Large gravity dam safety management: Iron Gate I case study

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Abstract: Dams are structures that, by their very nature, apart from their enormous significance, also carry certain risks and potential dangers to surrounding areas. The issue of dam safety is of the utmost importance, especially for large dams such as the HPP Iron Gate 1 Dam (HPP Đerdap 1). This paper gives an overview of the gravity dam safety management, with a particular focus on the safety of the HPP Iron Gate 1 Dam. The concept of the large gravity dam safety management system is described. The mentioned system consists of a modern hardware and software platform for monitoring the dam's condition while providing decision support in the management process. HPP Iron Gate 1 Dam is a concrete gravity dam on the Danube River that forms a reservoir with a maximum volume of about 2.8 billion m^3. It is essential because it is located on the border of two countries, Serbia and Romania, which further complicates its management, exploitation, and maintenance. Within the Safety Management System of HPP Iron Gate 1, a complex unified database of all previous measurements on the Serbian part of the structure has been formed, which is available for further data collection and review, with the desired analyses, including checking whether they are within the expected ranges calculated based on a statistical analysis of measurements from the previous period. Mathematical models were developed for the simulation of thermal, filtration, and stress-deformation processes in the part of the Serbian power plant and spillway dam, which, with the use of appropriate user tools, enable the calibration of all system parameters based on available measurements. The system allows computation, comparison of computation results with measurement results, and dam safety assessment.

INTRODUCTION

Dams are infrastructural facilities of exceptional importance for society and economic development. They generate electricity, water supply, irrigation, flood protection, and more. Dam failure can have catastrophic consequences for human life, as well as for social and economic conditions. In this regard, dams must be maintained and monitored throughout the exploitation period to detect and prevent any changes that may lead to damage or collapse. Large gravity concrete dams, which will be discussed in this paper, are the most common concrete dams, which are significantly different from, for example, arch concrete dams or embankment dams. The essential characteristic of gravity concrete dams is that they oppose loads' effect with the concrete structure's massiveness. They are built as massive concrete structures that are almost always in a state of pressure and achieve their load-bearing capacity by friction on the foundation joint and weight that opposes the uplift of the filtration forces and the overturning of the structure. Unlike arch dams built in substantial rock masses and narrow canyons that are usually significantly high, gravity concrete dams can be built in wider river valleys and rock masses with weaker mechanical characteristics than arch dams.

A significant challenge regarding gravity concrete dams is sliding on the foundation joint and deep-seated weak planes. Research [1] states that out of 100 analyzed dams in China, 92 have a problem with deep-seated weak sliding planes. The study [2] said that of the 300 considered dam breaks, about 35% result from foundation breaks. Fortunately, dam breaks are rare, but there are various examples around the world; for example, the arch-gravity dam St. Francis Dam in California collapsed back in 1928 as a result of an inadequate foundation of the dam. The dam was successively raised in relation to the height defined by design, while the foundations remained the same dimensions, and there were also problems with the foundation soil and material suffusion [3, 4]. The breakage of St. Francis Dam has attracted significant attention towards research in the field of dam safety as well as the regulation of procedures when designing these structures. Cracks in the body of a gravity dam and the opening of cracks on the foundation joint are also common. Among the damaged gravity concrete dams, the following cases are known: Koyna gravity dam with a height of 103 m in India, 1967 [5], Sefid-Rud buttress dam with a height of 106 m in Iran [6], Hsingfengkiang Dam, China, 1962 [7]. Problems with gravity dams can also occur in the form of water seepage under the dam body, which can significantly threaten the stability of the structure. As an example, the gravity dam of HPP Višegrad in Bosnia and Herzegovina should be mentioned. It is located on the Drina River, which is 79.5 m high, and during exploitation, significant seepage of water occurred under the dam body (max. 15 m^3/s), which was visually noticeable as a source in the tailwater downstream of the dam. The seepage was remedied with grouting works according to the project of the Jaroslav Černi Water Institute, so that the seepage was reduced to about 4 m^3/s, which was the design criterion, and about 35,000 m^3 of material was added. One of the problems with gravity dams is the damage (erosion) of the rock mass downstream of the dam due to downstream hydraulic conditions. For example, the HPP Iron Gate Dam should be mentioned, where damage to the rock mass caused by erosion downstream of the stilling basin was observed. The damage was successfully repaired in 2021-2022 by creating an appropriate protection wall from piles, based on a design by the Jaroslav Černi Water Institute.

The largest number of gravity dams were built in the previous decades. Considering the passage of time, the need to monitor their condition and react as necessary to prevent the possibility of damage, collapse, and uncontrolled water release is growing. Over time, the operating conditions in which the dam is located change, the characteristics of the materials from which the structures were built, and the characteristics of the geotechnical mediums in which the structures were built, change as well. Additionally, over time, the relationship between professional and social factors changes according to safety criteria and risks (hydrological, seismotectonic, and others), with occasional changes in standards and legal norms. Practically speaking, the safety of dams is managed during their entire operational life, and it is understood that the dam is always in a condition in which it can fulfill all its designed functions without adverse consequences for people, the environment, or property. With the advancement and technological development of appropriate software systems, the possibilities for their more comprehensive and easier maintenance, monitoring, and control have increased.

Concerning analyses, monitoring, and management of dam safety, in general, different countries have different approaches, which consist in defining different procedures for how dam safety assessment analyses are performed, the reporting methods, and so on. In South Korea, for example, their dam management organization has established a Dam Safety Management System that applies to all dams, and that defines detailed activities, warnings, reports, and the work process of all groups, from engineers in the field to engineers in the office and experts for dam safety, as well as central control of all information and databases [8]. Switzerland also implements a dam safety management system that includes a mandatory periodic visual inspection of dams and reservoirs and reviews of observation results, preparation of annual dam safety reports, and detailed inspection by an independent expert every five years [9].

In the Republic of Serbia, there are no clear legal frameworks regarding monitoring and managing dam safety. Legal entities that manage individual dams are most often required to prepare appropriate reports on the analyses and condition of dams based on the results of technical monitoring. However, in the last few years, reasonable progress has been made in this area related to the establishment of a dam safety management system accepted by the Jaroslav Černi Water Institute and supported through the technological development project TR37013 (Development of a system to support the optimal maintenance of large dams in of Serbia) by the Ministry of Science and Technological Development of the Republic of Serbia and by PC Elektroprivreda Srbije through investment for the establishment of a safety management system at HPP Iron Gate 1, HPP Iron Gate 2 and the Vlasina Dam. All the dams are hydroelectric facilities managed by the Electric Power Company of Serbia. The subject of this paper is the presentation and application of the Safety Management System of the HPP Iron Gate 1 Dam.

Figure 1. *Photo of the HPP Iron Gate 1 Dam, view from the Serbian coast*

Two hydroelectric and navigation systems were built on the joint Serbian-Romanian sector of the Danube River: HPP Iron Gate 1 and HPP Iron Gate 2. These systems are the most significant hydroelectric production systems in Serbia (they cover over 50% of hydroelectric production and about 22% of total electricity production). The HPP Iron Gate 1 and HPP Iron Gate 2 systems greatly influence the Danube River's levels, in a length of over 300 km.

The HPP Iron Gate 1 Dam is located at the chainage of 942.95 km of the Danube River course (Figure 1). The works on the construction of the dam were completed in May 1972. The first filling of the reservoir began in April 1971. The total length of the backwater front is 1278 m.

HPP IRON GATE 1 DAM

The system consists of the following hydro-construction facilities connected into one functional unit (in order from the Serbian coast to the state border with Romania, Figure 2):

- An embankment dam,
- A two-stage navigational lock with a command tower and fore-docks,
- A power plant with a mounting block and annexes,
- A spillway dam with seven spillway bays.

The embankment dam consists of a separation structure and an embanked plateau along the right flank of the upstream chamber of the navigational lock. The length of the embanked dam is 350.6 m in the crown. The dam consists of a watertight clay core, surrounded by a filter layer made of gravel and a filled part of the rock. Along the length of the dam, in the foundation of the core, there is a grout gallery.

The navigational lock consists of: upstream and downstream chambers, upstream, middle, and downstream heads, and upstream and downstream fore-docks. The upstream chamber is divided into 18 and the downstream chamber into 21 piers. The useful length of both chambers is 312 m, and the width is 34 m.

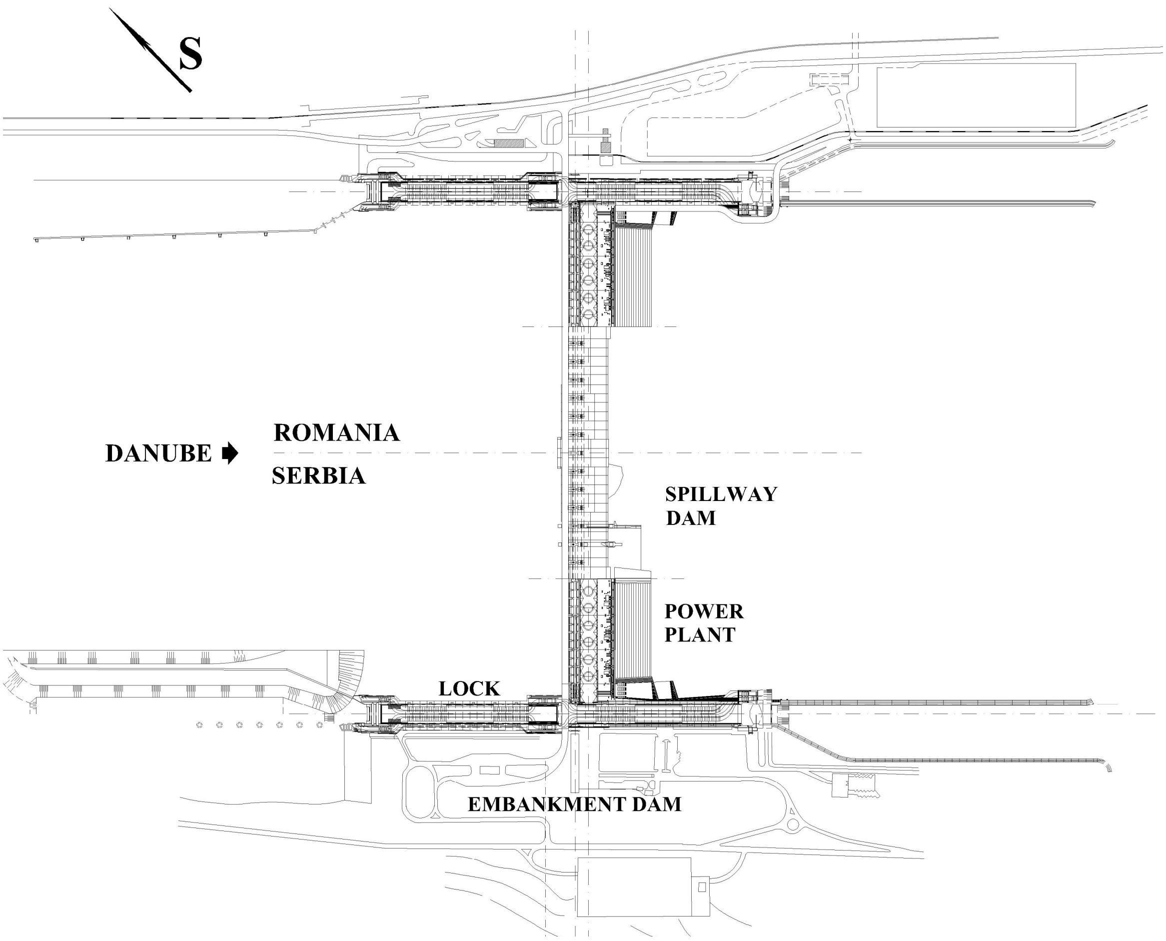

Figure 2. *The layout of the HPP Iron Gate 1 Dam*

The power plant consists of a mechanical building with a mounting block, a stilling basin with separation walls, and a spillway of the bottom outlet. The mechanical building is a reinforced concrete structure divided by expansion joints into three sections and a mounting block. The total length of the power plant is 214 m. The width of the foundation joint is 84 m. The total building height of the power plant is 76 m. In the foundations of the power plant, a grout curtain and a complex drainage system, consisting of 36 drainage boreholes and a system of pipes and ducts in the galleries, were constructed. In the foundations of the mounting block, the basins of the drainage pumping station and wet and dry galleries were erected, from which the water drained from the structure is pumped out by pumps into the stilling basin of the bottom outlet. The three-dimensional geometric model of the power plant is shown in Figure 3. Structural details are shown in Figure 4, and the drainage system in Figure 5. HPP Iron Gate 1 is equipped with Kaplan generators with a total installed power of 1203 MW for all 6 generators. The total installed flow is 5040 m^3/s. The gross drop varies from 17.5 m to 31.5 m, depending on the flow of the Danube River.

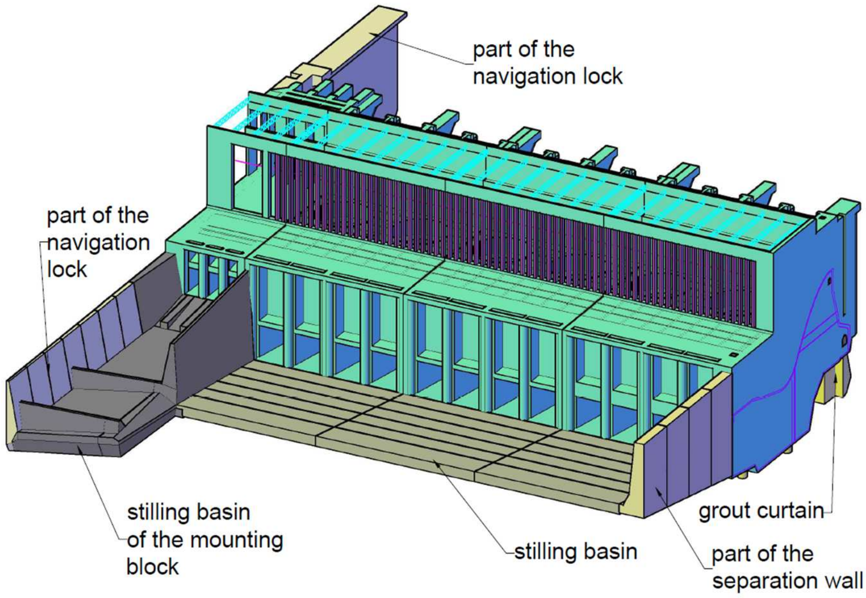

Figure 3. *Power plants (sections 1 to 3 and the mounting block), view from the downstream side*

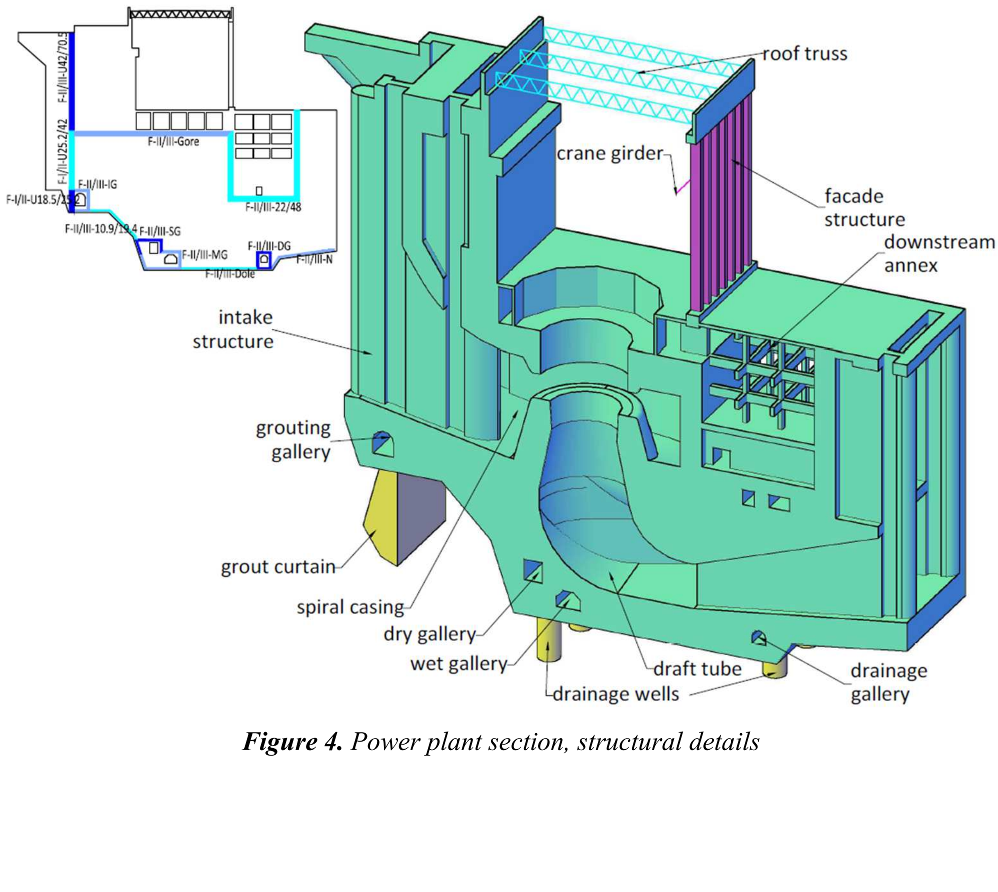

Figure 4. *Power plant section, structural details*

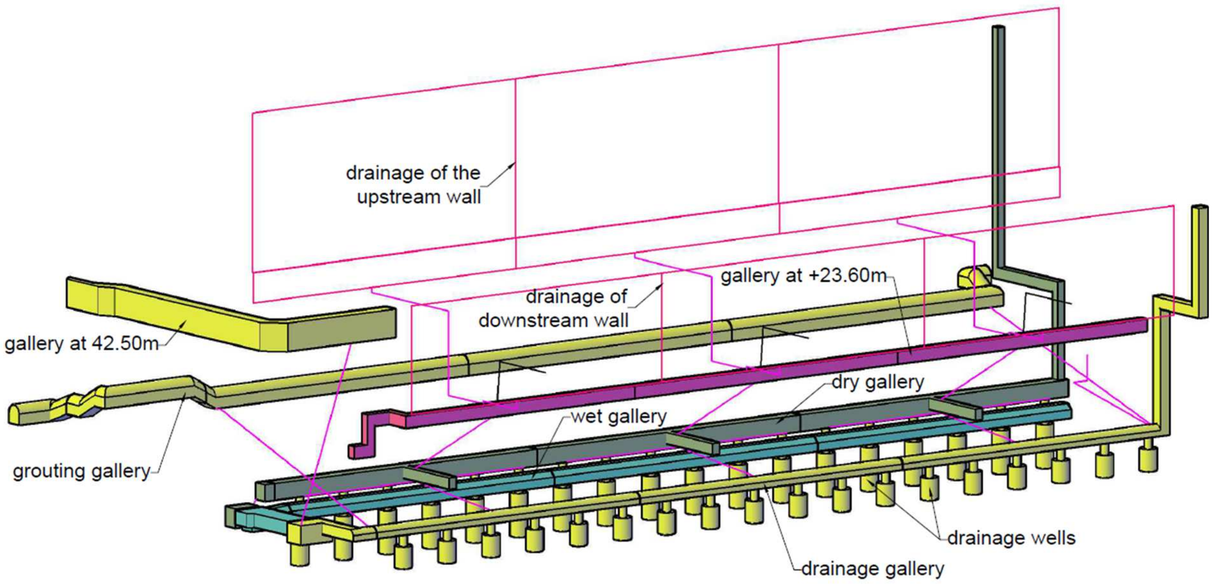

Figure 5. *The drainage system of the power plant*

The spillway dam is a massive reinforced concrete gravity dam, divided by expansion joints into 14 piers, mostly 16 m wide, and the joints are provided with adequate seals against water penetration into the gallery system. There are 7 spillway bays on the Serbian side, each 25 m long and 6.5 pillars, each 7 m wide. The lowest elevation of the foundation is 15.50 meters above sea level, the elevation of the spillway is 55.20 meters above sea level, and the elevation of the top of the column is 75.60 meters above sea level. The maximum capacity of one spillway bay is 1100 m^3/s. Inside the dam are the following galleries: grouting, drainage gallery system, and control galleries at elevations of 38.00 and 50.00 meters above sea level. The stilling basin, a reinforced concrete structure about 30 m long, is attached to the dam. The stilling gallery is located in the downstream part of the spillway. The spillway dam is founded mainly on crystalline schists that are disturbed and tectonically damaged. Beneath pier 11, in the direction of the Danube River, there is a tectonic fault.

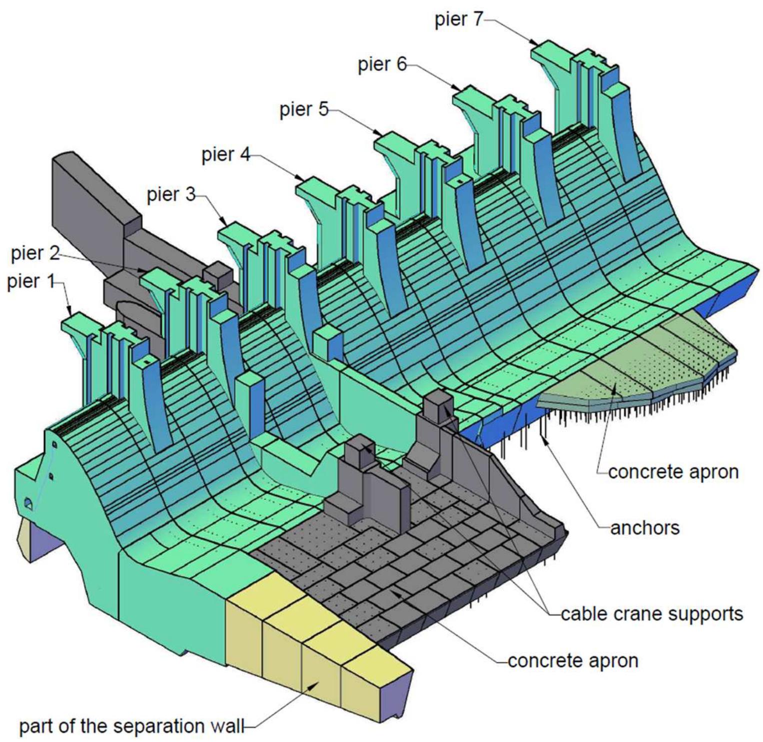

Figure 6. *Spillway dam (blocks from 1 to 14), view from the downstream side*

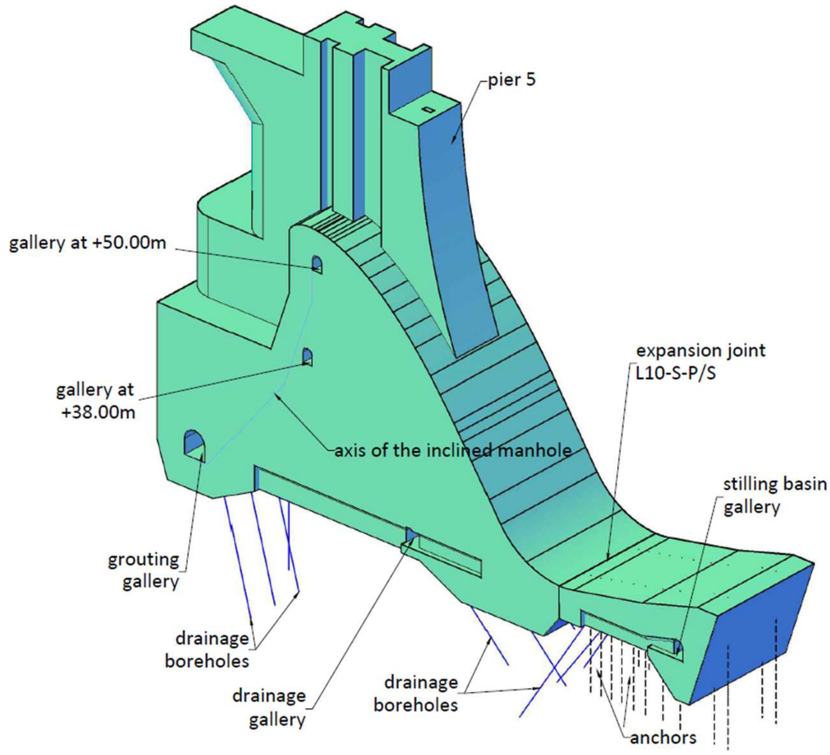

Figure 7. *Spillway dam blocks, structural details*

The grout curtain and a complex drainage system consisting of drainage wells (diameter 76 and 86 mm, length up to 15 and 20 m) and galleries in the direction of the river flow (in each axis of the pier and along the junction between adjacent piers) were constructed in the foundations of the dam. They flow into collection galleries with pipes or canals at the downstream end of the dam and the spillway. On the ground surface, filter material was laid in two layers along the galleries, with a total thickness of at least 30 cm. The three-dimensional geometric model of the spillway dam is shown in Figure 6. The structural details are shown in Figure 7, and the drainage system in Figure 8.

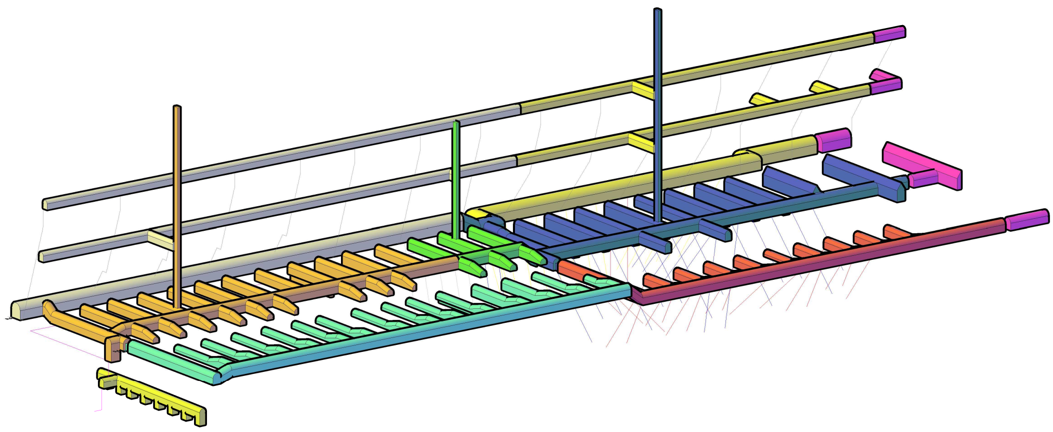

Figure 8. *A drainage system on the spillway dam*

Above the middle head of the lock, the cantilever of the columns of the entrance buildings of the power plant and the spillway dam, at an altitude of 72.50 meters above sea level, a concrete bridge was added, which also represents a border crossing.

CONCEPTUAL APPROACH TO SAFETY MANAGEMENT OF THE IRON GATE 1 DAM

The purpose of the development and application of the Safety Management System of HPP Iron Gate 1 is a continuous insight into the degree of safety of the structure, timely prevention of safety threats, and improvement of protection in case of need.

The safety management system ensures the fulfilment of the following key partial objectives:

- Continuous measurement and monitoring of all relevant quantities (which can show whether the actual condition of the dam in operation is following the intended behavior based on which the timely identification of processes that can cause a threat to the safety of the structure can be carried out),
- Effective implementation of periodical (annual) inspections with control calculations and preparation of appropriate reports on technical monitoring with safety analysis and assessment of the condition of the dam,
- Formation of a unique information system for data management, unification of safety criteria, unification of technology, and harmonization of the organization of the work of expert services related to the safety of all 6 large dams within the Đerdap company (HPP Iron Gate 1, HPP Iron Gate 2, Zavoj, Vlasina, Vrla 2 and Lisina),
- Facilitating timely decision-making regarding dam safety, and
- Transparent control of the dam safety management process.

The concept of dam safety management includes a series of procedures whose goal is to create a physically based, software-supported system that will ensure the collection of all data that is important for dam safety, the analysis of that data, and their engineering interpretation through mathematical models of relevant processes, and control safety of the dam and making appropriate conclusions regarding the measures that need to be taken to achieve safety.

The concept of dam safety management can be presented through the following most essential functions, which are closely related to each other:

- Provision of essential data for dam safety (validation, acquisition, archiving, determination of technical data quality, and unified access).
- Formation of physically-based FEM models for modeling thermal, filtration and stress-deformation processes.
- Dam safety monitoring using mathematical models for:
    - continuous monitoring of measurement results and determination of conformity of measured quantities and their expected values obtained by statistical models,
    - checking the dam's safety, i.e., determining the structure's condition and degree of protection using physical protection models.

DATA MANAGEMENT

Types of measurement

An extensive measuring system was created to monitor the condition of facilities within HPP Iron Gate 1. Measurements take place in the form of regular observations (using various manual and automatic instruments) and periodic geodetic observations (twice a year).

As part of regular monitoring, measurements of hydrological and meteorological variables (precipitation, water level in the reservoir and tailwater level, temperature of the outside air, temperature of the water in the reservoir, temperature at the foundation joint, and temperature in the galleries and the downstream annex) are performed, quantities that depict water filtration (water table, filtration pressure and filtration flow, pore pressure, drainage and seepage water and operation of pumps in the pumping station) and quantities that depict the behavior condition of the structure with rock deformations in the foundation zone (operation of expansion joints, relative horizontal displacement of parts of the structure, changes in the inclination of parts of the structure, effect of cracks, stress in the reinforcement, pressure at the concrete-rock point of contact, expansion, and temperature of the concrete).

Table 1 shows the number of functional measuring instruments, i.e., associated measuring points for regular monitoring of the dam, divided by name, measurement method (M - manual, A - automatic), and installation location, whether installed during construction or operation of the facility.

Geodetic measurements include the measurement of vertical displacements and the measurement of horizontal displacements (radial and tangential). Table 2 shows the number of geodetic points on the Serbian part of the structure, classified according to whether measurements of horizontal or vertical displacement are taken.

Table 1. *Overview of equipment as part of regular monitoring of the dam*

Name of the measuring instrument (or the associated measuring point)	Measurement method	Embankment dam	Lock	Power plant	Spillway dam	Total
Headwater level gauge	A		1			1
Tailwater level gauge	A			1		1
Air thermometer	A		1		2	3
Water thermometer	A				4	4
Rain gauge	M	1				1
Classic piezometer	M	27				27
Piezometer with a manometer and tap	M	40	32	173	100	345
Piezometer probe	A	10	15	7	18	50
Overflow weir	A		1	2	6	9
Drainage well	M			21		21
Pump	A			4		4
Thermometer for concrete	A		22	2	49	73
Electric coordinometer	A				8	8
Rectangular coordinometer with rulers	M				10	10
Electric clinometer	A				20	20
Supports for the clinometer with a horiz. base	M		5	23	6	34
Supports for the clinometer with a vert. base	M			5	20	25
3D supports for monitoring the operation of couplings	M	1	1	7	42	51
Caliper supports for monitoring the operation of joints	M		8	12		20
Electric instrument for monitoring the operation of joints	A		2	1		3
Supports for monitoring the operation of cracks	M			35		35
Electric instrument for monitoring the operation of cracks	A			15	5	20
Extensometer in concrete	A		16		15	31
Galileo pressure gauge	A		26		5	31
Basic pressure gauge (Russian)	A	1	25	2	9	37
Reinforcement dynamometer	A		7	23	1	31
TOTAL		80	162	333	320	895

Table 2. *Overview of points as part of geodetic observation of the dam*

Purpose of geodetic point	Primary network	Embankment dam	Lock with fore-docks	Power plant	Spillway dam	Total
Geodetic points for horizontal displacements	35		112	18	50	215
Geodetic points for vertical displacements	37	26	130	84	158	435

Data acquisition, processing and archiving

The systems with which manual entry, automatic acquisition, and storage of measurement data are carried out, which are then, using specially developed procedures, imported into the central database of the Safety Management System (where they are further archived and used), are a portable station with an RFID reader and a mobile tool for manual entry, Vista Data Vision software, and SCADA system. Data from Vista Data Vision and the SCADA system are automatically downloaded regularly according to previously developed patterns. Archival measurement data from earlier databases (Oracle, Vista Data Vision, Excel files, printed paper reports) were downloaded and consolidated in the central database. The system processes all collected data, i.e., calculation of engineering data from measured values and, if necessary, aggregation of data (average, maximum and minimum values) by a specific time step (daily, monthly, yearly).

For manual measurements, it is possible to enter data on the spot into a mobile device (model Trimble Juno T41) with the ability to read RFID tags, which detects the measuring point where the measurements are performed. A total of 385 tags are embedded. This functionality enables faster and simpler acquisition of measured values, reducing the possibility of error (measurements are subsequently simply transferred to the database). The person who performs the measurement can see through the available diagram whether the measurement was performed in accordance with the previous one. If a value is entered that is outside the previously defined range of possible values (in the broadest case, it is the range of the instrument), the user will receive a notification about it. When measuring the structure's slope using a portable clinometer with a horizontal or vertical base (models Huggenberger ECS1000HD and ECS1000VBL), it is possible to transfer data from the instruments to a mobile device via a Bluetooth system, which makes measurement significantly easier. A backup option for manual data entry of measurements is a desktop tool for manual data entry. Through this tool, geodetic measurement data, which were previously processed in dedicated software, are imported.

Data quality control

A measured technical piece of data, in addition to the value of the quantity, also has attributes that include a record of the conditions under which the measurement was performed, the time when the measurement was performed, information about the measuring instrument, information about the state of the measuring equipment and other relevant information. One of the more critical attributes is information about the quality of the data point itself. This attribute is calculated in the process called Quality Control of Measured Technical Data (hereafter QCMTD). QCMTD occupies an important place in the Safety Management System. It is carried out after the data acquisition process and its validation before entering the data into the central database with all the accompanying attributes. The task of data validation is to roughly evaluate and assess whether the data quality can and should be determined in the QCMTD process (if satisfied with the required data format).

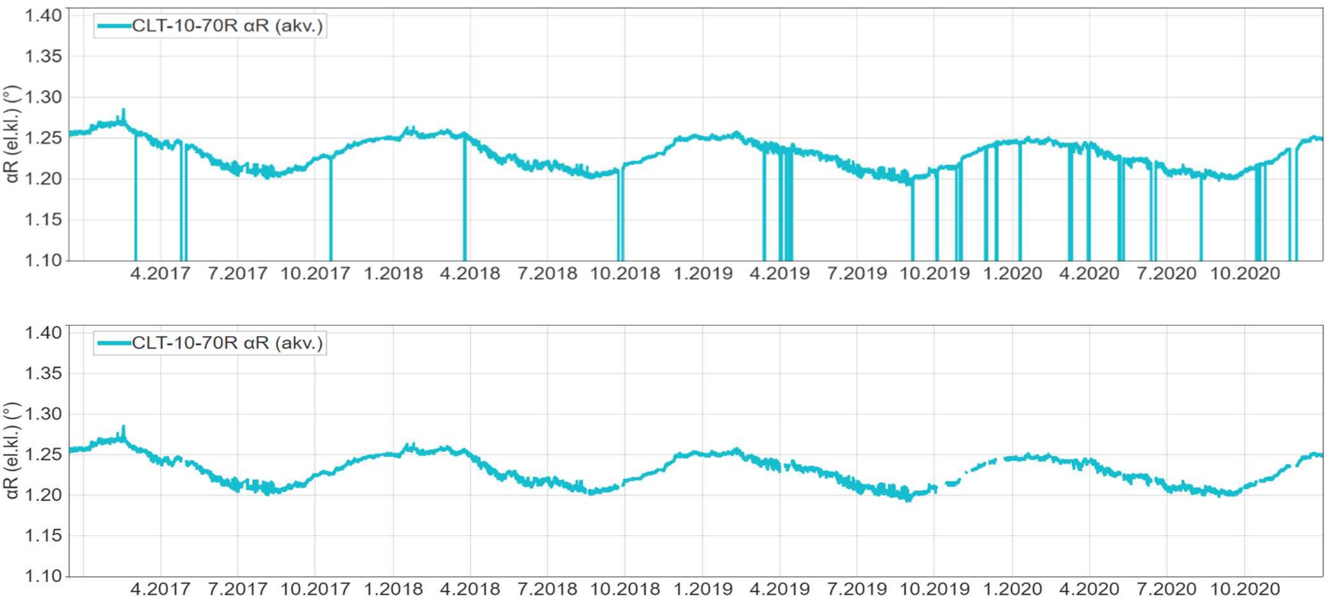

Figure 9. *Measured inclination values on the electric clinometer CLT-10-70R, before and after applying QCMTD*

In the QCMTD process, the following quality attributes are attributed to each piece of data: quality rating (in the range 0-1), a measure of the reliability of the quality assessment, and a diagram or list of methods by which the quality assessment was carried out. The quality rating represents an additional attribute that follows the data through further transformations and uses. QCMTD evaluators have a specific validity period; in a certain period, one evaluator may be responsible for a data series, while another evaluator may be responsible for another. Figure 9 shows an example of a series before and after the application of QCMTD.

Statistical data modeling

To determine whether the dam is behaving normally, it is helpful first to check whether the measured values of the observed quantities are within the expected ranges. The range of expected values of observed quantities is formed based on a statistical analysis of the results of previous measurements. Statistical models, under the rules of mathematical statistics, establish a connection between the indicators of the dam's behavior (quantities that are observed - displacements, deformations, stresses, etc.) and indicators that represent external influences on the structure (primarily, the temperature of the external environment and the water level in the reservoir). 590 such models are in use at the HPP Iron Gate Dam as part of the Dam Safety Management System. The process of forming a statistical model includes the following steps: rejecting irregular data, determining the training period of the model, adopting the form of the equation that best describes the relationship between causal and consequential quantities (for which the model is formed), determining the parameters of the model and assessing whether the model is suitable for use according to the parameters of its quality.

In the following section, we provide a specific example of using statistical data modeling to correct the series according to the reference series. From 2006 to 2008, the technical monitoring system was renewed and innovated by installing new supports (in the zone of already existing measuring points) to monitor joints' operation with a new instrument. The method of subsequent connection, that is, the relationship between the measurement results of the new system and the measurement results of the old system (in which parallel measurements were not performed using both systems), is shown in the example of the operation of the expansion joint (vertical shear) between piers 3 and 4 of the spillway dam, at a level of 23 masl (measurement point D-09). Figure 10 shows the results of measurements using both systems. The results of the measurement with the old instrument are the increments of the slope in relation to the zero measurement since the beginning of the observation (green series in the figure), while the results of the measurement using the new instrument are the increments of the slope in relation to the zero-measurement made on January 18, 2007 (blue series in the figure). The last measurement with the old system was performed in July 2006, before the installation of supports for the new instrument began.

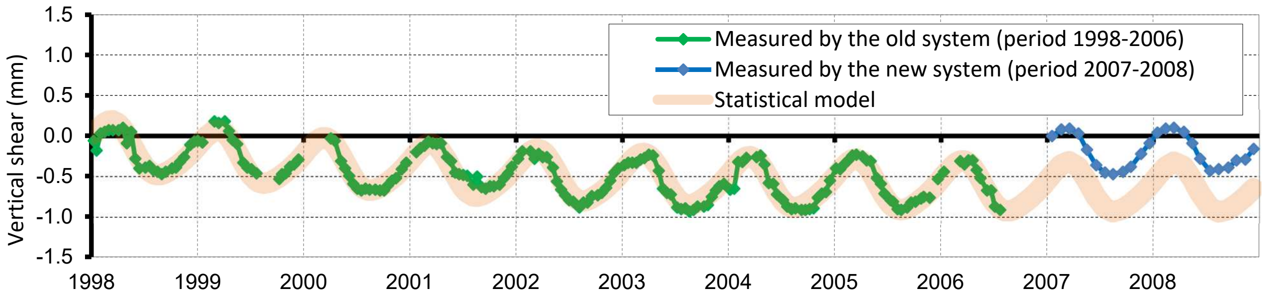

Figure 10. *Vertical shear of the joint at measuring point D-09, measured by the old and new system, along with a statistical model of expected measurement results with the old system*

The connection of the measurements was made with the help of a statistical model based on the data sets measured in the previous observation system from 1998-2006. The mathematical model gave the expected results of measurements with the old system for the period when they were no longer performed (in Figure 10, the model is shown with a solid orange line).

The measurement results were linked by obtaining the connection constant K as a linear parameter of the difference between the new system's measurements and the expected measurements by calculating the observed two-year period using the least squares method. By translating the measurement results with the new instrument for the value of the mentioned constant, the closest "overlap" of the measurement results of the increment of relative displacements with the new instrument is obtained with the expected calculated measurement values (in Figure 11, it is shown with the red line).

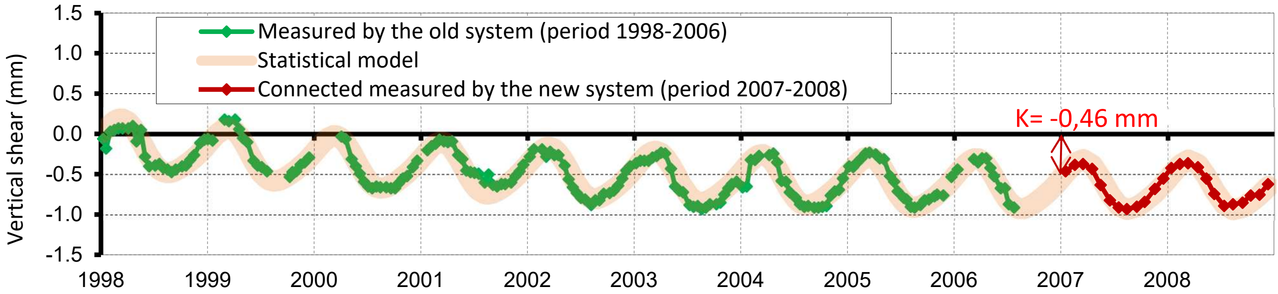

Figure 11. *Example of a unified series of measurements on D-09 using old and new measuring equipment*

Data review

Depending on the needs, data review is enabled through a historical and real-time data review tool.

With **the tool for viewing historical data**, the user can review the entire systematized system of technical observation with an organized and straightforward overview of all the measurements performed on the Serbian part of the dam, starting from the construction period of the structure, given that specific electrical instruments were installed during its construction (thermometers in concrete, pressure meters, reinforcement dynamometers...). In the tool, interactive graphics are available with the precise locations of all measuring points, as well as all available data series in the system with a defined convention (collected data, analytical series, composite series that combine data from multiple sources...), characteristics of the equipment used with accompanying documentation (calibration sheets, user instructions, photos...) and records of when the equipment was introduced into the system, serviced or archived, if it is no longer used for any reason. Predefined panels with appropriate bases and created diagrams have an efficient application. An example of several unified series of measurements using old and new measuring equipment is given in Figure 12, which shows one of the total of 240 created predefined panels of the mentioned tool.

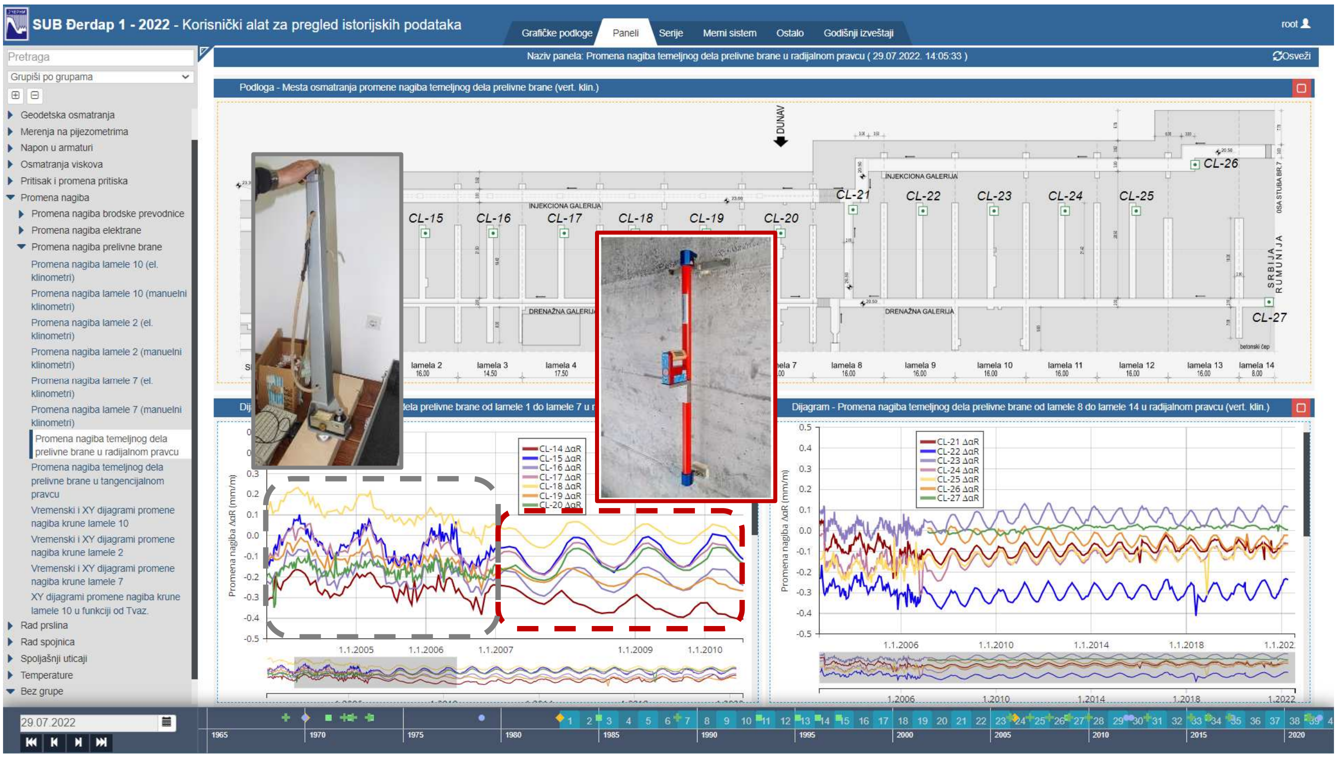

Figure 12. *User tool panel for viewing historical data with a consolidated display of the old (Pizzi, gray) and new clinometer (Huggenberger, red) measurements in the foundation galleries of the spillway dam*

In particular, this image shows a predefined panel entitled Change of inclination of the foundation part of the spillway dam in the radial direction, which includes the display of the position of the measuring points for portable mechanical clinometers with a vertical base and the results of measurements on them in the previous 20 years, while the time reference of the last displayed data point can be selected on the time scale at the bottom of the screen. In this way, data are available throughout the observation period. During 2007, measurements were made with both old and new measuring equipment, making it possible to connect their measurement results more reliably.

The tool for viewing data in real-time enables the review of current measurement values at the dam and measurements in the recent past. It is used for daily, regular monitoring of the structure's condition. The tool signals when specific measurements have been interrupted (in the case of missing data according to the previous collection dynamics), when the measurements are of poor quality (according to previously defined and implemented procedures and criteria), and when the measurements are outside the expected measurement ranges, calculated based on a statistical analysis of measurements from the previous period, and as a function of the measured causal variables (most often air temperature and water level in the reservoir). An example of the practical use of statistical models is given in Figure 13, which shows one of the 138 working screens of the mentioned tool created.

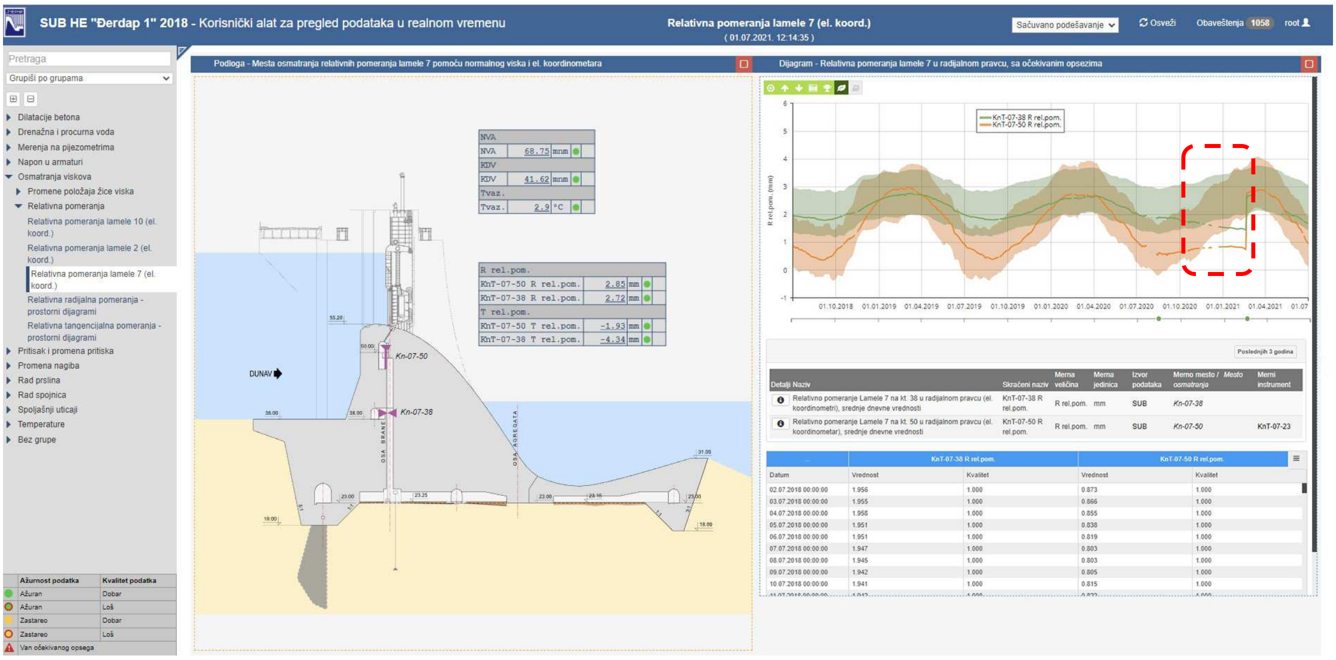

Figure 13. Relative radial displacements of block 7 of the spillway dam with expected ranges

On the predefined panel called Relative displacements of pier 7 that is shown, the results of observation of the wire of normal plumb using electrical coordinate meters are shown. The use of this tool, along with the formation of the expected measurement ranges, enabled the detection of problems with the measuring equipment at the end of 2020 (the measured values began to deviate from the expected ones, framed by a red dotted line). The plumb line was jammed due to corrosion of the measuring system, and this caused the deviations mentioned above. The plumb line was freed (returned to its regular position) in mid-February of 2021. On that occasion, rust was removed in the barrel area, which is an integral part of the structure of the plumb line measuring system. In other words, the deviations shown do not represent the behavior of pier 7 but are the result of a problem with the measuring equipment, which was subsequently resolved.

MODELING OF RELEVANT PROCESSES AT THE DAM IN ORDER TO DETERMINE THE STATE OF THE SYSTEM

General outline

Three types of processes are analyzed at dams based on the nature of the load and behavior: thermal, filtration, and stress-deformation processes. Within the framework of thermal processes, thermal fields inside the body of the dam are analyzed due to the action of thermal boundary conditions (air and water temperature). As part of the filtration processes, the fields of uplift, potential, and filtration forces inside the body of the dam and the surrounding rock mass are analyzed, and the flows along the defined boundaries. Within the framework of stress-deformation processes, which represent the most complex processes, stress and deformation fields on the dam are analyzed as consequences of the action of all relevant loads. Stress-deformation processes are influenced by their interaction with filtration and thermal processes.

To be able to analyze all relevant processes as well as their interaction, it is necessary to form appropriate mathematical models that are physically based; that is, they take into account all the structural and functional characteristics of the interaction system of the dam, rock mass, and water. In literature, there are various examples of the application of mathematical models for gravity dams based on the finite element method, distinct element method, and others [10-15]. For the HPP Iron Gate 1 Dam, a three-dimensional FEM model of the spillway dam and power plant, including the surrounding rock mass, was created to simulate thermal, filtration, and stress-deformation processes, taking into account the interaction of these processes.

To perform computations, numerical solvers were developed, which perform simulations of thermal (PAK-T) [16,17], filtration (PAK-P) [18,19], and stress-deformation processes (PAK-S) [20,21] which enables the determination of the temperature, filtration and stress-deformation field within any point of the model, based on the given boundary conditions. The thermal and filtration computations are carried out independently, while the stress-deformation computation considers the results of the thermal and filtration computations. The HPP Iron Gate 1 Dam is characterized by a concrete and complex drainage and sealing system, and determining the filtration parameters of the system was a challenging and intricate task.

For the FEM model to be applied for the analysis of the corresponding processes, it must be estimated for the given methods, which implies that it should be brought to a state that best reflects the realistically observed condition of the dam. Assessing the condition means that the values of the parameters of all relevant processes must be determined beforehand. For thermal processes, these are thermal conductivity coefficients, heat transfer from water to concrete and air to concrete, and coefficients of specific conductivity. For filtration processes, these are the filtration coefficients for individual quasi-homogeneous zones in the model. For stress-deformation processes, these are the parameters that define the elastic behavior of materials, compressive and tensile strength, material behavior in complex stress states, capacity for plastic deformation, the shape of the deformation curve, and others. The constitutive damage plasticity model [22-25] was applied to the behavior of concrete and rock mass materials. The procedures used to determine individual processes' parameter values are complex and require enormous hardware and software resources. Parameterization is defined as an optimization problem that is solved by the parallelized NSGA-II algorithm [26].

FEM model of spillway dam and power plant

The grid of the finite elements of the spillway dam and the power plant consists of tetrahedral finite elements with intermediate nodes, where the FEM of the spillway dam consists of about 1.4 million nodes and about one million elements, and the FEM of the power plant of about 1.8 million nodes and about 1.2 million elements (Figure 14).

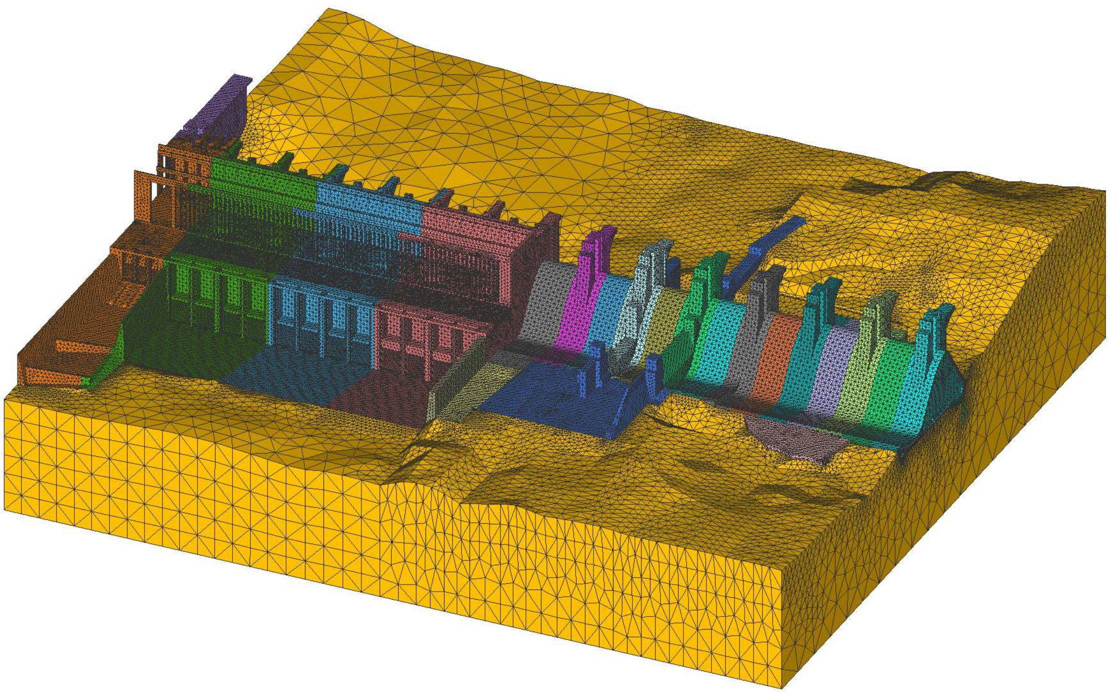

Figure 14. *Integral FEM model of the spillway dam and power plant, view from the downstream side*

The boundaries of the model are 200 m upstream and downstream from the axis of the dam. The lowest level of the model is at -40 masl. In contrast, the lateral border of the model towards Romania is the plane of the expansion joint between piers 14 and 15 of the spillway dam. The lateral border of the model towards Serbia is the plane of the expansion joint between the mounting block of the power plant and the navigational lock.

In the integral model, the following groups of elements are distinguished (Figure 15 and Figure 16):

- Surrounding rock mass (a total of 6 quasi-homogeneous zones were separated at the foundation of the spillway dam and HPP Iron Gate 1 power plant) (3D elements)
- Concrete structure of the spillway dam (dam body and spillway, divided into 14 piers, crane cable columns, ridge berm, concrete apron) and power plant (3 sections, mounting block, stilling basin, bottom outlet of the spillway) and other concrete structures (separation wall between the power plant and the spillway dam, part of the walls of the lock next to the mounting block) (3D elements)
- Grout curtain (3D elements)
- Expansion joints (2D elements)
- Seals in the zone of expansion joints (2D elements)
- Drainage blankets (3D elements) and drainage wells (1D elements) in the spillway dam area
- Drainage wells (3D elements) in the area of the power plant
- Anchors (1D elements) in the spillway area, ridge berm, and concrete apron on the spillway dam and in the stilling basin of the power plant.

The dam segments are modeled as 3D bodies - solids, with all their significant cavities (aggregate flow organs, upstream and downstream annex rooms, galleries, and larger shafts) and attenuations (niches for shutters and grates), which are modeled spatially, with their realistic geometry.

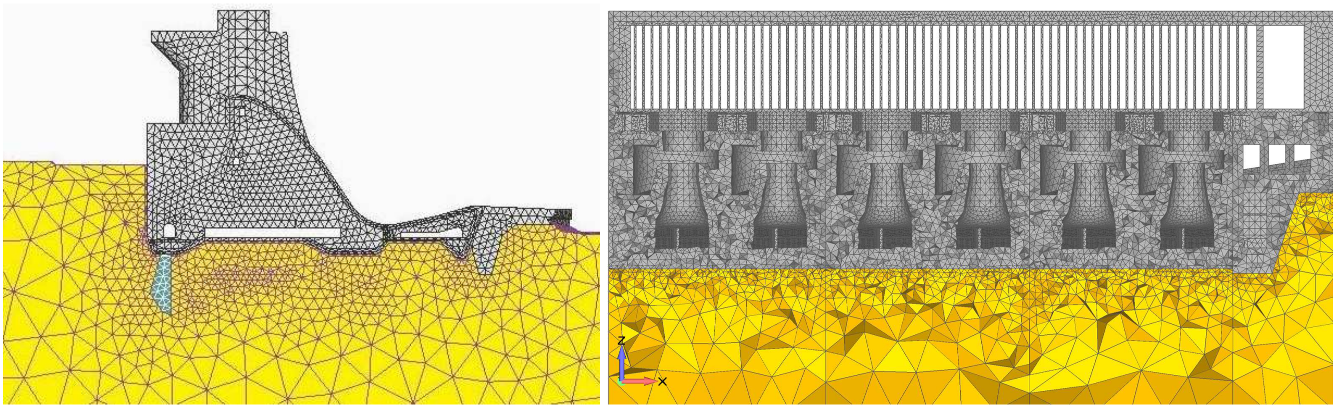

Figure 15. *3D finite elements of the model of the spillway dam (in the cross-section of block 10) and the power plant (in the aggregate axis)*

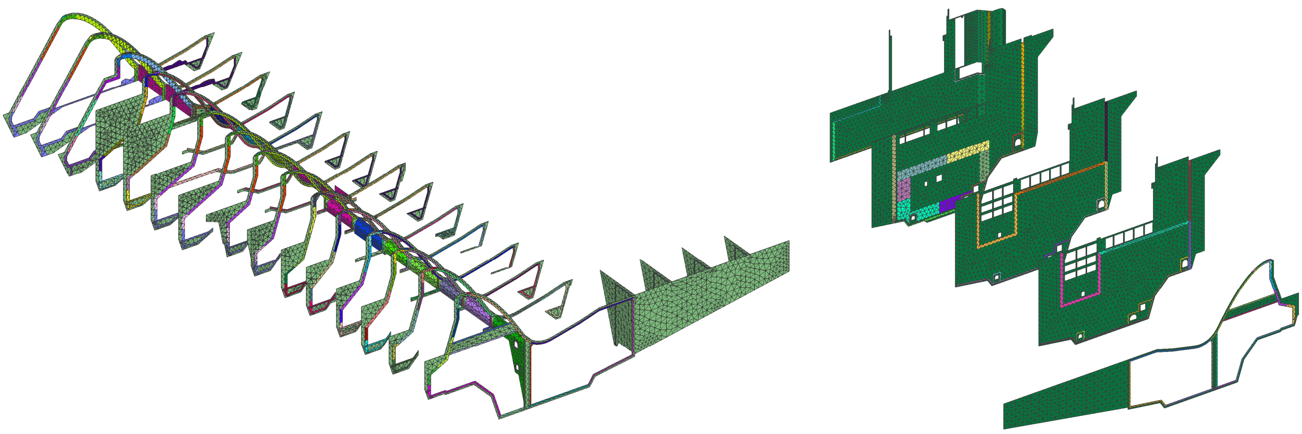

Figure 16. *2D finite elements of the model of the spillway dam and power plant*

DAM STATE ESTIMATION

Estimation of the state of thermal processes

Estimating the state of thermal processes implies that thermal fields in the dam's concrete are determined by applying the FEM model of the spillway dam and power plant so that the best agreement with the temperatures calculated using the FEM model is obtained at the concrete temperature monitoring points. Numerical simulations of thermal processes were carried out for non-stationary conditions. The procedure for determining parameter values is an optimization problem solved by optimization methods (genetic algorithms).

The parameters of thermal processes are heat conductivity coefficient, heat transfer coefficient (water-concrete and air-concrete), specific heat for concrete, and thickness of the headwater “layer” for estimating the tailwater temperature. The measurements used as input series (boundary conditions) are water level in the reservoir, tailwater level, air temperature, water temperature, and temperature at the foundation joint, while the measurements used for comparison with the results of numerical simulations are: concrete temperatures of piers 7 and 10 of the spillway dam and temperatures in the galleries. Figure 17 shows comparisons between measurement results and computation results for two thermometers for the estimated thermal state of the dam. Figure 18 shows examples of the effects of thermal computations (winter and summer) on pier 10 of the spillway dam for the estimated state of thermal processes.

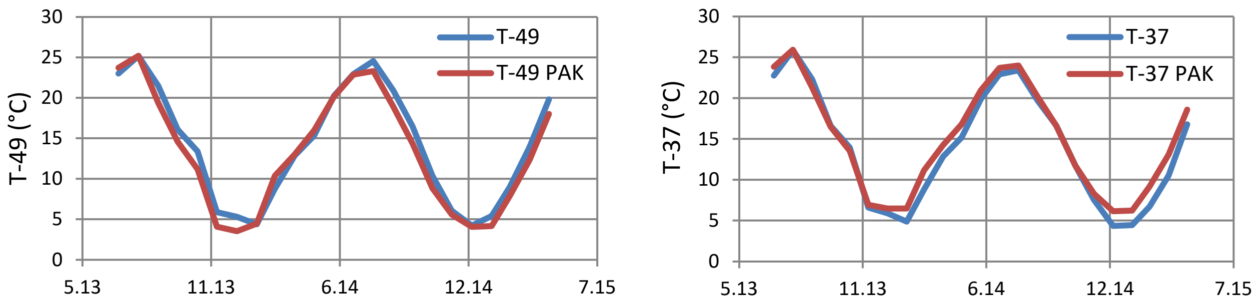

Figure 17. *Comparisons of measurement results and computation results of temperatures in concrete using the FEM model for all thermometers*

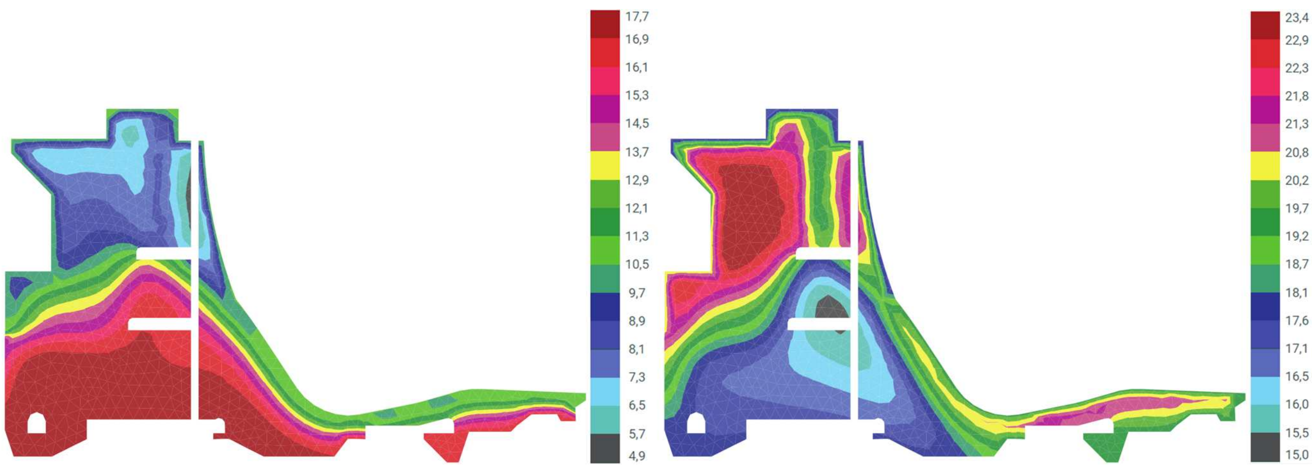

Figure 18. *Estimated thermal field of block 10 of the spillway dam on March 8, 2019 and September 30, 2019*

Estimation of the state of filtration processes

Estimation of the state of filtration processes involves the use of the FEM model of filtration processes, measurement of the water table and flow at overflow weirs and drainage wells, as well as the flow of pumped water from the system, to parametrize the FEM model, so that it adequately depicts the actual situation in terms of filtration processes at the dam at the measured upper and tailwater levels.

Estimating the condition of filtration processes is extremely important for the Iron Gate 1 Dam, bearing in mind the very complex drainage and sealing system, where any system malfunction can jeopardize the facility's functionality and damage the safety of the dam. The state estimation is analyzed on the integral model of the spillway dam and power plant and the associated rock mass.

When estimating the state, it is first necessary to determine the values of the parameters of filtration processes so that the best matches between the computation results and the measurement results at the considered measuring points are obtained. Numerical simulations of filtration processes were carried out for stationary conditions. Given that water tables and water flows fluctuate seasonally, the influence of seasonal changes in parameters was taken into account by adopting multiple time sections during the year and seasonal filtration characteristics of the material.

For the adopted realistically observed time sections, the following boundary conditions are set in the FEM model: on the wetted part of the structure and terrain with water from the reservoir, the potential of the measured headwater is set, and on the wetted portion of the structure and terrain on the downstream side, the possibility of the measured bottom water is set. All surfaces of the structure that are not wetted have an assigned free leakage; that is, the leakage is a function of the parameters of filtration processes. There is no water inflow on the lateral contours of the model.

The parameters of the filtration processes are the filtration coefficients for the materials (rock, grout curtain, drainage system...) and the effective permeability coefficients for the seals on the joints. The number of parameters to be determined included all significant non-homogeneities of all materials in the system, both spatially and temporally. Corresponding groupings of parameters in terms of quasi-homogeneity were performed (Table 3).

Table 3. *Overview of calibration parameters, grouped by material type*

Material	Number of model parameters	Total number of parameter groups	Number of fixed parameter groups	Number of variable parameter groups without seasonal characteristics	Number of variable parameter groups with seasonal characteristics
Concrete	36	9	9	-	-
Rock mass	8	8	-	8	-
Grout curtain	58	18	-	18	-
Drainage blanket	58	7	-	7	-
Drainage wells	36	5	-	5	-
Drainage boreholes	63	6	-	6	-
Seals on joints	215 (354*)	36	9	-	27
Connections between the body of the dam and the spillway	14	3	3	-	-
TOTAL	488 (627*)	92	21	44	27

*The number of model parameters for seals on the joints is 215. Of that number, 76 parameters have fixed values and were specified via 9 groups of fixed parameters. The other 139 parameters are classified into 27 groups of variable parameters with a seasonal characteristic (each of the 139 parameters has a summer and winter value of the filtration coefficient). Thus, the actual number of parameters is 139 (summer) + 139 (winter) + 76 (fixed) = 354.

The determination of parameter values is defined as an optimization problem that is solved by optimization methods (genetic algorithms) to determine the parameters of filtration processes within the limits of previously defined ranges so that the computed values of water tables and flow correspond as closely as possible to the measured values, which is achieved by using the following criterion functions:

- Criterion 1: the average value of the sum of the absolute values of the differences between the calculated and measured water levels in the zones of the piezometer heads should be minimal.
- Criterion 2: the average value of the sum of the absolute values of the differences between the calculated and measured flows of drainage, filtration, and seepage water at the overflow weirs should be minimal.
- Criterion 3: the average value of the sum of the absolute values of the difference between the calculated and measured flows of drainage water at the drainage wells and the flow of pumped drainage, filtration, and seepage water from the spillway dam and the power plant should be minimal.

We highlight the following conclusions based on the analysis of the sensitivity of the water table and flow in the system to changes in the parameters of the system elements:

- A change in the filtration coefficient of the grout curtain has a particular influence on the water levels in the zone of the grout curtain. Still, it is significantly smaller than the influence of the change in the filtration coefficients of the rock mass. In contrast, it has almost no effect on the flow of filtration and drainage water observed in the facility's foundation (grout and drainage) galleries and drainage wells. Failure of the grout curtain, in case of failure of the drainage system, does not endanger the facility. In that case, the uplift is slightly higher.
- Changing the filtration coefficient of drainage blankets has almost no effect on the water tables and flows in the system because filtration parameters of the rock mass have the most significant influence on the water tables, and the filtration parameters of the seals on the joints between the piers, that is, the sections of the structure, have the most significant influence on the flows. The mentioned phenomenon can be explained by the fact that all the foundation galleries can essentially be considered large drainage pipes, that is, conduits for seepage, filtration, and drainage water, and the water that is filtered to them is drained unhindered through drainage channels to the pumping station. A thin layer of drainage blankets will function equally successfully if it has a higher filtration coefficient than the rock on which it is located. In other words, as long as the foundation galleries are not submerged, the uplift on the spillway dam cannot be significantly more pronounced, and functional drainage blankets will further reduce it.
- Changing the filtration coefficient of the drainage boreholes has a particular influence on the water tables in the rock, while it has almost no effect on the flows.
- A change in the filtration coefficient of drainage wells has a significant impact on the water table in the rock. In contrast, their effects on flows are significantly smaller than the impact of the surrounding rock parameters.
- A change in the filtration coefficient of the seals on the joins has the most significant impact on the flows in the system. At the same time, their influence is significantly smaller on the water tables in the zone of the foundation joint.

The conclusions above provided directions for the further course of calibration, narrowing the search range of certain groups of system parameters and their adoption.

The problem of determining the parameters of filtration processes was translated into a multi-criteria optimization problem that was solved using evolutionary algorithms, specifically the NSGA-II genetic algorithm [26].

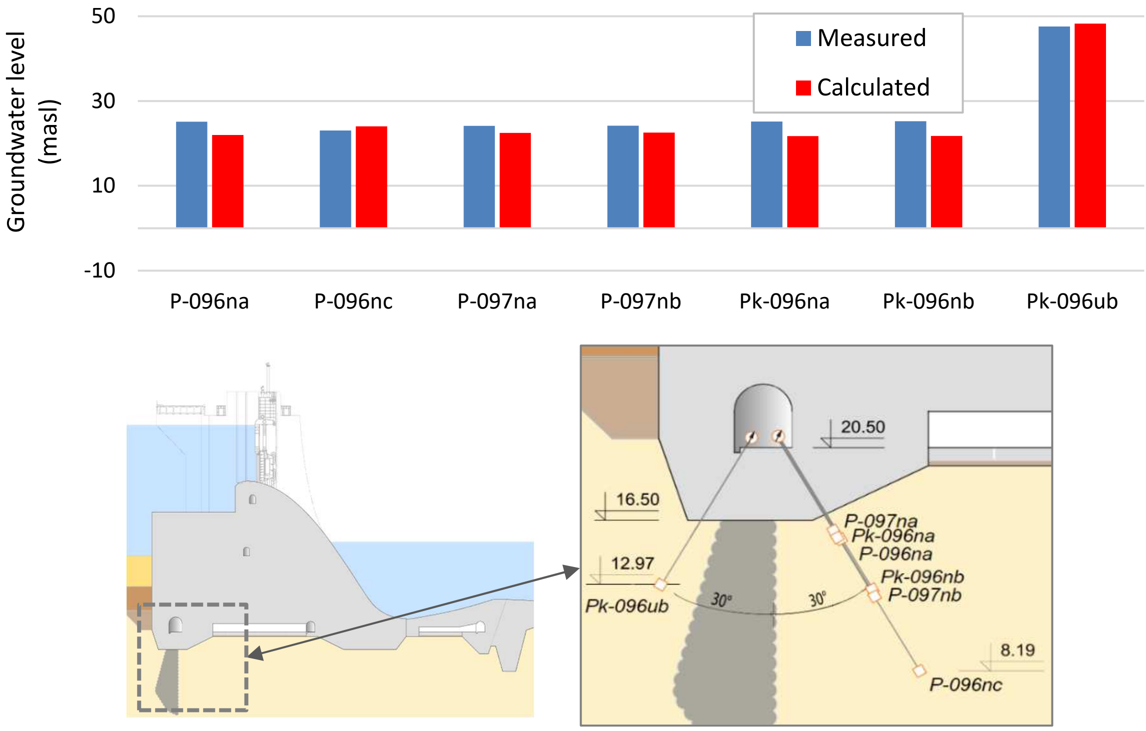

Figure 19. *Water tables in the zones of piezometer heads with manometers on block 11 of the spillway dam with a view of their positions*

Criteria were used to compare the measured and computed values of the following quantities:

- The water level in the zone of piezometer heads (water table) with a total of 270 measuring points
- The flow of drainage, filtration and seepage water at overflow weirs with a total of 7 measuring points
- The flow of drainage water at drainage wells with a total of 21 measuring points and the quantity of pumped drainage, filtration and seepage water from the structure with a total of 2 measuring points.

Examples of achieved matches of computed and measured values on January 27, 2020, are shown in Figures 19, 20, and 21.

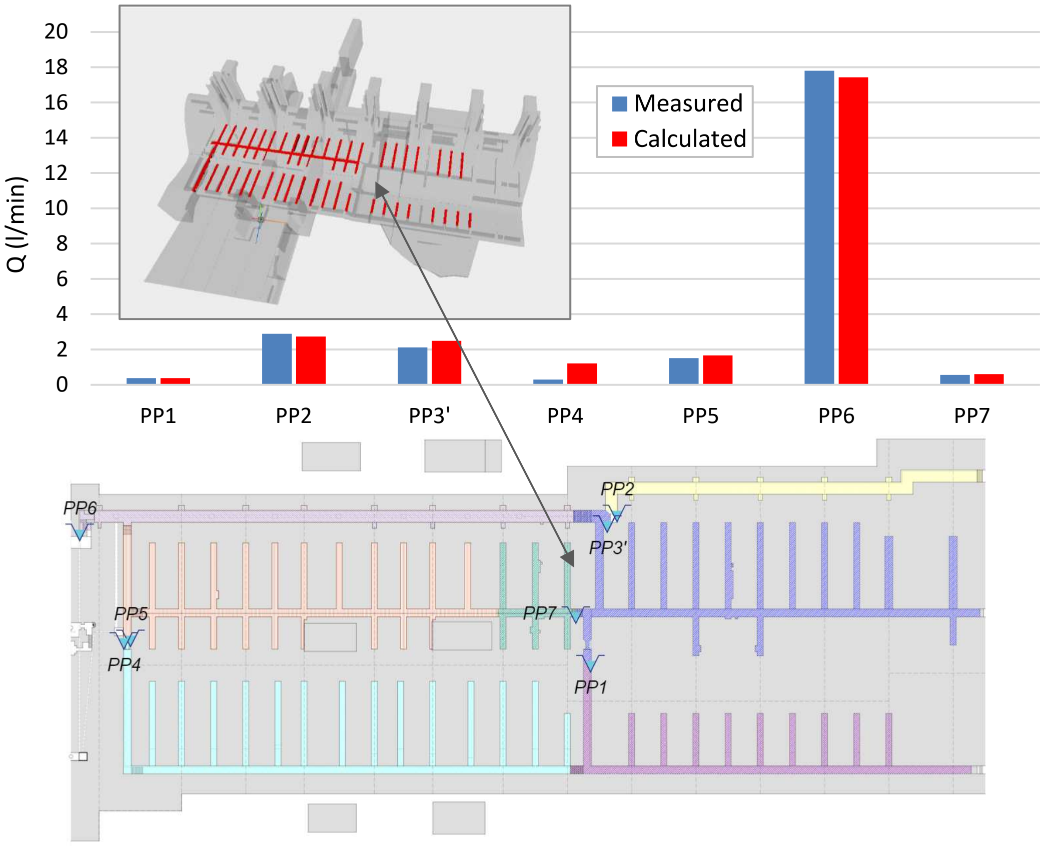

Figure 20. *Flows at the overflow weirs in the foundation galleries of the spillway dam with a view of the associated catchment areas*

Figures 22, 23 and 24 show examples of the results of filtration computation for computations created by combining the following effects and variations of the state of the drainage and sealing system:

- The water level in the reservoir and bottom water level at maximum Δh (at an inflow of 2000 m^3/s): WLR = 69.59 and BWL = 39.50 masl, where working floodgates are lowered on the spillway fields and the power plant, the shutters are raised, and the blades of the conducting apparatus are closed (the headwater is let into the spiral, and the tailwater is let into the siphon).
- The estimated state of the drainage and sealing system in summer conditions.
- A hypothetical situation in which the drainage system is not functioning (the galleries are submerged, and the drainage blankets and drainage wells on the spillway dam, as well as the drainage wells at the power plant, do not drain water, they are assigned a hydraulic conductivity of Kf=1.00E-10), which was simulated as follows: drainage wells, all hollow openings (galleries, rooms, and shafts) and expansion joints are submerged up to 40 meters above sea level. Other system parameters were calibrated, as in the previous case.

The estimation of the condition of the HPP Iron Gate 1 Dam, which mainly refers to the condition of the seals on the joints, the condition of the drainage system, and the grout curtain, is carried out based on information recorded by visual inspection, based on the results of the measurements carried out as part of the technical inspection and based on the obtained parameters of the filtration processes.

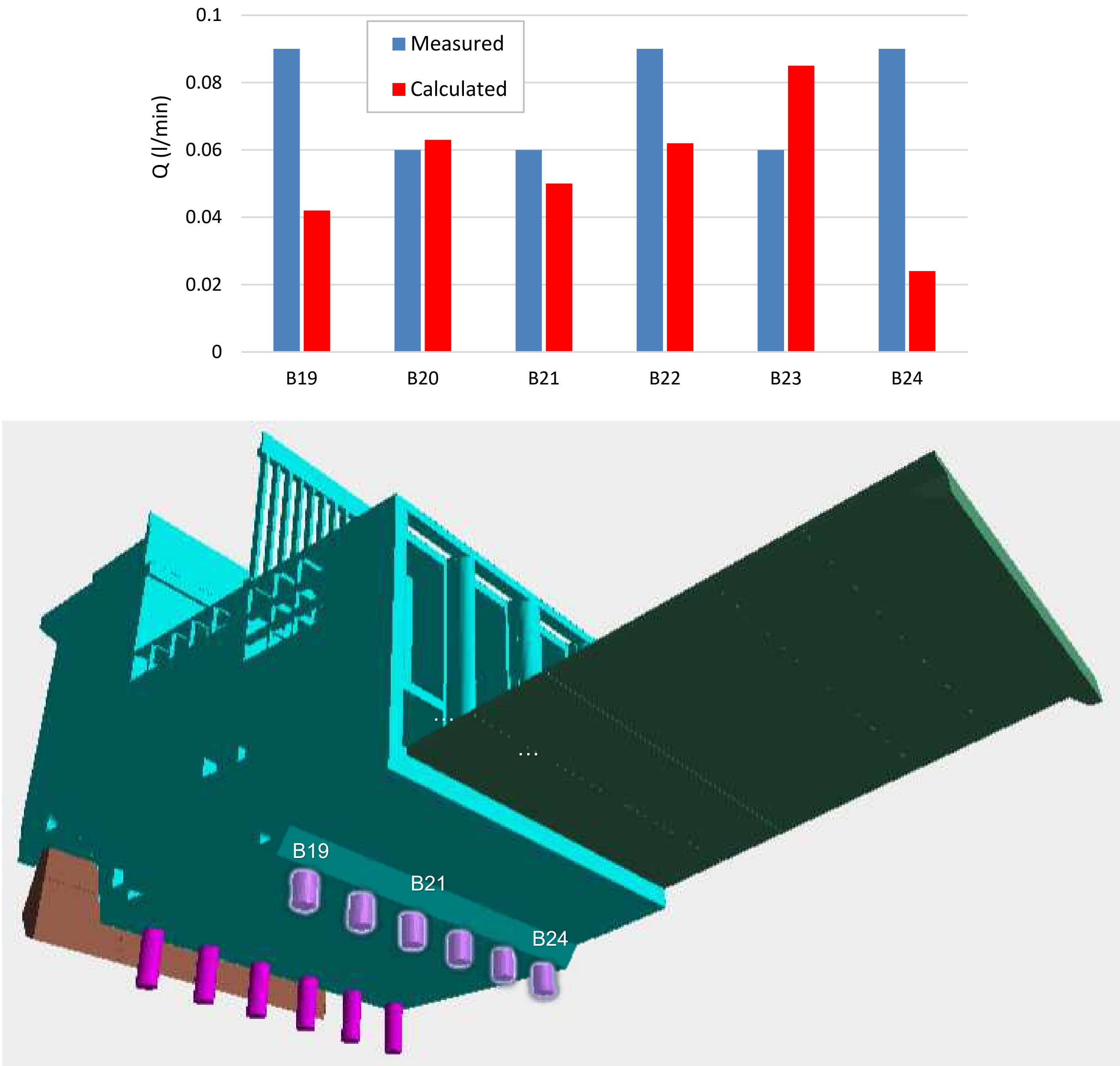

Figure 21. *Flows on the drainage wells in the drainage gallery on section I of the power plant with a view of their positions*

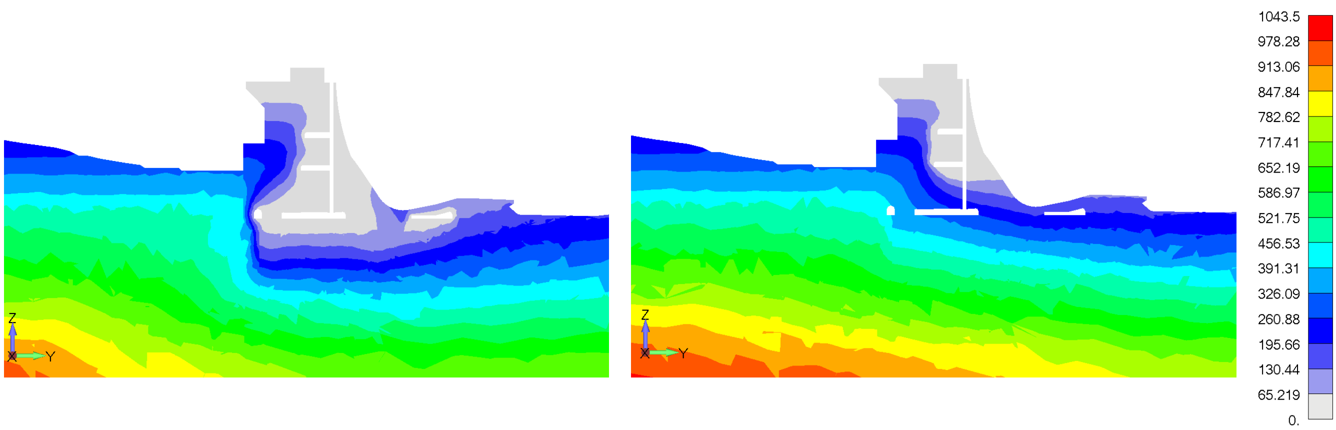

Figure 22. *Uplift pressure (kPa) on block 10 of the spillway dam with the estimated state of filtration (left) and with failure of the drainage system and grout curtain (right), for WLR=69.59 and BWL=39.50 masl*

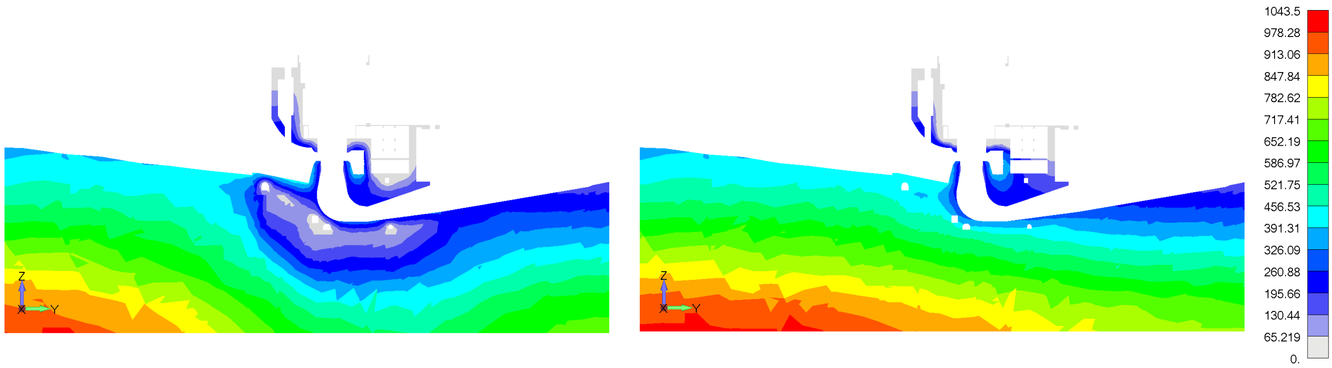

Figure 23. *Uplift pressure (kPa) on section II of the power plant (in the axis of aggregate A3) with the estimated state of filtration (left) and with failure of the drainage system and grout curtain (right), for WLR=69.59 and BWL=39.50 masl*

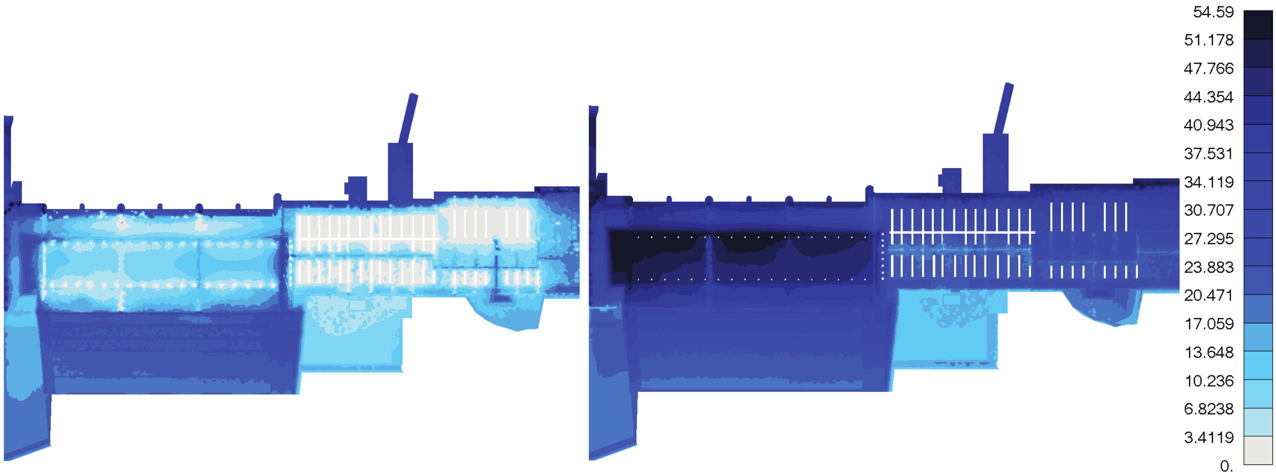

Figure 24. *Depth the water (m) at the foundation joint of the power plant and spillway dam (horizontal projection) with estimated filtration parameters (left) and with the failure of the drainage system and grout curtain (right), for WLR=69.59 and BWL=39.50 masl*

The results of the adopted set of filtration parameters of the elements of the FEM model belonging to the grout curtain, drainage wells, drainage boreholes, drainage blankets, and seals on the joints between the concrete segments of the system are shown in Figure 25, where all the mentioned parameters are divided according to the degree of functionality into 5 categories. In the rest of the text, we present conclusions about the state of the mentioned elements of the system:

- The grout curtain performs its function. According to the obtained filtration parameters, it can be said that the curtain in the zone of the first two sections of the power plant, as well as in the area of pier 11 of the spillway dam, has a slightly lower functionality compared to the surroundings. The most pronounced functionality of the curtains is in the middle of the river bed, i.e., in the zone of piers 12, 13, and 14.
- The drainage blankets on the spillway dam are functional, especially those in the area of the drainage gallery.
- The drainage boreholes on the spillway dam are mostly functional. Those from the spillway gallery are mostly partially functional.
- In the zone of the first section of the power plant, the drainage wells have minimal functionality, which is also true for wells of the dry gallery in the second section. The wells in the drainage gallery in the third section have the best functionality, while the wells of the dry gallery in the same section have partial functionality.
- The seals on the joints of the spillway dam are more functional than the seals on the joints of the power plant, which is in accordance with the fact that the method of monitoring their seepage and maintenance on the spillway dam is easier and more reliable (more accessible for inspection and repair from a large number of galleries and inclined manholes).

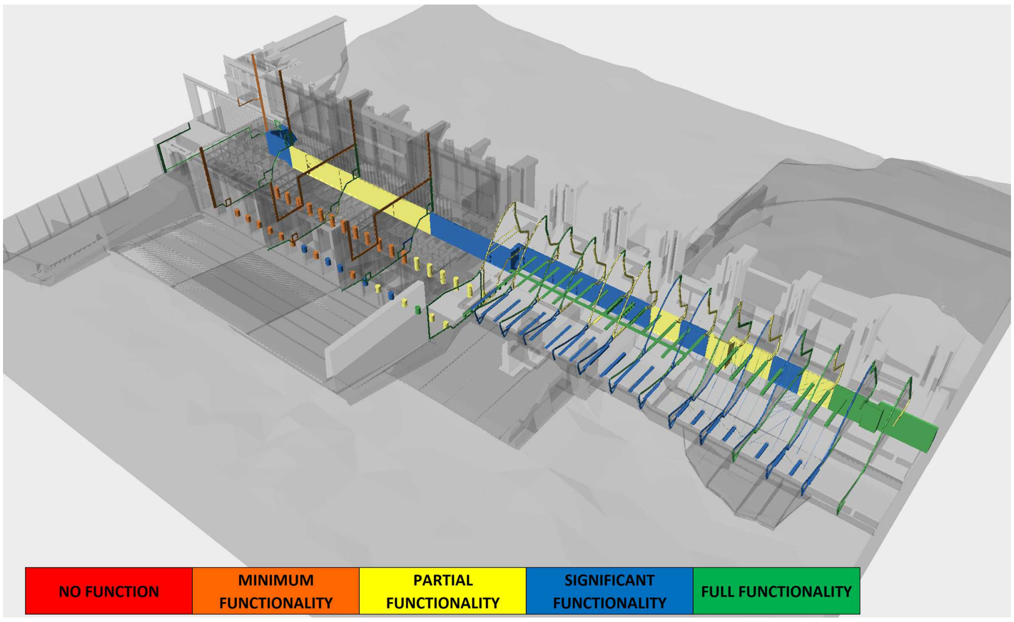

Figure 25. *An example of the results of the analysis of the condition of the seals on the joints, the drainage system and the grout curtain on the Serbian part of the facility (at the power plant and the spillway dam)*

Estimation of the state of stress-deformation processes

Estimation of the state of stress-deformation processes represents the most complex type of dam analysis, particularly the determination of dam safety. The state of the stress-deformation processes is determined by applying the FEM model; displacement fields, stress, and deformation fields are determined, and there is a good match between the measurement results and the computation results at the observation points. In connection with this, the values of the stress-deformation processes' parameters, representing the mechanical behavior of concrete and rock mass, must be determined.

The damage plasticity model defines the mechanical behavior of concrete and rock mass at the Iron Gate 1 Dam [22-25]. With the help of this material model, it is possible to simulate the most complex stress-deformation states in the material of concrete and rock mass, namely the material's behavior after reaching plastic deformations and the material's behavior after a fracture. This model has 16 parameters for which numerical values need to be defined for each material. It was assumed that the dam's concrete is the same for all piers and sections of the power plant. The rock mass is divided into six quasi-homogeneous zones, meaning a total of 16x7=112 mechanical behavior parameters must be determined.

Observation of stress-deformation processes' state occurs through a technical monitoring system where displacements, deformations, the behavior of cracks, and others are measured. However, based on these measured data, it is impossible to fully determine all the parameters of the damage plasticity model, especially those that define failure, given that the dam's behavior is predominantly in the elastic domain.

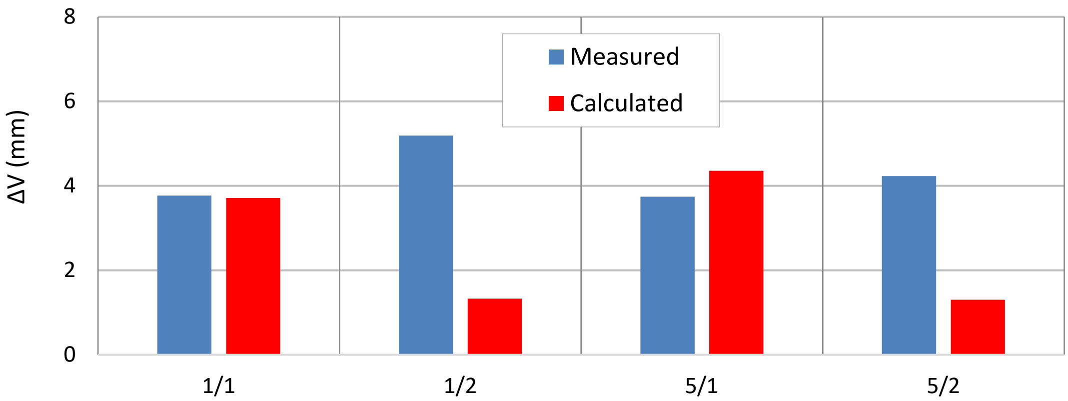

Figure 26. *Geodetic measurements - comparison between measurement results and computation results*

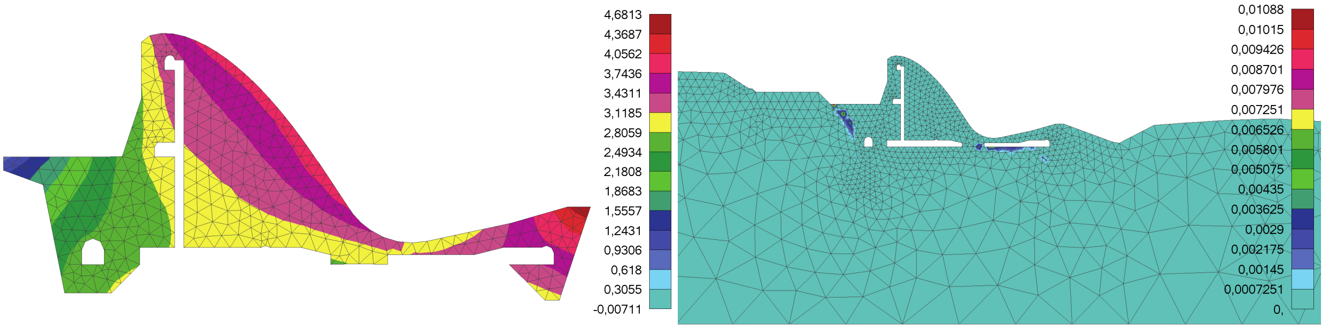

Figure 27. *Field of displacement in the direction of the Danube (mm) - left, field of damage (degradation) - right*

The results of in situ tests in the rock mass from the time of construction were used to determine the parameters that affect plastic deformation and fracture in the material. Here are the results of shear tests and hydraulic flat jack tests carried out in the investigation galleries during the dam's construction. In the research carried out by Radovanović [27], the algorithm and methodology for determining the parameters of the damage plasticity model based on the results of in situ tests were presented. Strength parameters for concrete were adopted based on literature guidelines and other facilities' experiences. For specific parameter values, states of stress-deformation quantities are computed. Figure 26 compares measurement and computation results of geodetic observations on the dam for particular dates. Figure 27 (left) shows the displacement in the direction of the Danube on pier 7 (section along the axis of the pier) for the computation scenario corresponding to September 2018. Figure 27 (right) shows the field of degradation (damage) in concrete and rock mass for the section along the axis of pier 7.

DAM SAFETY ASSESSMENT

Dame safety implies that the dam must be able to meet the appropriate criteria prescribed by specific regulations and rules at every moment of operation. The estimated state of the dam is a prerequisite for the safety assessment of the dam because it can be considered that the dam has been brought to a state that corresponds to the actual behavior of the dam. Another prerequisite to deciding on dam safety is the existence of adequate norms and regulations in the area of dam safety. In the Republic of Serbia, no particular dam calculation and safety assessment regulations exist. In current practice, when designing dams, recommendations and guidelines of various structural organizations (ICOLD, USBR, US Army Corps) were mainly used.

In the Republic of Serbia, at the beginning of 2020, a new Ordinance for Building Structures came into effect, which is essentially based on the application of European regulations (Eurocode). This Ordinance does not provide explicit provisions that apply to dams but implicitly provides guidelines for defining criteria. In this regard, the provisions of this Ordinance offer the only legal basis in Serbia that must be used to formulate criteria and prove the safety of all building structures, including dams. According to this Ordinance, the use of Eurocode standards is defined for the implementation of calculations and control of compliance with safety criteria of structures. Applying this Ordinance for dam safety analysis is possible with appropriate interpretations of the basic provisions of the Eurocode standards, based on the application of the reliability method and especially the provisions of Eurocode 0. In this sense, bearing in mind that dams are complex structures that must be viewed integrally with the rock mass and water, relying in principle on the basic provisions of the Eurocode, specific criteria were formulated that were applied for the safety analysis of the Iron Gate 1 Dam.

Safety control is carried out by calculating the global safety factor for the estimated condition of the dam using the FEM model using the shear strength reduction method. The computed value of the worldwide safety factor must be greater than the minimum required according to the defined criteria. Safety control of the Iron Gate 1 Dam was analyzed at Pier 7, 10, and Section 2 of the power plant for regular exploitation situations and incidents in which the drainage system failed. The dam's safety against the concrete structure's failure and rock mass's failure is satisfied for all calculation situations. It should be emphasized here that the most significant influence on the computed values of the safety factor for both boundary conditions mostly depends on the mechanical properties of the rock mass, i.e., concrete. The values of the parameters of the constitutive model, which defines the mechanical behavior of the rock mass and concrete, were determined based on earlier considerations: for the rock mass, based on the results of investigative works from the time of construction, and for concrete, based on recommendations from the literature and available information on the quality of concrete. The presence of the scale effect, which significantly affects the material's shear strength reduction, should be emphasized here. In connection with this, the obtained safety factor values must be taken with a certain degree of doubt.

As for uplifting the dam, this limit state depends on the vertical uplift forces, the weight of the dam's concrete structure, and other stabilizing effects (bearing capacity of anchors on the spillway). The limit state control of the spillway dam was checked separately for the body of the dam and the spillway part. Vertical uplift forces were calculated for the considered calculation situations and conditions of the drainage system using the FEM model of filtration processes. The weight of the concrete structure itself was calculated based on the structure's actual volume and the concrete's specific weight. The computation of the stabilizing forces in the case of uplift control also depends on the bearing capacity of the anchors in the spillway zone of the spillway dam.

Control of the uplift limit state was carried out for normal operating conditions and incidents when the drainage system failed (with submerged foundation galleries). In the case of normal operating situations, the obtained safety factor values are significantly higher than those obtained during incidents. Additionally, the safety factor values are higher for all computational situations at the dam body than at the spillway. In case of failure of the drainage system, safety factor values ranging from 1.6 to 1.8 and from 1.4 to 1.7 are obtained at the spillway. These values are obtained for the assumed values of the anchor layout without considering the changed hydraulic regime due to overflow, so the specified values may be even lower.

In the following period, it is necessary to determine the actual layout of the spillway zone's anchors to calculate the most reliable force from the bearing capacity of the anchors. In addition, to assess the safety of the spillway against floatation in case of overflow, it would be helpful to make a physical model of the spillway to evaluate the fluctuation and water level when the weirs are operating. This is especially significant because the flow regimes were changed after the rehabilitation of the spillway (it was completed at the beginning of 2022).

CONCLUSION

The development of the presented Safety Management System of the HPP Iron Gate 1 Dam greatly contributes to the upgrade and improvement of the monitoring and analysis of the condition of the Iron Gate 1 Dam, which was monitored by purposefully created monitoring systems during its operation. With the development of software systems that combine systematized and validated measurements made during decades of observation, the conditions for their application and use within the framework of complex analyses of the dam's behavior were obtained to assess its future behavior even under conditions that had not previously been realized. This type of predictive behavior of structures is made possible by the development of FEM models and the calibration of the parameters of their elements so that they better depict the realistically observed thermal, filtration and stress-deformation behavior of the structure. Systems such as this one require maintenance and improvement of their functionalities, which in the case of the HPP Iron Gate 1 Dam can be realized by expanding the scope of the FEM model to include a navigational lock and an embankment dam, as well as the Romanian part of this complex hydroelectric navigation system. The proposed safety management concept at the HPP Iron Gate 1 Dam can be applied to other dams for generating electricity, water supply, irrigation, etc.

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CONTEMPORARY WATER MANAGEMENT: CHALLENGES AND RESEARCH DIRECTIONS

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PREFACE

Institute of Hydrology was established in 1947 within the Serbian Academy of Sciences. The Hydraulics Laboratory was established that same year within the Federal Ministry of Electricity, a predecessor of the later Hydropower Institute created in 1950. These two institutions were soon merged under the auspices of the Serbian Academy of Sciences into the Hydrotechnical Institute Eng. Jaroslav Černi. This Institute merged with the Serbian Water Management Institute in 1959 to create today's Jaroslav Černi Water Institute.

Over the past decades, the Institute has been the backbone of scientific research in the field of water in Serbia and the former Yugoslavia. The international scientific conference Contemporary Water Management: Challenges and Research Directions is organized to celebrate 75 years of the Institute's long and successful history. The Scientific Board selected 26 papers to provide readers with the best view of the current research results, as well as the further scientific research directions and potential challenges in the future. Selected papers are classified into six conference topics according to the corresponding research field, although one should note that most of the presented works is multidisciplinary, which is after all a characteristic of a modern problem-solving approach in the field of water. Hence, the chosen conference topics and corresponding papers represent only one possible way of classification of the presented works.

We wish to express our gratitude to the International Scientific Board and the Organizing Committee of this international conference for their efforts in selecting the papers, reviewing, and organizing the conference. We also wish to express our gratitude to all the authors of selected papers for the time they spent presenting the results of their research in a way suitable for this conference, and for contributing to the celebration of 75 years since the establishment of the Jaroslav Černi Water Institute. Respecting the importance of jubilee and wishing to express gratitude to previous generations of scientific workers, the Honorary Committee was also formed.

Following the path of previous generations, the Institute's present and future staff remain privileged, and under duty and obligation to continue and improve the scientific and research work of the Institute in the years and decades to come.

Belgrade, October 2022

Editors

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