Flow division under a steady flow mode

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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

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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
\[ \Delta KD_x = [KD_2 - (KD_1 - KD_a \cos \varphi)] \Delta t = F_x \Delta t \]  
(1)

- on the OY axis

\[ \Delta KD_y = - KD_a \sin \varphi \Delta t = F_y \Delta t \]  
(2)

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

\[ \alpha_0 \rho (Q_2 V_2 - Q_1 V_1 + Q_a V_a \cos \varphi) \Delta t \]  
(3)

- in the projection on the OY axis

\[ \alpha_0 \rho Q_a V_a \sin \varphi \Delta t \]  
(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_a;
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_2;
d) friction forces T_1, T_2.

1. The sum of the projections of the hydrodynamic pressure forces will be:
- main flow axis

\[ \sum P_x = P_1 - P_2 - P_a \cos \varphi = \rho g \frac{h_1 \omega_1}{2} - \rho g \frac{h_2 \omega_2}{2} - \rho g \frac{h_3 \omega_3}{2} \cos \varphi = \]  
(5)

\[ = \rho g \frac{Bh_1^2}{2} - \rho g \frac{Bh_2^2}{2} - \rho g \frac{Bh_3^2}{2} \cos \varphi \]
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

\[
\sum R_x = R_s \sin \varphi = \rho g \left( \frac{B_\beta \tan \varphi}{2} \left( \frac{h_\beta + h_1}{2} \right)^2 \right) \sin \varphi = \rho g \frac{B_\beta}{2} \left( \frac{h_\beta + h_1}{2} \right)^2 \cos \varphi
\]  

(7)

- on the \( OY \) axis

\[
\sum R_y = R_s - R_6 \cos \varphi = \rho g \left( \frac{B_\beta}{2 \sin \varphi} \left( \frac{h_1 + h_\beta}{2} \right)^2 \right) - \rho g \frac{B_\beta \tan \varphi \cos \varphi}{2} \left( \frac{h_\beta + h_1}{2} \right)^2
\]  

(8)

3. The sum of the projections of gravity, respectively

- on the \( OX \) axis

\[
\sum G_x = G_1 + G_\beta \cos \varphi
\]  

(9)

\[
G_1 = \rho g \frac{B_\beta i_1 (h_1 + h_\beta)}{2}
\]

and approximately taking \( h_\beta = h_\beta' \), we will have

\[
\sum G_x = \rho g \frac{B_\beta i_1 (h_1 + h_\beta)}{2} + \rho g \left( B_\beta h_\beta L_\beta i_\beta + \frac{B_\beta^2 H_\beta i_\beta}{2} \cos \varphi \right) \cos \varphi
\]  

(10)

- on the \( OY \) axis

\[
\sum G_y = G_\beta \sin \varphi = \rho g \left( B_\beta h_\beta L_\beta i_\beta + \frac{B_\beta^2 H_\beta i_\beta}{2} \cos \varphi \right) \sin \varphi
\]  

(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 \( \Delta t \) and \( \rho g \) we have:

\[
\frac{\alpha_\beta \left( \frac{Q_\beta^2}{Bh_\beta} - \frac{Q_1^2}{Bh_1} + \frac{Q_\beta^2 \cos \varphi}{B_\beta h_\beta} \right)}{g} = \frac{B_\beta h_\beta^2}{2} - \frac{B_\beta h_\beta^2}{2} - \frac{B_\beta h_\beta^2}{2} \cos \varphi + \frac{B_\beta \cos \varphi}{2} \left( \frac{h_\beta + h_1}{2} \right)^2
\]  

(12)

\[
+ \frac{B(h_1 + h_\beta)l_1 i_\beta + B_\beta h_\beta i_\beta \cos \varphi (l_\beta + \frac{B_\beta \cos \varphi}{2})}{2};
\]

Making minor transformations and substituting the values of the parameters in (2), respectively, we will have:
Keeping in mind that in dependences (12) and (13), the unknown quantity is the depth \( h_1 \), in a more explicit form, we will have:

\[
\alpha_a Q_b^2 \sin \phi = - \frac{B_g h_b^2}{2} \sin \phi + \frac{B_g}{2 \sin \phi} \left( \frac{h_1 + h_2}{2} \right)^2 - \frac{B_g C \tan \phi \cos \phi}{2} \left( \frac{h_1 + h_2}{2} \right)^2 + \frac{B_g h_b^2}{2} \left( l_b \sin \phi + \frac{B_g \cos \phi}{2} \right).
\]

(13)

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 \( h_1 \), 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 $\varphi \leq 90^\circ$.

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 $h_1$ 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


