ISSN: 2181-3337 | SCIENTISTS.UZ VOLUME 5 ISSUE 8 AUGUST 2026

MORPHOLOGICAL PARAMETERS IN THE UPSTREAM REACH OF A FLOW CONSTRICTED BY A SPUR DIKE

Bakiev Masharif[1], Kuryozov Otaboy[2], Yakubov Kuvonchbek[3], Khasanov Khojiakbar[4], Khalimbetov Azat[5]

Professor, Head of the Department of Hydrotechnical Structures and Engineering Constructions, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers – National Research University (TIIAME-NRU), Tashkent, Uzbekistan[1]

Independent Researcher, Department of Hydrotechnical Structures and Engineering Constructions, TIIAME-NRU, Tashkent, Uzbekistan[2]

PhD, Associate Professor, Department of Hydrotechnical Structures and Engineering Constructions, TIIAME-NRU, Tashkent, Uzbekistan[3]

Assistant and Independent Researcher, Department of Hydrotechnical Structures and Engineering Constructions, TIIAME-NRU, Tashkent, Uzbekistan[4]

PhD, Associate Professor, Department of Hydrotechnical Structures and Engineering Constructions, TIIAME-NRU, Tashkent, Uzbekistan[5]

DOI: 10.67620/sai.58a0006

ABSTRACT

This paper presents the results of an experimental and theoretical study of the morphological parameters of flow in the upstream reach constricted by a spur dike (solid spur). The experiments were carried out in three flumes measuring40×60×1500 cm,40×60×800 cm, 100×50×800 cm. The first flume had glass walls and a wooden bed, the second had concrete walls and a wooden bed, and the third had concrete walls and a concrete bed. Experiments were carried out under the following flow and spur dike conditions: degree of flow constriction nb=lb sinθ /B; 0.125, 0.2, 0.3, 0.375. Here lb is the length of the spur dike; θ is the installation angle, 60–90°; water discharge from 5 to 25 l/s i_d=0.0001-0,0002. Fr_δ=0.02"–" 0.35 The influence of these factors on the formation of the section of maximum backwater and on the length of the upstream recirculation zone was examined. It was found that as the degree of flow constriction increases, the relative distance to the section of maximum backwater S_1/(B-b_0)decreases from 2.0 to 0.96, while the relative length of the upstream recirculation zone l_b/(B-b_0)increases from 3.0 to 4.55. An increase in the Froude number leads to an expansion of the zone of hydrodynamic influence of the structure and a shift of the maximum-backwater zone upstream. It was experimentally confirmed that as the spur dike installation angle increases, the processes of flow separation and circulatory flow in the upstream reach intensify. To provide a theoretical description of backwater propagation, the momentum equation was used, accounting for the influence of hydrostatic pressure forces, bed and bank resistance, and the redistribution of flow momentum in the zone of local constriction. A comparison of calculated results with the experimental data of K.Sh. Sharapov showed satisfactory agreement, including at a substantial bed slope of 0.004: the calculated backwater length was

ACCEPTED

03.09.26

Keywords: *spur dike (spur), backwater, upstream recirculation zone, degree of constriction, piezometric slope, specific energy, spur dike installation angle, Froude number, momentum equation.*

CC BY

L_p=0.86"–" 0.94 m against an experimental value of L_p=1.0 m. The relationships and calculation approaches obtained can be used in the design of channel-regulating and bank-protection structures, as well as in assessing the hydrodynamic conditions governing the formation of local backwater and recirculation zones in river channels.

Introduction

Channel flows interacting with bank-protection and channel-regulating structures are characterized by a complex spatial hydrodynamic structure, accompanied by velocity redistribution, changes in the free surface of the flow, and the development of recirculation zones and local backwater. A particularly complex flow pattern is observed in the upstream reach of flows constricted by spur dikes and groynes, where the local narrowing of the flow cross-section causes the main high-velocity core to shift, recirculation zones to form, and shear-stress distribution to change markedly. These processes directly affect bank stability, the intensity of local scour, sediment transport, and the reliability of hydraulic structures.

Recent studies show that when flow interacts with spurs and lateral constrictions, complex three-dimensional flows develop, accompanied by the growth of vortex structures and deformation of the free water surface. As a result of installing a spur, the main jet shifts toward the opposite bank, while in the nearshore zone regions of reduced velocity and reverse flow form (Gu et al., 2023; Liu et al., 2021). Near the spur head, high values of turbulent kinetic energy, local shear stresses, and intense turbulent mixing are observed, which leads to the intensification of channel deformation and local scour (Chen et al., 2022; Kang et al., 2023). The formation of the upstream and downstream recirculation zones, characterized by complex circulatory flows and secondary vortex structures, plays a particularly important role in the flow structure.

Significant influence on the hydrodynamic structure of the flow is exerted by the geometric parameters of channel-regulating structures. It has been established that the degree of channel constriction, the length of the spur, its installation angle, and the relative flow depth determine the pattern of displacement of the main high-velocity core, the size of the recirculation zones, and the intensity of free-surface deformation (Kang et al., 2023; Ohtsuki et al., 2024). As the degree of constriction increases, the influence of inertial and transverse velocity gradients grows, leading to stronger momentum redistribution and a change in the flow structure in the upstream reach.

The classical foundations for calculating constricted flows were laid in the works of Rotenburg, Avrova, Seleznev, Sharapov, and Zegzhda. Rotenburg (1960) examined the hydraulic design of bridge crossings over lowland rivers and proposed approaches for determining the position of the section of maximum backwater under significant flow constriction. Avrova (1969) studied the hydraulic calculation of river flow constricted by a cofferdam and showed the need to account for changes in flow structure within the zone of local narrowing. Seleznev (1958) studied the kinematics of flow in the vicinity of semi-dams, which is important for understanding the processes of jet separation and the formation of recirculation zones. Sharapov (1968) investigated the hydraulics of massive spurs and proposed approaches for assessing the influence of spurs on channel-flow structure. Zegzhda (1957) developed approaches for determining hydraulic friction losses in channels and pipelines, which provides an important basis for calculating bed and bank resistance (Avrova, 1969; Rotenburg, 1960; Seleznev, 1958; Sharapov, 1968; Zegzhda, 1957). Rotenburg (1960) also assumed that the piezometric slope along the near-bank streamline is zero, and that the section of maximum backwater has a curvilinear shape described by an elliptical relationship. Our studies have shown that these assumptions hold mainly for flows strongly constricted by bridge embankments.

ISSN: 2181-3337 | SCIENTISTS.UZ

At small degrees of constriction, the flow structure changes substantially. Modern experimental studies show that under conditions of weak lateral constriction, a contracted section forms, displaced downstream relative to the constriction section (Fakhri et al., 2020; Nowroozpour et al., 2022). In this case the flow separates from the protected bank considerably earlier, and in the interaction zone regions of intense turbulent mixing and recirculating flow form (Bakiev et al., 2023, 2024; Khalimbetov et al., 2020; Mulahasan et al., 2021; Mulahasan & Mohammed, 2021). The maximum backwater and the most intense deformation of the free surface are also frequently displaced downstream owing to the redistribution of flow momentum and the development of vortex structures.

Despite considerable progress in modern experimental and numerical research methods, many questions relating to the formation of the morphological parameters of flow in the upstream reach remain insufficiently studied. Most current work addresses local scour, turbulence, and numerical modeling of flow around spurs and bridge crossings, whereas the regularities governing the formation of the section of maximum backwater and the upstream recirculation zone under small degrees of constriction have been studied only to a limited extent. Flows constricted by solid spurs (spur dikes), which are characterized by early separation of the near-bank streamline and a positive piezometric slope along it, have been particularly insufficiently studied.

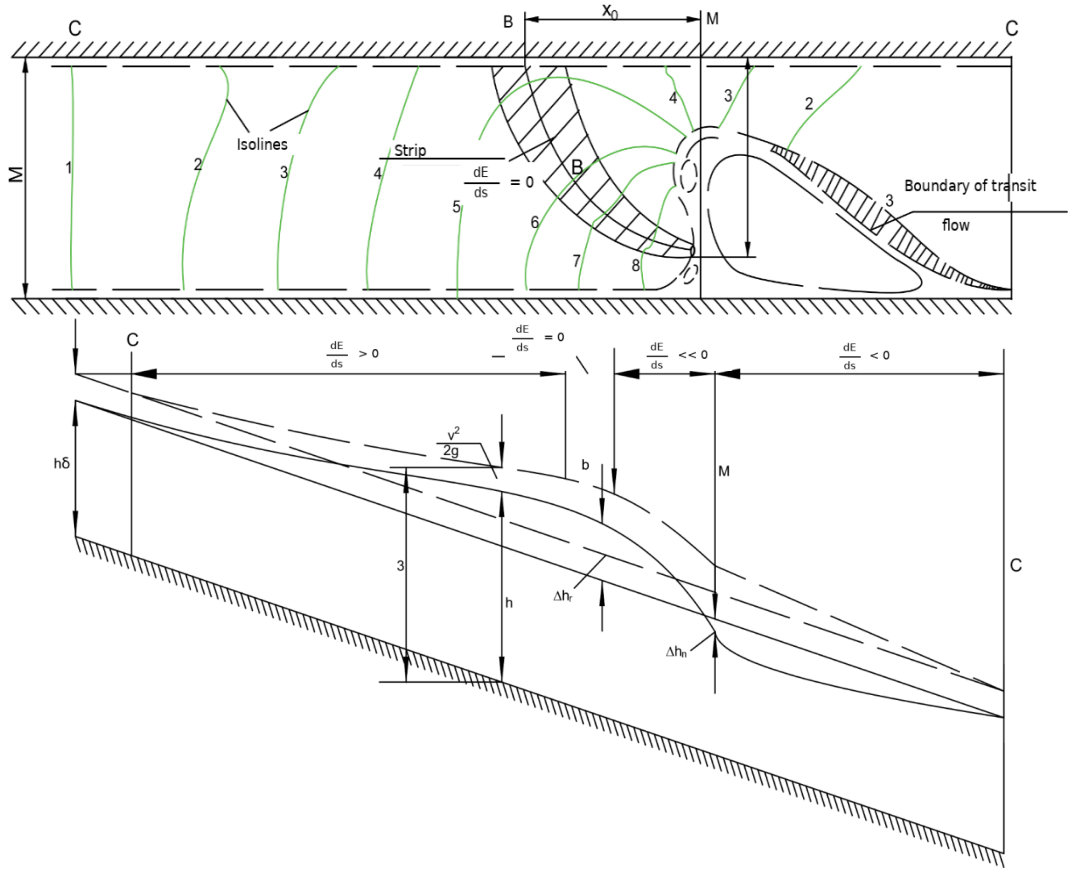


Fig. 1. Diagram of flow constricted by a bridge crossing (after I.S. Rotenburg).

This makes it necessary to further investigate, both experimentally and theoretically, the hydrodynamic features of flow in the upstream reach constricted by a spur dike, taking into account the degree of flow constriction, the spur installation angle, and the Froude number.

The aim of the present study is to determine the regularities governing the formation of the morphological parameters of flow in the upstream reach constricted by a spur dike, and to develop calculation relationships for determining the position of the section of maximum backwater and the length of the upstream recirculation zone as functions of the hydraulic parameters of the flow.

ISSN: 2181-3337 | SCIENTISTS.UZ

Materials and Methods

Experimental Setup

To study the morphological parameters of flow in the upstream reach constricted by a spur dike, laboratory hydraulic experiments were carried out in straight flumes with a non-erodible bed. The use of laboratory flumes made it possible to ensure controlled hydraulic conditions and to exclude the influence of random natural factors typical of field channel processes. This approach enables a detailed analysis of the regularities governing backwater formation, changes in flow structure, and the development of recirculation zones under various flow-constriction regimes.

Scheme of Flow Interaction with the Spur Dike

A spur dike (solid spur), installed at various angles to the flow direction, was used as the channel-regulating element. The main objective of the experiments was to investigate the influence of the spur dike on the redistribution of the hydrodynamic parameters of the flow in the upstream reach.

When the flow interacts with the spur dike, a local narrowing of the flow cross-section occurs, which changes the flow structure. The main flow shifts toward the free part of the channel, a backwater zone forms in front of the structure, and a region of recirculating flow arises in the nearshore area. At the same time, the near-bank streamline separates from the protected bank and an upstream recirculation zone forms.

Unlike flows constricted by bridge crossings, in the case under consideration the streamline separates considerably earlier, and a positive piezometric slope develops along the near-bank streamline:

$$J_s > 0$$

This leads to a change in the position of the line of maximum backwater and a shift of the contracted section downstream relative to the constriction section.

The hydraulic scheme shown in Fig. 2 was used to analyze these processes.

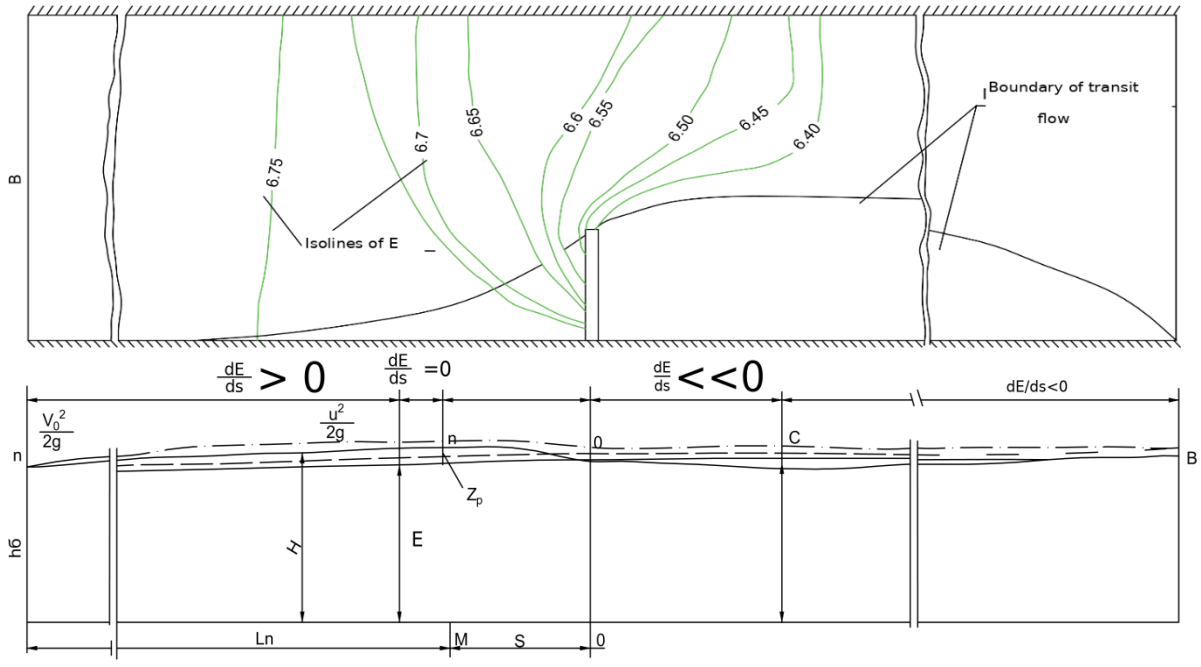


Fig. 2. Diagram of flow constricted by a spur dike (solid spur).

Main Hydraulic Parameters of the Study

To quantitatively describe the processes occurring in the upstream reach of the flow, the principal dimensionless hydraulic parameters were selected. The use of dimensionless characteristics makes it possible to generalize the experimental results and to apply the relationships obtained to channel systems of different scales.

One of the main parameters was the degree of flow constriction:

ISSN: 2181-3337 | SCIENTISTS.UZ

$$n = \frac{b_0}{B}$$

where: b_0— width of the constricted part of the flow; B— full width of the channel.

This parameter characterizes the relative reduction of the flow cross-section caused by installation of the spur dike. A change in the degree of constriction directly affects the intensity of backwater, velocity redistribution, and the development of recirculation zones.

To assess the position of the zone of maximum backwater, the following parameter was used:

$$\frac{S_1}{B - b_0}$$

where: S_1— distance from the spur head to the section of maximum backwater.

The use of a relative form made it possible to exclude the influence of the absolute dimensions of the flume and to analyze the general regularities governing the change in backwater position.

The size of the upstream recirculation zone was assessed using the parameter:

$$\frac{l_b}{B - b_0}$$

where: l_b— length of the upstream recirculation zone.

This parameter characterizes the intensity of the development of recirculating flow in the upstream reach and makes it possible to assess the size of the reverse-flow zone arising from the interaction of the flow with the spur dike.

The hydrodynamic regime of the flow was characterized by the Froude number:

$$Fr_\delta = \frac{V}{\sqrt{gh}}$$

The Froude number is one of the most important criteria of hydraulic similarity and reflects the ratio of inertial to gravitational forces in the flow. A change in this parameter substantially affects the flow structure, the size of the backwater zone, and the intensity of vortex formation.

Method for Determining the Section of Maximum Backwater

To determine the position of the section of maximum backwater, a series of experimental measurements was carried out for various values of the degree of flow constriction, the spur dike installation angle, and the Froude number.

During the experiments, the position of the free-surface line of the flow was measured, and the distance from the spur head to the section at which the maximum rise in water level was observed was recorded. Based on the data obtained, graphical relationships were constructed making it possible to determine the relative position of the section of maximum backwater (Fig.):

The use of graphical relationships is due to the complexity of an analytical description of the spatial flow structure in the zone of local constriction. The experimental approach made it possible to reveal stable regularities in the change of the morphological parameters of the flow.

Method for Determining the Length of the Upstream Recirculation Zone

One of the most important characteristics of the flow in the upstream reach is the length of the upstream recirculation zone. The formation of this zone is associated with separation of the streamline from the protected bank and the development of circulatory motion in the nearshore area.

To determine the length of the recirculation zone, visual observations of the flow trajectory were carried out and the boundaries of the stable recirculating flow were recorded. Based on the experimental results, relationships were constructed (Fig.):

The use of a relative parameter made it possible to exclude the influence of the absolute dimensions of the experimental setup and to obtain more universal relationships.

ISSN: 2181-3337 | SCIENTISTS.UZ

Theoretical Model for Calculating the Backwater Length

To provide a theoretical description of backwater propagation, the momentum equation was used. This approach makes it possible to account for the principal forces acting on the flow in the zone of interaction with the spur dike.

The calculation scheme included:

– hydrostatic pressure forces;
– bed and bank friction forces;
– the influence of the water's own weight;
– the change in flow momentum.

As can be seen from Figs. 1 and 2, the total backwater length L_n is determined as the sum:

$$L_n = l_n + S_1 \tag{1}$$

The distance to the section of maximum backwater S_1 was determined from the graphical relationships by interpolation, while to determine the length $l_n$the momentum equation was applied to the fluid element bounded by sections EB, MB, the bed, and the free surface of the flow (Figs. 1, 2).

The equation is written as follows:

$$\rho Q(\alpha_{o\delta}V_\delta - \alpha_{\text{омп}}V_{\text{мп}}) = \sum P + \sum T - G' \tag{2}$$

where ρ — is the water density; Q— the discharge; $\left.\begin{matrix}\alpha_{o\delta}V_\delta \\ \alpha_{\text{омп}}V_{\text{мп}}\end{matrix}\right\}$— the momentum correction factors and mean velocities, respectively, at the end-of-backwater section (EB) and at the section of maximum backwater; $\sum P = P_n - P_\delta$— the difference in hydrostatic pressure forces acting at sections EB and MB; $\sum T = T_d + 2T_\delta$— the sum of the external friction forces from the bed and the bank; G'— the component of the water's own weight between sections EB and MB.

Here

$$P_n = \frac{\gamma B H^2}{2};\ P_\delta = \frac{\gamma B h_\delta^2}{2}; \tag{3}$$

$$\left.\begin{matrix} T_{\text{д}} = \tau_{\text{д}} l_n B = \rho \frac{\lambda_{\text{д}} V_{\text{ср}}^2}{2} l_n B;\ G' = \gamma B l_n \frac{(H+h_\delta)}{2} i_{\text{д}} \\ T_\delta = \tau_{\text{б}} l_n \frac{(H+h_\delta)}{2} = \rho \frac{\lambda_\delta V_{\text{ср}}^2}{2} l_n \frac{(H+h_\delta)}{2} \end{matrix}\right\} \tag{4}$$

Substituting (4) into equation (2), after some transformation we obtain:

$$l_n = \frac{\frac{Q}{g}(\alpha_{\text{об}}V_{\text{б}} - \alpha_{\text{ОМП}}V_{\text{МП}}) - \frac{B}{2}(H^2 - h_{\text{б}}^2)}{\frac{\lambda_{\text{д}}(V_{\text{б}}+V_{\text{МП}})^2 B}{8g} + \frac{\lambda_{\text{б}}(V_{\text{б}}+V_{\text{МП}})^2(H+h_{\text{б}})}{8g} - \frac{B(H+h_{\text{б}})}{2} i_{\text{д}}} \tag{5}$$

Or, when $\lambda_{\text{д}} = \lambda_{\text{б}} = \lambda$ and $i_{\text{д}} = 0$ a simpler relationship is obtained

$$l_n = \frac{\frac{Q}{g}(\alpha_{\text{об}}V_{\text{б}} - \alpha_{\text{ОМП}}V_{\text{МП}}) - \frac{B}{2}(H^2 - h_{\text{б}}^2)}{\frac{\lambda(V_{\text{б}}+V_{\text{МП}})^2 B}{8g}(B+H+h_\delta)} \tag{6}$$

In formulas (4, 5, 6) the notation is as follows: $\left.\begin{matrix}\tau_{\text{д}}, \lambda_{\text{д}} \\ \tau_{\text{б}}, \lambda_{\text{б}}\end{matrix}\right\}$— shear stresses and the corresponding resistance coefficients of the bed and the bank, respectively $Bl_n\frac{H+h_\delta}{2}$— the volume of water between the sections; γ — the unit weight of water; g— the acceleration of gravity; H— the flow depth at section MB.

The remaining notation is clear from Figs. 1 and 2, and the hydraulic friction coefficient is determined from the formula of A.P. Zegzhda.

To improve the accuracy of the calculations, the values of the momentum coefficients were adopted on the basis of the experimental data. This made it possible to achieve satisfactory agreement between the calculated and experimental results.

Results and Discussion

Position of the Section of Maximum Backwater

ISSN: 2181-3337 | SCIENTISTS.UZ

Based on the results of the experimental studies, graphical relationships were obtained that make it possible to determine the position of the section of maximum backwater as a function of the degree of flow constriction, the spur dike installation angle, and the Froude number

The results obtained showed that as the degree of flow constriction increases, $n$the relative distance to the section of maximum backwater decreases. This regularity is explained by the fact that as constriction intensifies, a more intense redistribution of the velocity field occurs in the transverse direction. As a result, the flow adapts more quickly to the changed hydraulic conditions, and the zone of maximum backwater shifts closer to the spur head.

It was also established that an increase in the spur dike installation angle likewise leads to a decrease in the relative distance:

this is because as the installation angle increases, the degree of the structure's effect on the main flow grows, local jet contraction intensifies, and the intensity of momentum redistribution in the upstream reach increases.

The influence of the Froude number is of the opposite character. The experimental results showed that as Fr_δ increases, a certain increase in the relative distance to the section of maximum backwater is observed. This effect is explained by the increase in the inertial forces of the flow. At higher velocities the flow possesses greater kinetic energy, as a result of which the process of its hydrodynamic readjustment occurs over a greater distance upstream.

Thus, the position of the section of maximum backwater is determined by the combined influence of the geometric parameters of constriction and the dynamic characteristics of the flow. The relationships obtained reflect the regularities of pressure redistribution and the change in flow structure in the upstream reach during interaction of the flow with the spur dike.

Table 1. Experimental data used to construct the graph

(n)	(Frδ = 0.06)	(Frδ = 0.20)	(Frδ = 0.35)	a	δ
0.12	2.2	2.08	1.96	0.24	1.9
0.22	1.84	1.76	1.64	0.28	1.75
0.34	1.48	1.46	1.39	0.36	1.5
0.46	1.18	1.22	1.14	0.45	1.3
0.54	1	0.92	0.84		

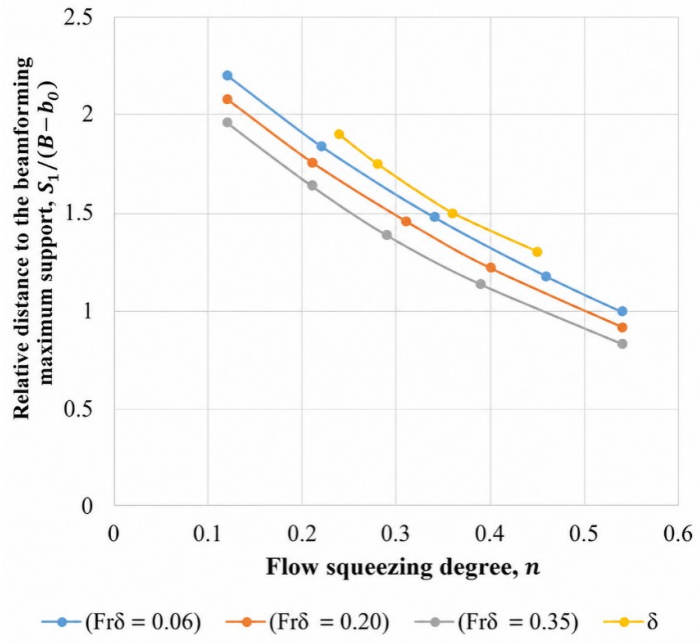


Fig. 3. Relationship between the relative position of the section of maximum backwater and the degree of flow constriction for various values of the Froude number.

ISSN: 2181-3337 | SCIENTISTS.UZ

Formation of the Upstream Recirculation Zone

One of the most characteristic hydrodynamic phenomena arising from the interaction of the flow with the spur dike is the formation of the upstream recirculation zone. The formation of this region is associated with separation of the near-bank streamline from the protected bank and the emergence of a local circulatory flow.

The experimental results showed that the length of the upstream recirculation zone depends substantially on the degree of flow constriction, the spur dike installation angle, and the Froude number (Fig. 4).

It was found that as the degree of flow constriction increases, the relative length of the recirculation zone also increases. This is explained by the fact that under stronger constriction the transverse velocity gradient increases and the process of streamline separation from the bank intensifies. As a result, the size of the recirculation region increases.

A similar regularity is observed with an increase in the spur dike installation angle. At larger angles the intensity of the flow's interaction with the structure increases, which leads to stronger vortex formation and an expansion of the recirculation zone.

The Froude number also has a significant influence on the size of the upstream recirculation zone. As it increases, the relative length of the recirculation zone increases.

This effect is related to the growth of the inertial forces of the flow and the increased stability of the separated streamline. As a result, the recirculating-flow zone extends over a greater distance upstream.

It should be noted that the formation of the upstream recirculation zone has a significant effect on the morphodynamic processes in the channel. Within this region, a decrease in flow velocities, a change in the distribution of shear stresses, and the emergence of local zones of sediment accumulation are observed. The determination of the size of the recirculation zone therefore has important practical significance for the design of bank-protection structures and the prediction of channel deformation.

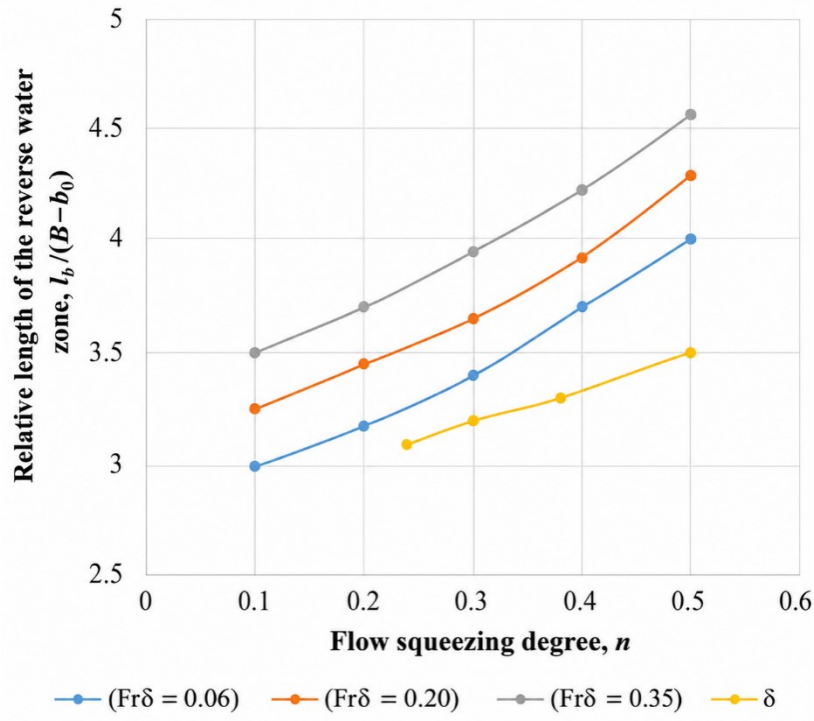


Fig. 4. Relationship between the relative length of the upstream recirculation zone and the degree of flow constriction for various values of the Froude number.

ISSN: 2181-3337 | SCIENTISTS.UZ

Table 2.

Experimental data used to construct the graph

(n)	(Frδ = 0.06)	(Frδ = 0.20)	(Frδ = 0.35)	a	δ
0.1	3	3.25	3.5	0.24	3.1
0.2	3.18	3.45	3.7	0.3	3.2
0.3	3.4	3.65	3.95	0.38	3.3
0.4	3.7	3.92	4.22	0.5	3.5
0.5	4	4.28	4.55		

Comparison of Calculated and Experimental Data

To assess the applicability of the proposed method, calculations of the backwater length were performed and the calculated results were compared with the experimental data of K.Sh. Sharapov (1957)

The calculations were performed for the conditions of a straight flume with a non-erodible bed, for the following hydraulic parameters: water discharge$q = 10$ л/с, mean flow velocity $V = 0.38$ м/с, degree of constriction $n = 0.225$, longitudinal bed slope $i_d = 0.004$

The results obtained showed satisfactory agreement between the calculated and experimental values of the backwater length. The discrepancies between the calculated and experimental data were within acceptable limits, which confirms the validity of the approach used.

Analysis of the results showed that expression (1) essentially determines the overall length of backwater propagation, which in a number of cases may exceed the size of the upstream recirculation zone. This is especially noticeable at small longitudinal channel slopes, typical of lowland rivers.

At

$$i_d < 0.0003$$

the backwater propagates over a considerable distance upstream, so that the backwater length substantially exceeds the size of the recirculation region. At larger slopes, however,

$$i_d \geq 0.004$$

the backwater is localized within a relatively small reach, and the backwater length becomes close to the length of the upstream recirculation zone.

The results obtained confirm that the developed method can be used to assess the morphological parameters of flow in the upstream reach constricted by a spur dike.

Table 3. Comparison of calculated and experimental values of the backwater length.

Test No.	1	2	3
α_b (°)	90	70	50
lb (m)	0.18	0.191	0.234
S1 (m)	0.34	0.37	0.41
H (m)	0.04	0.04	0.04
Vmp (m/s)	0.313	0.313	0.313
λ_d	0.0127	0.0127	0.0127
λ_δ	0.007	0.007	0.007
lp (II-7) (m)	0.6	0.6	0.6
lp (II-4) (m)	0.94	0.9	0.86
lp (II-4) (m)	0.88	0.882	0.9
lp (experiment) (m)	1	1	1

ISSN: 2181-3337 | SCIENTISTS.UZ

Conclusion

As a result of the experimental and theoretical studies carried out, the principal regularities governing the formation of the morphological parameters of flow in the upstream reach constricted by a spur dike have been established. The results obtained made it possible to reveal features of the redistribution of the hydrodynamic characteristics of the flow under local narrowing of the flow cross-section and to determine the influence of the principal hydraulic parameters on the processes of backwater formation and the formation of the upstream recirculation zone.

It has been established that the position of the section of maximum backwater depends substantially on the degree of flow constriction, the spur dike installation angle, and the Froude number. As the degree of constriction and the spur dike installation angle increase, the relative distance to the section of maximum backwater decreases, which is associated with a more intense redistribution of the velocity field and an acceleration of the flow's hydrodynamic readjustment. At the same time, an increase in the Froude number leads to a certain shift of the section of maximum backwater upstream, owing to the growth of the inertial forces of the flow.

It has been experimentally confirmed that the length of the upstream recirculation zone increases with an increase in the degree of flow constriction, the spur dike installation angle, and the Froude number. The formation of this zone is caused by separation of the near-bank streamline from the protected bank and the development of circulatory flow in the nearshore area. The relationships obtained reflect the regularities governing the development of vortex structures and make it possible to assess the size of the recirculation zones in the upstream reach.

Based on the momentum equation, a calculation method for determining the backwater length has been developed. The proposed model accounts for the influence of hydrostatic pressure forces, bed and bank resistance, and the redistribution of flow momentum in the zone of local constriction. A comparison of the calculated results with the experimental data showed satisfactory agreement, which confirms the validity and practical applicability of the developed approach.

The results obtained can be used in the design of channel-regulating and bank-protection structures, as well as in assessing the hydrodynamic conditions governing the formation of local backwater zones and recirculating flow in river and canal channels.

REFERENCES

1. Avrova, T. F. (1969). *Gidravlicheskii raschet rechnogo potoka, stesnennogo peremychkoi* [Hydraulic calculation of river flow constricted by a cofferdam] [Abstract of Candidate of Technical Sciences dissertation, Leningrad Polytechnic Institute named after M. I. Kalinin]. 18 pp.
2. Bakiev, M., Khalimbetov, A., Yakubov, K., Sagin, J., & Asamatdinov, I. (2023). Kinematic parameters of flow constrained by combined dams with through part of tetrahedra in compression region. *E3S Web of Conferences, 401*, 04046. doi:10.1051/e3sconf/202340104046
3. Bakiev, M., Matkarimov, O., Yakubov, K., & Khalimbetov, A. (2024). Study on velocity field of the flow asymmetrically constrained by through spurs. *E3S Web of Conferences, 563*, 02017. doi:10.1051/e3sconf/202456302017
4. Chen, Y., Lu, Y., Yang, S., Mao, J., Gong, Y., Muhammad, W. I., & Yin, S. (2022). Numerical investigation of flow structure and turbulence characteristic around a spur dike using large-eddy simulation. *Water, 14*(19), 3158. doi:10.3390/w14193158
5. Fakhri, A., Ettema, R., Aliyari, F., & Nowroozpour, A. (2021). Large-scale particle image velocimetry for estimating vena-contracta width for flow in contracted open channels. *Water, 13*(1), 31. doi:10.3390/w13010031

ISSN: 2181-3337 | SCIENTISTS.UZ

6. Gu, Z., Cao, X., Cao, M., & Lu, W. (2023). Integrative study on flow characteristics and impact of non-submerged double spur dikes on the river system. *International Journal of Environmental Research and Public Health, 20*(5), 4262. doi:10.3390/ijerph20054262
7. Kang, S. K., Lee, J., Kim, Y., & Khosronejad, A. (2023). Experimental and numerical study on the flow characteristics around spur dikes at different length-to-depth ratios. *Advances in Water Resources, 175*, 104428. doi:10.1016/j.advwatres.2023.104428
8. Khalimbetov, A., Bakiev, M., Shukurova, S., Choriev, J., & Khayitov, K. (2020). Study of submountain river flow patterns constrained by a combined dam. *IOP Conference Series: Earth and Environmental Science, 614*(1), 012053. doi:10.1088/1755-1315/614/1/012053
9. Liu, J. C., Hu, Z. Q., & Zhu, M. Y. (2021). Comparison and analysis of calculation of bridge backwater based on MIKE21 hydrodynamic model. *E3S Web of Conferences, 233*, 03043. doi:10.1051/e3sconf/202123303043
10. Mulahasan, S., Al-Osmy, S., & Alhashimi, S. (2021). Modelling of flow pattern in an open channel with sidewall obstruction. *IOP Conference Series: Materials Science and Engineering, 1090*(1), 012097. doi:10.1088/1757-899X/1090/1/012097
11. Mulahasan, S., & Mohammed, A. Y. (2021). Hydraulic characteristics of flow-through bridge openings. *Applied Engineering Letters, 6*(1), 21–28. doi:10.18485/aeletters.2021.6.1.3
12. Nowroozpour, A., Ettema, R., & Fakhri, A. (2022). A reassessment of contraction scour at bridge waterways. *Journal of Hydraulic Engineering, 148*(12), 06022016. doi:10.1061/(ASCE)HY.1943-7900.0002031
13. Ohtsuki, K., Kono, T., Arikawa, T., Taniwaki, H., & Itsukushima, R. (2024). Spur dike applications for the sustainability of channels in incised steep bend streams. *Water, 16*(4), 575. doi:10.3390/w16040575
14. Rotenburg, I. S. (1960). *Voprosy gidravlicheskogo rascheta i naznacheniia otverstii mostov na perekhodakh cherez ravninnye reki* [Issues of hydraulic calculation and sizing of bridge openings at crossings over lowland rivers]. Saratov University Press.
15. Seleznev, V. M. (1957). *Issledovanie kinematiki potoka v raione poluzaprud* [Investigation of flow kinematics in the area of semi-dams] [Abstract of Candidate of Technical Sciences dissertation]. Leningrad.
16. Sharapov, K. V. (1968). *Issledovanie gidravliki massivnykh shpor* [Investigation of the hydraulics of massive groynes] [Abstract of Candidate of Technical Sciences dissertation, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers]. Tashkent.
17. Zegzhda, A. P. (1957). *Gidravlicheskie poteri na trenie v kanalakh i truboprovodakh* [Hydraulic friction losses in channels and pipelines]. Gosstroyizdat.

ISSN: 2181-3337 | SCIENTISTS.UZ