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Hydraulic Modeling of Transient Water Movement in the Downstream of the Uchkurgan Hydroelectric Station

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ABSTRACT: This research paper presents the results of modeling unsteady water movement in the Large Namangan Canal due to a violation of the operating mode of the head water intake structure. In modeling, the Saint-Venant equation was used, which describes the one-dimensional unsteady motion of water along an open channel under the action of gravity. The adequacy of the hydraulic model was verified by comparing the results of numerical and field experiments.

KEYWORDS: head water intake structures, hydraulic model, numerical and field experiments, transient water movements.

1. INTRODUCTION

The world's forests are increasingly vulnerable to human activities (FAO, 2011). Natural or artificial forest fragmentation has become one of the greatest threats to forest biodiversity in Europe (EEA, 2011). Fragmentation changes the tropical forests dynamics and alters the reproductive cycles of species (Aguilar et al., 2006, Lindenmayer et al., 2006). It can help to change the microclimate in forest fragments (Heithecker et al., 2007, Laurance et al., 2008).
Large Namangan Highway Canal with a total length of 126.6 km. with a head project flow rate of 61.9 m³ / sec, which passes from the territory of Kyrgyzstan 13.8 km to the territory of the Republic of Uzbekistan 112.8 km. The total area of irrigated land suspended from the canal is 38.0 thousand ha, including 6.0 thousand ha in the territory of Kyrgyzstan. The main facility of the Large Namangan Canal is located on the back stream of the Uchkurgan Hydroelectric Power Station in Kyrgyzstan. Hydroelectric facilities with a daily regulatory capacity have completely exhausted their resources to date, which determines the continuously changing operation mode of the Uchkurgan Hydroelectric Power Station, which has an extremely negative impact on the operation of the entire hydraulic system of water supply, thereby creating unsteady water movement in the Large Namangan Highway Canal which negatively affects the operation of hydraulic structures [1].
In this regard, it became necessary to simulate the hydrodynamic processes in the Large Namangan Highway Canal due to a change in the operating mode of the head water intake structure.

II. MATERIAL AND METHODS

Currently, most researchers use the Saint-Venant differential equations as a mathematical model for describing the process of unsteady smoothly changing water movement in open channels. There are many different forms of writing these equations. R. R. Chugaev leads them in this form [2]:
Dynamic equilibrium equation

$$i-\frac{\partial h}{\partial x}=\frac{Q^2}{K^2}+\frac{u}{g}\frac{\partial u}{\partial x}+\frac{1}{g}\frac{\partial u}{\partial t} \qquad (1)$$

Balance equation cost:

$$\frac{\partial Q}{\partial x}+\frac{\partial \omega}{\partial t}=0 \qquad (2)$$

where: Q, K, u –consumption, flow modulus and average flow cross-sectional velocity; i – bottom slope; ω, h - living section and depth of flow in it; x – distance; t – time; g – gravity acceleration.

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On the left side of equation (1), the quantity $i - \frac{\partial h}{\partial x}$ is the slope of the free surface of the water. The first term on the right-hand side of equation (1) is the slope of friction; the third term $\frac{1}{g}\frac{\partial u}{\partial t}$ is the local part of the inertia forces.

When calculating the unsteady flow in the Large Namangan Highway Canal, the critical flow ($Fr \succ 1$) is considered, which requires one boundary condition to be specified in the upper and lower sections. In the upper section, the observed flow rates are set $u = u(t, x_0)$, and in the lower section, the dependence $u = u(t, x_{N-1})$. The latter dependence is a characteristic of the closing alignment, and when it is received, field data are used. However, it should be remembered that the flow curve in the general case changes continuously due to violation of the operating mode of the Uchkurgan hydroelectric station, since the water flow in the site depends not only on the level mark. When analytically defining the flow curve, one can use the Manning equation. The analysis shows that for real channels at high level marks, the Manning formula gives an overestimated flow rate, while for small it is underestimated [3].

We solve equations (1) using the method of integration of normal systems, for this we introduce the notation:

$$h(t,x) = Fr \cdot t \cdot u \qquad (3)$$

(3) put on (1) and get the first-order quasilinear partial differential equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g \cdot Fr \cdot t \cdot \frac{\partial u}{\partial x} = (i - \frac{Q^2}{K^2})g \qquad (4)$$

where: Fr – Froude criterion.

Equation (4) we compare the system of ordinary differential equations in a symmetric form:

$$\frac{dt}{1} = \frac{dx}{u+g \cdot Fr \cdot t} = \frac{du}{\left(i - \frac{Q^2}{K^2}\right)g} \qquad (5)$$

We represent (5) in the form:

$$\begin{cases} \frac{dx}{dt} = u + g \cdot Fr \cdot t, \\ \frac{du}{\left(i - \frac{Q^2}{K^2}\right)g} = dt \end{cases} \qquad (6)$$

From the system of equation (6) we obtain a solution to equation (1)

$$u = \int \left(i - \frac{Q^2}{K^2}\right) g \cdot dt \qquad (7)$$

Given (7) from (3) we get

$$h(t,x) = Fr \cdot t \cdot \int \left(i - \frac{Q^2}{K^2}\right) g \cdot dt \qquad (8)$$

Now we solve the equation of the balance of flow. Since there is a large lateral inflow from the Northern Ferghana Canal in the studied section of the Large Namangan Highway Canal, q should be specified in the equation (2) during the simulation.

We introduce the following notation:

$$Q = O_{yn} Fr \cdot \omega \cdot \frac{v}{a} \qquad (9)$$

where: v– kinematic viscosity of water, a – opening the shutter of a blocking structure, O_{yn} - control operator.

Given (9), equation (2) takes the form

$$O_{yn} Fr \cdot \frac{v}{a}\frac{\partial \omega}{\partial x} + \frac{\partial \omega}{\partial t} \qquad (10)$$

Equation (10) is associated with a system of ordinary differential equations, the symmetric form of which has the form:

$$\frac{dx}{O_{yn} Fr \frac{v}{a}} = \frac{dt}{1} = \frac{d\omega}{q} \qquad (11)$$

We represent (11) in the form:

$$\begin{cases} \frac{dx}{dt} = O_{yn} Fr \cdot \frac{v}{a}, \\ d\omega = q \cdot dt \end{cases} \Rightarrow \begin{cases} \frac{dx}{dt} = O_{yn} Fr \cdot \frac{v}{a}, \\ \omega = \int q \cdot dt \end{cases} \qquad (12)$$

from the system of equation (12) we obtain the solutions of equation (2)

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$$\begin{cases} \omega = \int q \cdot dt \\ Q = O_{ун} Fr \cdot \frac{v}{a} \int q \cdot dt \end{cases} \quad (13)$$

As a result, we obtain the general solution of the system of equations (1) and (2):

$$\begin{cases} h(t,x) = t \cdot Fr \cdot \int (i - \frac{Q^2}{K^2}) g dt, \\ Q = O_{ун} \cdot \frac{v}{a} Fr \int q dt. \end{cases} \quad (14)$$

III. RESULTS

For testing and verification of the described model, the Large Namangan Highway Canal section (PK362 + 93-PK432 + 93) with a total length of 17 km was considered. To verify the model, field data were used (Fig. 1).

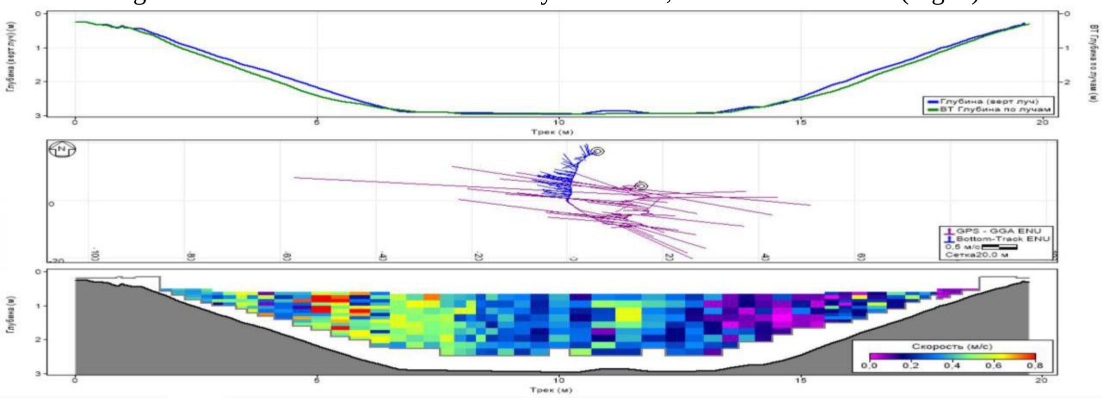

Fig 1. Picket PK362 + 93 of the Great Namangan Canal. The maximum flow depth is 2.6 meters, the average velocity vector is 0.5 0.8 m / s, and the water flow rate is 10.65 m^3 / s.

Test calculations were carried out on the basis of observational data in the spring-autumn period of 2019. In the spring, there are three pronounced highs of marks of the level of May 20-27, 2019. Moreover, maximum flow rates are observed only in May; moreover, the Q curve in May does not correspond to the dependence used in the calculations for the corresponding Large Namangan Highway Canal site. The fact is that fluctuations in the water level in the canal are associated with the unstable operation of the Uchkurgan hydroelectric station. Comparison of the results of a numerical and full-scale experiment is presented in the form of graphs in Fig. 2-5.

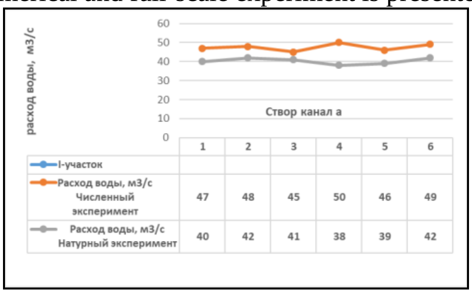

Fig. 2. Change in water flow in the I-section of canal

Fig.3. Changes in water level in the I-section of canal

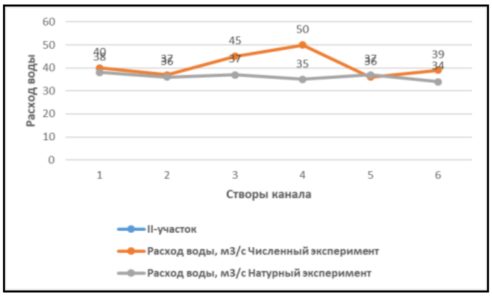

Fig. 4. Change in water flow in the II-section of the channel

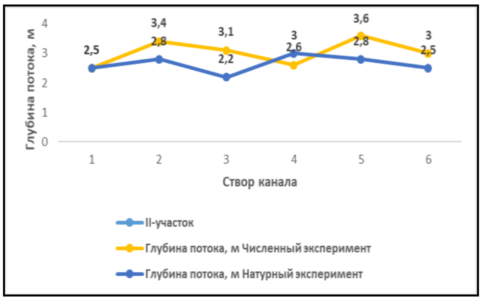

Fig. 5. Changes in water level in the II-section of the canal

IV. CONCLUSION

Numerical experiment demonstrates that when the maximum flow rate was released at 65 m^3 / s in the Large Namangan Highway Canal head regulator, in the closing section, the maximum flow rate was 39.7 m^3 / s (taking into account lateral outflows). The level in the closing range with this release exceeded the household depth by 1.2 m. The propagation velocity of the wave crest averaged 1.8 m / s. The results of numerical experiments show that due to the unstable operation of the Uchkurgan hydroelectric station in the Great Namangan Canal, unsteady movement of the water flow occurs, which leads to sharp fluctuations in the water level in the canal.

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