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Deflection of the dynamic axes of flow contracted by combined dam with tetrahedron through-flow part

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Abstract. The design of the track to control river channel directing flow to water intake point requires the solution of a number of issues. Including the magnitude of the deflection of the dynamic axes of flow contracted by control structures. The main goal of the work is to develop the design method for the deflection of the dynamic axes of flow unilaterally contracted by a combined dam with a through-flow part made of tetrahedrons. The task is accomplished using Varignon's theorem and the equation of conservation of discharges written for sections where flow natural condition is maintained in the headrace and contracted section. The concept of flow around the coefficient is introduced as the ratio of incoming discharge to the discharge passing the through-flow part of the combined dam. Design relationships have been proposed to determine the relative deflection of the dynamic axes of flow specific discharge in the non-contracted section of flow carrying capacity of the through-flow part is evaluated through the coefficient of flow-around. Numerical methods carried out for Chirchik river conditions have shown satisfactory results.

1. Introduction

Great attention is given to the decrease or prevention of the hazardous effect of flowing water on the environment [1, 2, 3]. Research studies of various channel control structures in valley rivers are carried out in this sphere [4, 5, 6, 7, 8, 9].

The main attention in most of the studies is given to the issues of determining scouring depth by control structures of various types [10, 11, 12, 13, 14]. The number of studies on the development and design of control structures in sub mountain parts [15] of rivers is not very large [16, 17], especially for through-flow dams [18].

Design methods for combined dams with a through-flow part made of piles are developed quite well and these studies have shown the advantage of combined dams [19-20] as opposed to blind and through-flow.

Combined dam with tetrahedron through-flow part has been proposed, which doesn't require driving piles onto channel bed and they are much cheaper than the pile ones.

Experimental studies were carried out. flow around mechanism was explored, equations were developed theoretically to set dimensions for deflection of the dynamic axes of flow, specific discharge values in the non-contracted part of the channel.

2. Methods

Experimental studies were carried out in a 40x75x800 cm laboratory channel with a changeable slope with a hard bed. The experiments are carried out for the following flow and structure characteristics: discharge is 3 to 10 l/sec, the total degree of flow contraction by the combined dam $n_d = l_t \cdot \frac{sin\alpha_t}{B}$ contraction by blind part $n_b = l_b \cdot \frac{sin\alpha_t}{B}$ contraction by through-flow part $n_C = l_{th} \cdot \frac{sin\alpha_t}{B}$, (where $l_t . l_b . l_{th}$ are lengths: total length, blind part length, through-flow part length. B is flow width), through-flow part build-up coefficient $P = 0.2 \div 0.4$; $P = W_z/W$ (through-flow part build-up area, total area), dam installation angle $\alpha_d = 75 \div 90^0$, bed slope $i_d = 0.0001 \ to \ 0.004$

Modeling was carried out according to Froude. A turbulent flow regime was maintained for all experiments. Target task conditions *B/h* > 6 were followed, 5x5 squares were painted on channel bed to ease visual observations. The discharge was measured using Thomson's triangular weir. The free surface was captured using gauge needle and leveling. Flow velocities were measured using CAIRI micro-propeller flow velocity meter with electronic sensor SISNB-5.

In theoretical studies, we used Varignon's theorem, the theory of Julaev R.J. [21] about transverse circulation in an open channel, initiated by flow redistribution, equation of conservation of discharge, the concept of flow around coefficient as the ratio of incoming discharge to the discharge passing through the through-flow part of the combined dam.

3. Results and discussion

The scheme of deflection of the dynamic axes of flow unilaterally contracted by a combined dam is shown in Figure 1.

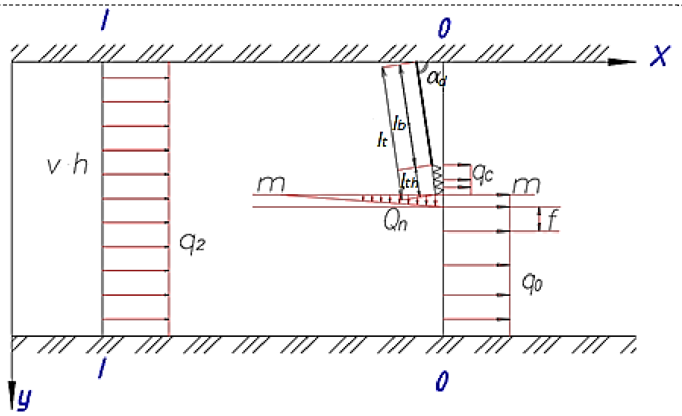

Figure 1. Scheme of deflection of the dynamic axes of flow unilaterally contracted by a combined dam.

To determine the deflection of the dynamic axis of sub mountain river flow unilaterally contracted by the combined dam with tetrahedron through-flow part the Varignon's theorem relative to X-axis for sections I-I and 0-0 is written as:

$$q_2 \cdot B \cdot \left(\frac{B}{2} + f\right) = q_c \cdot \ell_b \cdot sin\alpha_d \left(\ell_t \cdot sin\alpha_d + \frac{\ell_{th} \cdot sin\alpha_d}{2}\right) + q_0 \cdot b_0 \cdot (\ell_t \cdot sin\alpha_d + 0.5 \cdot b_0) \quad (1)$$

Where q_2, q_0, q_c are relative discharges for sections I-I and 0-0 respectively; l_t, l_b, l_{th} are the dam lengths: the total length, the lengths of blind and through-flow parts; α_d is the dam installation angle; B, b_0 are the flow widths: the total width, the width of the uncontracted zone; f is the deflection of the dynamic axes of flow.

The left and the right side of the equation is divided by B^2 and having carried out certain transformations we obtain relative deflection of the dynamic axes of flow

$$\lambda_f = \frac{f}{B} \bar{q}_c \cdot n_{th} \cdot (n_b + 0.5 \cdot n_{th}) + 0.5 \cdot \bar{q}_0 \cdot (1 - n^2) - 0.5 \quad (2)$$

Where $\bar{q}_c = q_c/q_2$; $\bar{q}_0 = q_0/q_2$ are relative specific discharges: for the through-flow part, for free part.

Relative discharges in uncontracted flow zone are determined from the equation of conservation of discharge written for sections I-I and 0-0 is as follows

$$q_2 \cdot B = q_0 \cdot b_0 + q_c \cdot \ell_{th} \cdot sin\alpha_d \quad (3)$$

Having divided both sides by $q_2 \cdot B$ and after transformation, we obtain the equation in the following form

$$\bar{q}_0 = \frac{1-\bar{q}_c n_{th}}{1-n_b} \quad (4)$$

Flow around coefficient is introduced for evaluation of carrying capacity for through-flow part of the combined dam

$$K_0 = \frac{Q_c}{Q_2} \quad (5)$$

Where Q_2, Q_c are discharge coming towards structure and discharge passing the through-flow part of the structure. Equation of conservation of discharge is written for sections *I-I* and *0-0* with boundary flows *m-m* passing through combined dam head part

$$K_0 \cdot \vartheta_b \cdot h_b \cdot \ell_t sin\alpha_d = U_c \cdot h_c \cdot \ell_{th} \cdot sin(\alpha_d + \beta_0) \cdot (1 - P) \quad (6)$$

From where

$$K_0 = \bar{q}_c \left(1 - \frac{\ell_b}{\ell_t}\right) \cdot (1 - P) \cdot a \quad (7)$$

Where: $a = \frac{sin(\alpha_d+\beta_0)}{sin\alpha_d}$; $\beta = 16^0$ is flow spreading angle beyond structure,

P is the hydraulic coefficient of build-up for tetrahedrons is determined by recommendations of Ishaev F.Sh. [22]

$$P = \frac{Ad}{\ell} n^{3/4} K \quad (8)$$

where *A-3* when tetrahedrons are installed in staggered-order; *A-5* when tetrahedrons are installed in a row; *d* is the side measure of square section or diameter of beam *b, m*; *l* is the length of beams *b, m*; *n* is the number of rows in the structure; *K=0.7* experimental coefficient (for single-row installation *K=1.0*)

For dense (herringbone) installation

$$P = K_1 \cdot W_m b \quad (9)$$

W_m is the volume of material, filling one unit of the object of structure body; *b* is the width of the structures *b, m*; $K_1=1.1$ is the experimental coefficient. Elevation drop is determined as follows

$$Z = \xi \frac{v_b^2}{2g} \left[\frac{1}{(1-P)^2} - 1\right] (n_b - n_{th}) K_z \quad (10)$$

Where: $\xi=1.1\div1.2$ is the coefficient of hydraulic resistance, $K_z=0.85$ is the experimental coefficient. Relative discharges beyond tetrahedron through-flow part can be determined as follows

$$q_c = q_2(1 - P) \quad (11)$$

To determine the impact of the combined dam with tetrahedron through-flow part on redistribution of specific discharges and dynamic axes of flow, design sample for Chirchik river section (Syrdarya river tributary) was carried out using the developed equations.

Design is carried out for the following parameters of the flow and combined dam: discharge *Q*=750 m³⁄sec river width *B*=250 m, undisturbed (natural condition) flow velocity V_b=2 m⁄s, depth is 1.5 m. specific discharge q_2=3 m²⁄s per meter, length of beam used for through-flow part *l* = 4 m, square beam cross-section size 0.17 m x 0.17 m, installation order factor for row installation $A=5$, number of tetrahedron rows N=2.

Design results are given in Table 1 and Figures 2 and 3.

As seen from the table 1 and figures 2 and 3, increasing the contraction degree n, n_r lead to the increase of relative specific discharges q_0/q_2 and the relative width of deflection of dynamic axes of flow λ_f. For $n_b=0$ in figure (the left end points), for $n_b = n$ (right end points) are subsequently for cases, when the flow is contracted by the through-flow dam with varying build-up coefficient and when the flow is contracted by a blind dam.

Table 1. Calculation results of a combined dam with a through part of a variable design

n	l_t (m)	l_b (m)	n_b	l_{th} (m)	n_c	l_b/l_t	q_c m^2/s	a	K_0	q_0/q_2	λ_f
0.1	25.0	0.0	0.00	25.0	0.10	0.00	0.75	1	0.56	0.93	-0.04
0.1	25.0	7.5	0.03	17.5	0.07	0.30	0.75	1	0.39	0.977	-0.01
0.1	25.0	12.5	0.05	12.5	0.05	0.50	0.75	1	0.28	1.013	0.00
0.1	25.0	20.0	0.08	5.0	0.02	0.80	0.75	1	0.11	1.071	0.03
0.1	25.0	25.0	0.10	0.0	0.00	1.00	0.75	1	0.00	1.111	0.05
0.2	50.0	0.0	0.00	50.0	0.20	0.00	0.75	1	0.56	0.850	-0.08
0.2	50.0	12.5	0.05	37.5	0.15	0.25	0.75	1	0.42	0.934	-0.04
0.2	50.0	25.0	0.10	25.0	0.10	0.50	0.75	1	0.28	1.028	0.00
0.2	50.0	37.5	0.15	12.5	0.05	0.75	0.75	1	0.14	1.132	0.05
0.2	50.0	50.0	0.20	0.0	0.00	1.00	0.75	1	0.00	1.250	0.10
0.3	75.0	0.00	0.00	75.0	0.30	0.00	0.75	1	0.56	0.775	-0.11
0.3	75.0	18.75	0.08	56.25	0.23	0.25	0.75	1	0.42	0.899	-0.06
0.3	75.0	37.5	0.15	37.5	0.15	0.50	0.75	1	0.28	1.044	0.00
0.3	75.0	62.5	0.25	12.5	0.05	0.83	0.75	1	0.09	1.283	0.09
0.3	75.0	75.00	0.30	0.00	0.00	1.00	0.75	1	0.00	1.429	0.15
0.4	100.0	0.00	0.00	100.00	0.40	0.00	0.75	1	0.56	0.700	-0.15
0.4	100.0	25.00	0.10	75.00	0.30	0.25	0.75	1	0.42	0.861	-0.08
0.4	100.0	50.00	0.20	50.00	0.20	0.50	0.75	1	0.28	1.063	-0.01
0.4	100.0	75.00	0.30	25.00	0.10	0.75	0.75	1	0.14	1.321	0.08
0.4	100.0	100.00	0.40	0.00	0.00	1.00	0.75	1	0.00	1.667	0.20

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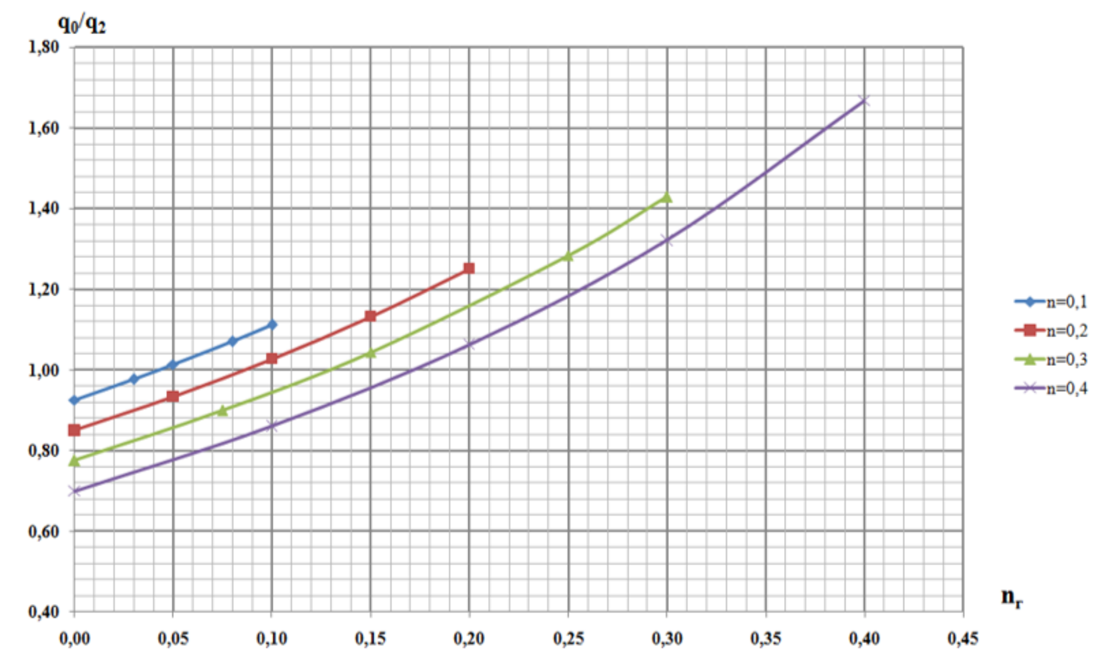

Figure 2. Impact of contraction degree of combined dam on relative specific discharges in contracted section

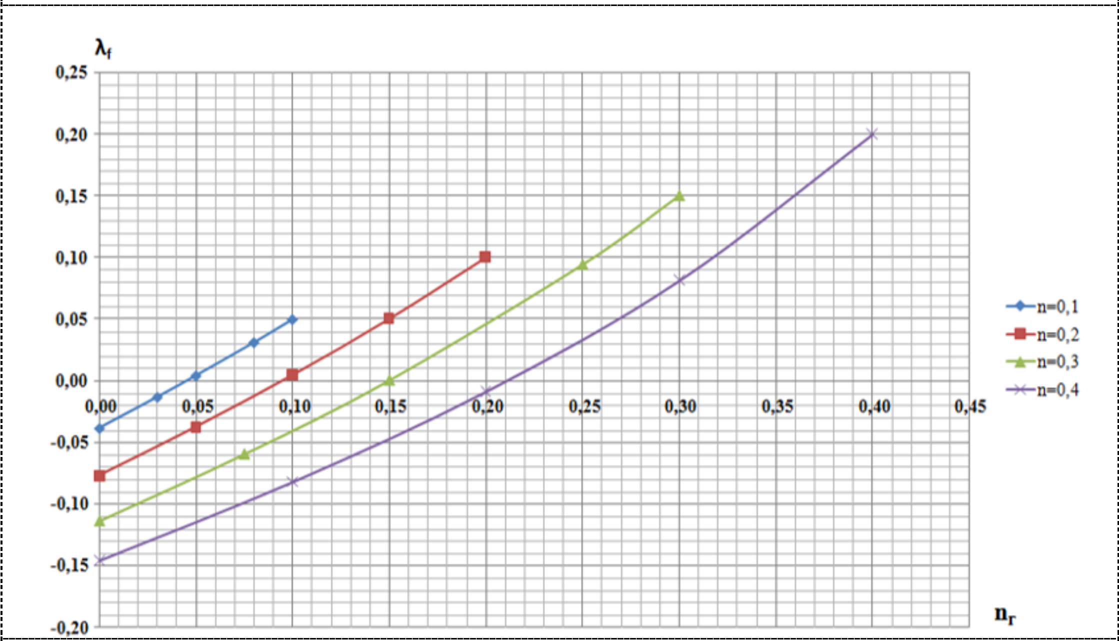

Figure 3. Impact of contraction degree of combined dam on dynamic axes of flow

We can see from the graphs:

Relative specific discharges $q_0 = q_2$ in contracted section increase with the increase of contraction degree for total part n and blind part n_b.

Relative deflection of the dynamic axes of flow contracted by a combined dam with varying build-up through-flow part depends on relative discharges, degree of contraction for total, blind, and through-flow parts. When they increase, λ_f increases too.

The design method is developed for evaluation of carrying capacity of the combined dam with tetrahedron through-flow part, which depends on the relative length of the blind part $\ell_b = \ell_t$, build-up coefficient P, installation angle α_d.

4. Conclusions

A combined dam structure is proposed which consists of the tetrahedron through-flow part and the blind part build of the local soil. They don't require driving piles and construction works are cheaper and they are easy to make. Through-flow part build-up coefficient depends on the installation method and the number of rows and ranges from 0.2 to 0.4.

Deflection of the dynamic axes of flow depends on natural specific discharges $\boldsymbol{q_2}$ ***the*** magnitude of through-flow part specific discharge $\boldsymbol{q_c}$ and discharge of non-contracted part of the flow $\boldsymbol{q_0}$ contraction degree: total n through-flow part $\boldsymbol{n_{th}}$ and blind part $\boldsymbol{n_b}$

The carrying capacity of the through-flow part is evaluated through the deflection coefficient expressing the ratio of incoming flow to flow passing the through-flow part. The increase of contraction degrees $\boldsymbol{n.n_b}$ result in the increase of relative specific discharges $\boldsymbol{q_0/q_2}$ and the relative width of relative deflection of flow dynamic axes $\boldsymbol{\lambda_f}$.

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