Bilateral contraction of flow by blind dams on easily erodible soils

A Ibrayimov* and O Kadirov

*Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

bakiev1947@rambler.ru

Abstract. In various parts of the Amudarya river, transverse dams are built for channel control and to protect riverbank from scouring. Studies were carried out in CAIRI laboratory to study the hydraulics of flow near structures (dams) on both sides of the channel, specifically spreading patterns of flow overtopping and its erosive capacity. Experiments carried out on 20m x 2m erodible model for discharge values $Q = 10.0, 20.0, 30.0$ l/sec, contraction degree of $n = B/(B-b_0) = 0.33, 0.5, 0.67$ and with the installation angle with respect to the streambank $a = 60°, 90°, 120°$ gave specific results. Based on theoretical and experimental studies, relationships were obtained, which allow establishing the boundaries for flow division, velocity distribution along the width and length of flow, vortex length, distances between structures, as well as the values for backflow velocities along the streambanks, that can be used to construct velocity field in the dam impact zone. The obtained methods allow to get the full picture of a flow spreading beyond dams at the presence of backflow.

1. Introduction

Deygish is an intensive streambank scouring process, one of the types of channel deformations, which is often observed in the Amudarya river [1, 2, 3]. Traverse dams, which consist of local materials (soils) with slope and head fixation are being practiced in rivers for the past decade for channel control and to protect riverbanks from scouring [4 - 8]. Studies, carried out in most parts of rivers, where deygish took place, as well as experiments [9-20], carried out on erodible models showed, that interrelated processes take place in intensive streambank erosion regions: sudden transverse flow overtopping with the formation of a strong jet, having high flow velocities; flow overtopping headed towards the streambank, concentrates along it, erodes the streambank since it has high velocity; then flow spreads along the streambank and eroded material is transported out of the point of streambank slope collapse. Spreading patterns of flow overtopping and its erosive capacity are subjected to special studies. In the “Channels” department of CAIRI they carry out experiments to study the hydraulics of flow near structures (dams) installed on both sides.

2. Methods

Experiments were carried out on erodible models, claydite with mean diameter $d = 0.63$ mm was used for erodible material. Model dimensions were 20 m in length and 2.0 m in width. The experiments were carried out for discharge values $Q = 10.0, 20.0, 30.0$ l/sec. Bilateral traverse dams were installed with contraction degree of $n = B/(B-b_0) = 0.33, 0.5, 0.67$ and with the installation angle with respect to the streambank $a = 60°, 90°, 120°$. Flow velocities were measured using CAIRI micro-propeller flowmeter with electronic sensor SISPV-6. Stationary rod-scales (measuring accuracy +/- 0.1 mm)
were installed at the head and the end of the channel to control water levels. Upstream and downstream vortex zone boundaries, longitudinal and transverse depth drops, flow velocities were experimentally studied. The number of measurement points along vertical was set as follows: every 2-2.5 cm in flow damming region, every 1-2 cm in flow contraction region, every 5-10 cm in flow spreading region. After setting locations and measurement points along vertical, free water surface elevations and flow velocities were measured, mean arithmetical values were taken as final elevations. Based on measurements, longitudinal and transverse water level drops in structure headrace and tailrace were set. From mean velocities and flow depths along verticals, elementary discharge diagrams were constructed for natural conditions, which came out to be equal discharge, used in the model with +/-5% deviation.

3. Results and Discussion

By recommendations from S.T. Altunin, to control channel in the tailrace, one of the two scheme options can be used – straight line or slightly curved channel, controlled by transverse structures.

The given article discusses the solution of the task only for one region of spreading, i.e. beyond contracted section C-C. To solve the task, certain rules of the theory of turbulent jets were used, flow division scheme into hydraulically homogeneous zones (Fig.1), in particular [1, 4, 20]:
- weakly distracted core zone with the width of $2b_c$;
- intensive turbulent mixing zone with the width of $2b$;
- backflow zone with width equal to $(2b(2b_y-2b))$ and velocity $U_h$;
Experimentally it was established that velocity distribution in intensive turbulent mixing zone complies with Shlihting-Abramovich’s relationship [21]:

\[
\frac{U_y - U}{U_y - U_h} = (1 - \eta^{1.5})^2
\]  

where:

- \(U_y\) is the velocity in the core;
- \(U\) is the velocity in the mixing zone;
- \(q = \frac{y - y_1}{b}\) is the relative coordinate of the point, where \(U\) is determined.

Therefore, the calculation of flow velocity in the zone of a weakly disturbed core in the contracted section is performed using the following relationship:

\[
U_y = \sqrt{U_{\text{min}}^2 + \left(\frac{y}{b}\right)^2 \left[(U_{\text{max}} \cos \varphi_{\text{in}})^2 - U_{\text{min}}^2\right]}
\]
Taking the velocity distribution velocities in the intense turbulent mixing zone by relationship (1) and performing certain transformations, we obtain the velocity change pattern for the contracted section in the following form:

\[
\frac{m}{c} = \frac{U_{nc}}{U_{y}} = \frac{Q}{2U_{sc} \cdot h \cdot b_{c}} - \left(\frac{\bar{b}_{sc} + 0.55b_{0}}{1 - n} - \frac{b_{sc} + 0.55b_{0}}{\bar{b}_{sc} + 0.55b_{0}}\right)
\]  

(3)

where \(\bar{b}_{sc} = \frac{b_{yc}}{2b_{0}}\); \(b_{c} = \frac{b_{c}}{2b_{0}}\); \(n = B - b_{0} / B\).

Width change for the weakly disturbed core can be determined from the differential equation of non-uniform motion, which has the following form:

\[
b_{y} = -0.416\bar{b}_{c} - 0.112\xi + \frac{(\bar{b}_{sc} + 0.416\bar{b}_{c})}{(1 + i \cdot \kappa \xi)}^{1/2}
\]  

(4)

where \(\kappa = \frac{b_{0}}{h_{l}}\); \(\xi = x / b_{0}\); \(\lambda\) is the hydraulic friction coefficient; \(i = \frac{h_{yl} - h_{b}}{l_{p}}\) is the slope of the bed.

To determine the velocity change pattern for weakly disturbed core, we used an integral relationship, describing the law of conservation of momentum in the flow [22].

\[
\left(\frac{U_{y}}{U_{y}}\right)^{2} = \frac{\bar{b}_{sc} + 0.416\bar{b}_{c}}{b_{y} + 0.416 \cdot h_{0}}(1 - i \cdot \xi) \left(\frac{\lambda}{\xi} \right)^{1/2}
\]  

(5)

The value for backflow velocities in the region of spreading is determined from the equation of conservation of discharge and law of change of relative velocity of backflow:

\[
m = \frac{U_{nc}}{U_{y}} = \frac{\frac{U_{sc}}{h_{0} - i \cdot x}}{\frac{1}{1 - n} - \frac{b_{sc} + 0.55b_{0}}{\bar{b}_{sc} + 0.55b_{0}}} + m_{r}
\]  

(6)

Where: \(\bar{b} = (1 - m_{r}) \cdot (\bar{b}_{sc} + 0.55b_{0}) + \frac{m_{r}}{1 - n}\).

It was established that the width of intensive turbulent mixing zone changes linearly:

\[b = b_{c} + cx\]

where:

- \(b_{c}\) is the width of the intensive turbulent mixing zone in the contracted section;
- \(x\) is the abscissa of cross-section, where “b” is determined;
- \(c\) is the constant.

Based on the experiments carried out for the spreading area \(c=0.40\). Obtained design relationships differ from design equations by the coefficient for erodible bed conditions, since they are somewhat different for hard bed conditions.

Based on theoretical and experimental studies, we obtained relationships, which allow to establish boundaries of flow division, velocity distribution along flow width and length, as well as values for backflow velocities along a riverbank, which can be used to build the velocity field for the zone of dam influence. The developed method allows to obtain the full picture of a flow spreading beyond dams at the presence of reverse slope.

The above-given design method is obtained for conditions of flow, moving in the channel, and between dams. During floods, the part of the flow passes through the top of dams, and they will
operate in a flooded regime. In this case, to determine flow spreading borders and to calculate the velocity field, it is necessary to use main rules of the theory of turbulent jets, spreading in cocurrent flow, having established flow velocities at dam crest (\(U_{dc}\)) and between dams (\(U_o\)), spreading coefficients \(C_2\) and \(C_1\) accounting for the degree of flow contraction (\(n\)); dam installation angle (\(\alpha\)), Froude number (\(Fr\)) and flooding coefficient (\(h_0\)), etc.

The developed method was used to perform the design of channel control by transverse dams in the Amudarya river at various locations and channel bilateral control downstream from Tuyamuyun hydro system. The cost-effectiveness of the developed recommendations for two regions of the Amudarya river with a total length of 24 km was 15880 million sums.

Experimental studies were carried out both for exploring the physical picture of flow around transverse dams, symmetrically contracting the flow, and for obtaining necessary relationships.

The studies were carried out for the following characteristics of flow and structure: contraction degree of \(n = B/(B-b_0) = 0.33, 0.5, 0.67\); with the installation angle with respect to the streambank \(\alpha = 60^\circ, 90^\circ, 120^\circ\); Froude number \(Fr_0 = 0.01 – 0.18\).

Experimentally it has been established that it is possible to use main rules of the theory of turbulent jets, scheme of flow division into hydraulic homogeneous zones.

A design relationship has been proposed to determine the boundaries of the channel and flow interaction zone.

Design relationships have been proposed to determine channel velocities, which were obtained by combining equations of conservation of energy and discharge in flow.

An experimental test of the obtained relationships shows their applicability.

4. Conclusions

Based on theoretical and experimental studies, relationships were obtained, which allow establishing the boundaries for flow division, velocity distribution along the width and length of flow, vortex length, distances between structures, as well as the values for backflow velocities along the streambanks that can be used to construct velocity field in the dam impact zone. The obtained methods allow getting the full picture of a flow spreading beyond dams at the presence of backflow.

The above-described design method is obtained for the condition of flow in channel and between dams. During floods, part of the flow moves through the top of dams, and the dams work in the flooded regime. In this case, to determine flow spreading boundaries and calculate velocity field, it is necessary to use the main regulations of the theory of turbulent jets, flowing in cocurrent flow, by setting flow velocity at dam crest (\(U_{dc}\)) and between dams (\(U_o\)), spreading coefficients \(C_2\) and \(C_1\) with the account of flow contraction degree (\(n\)), dam installation angle (\(\alpha\)), Froude number (\(Fr\)), coefficient of damming (\(h_0\)), etc.

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