Influence of Ice Cover on Operation of Concrete Dams' Gates

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Abstract. The experience of operating emergency gates under freezing conditions at a number of hydroelectric power plants has shown the insufficient efficiency of the applied methods of fighting against frost structure damage. The rules for the maintenance of spillway dams' gates in wintertime imply the heating of structures along their grooves, threshold and enclosure, combined with measures for the maintenance of hatches before the beginning of construction. However, heating the gates and arranging ice-free areas are not always sufficiently substantiated and justified. In order to obtain field data and scientific information for the development of recommendations on operation modes and for taking into account when designing, field research of stresses and deflections in the bearing elements of spillway dams' gate has been carried out. The results of the field research in comparison with the design values are presented in this article. This research is a source of information about the static operation of plane gates under wintertime conditions, which is of theoretical and practical interest. The materials can be used to clarify the rules of maintenance and to clarify the regulatory documents for the design of hydromechanical equipment at hydroelectric power plants.

Keywords: Hydromechanical equipment of hydroelectric power plant (HPP) · Plane gate · Field research · Ice load · Temperature conditions · Static operation

1 Introduction

One of the main elements in the water intake part of the hydroelectric power plant building is hydromechanical equipment, which includes the gates that block access of water to the wheel space of the hydro turbine. According to the purpose of their use, the gates are divided into repair and emergency. The emergency gates, unlike the repair ones, are installed in moving water. The many-year experience of operating emergency gates under freezing conditions at a number of hydroelectric power plants has shown the insufficient efficiency of the applied methods of fighting against frost structure damage.

The research in this area is highly relevant, especially in winter, when an ice cover forms on water surface. In order to obtain field data and scientific information for the development of recommendations on operation modes and for taking into account in the design of hydromechanical equipment for hydroelectric power plants, a research of stresses and deflections in the bearing elements of spillway dam's gate of Zhigulevskaya HPP was carried out in wintertime [1, 2].

P. Akimov and N. Vatin (Eds.): RSP 2021, LNCE 189, pp. 116–122, 2022.
https://doi.org/10.1007/978-3-030-86001-1_14

2 Materials and Methods

In the area, where the hydroelectric power plant is located, about 90–120 mm of winter precipitation falls annually. The presence of thaws with positive temperatures and winds up to 10 m/s contributes to the gradual decrease of the height of snow cover on ice. Thus, the height of snow cover on ice in the winter of 2017–2018 reached 17 cm in the first decade of December. At the end of December, because of a long thaw, the first snow melted.

In 2018, the second snow cover began to accumulate on the 15th of January and lasted until the 5th of March. In the winter of 2018–2019, snow fell on the 3rd of December and lasted until the 5th of March. The highest snow cover on ice during these years was 15 cm. The maximum height of snow cover in this area during entire observation period was 28 cm [1].

The ice cover on the reservoir usually establishes in November or December; during the period of research the reservoir froze in December, from the 2nd to the 5th.

The thickest ice cover on the reservoir was 103 cm, during the research period the maximum thickness did not exceed 70 cm. The thickest depth ice, which froze as an even layer like a shield at the gate lock, was 120 cm. The typical dimensions – the thickness of ice and the height of snow cover – during the period of observations at the near-dam part of HPP are presented in Table 1.

In the first days of freeze-up small temperature cracks form in the ice cover, which further increase in length along the entire width of the reservoir, and the crack opening reaches 50 mm.

During the observations, periodic movements of the central ice field were noted, which caused ice reefing along the cracks. In the compartments between division walls, due to temperature deformations and water level fluctuations, ice cracks with reefs are formed at the side edges and in the area of the division wall's head.

Water level fluctuations contribute to the breakdown of the ice cover along the contour of the division walls and gates (see Fig. 1).

Table 1. The thickness of ice and the height of snow cover on the near-dam part of hydroelectric complex

Years	Months	Average snow depth, cm	Average ice thickness, cm
2014/2015	XII	4	11
	I	18	33
	II	28	45
	III	–	48
2015/2016	XII	12	20
	I	14	44
	II	20	59
	III	–	68

(*continued*)

Table 1. (*continued*)

Years	Months	Average snow depth, cm	Average ice thickness, cm
2016/2017	XII	4	20
	I	8	45
	II	5	64
	III	2	74
2017/2018	XII	8	16
	I	–	–
	II	–	–
	III	–	–
2018/2019	XII	6	25
	I	6	47
	II	12	65
	III	–	59
2019/2020		–	20
		10	43
		15	55
		2	60

The intended fall of water level is up to 6 m. The water level fluctuations at the HPP during the day are significant, which is due to dramatic load change.

The daily and hourly water level fluctuations near the spillway dam are smoother and have a smaller amplitude of 20–30 cm, due to the spread of level differences from the building of the HPP to the spillway dam for a distance of almost 3 km.

However even these values, taking into account the general subsidence of the reservoir, contribute to the formation of cracks and faults in the ice cover in front of the dam, thereby softening the effect of ice on the gates by temperature expansion.

The rules for the maintenance of spillway dams' gates in wintertime imply the heating of structures along their grooves, threshold and enclosure, combined with measures for the maintenance of hatches before the beginning of construction.

The purpose of these activities is as follows:

1) to exclude the freezing of gates, in order to ensure maneuverability if necessary;
2) to eliminate the possible ice load due to the complete ambiguity of source information about the possible load, which makes it difficult to take it into account when designing.

These circumstances contributed to broad development and design of different measures, aimed at fighting against the freezing of gates and the formation of an ice cover in front of them with the help of arranging ice-free areas.

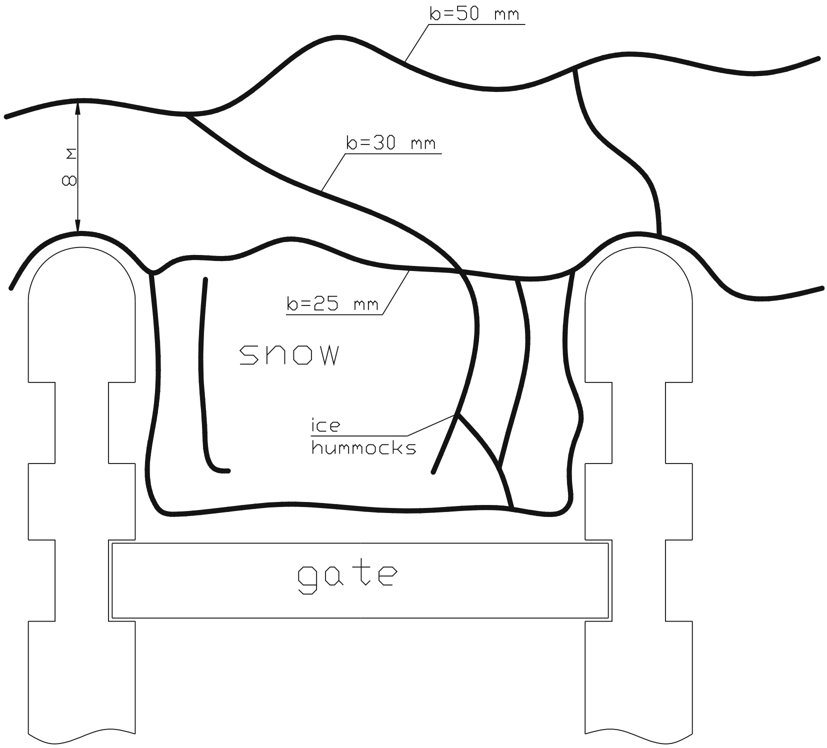

Fig. 1. Diagram of cracks in the ice field in front of the dam gate.

However, practice has shown that the measures aimed at heating and arranging ice-free areas are not always reasonable and justified enough.

At Zhigulevskaya HPP the up-freezing of some gates into ice was practiced for many years, thus the wintertime protection of the gates was provided [3]. Existing building regulations required that under difficult ice conditions basic design assumptions should be proved by field research data about the effect of ice on structures.

However, the process of directly measuring the pressure of ice on the gates was hindered by a number of serious difficulties, both due to the lack of reliable instruments and to the mixed interaction of the structure with the frozen ice cover with temperature deformations and water level fluctuations.

Devices installed at different points of the ice field in front of the gate give a large range of readings, which makes it difficult to get an objective idea of load distribution along the width of the span and the height of the gate [4].

It is possible to estimate objectively the pressure of ice on the structure, basing on the measured stress in the ice field, only taking into account the pre-stress state of the ice cover.

Force measurement devices in the ice field, that work only for compression, register an increase in pressure (compression) in the same way – both the decrease and the increase of ice temperature from the moment the ice cover spreads along the reservoir after all the cracks are filled.

When the devices are installed in gate enclosure, the interaction of the gate with the ice cover (depth ice) with temperature deformations of the gate distorts the true idea of ice field pressure. Considering this, during field research the greatest attention has been paid to the stresses and deflections of the gate bearing structures and their fluctuations under the impact of changing influencing factors [5].

Field stress measurements were carried out at gate No. 28 with the help of acoustic strain gauges TN-150, the pressure of ice on gate enclosure – with pressure sensors GD-6. The deflections of beams were registered with the help of taut strings in the gate span and with the help of mechanical recorders.

Field research showed that temperature deformations of ice were critical for ice pressure on the gate. The most important components of stresses in the beams from ice impact and from temperature deformations of structures under the conditions of complete freezing into ice (without ice-free areas and heating) reached 750 kgf/cm^2 (lower beam); the total measured stress was 1450 kgf/cm^2, the design stress was 2100 kgf/cm^2.

The maximum measured deflections of load-bearing beams reached 15 mm (the lower beam, 1.5 m below water level), the design deflections were 37.5 mm (at water level mark).

The actual deflections in wintertime were lower than the calibration values for hydrostatic load, due to the high rigidity of the structure caused by the deep freezing of ice on the enclosure in the form of a shield, the thickness of which reached 1.2 m.

3 Results and Discussions

The conducted research allowed us to make a conclusion about the possible protection of the gates, when following the recommended mode of operation levels, which is within design parameters.

Let us focus in more detail on the methodology of the conducted research. As mentioned above, the stresses in the load-bearing elements of the gate were measured using attachable acoustic strain gauges TN-150. The relative total error according to rated values was $+1\%$ within the temperature range from -30 °C to $+60$ °C. The devices were vocalized from a central generator station of TS-5 type with a measurement accuracy of $+1$ Hz.

The readings were taken discretely 2–3 times a day – at 7–8 o'clock am at minimum air temperature, and in the afternoon at 2–4 o'clock pm at maximum air temperature. The deflections of the gate beams were fixed with reference to the immobile string stretched in the span. The readings were recorded by a mechanical recorder with a clockwork mechanism.

Air temperature was measured with the help of standard meteorological alcohol-in-glass thermometers with a graduation mark of 0.2 °C, at the same time as stresses.

During the research, observations were made over the thickness of ice and the height of snow on the ice. Cracks in the ice cover, the presence of water in them and the destruction of ice by water level fluctuations were recorded.

The temperature of the ice was measured using resistance thermometers of MMT-4 type. The readings of ice thermometers were taken with the help of DC bridge of MVU-49 type, at the same time as voltages (see Fig. 2).

Fig. 2. DC bridge of MVU-49 type

Five surface-mounted force gages were installed at a height of 0.6 m from the upstream wall side, within 3 m from the stable autumn water level.

The devices were attached with the help of a special insert plate, made at the hydro-electric power plant at the request of the researchers, which protruded from the plane of the gate by 8 cm.

Calibration of the devices installed at the gate was carried out in autumn and spring by means of hydrostatic loading with the help of the repair gate.

Basing on the results of these calibrations, stable graphs of the dependence of stresses and deflections on hydrostatic load were obtained, which allowed us to calculate the value of ice loads [6–10].

4 Conclusions

Basing on field research results, the following conclusions and proposals were formulated:

1. The winter period in the area of Zhigulevskoe reservoir was characterized by average frosts, succeeded by thaws up to 1 °C, very little snow cover, systematic daily upstream level fluctuations within about 30 cm and the subsidence of the reservoir

in winter by 4.0 m. The highest measured total stress values at the batters were 450 kgf/cm^2, 1100 kgf/cm^2, and 1450 kgf/cm^2 in the upper, middle and lower gate beams respectively.

2. The thermal deformations of ice are critical for the formation of ice pressure on the gate. Field research has shown that an increase of air temperature causes an increase of tensile stresses in gate beams. Basing on the observations, we can say that sudden warming after severe frosts during low-snow winters with relatively stable reservoir level is the least favorable situation. The result is the formation of crystal ice without water layers, water-snow ice and snow in the wellhead part. The sum of negative temperatures is not large enough for the formation of a thick layer of depth ice on the gate's body, which could accommodate a part of the ice loads.
3. The maximum measured deflections in the middle and lower gate beams were 14 and 15 mm respectively, with a design deflection of 37.5 mm.
4. The freezing of plane gates into ice, i.e. wintertime protection without heating or arranging ice-free areas in front of Zhigulevskaya HPP building is not dangerous and is allowed within the frames of design and actual calculations, the observed period of HPP operation, the modes of daily water level fluctuations and the subsidence of the reservoir during ice-up period.
5. The research is a source of information about the static operation of plane gates under wintertime conditions, which is of theoretical and practical interest. The materials can be used to clarify the rules of maintenance and to clarify the regulatory documents for the design of hydromechanical equipment at HPPs.

References

1. Romanov, A.A.: Zhigulevskaya HPP. Hydraulic Structures Operation, 1 vol. Agni Publishing House, Samara (2010)
2. Romanov A.A.: Kuibyshev Hydroelectric Complex. Life Story. Art-Lajt, Samara (2018)
3. Technical report on the design and construction of the Volzhskaya HPP named after V. I. Lenin, 2 vol. (1950–1958)
4. Romanov, A.A. Ivanov, B.G., Evdokimov, S.V.: Assessment of seismic resistance of main hydraulic structures of the Zhigulevskaya HPP. Environmental Engineering, no. 5, pp. 49–53 (2012)
5. Naidenko, V.V.: The Great Volga at the turn of the Millennium. From Environmental Crisis to Sustainable Development. Book 1. Promgrafika Publishing House, Nizhny Novgorod (2003)
6. Balzannikov, M.I., Zubkov, V.A., Kondratieva, N.V.: Comprehensive survey of the technical condition of the building structures of the Zhigulevskaya HPP structures, no. 6, pp. 21–27 (2013)
7. Evdokimov, S.V., Dormidontova, T.V.: Assessment of the reliability of hydraulic structures, no. 1, pp. 49–53 (2012)
8. Evdokimov, S.V., Dormidontova, T.V.: Criteria for assessing the reliability and technological state of hydraulic structures, no. 2, pp. 105–109 (2011)
9. Evdokimov, S.V., Dormidontova, T.V.: Integrated Application of Methods for Assessing the Reliability and Monitoring of Building Structures and Structures. SGASU, Samara (2012)
10. Balzannikov, M.I., Rodionov, M.V.: Extending the operating life of low embankment dams in Russia, no. 6, pp. 60–63 (2013)