The Belogorsk reservoir hydraulic structures multifactor survey

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Abstract. The article analysed the long-term data from 2001-2015, presented by the hydraulic structures' observation post, and the Belogorsk Reservoir and the 2016-2017 study conducted by the Hydraulic Structures Safety Engineering Consulting Center on multi-factor surveys and in-kind data analysis with their reliability assessment. As a hydraulic structures visual survey result, their structures and nodes, a defective statement is drawn up, which reflects defects, the hydraulic structures safe operation damages and violations According to the defective statement, as well as the facilities condition monitoring study results, it can be concluded that the hydraulic structures overall technical condition is assessed as satisfactory.

1. Introduction
In recent years, water problems have become significantly aggravated due to anthropogenic changes in river run-off and changes in the hydraulic structures' owners: reservoirs, water intake, spillway, culverts, which are reluctant to invest in their operation, increasing the reliability and safety [1, 2]. In the country most inhabited regions, there are no large rivers that have not been disturbed by economic activity, both in the catchments and in the rivers themselves channels [1, 3, 4].

The freshwater shortage problem on the Crimean Peninsula has sharply worsened since joining Russia. In April 2014, the Ukrainian side completely blocked the North Crimean Canal. The water independence acquisition from Ukraine by the new Russian region has become the Russian Federation priority tasks. The water supply problems in eastern Crimea were partially solved after the water transfer from the Crimean river Biyuk-Karasu to the North Crimean canal, as well as the new wells drilling, but water supply to Crimean Peninsula densely populated areas is one of the regional socio-economic development leading factors and an urgent task [5, 6]. Also, much attention is paid to the existing reservoirs safe operation, including one of the largest in Crimea - the Belogorsk reservoir [7-9].

The study purpose is to determine the Belogorsk reservoir GTS general technical condition.

2. Materials and methods
The long-term data of 2000-2015 were used, provided by the Belogorsk reservoir GTS observation post and the studies of 2016-2017, which were carried out by the Hydraulic structures safety ICC employees. Hydrometeorological conditions observations were as follows: water level; air humidity; water and air
temperature; wind direction and speed; excitement; precipitation, after changes in the water level in the reservoir were made according to the marks applied to the water gauge rods, which are located on the dam upper slope. The water level absolute marks were determined with a 1 cm accuracy.

A field data analysis was carried out with their reliability assessment, which depends on the used measurement technique, the CIA work and the observers' qualifications. A readings' reliability indirect evidence over an observations long period can be considered the measured parameters established regularities preservation.

Hydraulic structures observations were subdivided into visual and instrumental.

Visual structures periodic inspections observations consisted of their condition description, sketches and photographs, observed violations measurements, the simplest measuring instruments use.

Instrumental observations consisted of conducting structures planned and high-altitude surveys, taking and analysing readings from installed control and measuring devices, and, if necessary, sampling and taking soil samples, concrete and water for analysis.

3. Results

The regulated watercourse purpose is the Bolshaya Karasevka (Biyuk-Karasu) river, the river Salgir tributary, the Azov Sea basin. The reservoir location is in the Crimean region, the Belogorsk district, 3 km above the city of Belogorsk. The distance from the river mouth to the hydroelectric complex is 72 km. The reservoir purpose (according to the project): the Crimean region Belogorsk, Nizhnegorsk and Soviet districts land irrigation and the Belogorsk city a part and several settlements water supply, located along the Biyuk-Karasu river, north of the city, with water intakes on the riverbed.

The reservoir type - channel. The flow regulation type is perennial. The reservoir filling source is the river spring flood and the run-off.

The reservoir is operated in a cascade with the Taigan reservoir, located in the Dzhaivagan gully on the B. Karasevka (The Biyuk-Karasu river) river left bank.

The reservoir was built according to the Institute Ukgiprovodkhoz Crimean expedition project in 1961.

The flooded area is 210 hectares.

The irrigated land area together with the Taigan reservoir is 9648 hectares.

The reservoir basin siltation actual volume is 0.27 million m$^3$ or 1.2% of the design volume over 13 years of operation.

The hydroelectric complex includes:
- earthen dam;
- water intake structure with a discharge pipeline;
- spillway structure with supply outlet channels;
- overflow facility to the Taigan reservoir;
- a cofferdam on the watershed between the Belogorsk and Taigan reservoirs.

Base soils - alluvial and diluvial deposits, with a thickness of 4.00 to 7.00 m, are represented by sandy loams, loams, clays with gravel-pebble layers and lenses (10-40%). Below there is an Aptian clays stratum, in which the upper part (alluvium) is characterized by the cracks' presence.

Effective methods for analysing the filtration regime observations results are regression analysis methods. Establishing dependencies between the determined parameters using approximation by linear functions is reduced to obtaining a confidence interval for the change in the observed value.

The observed values' stable deviation from the confidence interval in one direction or the other is analysed and deviations possible causes are identified. We used the piezometric level dependence on the water level in the headwater $H_n = f(UWL)$ [10].

The observation data analysis for piezometric levels in the second approximation consisted of excluding measurements that deviate from the obtained confidence intervals constructed from the actual measurements results, as well as obtaining the approximation reliability R-value $^2$. The approximation reliability value recommended values to substantiate the measurement accuracy are within the limits $R^2 \approx 0.80 \div 0.90$ [11, 12].
Thus, the all spillway structures total throughput is $Q_{\text{sums}} = 79.32 \text{ m}^3/\text{s}$, which differs from the design data by less than 1% and indicates our data accuracy and reliability.

Under the requirements for the work content, the GTS state field observations data analysis and the Belogorsk reservoir (CIA) control and measuring equipment readings was carried out.

One of the main tasks of the service for the silted reservoir operation is to protect the regulating tank from siltation, overgrowth and water blooming. The reservoir observations were organized from its filling moment and continue throughout the entire operation. The silted reservoirs state operational observations’ composition included reservoirs level observations, liquid and solid run-off, banks processing, sediments and overgrowth, sediments, reservoir total and regulating volumes. The water level in the Belogorsk reservoir is determined directly in the retaining structures’ area using water gauges.

For the measures timely adoption, observations’ the reservoir banks unfortified sections were made to establish the places of abrasion, flooding, flooding and the banks processing intensity.

A reservoir coast reconnaissance survey was carried out 3 times a year: in the spring after the flood, in the middle of summer, and the fall before the reservoir freezing.

The fishery requirements for the operation service provide for measures aimed at ensuring conditions conducive to improving the fish stocks natural reproduction in reservoirs and related basins and increasing their fish productivity.

One of the most important conditions for the Belogorsk reservoir hydraulic structures correct operation is constant supervision and systematic observations and measurements of instrument readings.

The Belogorsk reservoir TME includes 8 benchmarks for observing the structure deformations and 23 piezometers for observing the filtration regime in the reservoir zone.

According to the as-built drawings and the acceptance certificate, the following instrumentation was installed at the Belogorsk reservoir GTS: surface benchmarks - 2 pcs., Telescopic benchmarks - 6 pcs. (table 1), piezometers - 23 pcs. (table 2).

**Table 1.** Benchmarks and marks consolidated list installed on the Belogorsk reservoir dam.

| No. | The cross N | Picket | Benchmarks N and their location in the dam body | Benchmark type | Rod length, m | Executive marks, m |
|-----|-------------|--------|-----------------------------------------------|----------------|---------------|-------------------|
|     |             |        | N berms in NB | ridge | I | II | heads | soles |
| 1   | 7           | 1+76   | 1              | Telescopic | 28.6 | 215.81 | 191.71 |
| 2   | 7           | 1+76   | –              | Telescopic | 18.8 | 208.36 | 190.06 |
| 3   | 10          | 2+66   | 3              | Telescopic | 24.4 | 215.52 | 191.12 |
| 4   | 10          | 2+66   | –              | Telescopic | 17.4 | 208.80 | 190.90 |
| 5   | 15          | 3+86   | 5              | Telescopic | 25.5 | 215.45 | 189.95 |
| 6   | 15          | 3+86   | –              | Telescopic | 16.2 | 108.47 | 192.27 |

**Table 2.** Piezometers installed in the dam body consolidated list.

| No | Diameter | Picket | N piezometers and their location | Piezometer type | Piezometer length, m |
|----|----------|--------|---------------------------------|-----------------|---------------------|
|    |          |        | ridge | downstream slope | I berm | slope | II berm | banks | type | total | filter | diameter, mm |
| 1  | 9        | 2+36   | 1     | – | – | – | – | – | – | main | 28.48 | 21.48 | 75.0 |
| 2  | 9        | 2+36   | –     | 2 | – | – | – | – | – | main | 20.50 | 18.30 | 75.0 |
| 3  | 9        | 2+36   | –     | – | 3 | – | – | – | – | main | 18.40 | 16.00 | 75.0 |
| 4  | 9        | 2+36   | –     | – | – | 4 | – | – | – | main | 10.70 | 8.20 | 75.0 |
During the operation period, the hydraulic structures state was regularly monitored for:

- fluctuations in water levels in the structures upper and lower reaches;
- structures precipitation and deformation;
- the cracks' formation and the seams' condition;
- structures slopes and ridges condition and their fastenings;
- water filtration through structures and bypassing them;
- the anti-seepage and drainage devices work;
- exposure to water flows, waves and precipitation;
- the apron, bottom and banks erosion and destruction;
- the ice impact on structures and after their icing;
- the floods' passage;
- the canals' bottom and slopes reservoir bowl flooding and waterlogging;
- land flooding and water logging in the reservoir area, etc. (figure 1).

Based on the technical passport data analysis results, we built a schedule for the reservoir operation for 2001-2013 and 2015, presented in figure 2. It can be seen from the graphs that the reservoir operation is characterized by the reservoir maximum volumes in the spring (March-May) and the minimum in the autumn (September-October).

| No. | Month | Date | Type | Studied | Length (m) | Width (m) | Height (m) |
|-----|-------|------|------|---------|-----------|-----------|-----------|
| 5   | 9     | 2+36 | –    | –       | –         | –         | –         |
| 6   | 13    | 3+36 | 5    | –       | –         | –         | –         |
| 7   | 13    | 3+36 | 6    | –       | –         | –         | –         |
| 8   | 13    | 3+36 | 7    | –       | –         | –         | –         |
| 9   | 13    | 3+36 | 8    | –       | –         | –         | –         |
| 10  | 13    | 3+36 | 9    | –       | –         | –         | –         |
| 11  | 6     | 1+46 | 10   | –       | –         | –         | –         |
| 12  | 6     | 1+46 | 11   | –       | –         | –         | –         |
| 13  | 11    | 2+96 | 12   | –       | –         | –         | –         |
| 14  | 11    | 2+96 | 13   | –       | –         | –         | –         |
| 15  | 17    | 4+46 | 14   | –       | –         | –         | –         |
| 16  | 17    | 4+46 | 15   | –       | –         | –         | –         |
| 17  | –     | –    | 16   | –       | –         | –         | –         |
| 18  | –     | –    | 17   | –       | –         | –         | –         |
| 19  | –     | –    | 18   | –       | –         | –         | –         |
| 20  | –     | –    | 19   | –       | –         | –         | –         |
| 21  | 4     | 19   | 20   | –       | –         | –         | –         |
| 22  | 4     | –    | 21   | –       | –         | –         | 13.0      |

Destroyed expansion joints with formed voids under reinforced concrete slabs for fastening the dam upper slope. Cracks in reinforced concrete slabs for fastening the dam upper slope.
Reinforced concrete slabs other defects for fastening the dam upper slope.

Reinforced concrete parapet defects.

Reinforced concrete trays defects for surface run-off drainage on the dam downstream slope.

Trees and shrubs on the dam upper slope.

Corrosion on metal rings in the reinforced concrete gallery of the water intake structure.

Overflow structure inlet channel reinforced concrete elements defects.
Missing mechanisms for controlling gates at the bypass structure.

Spillway structure outlet channel reinforced concrete elements defects.

**Figure 1.** GTS facility state field observations.

The reservoir maximum volume was observed in the period from March to April 2004. For the given observation period, it amounted to 23.20 million m$^3$, which is 4.16% less than the design volume corresponding to the NWL. The reservoir minimum volume was observed in October 2015, it amounted to 3.76 million m$^3$, which exceeds the design volume corresponding to TDS by more than 2 times.

**Figure 2.** Water volumes graph in the Belogorsk reservoir by years.

The GTS monitoring the safety project developed by the operating organization of the Belogorsky reservoir was developed under Article 9 of the Federal Law of 21.07.1997 N 117 FL On the safety of hydraulic structures.

4. **Conclusions**

Based on the data analysis results from the Belogorsk Reservoir GTS state field observations and the CME readings, the following conclusions can be drawn about the monitoring being carried out: there is a systematic approach to the GTS inspection, there is a fairly consistent relationship between the
readings taken from the CME, which indicates the readings' reliability. But, it follows it should be noted that there is soil dam filtration regime insufficient monitoring, as well as of dam deformations (horizontal displacements).

The hydraulic structures visual inspection results, their structures and components are the compiled defect statement, which reflects the defects, Belogorsky reservoir GTS safe operation damages and violations.

Based on the compiled defective statement, as well as the structures state studying the monitoring results, the following conclusions can be drawn about the surveyed hydraulic structures technical condition:

- reinforced concrete slabs for fastening the dam upstream slope - satisfactory condition;
- reinforced concrete parapet on the dam - satisfactory condition;
- trays system for surface run-off drainage - pre-emergency (limiting) state;
- dam (South cofferdam) - satisfactory condition;
- water intake structure - satisfactory condition;
- spillway structure - pre-emergency (limiting) state;
- spillway structure - pre-emergency (limiting) state;

The Belogorsk reservoir GTS general technical condition is assessed as satisfactory.

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