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LOW FLOODED (SUBMERGED) GROINS AS CONSTRUCTIONS ACTIVATING MASS TRANSFER IN RIVER FLOWS

Abstract. This paper considers the operation of low submerged **(**flooded**)** groins oriented by the sharp angle relatively to the incoming flow. Helical flow with a spiral structure arise behind such construction which, due to high values of transitional velocity directed along the construction and rotating, providing a significant enhancement of mass transfer in the stream, washing of the riverside zone, and supposing additional attraction of atmospheric oxygen into the stream and also almost complete initial mixing of wastewater discharged behind the groin with the river flow.

INTRODUCTION

The purpose of present work was to study the mass transfer characteristics of low submerged groins placed at an angle to the direction of approaching transit flow and to develop practical recommendations. The objectives of the research were to study the mean velocity field in the flow around such constructions, patterns of mass transfer on the edge of the vortex roller providing the intensification of mass transfer in the flow, to study the pressure field and flow parametrs near such constructions, as well as to assess the impact of additional structural elements that enhance the progressive movement of the flow in the vortex roller.

The object of the study is the hydrodynamic processes and phenomena in the water flow flowing around the considered facilities. The relationships for the speed and cross current discharges in the stream initiated by the groin, as well as the distance from the riverside to which near-bank mass of water penetrate through the action of the groin can be considered as the subject of the study.

The relevance of this work is connected with a large number of small and medium-sized rivers in need of improving their environmental conditions. We know a lot of cases when ecology of rivers improved as a result of secondary flows activation in the stream. The use of bubble screens, artificial diffusers for this purpose always requires extra energy (installing compressors, twirlers, etc.). In this case, the intensification of secondary flows and subsidiary capture of oxygen from the air are performed exclusively by the internal energy of the flow. The initial dilution of wastewater that can be discharged into the river from downstream side of groins is also provided by the stream. You do not need to create an additional pressure, as in the case of traditional distributed jet device

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releases. Groins can be very simple in their construction and the materials used. For example, the bottom of the river can be stacked with plastic bags filled with soil and water. Conventional gabions, simple and cheap construction elements, can also be used.

On the other hand, the effectiveness of the considered constructions can be quite high, particularly from the appointment of additional elements that increase mass transfer flow: additional riverside barriers installed below the groins and riverside orifices (passages) providing easy penetration of the transit flow into the space behind the groins. As can be seen from the following materials, speed of the flow behind such groins can exceed speed of incoming transit flow from one and a half to two times.

CHARACTERISTIC OF RIVER FLOWS

The scientific novelty of this work consists mainly in the fact that a constructive solution of the construction for substantial increase of mass transfer processes in a flow, optimization of its design and rational parameters were found for the first time. Even Losievskiy A.I. [1] proposed to use low flooded thresholds and groins to enhance bottom currents and sediment transport control in case of the need to clean the fairway. He noted in his paper that the flow rate behind the bottom thresholds is significant, and the transporting power of such flows is sufficient for purposes of channel regulation. Rozovski I.L. [2] also noted a considerable speed and intensity of the vortex flow behind the bottom ridges skewed relatively to the flow. Rossinskiy K.I. [3] first proposed to release wastewater on the downstream side of groins skewed relative to the flow. These constructions were supplied with crest of the ridge in the direction of transit flow washing the construction. The named bias strengthened circulating currents created by the facility in the stream. According to this author research translational velocity of the flow behind the facility was 0.6-0.7 from that of the transit flow U_0. The K.I. Rossinskiy's project was implemented on the Volga River near the Balakovo plant of artificial fibers.

In the last decade systems of low flooded (submerged) groins are widely used for management of mountain rivers. The main purpose of such facilities is to reduce the speed near the riverside and to create circulating currents directing deposits to the bank. However, it is known that the same facilities enhance mass transfer in the stream essentially. At relatively low levels of water they provide creating eddy zones favourable for the fish. Fig. 2 shows a system of such facilities on the Lomnitsa River in the Ivano-Frankivsk Region which has been under surveillance for 25 years and which has confirmed its good quality as a riverbed-controlling and ecological system of installations.

Kirienko I.I. and his co-workers [4-6] have investigated low skewed groins which actively regulate the movement of bottom sediment at high discharge rate and flow levels as well as act as environmental facilities. These studies have established that the rational parameters providing the most intensive currents close to the bottom behind these facilities are the following: the angle of the construction relative to the flow should be 45-60 degrees (along the current or against it). The relative height of the facility *p/h* is in the range of 0.25-0.5. Further ideas for the use of flow behind the slantwise-directed low groins were developed in the works [7, 8]. Speeds behind these facilities, averaged by

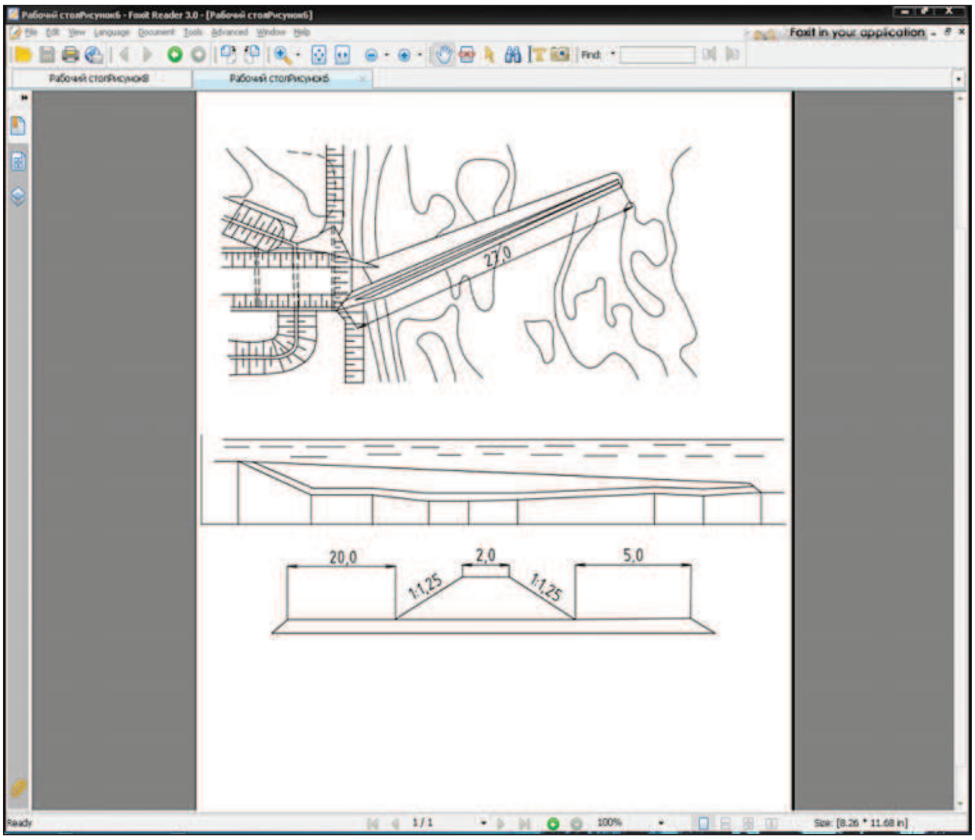

Fig. 1. The scheme of water-mixing groin installed on the Volga River near the Balakovo plant
Rys. 1. Schemat tamy mieszającej wodę zainstalowanej na Wołdze w pobliżu wytwórni sztucznych włókien Balakovo

the volume of the vortex roller depending on the length of the construction to its relative altitude are displayed in the graph of Fig. 3.

According to these studies the nature of mass transfer that occurs between the transit stream and the area of the separated flow over a bottom ledge or groin skewed relatively to the flow has the same nature and qualitative character (Fig. 4).

The trajectories of surface and bottom jets, recorded in experiments with groins are shown in Fig. 5. They certify the existence of both the rotatory and translational motion of the flow in the area of eddy roller behind the facility.

To intensify flows behind the groins placed downstream, it was recomended to arrange an additional obstacle near the riverside. This obstacle, slowing down the near-bank currents, increases the pressure in the primary zone of the eddy roller and thus accelerates the flow inside it. A detailed study of the kinematics of the flow behind the skewed plate mounted on the bottom was conducted by Yarnykh N.A. [9] with the help of filming method.

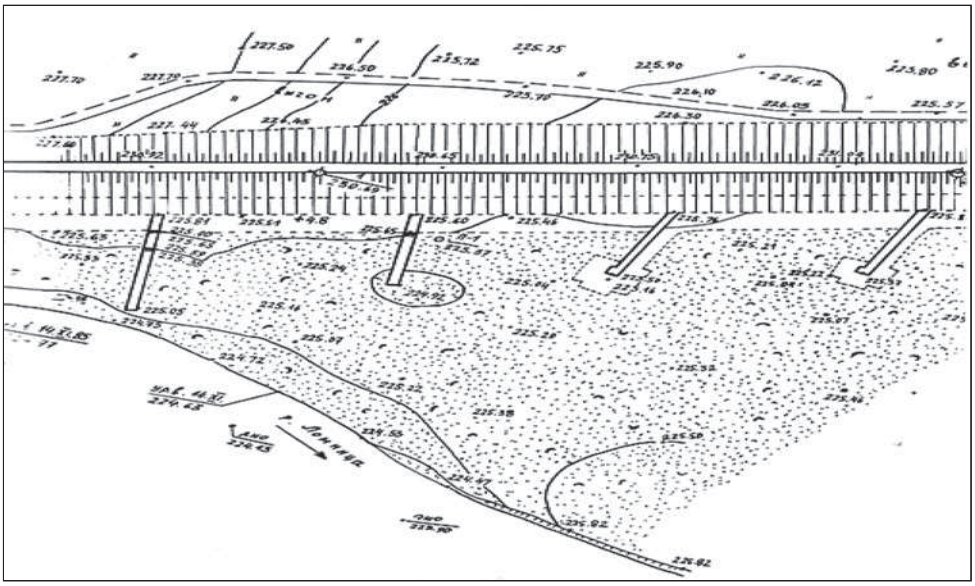

Fig. 2. Map of low flooded groins at the section of the Lomnitsa River which is under field observation since 1980-s.

Rys. 2. Mapa podwodnych tam poprzecznych na rzece Łomnica, która jest pod obserwacją od lat osiemdziesiątych XX w.

This work points to the high speed of translational movement along the base plate mounted at an angle of 30 degrees to the flow. The maximum velocity reached 1.45-1.5U_0. Groin study was also conducted at the Technical University of Zurich in the hydraulic laboratory by Unger Jens, Willi Hager and Alexey Shchodro [10]. This study

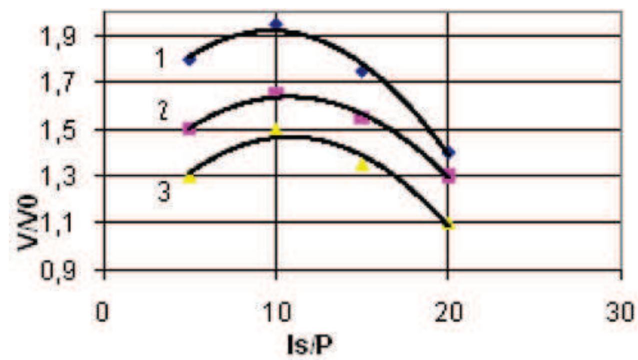

Fig. 3. Dependence of the relative translational velocities in helical flow behind a streamlined bottom groin from the length of the groin and its relative height: line 1 – (0,5), line 2 – (0,33), line 3 – (0,25).

Rys. 3. Zależność względnych prędkości translacyjnych w spiralnym nurcie za tamą denną o opływowym kształcie od długości tamy i jej względnej wysokości: linia 1 – (0,5), linia 2 – (0,33), linia 3 – (0,25) examined in detail the three-dimensional field of averaged and instantaneous velocities with a video camera detecting the movement of small particles of indicators carried by the flow. At the same time investigation of groins normally oriented relatively to the flow was carried out.

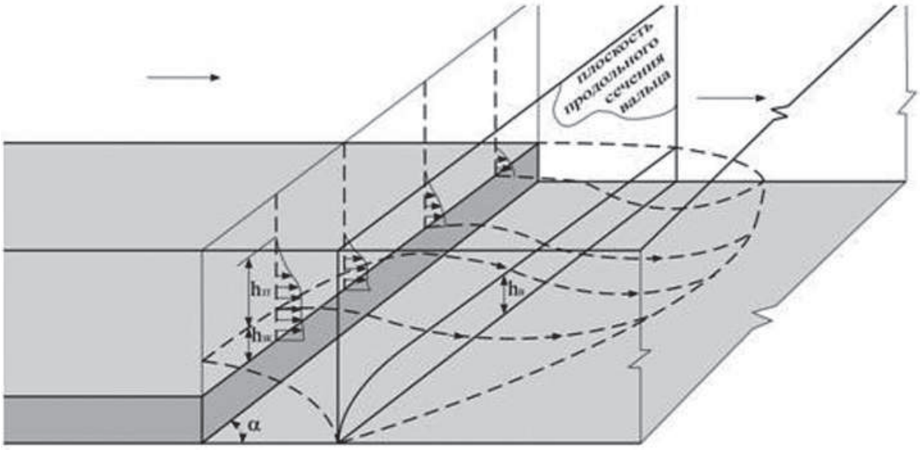

Fig. 4. Diagram of eddy roller spatial configuration and its water exchange with the transit flow
Rys. 4. Diagram ukształtowania przestrzennego walca wiru i jego wymiany wody z przepływającym nurtem

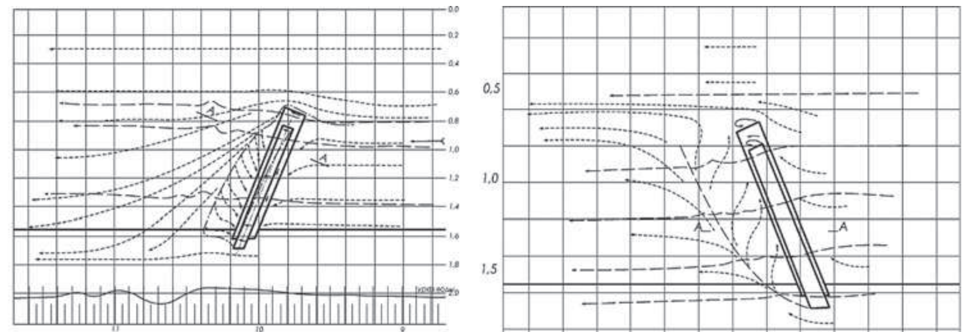

Fig. 5. Flow structure and trajectories of the bottom (----) and surface ( ) jets while flowing around a low groin placed at an angle of 67.5 degrees towards the stream (a), and 112.5° downstream (b) at $P / H = 0{,}25$; $l' / B = 0{,}568$; $Fr = 0{,}350$
Rys. 5. Struktura przepływu i trajektorie dennego (----) i powierzchniowego ( ) strumienia podczas przepływu wokół niskiej tamy umiejscowionej pod kątem 67,5 stopni pod prąd (a), i 112,5° z prądem przy $P / H = 0{,}25$; $l' / B = 0{,}568$; $Fr = 0{,}350$

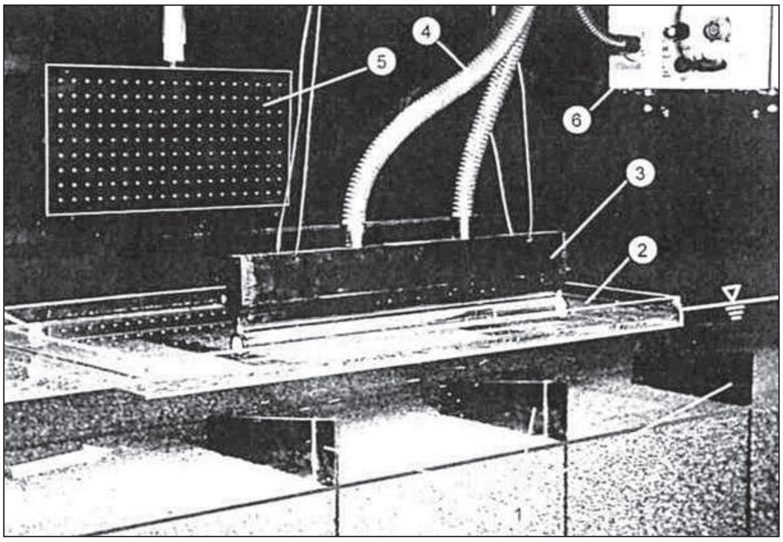

Fig. 6. Scheme of installing groins in a tray: (1, 2) – a floating basket of clear glass, (3) – a light knife, (4) – power cables, (5) – scoreboard for the camera settings, (6) – control panel

Rys. 6. Schemat instalacji tam w płaskim naczyniu: (1, 2) – pływający koszyk z przejrzystego szkła, (3) – nóż świetlny, (4) – przewody zasilania, (5) – tablica wyników dla ustawień kamery, (6) – pulpit sterowniczy

The computing system determines movement of particles at time intervals of 0.1 sec, which makes it possible to deduce the instantaneous velocity distribution diagrams on the screen and to record them in the machine memory. Such distributions were investigated for different flow cross-section planes located both horizontally and vertically (Figure 7).

The result of research presents instantaneous velocity fields in different sections of the flow shown in Fig. 7. These results allow us to draw a conclusion about the intensity of mixing and mass transfer, as well as about the size of separated zones and areas with poor water circulation. Velocities allow us to estimate the flow force impact on the constructions, elements of bank mounts, bottom particles, and to assess pump-regulating and eroding flow ability. The present study was conducted in a mirror hydraulic tray 1.3 m wide, 8m long, with maximum capacity up to 170 l/s. Model groins - wooden plates 7-10 cm high and 0.5 m long - were mounted in the tray at various angles to its axis.

A system of several groins (2-3 pieces) as well as single constructions of this type were studied. Mode of the stream flowing around groins was always calm (the Froude number was a lot less than 1). The depth varied from 12.5 to 25 cm. The angles at which the constructions were mounted were from 45 to 90 degrees. Behind the groin a riverside barrier was mounted which created additional pressure drop accelerating the flow in the separation zone behind the groin. There was an orifice (a passage) - an open space 7.5-10 cm wide - between the side wall of the tray and the groin. Existence of this open space helped the transit flow enter the space behind the groin, accelerated the behind-groin flow and increased penetration of the "torch" into the transit stream. That is it produced a positive impact on the mass transfer characteristics associated with the installation of the groin.

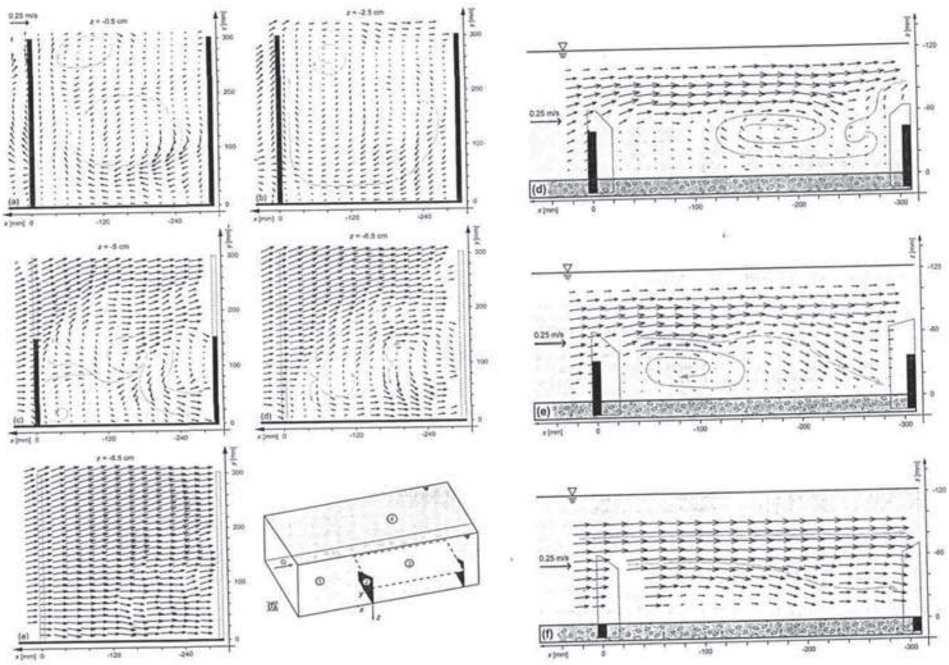

Fig. 7. Instantaneous velocity vector fields in horizontal and vertical sections of inter-groin spaces and groin installation scheme

Rys. 7. Pola wektorów prędkości chwilowej w przekroju poziomym i pionowym przestrzeni między tamą i schemat instalacji tamy

During the research it was noted that the work of a system of two or three groins is approximately the same in efficiency as that of a single groin. That is why further we consider and recommend to practice designing only single constructions of this type. In the experiments the flow rate was measured with the help of micro-rotators equipped with amperemeter.

At each point where the appliance is installed, its location is determined by the averaged velocity vector. Its pre-planned position was determined with the help of filament beacons input into the stream. Ampere meter readings allowed to count the minimum and maximum current which corresponded to a range of large- and medium-velocity fluctuations. Thus the speed measurements allowed to evaluate both the averaged and fluctuating velocities.

Mass transfer characteristics of the flow (consumption of water mass capture from transit flow into the separation zone and consumption of water discharge from this zone) were assessed with the help of polymeric tracer particles of specific gravity 1.02 and settling velocity 4,5 cm/s. Such settling velocity, according to our research , allows us to consider the motion of these particles to be identical to the motion of the particles of the water itself, as within the zone of separated flow the averaged velocities of the stream exceeded in every position.

a) b)

Fig. 8. Scheme of the studied system with the riverside orifices (passages) and a barrier a), and the nature of the stream inflow through the riverside orifice (passage) into the separation zone b)

Rys. 8. Schemat badanego systemu z otworami (przepustami) brzegowymi i barierą a), i charakter napływu cieku przez otwór (przepust) brzegowy do strefy separacji b)

In addition, photographing and filming of the stream carrying the particles within the vortex flow behind the groin and generally close to the structure was carried out. Special study was fulfilled of the distance from the tray to the axis of the jet leaving the area of the vortex roller into the transit traffic. Completing the studies we concluded that there is a significant increase of speed behind the groin compared to the coming stream velocity. Transitional speed of the vortex roller at the same time is 1.5-2 times higher than the speed u_0. In general the speeds and their values depended on the angle of the groin installation, its relative length and height, on the width of the passage and the lateral width of the obstacle. The last two parameters as well as the distance from the groin to the side barrier were accepted at once, on the basis of these preliminary experiments, and were not changed in subsequent experiments. See, for example, Fig. 9

The relative height and length of the groin as well as the angle of its installation have been optimized in course of special series of experiments planned on the basis of the well-known theory for experiment designing. These optimized values are the following: $a' = 60^0$-65^0, $(P/h)_{min} = 0.25$-0.3, $(P/h)_{aver} = 0.3$-0.55. The main results of these series of experiments are presented in figures 3, 9.

PRELIMINARY CALCULATION OF THE PRESSURE DISTRIBUTION ALONG THE LENGTH OF THE AREA UNDER CONSIDERATION

The objective of the hydraulic design is the definition of speed and flow discharge rate arising behind the groin at a given pressure distribution along the axis of the helical flow. These are the flow discharge rates and velocities carried from the bank to the center of the channel that contribute to the washing of the riverside zone, provide mix-

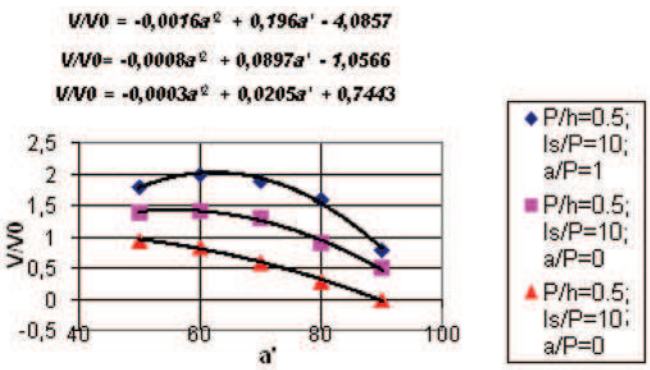

Fig. 9. A plot of dependence of the velosities relative rates behind the buna (V/V_0) on its angle of inclination a'(grad.), on relative lengths of the structure (l_s/P) and on the orifice opening (a/P)
Rys. 9. Wykres zależności prędkości względnych za kauczukiem syntetycznym (V/V_0) przy kącie pochylenia a'(grad.), długości względnej budowli (l_s/P), i przy wylocie otworu (a/P)

ing effluents released in the initial zone of the vortex roller, increase surface speed and facilitate capture of additional oxygen from the air, as well as arrange secondary flows in the whole mass of the stream.

Calculation of these rates may be useful for those cases when parameters of the designed structures do not correspond to the range of parameters at which the groins were examined in the laboratory.

For preliminary calculation of the pressure distribution along the length of the area under consideration we propose the following mathematical model of the flow in the vortex roller [11].

The transitional motion of the flow in the vortex roller occurs with a variable flow discharge along the way. In this case each particle of the liquid is influenced by the following powers:

1) the pressure drop along the main flow direction;
2) the transverse pressure drop (along the vortex roller) (ΔP);
3) the frictional forces between the transit flow and the vortex roller which are passed to every particle through the shearing stresses in the liquid mass and flow friction forces on the bottom and the wall ledge.

The movement of elementary jet with a variable discharge flow along the path is described by the following equation, derived in [11]

$$\rho v d\omega \Delta v + \rho(v - v_1)\Delta q_1 - \rho(v - v_2)\Delta q_2 = \Delta F \tag{1}$$

where $d\omega$ – area of infinitesimal living section of a jet;

v – jet speed in this section and its variation between this and another jet section sufficiently close to it;

v_1, v_2 – velocity projections of joining and separating liquid masses on the direction of jet axis;

$\Delta q_{1,2}$ – change of the joining and separating discharges between its two sections due to accession and separation of liquid mass from it;

ΔF – the resultant of all the external forces applied to the jet between the calculated cross sections.

The structure of equation (1) corresponds to the structure of basic equations of fluid motion along the path with a variable flow discharge rate derived by many domestic and foreign authors. After some mathematical transformations which are described in [11], this equation takes the next form:

$$\alpha_0 \cdot \Delta\bar{v} \cdot \bar{v} \cdot \omega \cdot (1 + A - B) + \alpha_0 \cdot \Delta\omega \cdot \left(A\bar{v}_1 - B\bar{v}_2\right) = = -\frac{\Delta\bar{P}}{\rho} + k \cdot u_0 \left[u_0 \cdot \cos(\alpha - \phi) - \bar{v}\right] \cdot \omega_n \quad (2)$$

Having a sufficient source of information, equation (2) allows to find the averaged value of transitional velocity (v) with the aid of additional information on the friction coefficient k, given by the figure 10 [11].

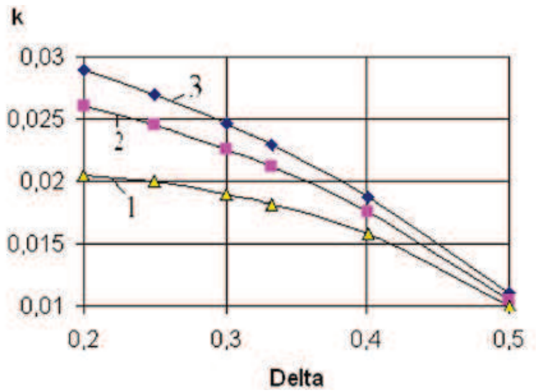

Fig. 10. A plot of dependence of the friction coefficient k – on the Delta=P/h and spur's angle of inclination a' (grad.) (1 – a' = 30°; 2 – a' = 45°; 3 – a' = 60°)

Rys. 10. Wykres zależności współczynnika tarcia k – przy Delta = P/h i kącie nachylenia ostrogi a'(grad.) (1 – a' = 30°; 2 – a' = 45°; 3 – a' = 60°)

CONCLUSIONS

Analysis of equation (2) leads to the following conclusions:

1. With increasing of negative gradients of the forces, activating the spiral motion along the vortex roller (right-hand side of the equation 2) the amount of motion in it must increase accordingly. Therefore, one of the possible ways to increase efficiency of the structures with a bottom ledge is to increase the negative pressure gradients.
2. If we artificially boost velocities in the initial zone of the vortex roller they must grow in all sections as a result of momentum transfer. Their rise is blocked partially

by frictional force. The last one is reduced with contraction of the vortex roller which may take place under increasing speed in intermediate sections of the roller.

3. Increasing of transitional velocity in the vortex roller when the right-hand side of the equation is unchanged may cause not only contraction of the roller but also reduction in its speed increase and cross-section (s), as well as the alignment of velocity profiles *v* in cross-sections associated with the decrease in a'.

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PODWODNE TAMY POPRZECZNE JAKO KONSTRUKCJE AKTYWUJĄCE PRZEPŁYW MASY W CIEKACH RZECZNYCH

Streszczenie

Niniejsza praca dotyczy działania podwodnych tam poprzecznych usytuowanych pod ostrym kątem w stosunku do nurtu rzeki. Za taką konstrukcją powstaje spiralny nurt ze spiralną strukturą, co z powodu wysokich wartości prędkości chwilowej wzdłuż konstrukcji i rotacji przyczynia się do znaczącego wzrostu przepływu masy w cieku, podmywania strefy brzegowej, przypuszczalnie dodatkowego przyciągania tlenu atmosferycznego do cieku oraz prawie całkowitego mieszania ścieków zrzucanych za tamą z nurtem rzeki.

TRANSVERSALE DEICHE UNTER DEM WASSERSPIEGEL ALS AKTIVIERENDE KONSTRUKTIONEN FÜR MASSENSTŐMUNG IN WASSERLÄUFEN

Zusammenfassung

Die vorliegende Bearbeitung betrifft den Einfluss der transversalen Deiche unter dem Wasserspiegel, die unter einem spitzen Winkel im Bezug auf den Stromlauf platziert sind. Hinter solcher Konstruktion ensteht ein spiraler Wasserlauf mit seiner Spiralstruktur. Wegen einer hohen momentanen Geschwindigkeit längs der Konstruktion und einer Drehung trägt es zu einer wesentlichen Erhőhung der Massenstrőmung im Wasserlauf, zum Unterspülen der Uferlinie, zur wahrscheinlichen zusätzlichen Anziehung des atmosphärischen Sauerstoffs in den Wasserlauf und fast voller Vermischung der Abwässer, die hinter dem Deich in Srőmungsrichtung abgeleitet warden.