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IMPLEMENTACIJA AUTOMATIZACIJE MJERENJA UZGONSKIH TLAKOVA I TEMPERATURA U BETONSKOJ BRANI HIDROELEKTRANE

IMPLEMENTATION OF AUTOMATED PROCESS MEASUREMENTS OF BUOYANCY PRESSURES AND TEMPERATURES IN THE CONCRETE DAM OF A HYDROPOWER PLANT

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ABSTRACT

The paper presents the implementation of the automation of existing measuring points by installing vibrating wire piezometers in the inlet and outlet tunnels of the hydropower plant. This achieved automatic recording and display of the data on the monitoring system so that the measuring points no longer have to be visited to read the measured values manually. The process measurements of the uplift pressures at the base of the dam allow the condition of the injection curtain to be monitored and the permeability of the dam to be checked in real-time, which is extremely important for the stability of the structure. This paper describes the functionalities and installation of all components of the measurement system. It also analyses the measurement data with a graphical representation of the measurement data to achieve optimal system operation.

Key words: *dam, buoyancy, temperature, measurement system, vibrating wire piezometer, data logger*

1. UVOD

1. INTRODUCTION

A dam is a structure [1] built across a river, estuary, or watercourse to hold back water. They are built for a variety of uses [1], such as providing water for human needs or for industrial processes.

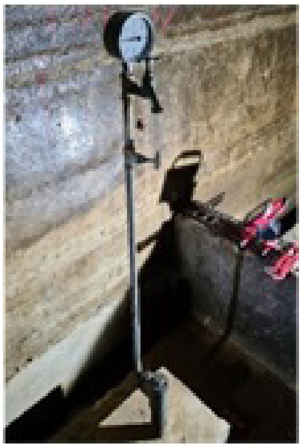
Various types of loads can act on them, such as [2]: hydrostatic pressure, buoyancy pressure, wind loads, seismic activity, thermal loads due to temperature changes over the seasons, etc. Buoyancy is the force acting on the foundation and concrete structure of a dam. The pressure occurs in the cracks and pores of the concrete, at the junctions of dams and foundations, and in the bedrock. High uplift pressure [2] can severely affect the stability of the structure and be a major cause of dam failure. Therefore, they must be analysed and considered in the design or evaluation of such structures.

In this paper, an automatic system for measuring the uplift pressure and temperature in dam foundations is presented. Due to the difficult availability of measuring points in injection and drainage tunnels, the automation of existing measuring points was carried out. This resulted in regular and reliable collection of information on the condition of uplift pressures. The operation of an automated measuring system with all its components is described here. In addition, the installation of this system is described. At the end of the article follows a presentation of the measurement data with a discussion.

2. PRIKAZ POSTOJEĆEG STANJA SUSTAVA

2. DESCRIPTION OF THE EXISTING STATE OF THE SYSTEM

Twenty-eight gaging stations were established in the injection and drainage tunnels of the dam, divided into three gaging sections with a manometer for visual readings of the water pressure below the dam foundation. Readings were taken at regular intervals by visiting all measuring points and entering the readings in the table. To reach the measurement points, it is necessary to descend about 15 meters via a ladder to the discharge and injection shroud, which poses a fall hazard and requires physical exertion. In addition, there is no electric lighting in the galleries and there is high humidity and calcification, which makes visiting the measuring points even more difficult. Based on the results of the gages, a diagram of the distribution of buoyancy across the width and length of the dam is created. These results allow conclusions to be drawn about the permeability beneath the dam and the condition of the injection curtain. The devices used to measure buoyancy consist of 2" diameter galvanized pipes inserted into boreholes that pass through the foundation material and penetrate 50 cm into the foundation soil.



Slika 1 *Mjerna točka prije montaže automatskog sustava*

Figure 1 *Measuring point before installing an automated system*

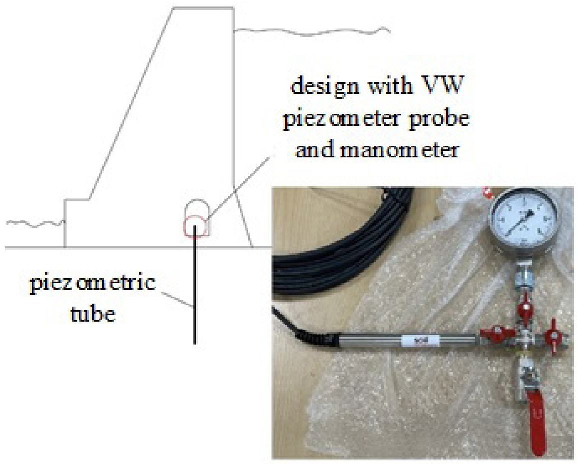
A reduction was made on the pipe dimension 2”, to which a ½” dimension pipe was connected. At the upper end of the reduced pipe there is a pressure gage from which the water pressure in the well is read, as well as a manual valve.

Due to the age of the equipment, several pressure manometers show incorrect pressures, do not work at all, or show questionable readings. Due to the high humidity in the drainage and injection tunnels, the valves on the piezometric pipes are badly corroded, and most of the valves are inoperable.

3. OPIS AUTOMATSKOG MJERNOG SUSTAVA

3. DESCRIPTION OF THE AUTOMATED MEASUREMENT SYSTEM

By automating the existing measuring points, higher reliability and easy availability of data from piezometers in the injection and drainage tunnels was achieved. Instead of the old design, a new design was installed on the existing piezometer tubes, which includes a VW piezometer for automatic measurement of uplift pressures and water temperatures, thus achieving automation of the system. Figure 2 shows a typical application of a piezometer in a concrete dam, manufactured by Soil Instruments.

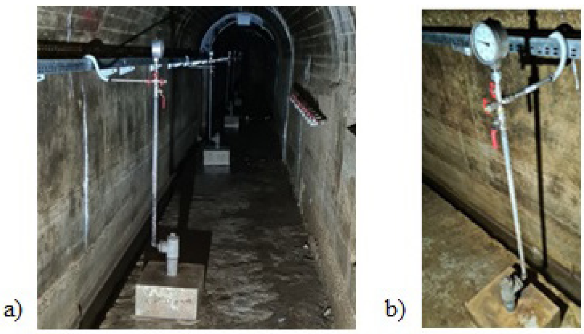


Slika 2 *Prikaz instalacije VW piezometra i manometra u betonskoj brani*

Figure 2 *Representation of the installation of a VW piezometer and manometer in a concrete dam*

The design of this type of piezometer is not available as a mass-produced product, but was made to technical specifications for the needs of this project. The orientation of the VW piezometer and manometer is such that the piezometer faces the wall-mounted cable shelves so that the sensor cable has a direct and shortest possible entrance into the cable tray. The manometer is pointed at the passage, allowing easy reading of the measurements from the manometer. Figure 3a. shows an automated measurement line, while Figure 3b. shows an automated measurement point.

In addition to the installation of a VW piezometer, which allows the automation of the system, the possibility of manual reading with pressure gauges remains. This allows checking the correctness of the measurements of the VW piezometer. Pressure gauges of model 232.50 from WIKA were used. The measuring range of the manometer is from 0 to 6 bar. Since the installation of the automated system takes place in a hydroelectric power plant, the pressure gauges are filled with glycerine due to the vibrations that occur there.



Slika 3 a) *Automatska mjerna linija, b) Automatska mjerna točka*

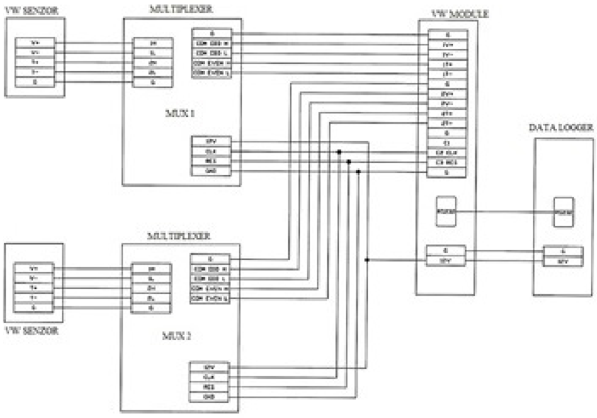
Figure 3 a) *Automated measuring line, b) Automated measuring point*

With this we want to reduce the vibrations and thus lessen their effects on the mechanical wear of the pressure gauges. Moreover, filling with glycerine limits the movements of the pointer under the influence of vibrations. Without the glycerine filling, the pressure gauge would not indicate the actual pressure condition, but the vibrations would cause the pointer to oscillate. In the case of a resonant frequency, a deflection angle of 180º is possible. Glycerine also serves as a protection for the internal parts of the manometer and reduces friction by adding a layer of lubricant between the moving parts. The case of the manometer is not completely filled, as glycerine absorbs additional water depending on humidity and ambient temperature and expands accordingly. To provide enough space for this expansion and to prevent the housing from leaking, the housing is filled to 80 to 90 %.

A ball valve is located at each branch, corresponding to the VW piezometer and pressure gauge. Its purpose is to allow a separate branch to be closed for the purpose of maintenance or replacement of the associated part without affecting the rest of the system. In the event of a VW piezometer malfunction, it is possible to remove the piezometer for maintenance purposes, while retaining the ability to manually check the uplift pressure for the duration of the service. Due to corrosion and malfunction of the old main valves, a new main ball valve was also installed in the new structure, which serves to close the entire structure. Thread sealant adhesive must be used on all joints to secure the joint at higher pressures and to further secure the joint due to the high humidity and vibration in the drainage and injection tunnels. The bleed valve is used to vent air when air occurs in the piezometric tube and thus inside the structure. The presence of air in the system can affect the measurement results and lead to erroneous measurements.

The piezometers used in this measurement work on the principle of vibrating wire [3]. Therefore, in order to receive the signals from VW piezometers, it is necessary to use a VW analyser module. In this way, not only the measured values of the sensor are adopted, but also the problem of inaccurate measurements due to external interference is eliminated. By using relay multiplexers, the number of sensors that can be connected to the analyser module can be expanded (Figure 4). An excellent style manual for science writers is [7].

It is possible to connect 32 VW sensors without thermistor or 16 VW sensors with thermistor to one multiplexer, and to connect two multiplexers to one analyser module. The analyser module is designed to work with and complement both Campbell Scientific and other manufacturers' data loggers. Using the direct RS - 232 connection, it is possible to connect four analyser modules to one data logger. For the needs of this measurement system, two multiplexers and one analyser module were used, which allowed the connection of all 28 VW piezometers to the data logger. Figure 4 shows a block diagram of the system.

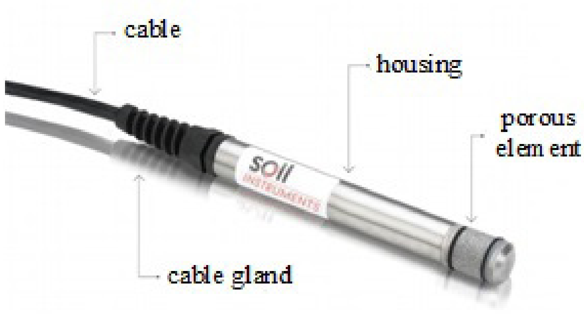


Slika 4 *Blok dijagram mjernog sustava*

Figure 4 *Block diagram of the measuring system*

VW piezometers (Figure 5) contain four output wires for signal transmission. The T + and T- signals are used for the temperature measurement output, while the V + and V- signals are used to measure the resonant frequency of the wire and thus the pressure. The signal marked G represents the sheath of the signal cable and is connected to the corresponding input of the multiplexer. The signals of the VW piezometer are connected to the input channels of the multiplexers marked H and L. Each VW piezometer occupies two channels, one for measuring frequency and the other for measuring temperature. The output channels of the multiplexer are marked with ODD and EVEN and are connected to the corresponding input channels of the VW analysis module. Communication between the data logger and the VW analysis module is via a direct RS - 232 connection. The vibrating wire piezometer accurately measures water pressure in the pores of a fully or partially saturated soil and is designed for pressure ranges from -50 to 4000 kPa. The small diameter piezometer is hermetically sealed and features temperature compensation with an internal thermistor to measure temperature. It also has built-in overvoltage protection in case of an overvoltage in the cable during a thunderstorm.

The main advantages of this measurement method are: accurate and repeatable measurements over long cable distances, long life and reliability, and fast response to pressure changes.



Slika 5 *Prikaz VW piezometra tip W9 (© Soil Instruments)*

Figure 5 *Representation of VW piezometer type W9 (© Soil Instruments)*

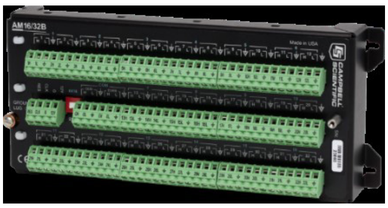
The piezometer consists of a porous element at the tip connected to a VW transducer made entirely of high-integrity material. The sensor wire, diaphragm, and sensor wire armature are enclosed in an independent unit. The transducer consists of a rigid cylinder sealed on one side with a waterproof bulkhead and on the other side with a thin membrane that serves as a sensor. Between these two points is a thin sensor wire. The tension of the sensor wire depends on the force acting on the membrane. So, if you change the voltage of the wire, its resonant frequency will change. This means that the resonant frequency of this wire is directly related to the pressure acting on the sensor membrane. This means that by measuring the resonant frequency, we are measuring an external parameter. The coil and magnet assembly excite the wire by applying a magnetic field, which then vibrates at a resonant frequency. This circuit is also used to read the oscillations of the wire by inducing a signal in a magnetic field, which is then analysed by an analysis module (Figure 6).

Slika 6 *Prikaz modula VW analizatora tip AVW200 (© Campbell Scientific)*

Figure 6 *Representation of VW analyser module type AVW200 (© Campbell Scientific)*

The AVW200 analysis module uses the patented Vibrating-Wire Spectral Analysis Technology (VSPECT) [4]. Namely, during long-term use of sensors, their amplitude or frequency may deteriorate. With the conventional method of measurement in the time domain [5], it is difficult to obtain accurate measurements. By using the module, the accuracy of data directly from the sensor is ensured. The use of VSPECT technology ensures 10 times higher measurement accuracy compared to the conventional time domain measurement method. The time domain measurement method analyses the response of the sensor as a function of time using a period average. The average time between a predetermined number of transitions above zero with an increasing slope is measured and the resonant frequency of the wire is determined. This method is applicable only under conditions of low interference. Manual removal of electrical noise from the measured data requires additional resources and time and complicates performance. In this way, the interference is removed before the measurement data is stored. No additional processing is required to remove the erroneous data. Accordingly, the measurement data can be used in real time, which is very important for alarm systems that must operate in real time.

The use of spectral analysis provides additional benefits in the form of diagnostics that include signal amplitude, signal-to-noise ratio, and spurious frequency. The diagnostic variables in this analysis allow the correct measurement to be extracted, the source of the interference to be understood and identified, and the condition of the sensor to be determined. This allows the sensor to be used for a longer period of time, reducing the number of sensors that need to be replaced during the use of the automated measurement system.



Slika 7 *Prikaz relejnog multipleksera tip AM16 (© Campbell Scientific)*

Figure 7 *Representation of relay multiplexer type AM16 / 32B (© Campbell Scientific)*

The main function of the AM16 / 32B multiplexer (Figure 7) is to increase the number of sensors that can be connected to the CR1000X data logger. Mechanical relays within the AM16 / 32B multiplexer connect each of the input channels to a common output.

This measurement uses multiplexers in a 4x16 configuration, which allows a maximum of 16 sensors to be connected to one multiplexer. For this reason, it is necessary to use two devices to ensure sufficient capacity for all sensors. The multiplexer is controlled by a data logger via the driver.

The data logger type CR1000X is an important part of the sensor data acquisition system that provides measurement and control. It is designed to acquire data from sensors, initiate direct communications and telecommunications, analyse data, control external devices, and store data and programs in the built-in, energy-independent memory. Accuracy of time measurement is achieved by using an internal clock with additional battery supply, which allows you to maintain the correct time even in the event of a power failure. It contains a central processing unit, analog and digital measurement inputs, analog and digital outputs, and memory. It also contains an operating system that synchronizes the functions of the listed parts together with the internal clock and the CRBasic application program. It can be programmed with the CRBasic Editor application, which uses the CRBasic programming language, or with the Short Cut application. Both applications are part of the LoggerNet software tool (© Campbell Scientific).

Slika 8 *Prikaz zapisivača podataka tip CR1000X (© Campbell Scientific)*

Figure 8 *Representation of data logger type CR1000X (© Campbell Scientific)*

The CRBasic Editor application is intended for experienced developers and offers greater flexibility compared to the capabilities of the Short Cut application. With the delivery of the data logger, the manufacturer has also created the program according to the required settings and the equipment used.

4. MONTAŽA AUTOMATSKOG MJERNOG SUSTAVA

4. INSTALLATION OF THE AUTOMATED MEASUREMENT SYSTEM

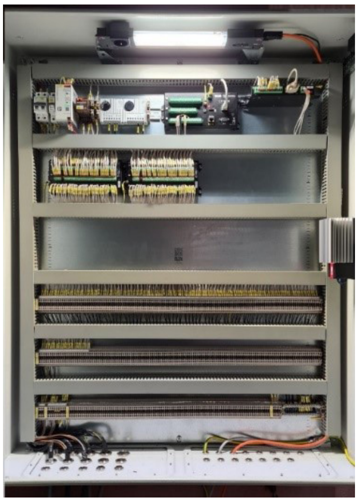
During installation the automated system for the technical observation of buoyancy pressure, preparatory activities had to be carried out so that the system could be installed correctly and in accordance with the professional rules. These preparatory activities include: the installation of cable racks for the laying of sensor and signal cables, the installation of junction boxes, the laying of sensor and signal cables, the laying of power cables, and the manufacture and installation of electrical cabinets.

In order to protect the original sensor and signal cables from mechanical damage, it was necessary to install cable trays for laying the cables. According to the required specification, perforated cable shelves made of galvanized steel were chosen due to their resistance to oxidation. Due to the limited dimensions of the corridor in the dam's drainage and injection gallery, most of the cable tray is mounted on brackets, while a smaller part is mounted directly on the wall.

The piezometers are supplied with an original sensor cable 20 meters long. Since the cable route from the sensor to the control cabinet is much longer, about 80 meters for each measurement section, the equipment costs would increase considerably if the original sensor cable were laid along the entire length of the cable route. Therefore, three junction boxes were used, mounted in the middle of the corresponding sensor cable. In the junction boxes, the original sensor cables are connected to the multi-core signal cables. The junction boxes and cable glands are designed in the IP 67 [6] version. Polycarbonate junction boxes PK 9524.0000 from manufacturer Rittal were used. They are marked in the order + SK1, + SK2 and + SK3. In addition, signal cables type YSLCY-OZ and YSLCY-JZ were used to connect the original sensor cables. A 230 VAC power supply is provided from a sub-distribution of a nearby distribution cabinet to power the lighting and heaters in the cabinet. An uninterruptible power supply with an autonomy of 3 hours is provided for 220 VDC power supply needs. For 230 VAC power supply and 220 VDC power supply, NYCY power cable of 3x2.5 / 2.5 mm2 type has been chosen.

According to the technical specification, it is necessary to install a cabinet with minimum dimensions of 1000x12000x300 mm and a mechanical protection degree of at least IP 55 [6]. The free-standing low-voltage cabinet AE 1213.500 from Rittal was chosen. To supply the measuring devices, the voltage must be reduced from 220 VDC to the corresponding voltage of 12 VDC.

In addition to the measuring devices, other components are installed in the cabinet: LED system lamps, thermostat, hygrostat, heater, circuit breaker, door position switch, AD converter and relay (Figure 9).



Slika 9 *Prikaz opreme u elektro upravljačkom ormaru*

Figure 9 *Representation of equipment in the control cabinet*

5. REZULTATI MJERENJA I DISKUSIJA

5. MEASUREMENT RESULTS AND DISCUSSION

The mathematical relationship between the frequency of the vibrating wire and the force applied to the piezometer is approximately linear between the square of the measured frequency and the applied force. Engineering units can be derived from frequency-based units that result from measurements made by measuring devices.

Engineering units [7] can be derived in three ways: from "period" units (t x 107) or "linear" units (f2 /1000) in two ways, using a simple linear equation or an equation with polynomials. In this case, "Linear" units and a linear equation were used to obtain engineering units for pressure measurements. According to the manufacturer's instructions, the formula (1) for calculating engineering units is as follows:

$$E = G \cdot (R_0 - R_1) \quad (1)$$

where following is:

E [kPa] - result in engineering units,

G [kPa/unit] - linear sensor factor,

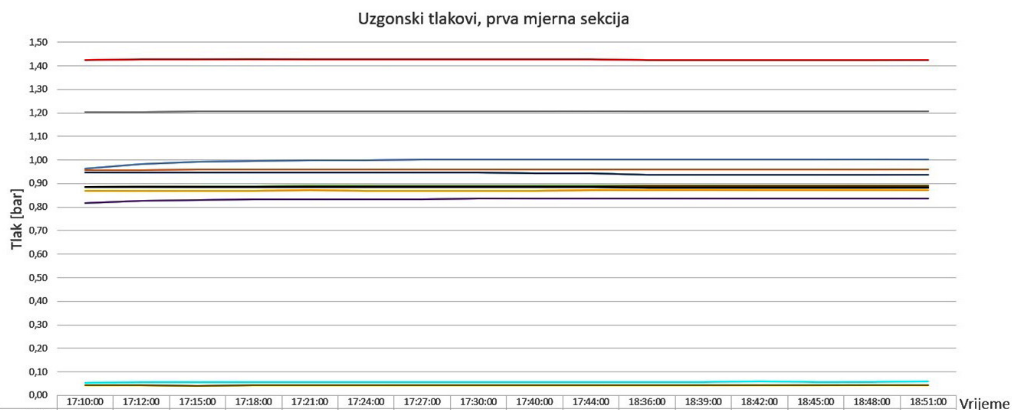
R_0 - zero measurement at the sensor mounting location,

R_1 - current measurement.

The linear factor of the sensor is specific to each individual sensor. When each sensor is shipped, you will receive a factory calibration sheet that contains the results of the factory calibration measurements and the sensor factors. A linear factor for the corresponding sensor was taken from each calibration sheet. Zero measurements were made at the dam site with no pressure influence on the piezometer, i.e. measurements under the influence of atmospheric pressure. It is not necessary to use engineering units for temperature measurements because the measurement results of the gauges are already expressed in units of ⁰C.

The measurement points in the measurement data are identified in the order MM1 to MM28. In the first measurement section, there are twelve measurement points, from MM1 to MM12, in the second measurement section, there are nine measurement points, from MM12 to MM21, while in the third measurement section, there are seven measurement points, from MM22 to MM28. In the following, only the measurement results for the first measurement section are shown. Figure 10 shows the results of the buoyancy pressure measurements from the first measurement section in the diagram. The diagram shows that most of the sensors indicate the approximate pressure value, while MM11 and MM3 indicate a slightly higher-pressure value. It can be observed that for the measurements with MM9 and MM10, the measurement results are almost 0 bar. From these measurement results, we can conclude that the piezometric tube is clogged.

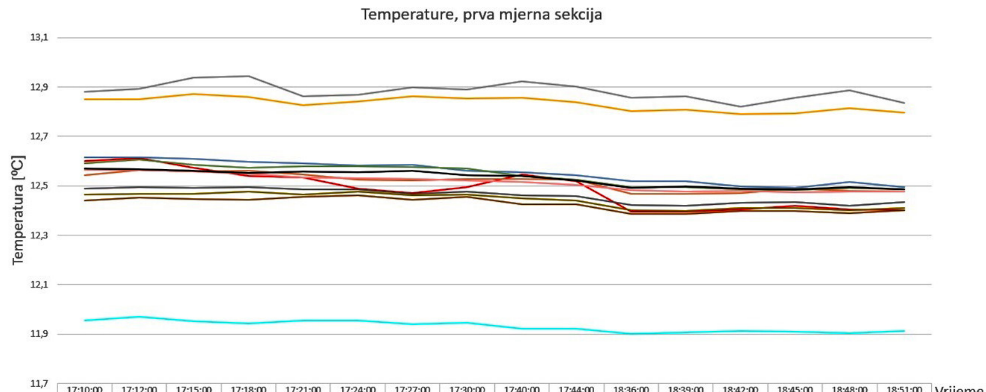
Figure 11 shows the results of measuring the temperatures of the first measuring section in the diagram. It can be seen that the measuring point MM7 shows a slightly lower temperature, while MM4 and MM3 show a slightly higher temperature compared to the other measuring points in the first measuring section.



	17:10:00	17:12:00	17:15:00	17:18:00	17:21:00	17:24:00	17:27:00	17:30:00	17:40:00	17:44:00	18:36:00	18:39:00	18:42:00	18:45:00	18:48:00	18:51:00
MM1	0,82	0,83	0,83	0,83	0,83	0,83	0,83	0,84	0,84	0,84	0,84	0,84	0,84	0,84	0,84	0,83
MM2	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96
MM3	1,20	1,20	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21	1,21
MM4	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87
MM5	0,96	0,98	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
MM6	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89
MM7	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,94	0,94	0,94	0,94	0,94	0,94	0,94	0,94
MM8	0,88	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89
MM9	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
MM10	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
MM11	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,42	1,42	1,42	1,42	1,42	1,42
MM12	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88

***Slika 10** Prikaz rezultata mjerenja uzgonskih tlakova dijagramom u prvoj mjernoj sekciji*

***Figure 10** Diagram representation of the results of buoyancy pressure measurements from the first measuring section*



Vrijeme	17:10:00	17:12:00	17:15:00	17:18:00	17:21:00	17:24:00	17:27:00	17:30:00	17:40:00	17:44:00	18:36:00	18:39:00	18:42:00	18:45:00	18:48:00	18:51:00
MM1	12,59915	12,61276	12,57211	12,54126	12,53384	12,48935	12,47073	12,49533	12,54742	12,52014	12,39499	12,39618	12,4043	12,42056	12,40363	12,40027
MM2	12,54245	12,56461	12,55792	12,56015	12,54614	12,52625	12,522	12,52893	12,52792	12,52521	12,46658	12,46667	12,4693	12,48828	12,48026	12,47556
MM3	12,88116	12,89267	12,93719	12,9447	12,86148	12,86923	12,89804	12,89053	12,922	12,90021	12,85748	12,86206	12,82059	12,85596	12,88739	12,83472
MM4	12,85123	12,85007	12,87241	12,85883	12,82764	12,84213	12,86353	12,85416	12,85773	12,83765	12,8031	12,80759	12,79013	12,79218	12,81281	12,79694
MM5	12,6142	12,61383	12,61035	12,59744	12,59015	12,58267	12,58514	12,56183	12,55405	12,54276	12,52029	12,51901	12,49872	12,49115	12,51483	12,49432
MM6	12,59189	12,60727	12,58499	12,57391	12,5784	12,57925	12,57501	12,5694	12,54111	12,5253	12,49542	12,49399	12,48703	12,48157	12,49142	12,48599
MM7	11,9566	11,96973	11,95184	11,94455	11,9556	11,95499	11,93884	11,94513	11,92303	11,9227	11,90128	11,90707	11,91284	11,91138	11,90543	11,91205
MM8	12,44189	12,45389	12,44583	12,44467	12,45679	12,46039	12,4433	12,45657	12,42621	12,42526	12,38583	12,38708	12,39816	12,39944	12,38974	12,40234
MM9	12,49002	12,4935	12,49304	12,49475	12,48654	12,48694	12,4664	12,47629	12,46219	12,45947	12,4216	12,41898	12,43265	12,43384	12,41855	12,43393
MM10	12,46384	12,46823	12,46832	12,47598	12,46375	12,47516	12,46289	12,4649	12,44922	12,44031	12,4006	12,39902	12,40936	12,40994	12,40158	12,4118
MM11	12,5639	12,56299	12,55777	12,54761	12,53452	12,52963	12,52771	12,52225	12,51663	12,50357	12,48184	12,47778	12,47815	12,47424	12,4772	12,47556
MM12	12,57031	12,56589	12,56064	12,55154	12,55829	12,5535	12,56229	12,54443	12,54092	12,52301	12,49246	12,4978	12,48889	12,48676	12,49396	12,48618

Slika 11 *Prikaz rezultata mjerenja temperatura dijagramom u prvoj mjernoj sekciji*

Figure 11 *Diagram presentation of the results of temperature measurements from the first measuring section*

6. ZAKLJUČAK I MOGUĆI SMJEROVI BUDUĆIH ISTRAŽIVANJA

6. CONCLUSION AND POSSIBLE WAYS OF FUTURE RESEARCH

Automation of the system for measuring buoyancy pressures and temperatures achieved reliable and regular collection of data on the condition of curtain injection and permeability of the dam, which is extremely important for analysing the stability of the dam structure. Therefore, it is important to mention that the obtained regular and reliable data allow the authorized experts to properly monitor the effects of uplift pressure on the dam.

After the installation of the automated system, measurements were taken at all 28 measurement points. It was found that two measurement points provided invalid data due to a blockage in the piezometric tube. In order to eliminate this problem and ensure correct and reliable measurement at all measurement points, cleaning of the piezometric tubes was performed at all measurement points in accordance with the recommendations.

After processing the measurement data and comparing it to the manual readings with the corresponding gages, it was determined that the system was functionally correct and the accuracy of the measurements was satisfactory. The measurement results of buoyancy pressures and temperatures are within expectations.

Since the buoyancy pressures change very slowly and the measurements were taken only over a short period of time, no major pressure changes in the system could be detected. The change in buoyancy pressures is largely dependent on the water level and the amount of precipitation. To detect major pressure changes, the measurement results should be observed throughout the year and several seasons.

Of course, it is also necessary to make estimation of the reliability and product life of the system, but they were not a subject of research and not presented here in this paper.

PRIZNANJE

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