Kinematic parameters of flow constrained by combined dams with through part of tetrahedra in compression region

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Abstract. Every major river in the world consists of mountainous, foothills, and flat areas characterized by different flow regimes. The foothill areas differ in slopes $i = 0.001 \div 0.004$, flow kinetics $Fr > 0.15$, and the size of sediments. The riverbed is unstable, and the banks are prone to erosion. The construction of coastal protection structures requires solving complex issues related to their design. The analysis showed that most of the studies, including ours, were carried out for the conditions of lowland rivers. This work aims to establish the flow features of the foothill sections of a combined dam with a through part of tetrahedra when the ratio of the through part ℓ_s to the total length of the dam ℓ_d is greater than or equal to 0.5, i.e., $\ell_s/\ell_d \geq 0.5$. The presence of a satellite flow behind the through part, a weakly perturbed core, and the presence of two zones of intense turbulent mixing was experimentally established, and the universality of the velocity distribution, which obeys the theoretical dependence of Schlichting-Abramovich, was confirmed. It is once again confirmed that the dependence is on the slope of the bottom, the Froude number, the degree of constraint, and the formation of "calm" and "critical" flow modes. The nature of the level changes along the length of the compression region in the core, and the satellite flow differ from each other, and the alignments occur in the vertical compression alignment. The problem is implemented for the "calm" mode using an integral relation characterizing the law of conservation of momentum in the flow, the equation of conservation of flow, and the differential equation of uneven motion recorded for the satellite flow behind the through part of the combined dam. The presence of a satellite flow, two zones of intense turbulent mixing, and the different nature of the leveled regime of the main and satellite flows are taken into account. A comparison of theoretical solutions with experimental ones shows their similarity.

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1 Introduction

Coastal erosion, as one of the types of water erosion, annually causes enormous damage, and combating them in all river systems is an urgent task [1-4]. Therefore, it is unsurprising that the design and development of methods for their calculation justification are given a large place in scientific research [5-9], many of which are made for the conditions of lowland rivers. Many authors have focused on determining the depth of local erosion at deaf dams [10-18]. Meanwhile, the foothill sections of the rivers have their own peculiarities consisting both in morphology and the hydraulics of the flows. [19]. the riverbeds are composed of pebbles, gravel, and sand, and the stream is abundantly saturated with sediments. The stream wanders in its sediments with a widely developed floodplain; the banks are mostly eroded. This is how the rivers Zarafshan, Chirchik, Kashkadarya, Akhangaran, etc., are characterized. The slopes of the riverbed vary within $i = 0.001 \div 0.004$, and the kinetics of the flow $Fr = 0.15 \div 0.5$. Studies for these conditions were carried out for deaf transverse structures [20,21], and studies [22] were considered for through structures; meanwhile, for conditions of flat rivers, the effectiveness of combined dams consisting of deaf and through parts is shown [23-30]. The through part is made of piles driven into the bottom of the riverbed. They are the most capital; their disadvantage is the high cost. A combined dam consisting of a blind part of local soil and a through part of reinforced concrete tetrahedral laid in the head of the dam is proposed.
Experimental studies were carried out in a tray with a variable slope; the physical picture of the flow constrained by a combined dam with a through part of tetrahedral was revealed for conditions when the relative length of the through part $\ell_s / \ell_d \geq 0{,}5$. The presence of two modes is set, "quiet" when $n_d < 0.3$, $Fr < 0.15$ and "critical" when $n_d > 0.3$, $Fr > 0.15$. Theoretical formulas for calculating the velocity field for the "quiet" mode are obtained.

2 Methods

The experimental research methodology is described in detail in our previous works [1-3]; therefore, we present the main characteristics of the flow and the channel: the dimensions of the tray of $40 \times 75 \times 800 см$. The coefficient of development of the through part $P = 0.01 \div 0.4 P = W_3 / W$ (building area of the through part, total area), angle of installation of the dam $\alpha_d = 60^0 \div 90^0$, and the bottom slope is from $i = 0.0001$ until $i = 0{,}004$ the relative length of the through part 0.2-0.6.

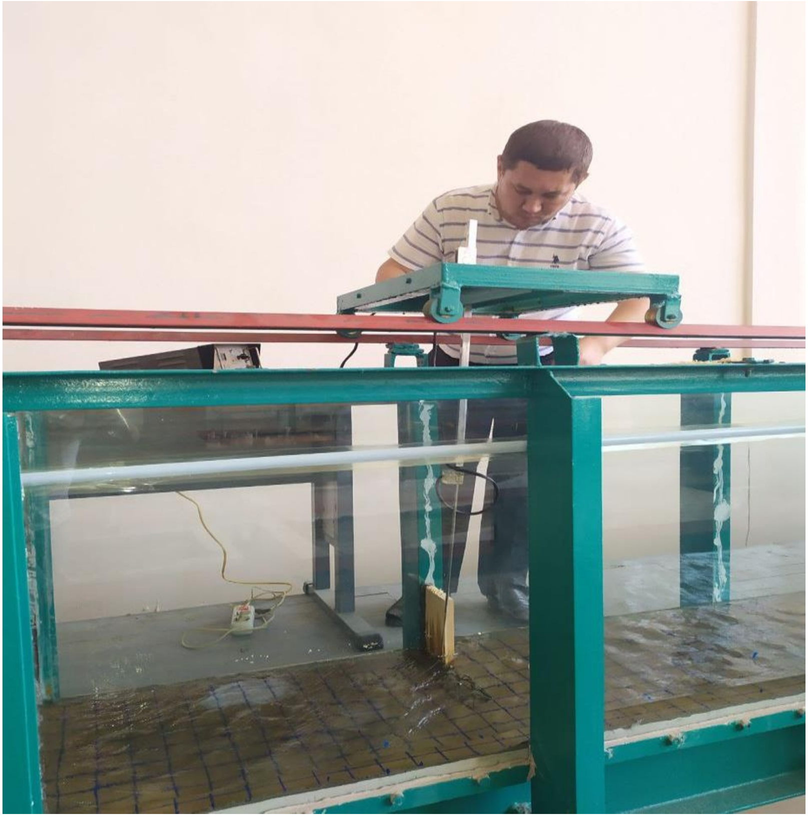

Fig. 1. Experimental studies of combined dam

Modeling was conducted by Freud number. In all experiments, the turbulent regime was maintained. The conditions of the planned task were met $B/h > 6$. A triangular Thomson spillway measured water flow rates. The free surface was fixed using a measuring needle with leveling. A micro turntable measured the water velocities with an electronic sensor. Theoretical studies have used the main provisions of the theory of turbulent jets propagating in a confined space, the flow division scheme into hydraulic homogeneous zones: weakly perturbed core, satellite flow, intense turbulent mixing, and reverse currents. To solve the problem, the basic equations of applied mechanics, the law of conservation of momentum in the flow, conservation of flow, and differential equations of uneven motion are used.

3 Results and Discussion

The jet character is preserved when the combined dam flows through the tetrahedron part. Flow occurs with the formation of a section of support between sections A-A and 0-0, planned compression between the gates 0-0 and PS, vertical compression between the gates PS-VS, a section of spreading between the gates PS and K-K, and recovery between the gates K-K and B-B (Fig. 2)

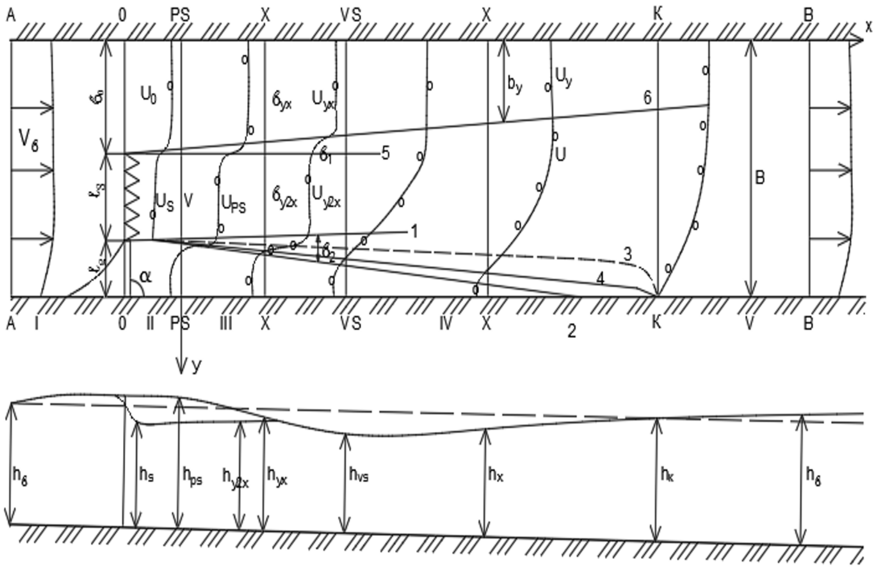

Fig. 2. Diagram of flow deformed by combined dam with through part of tetrahedra $\ell_s/\ell_d \geq 0.5$ (quiet mode)

The presence of a longitudinal slope $i_d < i_{kr}$ is characteristic of the foothill sections of rivers; the locations of the vertical and planned compression lines do not coincide. Vertical compression continues beyond the target of planned compression. Behind the vertical compression gate, the water level increases to the end of the whirlpool zone, and this rise continues within the recovery area. Behind the through part, there is a decline in levels and their recovery in the compression areas. In general, the transverse drop persists until the end of these areas.

The flow consists of a weakly perturbed core, a satellite flow, zones of intense turbulent mixing, and reverse currents. In the case under consideration, when $\ell_s/\ell_d > 0{,}5$ two zones of intense turbulent mixing are formed, the first is between a weakly disturbed core and a satellite flow, and the second is between a satellite flow and a whirlpool zone. It is established that the velocity distribution in the zones of intense turbulent mixing is subject to the theoretical dependence of Schlichting-Abramovich in the presence of the initial section of the jet (Fig 3).

$$\frac{U_y - U}{U_y - U_n} = (1 - \eta^{1.5})^2 \qquad (1)$$

Here U_{yix}, U_i, $U -$ are velocities in the core or in the satellite flow, reverse currents, and in the zone of intense turbulent mixing.

In the first zone from y_5 to y_6; $U_{yix} = U_{yx}$; $U_i = U_{y2x}$; $\eta = \dfrac{y_5 - y}{b_1}$;

$b_1 = (C_1 + C_2)x = (0.08 + 0.04)x = 0.12x$

In the second zone from y_1 to y_2; $U_{yix} = U_{y2x}$; $U_i = U_n = 0$; $\eta = \dfrac{y_2 - y}{b_2}$;

$b_2 = (C_3 + C_4)x = (0.1 + 0.14)x = 0.24x$

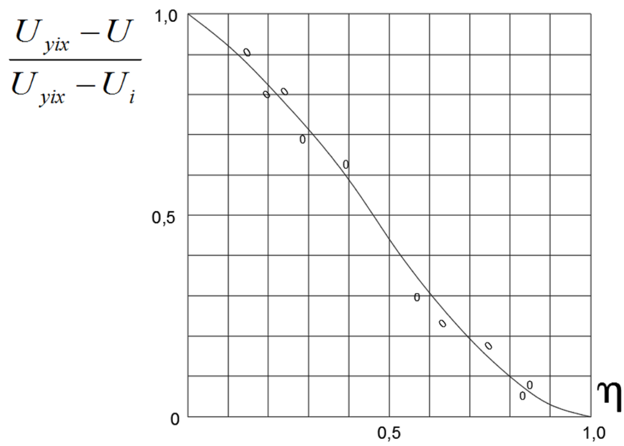

Fig. 3. Dimensionless velocity profile (initial section) – theory, 0-experimental.

To determine the flow rate in the constriction line U_0, we write down the flow conservation equations for the cross sections and the leaf in the upstream, where the household state of the flow is preserved.

$$v_{\text{в}} \cdot h_{\text{в}} \cdot B = U_s \cdot h_s \cdot \ell_s \cdot \sin\alpha_d + U_0 \cdot h_0 \cdot b_0 \tag{2}$$

Divide by $v_{\text{в}} h_{\text{в}} b_0$

$$\frac{B}{b_0} = \frac{U_s}{v_{\text{в}}} \cdot \frac{h_s}{h_{\text{в}}} \cdot \frac{\ell_s \cdot \sin\alpha_d}{b_0} + \frac{U_0}{v_{\text{в}}} \cdot \frac{h_0}{h_{\text{в}}}$$

It has been experimentally established that $h_0 = h_{\text{в}}$

Then

$$\frac{U_0}{v_{\text{в}}} = \frac{B}{b_0} - \overline{U}_s \cdot \overline{h}_s \cdot \frac{\ell_s \cdot \sin\alpha_d}{b_0} \tag{3}$$

where, $\dfrac{B}{b_0} = \dfrac{1}{\dfrac{b_0}{B}} = \dfrac{1}{\dfrac{B - (\ell_g + \ell_s) \cdot \sin\alpha_d}{B}} = \dfrac{1}{1 - (n_g + n_s)}$

Substituting in (3), we write

$$\frac{U_0}{v_{\text{в}}} = \frac{1}{1 - \left(n_g + n_s\right)} - \overline{U}_s \cdot \overline{h}_s \cdot \varepsilon_s \tag{4}$$

Where $v_{в}, U_0, U_s$ .speeds in the domestic state, in the non-crowded part of the flow in the line of constaint $0-0$, behind the through part.

$h_s -$ flow depth;

$\varepsilon_s = \ell_s \cdot \sin\alpha_d / b_0$;

$n_g = \dfrac{\ell_g \cdot \sin\alpha_d}{B}$ is obstruction of the flow by the blind part of the dam:

$n_s = \dfrac{\ell_s \cdot \sin\alpha_d}{B}$ is obstruction of the flow by the through part of the dam:

The speed behind the through part, as well as the hydraulic coefficient of tetrahedron construction, is determined according to the recommendations of the Central Asian Research Institute of Irrigation [22, 23].

It is necessary to establish the nature of the change in the velocity of the satellite flow V and the depth of the flow h_{sx} within the length of the compression region and the velocity in the zone of a weakly perturbed core U_{yx}.

The average velocities of the satellite flow are determined from the momentum conservation equation recorded for the part of the flow passing through the through part

$$\alpha_1 \cdot U_s^2 \cdot h_s \cdot \ell_s \cdot \sin\alpha_d - \alpha_x \cdot v^2 \cdot h_x \cdot b = \frac{g \cdot b \cdot h_x^2}{2} - \frac{g \cdot h_s^2 \cdot \ell_s \cdot \sin\alpha_d}{2} \tag{5}$$

From where, after some transformations, expressions were obtained to determine the average velocities along the length of the satellite flow of the compression region

$$v^2 = \frac{g \cdot \ell_s \cdot \sin\alpha_d \cdot \alpha_1^2 - b \cdot h_x^2}{2 \cdot \alpha \cdot h_x \cdot b} \tag{6}$$

$$b = \ell_s \cdot \sin\alpha_d + 0.08\,\text{x}.$$

Where $a_1 = h_s \cdot \sqrt{2 \cdot \alpha \cdot Fr_s + 1}$ - dimension m^2; $Fr_s = \dfrac{U_s^2}{g \cdot h_s}$ is the Froude number behind the through a part in the constraint line.

Adjusting the amount of movement by experiments $\alpha_1 = \alpha_x = \alpha = 1.2 - 1.25$

The change in the depth of the flow behind the through part is determined from the differential equation of motion

$$-\frac{dh}{dx} = \frac{d}{dx}\left(\frac{v^2}{2g}\right) + i_f \tag{7}$$

Taking on a short stretch $i_f = 0$, taking into account the expression for the average velocity, an expression is obtained by which the change in the depth of water behind the through a part in the compression region is determined.

$$\left(2\cdot\alpha-0.5\right)\cdot\frac{h_s^2}{a_1^2}\cdot\left[\left(\frac{h_x}{h_s}\right)^2-1\right]-\ln\frac{h_x}{h_s}=\frac{cx}{\ell_s\cdot\sin\alpha_d} \tag{8}$$

According to this dependence, the change in the depth of the water behind the through a part in the compression region is determined, according to experimental data c=0,08.

The regularities of velocity changes in a weakly perturbed core in the region of planned compression are found from the integral relation characterizing the law of conservation of momentum in the flow recorded for the valves 0-0 and X-X

$$U_0^2\cdot b_0\cdot h_0+U_s^2\cdot\ell_s\cdot\sin\alpha_d\cdot h_s=U_{yx}^2\cdot b_0\cdot h_{yx}+V^2\cdot h_x\cdot\ell_s\cdot\sin\alpha_d+ \\ +\frac{g\cdot b_0}{2}\left(h_0^2+h_{yx}^2\right)-\frac{g\cdot l_d\sin\alpha_d}{2}\left(h_x^2+h_s^2\right) \tag{9}$$

Divide by $U_0^2\cdot B\cdot h_0$ and after some transformations

$$\frac{U_{yx}}{U_0}=\sqrt{\frac{\left(1-n_d\right)+\overline{U_s^2}\cdot n_s\cdot\overline{h_s}-\overline{V^2}\cdot h_x\cdot n_s+\frac{(1-n)}{2Fr_0}\left(1-\overline{h_{yx}^2}\right)-\frac{n}{2Fr_0}\left(h_x^2-h_s^2\right)}{\overline{h_{yx}}(1-n_d)}} \tag{10}$$

where, $n=\frac{\ell_d\cdot\sin\alpha_d}{B}$; $n_s=\frac{\ell_s\cdot\sin\alpha_d}{B}$; $\overline{U_s}=\frac{U_s}{U_0}$; $\overline{V}=\frac{V}{U_0}$; $Fr_0=\frac{U_0^2}{g\cdot h_0}$; $\overline{h_s}=\frac{h_s}{h_0}$; $\overline{h_x}=\frac{h_x}{h_0}$; $\overline{h_{yx}}=\frac{h_{yx}}{h_0}$.

As can be seen from equation (10), the main difference from the previously obtained solutions is to consider the different nature of changes in the water equations in the longitudinal and transverse directions.

In the zone of a weakly perturbed core, the depths change in the longitudinal direction

$$h_{yx}=h_в+Z_p-JX \tag{11}$$

where J $=Z/(\ell_в+\ell_{VS})$; $Z_p=0.5\cdot Z$ is the support created by the dam and in the longitudinal direction behind the through parts, the nature of the change is determined by the above-obtained dependence (8). In the transverse direction comes from h_{yx} to h_x. In the vertical compression alignment VS, the depths are leveled here $h_{yx}=h_x\approx h_{VS}$. Length of the riding whirlpool zone $\ell_в$ and compression areas ℓ_{VS} determined by recommendations [26].

The obtained dependences allow us to establish the nature of the change in average speeds behind the through part V flow depths h_x, as well as velocities in the zone of a weakly perturbed core U_{yx} for the area of vertical compression and the velocity of the satellite flow U_{y2x}. We have at our disposal an integral relation characterizing the law of conservation of momentum and conservation of flow; we will use them to find these speeds.

Let us make up for the 0-0 and X-X gates the flow conservation equation for the entire flow in the vertical compression region

$$U_0 \cdot b_0 \cdot h_0 + U_s \cdot h_s \cdot \ell_s \cdot \sin\alpha_d = U_{yx} \cdot b_{yx} \cdot h_{yx} + 0{,}5(h_{yx} \cdot h_s)\int_{Y_5}^{Y_6} U dy + U_{y2x} \cdot b_{y2x} \cdot h_{y2x} + h_x \int_{Y_2}^{Y_1} U dy \quad (12)$$

Taking the velocity distribution in both zones of intense turbulent mixing according to Schlichting-Abramovich (1) and performing integration after some transformations, we obtain the following:

$$m_{y2x} = \frac{U_{y2x}}{U_{yx}} = \frac{\overline{U}_0(1-n) + \overline{U}_s \cdot \overline{h}_s \cdot n_s - \overline{b}_{yx} \cdot \overline{h}_{yx} - 0.275 \cdot \overline{b}_1 \cdot (\overline{h}_{yx} - \overline{h}_s)}{0.225 \cdot \overline{b}_1 \cdot (\overline{h}_{yx} + \overline{h}_s) + \overline{h}_{y2x}(\overline{b}_{y2x} + 0.55 \cdot \overline{b}_2)} \quad (13)$$

Where, $\overline{U}_0 = U_0 / U_{yx}$; $\overline{U}_s = U_s / U_{yx}$; $\overline{h}_s = h_s / h_0$; $\overline{h}_{yx} = h_{yx} / h_0$; $\overline{h}_{y2x} = h_{y2x} / h_0$; $\overline{b}_{yx} = b_{yx} / b_0$; $\overline{b}_1 = b_1 / b_0$; $\overline{b}_{y2x} = b_{y2x} / b_0$; $\overline{b}_2 = b_2 / b_0$; $n = \ell_d \cdot \sin\alpha_d / B$; $n_s = \ell_s \cdot \sin\alpha_d / B$; $h_0 = h_в$

To shorten the record with further transformations, we conditionally denote

$$m_{y2x} = \frac{U_{y2x}}{U_{yx}} = \frac{C_0 - M_1}{F} \quad (14)$$

where

$$C_0 = \overline{U}_0 \cdot (1-n) + \overline{U}_s \cdot \overline{h}_s \cdot n_s \quad M_1 = \overline{b}_{yx} \cdot \overline{h}_{yx} + 0.275 \cdot \overline{b}_1 \cdot (\overline{h}_{yx} + \overline{h}_s)$$

$$F = 0.225 \cdot \overline{b}_1 \cdot (\overline{h}_{yx} + \overline{h}_s) + \overline{h}_{y2x} \cdot (\overline{b}_{y2x} + 0.55 \cdot \overline{b}_2)$$

Let us make an integral relation characterizing the law of conservation of momentum in the flow for sections 0-0 and X-X in the compression region for the entire flow

$$U_0^2 \cdot b_0 \cdot h_0 + U_s^2 \cdot h_s \cdot \ell_s \cdot \sin\alpha_d = U_{yx}^2 \cdot b_{yx} \cdot h_{yx} + 0{,}5(h_{yx} + h_s) \cdot \int_{Y_5}^{Y_6} U^2 dy + U_{y2x}^2 \cdot b_{y2x} \cdot h_{y2x} +$$
$$+ h_x \int_{Y_2}^{Y_1} U^2 dy + \frac{gh_0^2}{2} \cdot b_0 + \frac{gh_s^2}{2} \cdot \ell_d \cdot \sin\alpha_d + \frac{gh_{yx}^2}{2} \cdot (b_{yx} + b_1) - \frac{gh_{y2x}^2}{2} \cdot (B - b_{yx} - b_1) \quad 15)$$

By performing the integration taking into account the velocity distribution in the zones of intense turbulent mixing (1), we obtain:

$$U_0^2 \cdot b_0 \cdot h_0 + U_s^2 \cdot h_s \cdot \ell_s \cdot \sin\alpha_d = U_{yx}^2 \cdot b_{yx} \cdot h_{yx} + 0{,}5 \cdot (h_{yx} + h_s) \cdot U_{yx}^2 \cdot b_1 \cdot (0{,}416 + 0{,}268 m_{y2x} + 0{,}316 m_{y2x}^2) +$$
$$+ U_{y2x}^2 \cdot b_{y2x} \cdot h_{y2x} + h_{y2x} \cdot 0{,}416 \cdot U_{y2x}^2 \cdot b_2 + \frac{gh_0^2}{2} \cdot b_0 + \frac{gh_s^2}{2} \cdot \ell_d \cdot \sin\alpha_d -$$
$$- \frac{gh_{yx}^2}{2} \cdot (b_{yx} + b_1) - \frac{gh_{y2x}^2}{2} \cdot (B - b_{yx} - b_1) \quad (16)$$

Divide by $U_{yx}^2 B h_0$ and after the transformations, we have

$$\left(\frac{U_0}{U_{yx}}\right)^2 \cdot (1-n) + \left(\frac{U_s}{U_{yx}}\right)^2 \cdot n_s \cdot \bar{h}_s = \bar{b}_{yx} \cdot \bar{h}_{yx} + 0.5(\bar{h}_{yx} + \bar{h}_s) \cdot \left(0.416 + 0.268\frac{U_{y2x}}{U_{yx}} + 0.316\frac{U_{y2x}^2}{U_{yx}^2}\right) +$$
$$+\left(\frac{U_{yx}}{U_{yx}}\right)^2 \cdot \bar{b}_{y2x} \cdot \bar{h}_{y2x} + 0{,}416\left(\frac{U_{y2x}}{U_{yx}}\right)^2 \cdot \bar{b}_2 \cdot \bar{h}_{y2x} + \frac{(1-n)}{2Fr_{yx} \cdot h_{yx}} +$$
$$+\frac{\bar{h}_s^2 \cdot n}{2Fr_{yx} \cdot h_{yx}} - \frac{\bar{h}_{yx}^2}{2Fr_{yx}}(\bar{b}_я + \bar{b}_1) - \frac{\bar{h}_{y2x}^2}{2\bar{h}_{yx} \cdot Fr_{yx}}(1 - \bar{b}_{yx} - \bar{b}_1) \qquad (17)$$

where $Fr_{yx} = \frac{U_{yx}^2}{g \cdot \bar{h}_{yx}}$; $m_{y2x} = \frac{U_{y2x}}{U_{yx}}$; let us introduce the notation $S_1 = 0.5 \cdot \bar{b}_1 \cdot (\bar{h}_{yx} + \bar{h}_s)$

$$S_2 = \left(\frac{U_0}{U_{yx}}\right)^2 (1-n) + \left(\frac{U_s}{U_{yx}}\right)^2 n_s \cdot \bar{h}_s \cdot$$

Then,

$$S_2 = \bar{b}_{yx} - \bar{h}_{yx} + 0.416 \cdot S_1 + 0.268\frac{U_{y2x}}{U_{yx}} \cdot S_1 + 0.316\left(\frac{U_{y2x}}{U_{yx}}\right)^2 \cdot S_1 + \left(\frac{U_{y2x}}{U_{yx}}\right)^2 \bar{b}_{y2x} - \bar{h}_{y2x} + 0.416\left(\frac{U_{y2x}}{U_{yx}}\right)^2 \bar{b}_2 \cdot \bar{h}_{y2x} + T \cdot$$

Where $T = \frac{1}{2Fr_{yx} \cdot \bar{h}_{yx}}\left[(1-n) + n\frac{\bar{h}_s^2}{\bar{h}_{yx}^2} - \bar{h}_{yx}^2(\bar{b}_{yx} + \bar{b}_1) - \bar{h}_{y2x}^2(1 - \bar{b}_{yx} - \bar{b}_1)\right]$

$$S_2 = \bar{b}_{yx} \cdot \bar{h}_{yx} + 0.416 \cdot S_1 + 0.268 S_1\frac{U_{y2x}}{U_{yx}} + \left(\frac{U_{y2x}}{U_{yx}}\right)^2 \cdot \left[0.316 S_1 + \bar{b}_{y2x} \cdot \bar{h}_{y2x} + 0.416 \cdot \bar{b}_2 \cdot \bar{h}_{y2x}\right] + T$$

$$S_2 = \bar{b}_{yx} \cdot \bar{h}_{yx} + 0.416 \cdot S_1 + 0.268 S_1\frac{U_{y2x}}{U_{yx}} + \left(\frac{U_{y2x}}{U_{yx}}\right)^2 \cdot \left[0.316 S_1 + \bar{b}_{y2x} \cdot \bar{h}_{y2x} + 0.416 \cdot \bar{b}_2 \cdot \bar{h}_{y2x}\right] + T$$

$$0 = \bar{b}_{yx} \cdot \bar{h}_{yx} + 0.416 \cdot S_1 + T - S_2 + 0.268 \cdot S_1 \cdot m_{y2x} + m_{y2x}^2\left[0.316 \cdot S_1 + \bar{b}_{y2x} \cdot \bar{h}_{y2x} + 0.416 \cdot \bar{b}_2 \cdot \bar{h}_{y2x}\right].$$

We come to the quadratic equation

$$A_1 \cdot m_{y2x}^2 + A_2 \cdot m_{y2x} + A_3 = 0 \qquad (18)$$

where $A_1 = 0.316 S_1 + \bar{b}_{y2x} \cdot \bar{h}_{y2x} + 0416 \cdot \bar{b}_2 \cdot \bar{h}_{y2x}$, $A_2 = 0.268 \cdot S_1$, $A_3 = \bar{b}_{yx} \cdot \bar{h}_{yx} + 0416 \cdot S_1 + T - S_2$

$$T = \frac{1}{2Fr_{yx} \cdot \bar{h}_{yx}}\left[(1-n) + n\frac{\bar{h}_s^2}{\bar{h}_{yx}^2} - \bar{h}_{yx}^2(\bar{b}_{yx} + \bar{b}_1) - \bar{h}_{y2x}^2(1 - \bar{b}_{yx} - \bar{b}_1)\right] \cdot$$

The roots of the equation are positive, one is greater than one, and the other is less. The root of the equation is greater than one is discarded because it contradicts the physics of the phenomenon it would mean $U_{y2x} > U_{yx}$. Therefore, the root is taken $m_{y2x} < 1$.

The flow parameters in the spreading area are calculated according to the recommendations [1-3]. Combined dams combine the main advantages and eliminate the disadvantages of blind and through regulatory structures. The blind part protects against bypass from the root and lengthens the length of the protected area, and the through-flow part of the flow reduces the depth of local erosion at the head of the structure. Existing structures, the through parts of which are of pile type, require significant material costs. A combined dam is proposed, the blind part is made of local soil, and the through part is prefabricated tetrahedra. To reveal the physical picture, experimental studies were carried out to the conditions of foothill rivers with slopes $i = 0.001 \div 0.004$, flow kinetics $Fr > 0.15$, the coefficient of development of the through part $P = 0.2 \div 0.4$, the degree of shyness $n_d < 0.5$, relative length of the through part $\ell_s / \ell_d \geq 0.5$, and installation angle of 60^0-90^0. The formation of two flow modes, "quiet" is set when $n_d < 0.3$, $Fr < 0.15$ "critical" $n_d > 0.3$, $Fr > 0.15$. Here the problem is realized for the first "quiet" mode using an integral relation characterizing the law of conservation of momentum, the equations of conservation of flow, and uneven motion. Calculated dependences are obtained for determining the velocity in the non-compressed part of the flow in the confining alignment, the average velocities of the satellite flow, the patterns of changes in the depth of the flow in the compression region, changes in velocities in the weakly compressed core and the actual velocities in the satellite flow, taking into account the presence of two zones of intense turbulent mixing as well as a transverse level drop. Direct calculations and their comparison with experimental research data have shown the acceptability of the theoretical solutions obtained. (Fig. 2).

4 Conclusions

1. The physical picture of the water flow around a combined dam with a through part of tetrahedra, when the relative length of the through part $\ell_s / \ell_d \geq 0{,}5$, it is characterized by the presence of a satellite flow, two zones of intense turbulent mixing, the difference between the dropped mode in the main and satellite flow.

2. The magnitude of the flow velocity in the non-crowded part in the constraint formation depends on the speed behind the through part, the degree of constraint by the deaf and through parts, and the depth of flows behind the through a part in the household state.

3. The jet character of the velocity distribution in the zones of intense turbulent mixing, which obeys the theoretical dependence of Schlichting-Abramovich, is established.

4. Dependences for determining velocities in a weakly excited core, satellite flow, average velocities, and the nature of depth changes behind the through part are obtained theoretically. With their help, the velocity field is calculated, comparing which with non-eroding velocities, it is possible to set the erosion boundaries. Knowing the planned dimensions of the whirlpool zones, the distances between the structures in the system are assigned.

5. Comparison of calculated and experimental data shows their acceptability; the maximum deviation does not exceed 8%-10%.

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