

Study of new designs of spillway channels with artificial roughness

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ABSTRACT

The effective functioning of agriculture and, as a consequence, the solution of the food problem is impossible without the use of scientifically based measures for water supply for food production. The paper presents the ways of regulating the transporting capacity of the grade-control structures and their new designs. For comparison, the works of leading experts in this field of were considered. The basis of the methodological and theoretical studies were the studies by Kazakhstani and CIS scientists on the problems of improving and researching new designs of overflow channels with artificial roughness. To solve the set tasks, general scientific methods were used to study improved designs of spillway channels. The results of experimental studies of new designs of spillway channels with artificial roughness are given; theory, methods, research data, and new designs of interfacing structures obtained on the basis of the findings of experimental studies in the Training Center for the Safety of Hydraulic Structures at the Department of Water Resources of the Taraz State University named after M.Kh. Dulaty. Taking into account the experimental studies of the structure under consideration, recommendations are proposed for conducting experimental studies of the structures of spillway channels with artificial roughness. The main conclusions and practical recommendations can be used as a methodological basis for further study of spillway channels with artificial roughness. A method has been developed for determining the position, alignment of the beginning of energy extinguishing under the condition of a fast flow regime (at the transit part of the flow) at the end section of the flume with artificial roughness. The results of calculations by the proposed method show good compatibility with the data of field studies.

Keywords: Water, Hydraulic Structures, Energy absorber, Water flow.

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1. Introduction

A programme for the construction and modernisation of hydraulic facilities of water management systems, currently being implemented in the Republic of Kazakhstan, requires the use of new economical and reliable engineering structures [1-7]. Today, about 60 large (with flow rates over 100 m³/s) and a large number of medium and small irrigation channels are operated in various climatic and geological conditions. One of the most common hydraulic engineering installations included in the complex of structures on reclamation channels, especially in rugged terrain, are the grade-control structures [8-12]. The role of the latter is increasing in connection with the reclamation of agricultural land to the previously undeveloped territories of the mountainous and piedmont regions of Kazakhstan [13-18]. The conjugation of channel sections located at different elevations in places where the terrain relief falls should be carried out with the maximum possible

degree of damping of the kinetic energy of the flow, provided that a favourable hydraulic regime is ensured within the entire range of flow rates. The grade-control structures must meet the requirements of efficiency, reliability and environmental protection [19-23].

An effective means of damping excess kinetic energy within the water-conducting part of the grade-control structure is a device of artificial or enhanced roughness, for example, at spillway channels. The use of such a technical solution imposes its own peculiarities on the hydraulic characteristics of the flow, a number of which, despite the large amount of existing fundamental and methodological studies, have not been sufficiently explored to date [24-30]. These features include flow damping and its effect on hydraulic resistances, which in turn determine the main parameters of the structure.

The constructions of spillway channels with artificial roughness used so far are characterised by relatively small slopes of the flume, and the types of artificial roughness used on them create an extremely uneven distribution of depth along the width of the flow during the passage. In other words, the free area of the flume is used irrationally, and its length is often very long. The question of determining the location of the roughness protrusion from the standpoint of avoiding an unfavourable hydraulic regime, which is expressed in water jet throw, requires substantiation. To solve the outlined problems, the theoretical and experimental studies of spillway with a slope [31-34] up to $i=0.10$ were carried out. And also new types of spillway channels with artificial roughness have been proposed. Their use allows to create a uniform distribution of depth along the width of the flow in the spillway. These types of roughness have, under certain conditions, a number of advantages over the previously known types of artificial roughness. The novelty of the engineering solution of the proposed roughness options is confirmed by an approval of the National Institute of Intellectual Property of the Republic of Kazakhstan. Several patents for a utility model have been issued, and the experimental research on these utility models is currently being conducted. The experimental results are provided in the following works [35-40]. Analysis of design data indicates the widespread use of spillway channels with artificial roughness as interface structures on reclamation channels. The existing methods of hydraulic design of such structures either do not take into account the phenomenon of flow damping, or have a limited range of applicability [41-47]. At the spillway channels with artificial roughness in the form of skew ledges, damping is caused by vortex phenomena when the flow is decelerated. In the section of the beginning of extinction, the critical value of the Froude number for spillway channels with artificial roughness is an order of magnitude less than for smooth ones, and depends mainly on the slope and relative roughness of the channel.

2. Material and methods

The study was carried out in two stages and included field and laboratory experiments. As an object of field studies, a typical grade-control structure with artificial roughness was selected [48-54]. The investigated spillway channel was located at the Ters-Ashchibulak reservoir in the Zhualyn district of the Zhambyl region (Figure 1).



Figure 1. Spillway channel with artificial roughness in the Ters-Ashchibulak reservoir (views of the upper and lower reaches): 1 – artificial roughness; 2 – partitions; 3 – discharge channel (downstream)

The Ters-Ashchibulak reservoir on the Ters river, located 20 km below the district centre, the village of Baurzhan Momyshulyin the Zhualyn district of the Zhambyl region and is an object of republican significance [54]. Year of construction – 1963. Operating organisation: 2nd category of importance. The watercourse is the Ters river. The average recorded flow is $4.4 \text{ m}^3/\text{s}$, the maximum recorded flow is $636 \text{ m}^3/\text{s}$. The estimated maximum discharge of the spillway is $586 \text{ m}^3/\text{s}$. Working and protection channels from monolithic reinforced concrete, respectively, with a capacity of $36.0 \text{ m}^3/\text{s}$ and $586.0 \text{ m}^3/\text{s}$. Structure type: earthen dam. Base soils are alluvial [55-60]. The maximum head is 21 m. The constructional depth is 30 m. The length along the ridge is

1960 m. The width along the ridge is 7.5 m. The width along the bottom is 157.5 m. The elevation of sill of the overflow spillway is 946.2 m [61; 62].

The spillway is located on the left bank of the dam. The spillway with a flow rate of $586 \text{ m}^3/\text{s}$ (at the maximum water-surface elevation) consists of an inlet bell mouth with six openings with a span of 8 m each, covered by segmental gates $3 \times 8 \text{ m}$ (the sill is located 2.4 m below the normal maximum operating level) of a concrete inlet cut into the rock. The total length of the spillwater channel is 950 m, the slope is 0.25. Its flume is made of monolithic reinforced concrete. Artificial roughness is made in the form of a zigzag against the flow with a height of $\Delta = 0.2 \text{ m}$ and a step $S = 8\Delta = 1.6 \text{ m}$. The height of the sides of the structure from the bottom is 2.2 m, and the width of the flume is 6 m. The interface with the supply channel is made as a skew surface (Figure 2). Dampers in the form of checkers and diffusers are designed, but not built on the bucket curve of spillway [63-67].

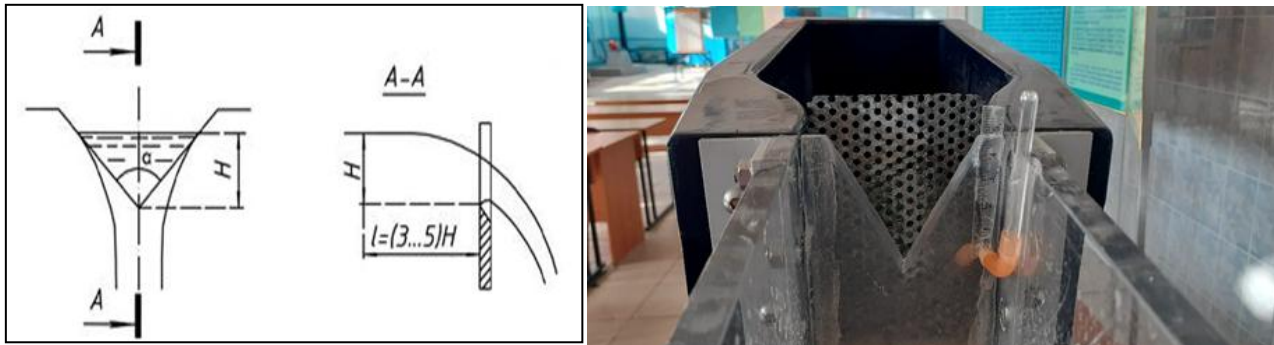


Figure 2. Thin-walled triangular weir

The study was preceded by a measurement and visual inspection of the structure. Measurement data indicate that the main dimensions correspond to the project. Over 57 years of operation, a number of working surfaces of roughness elements have partially collapsed under the influence of hydrodynamic loading and abrasion, bottom sediments and debris. The expansion joints are in good condition. The bottom of the flume is also worn out, there are irregularities and cavities, but not of cavitation origin. The downstream of the structure is cemented. In summer, due to the strong increase of the flow, the sides and adjacent surfaces are constantly wet, which indicates an incorrect design justification of the structure. The absence of a railing on the sides creates a danger to others [68-74].

The experiments were carried out in the Training Centre for the Safety of Hydraulic Structures at the Department of Water Resources of Taraz State University named after M.Kh. Dulaty. The S8-MkII model rig was chosen, which was used to demonstrate and conduct small experiments in open flow hydraulics for the S8-MkII flume. The model installation provides the ability to observe changes in slope or flow in a flume. This channel model is more compact and economical, does not require special maintenance, but no less functional. The S8-MkII allows for all the experiments and demonstrations possible with large scale laboratory flumes. The S8-MkII is extremely useful for demonstrating and conducting small experiments in open flow hydraulics and kinetic energy damping for training specialists in the construction of hydraulic structures [75].

It has a form of frame-mounted adjustable steep flume, equipped with a feed tank and a pump for water recirculation. The slope of the flume is set using a thin screw jack on which the slope indicator is attached. The walls are transparent, which makes it possible to observe changes in the shape of the flow. One section of the flume has a graphically marked grid, which allows a qualitative assessment of the dynamics of channel forms. A transparent channel flume with a variable slope and a mobile channel is intended for research and demonstration of a whole range of channel forms from the initial movement of rapid currents with artificial roughness [76-81]. The flume provides for water recirculation using a pump. Using the switch on the pump, 3 values of the water flow rate can be set from 0.2 to 0.6 l/s, followed by their measurement (Figures 3-4). The slope of the flume can be set from 0 to 10%. Working dimensions of the flume: length 1.55 m, width 78 mm, depth 110 mm. Single-phase power supply – S8MkII-A version: 220-240V. The first filling with water is approximately 22 litres. Parameters: height – 1.1 m, width – 0.4 m, length – 2.5 m [82-86].

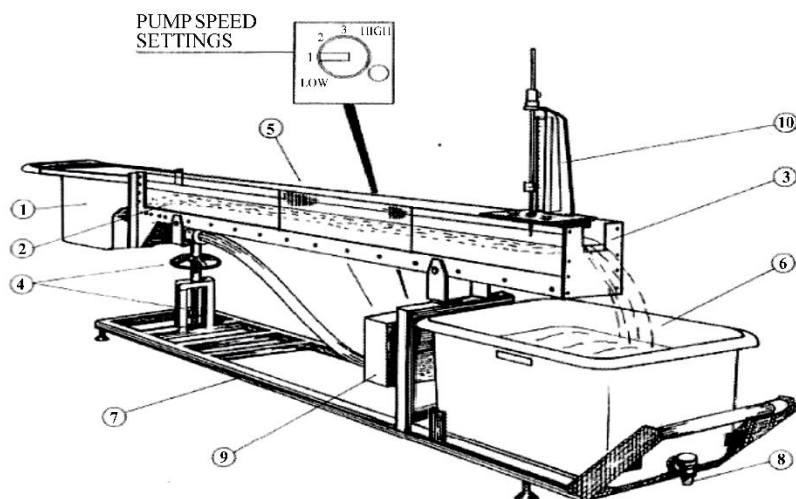


Figure 3. Installation for conducting experiments in the field of hydraulics of open streams of the S8-MkII flume: 1 – inlet, 2 – steep flume, 3 – thrown dam, 4 – jacking system, 5 – recirculation pump and control valve, 6 – water storage tank, 7 – iron stand, 8 – fastening the plastic storage tank, 9 – power switch/RCD (residual current device), 10 – additional items



Figure 4. Installation (spillway channel) for conducting experiments in the field of hydraulics of open streams of the S8-MkII flume

Operating procedure of laboratory experiments and measuring equipment: the studies were carried out with a slope of $i = 0.10$. When water passes through the model, the ratio h / Δ varied from 0.2 to 0.6 l/s. The flow rate was controlled by a gate valve, and the measurement was carried out using a triangular weir (Figure 2). For this slope, four types of roughness were considered: a upstream and downstream zigzag, and a new type of artificial roughness proposed later in the course of experiments in a square form, as well as a semi-square one [87-90]. The first two types of artificial roughness were selected and studied, because they are characterised by the best efficiency of damping excess kinetic energy of the flow and are the most widespread. In the experiments, the range of variation of the Froude number (Equation 1):

$$Fr = \frac{v_a^2}{(g h)} \quad (1)$$

and the Reynolds parameter (Equation 2):

$$Re = v_a h / \nu \quad (2)$$

for the region of uniform flow amounted to, respectively: $Fr = 2 - 12$; $Re = 0,6 \cdot 10^5 - 2,0 \cdot 10^5$, and in terms of the equivalent water flow: $Fr = 5 - 30$; $Re = 0,3 \cdot 10^5 - 1,0 \cdot 10^5$.

Triangular weirs with a thin wall are designed to measure the flow rate of a liquid that does not contain a significant amount of suspended particles. These weirs are recommended for use with large fluctuations in the flow rate of the measured liquid. The triangular weir cut can be made with a central angle α from 20° to

120°. The most common weirs are those with $\alpha = 90^\circ$. The deviation of the actual value of the central angle from the calculated one or the measurement error of this angle should not exceed $\pm 10'$. The edge of the spillway facing the supply channel (headwater) must be sharp [91-96]. The geometrical dimensions and surface roughness of the weir faces should correspond to those indicated in Figure 2. The weir should be installed so that the bisector of the central angle runs vertically. The deviation of the bisector of the angle from the vertical should not exceed 1° . Weirs, in which the wall thickness does not affect the shape of the overflowing stream, belong to weirs with a thin wall. This spillway has a wall thickness $S > 0.61 H$ (where H is the geometric head on the spillway; S is the thickness of the spillway wall). Weir (Figure 5), with a thin wall, is often used to measure water flow in an open flow.

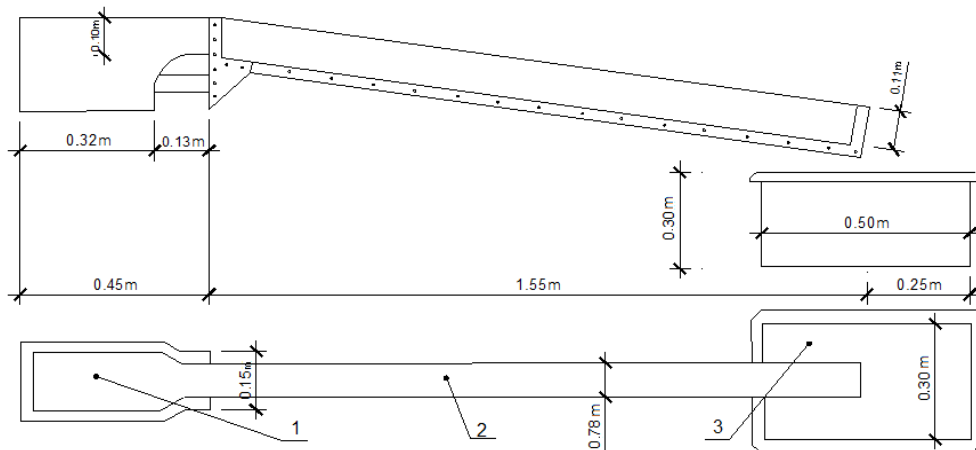


Figure 5. Laboratory setup diagram: 1 – input; 2 – spillway flume; 3 – water storage tank

To determine the flow through a thin-walled weir, use the formula (Equation 3):

$$Q = m_0 b \sqrt{2gH^{\frac{5}{2}}}, \quad (3)$$

where: Q – liquid flow rate through the weir, m^3/s ; m_0 – dimensionless weir discharge coefficient, taking into account the speed of approach to the weir; b – width of the spillway front, m .

To measure water flow, triangular (Figure 2), trapezoidal, rectangular (with and without lateral compression) and parabolic weirs are used. Triangular weirs (Figure 2) are useful for measuring low flow rates. They should be used at heads from 0.05 to 0.25 m. For these weirs with a square corner at the top, the discharge coefficient is $\tau_0 = 0.316$. The formula (Equation 4) of the flow rate for triangular weirs at $t_0 = 0.316$ and $g = 9.81 \text{ m/s}^2$ takes the form [17]:

$$Q = 1.4 \cdot H^{\frac{5}{2}}; \quad Q = 1.4 \cdot H^{\frac{5}{2}} = 1.4 \cdot 0.033^{\frac{5}{2}} = 0.56 \text{ m}^3/\text{s} \quad (4).$$

3. Results and discussion

The graph (Figure 6) shows that the flow rate for weirs with a triangular cut-out in a thin wall at $\alpha = 90^\circ$, in this case, is $Q = 0.56 \text{ m}^3/\text{s}$. According to the measurement results, such parameters as flow damping were obtained, such as average speed v , m/s , water flow rate Q , m^3/s . Laboratory experiments were carried out by the generally accepted method of hydraulic study, and in addition to instrumental determination of flow parameters, visual observations, photo and video recording of the flow were carried out [97-102]. Photographing and video recording were carried out in order to determine the characteristic sections and flow regimes, areas of distribution of vortex core, etc. Photographing and video filming was carried out with a Samsung Galaxy A-10 smartphone.

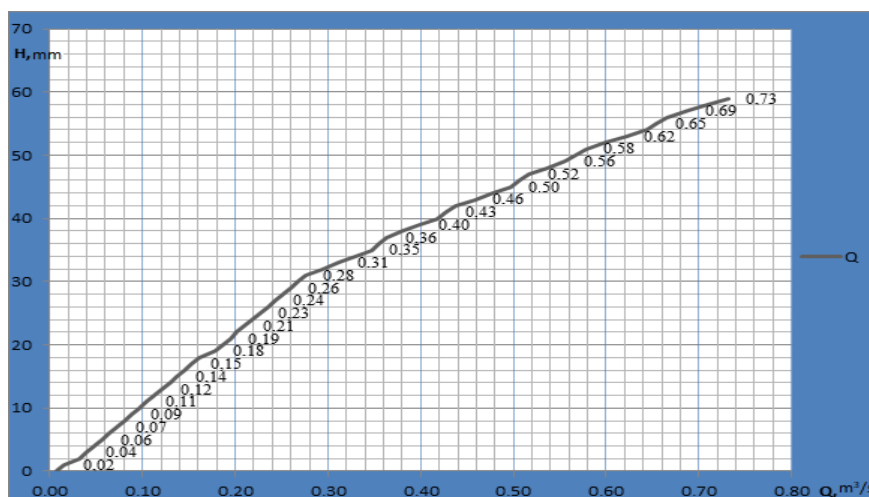


Figure 6. Thin-walled triangular weir flow graph, $Q, m^3/s$

In each series of the conducted experiments, the water levels, velocity fields, and the damping the kinetic energy of the flow in the sections were measured, starting from the compressed section, to the point where the stilling occurred, in the areas of uneven and uniform flow movement. Water levels and velocity were measured using a conventional Pitot hydrometric tube. The first one was located at a distance of 0.97 m from the beginning of the pressure head tank, and the second gauging Pitot tube was located at the end of the section at a distance of 1.99 m from the beginning of the head tank [103-109].

To measure the flow rate in the spillway channel, the Bernoulli equation was chosen, which is widely used in many hydraulic calculations and to explain many hydraulic phenomena. In particular, it can be used to measure the pressure and velocity of a moving liquid in the two considered sections. A piezometer is used to measure pressure (straight tube, Figure 7). To measure velocity, a Pitot tube is used in conjunction with a piezometer – a tube of full pressure. It is a tube bent at a right angle and installed against the flow. There are two tubes installed in the flume: a piezometer – for measuring the piezometric head, a curved tube – for measuring and total head (pressure). The tube is installed upstream, so that the liquid flows into it. In the event that the liquid in the flume is at rest, then the levels in both tubes will be the same – the total head is equal to the static head (Figure 7). When the liquid moves due to the velocity head of the flow, the total head will increase and be higher than the piezometric head, the liquid level in the second tube will be higher than in piezometer 1. A level difference Δh is created, which depends on the liquid flow rate v .

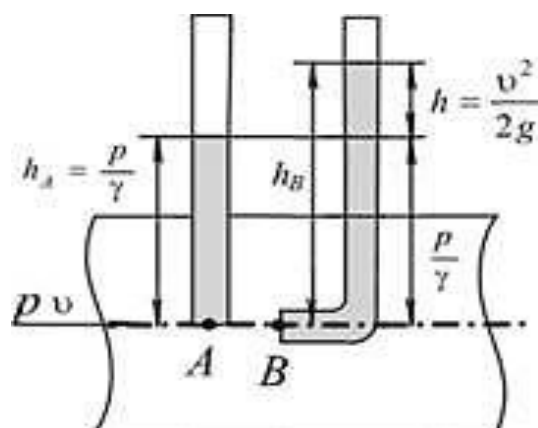


Figure 7. Scheme for determining the velocity of liquid flow using a piezometer and a Pitot tube

When liquid particles enter a curved tube, the speed of these particles decreases and drops to zero, the kinetic energy turns into potential energy, causing the liquid in this tube to rise to an additional height Δh . The stock of potential energy of a particle raised to a height Δh : taking into account that the kinetic energy has passed into potential $E_p = E_k$, the value of the level difference in the tubes Δh can be calculated. In this case, the flow rate in two sections was also measured, at the beginning and at the end of the spillway flume with different artificial roughness [110-112].

The liquid level in the piezometer is (Equation 5):

$$h_A = \frac{P}{\gamma} \quad (5)$$

The difference in levels in the piezometer and in the Pitot tube will be equal to the velocity head (Equation 6):

$$h = \frac{v^2}{2g}. \quad (6)$$

Let us write the Bernoulli equation for points A and B (Equation 7):

$$\frac{P_A}{\gamma} + \frac{v_A^2}{2g} = \frac{P_B}{\gamma} + \frac{v_B^2}{2g} \quad (7)$$

Since $P_A = P$, $v_A = v$, $v_B = 0$, then (Equation 8):

$$\frac{P_B}{\gamma} = \frac{P}{\gamma} + \frac{v^2}{2g}, \quad (8)$$

where: equation (9) – the height of the liquid in the Pitot tube; equation (10) the height of the liquid in the piezometer:

$$\frac{P_B}{\gamma} = h_B \quad (9)$$

$$\frac{P}{\gamma} = h'. \quad (10)$$

Therefore (Equation 11)

$$h = h_B - h_A = \frac{v^2}{2g}. \quad (11)$$

At the input of the spillway $h = 5.0 \text{ cm} = 0.05 \text{ m}$. Then the obtained equation can be used to determine the velocity of the fluid v , with a known level difference, which can be easily measured (Equation 12):

$$v = \sqrt{2gh} \quad (12)$$

Perform the calculation with the first Pitot tube which is installed 1.99 m from the beginning of the pressure tank (Equation 13):

$$v = \varphi \sqrt{2gh} = \sqrt{2 \cdot 9.81 \cdot 0.067} = 1.14 \frac{m}{s} \quad (13)$$

Several options for measuring the flow velocity v and damping the kinetic energy in a laboratory setup were considered. The most optimal result – $\vartheta = 0.95 \text{ m/s}$, obtained using the Pitot tube installed at 1.99 m from the beginning of the head tank, where the flow rate is lower than $\vartheta = 0.20 \text{ m/s}$ of the readings of the Pitot tube set at 0.97 m from the beginning of the head tank. From here it can be seen that the flow rate

decreased by 18% (Figure 8). These values are below (Table 1): $v = \varphi\sqrt{2gh} = 1.5\sqrt{2 \cdot 9.81 \cdot 0.045} = 0.94 \frac{m}{s}$.

Table 1. Flow rate measurement on a spillway in laboratory conditions

No.	Type of artificial roughness	Distance of artificial roughness from the beginning of the flume, m	Height and the reading on the Pitot tube, 0.52 m from the beginning of the flume	Height and the reading on the Pitot tube, 1.54 m from the beginning of the flume	Slope, $i - 0/00$	$\vartheta, m/s$
1	2	3	4	4	6	7
1	□	0.6-0.8-1.0	0.067	0.058	0.10	1.06
2	>	0.6-0.8-1.0	0.067	0.062	0.10	1.10
3	<	0.6-0.8-1.0	0.067	0.062	0.10	1.10
4	⊏	0.6-0.8-1.0	0.067	0.062	0.10	1.10
1	□	0.6-0.8-1.2	0.067	0.052	0.10	1.02
2	>	0.6-0.8-1.2	0.067	0.058	0.10	1.06
3	<	0.6-0.8-1.2	0.067	0.058	0.10	1.06
4	⊏	0.6-0.8-1.2	0.067	0.056	0.10	1.04
1	□	0.6-0.75-0.9	0.067	0.062	0.10	1.10
2	>	0.6-0.75-0.9	0.067	0.064	0.10	1.12
3	<	0.6-0.75-0.9	0.067	0.064	0.10	1.12
4	⊏	0.6-0.75-0.9	0.067	0.061	0.10	1.09
1	□	1.2	0.067	0.056	0.10	1.04
2	>	1.2	0.067	0.050	0.10	0.99
3	<	1.2	0.067	0.050	0.10	0.99
4	⊏	1.2	0.067	0.054	0.10	1.02
1	□	1.3	0.067	0.056	0.10	1.04
2	>	1.3	0.067	0.045	0.10	0.94
3	<	1.3	0.067	0.045	0.10	0.94
4	⊏	1.3	0.067	0.053	0.10	1.00

Pitot tubes are used to measure the liquid flow rates, the measurement error of instruments is usually 1-2%. Small holes in the tubes are easily clogged, so Pitot tubes are only used with clean liquids. The measurement accuracy of multi-sampling Pitot tubes reaches 1%. Here there was no such problem, since measurements were carried out with clean water from a storage tank with a filter.



Figure 8. The process of damping the kinetic energy in the spillway

To obtain reliable experimental results, in addition to reliable equipment, a correct choice of the data processing method is required. According to the theory, in a channel with a three-dimensional roughness, it is necessary to measure the distribution fields of the physical quantities of velocity, depth, concentration [113]. And only by integrating, and not averaging in advance over the diagram, the obtained functional dependencies, it is possible to determine with great accuracy the actual characteristics of the flow in the section. For each vertical j by calculation, according to the experimental data, the average concentration of water, the consumption of the mixture, respectively, according to the equations (Equation 14-17):

$$C_j = \int_0^{h_a} C_i dh / h_{aj} \quad (14)$$

$$Q_{Mj} = b_j \int_0^{h_a} u_{Mi} dh \quad (15)$$

$$Q_{air,j} = b_j \int_0^{h_a} u_{Mi} C_i dh \quad (16)$$

$$Q_{wj} = b_j \int_0^{h_a} u_{Mi} (1 - C_i) dh \quad (17)$$

In the calculations, it was assumed that there is no phase slip velocity, that is (Equation 18):

$$u_M = u_W = u_{air} \quad (18)$$

The flow depth was taken as the distance from the bottom to the point where the measured flow concentration was 96% (Figures 9-10). The debated question is where to measure the flow depth in a rough channel – from the bottom or from the top of the roughness ridge in the case of a spatial problem was solved as follows. The presence of the protrusion was taken into account using the Z parameter, which is the cross-sectional area of the artificial roughness protrusion in the alignment on the vertical flow (Figure 8).

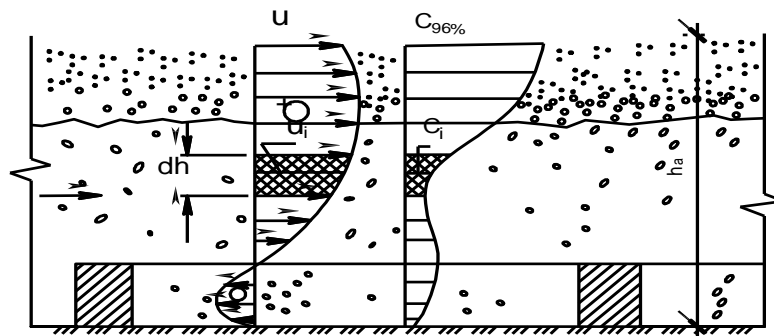


Figure 9. Determination of water flow rate Q_w , air flow rate Q_{air} b and mixture Q_m in the vertical flow

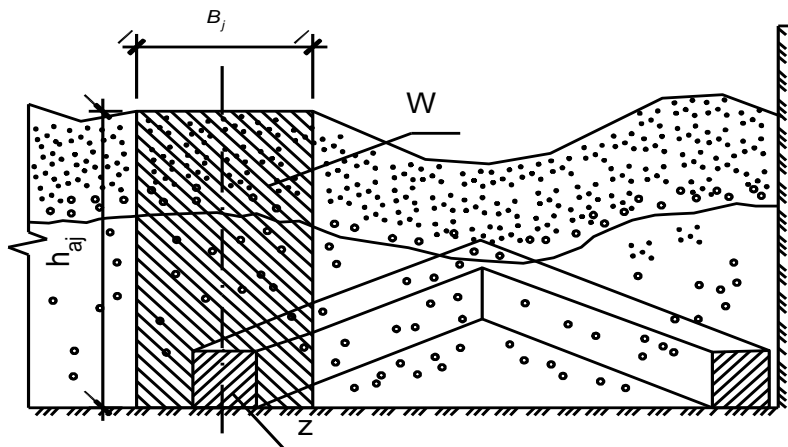


Figure 10. More on the choice of the zero reference plane in a channel with artificial roughness

In other words, the flow rate of the water mixture on the vertical Q_{Mj} passes through the section W determined by the depth, measured from the bottom of the spillway flume (Figure 9), minus the cross-sectional area of the ridge of roughness Z . Then the flow rate on the vertical equals (Equation 19):

$$Q_{Mj} = v_{Mj}(b_j \cdot h_a - Z) \quad (19)$$

In addition, for each vertical of the alignment, the values of the Coriolis and Boussinesq coefficients were calculated using the equations (Equation 20-21):

$$\alpha_k = 1 + 3 \frac{\int_0^{h_a} (v_{Mj} - u_{Mij})^2 dh_{ij}}{(v_{Mj}^2 - h_{aj})} \quad (20)$$

$$\alpha_b = 1 + \frac{\int_0^{h_a} (v_{Mj} - u_{Mij})^2 dh_{ij}}{(v_{Mj}^2 - h_{aj})} \quad (21)$$

Then, the obtained parameters were summed up along the vertical lines, and the averaged hydraulic parameters of the flow in the section were determined, as well as the parameters of the fictitious (without taking into account the air flow rate) flow. The relative measurement error is determined by the formula (Equation 22):

$$\sigma = 1 + \frac{Q_{w,r} - Q_{w,cal}}{Q_{w,r}} \cdot 100\% \quad (22)$$

where: $Q_{w,r}$ – actual water flow passed on the model, measured by the indication of the triangular weir; $Q_{w,cal}$ – calculated water consumption.

The fact that, in the entire range of the experiments carried out, the relative error in the water flow rate did not exceed 5%, testifies to the accuracy of the assumptions made, the adopted procedure for processing experimental data, and the reliability of the instrument readings [114-116].

4. Conclusion

To overcome the unfavourable hydraulic flow regime, which manifests itself in the water jet throw from the first protrusions, the authors proposed a construction at the end of a spillway flume with artificial roughness. This ensures a smooth increase in the depth of the turbulent boundary layer and dampens the kinetic energy of the water flow. Several design options were considered and one structure with an effective result, which is an artificial zigzag roughness, was identified. Investigation of the regularities of the flow around the square type roughness showed that there is an extremely uneven distribution of depth in the cross section of the flow. In this regard, the design of the zigzag type roughness was investigated. It allows to overcome this drawback and, in some cases, to achieve savings by reducing the height of the sides of the tray. The energy absorbing capacity of the zigzag is 5-10% lower than that of a square absorber.

The value of the hydraulic resistance coefficient of the flow depends on the slope, the type of relative roughness. It was found that there is a certain "effective" range of variation of the relative roughness, when for a given slope and type of roughness the value of the hydraulic resistance coefficient is maximum and practically does not change. And when going beyond this range, under conditions of a fast-flowing regime, the effect of energy damping decreases sharply. The regularities of the spatial distribution of the damping concentration at rapid currents with zigzag and other types of artificial roughness have been experimentally established. The type and the value of the relative roughness, taking into account the slope of the bottom, and the value of the relative roughness, differing in the greater accuracy of the results from the known formulas of other authors, are obtained. The recommendation of engineering hydraulic calculations of rapid flows with artificial roughness has been investigated, taking into account the damping of the flow, allowing the selection of the most economical structure of the construction. Studies have confirmed that, in most cases, the most economical type of grade-control structure are currents with artificial roughness.

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