Field target dimensions of flow constrained by a transverse dam

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Abstract. Construction and operation of channel control structures in valley rivers require carrying out a comparative study of their operation during design operational periods. The goal of this work is to set target dimensions for flow deformed by the transverse blind dam in field conditions, on the dam № 30 in Amudarya river: the length of upstream and downstream vortex zones, boundaries between the core and intensive turbulent mixing zones, vortex zone boundaries, and their comparison with experimental data. Locations of the sections are set based on the possibility to accomplish the goal, in the headrace, where flow natural condition is maintained, in contraction zone, and within the borders of downstream vortex zone. Sections were fixed with landmarks and leveling instrument Vegal 24 was installed there. Zone boundaries and vortex lengths were set with the use of floats directly from the riverside of the use of boats. Design relationships obtained from the results of laboratory experiments were used to determine the length of upstream vortex zone, contraction area, downstream vortex zone, boundaries of hydraulically homogeneous zones, which were then compared with the field data. It was also set, that coefficients characterized flow spreading beyond the contracted section were equal to $C_2=0.186$ and $C_3=0.545$ as compared to 0.11 and 0.16 in the theory of turbulent jets. The length of vortex zones is shorter by 11.9\% to 26.8\%, which shows how much the distance between dams must be decreased in the system.

1. Introduction

Sufficient attention is paid to the improvement of a structure, design methods, and designing of control structures around the world [1, 2, 3, 4, 5, 6, 7] and in Uzbekistan [8, 9, 10, 11, 12] in particular. The obtained results allow to determine local scouring depth, structure height, the distance between structures in the system, compute velocity fields, etc.

All these studies are carried out in laboratory conditions with the use of modern mathematical tools and software products. At the same time little attention is paid to the study of the operation of existing structures [13, 14]. The difficulties in organizing field research, requiring big expenses are the main reason for it. Nevertheless, these studies are very important for clarification and justifying experimentally and theoretically obtained results [15, 16].

Transverse dams are active type control structures and their installation results in flow and channel reformation. To forecast target dimensions of flow constrained by transverse dams, the use of the main rules of the theory of turbulent jets [17,18,19] was found to be the most effective in solving the task [9, 20].

2. Methods
Field research was carried out for transverse dam (dike) № 30 in the Amudarya River. It was chosen due to the condition that the main part of flow deviation from the bank being protected occurred in the given Turtkul section (Fig.1). Design length of the dam was 120 m, crest width – 10 m, base width – 18 m, height – 3 m, the distance between dams – 290 m, it was built in 1989, the dam body was built of fine sand by hydraulic fill method, and its head was fixed with 2094 m$^3$ rock fill. The effective length of the dam at the moment of study (4.08.2019) was 52m.

Target dimensions of deformed flow were determined with the use of floats.

To determine the length of the upstream vortex zone, the floats were thrown somewhat above upstream from this zone and the points of float separation from channel bank were marked, then the length of the zone was measured with a tape measure.

To determine the length of the downstream vortex zone, floats were thrown at the dam head. The end of the vortex zone is unstable due to constant mass exchange between the vortex zone and transit flow. That was the reason for its location to be determined by throwing floats more than 10 times with an observation period of 10 minutes.

After determining the lengths of vortex zones, the sections were set. The first section $P-P$ was set at the headrace at the beginning of the upstream vortex zone, the section $O-O$, target contraction section $C-C$, sections $X-X$ and $B-B$ were set within the downstream vortex zones. The sections were fixed with landmarks, which also served as the points for the installation of leveling instrument Vegal 24.

The sequence for determining the inner border between weakly disturbed core and the zone of intensive turbulent mixing was as follows: floats were thrown from section O-O at the head, they were fixed while passing at the rest of the sections with the use of leveling instrument and boat.

At the same time the floats, which turned to the bank being protected, where thrown back, the borders for the rest of the zones were determined after defining the distribution of turbidity by the flow width.

The obtained results of field research were compared with the results previously obtained in laboratory conditions.
3. Results

The following relationship was proposed for the determination of the distance between dams [8]:

$$L_p = l_D \cos \alpha_D + K_2 (l_{bb} + l_{CC} + l_{HB})$$

(1)

where $l_{bb}, \alpha_D$ are dam length and installation angle; $l_D, l_{CC}, l_{HB}$ are the lengths of upstream vortex zone, contractions zone, and downstream vortex zone before bed scouring; $K_2 = 0.4 \div 0.5$ is the experimental coefficient, accounting for the reduction of target dimensions of vortex zones due to local scouring of the base.

The length of the upstream vortex zone depends on the degree of contraction $n$, Froude number $Fr$ and dam installation angle $\alpha_D$:

$$\frac{l_{bb}}{B - b_0} = 3.13 + 2.7 \ln + 1.7 Fr - 1.2 \theta$$

(2)

and the length of the contraction region:

$$\frac{l_{cc}}{b_0} = 0.77 + 0.8 \ln - 0.68 \theta$$

(3)

in these formulas: $B, b_0$ are total width and width of the unconstrained part of flow; $n = \frac{B - b_0}{B}$ is contraction ratio; $Fr = \frac{v^2}{gH}$ is Froude number, where $v, H$ are velocity and depth of water before dam construction $\theta = 1 - \frac{\alpha_D}{180^\circ}$ is dam installation angle in radians.

Length of downstream vortex zone for the case, when there is $\lambda$ formation of back slope in the zone of spreading, i.e.

$$\frac{\lambda \cdot B}{h} \geq 0.2$$

$$l_{hb} = \frac{2 \alpha h}{B_{mean}} + \lambda_D + 2.88 \chi^2 \frac{h}{\alpha_{mean}} - 4 \alpha i_D \frac{B}{b_T}$$

(4)

where $\alpha = 1.3$ is the correction factor for kinetic energy in the zone of spreading; $h$ is mean flow depth; $\lambda, \lambda_D$ are hydraulic resistance coefficients for riverside and bed; $\chi = 0.21$ is Karman constant; $i_D$ is river bed slope; $b_T$ is width of transit flow in contracted section $C-C$.

In natural flow hydraulically homogeneous zones are clearly traceable, those are the zones of the weakly disturbed core, intensive turbulent mixing, and backflow.

The boundaries of these zones are described by the following relationships:

- the border between weakly disturbed core and turbulent mixing zone

$$y_i = \frac{y_i}{b_0} = 1 - (1 - \varepsilon K_i)(\frac{x}{l_{cc}})^a$$

(5)

- the border between the turbulent mixing zone and the back flow zone
\[
\begin{align*}
\bar{y}_2 &= \frac{y_2}{b_0} = 1 - C_i (1 - \varepsilon K_i) (\frac{x}{l_{cc}})^a \\
\bar{b} &= \frac{b}{b_0} = \frac{y_2 - y_i}{y_1} = (1 - C_i) (1 - \varepsilon K_i) (\frac{x}{l_{cc}})^a \\
\bar{y}_3 &= \frac{y_3}{b_0} = 1 - (1 - \varepsilon) (\frac{x}{l_{cc}})^a
\end{align*}
\] (6-8)

- width of the intensive turbulent mixing zone
- the border between transit flow and vortex region

Entered and reduced formulas for the coefficient of target constraint \( \varepsilon \) and the relative width of core \( K_1 \) is determined from the following relationships

\[
\varepsilon = \frac{b_T}{b_0} = 1 - 0.29(n \sin \alpha_D)^{0.5}
\] (9)

\[
K_1 = \frac{b_w}{b_T} = 0.86 + 0.3n - 0.21\theta
\] (10)

**Table 1.** Comparison of design and field data for target dimensions of flow constrained by a blind dam

|        | Design | Field | % deviation |
|--------|--------|-------|-------------|
| \( \varepsilon \) | 0.93   | 0.94  | 1.07        |
| \( K_1 \)     | 0.83   | 0.82  | 1.2         |
| \( y_1 \)     | 137.4  | 126.6 | 7.9         |
| \( y_2 \)     | 171.9  | 164.5 | 7.4         |
| \( b \)       | 34.5   | 38    | 10.1        |
| \( l_{bb} \)  | 67.6   | 60    | 11.9        |
| \( l_{cc} \)  | 41.5   | 36    | 14.2        |
| \( l_{nb} \)  | 184    | 140   | 26.8        |

Values \( l_{bb}, l_{cc}, l_{nb} \) are calculated with the account of bed scouring \( K_2=0.4 \).

As seen from the table, the maximal deviations are observed in determining the width of intensive turbulent mixing zone \( b \). These deviations are explained with the fact, that all design relationships are obtained on the basis of laboratory research for the parallel location of flow stem and riverside being protected. At dam №30 location we have a flow dumping onto the protected bank at the angle of 20\( ^0 \), the dam deflects the flow from the protected bank.

At the same time, the existence of flow dumping and channel scouring result in the decrease of length of vortex zones of flow contracted by a dam. Figure 2 illustrates the comparison curve of design data with experimental and field data. Results from this that deviations between these two values vary between 11.9% and 26.8%. With all this, the design lengths for all vortex zones are equal to 293.1 m, and the measured field length is 236 m and the deviation is 24.2%.
Figure 2. Comparison of the results obtained with experimental data with the ones obtained with field data for $\lambda=0.005 \ldots 0.007$.

It is recommended that this difference should be taken into consideration while setting the distance between dams.

In the theory of turbulent jets, the width of the zone of intensive turbulent mixing for submerged jet case in the region of spreading is determined with the following relationship.

$$b = K_2 x = (C_2 + C_3) x$$

where $C_2 = 0.11; C_3 = 0.16$ and $K_2 = 0.27$

If contraction zone is present

$$b = b_c + (C_2 + C_3) x$$

$y=f(x)$ relationship curves are constructed for field conditions.

Figure 3. Turbulent mixing zone boundary changing curves
According to these curves: $C_2=0.186$, $C_3=0.545$, $K=C_2+C_3=0.186+0.545=0.731$.

As seen from the curve, the inner border of turbulent mixing zone differs from the values for turbulent jets by the factor of 1.69, and the outer border in natural conditions with the presence of scouring bed is quite different from those with the Nén-scouring bed, which indicates of a more intensive flood widening.

4. Discussion

Transverse dams are the most popular type of control structure. They are active type structure and their installation result in flow and channel reformation.

As the research analysis show, the methods of design for these structures are mostly developed on the basis of laboratory research. The main measure of their accuracy are data from field experiments undoubtedly. Channel control is performed in the Amudarya river below Tuyamuyun hydrosystem at the distance of 185 km with the use of transverse dams.

The field experiment is carried out at dam № 30. The main goal of the experiment was also setting target dimensions of flow contracted by the blind dam, comparison of the obtained results with laboratory data.

The boundaries of hydraulically homogeneous zones were compared, and the highest deviation was obtained in comparing the design value by formulas obtained on the basis of laboratory and field research, thus, for the width of intensive turbulent mixing the deviation reached 10.1%.

The length of the upstream vortex zone computed from design formulas and field data differ by 11.9%, the length of contraction zone – by 14.2%, and the length of the downstream vortex zone – by 26.8%.

Based on these data, it is recommended to decrease the distance between dams by these values while designing new dams.

Spreading coefficients for intensive turbulent mixing zone came up to be equal to $C_2=0.186$ and $C_3=0.545$ as opposed to 0.11 and 0.16, taken in the theory of turbulent jets, respectively.

5. Conclusions

For the first time in Amudarya rive conditions on the dam №30 field experiment was carried out with the goal to set target dimensions for flow and compare them with design data, obtained from formulas based on laboratory research.

The scheme of division of flow into hydraulically homogeneous zones was used, as adopted in the theory of turbulent jets.

Flow spreading coefficients were obtained, $C_2=0.186$ and $C_3=0.545$, their sum 0.731 as opposed $C_2=0.11$ and $C_3=0.16$, $K_2=0.27$ according to the theory of turbulent jets.

The difference in the length of vortex zones was within 11.9% and 26.8% and it was recommended to decrease the distance between dams by these values while designing new dams.

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