 https://doi.org/10.1051/e3sconf/202336503029

Flow division under a steady flow mode

Farrukh Shaazizov*

"Tashkent institute of irrigation and agricultural mechanization of engineers", National research university, Tashkent, 100000, Uzbekistan

Abstract. Many scientists have been involved in the division of open streams. Existing methods for calculating fission nodes do not allow choosing their optimal designs that create a favorable regime for dividing flows. Most of the available results of studies of fission nodes are scattered, non-systematic, and in some cases, contain data that do not coincide with each other. The conducted studies of division nodes were carried out mainly for the steady flow regime; the flow turbulence issues in the flow division section have been little studied. However, in practice, an unsteady flow regime and an increase in flow turbulence are often observed, which leads to complex channel processes in the water intake area. The aim of the work is to develop a refined method for the hydraulic calculation of flow division nodes with a calm flow regime. This goal is achieved by an analytical solution to the problem of determining the water depth in the nodes of flow division under a steady flow regime. The paper uses theoretical studies using the equation for changing the momentum, laboratory studies on a hydraulic model, field surveys of existing water intake units, and an analysis of the experimental data available in the literature on this issue. According to the theoretical studies, calculated dependencies were obtained to determine the depth of the main flow in front of the fission node. The equation is a cubic equation concerning the OX axis and a quadratic equation concerning the OY axis. These two equations are solved independently of each other and are intended to determine the flow depth h1, which is established before the fission node. Taking into account the simplicity of the solution for practical calculations, we recommend the first dependence, and the second dependence is proposed for performing control calculations.

1 Introduction

The modern irrigation system in the Republic of Uzbekistan is characterized by a dense network of canals of various orders. Because most of the canals in our republic lie in an earthen channel, certain difficulties arise in ensuring their reliable operation during the operational period.

A dense network of canals requires the installation of numerous division nodes, which undergo significant channel deformations in the form of erosion and silting.

Existing methods for calculating fission nodes do not allow choosing their optimal designs that create a favorable regime for dividing flows[1–7]. Most of the available results

* Corresponding author: shosfarruh@mail.ru

of studies of fission nodes are fragmented, non-systematic, and in some cases, contain results that do not coincide with each other[8–17].

The existing results of studies of fission nodes are, as a rule, carried out for a steady flow regime; the issues of flow turbulence in these areas have been little studied[18–21].

However, in practice, an unsteady flow regime often occurs, and an increase in flow turbulence is observed, which leads to complex channel processes in the water intake area[22–27]. In this regard, the topical issue is the study of the division nodes of open flows and the compilation of a methodology for calculating these nodes.

Many issues related to the flow division and sediments in the case of a damless water intake are covered and are widely used in engineering practice. However, several unresolved issues should be given special attention. The most studied issues include:

- selection of the location of the water intake structure relative to the curvature of the bank and the direction of the river flow;
- influence of the angle of withdrawal on the hydraulic conditions of the water intake;
- hydraulic calculation of water intake structures;
- determination of the calculated horizon in the main channel under the conditions of operation of a single-head water intake;
- calculation of the width of the water withdrawal strip for water intake into the bank slot;
- rational means of dealing with bottom sediments, based on the creation of artificial transverse circulation of the flow with a direction along the bottom away from the water intake;
- the nature and consequences of intake heads located in the eroded banks of the river.
- the influence of the input threshold on the capture of bottom sediments in the diversion and many other issues.

Less explored issues include:

- the theory of flow division (having theoretical solutions to this issue are based on several assumptions or are special cases that greatly simplify the phenomenon of flow division during lateral water intake);
- study of flow turbulence in the nodes of flow division;
- study of the conditions for the occurrence and nature of changes in the size of whirlpool zones within the flow division node;
- channel deformations at lateral water intake, etc.

2 Materials and Methods

In this paper, we consider the case of flow separation in prismatic channels of the rectangular cross-section at the division angle $\varphi \leq 90^{\circ}$.

According to research data, depths h_2 and h_B, respectively, are set in the main and outlet channels behind the fission node, which are determined only by the flow regimes available here. In the case of a sufficient length of the channels, both the outlet and the main one, the depths of the flows in them will equal the depths of uniform movement and can be calculated using the well-known Chezy formula.

When an uneven, smoothly changing movement is established in the channels, to determine the depths h_2 and h_B, the conditions that create this movement must be known.

Thus, using known methods of hydraulics, the problem of determining the depths h_2 and h_B can be solved. To solve the problem, we will use the law of momentum, according to which for the design scheme presented in (Fig. 1) we have the following dependencies in projections:

- on the OX axis

$$\Delta KD_x = [KD_2 - (KD_1 - KD_{в}\, Cos\varphi)]\Delta t = F_x \Delta t \tag{1}$$

- on the OY axis

$$\Delta KD_y = - KD_{в}\, Sin\varphi\, \Delta t = F_y \Delta t \tag{2}$$

The momentums with mass flow rates will be:
- in the projection on the OX axis

$$\alpha_0 \rho (Q_2 V_2 - Q_1 V_1 + Q_{в} V_{в}\, Cos\varphi)\Delta t \tag{3}$$

- in the projection on the OY axis

$$\alpha_0 \rho\, Q_{в} V_{в}\, Sin\varphi \Delta t \tag{4}$$

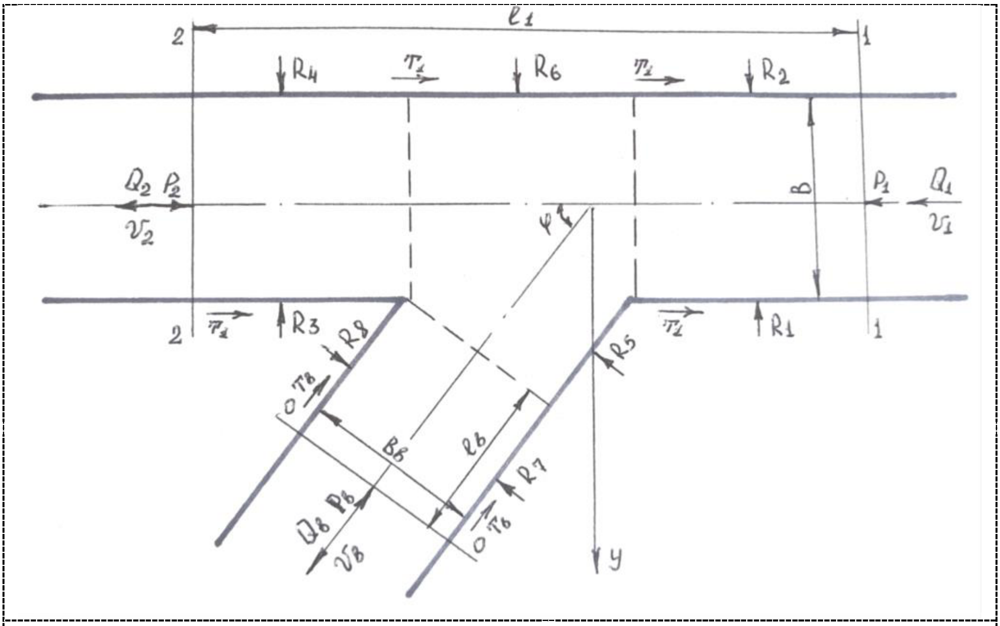

Fig. 1. Design scheme of dividing water stream.

The selected fluid compartment is in equilibrium under the action of:
a) hydrodynamic pressure forces applied in sections 1-1, 2-2, and 0-0. P_1, P_2, $P_{в}$;
b) reaction forces of side walls R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8;
c) gravity of the selected compartment G_1, G_B;
d) friction forces $\boldsymbol{T_1}$, T_B.
1. The sum of the projections of the hydrodynamic pressure forces will be:
- main flow axis

$$\sum P_X = P_1 - P_2 - P_B Cos\varphi = \rho g \frac{h_1 \omega_1}{2} - \rho g \frac{h_2 \omega_2}{2} - \rho g \frac{h_B \omega_B}{2} Cos\varphi = \\ = \rho g \frac{B h_1^2}{2} - \rho g \frac{B h_2^2}{2} - \rho g \frac{B_B h_B^2}{2} Cos\varphi \tag{5}$$

- OY axis

$$\sum P_Y = -P_B Sin\varphi = -\rho g \frac{h_B \omega_B}{2} Sin\varphi = -\rho g \frac{B_B h_B^2}{2} Sin\varphi \qquad (6)$$

2. The sum of the projections of the reaction forces of the side walls, bearing in mind that the reaction forces R_1 and R_2 ; R_3 and R_4 ; R_7 and R_8 are equal in magnitude and opposite in direction, will be:
- on the OX axis

$$\sum R_X = R_5 Sin\varphi = \rho g \frac{B_B Ctg\varphi}{2}\left(\frac{h_B + h_1}{2}\right)^2 Sin\varphi = \rho g \frac{B_B}{2}\left(\frac{h_B + h_1}{2}\right)^2 Cos\varphi \qquad (7)$$

- on the OY axis

$$\sum R_Y = R_6 - R_5 Cos\varphi = \rho g \frac{B_B}{2Sin\varphi}\left(\frac{h_1 + h_2}{2}\right)^2 - \rho g \frac{B_B Ctg\varphi Cos\varphi}{2}\left(\frac{h_B + h_1}{2}\right)^2 \qquad (8)$$

3. The sum of the projections of gravity, respectively
- on the OX axis

$$\sum G_X = G_1 + G_B Cos\varphi \qquad (9)$$

$$G_1 = \rho g \frac{BL_1 i_1 (h_1 + h_2)}{2}$$

and approximately taking hв=hв', we will have

$$\sum G_X = \rho g \frac{BL_1 i_1 (h_1 + h_2)}{2} + \rho g\left(B_B h_B L_B i_B + \frac{B_B^2 H_B i_B}{2} Ctg\varphi\right) Cos\varphi \qquad (10)$$

- on the OY axis

$$\sum G_Y = G_B Sin\varphi = \rho g\left(B_B h_B L_B i_B + \frac{B_B^2 h_B i_B}{2} Ctg\varphi\right) Sin\varphi \qquad (11)$$

4. Due to the smallness of their value, the friction forces are neglected.

Substituting the values of the parameters included in the dependence (1) and reducing by Δt and ρg we have:

$$\frac{\alpha_0}{g}\left(\frac{Q_2^2}{Bh_2} - \frac{Q_1^2}{Bh_1} + \frac{Q_B^2 Cos\varphi}{B_B h_B}\right) = \frac{Bh_1^2}{2} - \frac{Bh_2^2}{2} - \frac{B_B h_B^2}{2} Cos\varphi + \frac{B_B Cos\varphi}{2}\frac{(h_B + h_1)^2}{2} + \qquad (12)$$

$$+\frac{B(h_1 + h_2) l_1 i_1}{2} + B_B h_B i_B Cos\varphi\left(l_B + \frac{B_B Ctg\varphi}{2}\right);$$

Making minor transformations and substituting the values of the parameters in (2), respectively, we will have:

$$\frac{\alpha_0}{g}\frac{Q_B^2 Sin\varphi}{B_B h_B} = -\frac{B_B h_B^2}{2}Sin\varphi + \frac{B_B}{2Sin\varphi}\left(\frac{h_1+h_2}{2}\right)^2 - \frac{B_B Ctg\varphi Cos\varphi}{2}\left(\frac{h_B+h_1}{2}\right)^2 + +B_B h_B i_B\left(l_B Sin\varphi + \frac{B_B Cos\varphi}{2}\right). \quad (13)$$

Keeping in mind that in dependences (12) and (13), the unknown quantity is the depth h1, in a more explicit form, we will have:

$$ah_1^3 + bh_1^2 - ch_1 + d = 0 \quad (14)$$

$$eh_1^2 - fh_1 - m = 0 \quad (15)$$

Considering that equation (15) has two roots, one of which acquires a negative value to determine the depth h1, equation (15) is simplified and reduced to the form:

$$h_1 = \frac{f + \sqrt{f^2 - 4em}}{2e} \quad (16)$$

where:

$$a = \frac{4B + B_B Cos\varphi}{8}; b = \frac{B_B h_B Cos\varphi + Bl_1 i_1}{2}; c = \frac{\alpha_0}{g}\left(\frac{Q_2^2}{Bh_2} + \frac{Q_B Cos\varphi}{B_B h_B}\right) - \frac{5B_B h_B^2 Cos\varphi}{8} + \frac{Bh_2^2}{2} - -\frac{Bh_2 l_1 i_1}{2} + B_B h_B i_B Cos\varphi\left(l_B + \frac{B_B Ctg\varphi}{2}\right); d = \frac{\alpha_0 Q_1^2}{gB}; e = \frac{B_B Sin\varphi}{8}; f = \frac{B_B\left(h_B Cos^2\varphi - h_2\right)}{2Sin\varphi};$$

$$m = \frac{\alpha_0 Q_B^2}{gB_B h_B}Sin\varphi + \frac{B_B h_B^2}{2}Sin\varphi - \frac{B_B h_B^2}{8Sin\varphi} + \frac{B_B h_B^2 Ctg\varphi Cos\varphi}{8} - B_B h_{Bi} i_B\left(l_B Sin\varphi + \frac{B_B Cos\varphi}{2}\right).$$

Equation (14) is a cubic equation concerning the OX axis, and equation (15) is a quadratic equation concerning the OY axis. These two equations are solved independently of each other and are intended to determine the flow depth h1, which is established before the fission node. Considering the solution's simplicity for practical calculations, we recommend dependence (15), and dependence (14) can be used for control calculations.

3 Research results and Discussion

These dependencies gave discrepancies with experimental data ranging from -3.1 to + 2.9%, which allows us to recommend them for practical calculations.

4 Conclusion

1. An analysis of the performed studies of flow separation showed that, at present, there is no clear and reliable method for calculating fission nodes. In the overwhelming majority of cases, the calculated dependences proposed by the authors make it possible to determine the flow depth in the main channel only for certain conditions and lead to ambiguous results.

2. According to the theoretical studies, calculated dependencies were obtained to

determine the depth of the main flow before the fission node.

3. The paper considers the case of separation of flows in prismatic channels of the rectangular cross-section at the separation angle $\varphi \leq 90^o$.

4. According to research data, depths h_2 and h_B, respectively, are established in the main and outlet channels behind the fission node, which are determined only by the flow regimes available here.

5. To determine the unknown flow depth h1 before the fission node, two dependencies were obtained. In this case, dependence (14) is a cubic equation concerning h_1, and dependence (15) is a quadratic equation. Taking into account the simplicity of the solution for practical calculations, we recommend dependence (15), and dependence (14) can be used for control calculations.

References

1. Experiments of dividing the stream, so as to increase its effects, and render less water sufficient. J. Franklin Inst. 6, (1828). https://doi.org/10.1016/s0016-0032(28)90418-4.
2. Kroll, A.: Model test to keep a water intake free from bed load. (1977).
3. Rubel, M.T., Soliman, H.M., Sims, G.E.: Phase distribution during steam-water flow in a horizontal T-junction. Int. J. Multiph. Flow. 14, (1988). https://doi.org/10.1016/0301-9322(88)90020-1.
4. Rubel, M.T., Soliman, H.M., Sims, G.E.: Phase distribution during steam-water flow in a horizontal T-junction. Am. Inst. Chem. Eng. Work. 14, (1988).
5. Neary, V.S., Sotiropoulos, F., Odgaard, A.J.: Predicting 3-D flows at lateral water intakes. In: Waterpower - Proceedings of the International Conference on Hydropower (1995).
6. Qian, Y., Yang, Z., Xu, J.: Experimental study of phase separation in dividing two phase flow. Am. Soc. Mech. Eng. Heat Transf. Div. HTD. 334, (1996).
7. Azzopardi, B.J., Rea, S.: Phase Separation Using a Simple T-junction. Presented at the (2000). https://doi.org/10.2118/63040-ms.
8. Baker, D.B., Richards, R.P., Loftus, T.T., Kramer, J.W.: A new flashiness index: Characteristics and applications to Midwestern rivers and streams. J. Am. Water Resour. Assoc. 40, (2004). https://doi.org/10.1111/j.1752-1688.2004.tb01046.x.
9. McNeil, V.H., Cox, M.E., Preda, M.: Assessment of chemical water types and their spatial variation using multi-stage cluster analysis, Queensland, Australia. J. Hydrol. 310, (2005). https://doi.org/10.1016/j.jhydrol.2004.12.014.
10. Bertani, C., Malandrone, M., Panella, B.: Two-Phase Flow in a Horizontal T – Junction : Pressure Drop and. 5th Int. Conf. Heat Transf. Fluid Mech. Thermodyn. (2007).
11. Cataldo, J.C.: Prediction of Transmission Losses in Ephemeral Streams, Western U.S.A. Open Hydrol. J. 4, (2010). https://doi.org/10.2174/1874378101004010019.
12. Alamu, M.B., Azzopardi, B.J.: Flow pattern and slug dynamics around a flow splitter. J. Fluids Eng. Trans. ASME. 133, (2011). https://doi.org/10.1115/1.4005196.
13. Sawicki, J.M., Siebert, M.: Stream division by a channel bottom orifice. Arch. Hydroengineering Environ. Mech. 59, (2012). https://doi.org/10.2478/heem-2013-0005.
14. Hubbart, J.A., Kellner, E., Freeman, G.: A case study considering the comparability of mass and volumetric suspended sediment data. Environ. Earth Sci. 71, (2014).

15. Karami Moghadam, M., Shafai Bajestan, M., Sedghi, H., Seyedian, M.: An experimental and numerical study of flow patterns at a 30 degree water intake from trapezoidal and rectangular channels. Iran. J. Sci. Technol. - Trans. Civ. Eng. 38, (2014).
16. Azimi, H., Shabanlou, S.: Numerical Simulation of Free Surface and Flow Field Turbulence in a Circular Channel with the Side Weir in Subcritical Flow. Int. J. Nonlinear Sci. Numer. Simul. 18, (2017). https://doi.org/10.1515/ijnsns-2016-0115.
17. Alcocer-García, H., Segovia-Hernández, J.G., Prado-Rubio, O.A., Sánchez-Ramírez, E., Quiroz-Ramírez, J.J.: Multi-objective optimization of intensified processes for the purification of levulinic acid involving economic and environmental objectives. Chem. Eng. Process. - Process Intensif. 136, (2019).
18. Azimi, H., Shabanlou, S.: The Effect of Froude Number on Flow Field of U-Shaped Channel Along a Side Weir in Supercritical Flow Regime. Comput. Math. Model. 30, (2019). https://doi.org/10.1007/s10598-019-09452-z.
19. Dhanusree, M., Bhaskaran, G.: GIS-Based Approach in Drainage Morphometric Analysis of Bharathapuzha River Basin, India. J. Geogr. Environ. Earth Sci. Int. (2019). https://doi.org/10.9734/jgeesi/2019/v20i130097.
20. Montaseri, H., Asiaei, H., Baghlani, A., Omidvar, P.: Numerical study of flow pattern around lateral intake in a curved channel. Int. J. Mod. Phys. C. 30, (2019). https://doi.org/10.1142/S0129183119500839.
21. Calle, M., Calle, J., Alho, P., Benito, G.: Inferring sediment transfers and functional connectivity of rivers from repeat topographic surveys. Earth Surf. Process. Landforms. 45, (2020). https://doi.org/10.1002/esp.4765.
22. Shaazizov, F., Badalov, A., Ergashev, A., Shukurov, D.: Studies of rational methods of water selection in water intake areas of hydroelectric power plants. In: E3S Web of Conferences (2019). https://doi.org/10.1051/e3sconf/20199705041.
23. Shaazizov, F., Shukurov, D.: Physical modeling of the filtration process through the dam base. In: IOP Conference Series: Materials Science and Engineering (2020). https://doi.org/10.1088/1757-899X/869/7/072037.
24. Shaazizov, F.: The flow Confluence of river systems of the Pskem and Koksu river basins. In: E3S Web of Conferences (2021).
25. Shaazizov, F.: Studies of turbulent flow characteristics of dividing open water streams. In: IOP Conference Series: Materials Science and Engineering (2021).
26. Shaazizov, F.: Assessment of damage during the formation and passage of mudflows in the Tashkent region. In: E3S Web of Conferences (2021). https://doi.org/10.1051/e3sconf/202126403042.
27. Shaazizov, F., Shukurov, D., Shukurov, E.: System for ensuring the detection and elimination of fires in the building of the hydroelectric power station. In: IOP Conference Series: Materials Science and Engineering (2021).