DETERMINATION OF THE CIRCULATION ZONE WIDTH AT THE JUNCTION OF EARTHEN CANALS

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DOI: 10.67620/sai.58a0008

ABSTRACT
The junction of open canal flows significantly affects hydraulic conditions, sediment transport, and channel deformation processes. One of the main hydraulic features at canal junctions is the formation of a circulation (vortex) zone near the side bank, which reduces the effective flow cross-section and leads to sediment deposition. This study aims to determine the width and length of the circulation zone formed at the junction of earthen canals. Laboratory and field experiments were conducted, and statistical and regression analyses were applied to establish relationships between flow velocity ratios and cross-sectional parameters. As a result, empirical equations were obtained to predict the width and length of the circulation zone depending on flow conditions and junction angles. Comparison with experimental and existing formula results showed good agreement. The proposed relationships can be used in hydraulic calculations to forecast channel deformation and improve canal design.

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07.09.26

Keywords: *canal junction, circulation zone, vortex width, open channel flow, sediment transport, hydraulic modeling, regression analysis.*

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Introduction

The process of flow addition at the junction of the channel joining the main channel negatively affects the operating mode of the channels, leading to changes in the sediment transport process and channel deformations in the channels. Regardless of the scheme of water inflow into the canals from the sides at different angles, the direction of water and sediment movement varies significantly depending on the flow approach conditions.

As a result of the flow addition, as a result of riverbed reformation over time, a specific width, curvature, and depth appear, corresponding to the conditions of the riverbed, and a redistribution of sediments occurs depending on the amount of solid particles flowing in.

The process of transformation of large soil canals, for many reasons, in some cases does not reach equilibrium. These reasons include:

- seasonal and multi-year variability of the flow;
- erosion of the basin surface and accumulation of bottom sediments;
- the occurrence of specific deformation of the flow in the turning zone, etc.

During seasonal changes in the flow rate and the water level in the channels, which change depending on it, the hydraulic parameters of the flow also change and create conditions for channel reformation.

From practice, it is known that in such cases, the reformation of the channel leads to inconveniences for water users. This also leads to a disruption of the natural regime of rivers and canals, as well as a decrease in the water carrying capacity of the riverbed.

The bed of open canals is characterized by the living cross-sectional area and water permeability. When depicted on a plan, this situation takes on a complex appearance. The curvature of the channel bed mainly affects the formation of channel sections under the action of centrifugal forces and secondary flows that affect a number of local processes.

In practice, the disconnection of the flow from the side bank of the canal leads to the formation of vortex fields. This area can be called a vortex zone. Due to the decrease in the velocity of the fluid's translational motion in the vortex zone, sediments accumulate intensively, and the live cross-section of the channel joining the main channel decreases, resulting in coastal deformation. Therefore, determining the dimensions of this vortex zone is one of the important indicators in forecasting channel deformation.

Although a number of researchers have done positive work to find a solution to this problem and have achieved results corresponding to the conditions of their experiments, they have not found a general solution due to the complexity of the problem.

Related hydraulic studies have examined flow separation and redistribution at canal side outlets and junctions (Babazhanov, Babazhanova, et al., 2024; Eshev, Babajanova, et al., 2024), energy losses and vortex behavior in variable-width channels (Babazhanov, Zaripov, et al., 2025; Bobomurodov, Zaripov, et al., 2025), and hydraulic calculations for water-control structures (Eshev, Isakov, et al., 2024; Rakhmatov et al., 2026). Related work on cohesive-soil erosion and soil properties provides additional context for sediment transport and channel deformation (Bobomurodov, Azizov, et al., 2024; Bobomurodov, Khazratov, Dilshodova, et al., 2024; Bobomurodov, Mamatov, et al., 2024; Bobomurodov, Khazratov, Bobomurodov, et al., 2025; Eshev et al., 2022).

Materials and Methods

Experimental studies were conducted in the laboratory "Modeling of Hydraulic Processes" of the Karshi State Technical University to study deformations depending on the size of the vortex field in the channel flow junction zone. For this, we enter the necessary experimental data into Table 1.

We know that there is some kind of relationship between the hydraulic parameters of the flow. We consider that there is a relationship

$$B_b/B_3 = f(v_2/v_3) \quad (1)$$

between the ratios of the flow velocities v_2/v_3 and the ratios of the live-section widths B_b/B_3 that arise during the merging of channel flows. Based on the analysis results, we consider the following proportional relationship for the 2nd connecting channel, located at angles $\theta = 30°$, $\theta = 45°$, and $\theta = 60°$ relative to the main 1st channel:

$$B_b/B_3 = \varepsilon(v_2/v_3) \quad (2)$$

As a result of analyzing the data in Table 1 by the method of mathematical statistics, it was established that the values of the proportionality coefficient ε according to the location of the joining 2nd channel relative to the main 1st channel are $\varepsilon = 0.25$, 0.34, and 0.43 for $\theta = 30°$, $\theta = 45°$, and $\theta = 60°$, respectively. Also, based on this view, we will construct a graph of relationship (2) according to the data presented in Table 1 (Figure 1).

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Figure 1

Relationship Between Width and Velocity Ratios at Junction Angles of 30°, 45°, and 60°

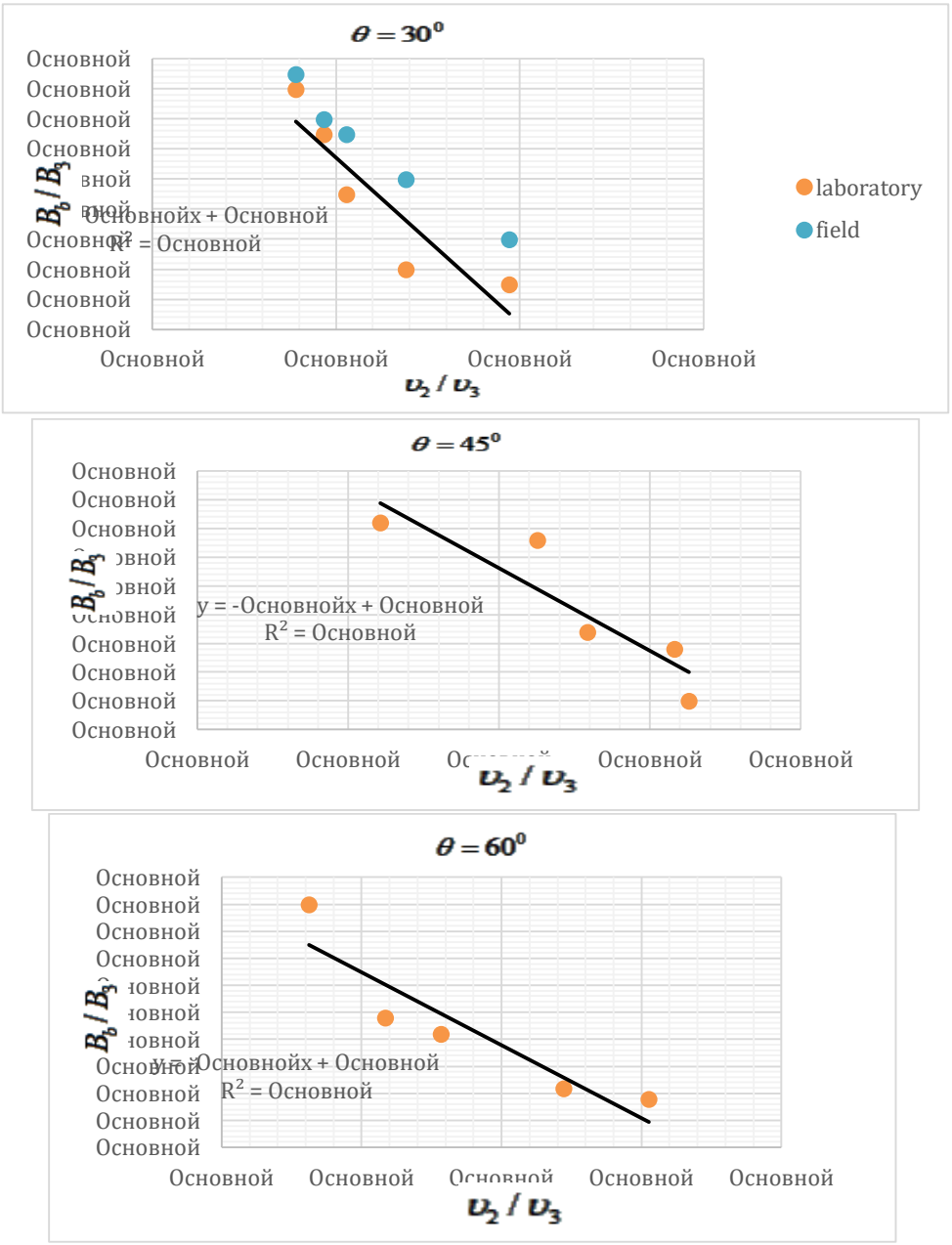


Table 1

Laboratory and Field Measurements and Calculated Circulation-Zone Parameters

No. exp.	h_1 (cm)	h_2 (cm)	h_3 (cm)	B_1 (cm)	B_2 (cm)	B_3 (cm)	B_c (cm)	B_b (cm), exp.	B_b (cm), calc.	B_b (cm), Gavr.	L_c (m), exp.	L_c (m), calc.	L_c (m), Gavr.	v_1 (m/s)	v_2 (m/s)	v_3 (m/s)	h_2/h_3	B_v/B_3	v_2/v_3	ε
θ = 30° (laboratory)																				
1	3.7	3.8	4.3	14	18	39	31	8.5	8.8	8.6	18.1	19	19.9	0.75	0.78	0.8	0.98	0.211	0.971	0.216
2	3.9	4.3	4.5	16	20	40	32.2	9.3	9.6	9.5	19	19.4	20.1	0.82	0.85	0.96	1.054	0.212	0.691	0.258
3	4.1	4.5	4.7	19	22	43	34	10	10.3	10.1	17.31	18.2	20.1	1.13	1.11	1.26	1.155	0.217	0.528	0.255
4	4.2	4.7	4.9	21	23	44	34.9	10.1	10.5	10.4	16.99	17.7	18.9	1.29	1.32	1.59	1.157	0.221	0.467	0.268
5	4.6	4.9	5.1	26	24	46	36	11.5	11.8	11.6	15.15	16	16.6	1.52	1.55	1.78	1.258	0.224	0.391	0.274
											17,31									0.284
θ = 30° (field)																				
1	313	323	383	2293	1598	3076	2419	662	690	668	1195	1242	1256	0.75	0.78	0.8	0.949	0.214	0.971	0.22
2	308	324	380	2291	1596	3093	2484	613	632	616	1089	1202	1218	0.74	0.75	0.78	0.951	0.218	0.691	0.21
3	306	322	377	2289	1594	3180	2525	658	691	662	1024	1055	1066	0.83	0.81	0.86	1.056	0.221	0.528	0.209
4	305	321	375	2288	1593	3298	2601	700	716	706	940	968	978	0.82	0.78	0.85	1.059	0.222	0.467	0.235
5	303	319	373	2286	1591	3394	2657	739	754	744	922	944	960	0.91	0.85	0.93	1.153	0.225	0.391	0.252
											1020.6									0.2752
θ = 45° (laboratory)																				
6	4.3	6.6	5.5	13.5	17.9	40	31	9.5	9.8	9.6	17.31	17.6	20.2	0.51	0.55	0.79	1.303	0.23	0.652	0.352
7	4.5	6.8	5.8	15.4	19.2	42	32.2	10.3	10.6	10.5	16.98	18	19.6	0.58	0.59	0.87	1.275	0.239	0.633	0.377
8	4.7	7.1	6	18.1	21.1	44	33.6	11.4	11.6	11.5	17.64	17.9	20.4	0.75	0.84	1.01	1.389	0.242	0.517	0.312
9	4.7	7.4	6.3	19.8	21.7	45	34	12	12.3	12.2	18.92	19.3	21.1	0.81	0.85	1.03	1.38	0.258	0.451	0.325
10	5	7.7	6.5	24.7	23	47	35.5	13	13.3	13.1	20.39	20.7	22.3	0.95	1	1.23	1.493	0.261	0.243	0.347
											16,45									0.362
θ = 60° (laboratory)																				
11	4.1	5.6	6	13	17.7	40	29.3	11.2	11.5	11.4	17.39	18.8	20.4	0.45	0.51	0.77	1.032	0.274	0.611	0.448
12	4.4	5.9	6.3	14.6	18.8	43	31.4	12.1	12.4	12.3	17.48	19	20.8	0.52	0.55	0.82	1.035	0.276	0.489	0.441
13	4.5	6.2	6.5	17.4	20.1	45	32.7	13.3	13.6	13.5	18.85	20.2	21.1	0.65	0.67	0.93	1.152	0.286	0.314	0.444
14	4.6	6.5	6.8	19	20.2	46	33.4	13.6	13.9	13.8	19.92	20.9	22.5	0.68	0.71	0.96	1.154	0.289	0.234	0.426
15	4.8	7	7.1	23.8	22.6	48	34.5	15	15.3	15.1	21.24	21.8	23.7	0.89	0.94	1.16	1.285	0.31	0.125	0.403
											19,17									0.432

Note. exp. = experimental; calc. = calculated; Gavr. = Gavryukhin. The Gavryukhin columns reproduce comparison values carried over from the source manuscript.

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Using regression analysis, we model the relationship between flow variables, i.e., depth and width, as well as predicted values based on the model.

Results and Discussion

Statistical analysis was carried out within the limits of the obtained data, and as a result, the following equations were obtained (Figure 2):

$$\text{if } \theta = 30°, \quad y = 2.9514x + 1.5144;$$
$$\text{if } \theta = 45°, \quad y = 3.9323x + 1.8037;$$
$$\text{if } \theta = 60°, \quad y = 4.7265x + 2.012. \qquad (3)$$

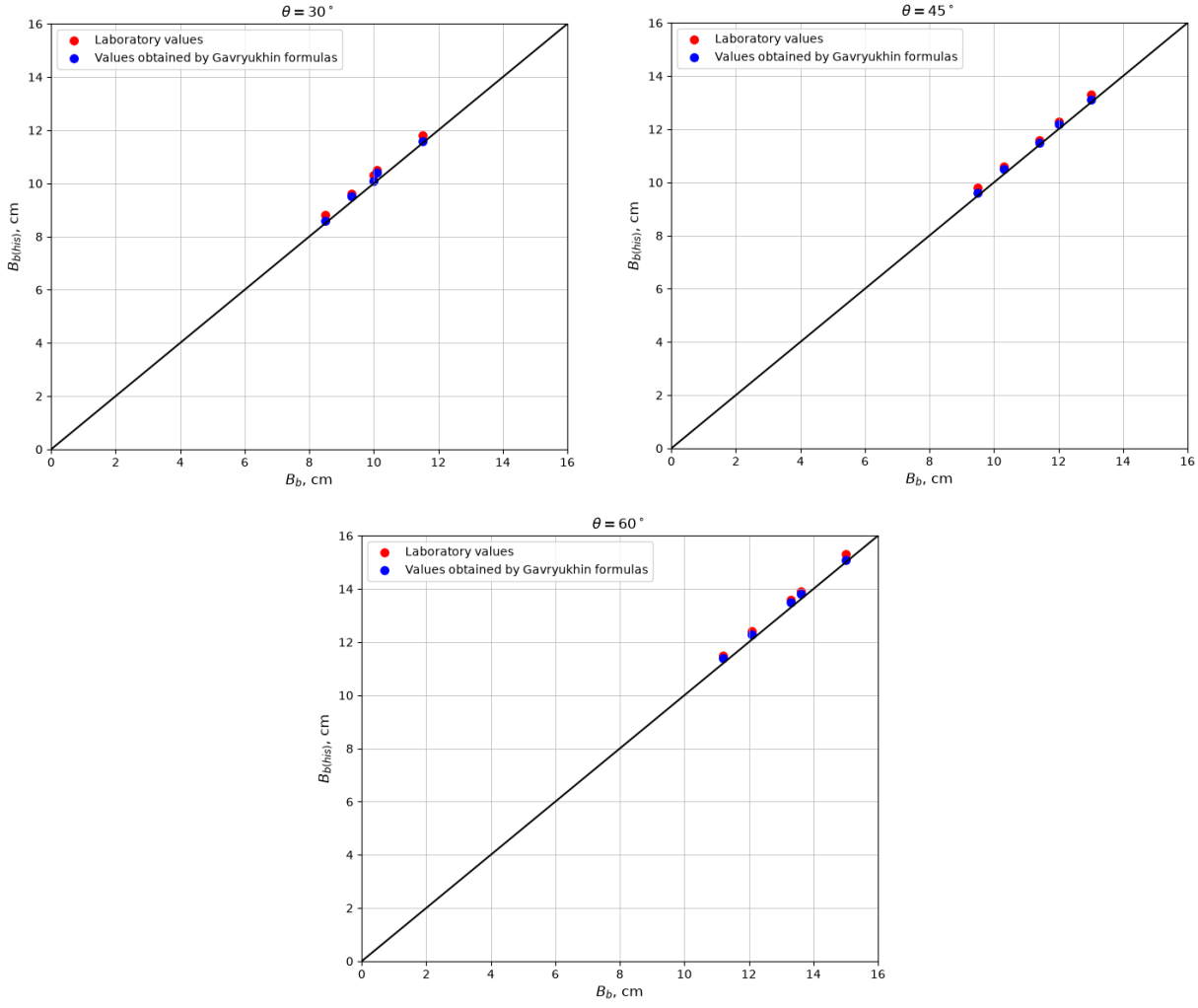
If we introduce the parameters $y = B_b/B_3$, $x = v_2/v_3$, and $\varepsilon = 0.25, 0.34, 0.43$ into these obtained equations (3), then these equations will take the following form, respectively:

$$\text{if } \theta = 30°, \quad B_b = 0.25B_3(2.95v_2/v_3 + 1.51);$$
$$\text{if } \theta = 45°, \quad B_b = 0.34B_3(3.93v_2/v_3 + 1.80);$$
$$\text{if } \theta = 60°, \quad B_b = 0.43B_3(4.73v_2/v_3 + 2.01). \qquad (4)$$

Using equations (4), it is possible to determine the width of the vortex field occurring in the merging zone (main channel 3) for junction angles $\theta = 30°$, $\theta = 45°$, and $\theta = 60°$ of the 2nd merging channel relative to the main channel 1.

Figure 2

Comparison of Calculated Vortex Widths With Laboratory and Gavryukhin Values



Comparison of the calculated values of the vortex width according to the obtained dependence (4) with the data obtained in the field, the values of mathematical modeling, and the values of the Gavryukhin dependence (Table 1) showed their similarity (Figure 2).

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Now let's consider determining the length of the rotation zone occurring in the flow addition zone. We will analyze the data of the laboratory experiment (Table 1).

From our side, we consider the following relationship between the parameters and velocities of the flow circulation zone, arising in the junction zone in the junction channels. We can express this relationship as follows:

$$B_b/L_c = f(v_2/v_3) \quad (5)$$

Let us construct the graph of this dependence (Figure 4).

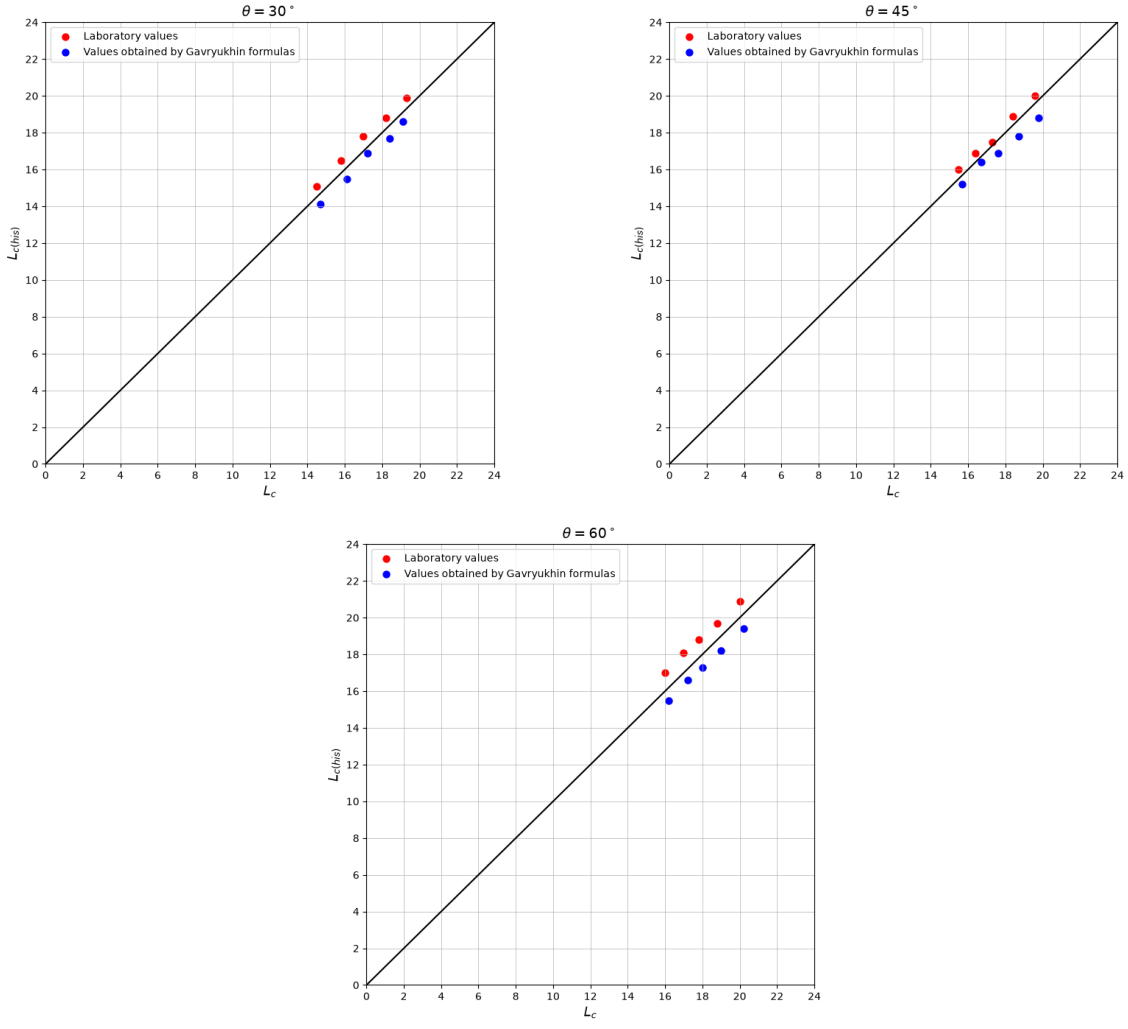
Based on the conducted regression analysis, the following equations for determining the length of the rotation zone were obtained:

$$\text{if } \theta = 30°, \quad L_c = B_3 / (0.27Q_2/Q_3 + 0.25);$$
$$\text{if } \theta = 45°, \quad L_c = B_3 / (0.27Q_2/Q_3 + 0.21);$$
$$\text{if } \theta = 60°, \quad L_c = B_3 / (0.19Q_2/Q_3 + 0.18). \quad (6)$$

Comparison of the calculated values of the vortex width according to the obtained dependence (6) with the data obtained in the field, the values of mathematical modeling, and the values of the Gavryukhin dependence (Table 1) showed their similarity (Figure 3).

Figure 3

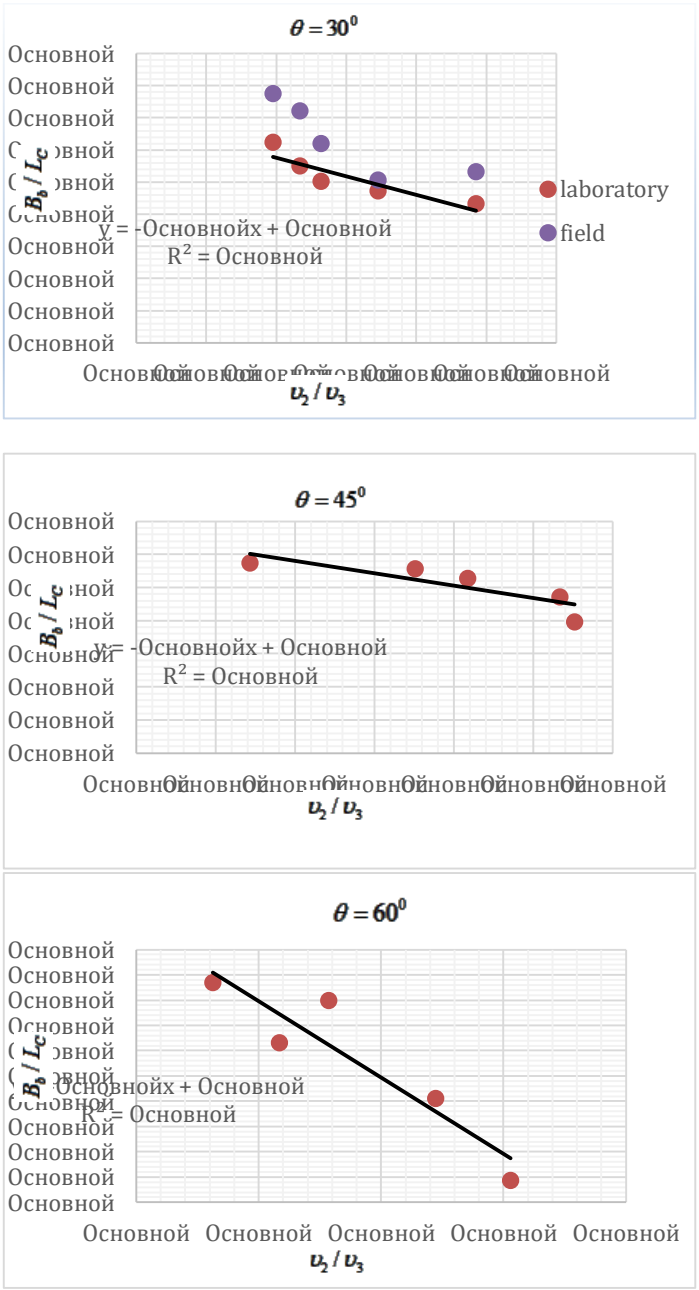
Comparison of Calculated Circulation-Zone Lengths With Laboratory and Gavryukhin Values



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Figure 4

Relationship Between Circulation-Zone Geometry and the Flow-Velocity Ratio at Junction Angles of 30°, 45°, and 60°



Comparison of the values of the length of the rotation zone, calculated according to this dependence, obtained under laboratory conditions and calculated according to Gavryukhin's formula, shows their similarity.

Conclusions

Flow junctions in earthen canals lead to the formation of a circulation zone that affects sediment transport and channel deformation.

- The width and length of the vortex zone depend on flow velocity ratios and junction geometry.
- Empirical equations were derived using regression analysis based on laboratory and field data.
- The calculated values showed good agreement with experimental results and existing formulas.
- The proposed relationships can be applied in hydraulic design and deformation forecasting of canal junctions.

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Consequently, the dependence of the parameters of the circulation zone, i.e., the width and length, on the flow velocity at the junction of open channel flows is important for assessing the hydraulic parameters and deformation properties of the transformed flow. Therefore, when calculating the parameters of the rotation zone occurring in the junction zone of the hydraulics of open channels, dependencies (4) and (6) can be used.

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