states that "a technical inspection of the internal condition of the drainage (sewerage) network, structures and devices on it is performed for: inspection wells and emergency outlets – once a year; collectors and channels – once every two years. Technical inspection of gravity collectors and channels with diameters of 1,500 millimeters or more is carried out by passing through them, provided that the wastewater supply is completely or partially stopped. Technical inspection of pressure collectors is carried out by checking valves, plungers and sewer outlets".

An intra-industry document is Resolution № 22 of the Ministry of Housing and Communal Services of the Republic of Belarus dated May 12, 2006 "On the procedure for carrying out scheduled preventive maintenance on centralized drinking water supply and sanitation (Sewerage) systems" [4], which defines the procedure for carrying out scheduled preventive maintenance on centralized drinking water supply and sanitation (sewerage) systems. Within its framework, the schedule of scheduled preventive maintenance system is presented as a complex of "technical and organizational and technical measures aimed at maintaining and (or) restoring the operational, structural, engineering, and aesthetic properties of structures and devices as a whole and (or) individual components of equipment, structural units, and elements of centralized sanitation systems (sewerage)". In Chapter 4, "Planning and organization of the schedule of scheduled preventive maintenance" of this Resolution [4], it is established that "the list of facilities subject to capital and routine repairs is determined by the technical council CWW on the basis of defective statements compiled based on the results of inspections, journal entries for the operation of water facilities and devices, as well as the results of surveys of commissioning organizations and modernization and technical re-equipment projects". At the same time, "when planning preventive maintenance and routine repairs, it is necessary to be guided by the timing of the frequency of repair work (inter-repair periods) according to the appendix, as well as the time standards for repair work, developed and approved in accordance with the established procedure. The required number of inspections is assigned, after which routine repairs are planned; structures, devices and equipment that require major repairs or replacement, including the relocation (reconstruction) of pipelines".

Collectors and pipelines made of reinforced concrete structures of WDS [6, 7] are especially critical in terms of reliability [5] and durability. The annex to the Decree of the Ministry of Housing and Communal Services [4] defines the following frequency and emphasis of inspection of collectors:

– at flow rate WW of more than 3 m^3/s: frequency once every 12 months; the degree of filling, the presence of backup (flooding), blockages and other violations visible from the surface of the earth is checked; the presence of gases in wells; the presence of a drainage surface or other water in the reservoir;

– at flow rate WW of more than 1–3 m^3/s: frequency once every 12 months; inspections are carried out during internal inspection of collectors and channels with a diameter of 1,5 m or more, changes in the geometric shape of the section, the presence of drains, cracks, through holes, voids for cladding, corrosion of concrete, reinforcement;

– at flow rate WW is less than 1 m^3/s: the frequency is once every 24 months; the precipitation of individual pieces of concrete and the subsidence of individual sections are checked.

Thus, it is possible to formulate the directions that need to be significantly improved in the framework of ensuring the control of all WW WDS, based on the regulatory framework currently in use (Figure 1).

Such inertia and a significant duration of inspection periods leads to uncontrolled and unpredictable decommissioning, including collapses, of collectors made of reinforced concrete structures. Their opening often shows that there are characteristic failures of the arch due to chemical corrosion of concrete and reinforcement.

An option to overcome this problem may be the introduction of a television inspection in systems of water supply and sewerage companies (CWW), which acts as one of the technical means of operational inspection and control of the technical condition of sewage systems. This allows you to remotely detect clogging sites, determine the presence of stationary objects, cracks, and identify areas of highway deformation and damage to reinforced concrete structures without dismantling or partially dismantling communications. At the same time, the use of such a technical tool only allows you to visually fix defects – decision-making without external support is carried out by a specialist of water supply and sewerage companies (CWW).

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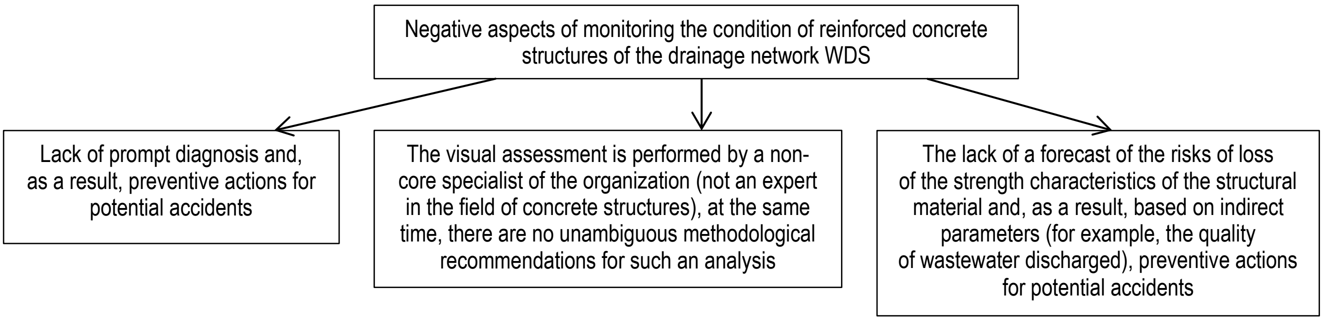

Figure 1 – The reasons causing a significant decrease in the controllability of the condition of reinforced concrete structures of drainage networks of municipal wastewater systems

At the same time, there is a potential possibility of integrating such remote operational control technologies into the control room control system. There is no Resolution of the Council of Ministers of the Republic of Belarus dated September 4, 2019 № 594 [3] it is stated that "the general operational management of the operation of centralized drinking water supply and sanitation (sewerage) systems, maintenance of the established modes of their operation are assigned to the dispatching service" and "the structure of the dispatching service of the of water supply and sewerage companies (CWW) organization is determined depending on the location of the premises and the performance of the sewerage systems, the length of the network and the complexity of technological processes".

Analysis of solutions for operational control of the condition of reinforced concrete structures in other industries

The methodological foundations and principles of assessing the technical condition of reinforced concrete structures, based on ensuring structural reliability in accordance with СТБ ISO 2394 [8], are currently set out in the new edition of СТБ ISO 13822 [9] in the Republic of Belarus. In accordance with the new requirements, the assessment of the technical condition of existing structures can be performed in the following cases:

– in case of an intended (planned) change in the purpose of an object (building, structure) or an extension of its service life or during structural reliability checks (for example, with the intensity of processes in the material of structures under various influences, the appearance of new influences, etc.) in the case of requirements of supervisory authorities, owners and buildings, etc.;

– wear of structures with degradation of material properties due to prolonged exposure and environmental influences (for example, corrosion or other damage, etc.).

Currently, in the Republic of Belarus, the main regulatory document for the inspection of buildings and structures is СН 1.04.01-2020 "Technical condition of buildings and structures" [10], which replaced the previous ТКП 45-1.04-305-2016 [11]. The document establishes the basic requirements for the technical condition of buildings and structures and the procedure for their assessment.

At the same time, when assessing the technical condition of building structures, other building codes and regulations apply, such as SP 1.04.02-2022 "General provisions for the inspection of building structures of buildings and structures" [12], SP 1.04.03-2022 "Inspection and reinforcement of stone and reinforced stone structures" [13], SP 1.04.04-2023 "Inspection and reinforcement of steel structures" [14] and others. The additional standards detail the examination procedures, supplement and clarify the general requirements, and suggest reinforcement options for specific types of structures.

The main objective of the survey is to develop recommendations and technical solutions for restoring the lost operational qualities of building elements or giving them new qualities in the changed operating conditions during repair or reconstruction. In some cases, it is necessary to assess the remaining service life of the building and develop restoration measures with an assessment of the feasibility of their implementation, or develop only supportive (temporary) measures to ensure the safe operation of the facility for a specific limited period of time set by the customer, etc. [15].

According to [10], the inspection of the technical condition of buildings and structures is carried out in three main stages: **stage 1** – preliminary inspection of the building; **stage 2** – general inspection (according to external signs); **stage 3** – detailed (instrumental) inspection.

A preliminary inspection of the building is carried out in order to draw up a technical specification for conducting a general survey, clarify the goals and objectives of the work, pre-determine the scope and timing of work, the amount of available design, executive and operational documentation, and access conditions to the building elements being examined.

The general survey is carried out for a general assessment of the technical condition of construction structures, adjusting the goals and objectives of the work, determining the actual volumes of the structures being examined and drawing up a detailed survey program. The general survey includes a general assessment of the structural scheme and compliance of the building with the design documentation in terms of spatial planning and design solutions, the type and nature of loads, and operating conditions. During the general examination, a visual inspection of all structures is carried out with the use of tools and devices, if necessary. The main purpose of the general (visual) inspection is to examine and record all damages or structural inconsistencies, their location, and includes verifying the reliability of the original drawings or determining basic information about the object; determining the main deviations not represented on the original construction documents; determining visible structural damage, such as cracks and delamination, as well as checking the quality of structures; determining the potential risk of falling of non-load-bearing structures, etc.; examination of the condition of soils and foundations; generating a report on the current status with photos. If necessary, tests and measurements are performed to obtain additional data on the condition of structures: an approximate assessment of the strength of concrete and its density, measurement of the opening width and depth of the most characteristic cracks, selective measurement of the largest deviations of the main dimensions from the design documentation, etc. [18]. Based on external signs (visually), an orientation assessment of the category of technical condition of individual structures is assigned with the determination of the need for emergency measures (if necessary).

A general inspection of the technical condition of structures (visual inspection) is the first and most effective method of preliminary assessment of the technical condition and identification of typical defects and damages. It is designed for a quick inspection of the structure and assessment of its general condition and provides valuable information to an experienced engineer regarding the quality of the construction, serviceability and mechanism of further destruction, and therefore is the basis for a detailed plan of further actions and a quantitative assessment of the degree of damage.

A detailed inspection of the building according to SP 1.04.02 [12] includes: detailed measurements of structures and their interconnections, geodetic survey (if necessary), measurement of cracks, deflections, slopes of elements; determination of reinforcement and assessment of the degree of corrosion wear; determination of the actual characteristics of structural materials by non-destructive methods or by testing samples selected from them; final schematization and classification of defects; obtaining data on the parameters of operational environments; clarification of the initial data required to perform structural calculations, including the determination of actual loads and impacts, clarification of actual design schemes, taking into account the actual characteristics of structures and their interconnections, etc.; analysis of survey results and development of recommendations for the repair of structures and (or) engineering systems, for their further safe operation; development of technical solutions for strengthening building structures (if necessary).

Based on the results of the survey and calculation, a certified building survey specialist justifies and formulates the necessary measures for repairing and strengthening structures, necessary changes in the operating mode, sets deadlines for their implementation, the duration and type of the next survey taking into account their frequency. If necessary, specific technical solutions are developed, on the basis of which the necessary project documentation should be developed in the future.

If the results of the assessment of the technical condition of structures are insufficient to make decisions based on the results of surveys in accordance with 12.1.1 [18], in addition to safety issues, in some cases it is advisable to take into account the results of economic, environmental, social and other consequences of failures and planned restoration measures [18, 21].

In general, according to table B.1 of Appendix B [18], for engineering water supply and sewerage systems, it is recommended to conduct an inspection once every 3–6 years, but at least once a year, depending on the operating conditions (the frequency of technical inspections within the established interval is determined by the operating organizations based on the technical condition and local conditions).

The concept of operational control of the condition of reinforced concrete structures of the WN WDS and the stages of its implementation are presented

One of the modern approaches by which a significant increase in the level of automation is achieved, and hence the efficiency of control and decision-making, is the digitalization of technological processes with the synthesis of digital twins (CD). In the international normative document ISO 23247 "Automation systems and integration – Digital twin framework for manufacturing" [17]. "Digital Twin" [17] is defined by "a digital model of a specific physical element or process with data connections that ensures convergence between physical and virtual states with an appropriate synchronization rate". In a practical context, the introduction of such virtual models in production facilities, including the introduction of operational approaches to monitoring the condition of reinforced concrete structures of VSS, requires very significant financial and material costs for the formation of information infrastructure and specialized software [18, 19]. Thus, it is necessary to create conceptual models of data centers, where new investments would be minimized while using an already working information base – a "non-destructive implementation" would be performed.

1. Maintaining the operability of existing systems.
2. Combining different types of technical platforms.
3. Multiple connection and simultaneous use.
4. Loading the database of objects of working data warehouses.
5. Rapid deployment of the system.
6. Low financial, time and personnel investments.

The proposed block diagram formalizes such a cross-programmatic approach and allows for integration into a single dispatching system of water supply and sewerage companies (CWW) (Figure 2).

One of the advantages of the structure (see Figure 2) is its platform type, which makes it possible to connect other specialized services (for example, wastewater treatment plant management, quality control of wastewater, maintenance and repair, environmental risk forecasting), with the creation of a single software environment for the organization of water supply and sewerage companies (CWW). The "Information and analytical module for monitoring the condition of concrete structures" is part of the "Service for monitoring municipal wastewater disposal systems", which allows integrated collection and processing of information not only based on the results of inspection by specialists, but also using technical means such as a television inspection. An additional significant factor in reducing the inertia of the observability of the condition of concrete structures is the use of mathematical modeling, which makes it possible to indirectly predict the negative impact of WW pollutants on the elements of sewage networks in populated areas [20].

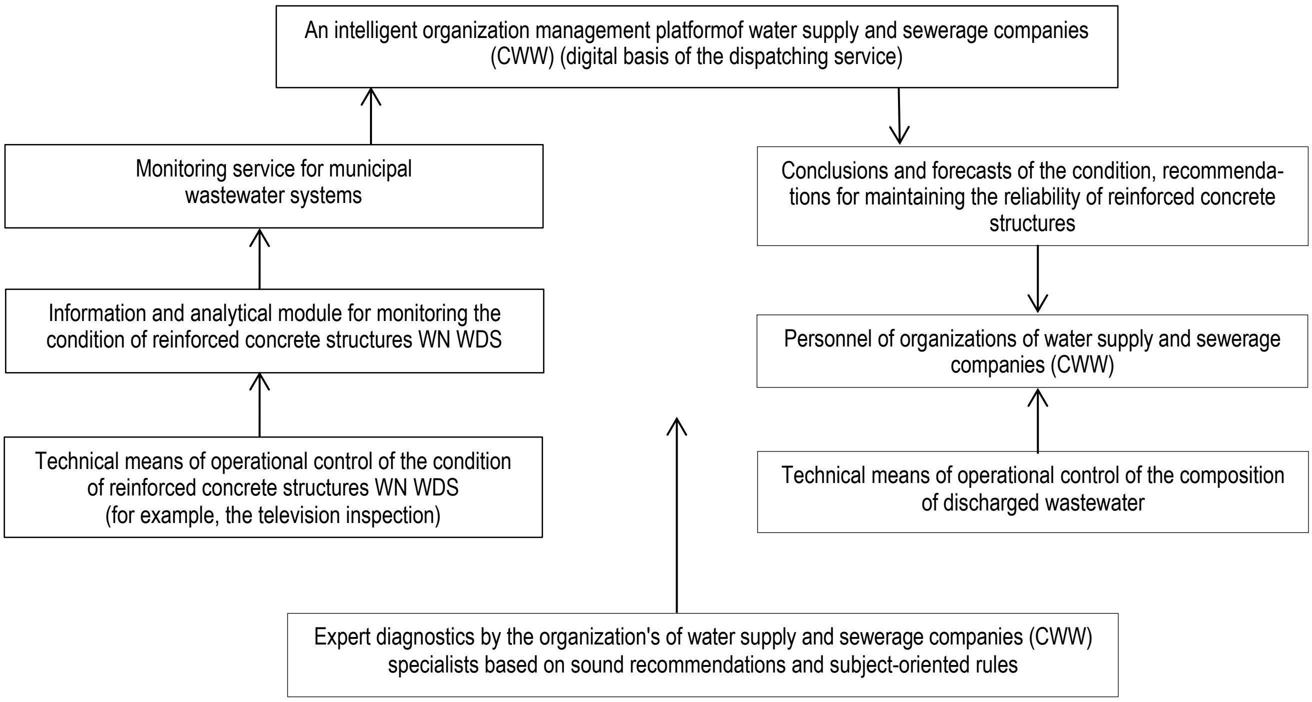

Figure 2 – The general structure of the implementation of operational information and analytical control of the condition of concrete structures of drainage networks of urban drainage systems

At the same time, in order to form a sufficient scientific and technological foundation for a sound structure for such information analytical operational control (see Figure 2), it is necessary to solve a number of interdisciplinary tasks.

1. System analysis of the theoretical basis of the reliability of concrete structures of WN WDS.
2. Formation of a database of typical defects in concrete structures of WN WDS.

3. Creation of a knowledge base on the influence of parameters and modes of operation of WN WDS systems on their concrete structures, including depending on wastewater quality indicators.

4. Creation and parameterization of mathematical models for assessing and predicting the condition of concrete structures all of WN WDS depending on the disturbing effects of internal and external nature.

5. Development of methodological recommendations for an expert assessment of the condition of concrete structures of the VSS.

6. Formation of a methodology for using hardware and technical means to analyze the condition of concrete structures of WN WDS.

7. Creation of technological regulations for the operational control of the condition of concrete structures of WN WDS.

8. Substantiation and development of a software and hardware complex for an information and analytical module for operational control of the condition of concrete structures of WN WDS.

9. Testing and adaptation on real objects of the software and hardware complex of the information and analytical module for monitoring the condition of concrete structures of WN WDS.

10. Substantiation and creation of methodological support for the unification and scaling of the application of the information and analytical module for operational control of the condition of concrete structures for the organization of water supply and sewerage companies (CWW) in the water supply organizations of the Republic of Belarus.

Conclusions

The article substantiates the need to implement prompt and adequate monitoring of the condition of drainage networks of municipal wastewater disposal systems, primarily made of iron-concrete structures, while focusing on the potential catastrophic consequences of their destruction. An analysis of the existing regulatory framework for such monitoring in the Republic of Belarus indicates the inconsistency of approaches adopted at the level of a number of ministries, while suggesting a direction for improving control over the technical condition of buildings and structures in the context of reducing the inertia of decision-making and increasing their adequacy. The structure of the implementation of operational information and analytical control of the condition of reinforced concrete structures of drainage networks of municipal wastewater disposal systems of the platform type is substantiated with the synthesis of mathematical models based on expert opinions, the use of television inspection and indicators of the quality of wastewater discharged; the scientific and practical tasks of implementing such a monitoring system are systematized.

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