Parameters of flow asymmetrically constrained by through spurs

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Abstract. Erosion of the banks of rivers brings enormous damage to the national economy of many countries. To combat them, various regulatory structures are being built: longitudinal dams, transverse traverse dams, watertight and permeable spurs, and combined transverse dams. Many issues of their design are sufficiently developed, including in our works, and are successfully applied.

This research aims to develop a method for hydraulic flow asymmetrically constrained by through pile-type spurs. The conditions of the planned task of the ratio of the flow width to the depth of more than 6 were also observed. The degree of restriction of the flow by spurs varied from zero to one, and the installation angle of the spurs from 600 to 900. The study of the velocity field showed their similarity with the main provisions of the theory of turbulent jets. The velocity distributions in both zones of turbulent mixing are universal and obey the theoretical Schlichting-Abramovich dependence. The expansion coefficient of the jet is 0.20. Theoretical studies have obtained dependences for determining the velocity in a weakly disturbed core, occurrent flows, and the spreading regions' lengths, which determine the installation locations of subsequent spurs.

1 Introduction

The design of regulatory structures requires the solution of many issues: the choice of a route, hydraulic calculations to determine the distances between structures, the velocity of a deformed flow, the depth of local erosion, etc. [1-3]. These issues are partially resolved for cases of unilateral constraint [1, 4–6], symmetrical constraint [7], and longitudinal through structures [8, 9]. Methods for designing through spurs from shell piles were considered [10] and specifically used in constructing the Takhiatash hydroelectric complex.

For the first time, the issues of hydraulic calculation of through spurs with stepped buildings were solved in work [11].

Considerable attention is also paid to studying permeable structures abroad [12]. The turbulence around the through spur was studied using the Doppler system. In work [13], experimentally and numerically influenced various permeable spurs with different throughputs and achieved 21.08% velocity dissipation in a bend. In the studied [14,15], the

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flow characteristics around the permeable spur are considered by the program (ANSYS Fluent), creating pores with different permeability from 22% to 52% with a pore inclination angle from 00 to 600. The latter had the best effect in diverting the flow from the protected shore. Research [16] considers riprap structures as permeable spurs, including those with flooding. The degree of immersion and enlargement of the pores increases the kinetic energy behind the structure. In work [17], the operation of a through pile-type spur was studied. It is noted that this type of spur is more effective than blind spurs. This effect was proved by us in 1992 [7].

The analysis of these works showed that many issues of calculation and design of through spurs had been sufficiently studied and successfully used. However, all these studies were performed for unilateral or symmetrical flow obstruction. At the same time, no studies are devoted to asymmetric flow obstruction through spurs. Based on this, the purpose and objectives of this work were formulated.

2 Methods

The studies were carried out according to the generally accepted methodology for conducting experimental studies. The experiments were carried out on a tray with dimensions of 40x75x800cm. The concept is introduced-the coefficient of asymmetry changed from 0 to 1.

$$K = \delta_1 / \delta_2$$

Where $\delta_1 = \ell_{u_1} \sin \alpha_{u}^{\circ}$; $\delta_2 = \ell_{u_2} \sin \alpha_{u}^{o}$ projections of spur lengths on the normal; - the angle of installation of spurs). The degree of flow restriction by through spurs $\alpha_{u}^{\circ} 60^0 - 90^0$ $n = (\delta_1 + \delta_2) / B$ (here B is the width of the channel) was taken from 0 to I. Development coefficient $P = d / (d + S) = 0,33; 0,5; 0,67$ (Here d, S are diameter and pitch of pile elements). Froude number in the domestic condition $F_{r_\delta} = V_\delta^2 / gh_\delta < 0,25$ in all experiments, the self-similar region was maintained. The conditions of the planned task B/h>6 were observed. Water discharges were measured by a triangular Thompson weir. Longitudinal and transverse differences in depths, speeds, and length of the zone of influence of through spurs were experimentally measured. The free surface was measured using a leveled measuring needle. Water velocities were measured by a Scientific Research Institute of Irrigation and Water Problems system micro-rotator with an electronic sensor TSNV-5. Theoretical solutions were implemented using the basic provisions of the theory of turbulent jets propagating in a limited space, particularly the scheme for dividing the flow into hydraulic homogeneous zones: a weakly disturbed core, intense turbulent displacement, and co-current flow[18–20]. Also used the basic equations of applied mechanics, the equations of conservation of flow, and the law of conservation of momentum in the flow. To assess the level regime, longitudinal profiles of the water surface were constructed, the analysis of which showed that the change in depths mainly co-occurs near the structure: backwater in the upper pool and level difference behind the spur [21].

3 Results and Discussion

An analysis of the distribution of average depth velocities in the plan showed that the pattern of a flow spreading behind asymmetrically located through spurs has much in common with the propagation of jets in a co-current and consists of zones: a weakly perturbed core, turbulent mixing, and a co-current behind the spur. In this case, the following are formed depending on the degree of constraint: the initial (Fig. 1.) and the main sections of the jets. n<0.5 n=0.5; 0.75.
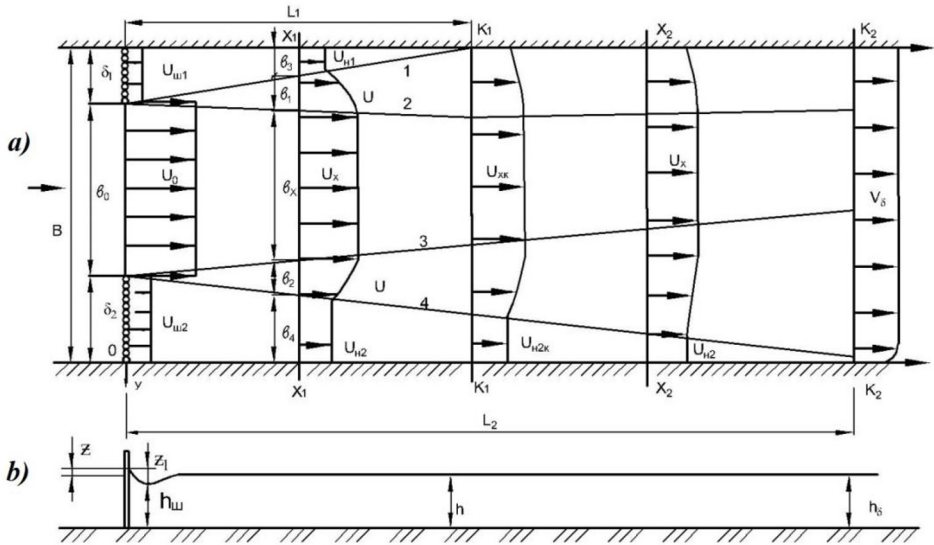

Fig. 1. Scheme of flow asymmetrically constrained by through spurs in initial section: *a)* plan; *b)* longitudinal profile.

This article discusses the solution to the problem in the initial section. In principle, these constraints can lead to shaft flow towards a through spur having a shorter length. We have established that this should not be allowed with large degrees of constraint; the building coefficient of a long spur should not exceed 0.5. An analysis of the distribution of velocities in the zone of turbulent mixing showed the universality of the velocity field and obeyed the theoretical dependences of Schlichting – Abramovich (Fig. 2.).

$$\frac{U_x - U}{U_x - U_{H_i}} = (1 - \eta^{1.5})^2 \qquad (1)$$

where - speeds: in the core, co-current flows, in the zone of turbulent mixing; - relative ordinate of the point at which the U_x, U_{H_i}, η U .
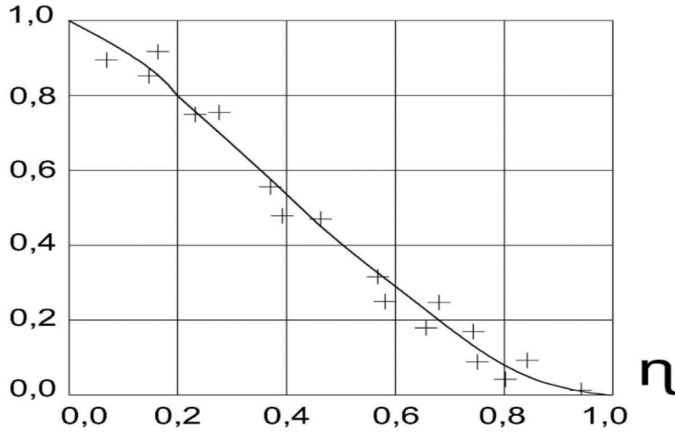
Fig. 2. Velocity distribution in the zone of turbulent mixing (initial section)

The width of the zone of intense turbulent mixing (Fig. 3) according to experimental data in the initial section $б=0.20x$. The task of theoretical studies was to determine the velocities U_k, U_{H_i}

To solve the problem, equations that characterize the law of conservation of momentum in the flow and conservation of flow are used. In this case, the hydrostatic law of pressure distribution is assumed, water depths along the spreading area are constant, and friction forces are taken into account from body forces.
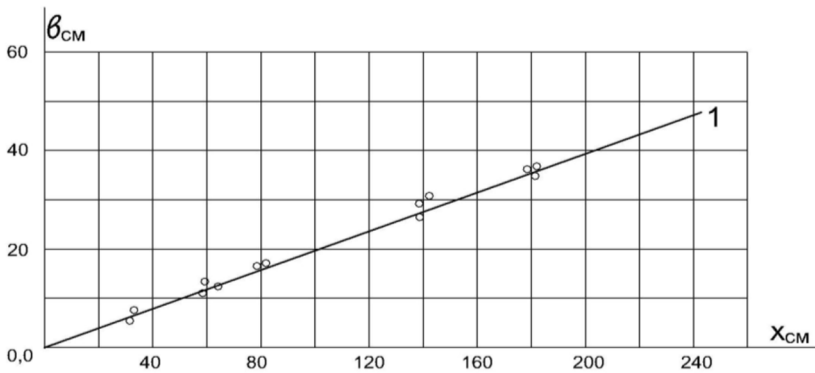
Fig. 3. Width of the turbulent mixing zone 1- initial section

The scheme of the flow asymmetrically constrained by through spurs in the presence of the initial section of the jets is shown in Fig. 1, where the designations are accepted: 0-0 - constraint target; $K_1 - K_1$,-end of the first spreading section; - - end of the second spreading section; $K_2 - K_2$, y_1, y_2, y_3, y_4, are boundaries of turbulent mixing zones; The X-axis coincides with the flow direction, and the Y-axis is perpendicular to it.

The law of velocity change in the zone of a weakly perturbed core is determined from the integral relation characterizing the law of conservation of momentum in the flow for sections 0-0 and $X - X$ and looks like

$$\frac{U_{\mathrm{x}}}{U_0} = \sqrt{\frac{\theta_1}{\theta_2}} e^{-\frac{\mathrm{a}\zeta}{2}} \bar{b}_0 \tag{2}$$

Where

$$\theta_1 = 1 + m_{0_2}^2 \bar{\delta}_2 + m_{0_1}^2 \bar{\delta}_1$$

$$\theta_2 = \bar{B}_{\mathrm{x}} + m_1^2 \bar{B}_3 + \bar{B}_1 F_1 + \bar{B}_2 F_2 + m_2^2 \bar{B}_4$$

$$m_{0_2} = U_{\mathrm{ш}_2} / U_0; \ m_{0_1} = U_{\mathrm{ш}_1} / U; \bar{\delta}_1 = \delta_1 / \ell_0$$

$$\bar{\delta}_2 = \delta_2 / b_0; m_1 = U_{\mathrm{н}_1} / U_{\mathrm{x}}; m_2 = U_{\mathrm{н}_2} / U_{\mathrm{x}};$$

$$\mathrm{a} = \lambda \mathrm{B}/h; \zeta = \mathrm{x} / b_0; \bar{b}_0 = b_0/B; \ \bar{b}_3 = b_3/b_0;$$

$$\bar{b}_1 = b_1/b_0; \bar{b}_2 = b_2/b_0; \bar{b}_4 = b_4/b_0; \bar{b}_{\mathrm{x}} = b_{\mathrm{x}}/b_0;$$

$$F_1 = 0.416 + 0.268 m_1 + 0.316 m_1^2;$$

$$F_2 = 0.416 + 0.268 m_2 + 0.316 m_2^2$$

λ is the coefficient of hydraulic friction.

The co-current velocity behind a long spur is found from the dependence, which is obtained by jointly solving the flow conservation equation and equation (2) and has the form:

$$A_1 m_2^2 + A_2 m_2 + A_3 = 0 \tag{3}$$

$$A_1 = 0.316 \bar{b}_2 \Phi + \bar{b}_4 \Phi - (0.45 \bar{b}_2 + \bar{b}_4)^2 \mathrm{M};$$

$$A_2 = 0.218 \bar{b}_2 \Phi - 2\psi(0.45 \bar{b}_2 + \bar{b}_4)\mathrm{M};$$

$$A_3 = (m_1^2 \bar{b}_3 + \bar{b}_1 F_1 + \bar{b}_{\mathrm{x}} + 0.416 \bar{b}_2)\Phi - \Psi^2 \mathrm{M}$$

$$\Phi = (1 - m_{0_1}\bar{\delta}_1 + m_{0_2}\bar{\delta}_2)^2 e^{-\frac{\alpha\zeta}{2}} \bar{b}_0$$

$$\mathrm{M} = 1 + m_{0_2}^2 \bar{\delta}_2 + m_{0_1}^2 \bar{\delta}_1,$$

$$\Psi = \bar{b}_{\mathrm{x}} + m_1 \bar{b}_3 + \bar{b}_1(0.55 + 0.45 m_1) + 0.55 \bar{b}_2$$

At the end of the first spreading section for the alignment K_1, K_1 fair

$$\mathrm{X} = L_1; \ U_{\mathrm{H}_1} = V_\delta; \bar{L}_1 = L_1 / b_0; \ m_1 = m_3$$

$$V_\delta / U_{\mathrm{x}K}; \ m_2 = m_5 = U_{\mathrm{H}_2 K} / U_{\mathrm{x}K}; \ b_3 = 0; L_1 = \delta_1 / 0.08$$

And the resulting dependencies (2) and (3) are greatly simplified. For the second section of spreading, between the cross-sections, it is characteristic that the velocities along the coast protected by a short spur are close to normal, the width of the turbulent mixing zone is equal to

$$K_1 - K_1 K_2 - K_2 b_{1K} = sonst$$

The solution of the momentum conservation equation in the flow recorded for the gates and leads to dependence (2), where it is necessary to take

$$K, - K_1 X_2 - X_2$$

$$U_0 = U_{xK} \; ; \quad \theta_1 = \bar{6}_{1K}F_3 + \bar{6}_{xK} + \bar{6}_{2K}F_5 + m_5^2 \bar{6}_{4K} \; ;$$

$$\theta_2 = \bar{6}_{1K}F_4 + \bar{6}_x + \bar{6}_2 F_2 + m_2^2 \bar{6}_4 \; ; \quad \bar{6}_{1K} = \bar{6}_{1K} \, / \, 6_0 ; \qquad (4)$$

$$F_3 = 0.416 + 0.268 m_3 + 0.316 m_3^2 \; ; \quad \bar{6}_{xK} = 6_{xK} \, / 6_0 \; ;$$

$$F_4 = 0.416 + 0.268 m_4 + 0.316 m_4^2 \; ; \quad \bar{6}_{2K} = \bar{6}_{2K} \, / 6_0$$

$$F_5 = 0.416 + 0.268 m_5 + 0.316 m_5^2 \; ; \quad \bar{6}_{4K} = 6_{4K} \, / 6_0$$

$$m_3 = V_\delta \, / \, U_{xK} \; ; \; m_4 = V_\delta \, / \, U_x \; ; m_5 = U_{H2K} / \, U_{xK}$$

(here, x is counted from the target, and the index K means that the values refer to the target). $K_1 - K_1 K_1 - K_1$

The joint solution of the equations of conservation of momentum in the flow and the flow rate recorded for the same sections leads to a dependence of the type (3), where it is necessary to crush.

$$A_1 = 0.316 \bar{6}_2 \, \phi + \bar{6}_4 \, \phi - (0.45 \bar{6}_2 + \bar{6}_4 \,)^2 M;$$

$$A_2 = 0.268 \bar{6}_2 \, \phi + 2\psi M - (0.45 \bar{6}_2 + \bar{6}_4);$$

$$A_3 = [\bar{6}_{1K}F_5 + \bar{6}_x + 0.416 \bar{6}_2]\phi - \psi^2 M \; ;$$

$$\Phi = [\bar{6}_{xK} + \bar{6}_{1K}(0.55 + 0.45 m_3) + \bar{6}_{2K}(0.55 + 0.45 m_5) + + m_5 6_{4K}]^2 e^{-\frac{\alpha\zeta}{2}\bar{6}_0}$$

$$M = \bar{6}_{1K}F_3 + \bar{6}_{xK} + \bar{6}_{2K}F_5 + m_5^2 \bar{6}_{4K} \; ;$$

$$\psi = \bar{6}_x + \bar{6}_{1K}(0.55 + 0.45 m_4) + 0.55 \bar{6}_2$$

The dependencies obtained include unknown quantities, and the problem remains somewhat uncertain. To eliminate this, we use the boundary conditions that at the end of the second spreading section, we have $m_3 m_5$

$$x = L = L_2 - L \; ; \; U_x = U_{H_2} = V_\delta \; ; \; m_2 = m_4 = 1$$

Using this condition, as well as the initial equations for the alignments, the following dependencies are obtained $K_1 - K_1 K_2 - K_2$

$$m_3 = [D_1 + m_5(0.45 \bar{6}_{2K} + \bar{6}_{4K})]/D_2 \qquad (5)$$

$$A_1 m_5^2 + A_2 m_5 + A_3 = 0 \qquad (6)$$

Where $A_1 = (0.45 \bar{6}_{2K} + \bar{6}_{2K})^2 \left(e^{\frac{\alpha l}{2}\bar{6}_0} - 1 \right) - D_1(0.316 \bar{6}_{2K} + \bar{6}_{4K});$

$$A_2 = 2D_1\left(0.45\bar{6}_{2K} + \bar{6}_{4K}\right)\left(e^{\frac{\alpha l}{2}\bar{6}_0} - 1\right) - 0.268\bar{6}_{1K} \cdot D_2\left(0.45\bar{6}_{2K} + \bar{6}_{4K}\right) - 0.268\bar{6}_{2K}\bar{6}_{2K} \cdot D_2$$

$$A_3 = D_1^2 e^{\frac{\alpha i}{2}\bar{6}_0} - 0.268\bar{6}_{1K}D_2 D_1 - 0.316\bar{6}_{1K}\, D_1^2 - (\bar{6}_{xK} + 0.416\bar{6}_{2K})D_2$$

$$D_2 = \left(1 - 0.45\bar{6}_{1K}\right); D_1 = \bar{6}_{1K} + 0.55\bar{6}_{1K} + 0.55\,\bar{6}_{2K}$$

An analysis of equations of the type (5), (7), (9) shows that its roots are positive, and one of them is less than one, and the other is greater than the root of the equation greater than one does not correspond to the physics of the phenomenon and is therefore discarded.

4 Conclusions

➢ Experimental diagrams of the distribution of velocities in the plan showed similarity with the scheme adopted in the theory of turbulent jets propagating in a limited space.

➢ The nature of the spreading of a flow asymmetrically constrained through spurs differs from one-sided constraint and two-sided symmetrically constrained flows by the presence of an asymmetrical flow spreading, two zones of intense turbulent mixing.

➢ The lengths of the spreading sections depend on the length of the through spurs, the coefficient of hydraulic friction, and the flow parameters in the initial alignment. The installation locations for subsequent spurs are determined by their size.

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