Spillway hydraulic performance assessments of the Belogorsk reservoir

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Abstract. The article presents the calculation of the hydraulic performance of the spillway structure of the Belogorsk reservoir, one of the largest freshwater bodies on the Crimean Peninsula. Due to its geographical location and natural features, Crimea has always been and remains one of the poorest regions of Russia with water resources and water delivery to the consumers is a priority. Hydraulic performance assessment of the spillway structure is carried out for two design cases: 1) with a variable upstream water level rate and a fully open gate with a = 1.00 m; 2) with a constant upstream water level (UWL) equals highest water level (HWL) and a variable value of the shutter opening. Based on the results of determining the hydraulic performance of the water intake structure, the maximum discharge flow rate (at the mark UWL equals HWL) was obtained, which was Q = 6.06 m³ / s, which is 1% higher than the design data of the throughput of the structure (Q = 6.00 m³ / s) and the total throughput of all spillway structures Qtotal = 79.32 m³ / s, which differs from the design data by less than 1% and indicates the accuracy and reliability of the obtained data.

1. Introduction

Water supply to densely populated areas of the Crimean Peninsula is one of the leading factors of socio-economic development. Due to its geographic location and natural features, Crimea has been and remains one of the poorest regions of Russia with water resources [1, 2]. The transformation and improvement of the hydro transport system for delivering water to the consumer is an urgent task and a real way to optimize water consumption and the development of various sectors of the socio-economic sphere of the region [3-5]. Cities and rural settlements of Crimea are supplied with water from surface (reservoirs) and underground (artesian wells, capturing) sources, the main of which are reservoirs [6].

The Belogorsk reservoir (popularly still called the Karasubazar Sea) is one of the largest fresh water bodies. It was built in 1970 due to a lack of water in the neighboring Taiginsky reservoir, which had been functioning since 1938 and could no longer cope with irrigation tasks [7-9].

The length of its coastline is 15 km, the basin length is just over 4.5 km. The reservoir has an elongated, highly prolate form, up to 600 m wide. The coastline is winding - there are a lot of large and small bays. In some places, the depth is up to 29 m, which is twice the depth of the Azov Sea.

Water flows from the Belogorsk reservoir to the Taiginskoe reservoir, by means of a hydroelectric complex and other structures, separated with a narrow isthmus. Both reservoirs are fed by the Bijuk-
Karasu River, which originates from the most powerful source of the Crimean Peninsula, Karasu-Bashi, through this process the water in the Belogorsk Sea is very clean and transparent [10-13].

The purpose of the study is to determine the hydraulic performance of the spillway structure of the Belogorsk reservoir.

2. Materials and methods
General scientific and geographical methods were utilized in this study - statistical, cartographic, etc., which are a combination of field and cameral techniques; deciphering of detailed Google space images using GIS technologies was carried out. Hydraulic structures were inspected in accordance with the current instructions using special measuring equipment. Factual material collected by the Engineering Consulting Center "Safety of Hydraulic Structures" during the period 2014-2019 was applied.

3. Result
The spillway structure consists of:

- a supply channel with a bottom width of 18.00 m and a length of 185.00 m; slope laying coefficient \( m = 1.5 \); fastening the bottom and slopes with reinforced concrete slabs;
- input reinforced concrete head, 15.90 m long; two-span head, covered by segmental metal gates \( 6.00 \times 2.00 \) m in size;
- a connecting channel with a width of 18.00 m along the bottom, 79.00 m long with a slope factor of \( m = 1.5 \);
- rapid flow of rectangular section, 15.20 m wide along the bottom, 158.00 m long and slope \( i = 0.172 \); the swiftness ends with a stilling well 15.40 m wide, 12.00 m long, 1.50 m deep.
- outlet canal, 20.00 m wide along the bottom, 201.00 m long with slopes \( m = 1.5 \).

The calculations were made for the entrance head made of monolithic reinforced concrete, supplying the connecting and outlet channels and the flow from precast concrete. A rack and pinion post is installed at the culvert inlet of the spillway structure (figure 1).

Since the discharge rates are regulated by segment gates at the inlet reinforced concrete, the head, the throughput was calculated for each span [14-16].

![Figure 1. Structural design diagram of the inlet head of the spillway structure.](image)

Determination of the discharge capacity of one span of a reinforced concrete head was calculated as for the outflow of water flow from under the gate according to the formula:

\[
Q = \varphi \frac{bea}{\sqrt{1 + \epsilon \frac{a}{H}}} \sqrt{2gH},
\]
where \( \phi \) is a correction factor that takes into account the effect of pressure losses, was taken, according to equal to 0.97;

- \( b \) - span width, m;
- \( \varepsilon \) - is the compression ratio, taken as equal to 0.78;
- \( a \) - gate opening value, m;
- \( H \) - effective head, m;
- \( g \) - free-falling acceleration, m/s².

The hydraulic performance was determined for two design cases:

- with variable UWL and fully open gate \( a = 1.00 \) m;
- with a constant UWL = HWL and a variable value of the gate opening.

For convenience, the calculation of the hydraulic performance of the spillway structure is performed in tabular form (tables 1, 2). Based on the calculation results, the graphs of the hydraulic performance \( Q = f (H) \) were constructed (figure 2).

Hydraulic performance graphs of the Belogorsk reservoir for the first design case

![Graph of hydraulic performance for one span](image1)

![Graph of hydraulic performance for two spans](image2)

Diagram of the hydraulic performance of the Belogorsk reservoir for the second design case

![Graph of hydraulic performance for one span](image3)

![Graph of hydraulic performance for two spans](image4)

**Figure 2.** Hydraulic performance diagrams for two calculated cases of the Belogorsk reservoir.
Table 1. Determination of the hydraulic performance of the spillway structure of the Belogorsk reservoir for the first simulation case.

| Evaluating factor, \( \varphi \) | Width of span, \( b, \text{ m} \) | Contraction coefficient, \( \varepsilon \) | Shutter opening value, \( a, \text{ m} \) | Free-falling acceleration, \( g, \text{ m/s}^2 \) | Available pressure head, \( H, \text{ m} \) | Elevation of upstream water level, \( \text{m BES} \) | Hydraulic performance of single width of span, \( Q, \text{ m}^3/\text{s} \) | Hydraulic performance of double width of span, \( Q, \text{ m}^3/\text{s} \) |
|-------------------------------|-------------------|-----------------|-----------------|-----------------|-----------------|-------------------|-------------------------------|-------------------------------|
| 0.01                          | 211.81            | 0.23            | 0.45            | 212.00          | 4.06             | 8.12               | 212.20                        | 7.40                          |
| 0.20                          | 212.20            | 10.27           | 20.54           | 212.40          | 12.80            | 25.60              | 212.60                        | 15.07                         |
| 0.60                          | 212.80            | 15.07           | 30.14           | 213.00          | 17.15            | 34.30              | 213.20                        | 19.07                         |
| 0.80                          | 213.20            | 19.07           | 38.13           | 213.20          | 20.85            | 41.71              | 213.40                        | 22.53                         |
| 1.00                          | 213.60            | 22.53           | 45.07           | 213.60          | 24.12            | 48.24              | 213.80 (NWL)                 | 25.63                         |
| 1.40                          | 214.00            | 26.50           | 53.00           | 214.12 (HWL)    | 27.06            | 54.12              | 214.20                        | 29.09                         |

Table 2. Determination of the hydraulic performance of the spillway structure of the Belogorsk reservoir for the second simulation case.

| Evaluating factor, \( \varphi \) | Width of span, \( b, \text{ m} \) | Contraction coefficient, \( \varepsilon \) | Shutter opening value, \( a, \text{ m} \) | Free-falling acceleration, \( g, \text{ m/s}^2 \) | Available pressure head, \( H, \text{ m} \) | Elevation of upstream water level, \( \text{m BES} \) | Hydraulic performance of single width of span, \( Q, \text{ m}^3/\text{s} \) | Hydraulic performance of double width of span, \( Q, \text{ m}^3/\text{s} \) |
|-------------------------------|-------------------|-----------------|-----------------|-----------------|-----------------|-------------------|-------------------------------|-------------------------------|
| 0.00                          | 214.12            | 8.76             | 17.51           | 214.12          | 11.50            | 23.00              | 214.12                        | 14.17                         |
| 0.10                          | 214.12            | 11.50            | 23.00           | 214.12          | 14.17            | 28.34              | 214.12                        | 16.76                         |
| 0.20                          | 214.12            | 14.17            | 28.34           | 214.12          | 16.76            | 33.53              | 214.12                        | 19.34                         |
| 0.30                          | 214.12            | 16.76            | 33.53           | 214.12          | 19.34            | 38.71              | 214.12                        | 21.71                         |
| 0.40                          | 214.12            | 19.34            | 38.71           | 214.12          | 21.71            | 44.07              | 214.12                        | 24.11                         |
| 0.50                          | 214.12            | 24.11            | 48.41           | 214.12          | 27.21            | 53.71              | 214.12                        | 29.61                         |
| 0.60                          | 214.12            | 29.61            | 58.11           | 214.12          | 32.11            | 63.41              | 214.12                        | 35.11                         |
4. Conclusions

According to the assessment results of the spillway structure, it can be seen that the maximum hydraulic performance during the passage of floodwaters (the water level in the reservoir is at the HWL = 214.12 m BES) for the first and second calculated cases is \( Q = 53.00 \, \text{m}^3 / \text{s} \), which corresponds to the design the hydraulic performance of the structure.

According to the determining results of the hydraulic performance of the water intake structure, the maximum discharge flow rate (at the mark upstream water level equals HWL) was obtained, that was \( Q = 6.06 \, \text{m}^3 / \text{s} \), which is 1% higher than the design data of the hydraulic performance of the structure (\( Q = 6.00 \, \text{m}^3 / \text{s} \)).

Thus, the total hydraulic performance of all spillway structures is \( Q_{\text{total}} = 79.32 \, \text{m}^3 / \text{s} \), which differs from the design data by less than 1%, and indicates the accuracy and reliability of our data. Figure 3 shows a graph of the hydraulic performance of all spillway structures of the Belogorsk reservoir.

**Figure 3.** Diagram of the total hydraulic performance of the spillway structures of the Belogorsk reservoir.

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