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Design and Implementation of Filtration Flow Measurement Systems for Drainage Structures: A Case Study at Baipazinsk Hydroelectric Power Station

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ABSTRACT

As a result of in-kind surveys of drainage structures of the Baipazinsk hydroelectric power station, recommendations are given on the selection of water flow measurement devices. The recommendations are given in the form of drawings and diagrams in relation to specific conditions of the facility. The water flow measurement devices recommended in this work can be used in the design and construction of other similar hydroelectric power stations in Uzbekistan.

Key words: *hydraulic structure, drainage structures , water flow, water level measuring device, thin-walled spillway, water meter threshold, end spillway, elbow nozzle, U-shaped nozzle, measuring instruments, filtration, digitalization, automation.*

Introduction.

Monitoring and control of water filtration through the body and base of water-retaining structures is one of the important tasks of the hydraulic engineering unit operation service.

These data are used to judge the efficiency of drainage systems, to assess the permeability of base rocks, to assess filtration regimes caused by changes in water levels in pools, to assess suffusion processes, etc.

Similar observations were also conducted at the drainage structures of the Baipazinsk hydroelectric power station. However, the results of filtration observations revealed insufficient information on drainage flow due to imperfections in control equipment, improper operation, and their insufficient quantity.

An inspection of the structures of the Baipazinsk hydroelectric complex was carried out with the aim of studying the condition of the measuring devices that monitor filtration flows and assessing the qualifications of the observations carried out on these flows.

Based on the inspection of structures and familiarization with the observations, we came to the conclusion that in almost many drainage areas there are no water metering devices, and in those places where they are present, water consumption is recorded with an unacceptably large error.

Therefore, for proper and effective control of filtration costs at the Baipazinskaya hydroelectric power station, it is necessary to develop a project for equipping drainage structures with appropriate water measuring devices.

The results of the field surveys of the drainage structures of the Baipazinskaya hydroelectric power station are briefly presented , in which recommendations are given on the selection of means for measuring water consumption. The recommendations are given in the form of drawings - diagrams in relation to the specific conditions of the facility.

The aim of the research is to provide the drainage structures of the Baipazinskaya hydroelectric power station with water measuring devices for systematic monitoring of filtration rates.

Research Questions :

The main questions to be addressed included:

1. Inspection of drainage structures of the Baipazinskaya hydroelectric power station and currently operating means of measuring water filtration flow rates.

2. Carrying out measurement work of all drainage devices at the hydraulic structure and selecting means for measuring filtration flow rates applicable to specific conditions.

3. Development of drawings and diagrams of selected measuring instruments in relation to structures.

Research methods – experimental-industrial and office, generalization of experience in designing, constructing and operating water metering devices.

The choice of means for measuring filtration flow rates was justified depending on the following factors:

- technical and economic feasibility of the construction of a water metering device,
- hydraulic elements (water flow rate, flow depth, longitudinal slope of the bottom, etc.),
- overall dimensions of drainage devices (channel type, cross-section shape, etc.

In addition, when selecting the means for measuring filtration flow rates, the designs that meet the following requirements were taken into account first and foremost:

- simplicity and reliability in operation;
- efficiency of water metering;
- the permissible error in measuring water flow should be no more than ±5%;
- the design of the water metering structure and its equipment should not, in the long term, hinder any degree of automation of water metering.

Literary, regulatory and other sources containing information on water metering devices were also reviewed and analyzed. The experience of construction and operation of water metering devices in melioration systems, water supply systems, etc. was used.

Research Results .

The results of field surveys of drainage structures of the Baipazinskaya hydroelectric power station, on the basis of which recommendations were given for the selection of means for measuring water consumption are given in Table No. 1

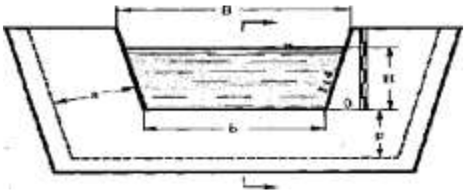
Name of the object of examination	**Description of the object and the state of water metering**	**Recommendations for choosing water consumption meters**	**Additional repair and other work to ensure normal operation of water metering devices**
2	3	4	5
Drainage tunnel in the area of the station site	The tunnel consists of two parts – the head and the main part. The head part is 43 m long and has a circular cross-section with an internal diameter of d = 1.0 m. The estimated flow rate is Q = 10-80 l/s. The main part of the tunnel has a rectangular cross-section measuring 1.8 x 3.0 m; 57 m long, and is made of reinforced concrete elements. The estimated flow rate is Q = 80-120 l/s. In the main part of the tunnel, at its initial part, a trapezoidal thin-walled Cipoletti spillway is installed , which is currently completely silted up and out of operation.	It is recommended to measure water in two places: at the exit from the head of the tunnel (mouth) and at the beginning of the main part of the tunnel. 1. At the outlet of the tunnel (mouth), a water meter of the end spillway type is recommended. 2. At the beginning of the main part of the tunnel (instead of the existing trapezoidal thin-walled spillway), provide for a SANIIRI water-measuring threshold.	To prevent water from bypassing the tubular drainage at the end (mouth), it is necessary to provide a concrete wall along the entire height, recessed into the base by approximately 60-70 cm. In the main part of the tunnel, clean the bottom of gravel and sand soil along its entire length. For ease of access to water metering devices, provide service bridges.

2	Drainage gallery (under- drainage)	The drainage gallery has a horseshoe-shaped cross-section and a collecting tray is provided at the bottom of the gallery, into which water flows and from there it is discharged outside into a rapid current. The collection tray for monitoring drainage water is provided with a Cipoletti spillway of width b=0.6 m. However, as the survey showed, part of the drainage water is not monitored, since the water flow moves around the spillway, and the water level measuring rod is installed unacceptably close to the spillway in the decline curve zone. In addition, the spillway itself operates in the flooded outflow mode , which is unacceptable.	It is recommended to install water metering points in two places - in the line of the existing water metering device and at the outlet section : 1. In the existing branch it is necessary: Option 1. Reconstruct the existing spillway by raising the spillway threshold by 20 cm. Option 2. Instead of the spillway, provide for a SANIIRI water-measuring threshold. 2. At the outlet of the drainage gallery, a SANIIRI water meter threshold must also be provided. .	To prevent water from flowing around the spillway, it is necessary to raise (complete) the wall of the tray (left side) to a height of 20-30 cm over a propagation length of 3-4 m. In the area of the tray behind the spillway, clean the bottom of sediment and debris . For ease of access to the spillway, provide service bridges and install lighting.
3	Discharge (main) pipeline of vertical drainage wells	All seven vertical drainage wells are connected to one common metal pipeline with a diameter of D=550 mm, which discharges the water pumped out of the wells into the rapid. The discharged water is not recorded.	It is recommended to install a water control point at the end section of the pipeline. Option I "U"-shaped landing. In case of a large range of changes in water flow rates in the pipeline (part of the wells are operating), it is recommended to weld an additional pipe with a diameter of ø 250 mm with a "U"-shaped landing to measure small flows at the end section of the main pipeline. Option 2 - install a Chipoletti spillway in a specially constructed reinforced concrete tray measuring 2.6x4.55 m.	For ease of operation of water metering devices, provide service bridges, approaches, and stairs.
4	Wall drainage of rapid flow	Along the entire length of the rapid flow, a stent drainage is provided on both sides. The latter consists of drains laid along the longitudinal walls of the rapid flow. The end part of the drains is led out into the lower pool. To monitor the operation of the drainage, its cleaning, 7 inspection wells with a diameter of 1.2 m are provided on each side every 10-15 m along the length. The right side of the rapid current. Inspection wells 1,2,3,4 are practically dry. Inspection well No.	It is recommended to designate drainage water control points in the following locations: a) at the end part (mouth) of the wall drainage. b) in inspection wells No. 6, No. 7. At the end (mouth) section of the wall drainage , provide for: Option 1 – end drain. Option 2 – elbow-nozzles.	For convenience and safety during measurements it is necessary: At the end section of the drainage, replace the existing ladder for descending to the water metering device that is unusable with a metal one. At the metering point where the water metering device is installed, make fences from metal pipes along the entire perimeter (fence height 1.5 m, length 3 m, width 2.5 m). For the convenience of placing water meters in inspection wells No. 6, No. 7 on the left and right sides, it is necessary:

		5 is filled with stones. Inspection well No. 6 Q = 5-8 l/s, drain diameter ø 500 mm. Inspection well No. 7 Q = 50 l/s, drain diameter ø 460 mm. reinforced concrete wells in plan, circular cross-section ø 1.2 m. Left side of the rapid current. Inspection wells No. 1,2,3,4,5 are practically dry. Inspection well No. 6 Q =20 l/s, drain diameter ø=360 mm. Inspection well No. 7 Q = 30-40 l/s, drain diameter ø 360 mm. Inspection wells with a square cross-section of 1.2 x 1.2 m. There is no monitoring of drainage water.	Right side of the rapid current. In inspection wells No. 6,7, provide: Option 1 – water meter with instruments. Option 2 – a water metering device of the end spillway type. Option 3 – install a thin-walled Cipoletti -type drain in the inspection wells . Thomson spillway - in inspection well No. 6 Left side of the rapid current. In inspection wells No. 6 and No. 7, provide the same water metering devices as in inspection wells No. 6 and No. 7 on the right side.	Deepen the bottom by about 20-40 centimeters and concrete the bottom.

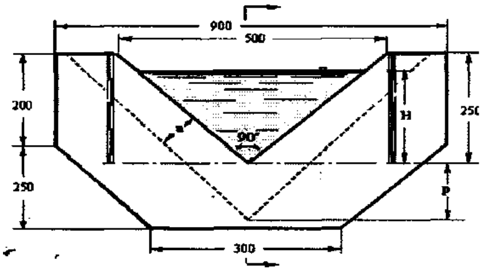
Below are the designs and calculations of some water metering devices that are recommended for this facility.

***Measuring weirs* [5].** Determination of water flow by weirs is reduced only to measuring the pressure above its threshold, which creates favorable opportunities for automation of water accounting. In this case, level meters, flowmeters and flow meters can be used. It has good water-measuring qualities (the error with correct installation does not exceed ± 3...5%); simple design



Consumption formula: $Q = 1.86 \cdot b \cdot H^{3/2}$ m3/s (1)

Fig. 1. Cipoletti drain (CDC)



Consumption formula : $Q = 1.4 \cdot N^{5/2}$ m^3/s (2)

Fig. 2. Thomson spillway

water-measuring threshold [5] This is a spillway with a wide threshold (Fig.).. Allows determining water flow rates in open watercourses by measuring only one value - the pressure H_p above the threshold with relative flooding from the lower pool $h_n / H_p < 0.8$. The threshold passes sediment well, keeping the crest clean. Water flow rate Q and pressure above the threshold H_p are related to each other by the ratio.

$$Q = (0.37 + 0.04\, H_p / p_p)\,(b_p + m_K H_n)\, H_n \sqrt{2gH\pi} \quad (3.)$$

where b_p is the threshold width, m; p_p — threshold height, m; t_k — coefficient of channel slopes.

Hydraulic calculation and determination of the threshold dimensions is carried out by selection according to the formula, knowing the maximum water flow in the channel, the bottom slope, the transverse profile of the channel in the selected section, and specifying the threshold height as a first approximation

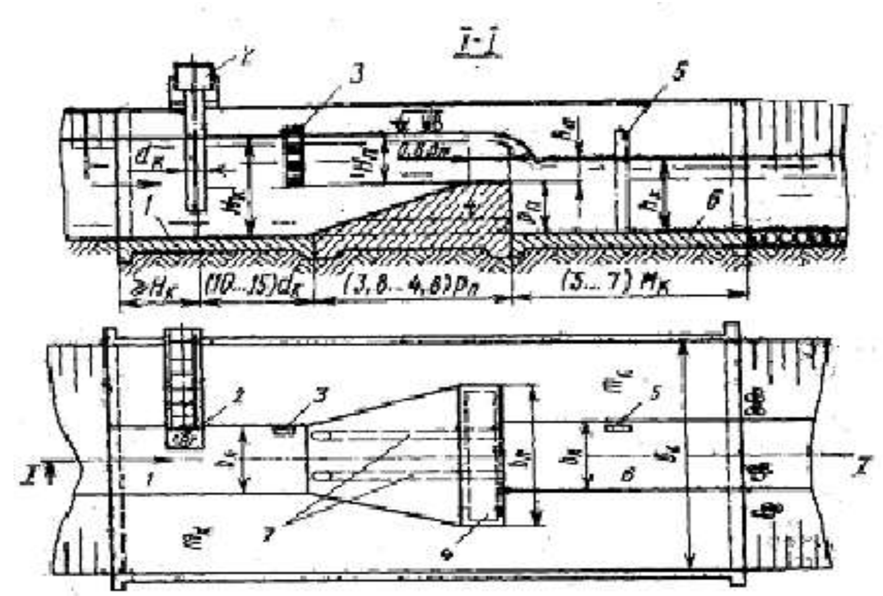


Fig. 3. SANIIRI water meter threshold:

/ — concreted part of the channel bed; 2 — remote level measuring well; 3 — rail;

4 — threshold; 5 — control rail; 6 — fastening of the lower pool of the channel; 7 pipe for emptying the upper pool.

End drain [3] . Consists of a metal pipe2, hermetically seated on an existing drain1, an end drain hole3, which is formed by segmented gussets welded to the pipe (the angle between them is 60^0, the distance along the bottom is b = 0.2 d); a nipple 4 with an internal hole of 10 mm, located at a distance of 3 d from the end hole at the bottom of the pipe, a frame with a piezometer and a scale 5, welded to the pipe at a distance of 60-100 mm from the nipple. The piezometer is connected to the nipple by a rubber tube, which allows cleaning the hole. If it is necessary to automate water metering, a well corresponding to this device is attached to the frame.

According to the operating principle, this device belongs to the primary converters of variable pressure, that is, the water flow rate clearly depends on the pressure above the bottom of the drain hole, that is, Q = f (H).

The calculation consists of determining the throughput capacity for the adopted diameter d of the water meter, which depends on the outer diameter of the pipe, i.e.

$d = d_n + 6\ldots10$ mm. The flow rate formula is:

$$Q = \mu\, w_0 \sqrt{2gz} \qquad (4)$$

Where μ is the flow coefficient. It is taken from the graph μ= f (H / d)

w_0 – the flow area which is calculated at $H / d \leq 0.65$ using the trapezoid formula

$w_0 = (b + 0.58\,H)\,H$, when H / d =0.65…1, the area of a segmental trapezoid with a height of H -0.65 d is added to the trapezoid formula .

Other dimensions are accepted according to the drawing.

a) b)

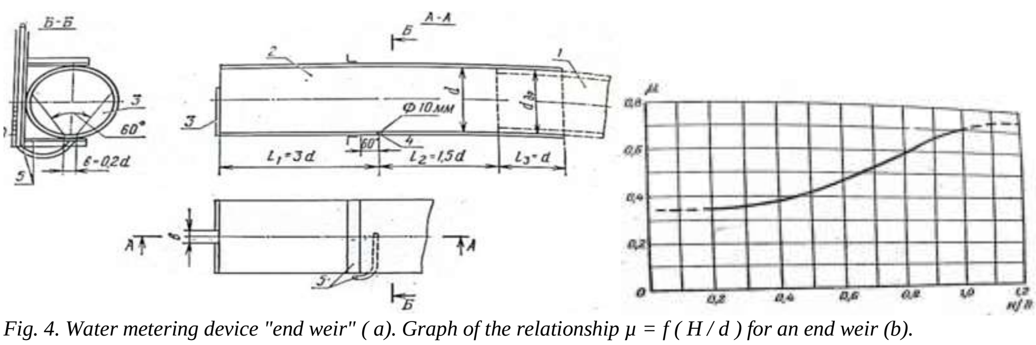


Fig. 4. Water metering device "end weir" (a). Graph of the relationship μ = f (H / d) for an end weir (b).

1- drain; 2- pipe; 3- end drain hole; 4- nipple; 5- piezometer

Water metering device "elbow-nozzle" [6] . Consists of a straight section of pipe and a conical nozzle directed at an angle of 45 ^{0} upwards. The pipe with the nozzle is made of 2 mm iron, the branch pipe is made of a tube d = 20 mm. The principle of operation is that the nozzle directed upwards provides a pressure mode and, as a local resistance, creates a pressure H in the branch pipe, which determines the water flow rate according to the formula:

$Q = \mu 0.785\, D^2 \sqrt{2gH}$ (5)

where μ is the flow coefficient of the water meter, determined by the dependence

$\mu = f(H / D)$ (6)

where: D – internal diameter of a straight section of pipe, m

H – piezometric pressure from zero coinciding with the upper point of the outlet section of the nozzle, m.

a) b)

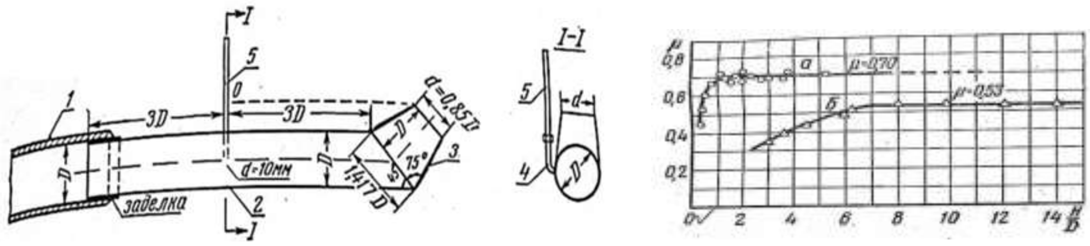


Fig. 5. *Water metering device "elbow- nozzle" (a), Graph of dependence* μ = f (H / D) for water metering devices of *the "elbow-nozzle" and "U-shaped nozzle" types (b)*

1 - drain mouth; 2 - straight section of pipe; 3 - nozzle; 4 - branch pipe; 5 - piezometer;

Water metering device "U-shaped nozzle" [5] . It consists of a nozzle, which is connected with flanges or welding to the end of the branch pipe, branch pipes for connecting a pressure gauge or piezometer at the pressure sampling point at a distance of 3 D from the vertical rise of the nozzle. The nozzle is formed from a straight section of length (6-8) D , an upward rise of 2 D, a horizontal transition of 3.5 D and a downward turn of 2.5 D. The operating principle of the water meter is that the upward rise of water ensures a pressure mode at any flow rate. Water flow is determined by the formula.

For automation of water metering on water metering devices of the type *"end drain"*, " *elbow nozzle"*, *"U-shaped nozzle"* you can use bellows self-recording pressure gauges. In this case, the devices are installed in a specially equipped booth . .

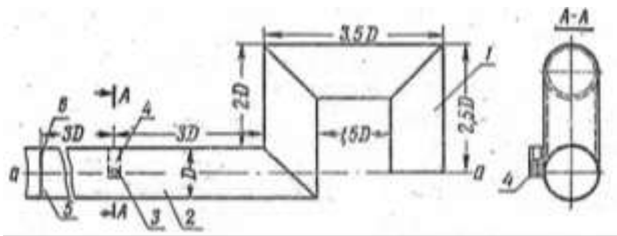


Fig. 6. *Water meter device "U-shaped nozzle"*

1- *"U-shaped nozzle"; 2- straight section of pipe; 3- hole; 4- branch pipe; 5- pipeline; 6- joint, welding for flange .*

Water meter in a manhole [5] . It consists of a metal horizontal shelf covering half or one third of the manhole and a vertical wall rigidly connected to the shelf, blocking the flow. There are four holes in the horizontal shelf, one of which is sealed with a measuring device pipe. This entire metal structure is sealed in the manhole so that the shelf is below the drain. The water meter operates on the principle of variable pressure drop with flow through the hole when measuring water flow from 0.5 to 15 l / s , which is achieved by sequentially opening the slamming covers of the holes. The maximum difference in water levels in the manhole is 5-6 cm, which is acceptable for drains.

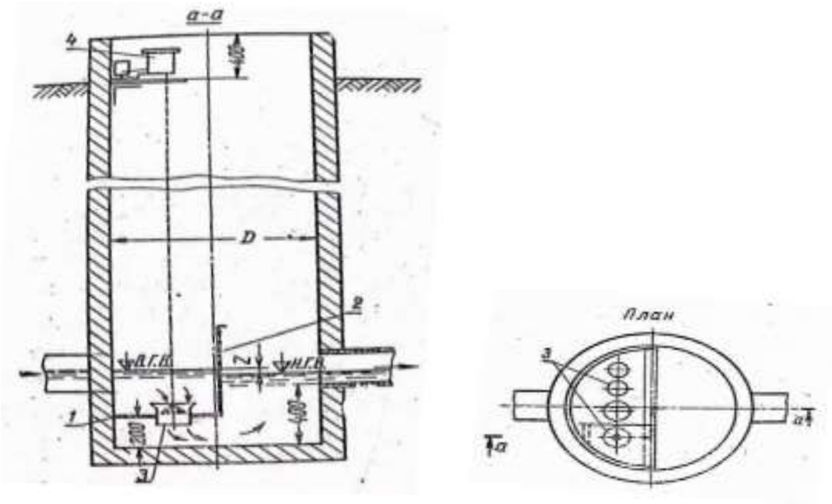


Fig. 7. *Water meter in the inspection well*

1- Horizontal shelf; 2- wall; 3- two holes d = 150 mm and two d = 100 mm

4- a device with a recorder.

It should be noted that all recommended water meters should be equipped with modern digital measuring devices for measuring water levels and flow rates , and the data obtained should be transmitted online. For example: ***[2] .*** as part of the digitalization and automation measures carried out at reservoirs at the hydroelectric stations of the Uzhydroenergo system Modern digital measuring devices for measuring water level and flow , which are analyzed online, are installed on 40 thin-walled weirs .

Conclusions.

1. Our analysis of existing designs of water metering devices allowed us to identify the following:

a) most designs of water metering devices are developed primarily for open canals, regulating and discharge hydraulic structures, and irrigation collector and drainage networks.

b) insufficient attention is paid to the accounting of water consumption at drainage structures of hydroelectric power plants.

Moreover, the specific operating conditions of drainage structures (low flow rates, minor slopes, inadmissibility of significant backwaters) require the use of simple and sufficiently reliable designs of water metering devices that meet the above requirements.

c) the experience of using some designs of water metering devices applied in the collector-drainage network of irrigation systems (U-shaped nozzle, knee-nozzle, end drain, etc.) deserves attention. They can be used to measure drainage water at the Baipazinskaya and other hydroelectric power plants.

2. Based on field surveys of drainage structures, experience in the design and operation of water metering devices, recommendations are given for the selection of optimal means of monitoring drainage water consumption.

3. Drawings and diagrams of the selected means of measuring drainage water flow were developed in relation to specific operating conditions.

4. All recommended water metering devices must be equipped with modern digital measuring devices for measuring water level and flow , and the obtained data must be transmitted online.

5. The means for measuring drainage water flow recommended in this work can be used in the design and construction of other similar hydroelectric power plants in the Uzhydroenergo system .

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