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EXPERIENCE OF USING THE HOME-MADE MONITRON AUTOMATED HYDROSTATIC-LEVELING SYSTEM FOR MONITORING OF HYDRAULIC STRUCTURES

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The monitoring of hydraulic structures as high-risk facilities is discussed. Monitoring should ensure the reliability and functioning of a hydraulic structure during the entire period of operation. Particular attention should be paid to the monitoring of the settlements of a hydraulic structure, which are one of the main causes of accidents that can lead to the loss of the function of the structure or, in some cases, to total collapse. Various monitoring systems for hydraulic structures are compared. It is noted that automated hydrostatic leveling systems have widely been used all over the world. They are characterized by high performance and allow obtaining monitoring data in real time. The experience of using the home-made Monitron automated hydrostatic-leveling system is considered as an example. The system showed efficiency and reliability in monitoring the settlement of various engineering structures.

Keywords: automated monitoring; hydrostatic leveling.

An operational feature of hydraulic structures (HS), which are legislatively assigned to high-risk facilities [1 – 3], is the requirement to provide regular instrumental and visual full-scale monitoring during the entire period of operation. In this case, it is necessary to take into account the increase in the risk of emergency situations and accidents with decrease in the remaining service life of HSs. Considering the life cycle of a hydraulic structure and the consequences of its collapse, *the efficiency and reliability of monitoring* of HS during both construction and operation should be ensured, meeting the most stringent requirements.

The efficiency of monitoring is meant its capability of detecting, on a timely basis, abnormal operation of the HS and, as a result, increased risks of emergency situations and accidents, which will allow developing and taking preventive measures.

The reliability of monitoring is understood smooth functioning of the monitoring system irrespective of engineering, climatic, and organizational factors.

Instrumental measurements can be either automated or manual. Manual recording and processing of measurements require long time, which does not allow constant monitoring of the diagnostic criteria characterizing the functioning and safety of the HS. Thus, it is necessary to develop real-time monitoring systems based on fully automated recording and processing of measurements. This is achieved by developing an automated diagnostic monitoring system (ADMS) that, in turn, consists of an automated control-and-measurement instrument polling system (ACMIPS) and an information and diagnostic system (IDS).

It should be noted that the monitoring systems of Russian HSs in many cases do not meet the requirements mentioned above because some of their subsystems have not been automated yet and the associated instrumental measurements are performed manually.

One of the major diagnostic criteria used to assess the safety of HSs is the settlement of the foundation (Fig. 1).

Statistics shows that most accidents at various concrete HSs, such as St. Francis Dam (USA), Malpasset Dam (France), and the powerhouse of the Zagorsk PSPP-2 (Russia), occurred because of the excessive settlements caused by damage of the foundations [4 – 5]. The damage of the foundation is usually caused by off-design seepage flows leading to uncontrollable suffosion. Studies show that these processes develop gradually until the volume of soil washed away becomes critical. The subsequent destructive processes can hardly be predicted. To prevent such accidents, the settlements of the structure should be monitored constantly (in real time).

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During the operation of an HS, it is also very important to monitor the displacements of tall concrete dams during filling and drawdown of the reservoir because this causes sign-variable loads on the foundation, affecting adversely its stress-strain state.

Currently, in Russia, the settlements of HSs are monitored manually, performing optical leveling once a month or rarely. It should be noted that the atmospheric conditions often complicate optical leveling, or even make it impossible in open areas outside the structure.

An alternative method widely used abroad to measure the settlements of various structures is hydrostatic leveling (HL). It employs communicating measuring pots in which the fluid levels are the same (Fig. 2).

International experience demonstrates the universality of this method-it ensures measurements with any accuracy at any leveling spacing determined by the dimensions of the structure [6 – 8].

Foreign HL systems began to be designed in the middle of the last century. For example, an automated liquid-metal (mercury) HL system was developed in the 1960s. It was intended for the installation of the magnets of a proton synchrotron and ensured a leveling accuracy of ±0.025 mm for a facility diameter of 1.6 km [7].

The HL technique was tried and tested both theoretically and practically. The origins of errors and the methods of their compensation are well understood. This allows designing HL systems of necessary scale and accuracy.

The complexity and cost of a HL system is determined by the level recording system. Foreign levels intended for monitoring of HSs and other structures usually include a high-precision pressure converter for measuring the level of the fluid (usually antifreeze solution) with an accuracy of ±0.1 mm.

Despite the obvious advantages of HL, such monitoring systems have not been widely used in Russia. The recent trends, however, have been toward the increased use of HL.

An example is the Russian-made Monitron hydrostatic leveling system used at lock 9 of the Karamyshevo Hydraulic Project of the Moscow Canal during the construction of two 6.0-m diameter running tunnels between the Khoroshevskaya and Mozhaiskaya Moscow Metro stations. The minimum distance between the running tunnels and the foot of the lock chamber was 15 m, the total length of the lock chamber being 300 m and the cross-sectional dimensions being 30 × 12.5 m^2. To ensure the operational reliability in constructing the running tunnels, the lock chamber was equipped with a monitoring system including a portable electronic tacheometer measuring angles with an accuracy of 0.5″ and 24 DGTs-18 hydrostatic levels united into a single system, installed on the lock walls (Fig. 3), and providing a measurement accuracy of ±0.1 mm.

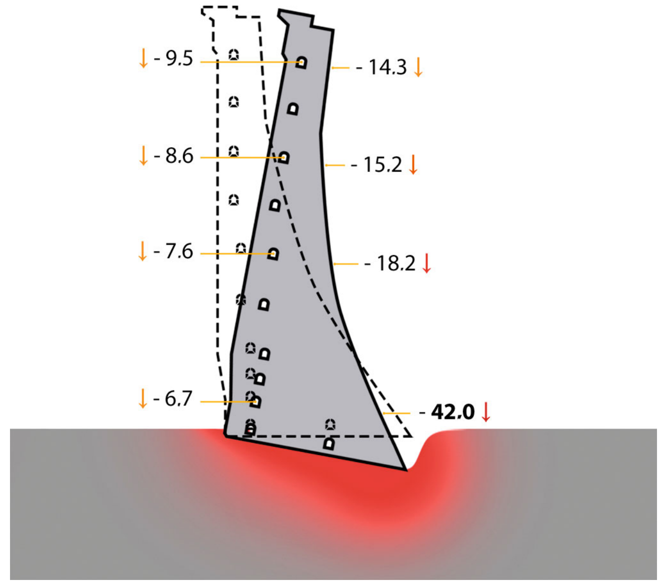

Fig. 1. Displacements of a tall concrete dam on deformed foundation.

The maximum difference between the tacheometric data and the hydrostatic-leveling data is 0.3 mm (Fig. 4). The latter were arrived every minute (1440 times a day) and the former were received four times a day, every six hours.

Of special interest is the use of the Monitron system when lifting and leveling the powerhouse of the Zagorsk PSPP-2 by the controlled compensation grouting technique. The project provides automated measurement of the vertical displacements inside and outside the powerhouse during the rehabilitation work. Currently, the foundation-plate model

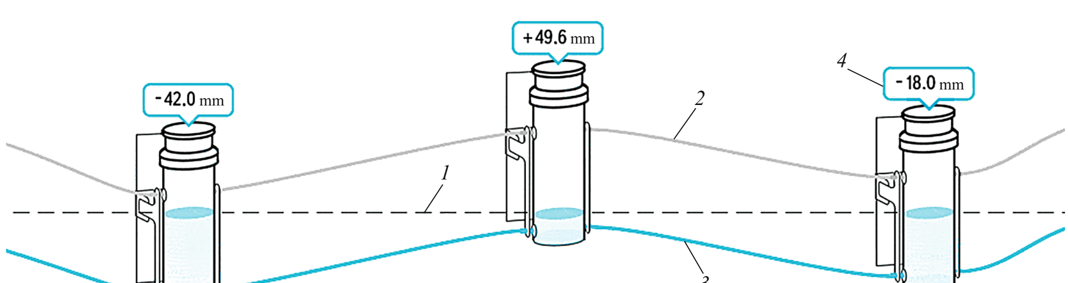

Fig. 2. Principle of operation of hydrostatic leveling (HL): *1*, fluid level of hydraulic system; *2*, air hose; *3*, hydraulic hose; *4*, change in the elevation of measuring pot.

has been equipped with DGTs-17 hydrostatic levels used in lifting it on test site No. 3 (Fig. 5). The hydrostatic levels used on the test site transmitted data to the cloud IDS https://monitron.ru every minute. This allowed remote access to the measured displacements and their analysis over any period of observation compared with the design data. Figure 6 shows, as an example, the curve of vertical displacements drawn using the hydrostatic level data collected over the period from 6/20/2017 to 6/27/2017 (7632 measurements). For comparison, the figure shows the dashed curve for the measurement point D-07 representing the numerical simulation of the controlled compensation grouting for lifting the foundation-plate model. Since the displacements were measured in real time, the design and actual results of powerhouse lifting were compared at all measurement points at each stage of injection, which allowed identifying the sleeve pipes through which additional volumes of grout should be injected [9 – 10].

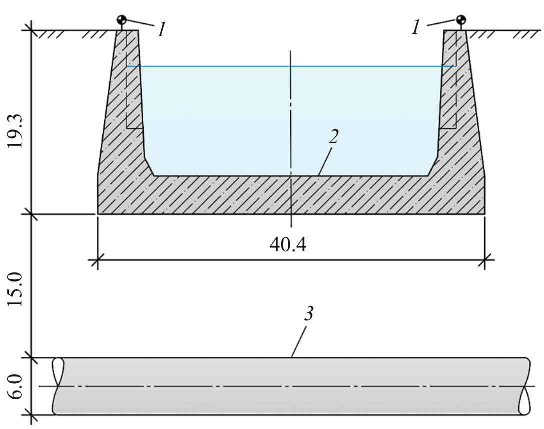

Fig. 3. Automated hydrostatic levels and deformation marks of tacheometer (*1*) on lock 9 of the Karamyshevo Hydraulic Project (*2*) when constructing running tunnels (*3*).

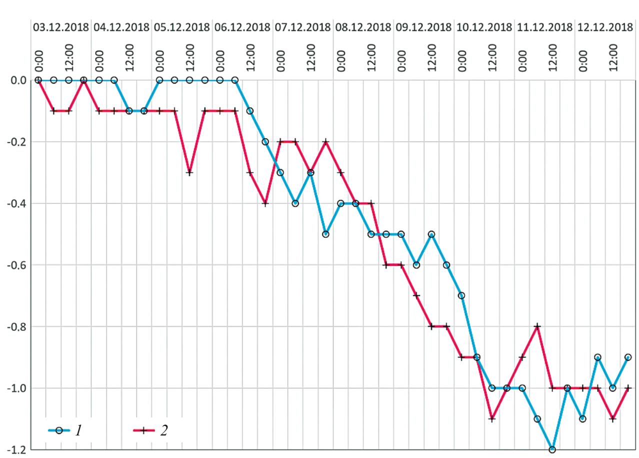

Fig. 4. Comparison of hydrostatic-level (*1*) and tacheometer (*2*) data of monitoring lock 9 of the Karamyshevo Hydraulic Project from 12/3/2018 to 12/12/2018.

The international requirements and specifications for HL systems have been fully satisfied in developing and manufacturing the Monitron monitoring system. The system is based on an essentially new technology of electro-optical readings, which ensures similar accuracy yet much lower (by an order of magnitude) total cost of the measuring equipment than that of the foreign-made equipment.

The basic element of the HL system is a DGTs-21 digital hydrostatic level (Fig. 7). It has the following characteristics:

— accuracy: ±0.05 mm;

— measurement range: 100 mm;

— measurement rate: once a minute;

— operating temperature range: from –65°C (internal heating is used) to +50°C;

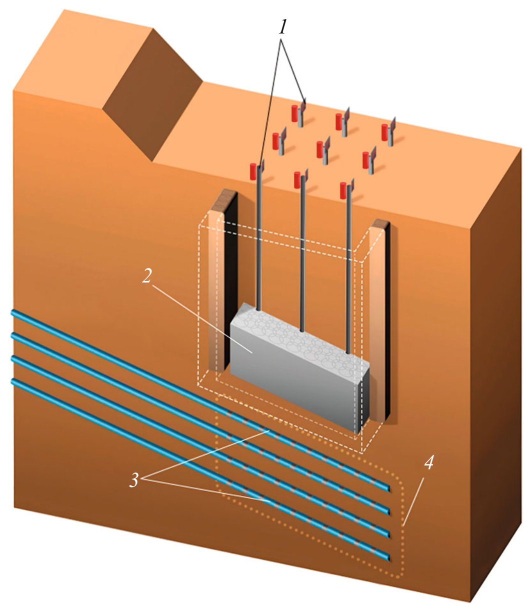

Fig. 5. Levels on the foundation-plate model of the Zagorsk PSPP-2: *1*, ground reference marks, 18 to 22 m long with hydrostatic levels; *2*, foundation-plate model 10 × 10 × 6 m; *3*, sleeve pipes, 70 to 90 m long; *4*, compensation grouting zone.

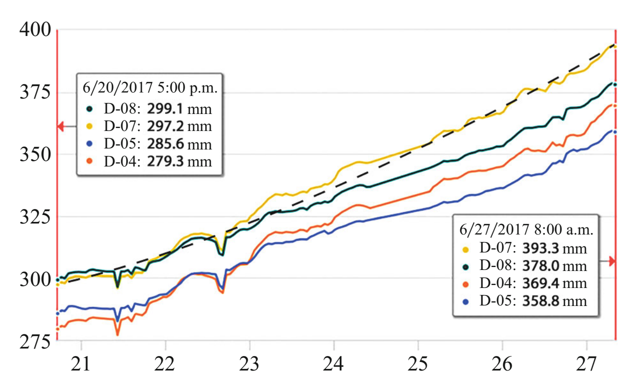

Fig. 6. Fragment of the curve of actual (color) and design (dashed line) vertical displacements in lifting the foundation-plate model of the Zagorsk PSPP-2 in 6/20/2017 to 6/27/2017, according to the cloud-based IDS https://monitron.ru.

— protection: IP66 (complete protection from dust and powerful jets of fluid);

— service life: more than 15 years.

Such levels were used in Russia at several tens of facilities such as the Moscow Metro and abroad to monitor the settlements of the foundations of wind towers.

Noteworthy is the following important advantage of hydrostatic levels: they can easily be united into a single system, irrespective of their number and location, either indoor or outdoor, considering the HS dimensions. In similar conditions, the use of automated optical leveling methods with robotized tacheometers would be very expensive because a large number of tacheometers are required to unite the levels into a single system.

The Monitron system includes ACMIPS + IDS software with a built-in message mailer, which allows quick deployment of the system at a facility and start of monitoring.

As mentioned above, the number of hydrostatic levels within one system is almost unlimited. When there are a great many levels, it is reasonable to group them into subsystems for performance reasons. Thus, it is possible to monitor a hydraulic structure of any size.

Owing to their compactness, hydrostatic levels can be placed in various service premises, posterns, turbine halls, on buildings, either inside or outside of the structure, including surfaces exposed to the environmental impact. The cases of hydrostatic levels can be combined with lamps and installed at elevations sufficient to prevent accidental mechanical damage. On the surface of dams made from local materials,

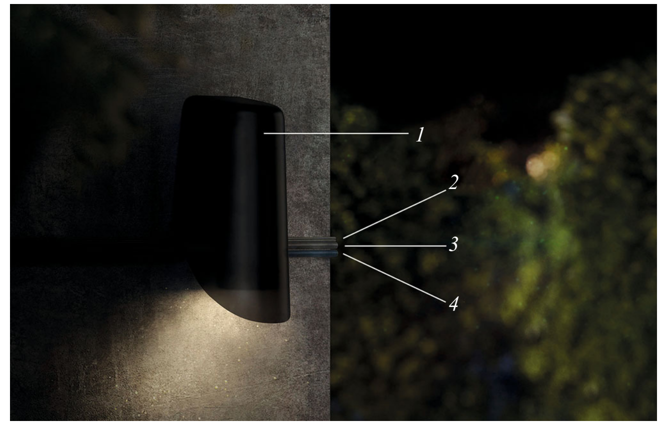

Fig. 7. Monitron DGTs-21 automated hydrostatic level: *1*, measuring equipment disguised as a LED lamp; *2*, cables; *3*, air hose; *4*, hydraulic hose.

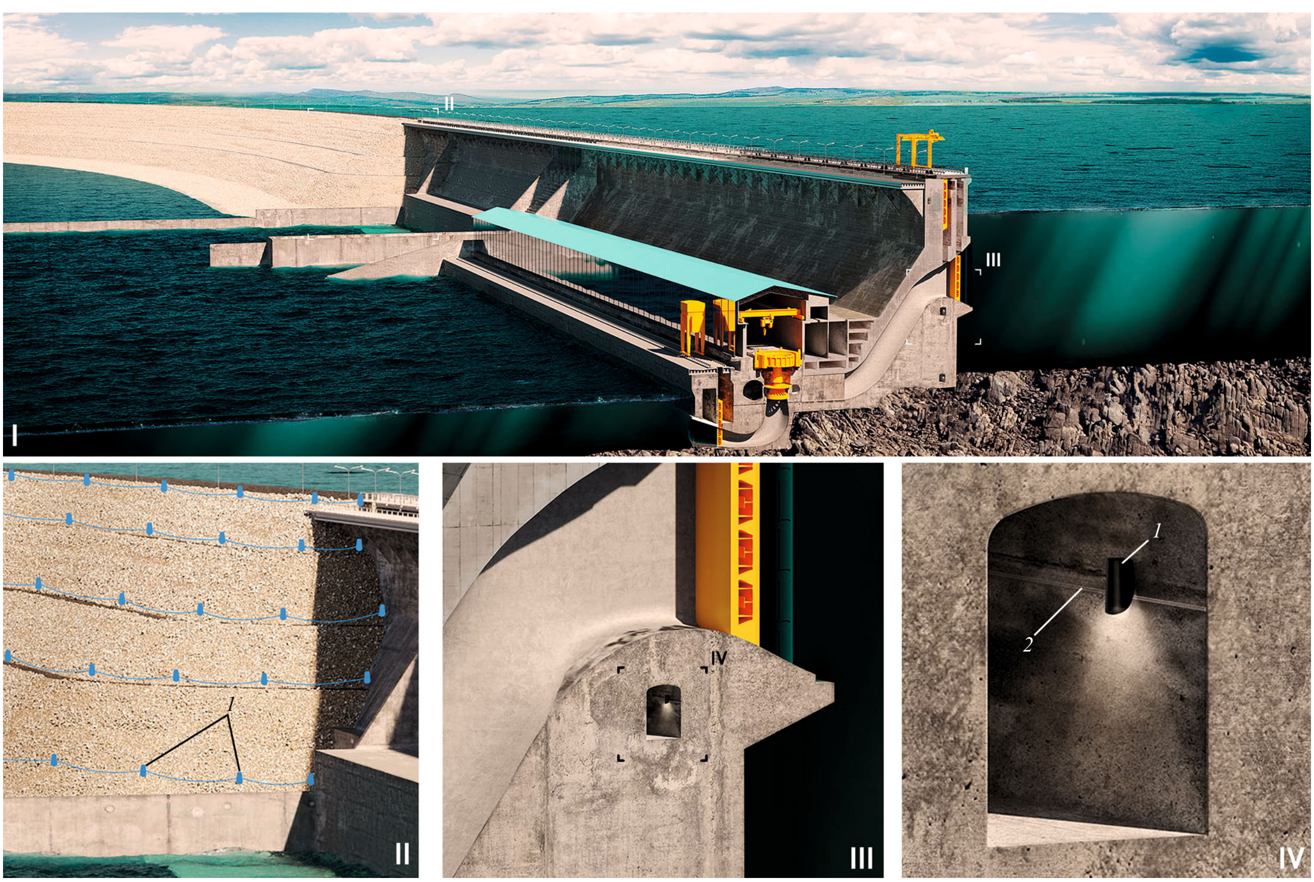

Fig. 8. Examples of arrangement of automated hydrostatic levels at HS: I, general view of hydraulic project; II, arrangement of hydrostatic levels on earth-fill dam; III, postern in powerhouse; IV, fragment of powerhouse; *1*, hydrostatic level; *2*, hydraulic, air, and communication lines.

hydrostatic levels are placed at ground reference points (Fig. 8).

The most important function of the Monitron system is continuous measurements, which makes it possible, owing to the automated messaging, to predict and prevent emergency situations. Owing to its simplicity and reliability, the system can easily be combined with automated digital systems, either operating or being developed, for monitoring and analyzing the stress-strain state of HSs [11 – 12].

CONCLUSIONS

1. The hydrostatic-leveling method allows substantially improving the full-scale monitoring of the settlements of hydraulic structures.

2. The experience of using the Monitron hydrostatic-leveling system is indicative of its high operational reliability and high accuracy of real-time monitoring data.

3. The possibility to easily unite hydrostatic levels into a single system, irrespective of the number and location of measuring devices, allows quick deployment and start of the system, combining it, if necessary, with currently operating digital automated monitoring systems.

4. If there are many levels to be installed, the system can be divided into subsystems, which, in turn, allows it to be used at HSs of any size.

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