Analysis of stream-guiding structures for the use of sediment management in river beds

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Abstract: The article analyzes the stream-guiding structures of M.V. Potapov and Odgaard, A.J. in order to use sediment management in the river bed. Odgaard, A.J. and other authors have developed the continuation of the use of artificial transverse circulation for sediment transfer within the cross-section of the channel, developed by M.V. Potapov, and created a method for calculating bottom guide sills for various application conditions. The authors have developed and tested by model and field studies typical configuration of the panel system. Convergence of the main parameters of bottom shields according to Odgaard, A.J., and M.V. Potapov argues that the way Iowa's submerged shields are used has its merits and is a sediment control method for waterways and rivers in general.

1. Introduction

To regulate the erosion of channels, very effective methods were successfully applied, proposed by Soviet scientists M.V. Potapov [1-4], A.I. Losievsy [5] and others. According to Potapov's method, the destruction of banks, erosion of the bottom near structures, as well as sedimentation in water intake structures and along the route of the irrigation canal are prevented by regulating the hydraulic structure of the flow, i.e. creation of artificial transverse circulation in it, which changes the natural direction and conditions of the sediment movement. The transverse circulation of the flow is provided by a system of guide shields that create a helical movement of water jets in the desired direction (figure 1).

Potapov M.V. proposes to consider and further proves that the main physical reason for the transverse circulation of the flow is the action of the forces of internal friction that appear inside the flow with an uneven distribution of the transverse velocity over the section [1].

The helical flow created by the guiding system generally corresponds to such a kinematic scheme in which the longitudinal velocity is uniformly distributed over the section, the angular velocity vector $\xi$ is directed parallel to the flow axis and its value satisfies the equation:

$$\frac{\partial^2 \xi}{\partial y^2} \frac{\partial^2 \xi}{\partial z^2} + k^2 \cdot \xi = 0$$

provided $\xi = 0$ at the flow perimeter.
Figure 1. Cross circulation of the riverbed flow during installation of the system by M.V. Potapov. 1 - surface shields, 2 - directions of surface jets, 3 - directions of bottom jets, 4 - zone of circulation currents.

The layout of the coordinate axes is shown in figure 2.

Figure 2. Layout of the coordinate axes.

In the river bed of a rectangular section with width $B$ and depth $H$, these conditions lead to expressions for the velocity components of a single screw motion with counterclockwise rotation:

$$ u = u_0 = \text{const} $$

$$ u = \frac{w e r_c}{H} \sin \frac{\pi y}{B} \cos \frac{\pi z}{H} $$

$$ \omega = \frac{w e r_c}{B} \cos \frac{\pi y}{B} \sin \frac{\pi z}{H} $$
\[ \xi = \frac{2\pi u_c}{H} \sin \frac{\pi y}{B} \cos \frac{\pi z}{H}. \]

Here \( u_c \) is the media square velocity of the transverse circulation

\[ u_c = \frac{1}{\omega} \int (u^2 + \omega^2) \, d\omega \]

and \( r_c = \frac{2BH}{\sqrt{B^2 + H^2}} \) — the linear size of the section, which plays the role of the hydraulic radius.

The equations give a sinusoidal distribution of transverse velocities over the width and depth of the flow.

The greatest transverse velocity \( u_m \) occurs at the bottom or surface in the middle of the river bed width and is related to the \( u_c \) dependence

\[ u_m = u_c r_c \frac{H}{r_c}, \text{ where } u_c = u_m \frac{H}{r_c}. \]

On the other hand, \( u_m = u_0 \tan \varphi_m \), where \( \varphi_m \) is the angle of deviation of the bottom or surface velocity from the flow axis. Therefore

\[ u_c = u_0 \frac{H}{r_c} \tan \varphi_m. \]

Therefore, an important characteristic of the screw flow \( u_c \) can be obtained by measuring \( u_0 \) and \( \varphi_m \) [1].

Losievsky’s method is used to combat sediment deposition on navigable rivers; here flow circulation is created by barrier walls (rapids), which are installed on the river bottom at an angle of 20-25° to the direction of the current. In this case, the surface jets deviate to the river centerline, and the bottom ones, saturated with sediments, toward the coast [5].

Due to the difficulty in the technical implementation of these structures, their use has not found proper development in river structures.

Until now, spurs, dams, ponds with their unresolved long-term problems in their operation and efficiency are used for bank protection and protection from siltation of canals and pumping stations.

2. Methods

The work carried out in the bend of the East Nishnabotna River, Iowa (Odgaard and Mosconi, 1987) [6-8] has received a new direction and development of the use of cross-circulation for hydraulic construction.

The first designs of which were tested in natural conditions were later called Iowa shields. These are small structures designed to alter flow near the bottom and redistribute flow and sediment transport within a channel cross-section. The functioning of the shields is ensured by generating secondary circulation in the flow [9, 10].

An immersed shield, when installed at a low angle, induces horizontal circulation in the downstream flow (Figure 3). The circulation is due to the pressure difference between the two sides of the shield, which creates a flow from the high pressure side through the top of the shield and down to the low pressure side. The resulting vortex is carried downstream by the flow, where it gives rise to a spiral movement of the flow and associated with these changes in the direction of sediment movement and, accordingly, the bottom topography.

The circulation changes the magnitude and direction of fluid movement, and causes a decrease in velocity and transfer of sediment to a given area of the shield.

The shields are located so that they generate secondary currents, eliminating the lateral circulation of the channel flow, which is the primary cause of erosion of the banks and the bottom.

The flow area affected by one shield is limited. In the transverse direction, one shield has an insignificant effect approximately multiple of its height.
Figure 3. Shield installed at an angle to the stream and generated downstream circulation.

To increase the width of the area of impact on the flow, the shields are placed in the array (figure 4).

A)

Figure 4. Diagram of an array of three shields (a) and a change in the bottom profile (b).

To maintain a certain induced circulation and induced shear stress of the downstream layer, the shield array must be repeated at regular intervals in the downstream direction. The distance between the arrays L1 depends on the purpose of the design and the location of the shields in the river bed [6-8].

The main parameters of the shields are the relative height of the shield P / h, the aspect ratio P / L, the slope of the river bottom, and the distance between the shields L1 and l, as well as the distance of the shields from the bank l0, the average flow depth h0, the velocity u0, the ratio of the channel width to the depth B / h0 and the ratio of the radius to the width R / B, as well as the Froude number for sediments moving in the river bed, which is defined as
\[ F_D = \frac{u_0}{\sqrt{gD\%}} \]

where \( D\% \) - average values of sediment diameter in\% availability.

The Froude sediment number measures the mobility of the sediment. The general trend is that the changes in the impact on the flow caused by the shields increase with the Froude number.

One of the most important observations made during both curved and rectilinear surveys is that the changes caused by the shields did not change the cross-sectional area and longitudinal slope of the water surface.

This observation is important because it implies that the shields will not cause any change in the ability of the stream to transport sediment downstream of the shield field, and therefore the overall flow characteristics should not be changed.

3. Results

The authors have developed and tested typical layout of the panel system by model and field studies. Figure 5 shows the schemes for installing shields near a bridge on a river with an expanded cross-section, on a curved bed and a straight section.

![Figure 5](image)

**Figure 5.** Layouts of shields when regulating a curved river bed (a), a bridge on a river with an extended cross-section (b).

Thus, Odgaard, A.J. and other authors have developed the continuation of the use of artificial transverse circulation for sediment transfer within the cross-section of the channel, developed by MV Potapov, and created a method for calculating bottom guide sills for various conditions of use [7-12].

A significant amount of research performed and the number of authors working on this topic requires a generalization of the obtained material and arouses interest in the further development of the use of transverse circulation in river hydraulics.
4. Discussion
To compare the parameters of the shields, the dimensions according to M.V. Potapov, Odgaard, AJ were taken: the depth of immersion of the shield (c / H), the dimensions of the shields L, the angle of installation relative to the flow α, the distance between the shields a and the length of the system D. All parameters are summarized in the table # 1.

Table 1. The main parameters of the jet shields according to the authors Odgaard A.J., M.V. Potapova.

| Author of structures and type of structure | Installation angle (α) | Shield length (L) | Immersion depth (c/H) | Distance between shields (a) | System action length (D) |
|-------------------------------------------|------------------------|-------------------|-----------------------|-----------------------------|-------------------------|
| The jet-guiding system by M.V. Potapov     | 18-24                  | (1.0-1.5)H        | (0.2-0.5)H            | (0.75-1.15)H                | (15-45)H (system)       |
| Iowa Bottom Shields (Odgaard A.J.,)        | 20-40                  | (0.9-1.0)H        | (0.3-0.5)H            | (0.6-0.9)H                  | 9.0 H (one row)         |

Analyzing the data in the table, we can note the convergence of the average parameters of the shields by the immersion depth 0.3H, the length of the shield 1H, the angle of installation 18-20, the distance between the shields 0.9H, the length of the system 9H for Odgaard A.J., And for M.V. Potapov from 15H to 45H, but he did not have studies of systems installed one after another [1].

5. Conclusions
Based on the analysis carried out, it could be argued that:

- convergence of the main parameters of bottom shields according to Odgaard, A.J., and M.V. Potapov proves that the way Iowa’s submerged shields are used has its merits and is a sediment control method for waterways and rivers in general.
- Iowa shields can make significant changes in the distribution of speeds and depths without changing the slope and transporting capacity of the flow in the area where the shields are installed.
- the main parameters affecting the efficiency of the work are the relative height of the shield, the aspect ratio of the shield and the angle of installation in the flow, the density of the shields (quantity per unit area), the resistance of the river bed and sediments (Froude number of sediments).

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