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ASSESSMENT OF TECHNICAL STATE OF UNFINISHED STRUCTURES OF THE DNISTROVSKA PSP

ABSTRACT

The paper considers the results of the research of civil structures reliability and safety of the Dnistrovska PSP hydraulic structures (HS).

The considerable attention is paid to the reliability issues in the world. The reliability and safety of hydraulic structures must be ensured during their operation, as well as during their repair, reconstruction, maintenance and their liquidation. The HS are widely used in the various areas of the economy. Therefore, an important task of the Ukrainian hydropower industry is to ensure the safety and reliability of these structures.

The HS operation features that require to be considered in the design, construction and operation are presented, and a brief description of the Dnistrovska PSP hydraulic structures is given. The NIISK State Enterprise experts commissioned by the PJSC "Ukrhydroproekt" performed a visual and instrumental survey (by destructive and non-destructive methods) of the reinforced con-crete structures of the fixture of the water intakes and water outlets flow-through part for hydraulic units 5 and 7 and the reinforced concrete areas of the penstock conduits 5 and 6 of the Dnistrovska PSP, as well as conducted an instrumental survey of bored piles of the upper structure of the PSP building and the technological building within hydraulic

units 5-7 and based on the survey results prepared their technical condition assessment. The concrete carbonation depth was determined in all surveyed areas. The concrete strength determination was carried out with core drilling in labora-tory conditions at the NIISK State Eenterprise.

It is shown that the regulatory criteria for safety and technical conditions of hydraulic struc-tures being in operation are outdated and therefore it is necessary to develop a standard (DBN) to regulate the principles of determining the criteria of safety, reliability and technical conditions of hydraulic structures. To ensure the hydraulic structures reliability and safety and legal regulation of relations, it is necessary to complete the draft development as soon as possible and adopt the law of Ukraine "On the Hydraulic Structures Safety".

KEYWORDS: safety, water conduit, water outlet, water intake, hydraulic structures, pumped storage power plant (PSP), carbonation, strength, reliability, assessment of technical condi-tion, survey, technical condition

ОЦІНКА ТЕХНІЧНОГО СТАНУ НЕДОБУДОВАНИХ КОНСТРУКЦІЙ ДНІСТРОВСЬКОЇ ГАЕС

АНОТАЦІЯ

В статті розглянуті результати досліджень надійності та безпеки будівельних конструкцій гідротехнічних споруд (ГТС) Дністровської ГАЕС.

Питанням надійності у світі приділяється значна увага. Надійність і безпека споруд повинні бути забезпечені в період експлуатації, а також при ремонті, реконструкції, консервації та їх ліквідації. ГТС широко застосовуються в різних сферах господарства. Тому важливою задачею гідроенергетики України є забезпечення безпеки та надійність роботи цих споруд.

Наведені особливості роботи ГТС, що потребують їх врахування при проектуванні, будівництві та експлуатації та дана коротка характеристика ГТС Дністровської ГАЕС. Співробітники ДП «Державний науково-дослідний інститут будівельних конструкцій» (ДП НДІБК) на замовлення ПРАТ «Укргідропроект» виконали візуальне та інструментальне обстеження (руйнівними та неруйнівними методами) залізобетонних конструкцій кріплення проточної частини водоприймачів та водовипусків для гідроагрегатів №№ 5, 7, залізобетонних ділянок підвідних водоводів №5 та №6 Дністровської ГАЕС, а також про-вели інструментальне обстеження буронабивних паль верхньої частини будівлі ГАЕС та технологічного корпусу в межах гідроагрегатів №№ 5-7 і за результатами обстежень дали оцінку їх технічного стану. Визначення глибини карбонізації бетону виконувалося на всіх обстежуваних ділянках. Визначення міцності бетону проводилося із вибурюванням кернів в лабораторних умовах в ДП НДІБК.

Показано, що нормативні критерії безпеки і технічні стани щодо гідротехнічних споруд, які знаходяться в експлуатації, є застарілими і тому слід розробити ДБН, що регламентує принципи визначення критеріїв безпеки, надійності та технічних станів гідротехнічних споруд. Для забезпечення надійності та безпеки гідротехнічних споруд і правового регулювання відносин необхідно якнайшвидше завершити розробку проекту та прийняти Закон України «Про безпеку гідротехнічних споруд».

КЛЮЧОВІ СЛОВА: безпека, водовід, водовипуск, водоприймач, гідротехнічні споруди, гідроакумулююча електростанція (ГАЕС), карбонізація, міцність, надійність, оцінка технічного стану, обстеження, технічний стан

ОЦЕНКА ТЕХНИЧЕСКОГО СОСТОЯНИЯ НЕДОСТРОЕННЫХ КОНСТРУКЦИЙ ДНЕСТРОВСКОЙ ГАЭС

АННОТАЦИЯ

В статье рассмотрены результаты исследования надежности и безопасности строительных конструкций гидротехнических сооружений (ГТС) Днестровской ГАЭС.

Вопросам надежности в мире уделяется значительное внимание. Надежность и безопасность этих сооружений должны быть обеспечены в период эксплуатации, а также при ремонте, реконструкции, консервации и их ликвидации. ГТС широко применяются в различных отраслях народного хозяйства. Поэтому важной задачей гидроэнергетики Украины является обеспечение безопасности и надежности работы этих сооружений.

Приведены особенности работы ГТС, требующие их учета при проектировании, строительстве и эксплуатации и дана краткая характеристика Днестровской ГАЭС. Сотрудники «Государственного научно-исследовательского института строительных конструкций» (ГП НИИСК) по заказу ЧАО «Укргидропроект» выполнили визуальное и инструментальное обследование (разрушающими и неразрушающими методами) железобетонных конструкций крепления проточной части водоприемника и водовыпусков для гидроагрегатов №№ 5, 7, железобетонных участков подводящих водоводов №5 и №6, Днестровской ГАЭС, а также провели инструментальное обследование буронабивных свай верхнего строения здания ГАЭС и технологического корпуса в пределах гидроагрегатов №№ 5-7 и по результатам обследований дали оценку их технического состоя-

ния. Определение глубины карбонизации бетона выполнялось на всех обследуемых участках. Определение прочности бетона проводилось с выбуриванием кернов в лабораторных условиях в ГП НИИСК.

Показано, что нормативные критерии безопасности и технические состояния в отношении гидротехнических сооружений, находящихся в эксплуатации, являются устаревшими и поэтому следует разработать ДБН, регламентирующий принципы определения критериев безопасности, надежности и технических состояний гидротехнических сооружений. Для обеспечения надежности и безопасности гидротехнических сооружений и правового регулирования отношений необходимо как можно быстрее завершить разработку проекта и принять Закон Украины «О безопасности гидротехнических сооружений».

КЛЮЧЕВЫЕ СЛОВА: безопасность, водовод, водовыпуск, водоприемник, гидротехнические сооружения, гидроаккумулирующая электростанция (ГАЭС), карбонизация, прочность, надежность, оценка технического состояния, обследование, техническое состояние

INTRODUCTION

The hydraulic structures (hereinafter HS) are the main engineering structures that ensure the reliable and safe operation of hydroelectrical power plants (hereinafter HPP) and pumped storage hydroelectric power plants (hereinafter PSP) and significantly affect the economic, environmen-tal and social situation in the regions of their location [1]. The HSs are the special engineering structures that constantly contact with calm or moving, salty or fresh waters that have mechanical, physical, chemical and biological effects on the structures. The HSs features are manifested in the uniqueness of hydraulic, topographic, engineering-geological and natural conditions of their operation, which should be considered in the process of their design. The HPP and PSP play an important role in the operation of the United Power System of Ukraine. The waterpower engi-neering in the Ukrainian is based on the Dniprovskyi hydroelectric power chain (with 3920 MW capacity), Dnistrovsky hydroelectric power chain (with 744 MW capacity) and some operating small HPPs (the total capacity is near 100 MW). The hydroelectric developments of the Dniprovsky and Dnistrovsky hydroelectric power chains mainly belong to the CC3class of consequences (responsibility). The possible accidents at these potentially hazardous facilities would have a multivariable impact on the natural environment, human lives and business activities. The reliability and safety of these hydroelectric developments must be ensured for their operating period, as well as during their repairs, reconstructions, conservation and liquidation. Therefore, the HSs reliability and safety issues are given a considerable attention around the world.

Besides, the HPPs, as a rule, cover the peak part of the energy system load curve, and PSPs cover the load curve failed part and perform the function of emergency and load reserves. It is the HPPs with the large water reservoirs of complex purpose and their chains (Dniprovskyi and Dnistrovskyi) that perform the tasks of regulating river flow and form water management sys-tems. This gives rise to the acceleration of the surrounding infrastructure development and economic growth of Ukraine.

The goal of the work. Assessment of the technical condition of the HS civil structures at the Dnistrovska PSP, one of the main hydropower facilities of Ukraine, which are in an unfin-ished condition, to ensure their further completion and reliable and safe operation

Research methodology. The destructive and non-destructive methods use for the visual inspections and instrumental surveys of the concrete condition at the HS, which is in an incomplete construction state for a long time.

GENERAL CHARACTERISTICS OF HYDROPOWER FACILITIES OF UKRAINE

Dniprovskyi chain of HPPs (93 hydroelectric units with a capacity of 3920.8 MW). The Dniprovskyi chain of HPPs includes six hydropower plants, namely, Kyivska (capacity 361/440 MW), Kanivska (capacity 528 MW), Kremenchutska (capacity 682.8 MW), Seredniodniprovska (capacity 387 MW), Dniprovska (capacity 1548 MW) and Kakhovska (capacity 335 MW), which were built in the period from 1932 to 1972, as well as the Kyivska PSP (capacity 235 MW) [2, 3].

Dnistrovskyi chain of HPPs (9 hydroelectric units with a capacity of 744 MW without the Dnistrovska PSP). The Dnistrovskyi chain of HPPs includes two hydropower plants, namely, Dnistrovska HPP (6 hydroelectric units with a capacity of 702 MW) and Nyzhniodnistrovska HPP (HPP-2) (3 hydroelectric units with a capacity of 41.8 MW), as well as the Dnistrovska PSP (7 hydroelectric units with a design capacity of 2268 MW in a generation mode and 2947 MW in a pump mode). The first units were commissioned in the period from 1981 to 2009 [2, 3].

Dnistrovska PSP. The location plan and general view of the Dnistrovska PSP are shown in Fig. 1. The Dnistrovska PSP is one of largest pumped storage hydroelectric power stations in the world. The Dnistrovskyi Hydropower Complex project was designed in the 1970s and envisaged a number of facilities, including the hydropower plants 1 and 2 (HPP-1 and HPP-2), a pumped storage hydroelectric power station (PSP) and a nuclear power plant (NPP). The role of regulatory power for a nuclear power plant was assigned to the PSP. Later, the NPP construction project was removed from the plan of the hydropower complex, and the construction of the PSP was stopped in 1991 due to lack of funds and resumed in 2001. The Dnistrovska PSP is located near the village of Vasylivka, Sokyrianskyi district, Chernivtsi region. The town of Novodnistrovsk (Chernivtsi region) with a population of over 15,000 people located 8 km from the construction site of the PSP upstream of the Dnister River is the closest to the PSP.

The location of the Dnistrovska PSP in this region is due to the exceptional possibilities of using the buffer reservoir of the Dnistrovska HPP as the lower basin of the PSP and the presence of a height difference of about 150 m between the lower reservoir level and the plateau on the right bank with the PSP upper reservoir arranged on it, construction production base, roads, communications, pits, as well as a team of builders dismissed after the Dnistrovska HPP con-struction completion who accumulated a considerable experience in the construction of large energy facilities. All buildings of the Dnistrovskyi complex are connected by the existing highway from the Dnistrovska HPP to the Nyzhniodnistrovska HPP. The road from Novodnistrovsk city to the buffer reservoir of the Dnistrovska HPP passes through the dam of the Dnistrovska HPP and further along the left bank of the Dnister River through the Ukrainian territory.

The Dnistrovska PSP was designed by the Ukrainian Design and Research Institute Ukrhydroproekt in 1984 with the indicators shown in Table 1.

The main functions of the Dniester PSP are to regulate the frequency and schedule of loads, cover the variable loads of the power system, improve the mode of operation of thermal power plants by reducing their daily shutdowns and reducing fuel consumption. The Dnistrovska PSP is included in the list of the priority energy projects, as well as in the updated Energy Strategy of Ukraine until 2030. With a planned capacity of 2268/2947 MW, the Dnistrovska PSP is the largest in Europe among PSPs of this type currently under construction. The Dnistrovska PSP is unique as it operates in a "pump-turbine" mode, which allows the use of the energy stored at night to generate electricity during peak loads in the grid. Preparatory works for the station construction began in 1983, but due to external circumstances the construction period was extended.

The first hydroelectric unit of the Dnistrovska PSP was put into the trial and industrial op-eration in December 2009, the second one - in 2014 and the third one - in 2016. The total capacity of the three hydroelectric units is 972 MW in generator mode and 1263 MW in pump mode. The numbers of starts of GD1 ÷ GD3 hydroelectric units by years is shown in Table 2.

In December 2020 the start-up operations were carried out on the PSP hydroelectric unit 4. The fourth unit will have a capacity of 324 MW in generator mode and 421 MW in pump mode. The commissioning of the hydroelectric unit 4 is scheduled for 2021. In total, 7 hydroelectric units with a total capacity of 2268 MW in generator mode and 2947 MW in pump mode will be installed at the Dnistrovska PSP.

Table 1 – The main design indicators of the Dnistrovska PSP

Parameter name	Unit	Value (for 7 hydroelectric units)
1 **Installed electric power**:		
- in generator mode - in pump mode	MW MW	2268 2947
2 Annual electricity generation (operation time of 4 hours per day)	mln kW·h	2720
3 Annual electricity consumption per charge (operation time of 4.4 hours per day)	mln kW·h	3609
4 Main equipment:		
- turbine pump of OPO 170-B-730 type - hydroelectric generator-motor СВО 2-1255/255-40УХЛ4	pcs pcs	7 7
5 Normal water level (NWL):		
- headwater pond - lower reservoir	m m	+229,500 +77,100
6 Lowest operating level (LOL):		
- headwater pond - lower reservoir	m m	+215,500 +67,600
7 Heads (gross):		
- maximum - minimum	m m	161,90 138,40
8 Storage volume:		
headwater pond – total storage - active storage lower reservoir - total storage - active storage	mln m^3 mln m^3 mln m^3 mln m^3	41,43 32,70 58,10 51,60

Table 2 – Numbers of ГД1÷ГД3 hydroelectric units starts by years

Hydroelectric units	Years										Total starts since 2009
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
ГД-1	28	202	477	532	710	600	901	642	543	449	5249
ГД-2	-	-	-	-	-	267	835	713	617	521	2952
ГД-3	-	-	-	-	-	-	-	398	566	523	1487

On October 2, 2020, President of Ukraine V.O. Zelensky visited the Dnistrovska PSP. "The complete construction of the Dnistrovska PSP will increase the reliability of energy supply and expand the export potential of the state energy system. It is possible to maintain high-quality electricity supply to Moldova and Romania", he said. According to the preliminary plan, the construction of all hydroelectric units is planned to be completed by 2028. While at the power plant, the head of state discussed with the PSP management the possibility of the units faster completion.

After completion of construction, the Dnistrovska PSP will ensure the reliable operation of nuclear power plants, bring to the regulatory level by frequency the produced electricity quality, significantly increase the energy supply reliability, strengthen Ukraine's energy security and expand the export opportunities. Currently, three units of the first stage have been put into operation. The construction of the fourth unit is in the final stage. In the nearest future, the so-called "scrolling" of the unit and the start of commissioning operations are expected. “In 2020, we plan to make the first start of unit 4 by the Power Engineer Day, and in the next 2021 to put it into commercial operation", said Vasyl Subota, the Dnistrovska PSP Director.

According to PJSC Ukrhydroenergo data, the PSP is able to replace 200 MW produced by thermal power stations (TPS), which will save 125 million m^3 of gas annually (about $ 48.128 million) and 1.1 million tons of coal ($ 99.3 million).

The Dnistrovska PSP includes the following main structures of hydroelectric developments (Figure 1):

- upper reservoir;
- advance camera and water intake;
- penstock;
- PSP building and hydroelectric units shafts;
- tailrace conduits;
- water outlet;
- tailrace channel;
- lower (buffer) reservoir with a complex of protective structures;
- station platform with auxiliary structures.

General view of the Dnistrovska HPP and the buffer reservoir of the Dnistrovska HPP (HPP-2) of the Dnistrovskyi chain of HPPs is shown in Fig. 2.

Currently, the operation of the HS, which are the parts of the hydroelectric developments of the Dniprovsyi and Dnistrovskyi chains of HPPs (except for the Nyzhniodnistrovska HPP (HPP-2)), is carried out by the owner of these hydroelectric developments, namely the PJSC "Ukrhydroenergo". To increase the efficiency and

Figure 1 –Plan and general view of the Dnistrovska PSP

Figure 2 – General view of the Dnistrovska HPP and the buffer reservoir

reliability of control over the safety and reliability of HS of the Dniprovskyi and Dnistrovskyi chains of HPPs (stress-strain state of concrete, subsidence of structures and foundations, piezometric water levels and filtration costs in the body, foundation and adjacent to the shores of earth dams etc.) they are equipped with automated control systems (hereinafter - ACS). The reliability and safety of these hydroelectric develop-ments HSs are ensured on the basis of their technical condition assessment by the analysis and generalization of the data of field visual and instrumental observations on the basis of ACS and system of monitoring of buildings spatial displacements and the complex research of the hydrau-lic structures current condition.

During the long operation of the hydroelectric developments HSs at the Dniprovskyi and Dnistrovskyi chains of HPPs no significant accidents occurred there, which indicates the reliabil-ity and safety of these facilities and the necessity to develop the special measures for ensuring their further reliable and safe operation at the appropriate level.

Some of the reinforced concrete fixture structures of the flow-through areas of water in-takes and water outlets of hydroelectric units 5 and 7, as well as the reinforced concrete areas of inlet water conduits 5 and 6 at the Dnistrovska PSP were not completed and during several years were affected by atmospheric factors or moisture, which has caused the necessity to assess the technical condition of these structures concrete. On the request of the PJSC "Ukrhydroproekt" the NIISK's experts performed a visual and instrumental survey (destructive and non-destructive methods) of reinforced concrete fixture structures of the flow-through areas of water intakes and water outlets of hydroelectric units 5 and 7, reinforced concrete areas of penstock conduits 5 and 6 at the Dnistrovska PSP, as well as conducted an instrumental survey of bored piles of the upper structure of the Dnistrovska PSP building and the technological building within the hydroelectric units 5-7 and assessed their technical condition based on the results of surveys. The determination of the concrete carbonation depth was performed at all surveyed zones. In laboratory condi-tions at the NIISK the concrete strength was determined with cores drilling.

The flow-through system plan is shown in Fig. 3. The longitudinal section of the flow-through system is shown in Fig. 4.

Water intake channel (Figures 3 and 4). The water intake structure dimensions are 8.0 m along the waterfront and 64.7 m along the flow. The maximum height from the bottom is 35.25 m. Water intake channel consists of two sections. The first section includes the flow-through sys-tems of water conduits 1- 3 and the second one – the flow-through channels of conduits 4 - 7. At the area of its connection with the vertical water pipes, a contraction joint is arranged. The water conduits areas, which ensure the transition from a square section to a round one, are made with metal cladding. The metal cladding of the water intake structure is connected with the metal cladding of the water conduits by means of compensators installed in reinforced concrete chambers (compensator chambers). Each flow-through channel has two rows of grooves with the first one being designated for a plane repair gate and the second one is for an emergency repair gate. The gates are serviced by a gantry crane with a capacity of 2x180 + 5 tons, which moves along the water intake top. During the units 1 - 4 operation the water intakes 5 – 7 are blocked by the construction fences. The gates storage facilities (section 1 and section 2) are built on both sides of the water intake structure to store the gates.

To increase the units 1-7 operation reliability, it is envisaged to install the high-speed valves with individual drive (rope mechanism with a capacity of 2x180 tons) in the grooves of emergency and repair valves of the water intake structure. The repair access to the flow-through part of the water intake structure is possible through the grooves of emergency and repair gates after dismantling the lifting system of high-speed gates.

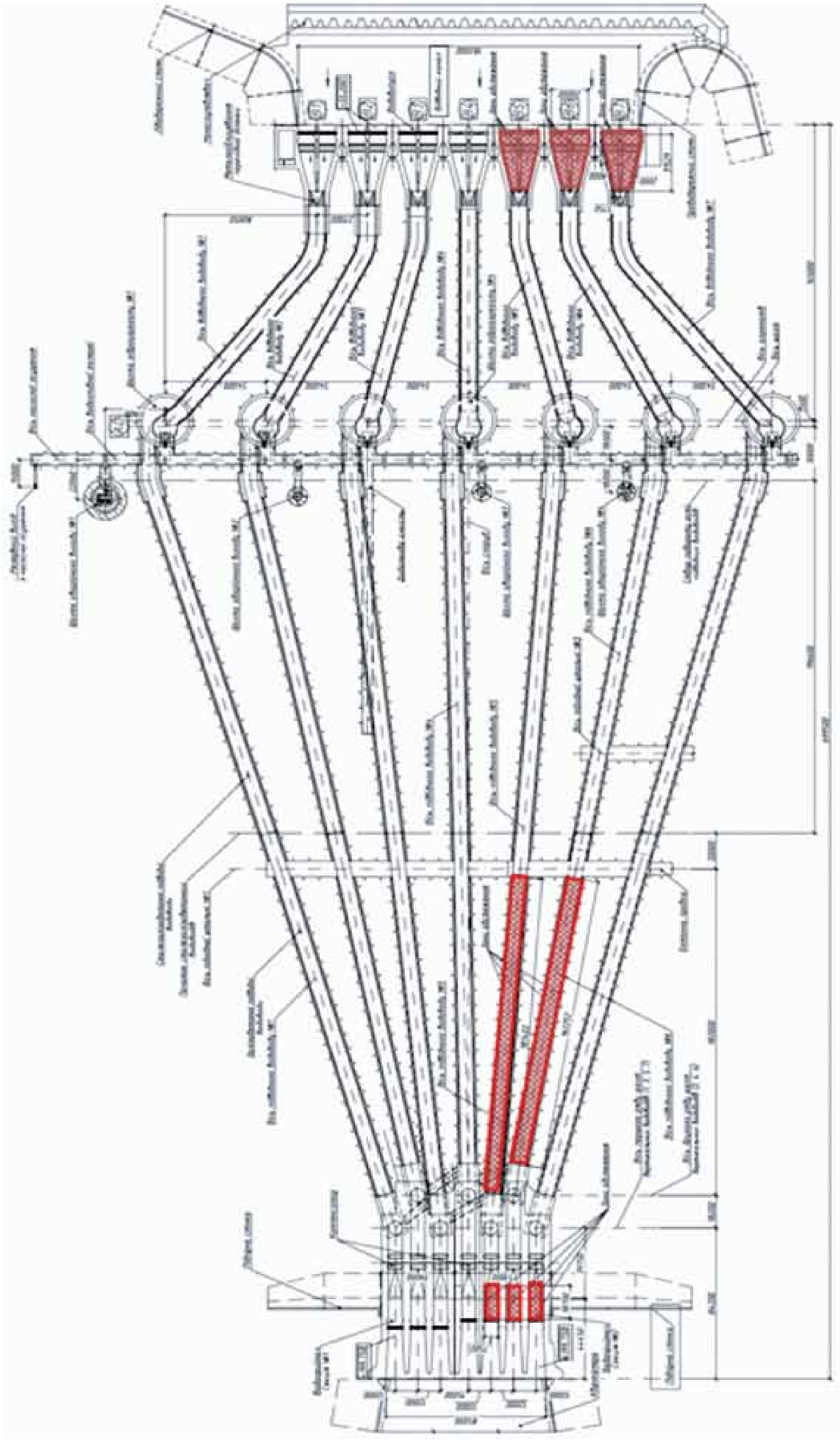

Figure 3 –The plan of the flow-through system at the Dnistrovska PSP
Note:. The red color shows the flow-through elements, the technical condition of which is sur-veyed by the NIISK experts

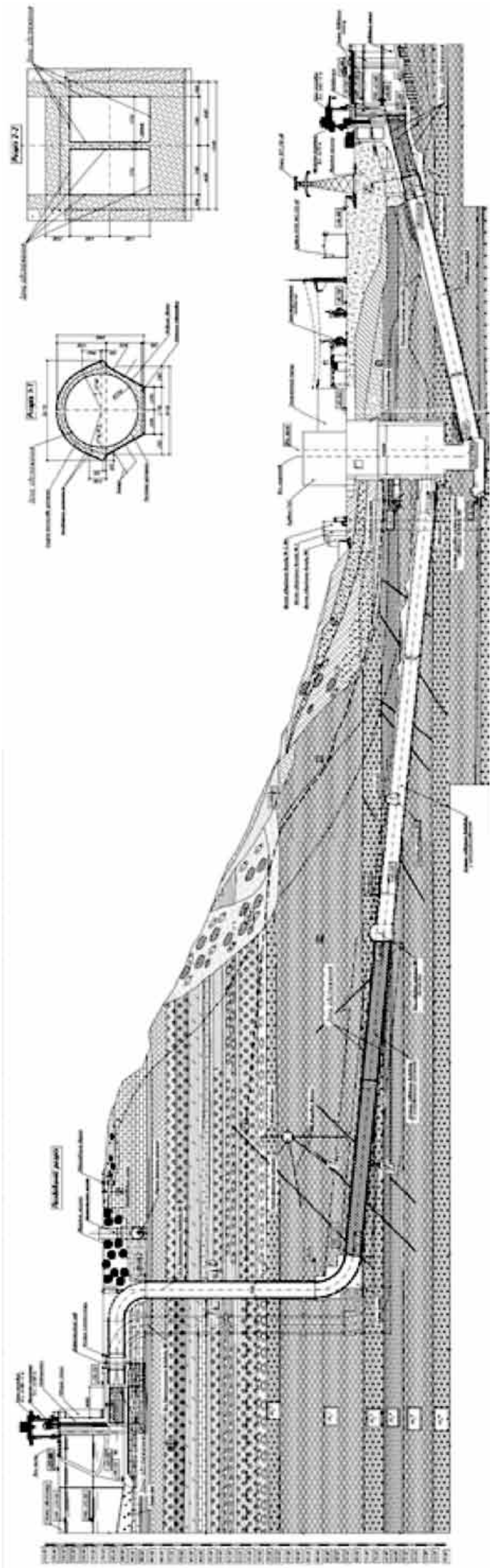

Figure 4 –The longi-tudinal section of the flow-through system of the Dnistrovska PSP

Penstock (pressure water conduits) (Figures 3 and 4). Seven threads of penstock tunnel conduits come from the water intake to the hydroelectric units shafts of the PSP building, with each thread including:

- a vertical area with a steel-concrete composite fixture of 100 m height and 7.5 m diame-ter. The vertical area consists of the upper leg, vertical chamber and lower leg; and
- a horizontal area with a diameter of 7.5 m and a length of about 400 m, of which 200 m behind vertical areas are made with the 400 mm thick reinforced concrete fixture and 200 m to hydroelectric units shafts - with 500 mm thick steel-concrete composite fixture.

Soils along the route are formed of sandy loam and loam, semi-rocky and rocky. For the compact arrangement on the site and preservation of the rocks natural state during construction and operation, the vertical shafts are arranged in a checkerboard pattern.

The vertical water conduits 1-3 are made with a full design readiness as a part of the first PSP stage. As a part of the second PSP stage, the installation of borehole drainage is envisaged on the areas of penstocks 5 - 7 with steel-concrete composite fixture.

For start-up of hydroelectric units 5-7 it is necessary to arrange the permanent fixture of penstock 5 at the vertical and horizontal areas with metal cladding, to perform the penetration of the temporary and permanent fixtures of the penstock 7 vertical area and penetration of the lower benches of the penstocks 6 and 7 horizontal areas with temporary supports and to arrange the penstocks 6 and 7 permanent fixture and reinforcing cementation.

Upon completion of the construction of the penstock tunnel conduits and connecting gal-lery, access adits used for their construction will be liquidated. The access adits 1 and 3 behind the penstock 7 will be liquidated by backfilling with rocky soil and subsequent cementation. The access adit 4, which connects the penstock 7 with the gallery, will also be liquidated.

Water outlet (Figures 3 and 4). A water outlet, which includes seven discharge openings connected from the tail water side by one reinforced concrete structure, is adjacent to the tailrace conduits. The water outlet front length is 182.0 m, width - 45 m and height - 28.8 m.

In each flow-through part, the discharge opening is divided by a center pier into two spans, which are closed by the plane repair gates. To prevent the debris entering into the flow-through part from the tailrace channel, garbage-retaining gratings are installed in the spans. Maneuvering of gates and gratings is carried out by the gantry crane with a loading capacity of 2x63 + 5 t. The water outlet is equipped with operational repair gates and building fences. Next to the water outlet the gate storage facility has been built to store the gates. The water outlet is structurally divided by deformation joints into seven sections. In the water outlet sections there are the following premises: for drainage pumps, fire extinguishing pumps, technical water supply pumps of hydroe-lectric units; premises of deaerators, water intake valves of technical water supply and filters. The section of electrical switchboards and ventilation rooms and the gate storage space are adjacent to the first water outlet section. The galleries of technical water supply conduits of hydroelectric units 1-7 come from the filters premises of the water outlet sections 1, 2, 5 and 6 towards the hydroelectric units shafts. To increase the operation safety of the first stage at the water outlet the installation of high-speed gates in the grooves of emergency repair gates of hydroelectric units 1-7 with individual drives (rope mechanism with a capacity of 2x75 tons) is envisaged.

The technical condition of individual structures was determined as by the general analysis of defects and damages revealed based on the survey results. Considering the bearing capacity and operational properties, the structure technical condition is referred to one of the following categories [4]: normal condition, when no defects and damages that reduce the bearing capacity and durability or interfere the normal operation exist; satisfactory condition, in which the performance of the structure corresponds to the category of technical condition 1, but there are partial deviations from the design requirements, defects and damages that may reduce the structure durability or partially violate the requirements of the second group of limit states; unusable condition in which the structure does not meet the categories of technical condition 1 and 2 in terms of load-bearing capacity or normal implementation of protective functions, but the defects and damages analysis with verified calculations reveals the possibility of ensuring its integrity before repair, reinforcement , or replacements; emergency condition, in which the requirements of the first group of limit states are violated and the defects and damages analysis with verified calcula-tions shows the impossibility to guarantee the structure integrity before its repair, reinforcement or replacement.

Inspection of the reinforced concrete fixture of water conduits 5 and 6, and flow-through parts of water intakes and water outlets of hydroelectric units 5-7 in the specified areas (Figures 3 and 4) was carried out with the following methods application:

1) the full-scale visual inspection with detecting the reinforced concrete fixture defects and damages, their volume determination depending on types, recording in a graphic and tabular forms, and also photofixation;
2) the instrumental concrete strength determination by a non-destructive shock-pulse method;
3) the concrete strength laboratory determination based on the results of testing drilled cores;
4) determining the concrete carbonation depth on drilled holes.

The technical condition of reinforced concrete fixture of these structures was assessed taking into account the results of all survey components 1 - 4.

Visual inspections. When performing the full-scale visual inspections of the flow-through parts of the water intakes and water outlets for hydroelectric units 5-7 and the reinforced concrete sections of the penstock conduits 5 and 6 of the Dnistrovska PSP, the following operations were performed [4]:

- inspection of wall elements, ceiling and bottom and water conduits fixtures to determine the nature and parameters of damages;
- photofixation of defects and damages; and

Figure 5 – The general view of water intake 7 and water outlet 6

- graphic design of survey materials.

A general view of the flow-through parts of the water intake 7 and water outlet 6 is shown in Fig. 5.

The flow-through parts of water intakes and water outlets. During the visual inspection of the fixtures of the flow-through parts of water intakes and water outlets of hydroelectric units 5-7, the following defects and damages were recorded: soaking in the areas of walls, ceiling and bottom; cracks with opening width from 0.1 mm to 0.4 mm in the walls areas; bared and corrod-ed reinforcement; poor concreting; efflorescences on walls areas, ceilings and bottoms due to filtration of water through concrete in some areas of the water intake flow-through part are not removed.

Based on the visual inspection of flow-through parts of water intakes and water outlets of hydroelectric units 5-7 the following is recommended: to inject the zones of concrete contact with soil mass in order to reduce filtration; to perform cracks cleaning and injection of appropriate solutions in the area of cracks in the concrete of the flowing part fixture of the water intakes; to eliminate protrusions, sags and cavities in areas of poor concreting, and treat the concrete surface with polymer solutions to reduce its hydraulic roughness.

According to paragraph 5.2 of DSTU-N B V.1.2-18: 2016 [4], the results of the fixture inspection of the flow-through parts of water intakes and water outlets of hydroelectric units 5-7 allow to characterize the technical condition of the fixture reinforced concrete as satisfactory.

Penstock conduits. Water is fed to each hydroelectric unit by an individual conduit, the numbering of which corresponds to the hydroelectric unit number. During the time of construc-tion, all penstock conduits are connected by an 8.7 m wide access adit 1, through which materials are fed, soil and garbage are removed etc. Before water feeding to each water conduit, the corre-sponding section of the adit should be closed with a concrete plug.

Penstock conduits 5 and 6, which are under construction, are designed to feed water to the appropriate hydroelectric unit. Water conduits consist of the following main elements (Figures 3 and 4):

Figure 6 – Conduits 5 and 6: а – cross section; б – conduit reinforcement; в, г – gen-eral views on ПК1+96.4 and on ПК1+85.04 from access adit 1 of conduit 5 and conduit 6, respectively

1) the water intake of a square cross-section 7.5 x 7.5 m, which is arranged as a part of the retaining wall of the upper reservoir;
2) the vertical area of the water conduit having a round cross-section with a diameter of 7.5 m;
3) the inclined area (i = 0.005-0.097) of a round cross-section with a diameter of 7.5 m with a reinforced concrete fixture (at the time of construction this area is crossed by a transverse access adit 1);
4) the inclined area (i = 0.103) of a round cross-section with a diameter of 7.5 m between the access adit 1 and the shaft of the hydroelectric unit 6; at about 20 m distance from the adit, this area has a reinforced concrete fixture, and further - a metal cladding of a reinforced concrete cross-section of the conduit.

At the survey time in December 2020, all these areas of water conduits 5 and 6 were mainly completed (Fig. 6). The transition area with a length of about 12 m, which should be arranged at the intersection of water conduits and access adit 1, remained unfulfilled.

During the full-scale inspection of water conduits 5 and 6 several defects and damages of the reinforced concrete fixture were revealed. They were included in the following groups:

- a map cracking on a fixture surface;
- poor quality of concreting the local areas of walls with sinks, cracks and formwork shear traces on the surface;
- fixture surface unevenness and concrete sags around the concreting joints;
- cracks at the concreting joints;
- cracks in concrete sags near concreting joints;
- individual cracks up to 1.0 mm in the walls;
- concrete sags on the tunnel walls;
- concrete massifs in the flume part of the tunnel;
- the presence of soil, rock fragments and construction debris in the flume part;
- point seeping through the walls and vaults of the tunnel, some with water dripping;
- walls soaking with local strips from 0.2 to 2 m wide;
- separate soaking of walls with traces of rust;
- efflorescences on the walls in places of previously removed seeping;
- water flows from the vertical areas of water conduits with the stagnant strips formation at the bottom.

Taking into account the results of the field survey, as well as the results of instrumental and laboratory tests, the technical condition of reinforced concrete fixture of water conduits 5 and 6 within the surveyed areas was assessed as satisfactory according to paragraph 5.2 DSTU-N B V.1.2-18: 2016 [4].

Instrumental studies of concrete strength by a non-destructive method. The concrete compressive strength for the flow-through part of the water intakes and water outlets of hydroe-lectric units 5-7 and reinforced concrete fixture of the flow-through part of water conduits 5 and 6 was determined by non-destructive methods (shock pulse method) in accordance with the requirements of DSTU B V. 2.7-220: 2009 [5] using an ONYX-2.5 universal strength meter for building materials. To significantly increase the measurements reliability the measurements were performed simultaneously by the shock pulse and elastic rebound. The measurement results were recorded after applying a series of 10 impacts to the reference area of the structure and obtaining 20 primary results (by shock pulse and rebound), their further processing and variation coefficient calculation.

As a result of the concrete strength instrumental testing by the non-destructive shock pulse method, the actual concrete compressive strength was determined for the reinforced concrete structures. It appeared to be not lower than the class established by the project (B15), in particular:

- concrete strength of water intake of the hydroelectric units 5-7 flow-through part was in the range of 19.9 ÷ 41.3 MPa, which corresponded to the C12 / 15 (B15) ÷ C25 / 30 (B30) con-crete grade;
- concrete strength of water outlet of the hydroelectric units 5-7 flow-through part was in the range of 20.1 ÷ 37.6 MPa, which corresponded to the C12 / 15 (B15) ÷ C25 / 30 (B30) concrete grade;
- concrete strength of the water conduits flow-through part of the hydroelectric units 5 and 6 was in the range of 32.7 ÷ 44.6 MPa, which corresponded to the C20 / 25 (B25) ÷ C25 / 30 (B30) concrete grade.

Laboratory studies of concrete strength. To determine the concrete compressive strength the cores were drilled from the structures body. In accordance with DSTU B V.2.7-223 [6], three samples were made from the cores for each point. The strength determination was performed based on the results of laboratory tests in accordance with DSTU B V.2.7-214 [7] and DSTU B V.2.7-223 [6].

Flow-through parts of water intakes. The concrete compressive strength determined on the cores drilled from the structures of the water intake of wall and from the bottom was in the range from 24.8 to 40.3 MPa and 27.4 MPa, respectively, which corresponded to the C20 / 25 (B25) concrete grade. Thus, the concrete grade of reinforced concrete fixture of flow-through part of water intakes of hydroelectric units 5-7 was not lower than the grade specified by the project (B15).

Flow-through parts of water outlets. The concrete compressive strength determined on the cores drilled from the structures of the water outlets of the wall and from the bottom was 32.2 MPa and from 26.2 to 36.0 MPa, respectively, which corresponded to the C20 / 25 (B25) con-crete grade. Thus, the concrete grade of reinforced concrete fixture of water intakes of the flow-through part of hydroelectric units 5-7 was not lower than the grade specified by the project (B15).

Penstock conduits. The average compressive strength of drilled cores was 39.4 MPa, which corresponded to the C20 / 25 (B25) concrete grade. Thus, the concrete grade of reinforced con-crete fixture of the flow-through part of the water conduit 5 and 6 was not lower than the grade specified by the project (B15)

Concrete carbonation. The corrosion damage of concrete (carbonation depth) was determined according to the procedures [8 and 9] by drilling a core sample by means of a percussion bit (diameter 40 mm) and a perforator.

After the core retrieval, its surface and drilling area were thoroughly cleaned of dust by blowing out with air.

A phenolphthalein solution prepared according to DSTU 7258 [10] was applied to the drill-ing area. A few seconds after the phenolphthalein solution application, the depth of structure concrete carbonation was assessed based on the phenolphthalein solution crimson color when it interacted with the alkaline medium of concrete. In points where the reaction did not take place, phenolphthalein did not change its color to crimson, which indicated the concrete carbonation. The concrete carbonation depth was measured using a caliper with a precision up to 1.0 mm. The depth of a core drilling was up to 45 mm. Carbonation was measured at a height of 1.3-1.7 m. To prevent the reinforcement corrosion, it was recommended to treat the protective layer of concrete structures with clogging hydrophobic solutions containing corrosion inhibitors.

Flowing parts of water intakes. The carbonation depth of the reinforced concrete structures of the water intake walls, in most cases, was up to 55-60 mm, near the gate grooves the concrete carbonation was less reaching up to 27 mm, bottom concrete was carbonized to a depth of 7 mm. The walls concrete was carbonized for almost the entire thickness of the protective layer (60 mm).

Flow-through parts of water outlets. The carbonation depth of the walls reinforced concrete structures of the water outlet to the hydroelectric unit 5 along the entire structure length was from 33 to 45 mm and more in some points.

The carbonation depth of epy walls reinforced concrete structures of water outlet to the hydroelectric unit 6 from the left side reached up to 41 mm; pier was carbonized up to 17 mm and from the right side the carbonation was up to 6 mm.

The carbonation depth of walls reinforced concrete structures of water outlet to the hydroelectric unit 7 from the left side and the pier was from 23 to 45 mm and more; from the right side it was up to 16 mm.

The bottom carbonation depth was up to 22 mm.

The protective layer of walls and piers measured during the cores drilling had a thickness of 100-130 mm. Thus, the concrete was carbonized to almost half of the protective layer.

Penstock conduits. The carbonation depth of the fixture concrete of water conduits 5 and 6 was from 2 mm to 5 mm at the 70 mm thickness of the concrete protective layer.

In all surveyed structures there were partial deviations from the design requirements and defects or damages that could reduce the structures durability or partially violate the requirements of the second group of boundary conditions, which in the specific conditions of the structures operation did not limit the intended use.

Almost all developed countries, which successfully use the energy potential of rivers, have adopted the laws "On the safety of hydraulic structures", which is due to the extremely high efficiency of hydroelectric developments based on the rivers energy recovery, the necessary depths creation on the waterways and the reservoirs use for water supply and irrigation. Ukraine has not yet adopted any relevant law, though the draft law has been under development for quite some time.

The existing safety criteria for the HS, adopted in 1985, are largely outdated [11], so it is necessary to develop new state building codes (DBN), which should set out the basic require-ments for determining the HS safety criteria and corresponding structures conditions to ensure safe operation of the HS.

CONCLUSIONS

1. Taking into account the field survey results, as well as the instrumental and laboratory tests results, the technical condition of the flow-through parts of water intakes and water outlets for hydroelectric units 5-7 and of the reinforced concrete fixture of water conduit 5 and 6 in the surveyed areas is assessed as satisfactory according to paragraph 5.2 of DSTU-N B V.1.2-18: 2016 [4]. In general, the surveyed structures meet the design requirements, but to ensure their reliability and safe operation, it is necessary to develop some additional measures.
2. To ensure the implementation of the Hydropower Development Program for the period up to 2026 and the Dnistrovska PSP construction project completion in general, it is necessary in 2021 to approve and fulfil the project titled Dnistrovska PSP.

Construction of the PSP third stage as a part of hydroelectric units 5-7.

3. To ensure the HS safety and the activities legal regulation in the hydropower engineering field, it is necessary to complete the draft law development and adopt the Law of Ukraine "On Safety of Hydraulic Structures", as well as to develop the DBN on requirements for determining the HS safety criteria.

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