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CALCULATION OF FLOODPLAIN DAMS CONSIDERING PARTIAL DEVELOPMENT OF INTER-DAM SPACE

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Themonograph presents the existing scientifice approaches to studying research inthe interaction of riverbed and floodplain flows, regulatory structures, formulated then goals and objectives of further research, the methodology for conducting experimental studies, studied the results of experimental studies of constrained flow in the areas of support and compression, taking into account the development of inter-river floodplain space, a theoretical study of spreading patterns, An example of the calculation of dams, taking into account partof the potential development of inter-dam space, is given for a stream constrained by a system of dams.

The monographe was prepared based on the results of research in the frame work of the dissertation of Doctor of Philosophy (PhD).

It is of interest to undergraduates, researchers and specialists in the field of hydraulic engineering.

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Table of contents

PREFACE

The role of floodplains for the national economy has significantly increased in recent years. This is primarily due to their agricultural use. Floodplains, due to their proximity to fresh water sources at low material costs, are able to produce high yields. The energy use of rivers has significantly increased, which has raised questions about the formation and development of floodplains in the start-up mode of operation above located hydroelectric power plants, when floodplains are flooded only if catastrophic floods and floods are missed. The development of floodplain lands is carried out under the protection of regulatory structures such as transverse massive dams made of local material.

In the world, the development of methods and technologies for calculating and designing transverse dams, taking into account the development of inter-dam space, is of particular importance. In this regard, improving the methods of calculating and designing transverse dams on rivers with a one-sided floodplain, taking into account the impact of the development of river floodplain space and the presence of a dam system on the existing regime of regulated flow, is one of the most important tasks.

In this regard, one of the most important tasks is the development of technologies for revealing the regularities of a regulated flow that is one-sidedly constrained by transverse floodplain dams, determining the length of areas of support, compression and spreading, developing methods for calculating planned flow sizes, and establishing compression coefficients in plan and area.

When the dam interacts with the flow, intensive siltation of the inter-dam space is observed. In these areas, spontaneous and unjustified development occurs, which leads to a violation of the design regime of the regulated section of the river. The design of a system of regulating structures on a floodplain has its own peculiarities, which consist in the need to take into account the shape of composite sections, different roughness of the riverbed and floodplain. At the same time, the flood movement in riverbeds with a flooded floodplain is formed under the influence of the complex morphology of floodplains, kinematic and dynamic interaction of riverbed and floodplain flows. In this regard, the development of methods for calculating the justification of the flow constrained by the floodplain dam system during partial development of the inter-floodplain space is one of the urgent problems that has scientific and practical significance in the design of protective and regulatory structures, their construction and operation.

Inlarge rivers of the republic, measures are being taken to protect the banks from erosion and regulate the channels in order to create a guaranted water intake to irrigation channels.The Strategy of Actions for Further Development of the Republic of Uzbekistan for 2017-2021 sets out the following tasks: "... development of a network of reclamation and irrigation facilities, widespread introduction of intensive methods into agricultural production, primarily modern water-and resource-saving agricultural technologies, use of high-performance agricultural machinery"[1]. It is important to perform this task, which is aimed at improving the methods of designing and calculating the parameters of a one-way restricted regulated river flow with a wide floodplain for re-regulating riverbeds, protecting the new river bank from erosion, and for efficient use of floodplain lands.

This monograph serves to a certain extent to full fill the tasks stipulated in the Law of the Republic of Uzbekistan "On the Safety of Hydraulic Structures" (1999), the Strategy of Action on five priority areas of development of Uzbekistan in approved by the Decree of the President of the Republic of Uzbekistan UP-4947 of February 7, 2017, the Decree of the President of the Republic of Uzbekistan PP-3286 of September 25, 2017 Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 13 of January 21, 2014 "On approval of the Program for the stable and safe passage of water through watercourses of the Republic of Uzbekistan for 2014-2015 and for the future up to 2020", as well as in other regulatory documents adopted this year direction.

[1]Resolution of the President of the Republic of Uzbekistan PP-4947 dated February 7, 2017 "Strategy for further development of the Republic of Uzbekistan"

CHAPTER I.CURRENT RESEARCH ON THE INTERACTION OF RIVERBED AND FLOODPLAIN STREAMS ANDCONTROL STRUCTURES

1.1. Interaction of riverbed and floodplain streams

Riverbeds with floodplains are a special case of composite channels, the distinctive-feature of which is the presence of two or more streams moving at different speeds in parallel or at an angle to each other. When such flows interact, additional resist ancesarise that significantly change the flow capacity of these channels.

The interaction of floodplain and channel flows, the irregulation, and development of floodplain lands are discussed in the works of a number of authors [18, 20, 33, 34, 49, 60, 73, 93]. The problems of development of floodplain lands of the Chirchik River are covered in the work of F.Sh.Ishaeva[33]. On the basis of field studies, performed on the Oka River by S.K.Koryukin [40], the effectiveness of protecting floodplain lands from erosion is proved and a method for regulating floodplain flow using tree stands is proposed. The analysis of the problem of interaction between riverbed and floodplain streams, performed by N.B.Baryshnikov [20 Chapter 3], allowed us to develop a fundamentally new direction of research and calculation of the parameters of such flows [20 Chapter 4]. The determining influence of the morphological structure of the calculated area on the flow hydraulics in riverbeds with floodplains is revealed [20 chapter 5].

The analysis of experimental works is impractical due to their large number, and in some cases, the repetition of conclusions. Therefore, the main conclusions obtained in these works on the basis of experiments are given below:

-the main regularities of the interaction of riverbed and-riverbed flows with different roughness in width are revealed when their axes are parallel;

- with th ehelp of the developed typification [20], four types of interaction of riverbed and floodplain streams are distinguished, based on the difference between relative position of dynamic flow axes.

- the nature of the transformation of the channel flow velocity fields under the influence of floodplain flow and vice versa is established for each of the four types of interaction[1, 18, 20];

-various specific recommendations have been developed to take into account-the interaction of riverbed and floodplain streams when calculating the throughput-capacity of composite sections [1, 18, 20].

It is noted in [20, 67] that when water enters the floodplain, the movement within the main channel occurs with a variable flow rate along the path. This leads to a significant change in a number of hydraulic characteristics of the channel flow, in particular, the slope of the free water surface.

Numerous works by foreign authors are also devoted to the issues of interaction between channel and floodplain flows [53, 63]. Rajaratnam N., R.Ahmadi. [63] substantiate the affinity of the velocity field in the area of interaction between riverbed and floodplain flows.

W.R.Myers, E.K.Brennan [53] conducted comparative studies of the resistance to movement in channels of trapezoidaland composite with floodplains.

It was found that failure to take into account the interaction of riverbed and floodplain streams can lead to large errors.

Unique large-scale studies were conducted on the SERC flood channel in England by several groups of scientists WormleatonP.R., MerrettD.J. [89], Knignt D.W, Shiono K. [34] and Elliot S.C.A., Sellin R.H.J [25].

The laboratory set up is unique in its scale: 56 m long, 10 m wide, flowrate 1.1m^3/sec.

The first group offers calculated dependences for determining the throughput of the composite cross section and the stress in the interaction zone

$$Q=\alpha\left(H-h\right)^{\beta}+Q_{в},$$

where h, $Q_{в}$ are the depth and flow rate of the riverbed;

$H=h+h_n$ -total depth;

h_n - depth on the floodplain.

α,β - experimental coefficients depending on the type of schematization.

The second group of scientists [34] estimated the distribution of tangential stresses, the intensity of the channel and kinetic energy of the flow in the interaction zone.

The main difference between the work of the third group [25] is that the experiments were carried out under conditions when the dynamic axes of the channel and floodplain streams do not coincide. Calculated dependences for determining the longitudinal velocities and intensity of secondary flows are proposed.

Based on this, it can be concluded that hydraulic calculations of flows in complex cross-sections with water out put to the floodplain should be carriedout, taking into account the interaction of channel and floodplain flows, as well as the partial development of the interstitial space and its impact on the regulated flow regime.

1.2. Flow hydraulics at protective and regulatory structures

To protect the banks and regulate riverbeds, protective and regulatory structures of various designs are widely used in practice. Analysis of available data in the literature [6, 8, 28, 29, 30, 31, 32, 33, 46, 56, 66, 71, 79] information and generalization of the results of field observations and operation of protective and regulatory structures [4, 7, 27, 30, 38, 41] shows that one one of the most effective ways to protect the banks and create favorable conditions for turning a wandering section of the river into a normally meandering riverbed is through transverse dams built from local soil. In addition, in this case, there is a possibility of developingfloodplain lands.

The restriction of the riverbed by deaf protective and regulatory structures strongly violates the domestic flow regime. In the upstream, a backwater area is formed, while at a certain distance from the constraint target, the water level reaches a maximum, then the planned and vertical compression of the flow occurs, and at a certain distance below the constraint target, the maximum compression of the flow is observed, in the future, the water level gradually rises to the household horizons. In this regard, the interaction of flow and structure can be divided into three characteristic areas:

1.Area of support (from the constraint gate to the end of the support).

2.Compression area (from the constraint gate to the compressed section).

3.The spreading area (from the compressed section to the end of the whirlpool).

Below is a brief overview and analysis of works devoted to the study of the above areas in the interaction of flow with blind protective and regulatory structures.

1.2.1. Background

When calculating the backwater area, it is necessary to determine the size of the backwater, the length of its propagation, the flow plan and the length of the upper whirlpool zone. Solutions to these problems were consideredin the works of M.R.Bakiyev [9, 10], Abdulkarim S. Shihab [1], A.M.Latyshenkov [41, 42], and I.V.Lebedev [43, 44, 45, 46], V.N.Martensen [54], M.M.Chinnikov [60], K.S.Sharapova [84] and foreign researchers Y.Kozeny [39], H.Y.Tracy & R.W.Carter [72], the results of which are mostefully covered in the book by V.T.Chow [82], Messein Azinfar, James A. Kells [58].

The question of the size of the support before the construction is solved by different authors in different ways, depending on the nature of the research (fig. 1.1).

S.T.Altunin [6], determines the amount of backwaterin front of the coastal protection spur according to the dependence:

$$z = \xi \frac{v^2}{2g}, \tag{1.1}$$

where v - the average velocity of the incoming stream on the spur;

g - acceleration of gravity;

ξ-an experimental coefficient determined from the table, depending on the degree of constraint and the stage of local erosion atthe head of the structure.

The accuracy of determining the support in this case is small, but sufficient to assign a mark to the top of the spur. In the works of M.R.Bakiev [9], based on experiments conducted using the method of T.F.Avrova, the dependence for estimating the water level in the area of a deaf spur is established by constructing a longitudinal profile of the water surface in dimensionless coordinates:

$$\frac{h - h_{СЖ}}{\Delta h_u} = f\left(Sx/b_o\right), \tag{1.2}$$

where h-$h_{СЖ}$- the depth of water in the compressed section;

Sx - distance from the spur head in the longitudinal direction upstream to the target with a depth hx;

$\Delta h_u = U_{ЯС} /(2g)$ - high-speed pressure in the compressed section;

$U_{яс}$ - average speed in the compressed section;

b_o - width of the riverbed in the spur alignment.

The obtained dependence can only be used for a qualitative assessment of the level regime in the backwater area, since it does not include other factors that determine the level change. Todetermine the distance from the spur target to the maximum support target in [3,9], graphical dependencies are constructed in the form:

$$S/(B-b_o) = f(Fr_o, \alpha, n), \tag{1.3}$$

where B- the width of the riverbed in front of the spur;

$Fr_o = U_0^2 /(gh_o)$ - Froude number in the flow undisturbed by the spur;

U_o - average flow rate in domestic conditions;

h_o - flow depth in domestic conditions;

α - angle of the spur installation;

n - the degree of flow restriction over the area.

The obtained dependences did not take into account the roughness of the bottom and the curvilinear outline of the maximum support gate, as the authors themselves note, it was schematically assumed to be straight, which was reflected in the results obtained.

In [21], the authors propose to define the support in front of a massive spur for the purpose of assigning the top of a non-flooded structure by the usual expression:

$$z = v^2 /(2g), \tag{1.4}$$

where v -the average vertical speed in everyday conditions.

This issue is covered in more detail by the authors who have studied the capacity of bridge crossings and the kinematics of the flow near lintels and semi-dams. I.S.Rotenburg [64] studied the most widely backwater that occurs in front of bridge crossings.He found that the target with maximum backwater has a curvilinear

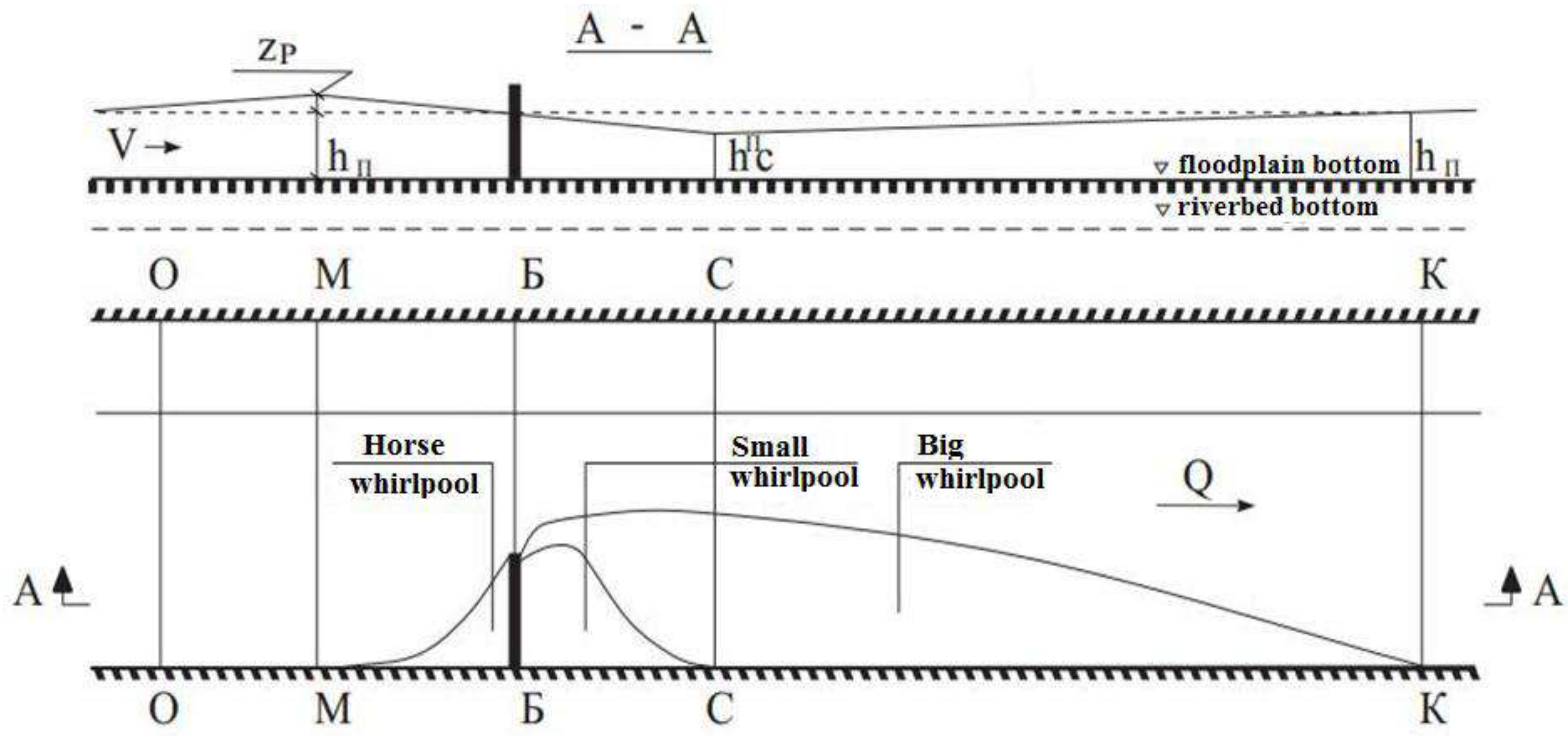

Fig. 1.1. Scheme of flow around the dam

О_О - The point where a noticeable change in the velocity field begins

М_М - Maximum support target

Б_Б - Target of constraint

К_К - The end of the whirlpool

МБ - Backup area. БС - Compression area. СК - Spreading area shape along the width of the river, and proposed an elliptical relationship to determine the location of this target. He found that the target with maximum backwater has a curvilinear shape along the width of the river, and proposed an elliptical relationship to determine the location of this target:

$$s = B\left(\sqrt{\frac{Fr_б}{i_\delta} + \frac{Fr_o}{i_\delta}}\right), \tag{1.5}$$

where $Fr_б = v^2/(gB)$ - the flow Froude number;

i_δ - the longitudinal slope of the free surface in domestic conditions.

The relationship shows that the distance between the compressed cross-section andthe maximum backwater target S increases with increasing flow width B, incoming flow v, and with decreasing slope of the free surface i_δ. To determine the backstop, the author obtained the following dependency:

$$h_H = Dh_\delta + \frac{B_i}{2}\delta\sqrt{\frac{Fr_б}{i_\delta}}\left((Q/Q_M)^2 + 1\right) + v^2/g\ , \tag{1.6}$$

where h_δ -the total flow depth;

$$D = \frac{Fr_б}{2}\left((Q/Q_M)^2 - 1\right);$$

$Fr_б$ - the Froude number of the household flow;

Q- total consumption;

Q_M -the flow rate that occurs on the blocked partof the streambed undernatural-conditions.

Comparison of the calculation results with the data of field and laboratory studies, given by the author, shows good convergence.

In the works of M.M.Ovchinnikov [59, 60], the results of extensivestudies of semi-dams in channels of increased roughness are presented, taking into account the following flow characteristics and limits of their change: bottom slope $i = 0.0045....0.0015$; Shesi coefficient C=15...30; relative depth $h_o/h_K = 1.3...2.3$ (h_K - critical depth); Froude $Fr = 0.10...0.42$; degree of constraint *n*=0.2...0.7 and the angle of setting the spur relative to the SKIPIF flow =30^0...60^0.

Dependencies are obtained for determining:

-distances fromt he upperedgeof the half-dam to the section with maximum support

$$S = (0.25...0.3)\ b_o + l \sin\alpha, \qquad (1.7)$$

where l - the length of the half-dam.

- length of the support curve

$$S_n = (14...16)\ (B - b_o)\ , \qquad (1.8)$$

- the depth of water in the maximum backwater alignment

$h_1 = h_o + Z_{max}$

where $Z_{max} = (1.03...1.05)\ (h_2 - h_0)$;

h_2 - the water depth in the constraint section is determined by graphic dependencies.

A.M.Latyshenkov [41] suggests calculating the amount of backwater in the riverbed when the floodplain flow is constrained by embankments of bridge crossings using the formula obtained by solving the equation of change in the amount of movement for the liquid compartment enclosed between the compressed section and the maximum backwater gate (with disregard for friction forces and assuming a hydraulic pressure distribution over the flow depth). In this case, the formula that took into account the redistribution of velocities in the riverbed and on the floodplain in a compressed section without taking into account energy losses due to hydraulic resistances has the form:

$$Z_p = D\frac{\alpha v_1^2}{2g}, \qquad (1.9)$$

where $D = 2\delta(1 - \tau - \tau/\alpha_0)$; $\alpha_0 = v_n / v_p$;

$\delta = Q_{nep}/Q$ - flow constraint by flow rate;

Q_{nep} - consumption on the blocked part in domestic mode;

Q - total consumption;

$\tau = Q_p / Q$ - relative flow rate of the riverbed;

Q_p - flow rate in the channel;

v_1 - average speed in the compressed section;

v_h - average speed in the channel (household) ;

v_n - average speed on the floodplain (domestic);

$\alpha = 1.05$ - correction of the amount of traffic.

I.V.Lebedev [46] suggests determining the amount of support at lintels by the formula:

$$z = (\bar{i} - i_\delta)(K_{bx} b + L_b) + (i_n - i_\delta) L_2 + \theta^2 \frac{v_1^2}{2g}, \tag{1.10}$$

where $\bar{i}, i_\delta$ - are the average friction slopes, respectively, for the input section andspreading areas;

K_{bx} - input coefficient;

$K_{bx} = 1.0$ when $Q_{nep} / Q < 0.8$;

K_{bx} = 0.5 for $Q_{nep} / Q > 0.8$;

L_b - length of the bottom whirlpool;

L - length of constraint structures along the river;

v - average speed in the channel.

The author suggests calculating the friction slopes based on the following dependencies:

$$\bar{i} = \sqrt{i_\delta i_n}, \tag{1.11}$$

where $i_б = v_б / (C_б R_b)$; $i_n = v_n / (C_n R_n)$;

$v_б, v_n$ - average velocities of the flow undisturbed by the structure and inthe channel;

C_b,C_n- Chi coefficients;

R_b,R_n- hydraulic radii.

The dependence for determining the distance from the top edge to the maximum support gate is given:

$$S = Rb_x - b_o \tag{1.12}$$

The disadvantage of the proposed dependences is the occurrence of unknown planned flow sizes in the spreading region, and the range of their applicationis limited by the conditions of the experiments performed.

A review of works, that consider the upper whirlpool zone in front of the structure shows that, according to V.M.Seleznev [68], the upper whirlpool zone near the half-dam is formed due to a gradual decrease in the flow rate and an increase in pressure along the studied shore. At a certain point, the slope of the free water surface turns to zero, and slightly below this point, the current velocity near the shore also becomes zero, which corresponds to the point of separation of the boundary layer of the water jet from the shore (beyond this point, the reverse flow velocities). In this case, the separation point in front of the half-dam is observed at a distance $l$of l=(1.3...0.6)l_n, depending on the degree of flow restriction n=0.2...0.75, where l_n-the length of the half-dam located perpendicular to the shore.

V.V.Balanin and V.M.Seleznev [19] propose experimental dependences for determining the parameters of the whirlpool in front of channel- limiting structures. The length of the upper whirlpool zone along the shore is determined here by the graph of the dependence l_1/B=f(l/B,α), and the maximum distance of the whirlpool boundary from the shore is calculated by the formula:

$$l_2 = 0.67\ l\ \frac{l}{60}(\alpha - 30)\ , \tag{1.13}$$

where l-the length of the dam

K.S.Sharapov [84], taking the value of the flow backwater at the root of the spur equal to the average velocity head of the stream running on the spur, assumed that the length of the whirlpool l_1 equal to the length of the backwater, and proposed the following dependencies:

$$l_1 = \frac{v^2 \delta}{2g\, i\delta}\left(\frac{2-n}{2(1-n)}\right) \tag{1.14}$$

$$\frac{l_2}{l_1} = \frac{0.444 - 0.0351\ \alpha_ш^2}{1 - 0.143\alpha_ш^2 + 0.0069\alpha_ш^4}\ , \tag{1.15}$$

where $\alpha_ш$ - the angle of inclination of the spur to the flow, rad.

This assumption, however, somewhat contradicts the opinion of the authors of the above-mentioned works, who believe that the jet breaks off from the shore when the pressure reaches a certain value, and not at the beginning of the backwater.

According to M.R.Bakiev [9], the total length of the support is determined by the dependence:

$$L_n = l_n + S, \tag{1.16}$$

where S - the distance from the head of the spur to the target of the maximum support, determined by graphical dependencies;

l_n -length of backwater propagation.

To determine l_n, the motion quantity equation is applied.

Hossein Azinfar, and James A.Kells [58] study the flowresistance of a single damin an open channel.Arecord would be used as the ladies. The experiment was carried out on a non-removable model, it is established that the main factor leading to an increasein the coefficient of resistance - the degree of tightness of sweato. Based on experimental studies, the amount of backwater at a single dam was estimated.

In the book by W.T.Chow [82], the issue of determining the backwater constrained by transverse dams, carried out by H.Y.Tracy, R.W.Carter [72] in the US Geological Survey, is described in detail.

Ananalytical dependenceis proposed for determiningthe flow rate through a compressed cross section

$$Q = RW_{III}\sqrt{2g(\Delta \mathrm{h} - \mathrm{h}_{\mathrm{TP}}) + \alpha_1 \frac{v_i^2}{2g}},$$

where $\Delta \mathrm{h} = \mathrm{h}_I - \mathrm{h}_{III}$; *R*-the total coeffican dunt of the flow $R = K' K_{Fr} K_r K_W K_P K_h K_x K_e K_t K_j$

Graphical dependencies were developed to calculate individual coefficients. At the same time, the authors suggest the influence of the shape of the cross-section on the coefficient of support and compression ratio. In our case, when there is a one-sided floodplain, as wellas part of its development, additionalresearch is required.

The disadvantages of the proposed methods for calculating the upper whirlpool zone are: limited application due to the conditionsof experiments; neglect of the influence of the roughness of the channel, the coefficient of laying the slopes of spurs, uneven distribution of the speed of the incoming stream over the cross-sectional area; lack of floodplain, lack of accounting for partial development of the floodplain.

1.2.2. Compression area

a. Planned and vertical compression, area length

In the case of a detached flowaround the contracts, the flow is compressed both in the plan and in the vertical plane, which is estimated by the coefficients of planned, vertical andspatialcompression. The planned compression ratio is defined, as the ratio of the width of the transit flow in the compressed section to the width of the flow in the tightness $(E = b_T / b_o)$, and the vertical compression ratio ist he ratio of the depth in the compressed section to the domestic flow depth ($Eb_B = h_{СЖ} / h_Б$).The spatial compression ratio is compression ratio is determined by the ratio of the area of the transit flow in the compressed section to the area of the flow in the constraint $(\mathrm{E}_n = \omega_T / \omega_O)$. This coefficient can also be expressed as: $E_n = E\,E_B$.

In contrast to them, A.V.Garzanov [24] solved a system of differential equations of potential fluid motion:

$$\left.\begin{array}{l} \frac{\partial}{\partial x}(h\,vx) + \frac{\partial}{\partial y}(h\,vy) = 0 \\ \text{(continuity equation)} \\ \frac{\partial\,vx}{\partial \mathrm{x}} - \frac{\partial\,vx}{\partial y} = 0 \\ \text{(equation for the absence of vortices in a} \\ \text{non-separated flow)} \end{array}\right\}, \tag{1.17}$$

where $h=h(x, y)$- the flow depth at the point with x and y coordinates.

v_x, v_y - projections of the average velocity on the coordinate axes.

The joint solution of this system and the Bernoulli equations written with allowance for energy losses due to friction allowed the author to obtain the equation of non-uniform motion, taking into account changes in potential energy along the flow and energy losses due to additional hydraulic resistances. As a result of solving this equation using the Kirchhoff-Chaplygin method, the dependences for determining the flow depth in the upstream half-dam and in the restriction section, the outline of the boundary current line at the structure, and the planned compression coefficient are obtained. The solution was obtained for the case when the maximum planned and vertical compressions coincide. The planned compression ratio, according to A.V.Garzanov, is determined by the dependence:

$$E = b_c / a = 1 \Big/ \left(2\frac{\pi}{\theta}\sqrt{M_o y}_{\max}(1-\delta_{CЖ}) + 1 \right), \tag{1.18}$$

$$M = (1-3\delta)/(1-\delta)^3; \quad \delta = \frac{\Delta h + v_0^2/(2g)}{Э_0(1+r)}; \quad r = \frac{m_o - m}{Э_0},$$

where b_c- width of the compressed number;

a - the largest reversal of the current line;

θ- the largest angle of the current line reversal.

$y_{\max}$ -dimensionless coordinate corresponding to the largest turn of thetreamline;

M_o-the average value of the function M along the current line under consideration;

$\Delta h = h_Б - h$- the depth difference along the selected vertical with uniform and uneven traffic;

$Э_o$- the specific energy in the initial cross-section;

$v_o v_2$ - approach speed;

$m_0 - m$- difference of the watercourse bottom marks measured in the transverse direction to the flow axis.

The author did not complete his solution and did not obtain numerical values of the compression coefficients, which makes it difficult to draw specific conclusions from his proposed solution. In addition, the accuracy of determining the compression ratio from the proposed dependence largely depends on the accuracy of determining the angle of rotation of the stream line, which varies with the depth of the flow.

Numerous experimental studieson aerodynamic models for determining the compression ratio for the flow constraint scheme with jumpers are covered in the works of I.V.Lebedev [44, 45, 46]. According to the following characteristics of the flow and structure: the degree of constraint over $\Omega/\omega = 0.25...0.60;$the Froude number in the undisturbed flow $Fr_o < 0.01$; the angle of inclination of the upper face of the bridge to the flow $60^0...90^0$; the Shezy coefficient C=40...65; relative radius of curvature of the top face of the lintel $R/b_o > 0.2$.

The author proposed a new characteristic of flow constraint and called it flow constraint by momentum:

$$n_{КД} = \theta \sigma_n^2 \sin \alpha \,, \tag{1.19}$$

where $\sigma_n = \dfrac{C_n \sqrt{R_n}}{C\sqrt{R}}$;

C_n- the Chi coefficient for the flow;

C-the Shezi coefficient for the entire riverbed;

R_n - hydraulic radius of the channel;

R-the hydraulic radius of the riverbed.

The author established the dependence of the compression ratio for jumpers, noting that the given formulas are approximate and valid only under the conditions of the experiments carried out:

$$E = 1 - 0.25\theta_{КД} \text{(with rounded upper edge)} \tag{1.20}$$

$$E = 1 - 0.60\theta_{КД} \text{(with non-rounded upper edge)} \tag{1.21}$$

A.M. Latyshenkov [41]offers a graph of the dependence for determining the spatial compression coefficient in riverbeds with floodplains $E=f(Q_{per}/Q)$, where Q_{per}- the domestic flow rate of the blocked part of the floodplain; Q-the total flow rate. The established dependence is in good agreement with the experimental data of T.F.Avrova [3], which were obtained taking into account the Froude number and-the hydraulic friction coefficient within a wide range of their variation $(Fr_o = 0.05...0.95; \lambda = 0.005...0.20)$.

M.R.Bakiev [9] suggests determining the coefficient of planned compression of a stream constrained by a coastal protection spur using the empirical formula:

$$E=1-0.29\sqrt{n_{КД}} \tag{1.22}$$

where $n_{КД}$- the constraint on the amount of movement, determined by the dependence (1/19).

The values calculated using this formula are in good agreement with the results of calculations for other dependences proposed in [43].

I.V.Lebedev [45, 46] proposed a method for determining the depth in a compressed section ($h_{сж}$), which is based on applying the Bernoulli equation to the fluid compartment enclosed between the compressed section and the section with maximum back-up. The method took into account energy losses in the selected area. As a result, the author obtained an equation written with respect to the dimensionless value $\zeta_c = h_{сж}/h_к$, where $h_к$ the critical depth:

$$\zeta_o = \zeta_C + 1/(2\mu^2\zeta_c^2(1-\theta)^2) \tag{1.23}$$

where μ - the flow rate coefficientdetermined from empirical dependences.

$\zeta_O = T/h_к; T = (h_б + z' + iLc)$;

T-the specific potential energy in the alignment of the maximum support;

z'- the amount of backwater;

$Lc = KB+L_2$-distance from the upper edge of the jumper to the compressed section;

L_2 - the length of its longitudinal face;

K=1.1 for θ<0.8; K=0.5 for θ>0.8.

For convenience, we constructed graphs in the form $\zeta_O = f(\zeta_c, \mu, \theta)$.

M.M.Ovchinnikov [59, 60]presented a hydraulic method for calculating the depths of a calm stream constrained by a semi-dam in channels with significant bottom slopes and increased roughness. The calculated expression that allows us to determine the depth of flow in the alignment of the maximum vertical compression, while neglecting the wall resistance, has the form:

$$\frac{\theta}{g}\left(\eta\frac{\alpha_{05}}{b_3h_3} - \frac{\alpha_{06}}{Bh_0}\right) = \frac{Bh_0^2}{2} - \left(\frac{b_3h_3^2}{2} + \frac{b_Bh_3^2}{2}\right) - \frac{1}{2}K(h_3 + h_0)S_3B_{io} + \frac{\lambda_cQ^2\left(\frac{1}{B_3h_3Bh_0}\right)^2(B+b_3)S_3}{16\ g} \tag{1.24}$$

where b_3, h_3- the width and depth of the transit flow inthe maximum vertical compression channel;

$b_В$, h_3- width and depth of the flow within the whirlpool;

h_0- normal depth at the end of the whirlpool;

α_{o5}, α_{o6}- adjustments to the maximum amount of traffic, in swaps compression and end of the whirlpool;

η, K - experimental coefficients.

The expression is obtained by applying the equation of change in the amount of movement to the fluid compartment between the maximum vertical compression valves and the end of the whirlpool. The formula can only be used if the planned size of the whirlpool is known.

On the basis of numerous experiments, I.S.Rotenburg [64] found that the relative pressure drop (a_i) and the relative drop of the free surface (b_i) for a given planned outline of the bulkhead are a constant value that does not depend on the hydraulic parameters of the flow around the bulkhead:

$$\alpha_i = \frac{T - P_i / \gamma}{Z_0} = Const \tag{1.25}$$

$$b_i = \frac{T - P_i / \gamma}{Z_0} = Const, \tag{1.26}$$

where *T*- the mark of the free water surface in the upstream;

Pi, h_i - bottom pressure and flow depth at the planned point;

Pi, h_i -coordinates x_i,y_i.

This conclusion is valid, as the author noted, in the region characterized by the following relation: $0 < Z_o / t < 0.25$. The author obtained plans with isolines of hydraulic characteristics α_i , b_i, as well as graphs of changes in these parameters along the side walls limiting the flow for various schemes of flow restriction by jumpers. These characteristics were used to solve the following tasks:

establishing the shape of the free surface;

b. calculation of values of surface and bottom velocities in the area of the bridge;

b. building a flow plan;

d. approximate calculation of fastenings of various types in the area of the upper edge of the lintel.

The flow depth can be determined by the following relationship:

$$h_i = T - b_i Z_o \tag{1.27}$$

The results obtained by the author are applied to channels of rectangular cross-section with uniform roughness.

To determine the depth in a compressed section, M.R.Bakiev [9] used the I.V.Lebedev dependence for a flow constrained by a bank protection spur, by applying the Bernoulli equation to a liquid compartment enclosed by a water barrier. between the upper whirlpool gate and the compressed section:

$$Z = \frac{\alpha_c}{2g}\left(\frac{q}{E\ b_o\ h_c}\right)^2 + h_i - \frac{\alpha_{bc}}{2g}\left(\frac{q}{BH}\right)^2, \tag{1.28}$$

where Z - the water level difference between the design gates.

h_i - head loss along the length;

H - depth in the upstream;

h_c - the average depth in the compressed section;

α_c=1.05, α_{bc}=1.10 - motion adjustments set by the experienced driver by;

E - the compression ratio determined from the dependence (1.22).

M.R.Bakiyev found that the gates with the maximum planned and vertical compression coincide if the degree of flow restriction in the plais not *n=0.1...0.35*, and the Froude number in the compressed section Fr = 0.01...0.35 and the slope of the river bed is less than 0.0003. If any of these conditions is not met, then the location of these alignments does not match.

In the work of A.M. Latyshenkov [41], as a result of experimental studies, it was established that the distance from the upper edge of the structure to the compressed section *Lcc* can be taken equal to (2.5...3.0)*a*,

Where, $a=b_o-b_{TC}$; b_{TC} - the width of the transit flow in the compressed section.

M.M.Ovchinnikov [60] suggests an empirical relationship for determining the value of *Lcc*, expressed in fractions of the length of the whirlpool zone, the error in determining which exceeds the limits of the change in the desired distance.

M.R.Bakiyev confirms the conclusions obtained by some authors that the Froude number has almost no effect on the *Lcc* value and provides graphs $Lcc/b_o=f(n)$ applicable to coastal protection spurs.

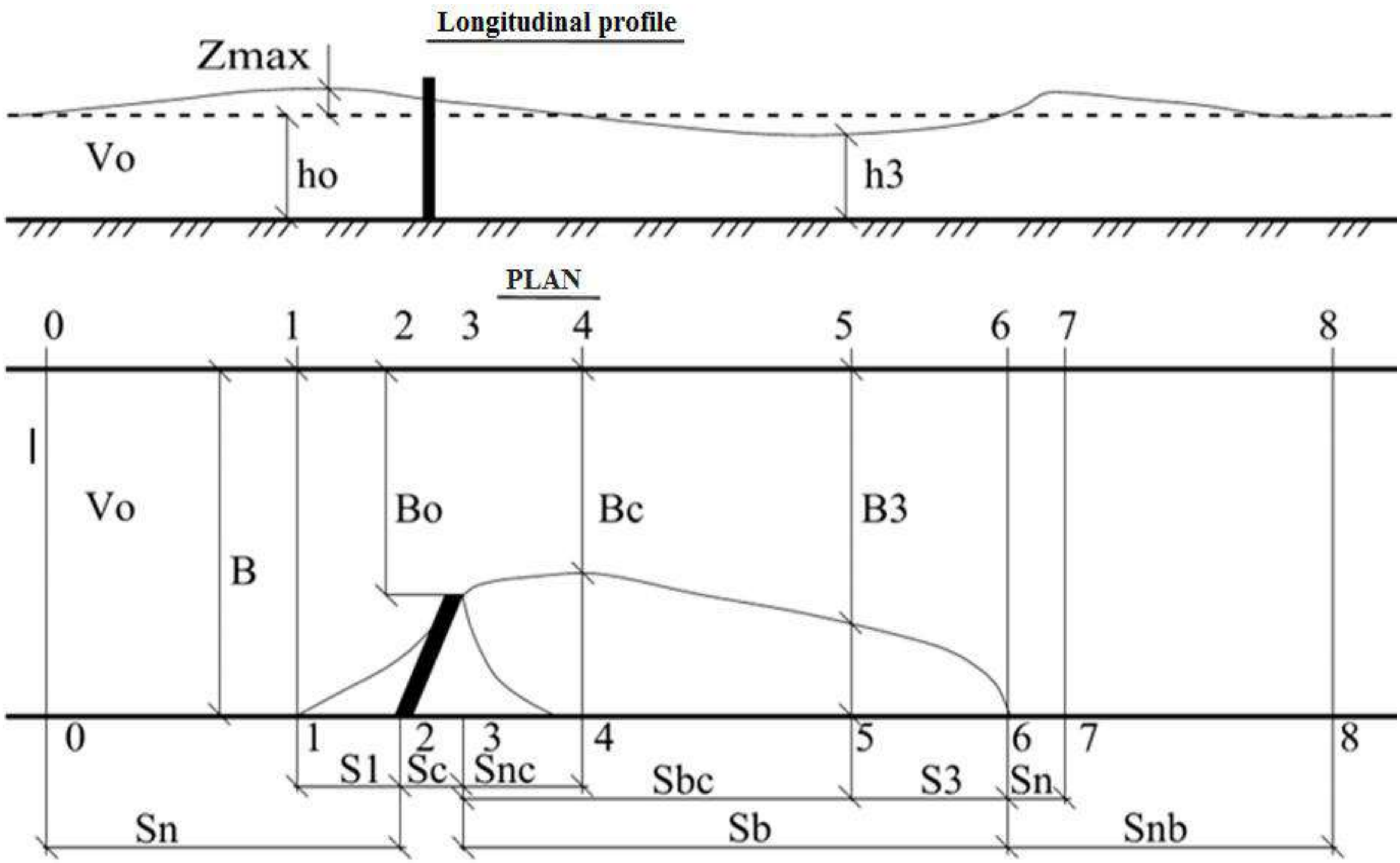

Fig. 1.2. Design scheme according to M.M.Ovchinnikov

b. Calculating the velocity field and plotting the flow plan

The calculation of the velocity field is considered the main task in the design of protective and regulatory structures. Knowing the velocity field of the flow, it is possible to predict the deformation of the channel in the area of the structure and take the necessary measures to protect the structures from destruction.

A number of works are devoted to this issue, which are based on thetheory of plane potential motion of an ideal fluid. Among them, we should highlight the work of V.V.Balanin [19], where a method for constructing the velocity field with an uneven velocity distribution in the initial alignment is proposed. The author applied the equatione proposed by I.M.Konovalovbased on the theory of free turbulent jets:

$$\nu^2 = \frac{1}{2\gamma y\sqrt{\pi}}\int \Phi(\alpha) e^{\frac{(\alpha-x)^2}{4\gamma^2\gamma^2}} d\alpha \ , \qquad (1.29)$$

where γ = 0.0351...0.0469 - experimental coefficient;

x,y- coordinates of the point under study;

$\Phi(\alpha)$-a function of the initial velocity distribution.

The author also applied a parabolic dependence

$$v = v_b\sqrt{c+y^2}d \ , \qquad (1.30)$$

where *v* - the average vertical speed;

C = $(v_c/v_b)^2$; $d = (\nu_c^2 - \nu'^2_c)/(\nu_o^2 a^2)$

v_{vc}- scab in the compressed section;

$\nu_c^{'}$- speed inthe restricted area on the bank opposite the structure;

a - width of the flow in constraint.

The calculation results are represented by graphs of the-relative velocities ν_c/ν_b and $\nu_c^{'}/\nu_b^{'}$ depending on the degree of constraint and the angle of inclination of the upper face of the structure to the flow. The calculation by this method leads to rather significant errors, which is explained by the application of the theory of plane potential motion of an ideal fluid to a real flow.

In the works of T.F.Avrova [3] and M.R.Bakiev [29], based on experimental studies, more accurate solutions were obtained in this area, where the flow from the construction target to the end of the whirlpool is divided into homogeneous hydraulic zones:

a. a weakly disturbed core;

b. intensive turbulent mixing;

b. reverse currents.

The boundaries of these zones are determined experimentally in the form of graphs and calculation formulas. It was found that the velocity distribution in any alignment fromthe upper edgetothe compressed sectionalong the core width-is satisfactorily described by the parabolic dependence:

$$U_{Я} = \sqrt{U_{\min}^2 + (y/b_{Я})^2 (U_{\max}^2 - U_{\min}^2)}\,, \tag{1.31}$$

where: $U_{Я}$ - average speed on the *i*-th vertical in this section;

y-ordinate *i*-of the vertical line;

U_{max}-the maximum velocity in the section under consideration, which is formed at the boundary of the weakly disturbed core and the zone of intense turbulent mixing;

U_{min}-the minimum speed in the considered alignment, which is formed at the bank opposite the bridge;

$b_{Я}$- the width of the weakly perturbed kernel.

Numerical values U_{max}, U_{min} are determined from graphs.

In the zone of turbulent mixing, the velocity distribution is assumed according to the Schlichting-Abramovich dependence:

$$\frac{U - U_n}{U_{\max} - U_n} = (1 - \eta^{3/2})^2, \tag{1.32}$$

where *U*-the speed at a given point in the zone;

U_n -reverse speed;

$\eta = (y - y_1)/b$- the relative ordinate of the point where you definespeed;

b-the widthof the zone of intense turbulent mixing-calculated from the experimental dependence.

Changes in the direction of the velocity vector were considered in the work of M.R.Bakiyev, and based on the analysis of experimental studies, a graphical dependence was obtained for determining the direction of the velocity vector in the zone of a weakly perturbed core. Then the distribution of the longitudinal component of the velocity vector over the width of the weakly perturbed core obeys the dependence

$$U_{np} = \sqrt{U_{min}^2 + (y/b_Я)^2\left((U_{\max}\cos\varphi_{cp})^2 - U_{\min}^2\right)} \qquad (1.33)$$

using formulas (1.33) and graphs based on experimental data, the author managed to construct a flow plan in the compression region without successive approximations.

1.2.3. Spreading area

a. Calculating the velocity field and plotting the flow plan

In the downstream part of the structure, the transit flow begins to expand beyond the compressed cross-section. In this case, the velocities change not only along the flow and along its depth, but also in the transverse direction. The problem of calculating the velocity and pressure fields of an expanding flow is often encountered in hydraulic engineering, which is why the literature studies of this issue are so extensive and diverse.

The theoretical solution of the planned problem of expanding flow was obtained in the work of N.M.Bernadsky, but it did not take into account the tangential stresses on the side surfaces of the jets. This drawback was eliminated in the works of I.I.Levy [47], where turbulent tangential stresses were taken into account according to the formula of L.Prandtl:

$$\tau = \rho\varepsilon\frac{\partial U}{\partial n}\ , \qquad (1.34)$$

where ε - the kinematic coefficient of turbulent viscosity;

U-the projection of the averaged velocity on the tangent to the current line;

n - normal to the current line.

The planned problem was further developed in the method of V.V.Balanin-planes in the direction of flow with the dependence:

The first of them is based on the application of the theory of free turbulence. Average turbulent shear stresses in the vertical

$$(\tau_{xy})_{cp} = \rho a_\kappa^2 x\frac{\partial U^2}{\partial y}\ , \qquad (1.35)$$

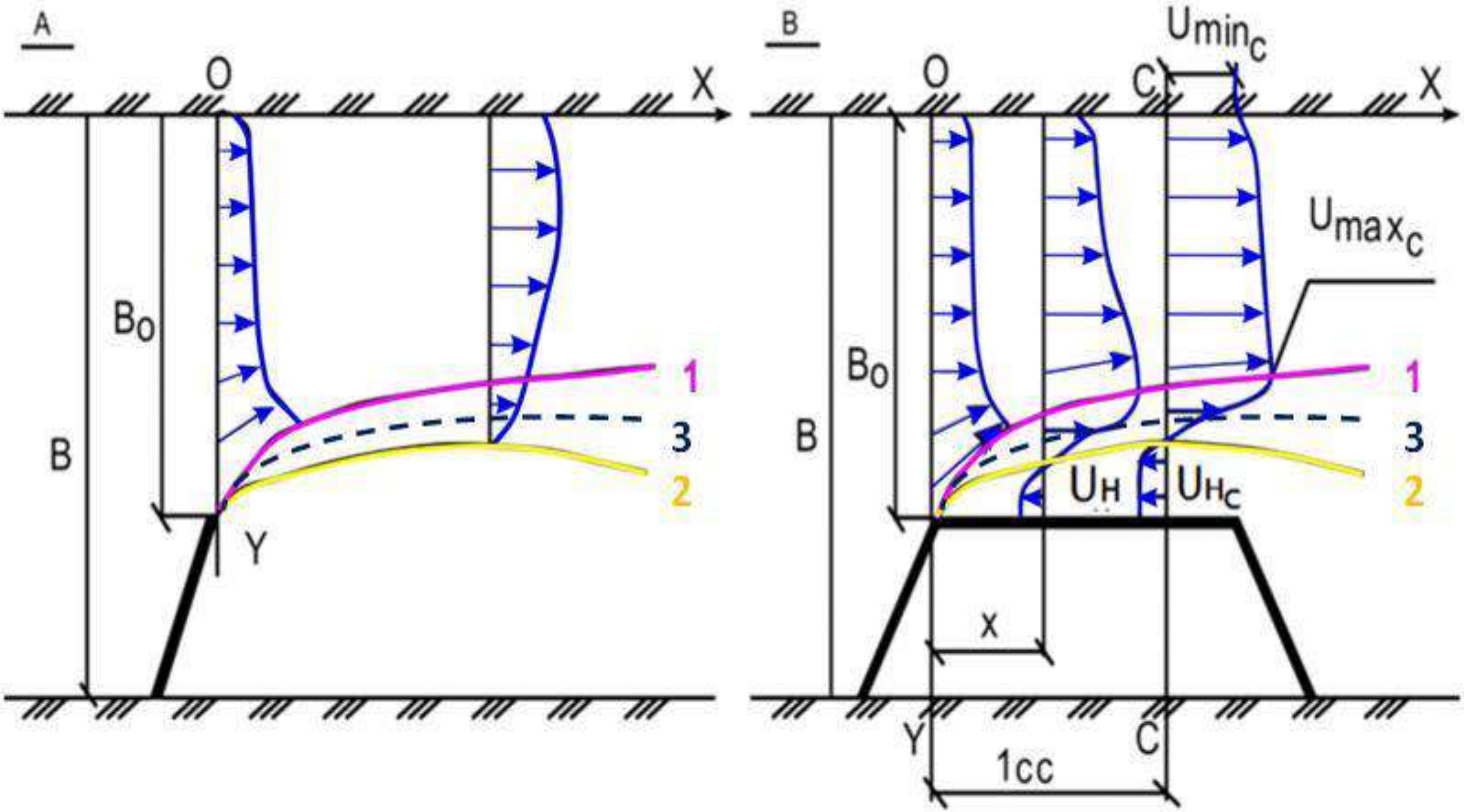

Fig. 1.3. Schemes for calculating the velocity field in the compression region.

A.Calculation scheme of V.V.Balanin.
B.Calculation scheme of T.F.Avrova.

where a_k - the empirical coefficient;

x, y-coordinates, respectively, along and across the directionstream flows;

U -the vertical-averaged speed.

The equation of motion in projections on the longitudinal axis under the condition $V < U$ is taken as:

$$U\frac{\partial U}{\partial x} = gJ_x - g\frac{U^2}{C^2h} + a_K^2 x\frac{\partial^2 U}{\partial y^2}, \tag{1.36}$$

where U -projection of the vertically averaged velocity onto the x-axis; $J_к = \frac{\partial h}{\partial x}$;

$h = h(x)$;

C-the Chi coefficient.

If the bottom is horizontal after integration, this equation is converted to the following expression:

$$U^2 = \frac{EXP\left(\frac{-2gx}{C^2h}\right)}{2\sqrt{\pi}a_K x}\int_{-}^{+}\Phi_o(\alpha)EXP\left(-\frac{(\alpha - y)^2}{4a_K^2x^2}\right)d\alpha - 2g(h - h_o), \tag{1.37}$$

where$\Phi_o(\alpha)$ -a function that takes into account the velocity distribution in the inputcross-section;

h_o - depth in it;

α - integration variable.

To construct the flow plan, equation (1.39) is solved together with the continuity equation by the method of successive approximations. The value of $C\ h$ is constant over the length of the section and is equal to $C^2\ h_o$.

V.V.Balanin and V.M.Seleznev proposed an approximate method for constructing a plan for a breakaway flow in a channel with an arbitrary bottom shape. The method of I.M.Konovalov [85], used in the work of A.A.Shikshnis[86], despite cumbersome calculations, takes into account the influence of the initial nonuniformity of the velocity distribution on the character of flow expansion. The disadvantage of this method is that the influence of channel resistance is not taken into account explicitly, the length of the whirlpool zone is determined after calculating the velocity field for the entire spreading section, and the results are refined by an experimental coefficient.

The method of M.A.Mikhalev [55] uses the solution of G.N.Schlichting for a plane turbulent wake of a body moving in a liquid.

The tangent stress here is determined by the formula of L.Prandtl:

$$\tau_1 = \rho l^2 \left| \frac{\partial u}{\partial y} \right| \frac{\partial u}{\partial y}, \tag{1.38}$$

where l - "path" of mixing in the region of intense turbulent mixing of the flow.

The velocity distribution in this region was assumed by the author according to the universal Schlichting-Abramovich dependence:

$$(U - U_n)/(U_m - U_n) = \left(l - \eta^{3/2}\right)^2, \tag{1.39}$$

where U - the reverse flow velocity in the whirlpool;

U_m - maximum speed at the boundary of the mixing area;

$\eta = (y - y_1)/b_T$ - relative transverse coordinate;

y_1 -the ordinate of the inner border of this area.

By solving the equation of change in the amount of motion, taking into account the resistance of the bottom and side walls, the author obtained a dependence for calculating the velocity field for one-sided and two-sided symmetric expansion of the flow. This method was used to calculate the expanding flow behind a compressed cross-section with an uneven velocity distribution in this cross-section in the works of T.F.Avrova [3] and M.R.Bakiev [9,10]. In [10], the presence of the reverse slope of the bottom was also taken into account.

Numerical studies were performed by R.Mayerle, S.S.Y.Wang, F.M.Toro [52]. The paper focuses on pathemodeling of thewake behind the dam and the influence of viscosity on the velocity field of the flow and depth. Comparisons of the obtained data with the data of scientists from Franceand Germany showed good convergence. In Sharma Kedar, K.Mohapatra [71].The flow of the dam around awinding channele with atrapezoidal crosse-section is considered.An acoustic Doppler speed meter is used for speed measurement. The length of the dam impactvaries from 4.0 to 22.8 of its length.

Despite the presence of a large number of different studies on solving this problem, it is difficult to give preference to any of them. Almost all solutions contain experimental parameters and corrections, and their areas of application are different. Most of the works relate to the simplest cases of an expanding stream with a rectangular cross-section of the channel with a horizontal bottom and parallel side walls before and after expansion, with a uniform distribution of velocities in the initial section, the influence of the development of an intertidalspace on the channel flow isnot taken into accountвается.

b. Length of the spreading area

Most of the design results of coastal protection structures are based on research projects and studies of the whirlpool area behind the structure are covered in the works [2,81,85,86,89].

In the work of S.T.Altunin and M.A.Buzunov [6], it was noted that the-distance between the spurs operating in the system should be taken equal to the length of the whirlpool area behind the spur. To determine this value according to a simplified flow spreading scheme, the dependence is proposed:

$$L = l_p \left(\sin a_{Ш} ctg\beta + \cos a_{Ш} \right), \qquad (1.40)$$

where β - the angle of flow spreading behind the spur.

l_p - working spur length.

α - the angle between the directions of the spur axis and the dynamic flow axis.

When the jets move in parallel, the flow spreading angle in the spur system is recommended to be taken equal to 9.5 deg., therefore, $z=6l$p.The spurs of the dependence recommend setting the spurs downstream at an angle of 67...75 deg., because in this case the flow deviates further, and the depth of local erosion at the heads becomes relatively smaller.

It is also noted that for large longitudinal slopes of the free water surface ($i>0.005$), vertical compression of the jets is observed, therefore, to reduce the differences in water levels that worsen the working conditions of the spur, it is recommended to take the distance between structures equal to $3l_p$, and for $i>0.01$ to $2l_{p.}$.

In R.M.Khachatryan et al. [81], the maximum distance between spurs is found by the expressions:

$$L = l(\cos\beta + \sin\beta ctg\,\omega)\ L = 2/3l\cos ec\,\omega, \tag{1.41}$$

where β, ω - the angle of attack and flow spread;

l - spur length.

Many authors rightly point out that the angle of flow spreading behind the spur is not a constant value, so the constant values of this angle proposed by the authors are valid only under the specific conditions of the experiments performed. In order to obtain the maximum distance betweenspurs, the authors proposed the following relationship:

$$L = l_p co\sec\Delta\alpha, \tag{1.42}$$

in which the spreading angle is calculated based on an empirical relationship:

$$\Delta\alpha = 15.2(z_1/h_b)^{1/3}, \tag{1.43}$$

where $z_l = 12.4K_c \dfrac{v_b^2}{2g}$ (for a non-eroded riverbed) (1.44)

$z_l = 5K_c \dfrac{v_b^2}{2g}$ (for the riverbed that is being eroded) (1.45)

z_l - drop directly at the spur;

$K_c = l_p \sin\alpha_{Ш}/b_o$ - coefficient of channel tightness.

In the work of M.R.Bakiev [9], it is noted that the use of the spreading angle between spurs is not justified by anything and does not correspond to the actual picture of flow around the spur.

I.A.Sherenkov [85] notes that the length of the whirlpool area behind the spur is determined by constructing the interface between the transit flow and the whirlpool. The corresponding formula proposed by the author has the form:

$$\frac{l}{\tau} = K(S_{\max} - S), \tag{1.46}$$

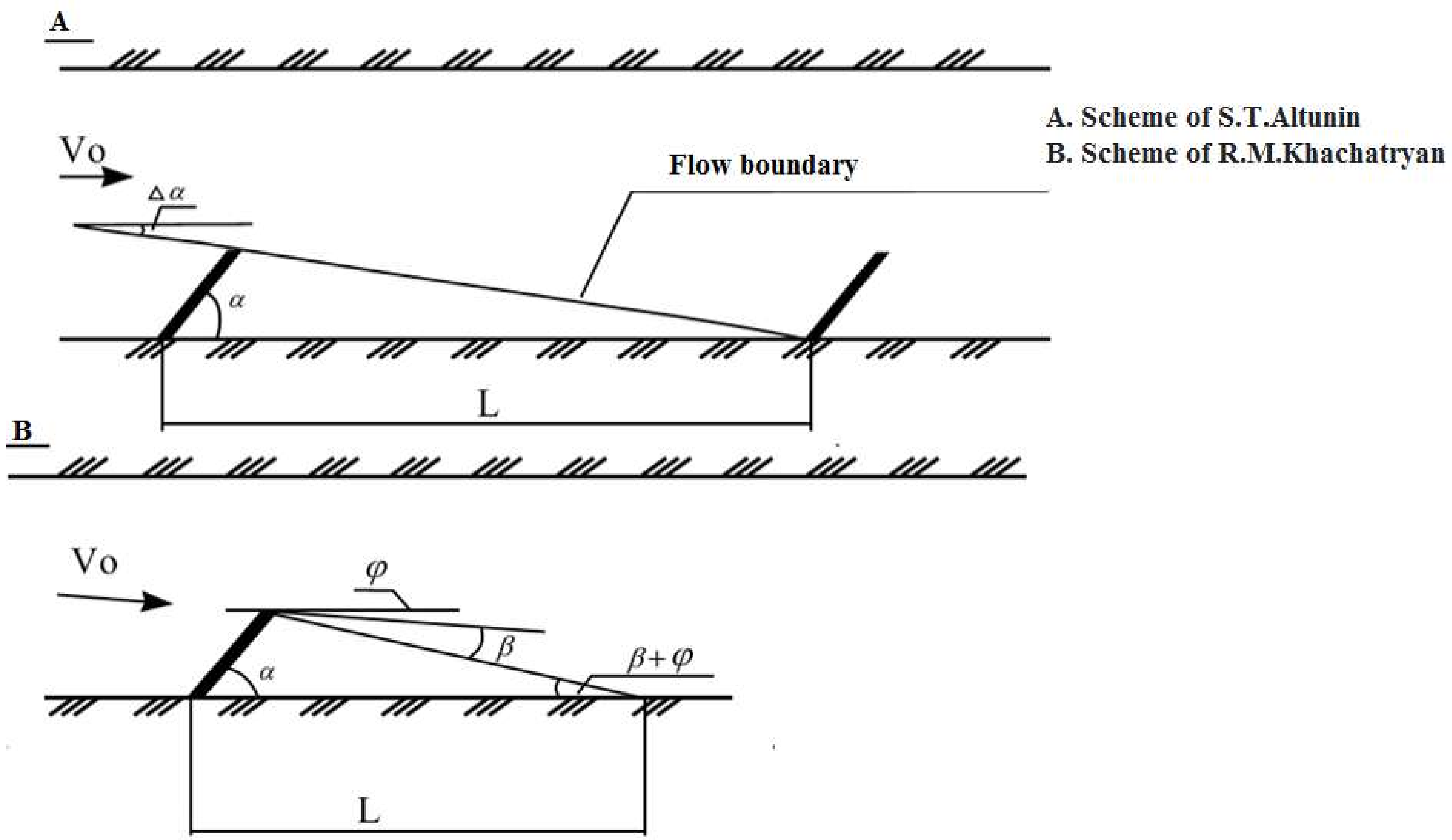

Fig. 1. 4. Flow spreading scheme behind a blind spur

where S_{max}- the length of the section line from the spur tip to the point where τ the radius of curvature of this line;

S - length to the point under consideration;

K-the empirical coefficientis taken depending on the actual conditions.

To determine the length of the whirlpool zone, the relationship between the radius of curvature of the flow jets along the interface line and the transverse slope at the spur head was considered. The resulting dependency looks like this:

$$\sqrt[\eta_y]{\frac{\Delta\alpha}{\eta_x}} = 2.1\, l_{Ш} \sin\alpha_{Ш} \sqrt{\frac{(1-n)g_i}{v_б^2 B}} \ , \qquad (1.47)$$

from which the length of the whirlpool zone is found by the formula:

$$L = \frac{\eta_x}{\eta_y} l_{Ш} \sin a_{Ш} \ , \qquad (1.48)$$

where $\frac{\eta_x}{\eta_y} f\left(\eta_y \sqrt{\frac{\Delta\alpha}{\eta_x}}, \alpha_o \right)$- determined from the graphs.

α_0 -the angle between the tangent to the trajectory and the abscissa axis in the spur edge alignment (at $S=0$).

1.3. Depth of local erosion

When designing a system of transverse dams in order to prevent river meanders and washout of banks over a long length, it is important to establish the processes of re-formation of the channel constrained by transverse dams.

The forecast of channel deformation regulated by transverse dams allows us to determine the amount of bottom erosion. Knowing the amount of deformation, it is possible to determine how much of the sediment from the erosion products will be deposited in the whirlpool zones, which is important for the development of floodplain lands. Channel deformations (erosion or alluvium) in a regulated channel occur mainly at the head of dams and in the middle part of the stream, where the highest velocities are formed.

There are various methods and formulas for calculating the expected washout depth at the head of dams.

A detailed analysis of the change in the depth of the local erosion funnel, which forms near the head of the bank protection structures in eroded soils, can be found in [36, 84].

S.T.Altunin [6] recommends the following formula for determining the depth of the washout crater at the head of the dam:

$$H_{\max} = CH, \tag{1.49}$$

where H - the average flow depth on the approach to the structure.

C -the local washout coefficient, see(1.52).

$$C = \frac{1}{\sqrt{1+m^2}}\left[\sigma\left(\frac{v_{cp}}{v'_{cp}}\frac{\sin\alpha}{U}\right)^K + \sin a(m-\sigma/U)\right]+1, \tag{1.50}$$

where*m*-the foundation of the pressure slope of the spur;

v_{cp} -speed of riverbed formation;

v'_{cp} -the permissible speed at the bottom of the transverse slope, at which the washing out of small particles stops;

α -angle of approach of the flow to the spur;

U-length of the pressure slope perimeter;

$K = \frac{l}{l-a}$ - exponent (*a*=1/5...1/3).

A large series of studies on local erosion in massive transverse spurs and dams were carried out by O.A.Kayumov [36], where they proposed a relationship for determining the greatest depth of local erosion in deaf spurs and dams:

$$H_{\max} = 10.4\frac{(\sin\varphi)^2(\cos\theta)^{0.5}Fr^{0.5}h}{n\xi_{85}^{0.17}(1+0.09\rho)(1+1.35Fr)^{1.5}}, \tag{1.51}$$

where φ - the angle of installation of the structure;

θ - angle of inclination of the pressure face of dams from the vertical plane;

n - coefficient of flow restriction by the dam;

$\xi_{85} = \frac{d_{85\%}}{d_{50\%}}$ - coefficient of soil heterogeneity;

ρ -flow saturation with sediments;

Fr - Froude number.

In case of one-way flow restriction for rivers with a fine sandy bed in the presence of a trunk, the flowrate can be determined by the formula:

$$H_{\max} = h\left[1 - \frac{sin(\varphi - a)}{K\sqrt{1+(\beta m)^2}}(v / v_{Д} - 1)\right], \tag{1.52}$$

where φ -the angle of installation of the structure;

α - flow stall angle;

K= 0.2, β =0.6-experimental coefficients (for fine sandy channels).

In studies by A.S.Lodhi, R.K.Jain, and P.K.Sharma [49], the effect of coupling on deepy-sea erosion in blind spur dams was studied. At the same time, a mixture of clay, sand and gravel is used as the eroding material. As was expected, the percentage of clay in themesimainly determined the maximum extent of erosion at the head of the flooded spur.

In the worksof A.Masjedi, V.Dehkordi, M.Alinejadi, and A.Taeedi (Iran) [50], A.Masjedi, A.Nadri, A.Taeedi, and I.Masjedi (Iran) [51] experimentally studied the depth of local erosion in T-shaped andL- shaped spurs.

An increase in the depthof erosion was found with an increase in the Froude number. The presence of a wing helps to reduce the depth of erosion.

In the work of Roger A.K,CarlosV.A, Douglas F.Sh. [65] studied the influence of the angle of dam installation on the depth of erosion. Setnande of the maximum washout depth at $\alpha = 135^0$.

The analysis of dependences to determine the maximum depth of erosion near blind spurs allows us to conclude that the main factors determining the magnitude of local erosion are the hydraulic characteristics of the flow (v, h, B) in the approach section, the size and amount of bottom sediments, the angle of approach of the flow to the structure and the design structures.

CONCLUSIONS OF CHAPTER I

Analysis of works on flow hydraulics at protective and regulatory structures has shown that many topical issues have been studied in sufficient detail and brought to practical application. However, not all the problems under consideration have been fully solved. In particular, the interaction of the system of transverse dams with the water flow, the impact of introduction or development of inter-dam space on the design regime of a regulated riverbed. Thus, N. Rakhmatov [62] considers the impact of inter-river space development only for a rectangular channel (in the absence of a floodplain), which is a special case of composite channels.

CHAPTER II. PURPOSE AND OBJECTIVES OF RESEARCH, MODEL, EQUIPMENT AND METHODS OF CONDUCTING EXPERIMENTS. INTERACTION OF RIVERBED AND FLOODPLAIN STREAMS

2.1. Goals and objectives of the study

The aim of the study is to develop methods for calculating the regulated flow of one-way dammed rivers on rivers with a single-sided floodplain, taking into account the impact of the development of inter-river floodplain space. Taking into account the above, the goals and objectives of our research were formed:

1.In the hydraulic calculation of a flow in a complex cross-section with a water outlet to the floodplain, the interaction and mutual influence of the channel and floodplain flows are taken into account, as well as partial development of the interstitial space.

2.For the backup area - determination of the amount of backup, the location of the target with the maximum backup and the length of the upper whirlpool zone;

3.For the compression region-determination of the influence of partial development of inter-surface space on the planned flow dimensions, on the value of the compression coefficient and the location of the maximum compression target, calculation of the velocity field and construction of a flow plan;

4.When calculating the flow in the spreading area, determine the influence of the width of the development of interstitial space on the values of water level differences and plot the velocity field in the flow.

2.2. Model installation and measuring equipment

When designing many hydraulic structures and, first of all, designed for effective protection of banks, it is of great importance to know the laws of flow movement in composite sections. In order to identify the influence of the development of interstitial space on the flow regime, in the case when the processes are significantly affected by the interaction of channel and floodplain flows, experimental studies were conducted on a schematized model. The experiments were carried out in the laboratory of the Department "Hydraulic Structures and Engineering Structures" of the National Research University "TIIAME" [12].

The model installation is a concrete hydraulic tray with rectangular cross-sections of the riverbed and floodplain. Tray dimensions 1500x200x50 cm. The length of the working part of the tray is 1250 cm.The tray has a concrete bottom of the riverbed and floodplains and concrete walls (i.e. the same roughness).

The chute supply system consists of an underground tank, a pumping station that raises water to the upper pressure tank with a fixed water level, and a supply pipeline. Water from the supply pipeline enters the calming pool, then the energy is extinguished in the quenching device and the water is evenly distributed across the width of the tray. The water flow rate is set by a gate valve, and is measured by a triangular spillway. The slope of the water surface in the tray is changed by means of louvers installed at the end of the tray. A service bridge for measuring equipment is installed on the tray, which moves along horizontal rails mounted on top of the tray walls.

The flow velocities were measured by a SANIIRI CISPV-6M microwheel. The operation of the device is based on measuring the number of pulses generated by the sensor over a certain period of time (1, 10, 50, 100 seconds). The sensor converts the rotation of the micro-reel into electrical vibrations, which are modeled, detected and transformed into pulses in the conversion unit. The pulses in the counting unit are decoded and displayed on the indicator in units of speed measurement (cm/sec). The device's serviceability is checked by the calibration generator in the "control" mode. The depth and level of the flow were measured using a measuring needle. Bottom and surface floats and dye were used to determine the planned parameters of the flow constrained by structures.

Models of dams were made of wood and installed with nails and plasticine.

2.3. Methods of conducting experiments

Experimental studies were carried out on the model under the following conditions:

a)water consumption Q=10 ... 20 *l/sec*.

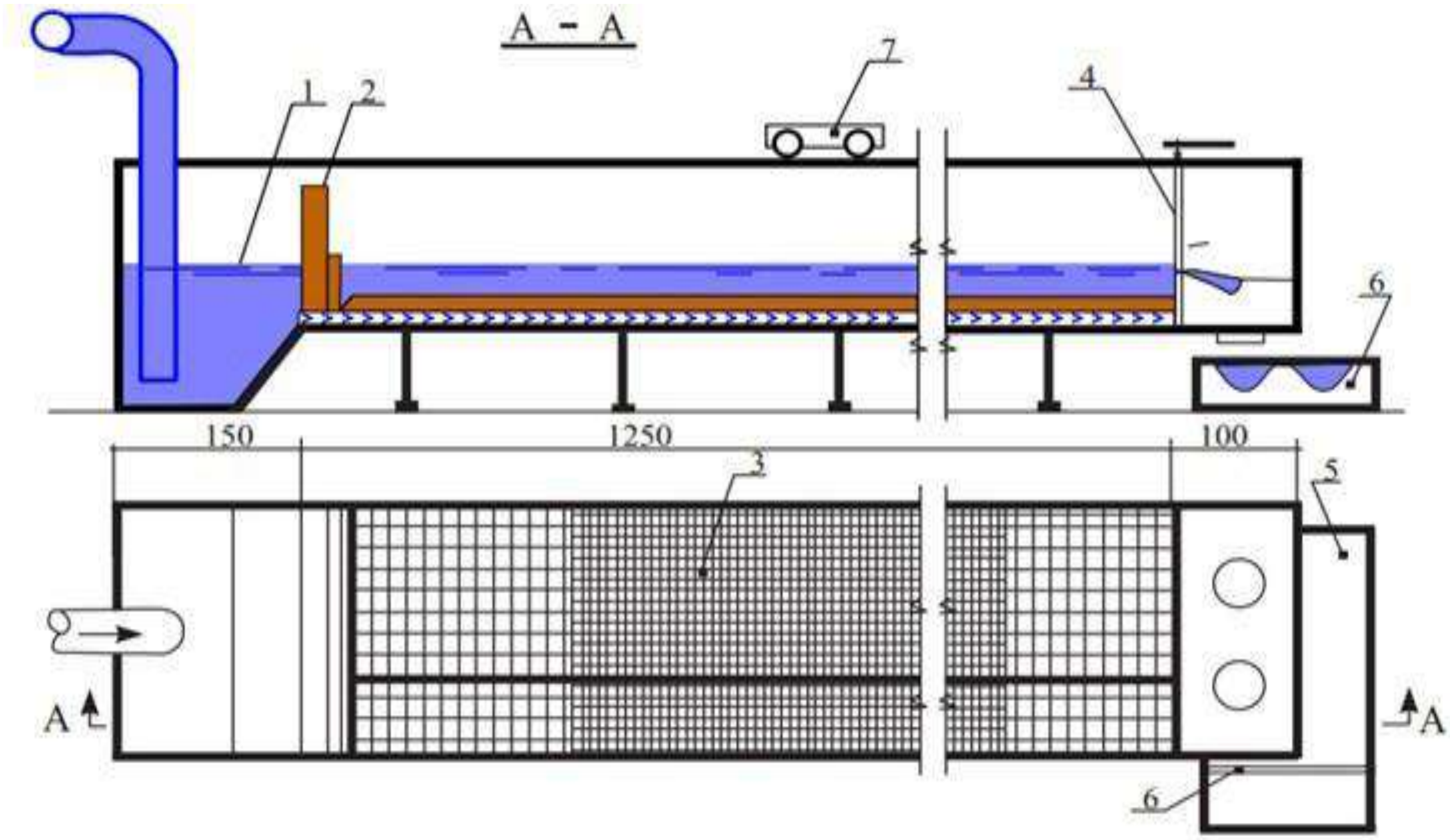

Fig.2.1. Experimental trough drawing

1. Reservoir 2.Energy reducer 3.Working part 4.Blinds
5.Water collection well 6.Triangular-shaped aqueduct 7.Carrier

Photo 1

Photo 2

Photo 3

Photo 4


Photo 5


Photo 6


Photo 7


Photo 8

b)the degree of flow restriction by flow rate

$\theta_q = Q_{per}/Q = 0...0.5$,

where Q_{per}- the flow rate on the blocked part of the floodplain in the domestic mode;

Q - total flow rate.

c) coefficient of development of interstitial space;

$K_o = l/(l_{Ш} \sin\alpha) = 0...1.0$,

where $l_{Ш}$ - the spur length;

l - development width;

α - angle of the spur installation;

d) skipi spur mounting angle $\alpha = 30^0...135^0$;

e)relative inter-room distance

$\xi = L/(l_B + l_H) = 0.5...1.0$,

where L- the actual length of the section between dams;

l_B - length of the upper whirlpool;

l_H -length of the bottom whirlpool;

f)the number of froude in domestic conditions on the floodplain is less than 0.2 $Fr_б < 0.2$;

g) the Reynolds number on the floodplain is more than 4000, in the channel it is more than 10000. (i.e., a turbulent regime was maintained)

During the experiments, the longitudinal and transverse differencesin the watersurface levels,velocity, flow direction, and planned flow sizes were determined.

The boundaries and lengths of the whirlpool zones were determined using floats and dye. To measure the length of the upper whirlpool zone, floats were launched, and tinting was performed slightly above the beginning of this zone, and when measuring the length of the lower whirlpool zone - at the head of the overlying dam. Due to a significant fluctuation in the length of the water-gate zone in the downstream, its average position over time was determined by long-term observations (10...15 minutes) of the jets near the walls of the trough. Tinting the flow also made it possible to record the direction of bottom and surface currents.

After the pre-established planned dimensions-of the deformed flow, a breakdown was made into separate characteristic alignments and verticals. Measurements were necessarily made in the areas of maximum support, tightness, maximum planned compression and the end of the whirlpool zone. The number of measurement verticals was assigned depending on the nature of the velocity change. In the area of support and compression after 2...3 cm, and in the area of spreading after 5...10 cm. The minimum step between the verticals was taken in places with a sharp change in velocity, including: in the zone of intensive mixing, at the head of the structure, in the zone of interaction of riverbed and floodplain flows, and in the zone of reverse currents. Free surface marks and flow rates were measured on the designated measurement verticals. The final values were taken as the arithmetic mean.

Depending on the depth of the flow, vertical velocity measurements were performed using three - and five-point methods. The average vertical speed was calculated using the formulas [37]:

for three-point measurement $v_{cp}=0.25\left(v_1+2v_2+v_3\right)$.

for five-point measurement $v_{cp}=0.1\left(v_1+3v_2+3v_3+2v_4+v_5\right)$

Based on the calculated values *of* v_{cp}, plotsof the planned velocity distribution along the lines in the studied area were constructed. Based on the distribution of average flow rates and depths on the verticals, plots of elementary water consumption in the domestic state were constructed. This made it possible to check the accuracy of the spillway flow measurement, since the difference between the obtained values was less than 5%.

2.4.Study of the interaction of riverbed and floodplain streams

At the boundary of two streams moving at different speeds, an intensive mass exchange occurs, the channel flow slows down, and the floodplain receives an additional impulse, and at a certain width the speeds of the floodplain flow increase [75].

In [63], N. Rajarnatam and R.AhmadI prove the universality of the velocity field in the interaction zone of two flows.

$$(U-U_m^{'})/(U_m-U_m^{'})=1\text{-}0.75\,\eta^2, \qquad (2.1)$$

where *U*- the velocity at the point with the z coordinate;

$U_m^{'}$ - speed at the point with the coordinate z=y/2;

U_m - speed in points with coordinate z=0;

$\eta=z/b_m$-dimensionless coordinate;

z-coordinate from the beginning of the interaction zone in the riverbed;

b_m-coordinate of the riverbed and floodplain boundary. $\eta=1.0(U-U_m^{'})/(U_m-U_m^{'})=0.25$.

However, not all experimental dependences satisfy-the boundary conditions. It is also difficult to determine the width of the zones where there is mutual influence of two flows. The coordinate of the channel boundary is determined from the condition that at $\eta=1.0(U-U_m^{'})/(U_m-U_m^{'})=0.25$, M.R.Bakiyev, M.Khafizov [18], and A.K.Shihab [1] proposeют dependences for determining the velocities in the interaction zone on the floodplain and in the riverbed. And according to our data, in the presence of development, the velocity distribution in the channel part within the zone of influence of the floodplain flow is also satisfactorily described by the dependence (fig.2.2. a):

$$(U-U_p^{'})/(U_p-U_p^{'})=1-0.12\eta_p\text{-}0.88\,\eta_p^2, \qquad (2.2)$$

where *U* - the water velocity in the interaction zone in the riverbed.

U_p -maximum water velocity in the channel part of the interaction zone.

$U_p^{'}$ - water velocity at the border of the riverbed and floodplain.

$\eta_p=y_p/bp$-relative coordinate of the riverbed.

y - distance from the beginning of the interaction zone in the riverbed.

b_p - width of the interaction zone in the riverbed.

The width of the interaction zone depends on the ratio of depths h_p/h_n and obeys the equation (fig.2.3):

$$b_p/h_n=1.4h_p/h_n\text{-}1.4, \qquad (2.3)$$

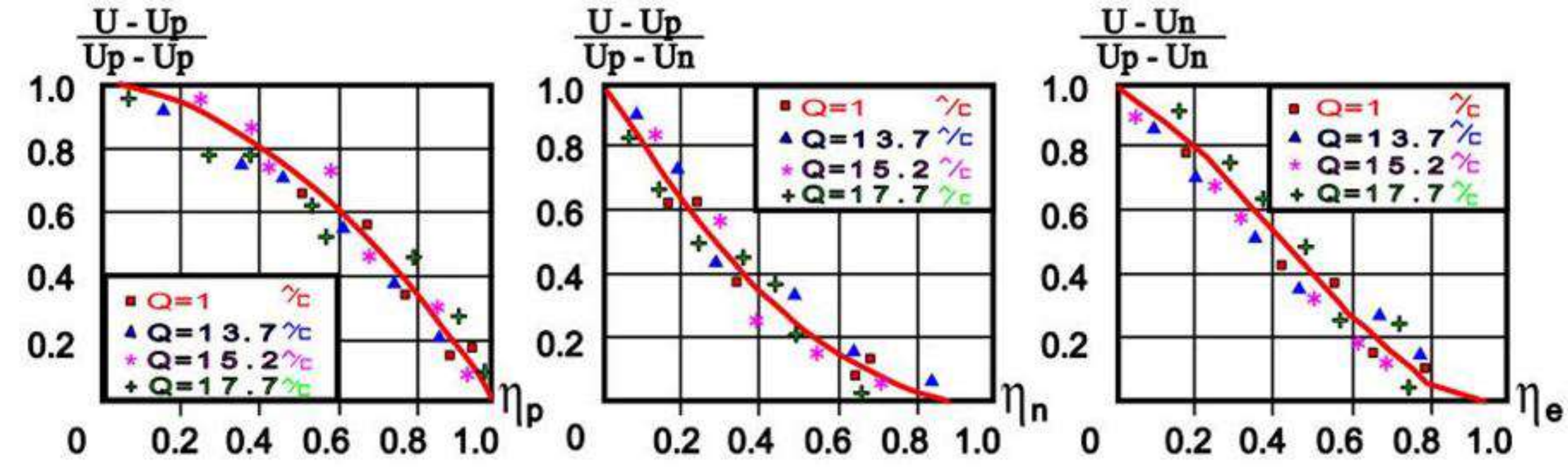

Fig.2.2. Dimensionless velocity profiles in the zone of interaction between channel and river flows
A. On track B. On the floodplain V. In a single zone

▲,✚,✱ - according to A.Shihab
■ - according to the authors M.Bakiev, M.Khafizov, Kh.Khaitov

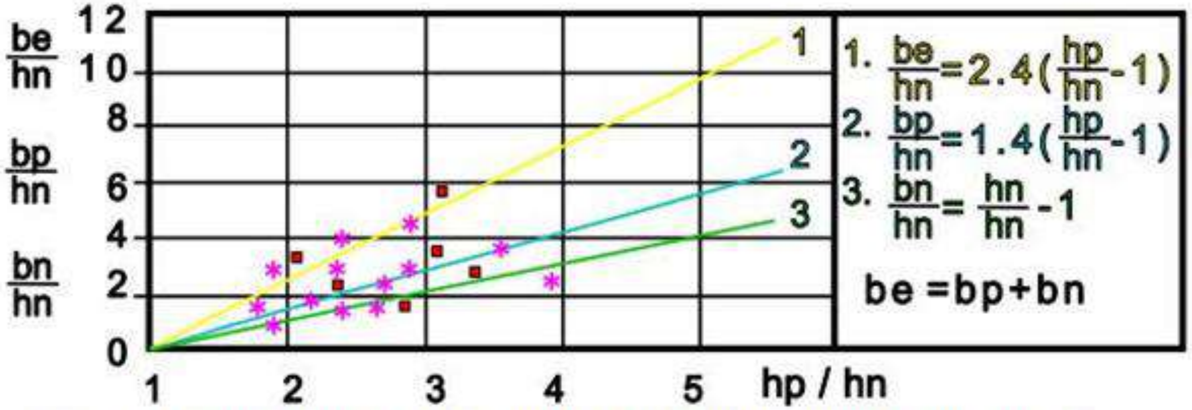

Fig.2.3. Dependence of the width of the flow interaction zone on the ratio of flow depths on the floodplain and in the channel.

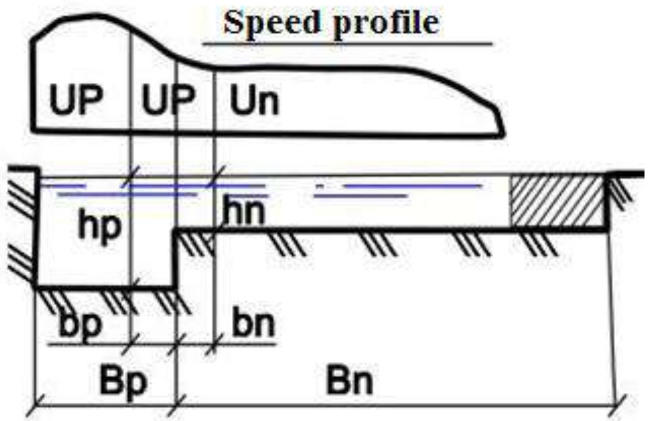

Fig.2.4. Cross section of the model

where h_p-the depth of water in the main channel.

h_n - water depth on the floodplain.

The velocity distribution in the floodplain part of the interaction zone is described by the dependence (Fig.2.2.b)

$$(U - U_n)/(U_p^{'} - U_n) = (1 - \eta_n)^2 \tag{2.4}$$

where U- the water velocity in the interaction zone on the floodplain.

U_n- water velocity on the floodplain at the end of the interaction zone.

$\eta_n = y/b_n$bn-relative coordinate of the floodplain.

y - distance from the beginning of the interaction zone on the floodplain.

b_nb$_n$ - width of the interaction zone on the floodplain.

The width of the interaction zone obeys the equation (fig.2.3):

$$b_n/h_n = h_p/h_n - 1.0 \tag{2.5}$$

The author also established the existence of a single interaction zone on the border of floodplain and channel streams, where the velocity distribution obeys the universal Schlichting-Abramovich dependence (fig.2.2.b)

$$(U-U_n)/(U_p-U_n) = \left(1 - \eta_e^{3/2}\right)^2, \tag{2.6}$$

where $\eta_e = y/b_e$- the relative coordinate.

b_e - width of the zone of interaction between riverbed and floodplain streams.

The width of the zone is described by the equation (fig.2.3):

$$b_e/h = 2.4h_p/h_n - 2.4 \tag{2.7}$$

CONCLUSIONS OF CHAPTER II

Based on studies of the interaction of riverbed and floodplain streams in the presence of development, we can say that:

1. The basic concepts Ko of an inter-dam floodplain space are given as the ratio of the development widthto the length of the dam projection on y.

2. We also introduce the concept of ξ as the ratio of the actual distance between dams to the sum of the lengths of the upper and lower wateroareas of a single dam.

3. The interaction of riverbed and floodplain streams is similar to the propagation of turbulent satellite jets in a limited space;

4. The development of interstellar space does not significantly affect the distribution of velocities in the interaction zone (2.6) and the widthof this zone (2.5, 2.7).

CHAPTER III. RESULTS OF EXPERIMENTAL STUDIES OF CONSTRAINTED FLOW IN THE AREA OF BACKUP AND COMPRESSION TAKEN INTO ACCOUNT OF THE DEVELOPMENT OF INTER-DAM FLOODLAND SPACE

The construction of blind transverse structures on the floodplain violates the domestic flow regime. The restriction of the living cross-section of the stream on the floodplain by across embankment (dam) causes before the construction: backwater, changes in the longitudinal and transverse slopes of the free surface (compared to domestic ones) and the associated redistribution of costs and speeds, both in the riverbed and on the floodplain. In this case, three regions are formed, the hydraulic characteristics of which differ significantly from each other (fig.1.1). In the upper stream, at some distance from the head of the dam, the water level rises and reaches its highest value in the range of MM.Here, potential energy is accumulated, which is necessary to overcome additional resistances caused by the influence of the structure on the flow. In the alignment of the dam, the transit flow breaks away from its head and, continuing to contract, reaches its minimum planned size in the compressed section. Beyond the" compressed " cross-section, the depth and width of the transit flow increase.

This chapter presents the results of studies of the flow hydraulics constrained by a system of floodplain dams, taking into account the development of interstitial floodplain space, in the areas of backwater and compression.

3.1. Level regime of the flow constrained by the dam system

The conducted studies were aimed at studying the influence of the development of inter-dam floodplain space in complex sections on the hydraulics of the deformed flow. During the study, the level and speed modes of the flow were measured in the tray. The experiments were carried out atvariouscoefficientsof development of inter-river floodplain space and distances between dams [12].

Based on experimental studies, profiles of changes in water surface levels were constructed in dimensionless coordinates:

$$\Delta h_i / hu = f\ \left(S / b_o, \theta q, \alpha, K_o, \xi\right),$$

where $h_i = h_i - h_c$ - the difference in water levels between the calculated and compressed gates.

$h_u = U_{ЯС}^2 / 2g$ - high-speed pressure in the compressed section.

S - distance from the constraint gate to the design gate.

From fig.3.1. it is possible to judge the nature of changes in the transverse slopes of the flow deformed by a single dam. In the area of the support, the resulting transverse differences in the water surface level deflect the current lines from the shore, which is adjacent to the structure-, to the opposite one. In the restricted area, the water levels of the transit flow are equalized. In the area of compression, there is a transverse slope of the free water surface, directed towards the protected shore. The transverse slope of the water surface in the spreading area is also directed to the protected shore and is almost zero.

Beyond the compressed cross-section, with the deformed flow spreading freely, the depth increases gradually. And when installing a dam system, under the influence of the underlying dam, the depth behind the compressed section increases more intensively (fig.3.2. A). In this case, the distance between dams has a significant impact. The amount of backwater in front of the underlying dam changes in proportion to the distance between the dams. A decrease in this distance leads to an intensive increase in the depth of water in the spreading area. When the relative distance between dams is less than 0.5, the underlying dam falls into the whirlpool area and its influence on the flow parameters deformed by the first dam disappears.

Based on the combinedlongitudinal profilesof the water surface along the middle of the deformed flow (fig.3.2.B), we can conclude that the angle of the dam installation affects the nature of changes in water level differences. With an increase in the angle, the beginning of the level decline gradually-moves to the upstream of the structure, the amount of backwater increases, and the transverse slopes of the flow are more pronounced [73].

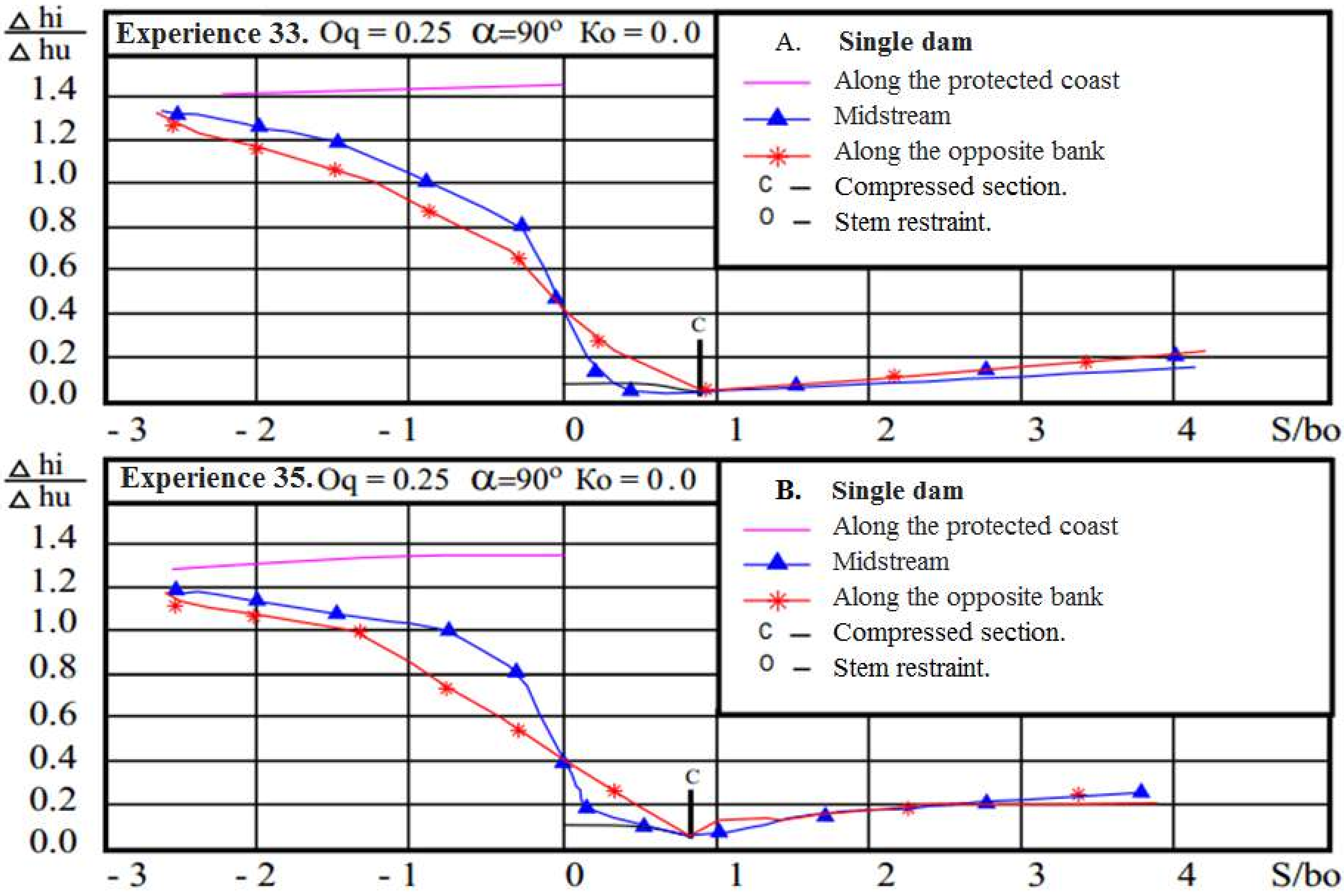

Fig.3.1. Longitudinal surface profiles

The level regime of a stream deformed by a system of dams is significantly affected by the development of inter-dam floodplain space (fig.3.3). With an increase in the width of development in the compression area, water levels are equalized in the middle of the stream and at the opposite bank, and the water level decreases at the protected bank. If the development coefficient is greater than 0.5, the small whirlpool zone formed behind the dam disappears. According to the combined longitudinal profiles of the water surface, it can be seen that with increasing development width, the influence of the underlying dam on the water level disappears, and the intensity of the level rise increases. When the development coefficient reaches a value of 1.0, an abrupt rise in the level is observed behind the compressed section. The difference in upstream and downstream levels is inversely proportional to the Ko value. The amount of backwater before subsequent dams is significantly lower in comparison with the first dam (fig.3.5).

Analysis of changes in the longitudinal profiles of the water surface along the middle of the stream (fig.3.4.B) shows that an increase in the degree of flow constraint leads to an increase in the length of the compression region and the differences in the levels of the upper and lower reaches.

Based on the above, it can be concluded that changes in the level regime of the deformed flow, in addition to the degree of flow constraint, the angle of dam installation and the kinemticity of the flow, are influenced by the coefficient of development of the inter-dam floodplain space and the distance between dams.To determine the location of the target with the results of experimental studies, graphical dependencies are constructed (fig. 3.6). As can be seen from the figure, the relative distance from the maximum support along the head of the dam to the target of the maximum support decreases with increasing degree of constraint and angle of installation of the dam. In this case, the absolute value of the distance (l_n) increases. An increase in the number of household flow Frouds on the floodplain leads to a certain increase in the relative distance. As a result of processing the experimental data, the following results were obtained:

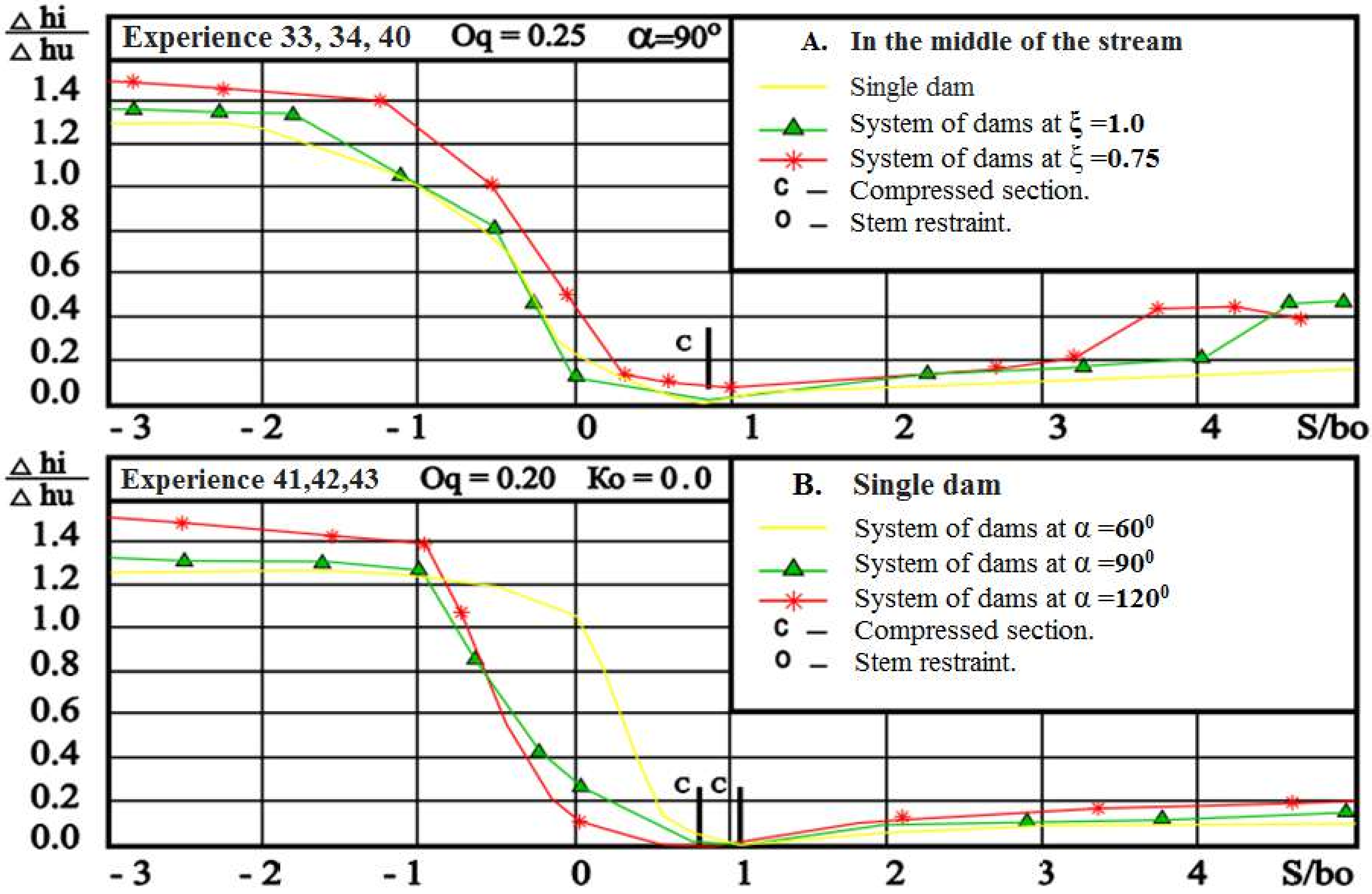

Fig.3.2. Longitudinal profiles of the water surface

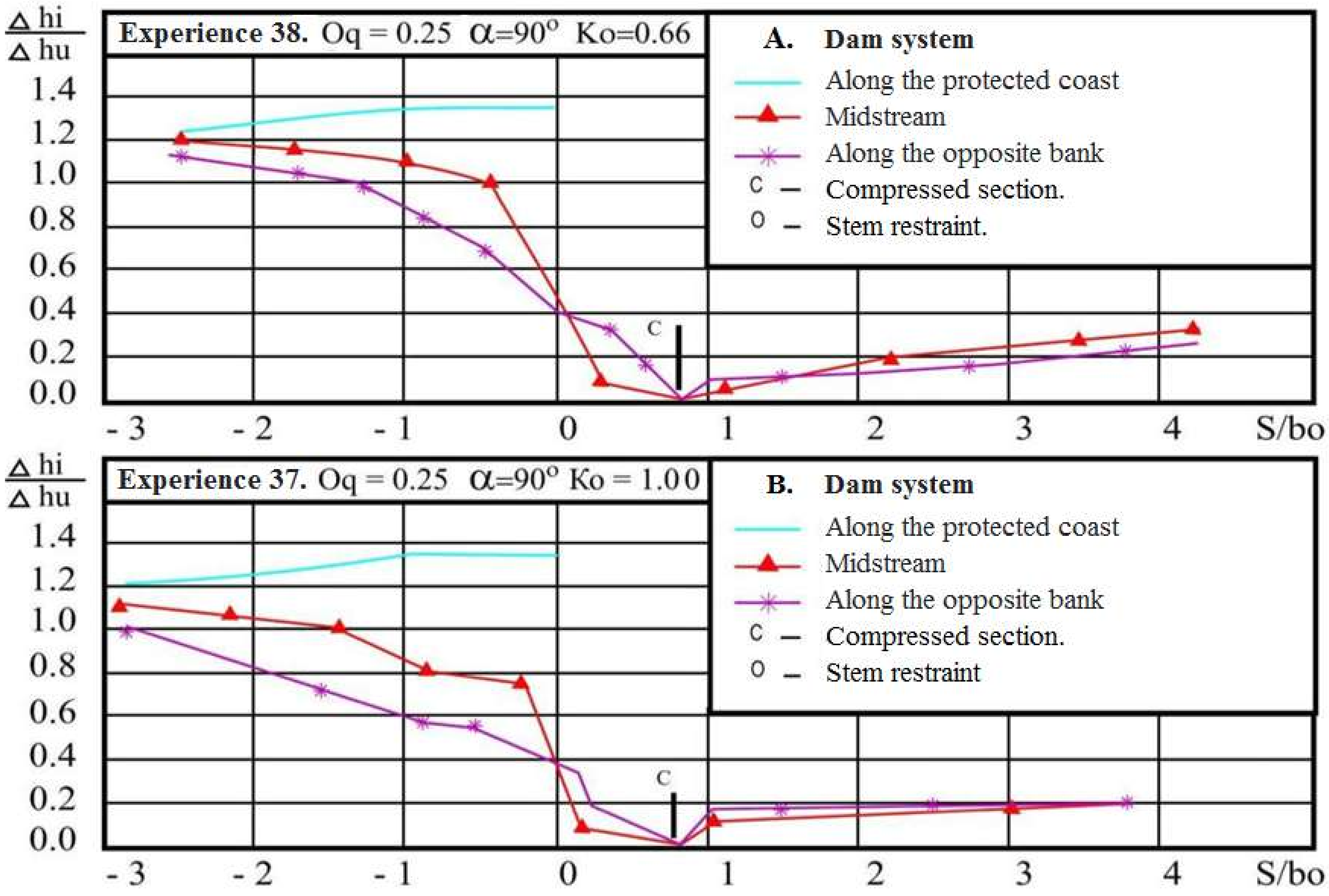

Fig.3.3. Longitudinal profiles of the water surface

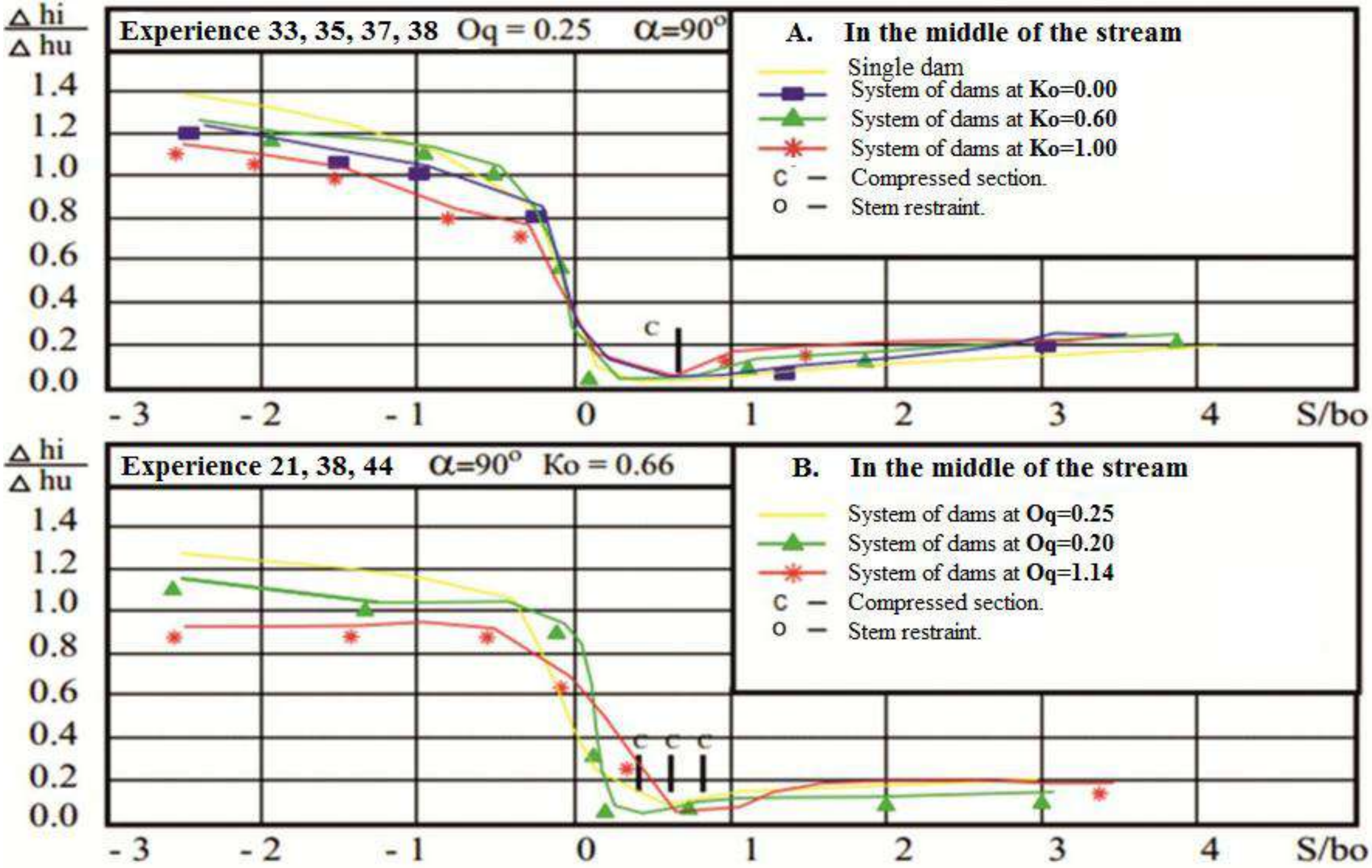

Fig.3.4. Longitudinal profiles of the water surface

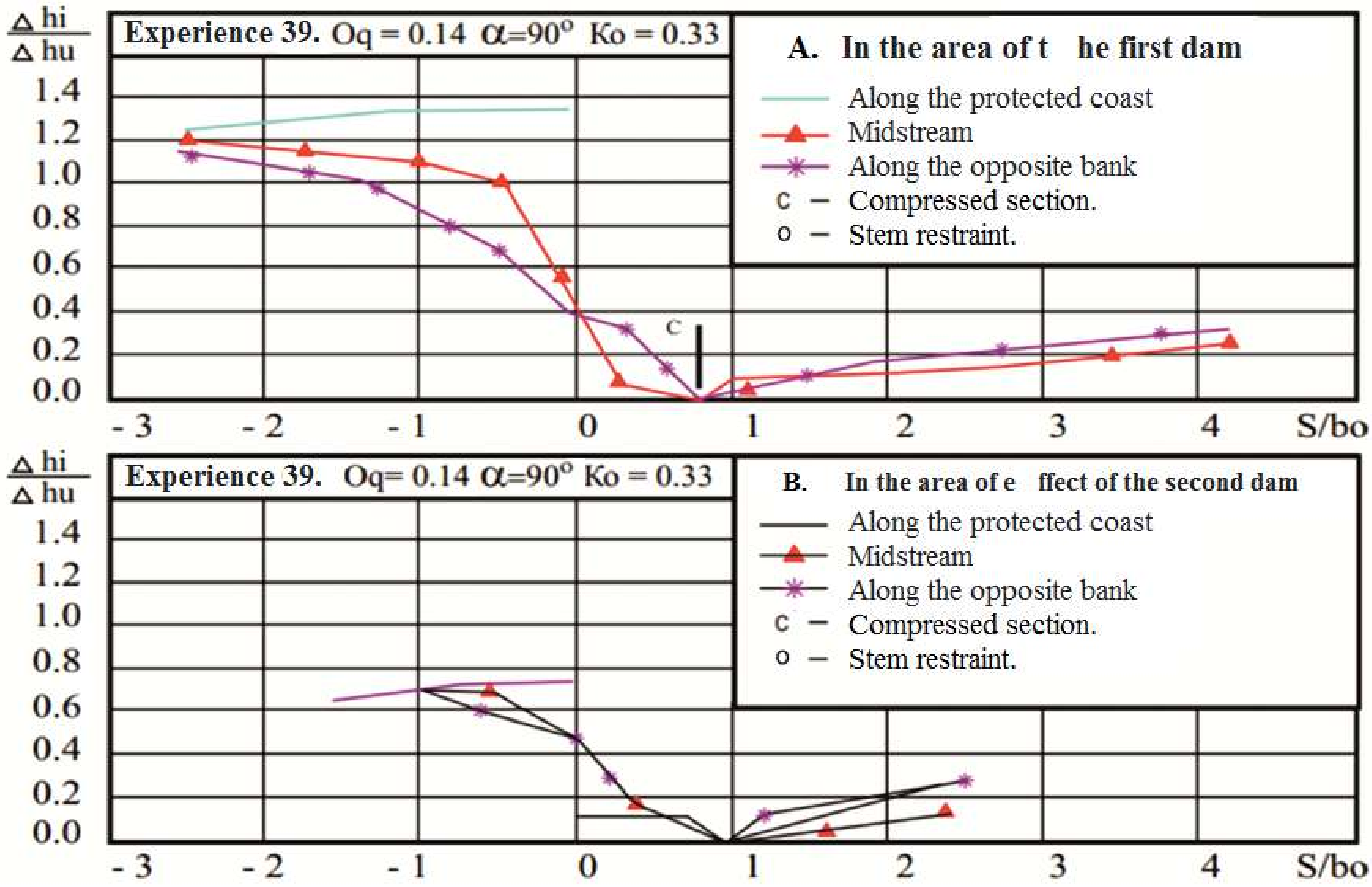

Fig.3.5. Longitudinal profiles of the water surface

the approximate equation for the analytical expression ofthe relative distance from the head of the dam to the target of the maximum support in the following form [78]:

$$l_n^2 / \omega_{nep} = 95.7 Fr^{0.1} \theta_q^{-0.126} (\alpha / 180), \quad (3.1)$$

where ω_{nep} - the residential area occupied by the dam.

The location of the compressed section, in experiments, was previously determined visually, using bottom and surface floats, and then clarified by velocity plots. Experimental data show that the location of the compressed cross-section is mainly influenced by the degree of flow restriction in terms of flow rate, the angle of dam installation, and the coefficient of development of the inter-dam floodplain space (K_o). Analysis of graphical dependencies-(fig.3.7) shows that the relative length of the compression lcc/b_o. The intensity of the increase in the relative compression length is uneven. For values of θ_q>0.24 there is a decrease in the increment of the abscissa function at constant ordinate increments. And for K_o=1.0, when θ_q>0.3 values, even a certain decline lcc/b_o. Analyzing the influence of the development coefficient K_o, it can be noted that up to the value θ_q=0.1, the influence of K_o is insignificant. With a further increase in the degree of constraint, the influenceof the mastering coefficient increases [78].

For an analytical expression of the relative length of the compression region (lcc/b_o) in the following form:

$$l_{cc} / b_o = \left[(1{,}92 K_o + 6{,}95)\theta_q^2 + (0{,}6 K_o - 6{,}2)\theta_q \right] \sin(\pi + \alpha) \quad (3.2)$$

where lcc - the length of the compression area.

b_o- width of the non-crowded part of the flow in the restricted area.

K_o - coefficient of development of inter-dam floodplain space;

α - angle of the dam installation.

θ_q - the degree of flow restriction by flow rate.

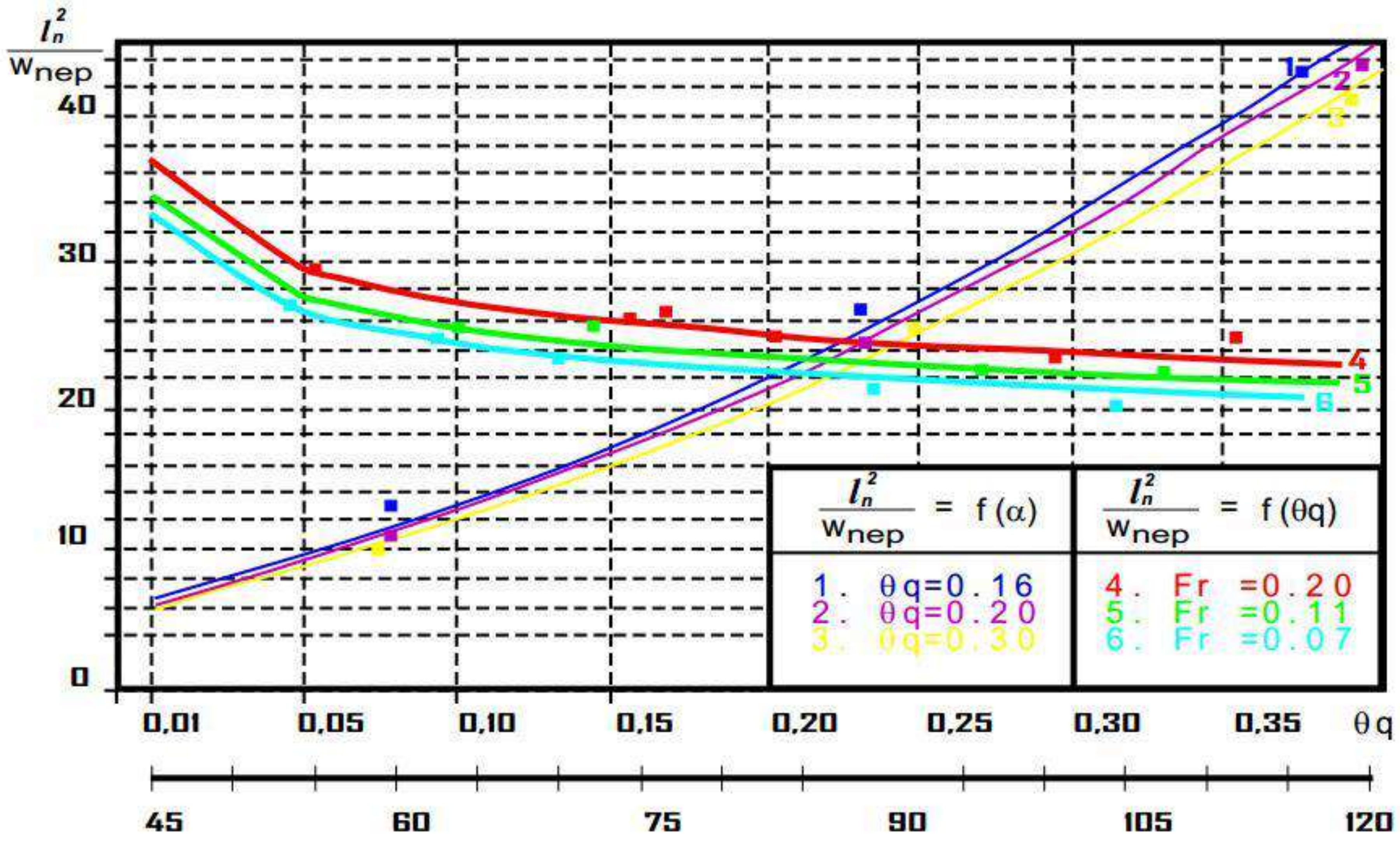

Fig.3.6. Function graphs $\frac{l_n^2}{\omega_{nep}} = f(\theta_q, Fr_{\Pi}, \alpha)$

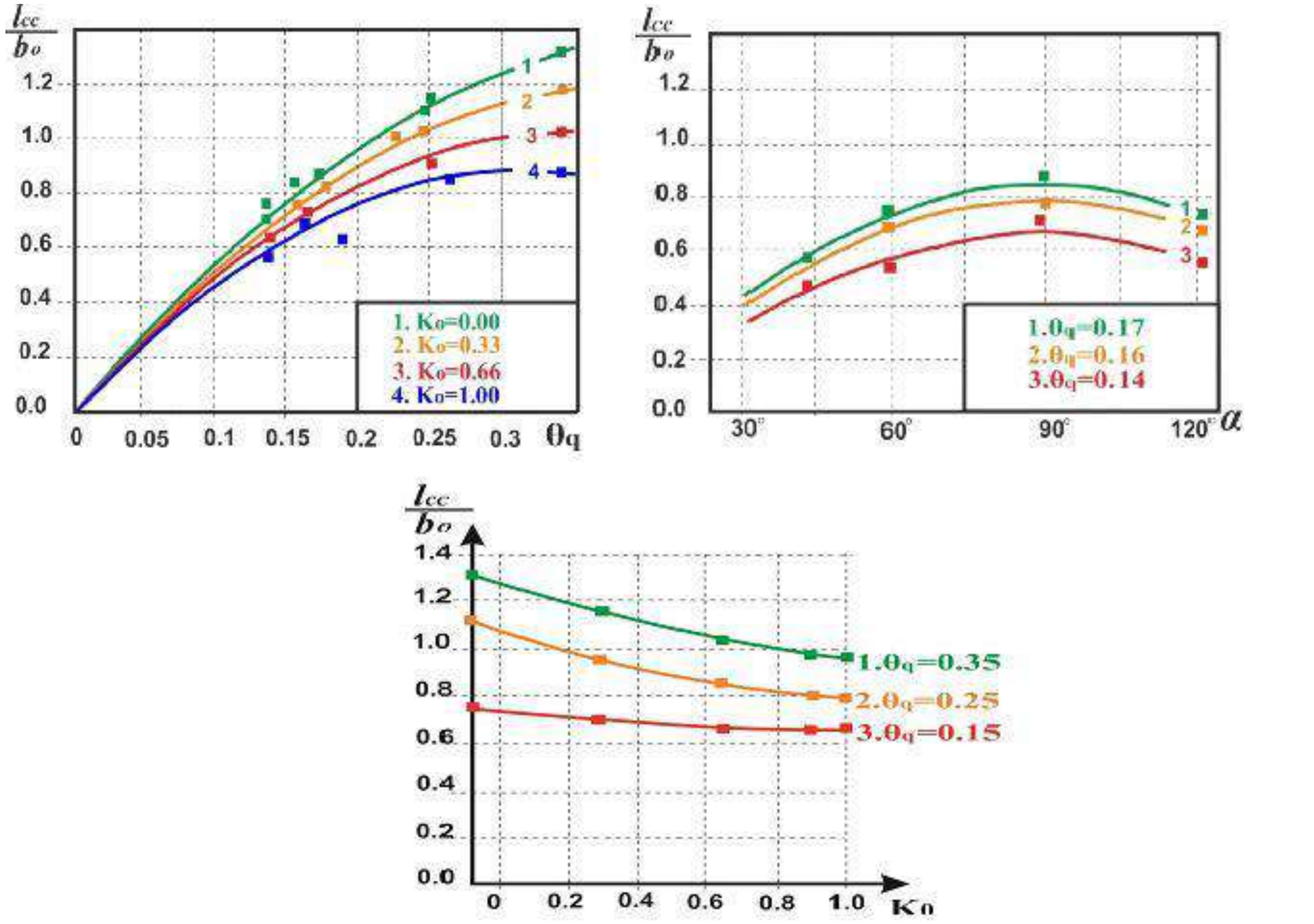

Fig.3.7. Graphs of the dependence $l_{lcc}/b_o=f(\theta_q, K_o,\alpha)$

3.2. Determination of the backstop in front of flow-limiting structures

The restriction of the flow by blind structures causes backwater in the riverbed and on the floodplain [77]. The largest support in the Z_p channel is created slightly higher than the structure. On the floodplain, the largest support Z_n is formed in front of the structure and determines the necessary mark of its top [15].

Currently, there are various methods for determining the backwater, which differ both in computational accuracy and physical validity. A.M.Latyshenkov proposed an approximate method for determining the largest backwater in the channel Z_p, based on the application of the equation of motion and taking into account the actual plot of the velocity distribution in the compressed section (fig.3.8). The author highlights the volume of liquid bounded by two cross-sections 1-1 (the maximum backwater in the channel) and C-C (compressed cross-section), and makes the following assumptions:

1- due to the low slope of the bottom (for flat and foothill rivers), the projection of gravity on the flow direction is zero.

2-due to the small length of the section 1-C, the friction force along the bottom is zero.

3-the motion in sections 1-1 and C-C is smoothly changing, and-the pressure distribution obeys the hydrostatic law.

4-there is no transverse slope of the free surface in sections 1-1 and C-C (due to its small size).

5-the ratio of the actual amount of movement inthe section to the amount of movement calculated from the average speed for sections 1-1 and C-Cis considered the same (α=1.05).

Solving the equation of the amount of motion for the selected volume of liquid and making the necessary substitutions by A.M.Latyshenkov [41], we finally obtain:

$$Z_p = D\frac{\alpha^1 v_p^2}{2g}, \tag{3.3}$$

where D-a term that takes into account the influence of the shape of the velocity plot in a compressed section on the change in the amount of movement in it;

v_p - household average speed in the channel.

$$D = \frac{2K'(\Omega_p + \Omega_n/\alpha_0)}{\Omega_p + \varepsilon_{np}\omega_n}, \tag{3.4}$$

where K' - a coefficient that takes into account the redistribution of velocities in the riverbed and on the floodplain in section C - C compared to section 1-1.

$$K' = (\beta_p - 1)\left(1 + \tau - \frac{\tau}{\alpha_o}\right) \tag{3.5}$$

Ω_p - cross-sectional area of the riverbed.

Ω_n - cross-sectional area of the floodplain.

$\varepsilon_{np} = \Omega_{сж} / \Omega_o$ - area compression ratio.

Ω_o - the area of the live cross-section of the flow in the restriction area.

$\alpha_o = v_p / v_n$ -coefficient of uneven velocity distribution in the domestic state as the ratio of velocities in the channel v_p and on the floodplain v_n.

v_n -the average household speed on the floodplain.

where β_p - the coefficient of velocity increase in the channel part of the compressed section

$$\beta_p = 1 + \frac{Q_{nep}}{Q_p}\frac{\Omega_p}{\Omega_p + \varepsilon_{np}(\Omega_p + \omega_n)} \tag{3.6}$$

$\tau = Q_p / Q$; - relative flow rate of the riverbed as the ratio of the flow rate of the riverbed Q_p to the total flow rate of the river $Q = Q_p + Q_n$;

Q_p - domestic flow rate in the riverbed; Q - total flow rate.

Q_{nep} - flow rate coming to the blocked part of the floodplain.

ω_n - the area of the free part of the floodplain in the restricted area.

To determine the compression coefficient over the area ε_{np} included in formulas (3,4) and (3,6), experimental studies were carried out. Based on the results of these studies, graphical dependences of $\varepsilon_{np} = f(\theta_q, \alpha, \mathrm{Ko})$

Figure 3.9 shows the summary data on the experiments performed with by calculating the values ε_{np}, which for different angles of the planned location are superimposed as a function of the degree of flow constraint by flow $\theta_q = Q_{nep} / Q$, i.e.

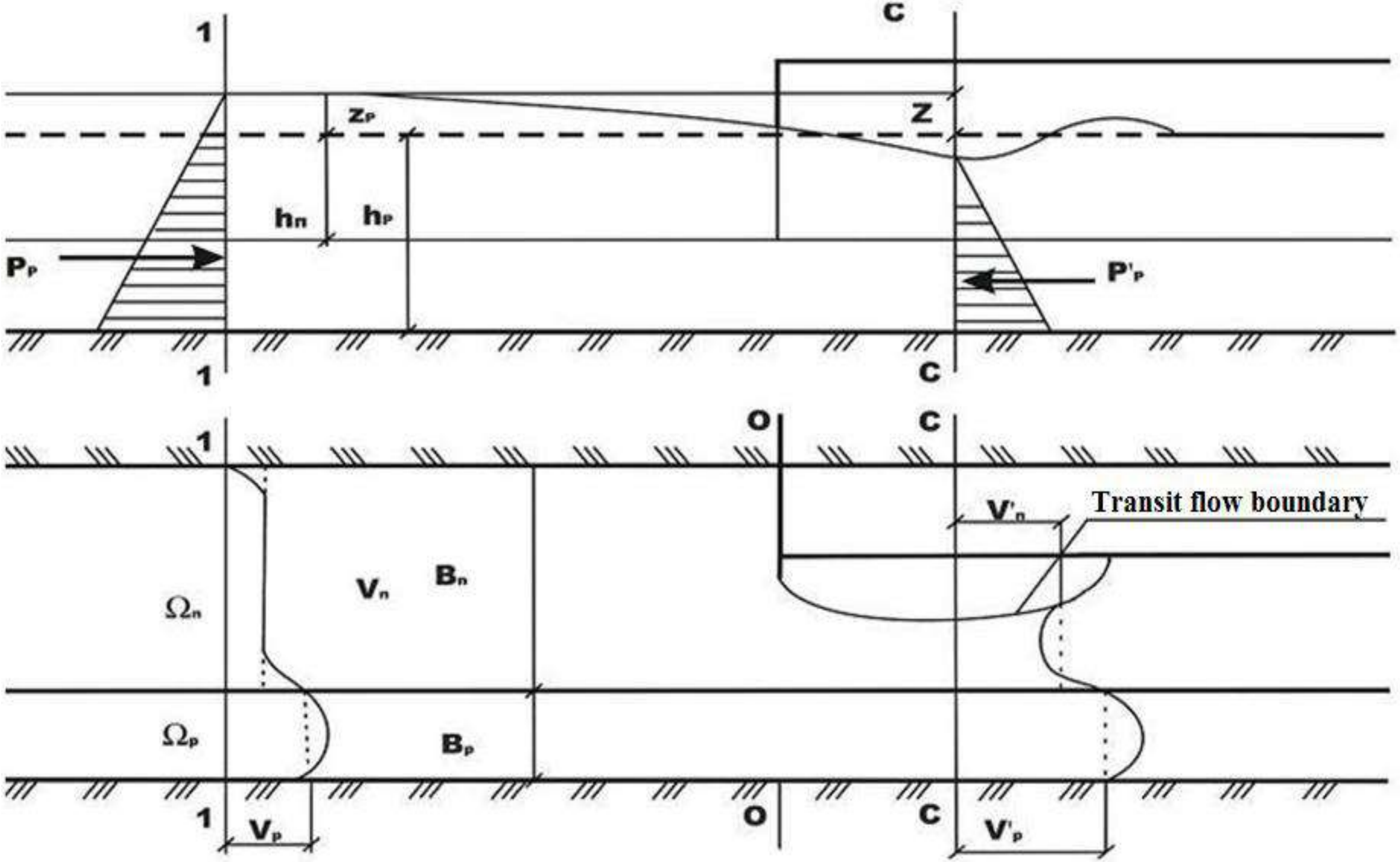

Fig.3.8. Scheme for determining the amount of support before construction

$\varepsilon_{np}=f(\theta_q)$ for angles $45^0..120^0$. The figure shows that as the angle decreases from 90^0 to 45^0, the spin times decrease and ε_{np} increases.

Figure 3.9 also shows the results of processing experiments conducted with different widths of development of inter-river floodplain space. When the coefficient of development of inter-river floodplain space increases from 0 to 1, the spatial compression coefficients increase.

Comparison of the experimental results for K_o=1 (jumper) gave good agreement with the results given by A.M.Latyshenkov [41].

The amount of backwater on the floodplain that forms directly in front of the dam:

$$Z_n = Z_p + il_n, \tag{3.7}$$

where i - the average slope of the water surface.

l_n - distance from the constraint gate to the maximum support gate.

Difference between back-up and compressed sections

$$Z = Z_p + i(l_n + l_{сж}) \tag{3.8}$$

Water depth in the maximum backwater alignment

$$H_p = h_p + Z_p; \; H_n = h_n + Z_p$$

Water depth in compressed section

$$H_{сж.p} = H_p - Z; \; H_{сж.n} = H_n - Z$$

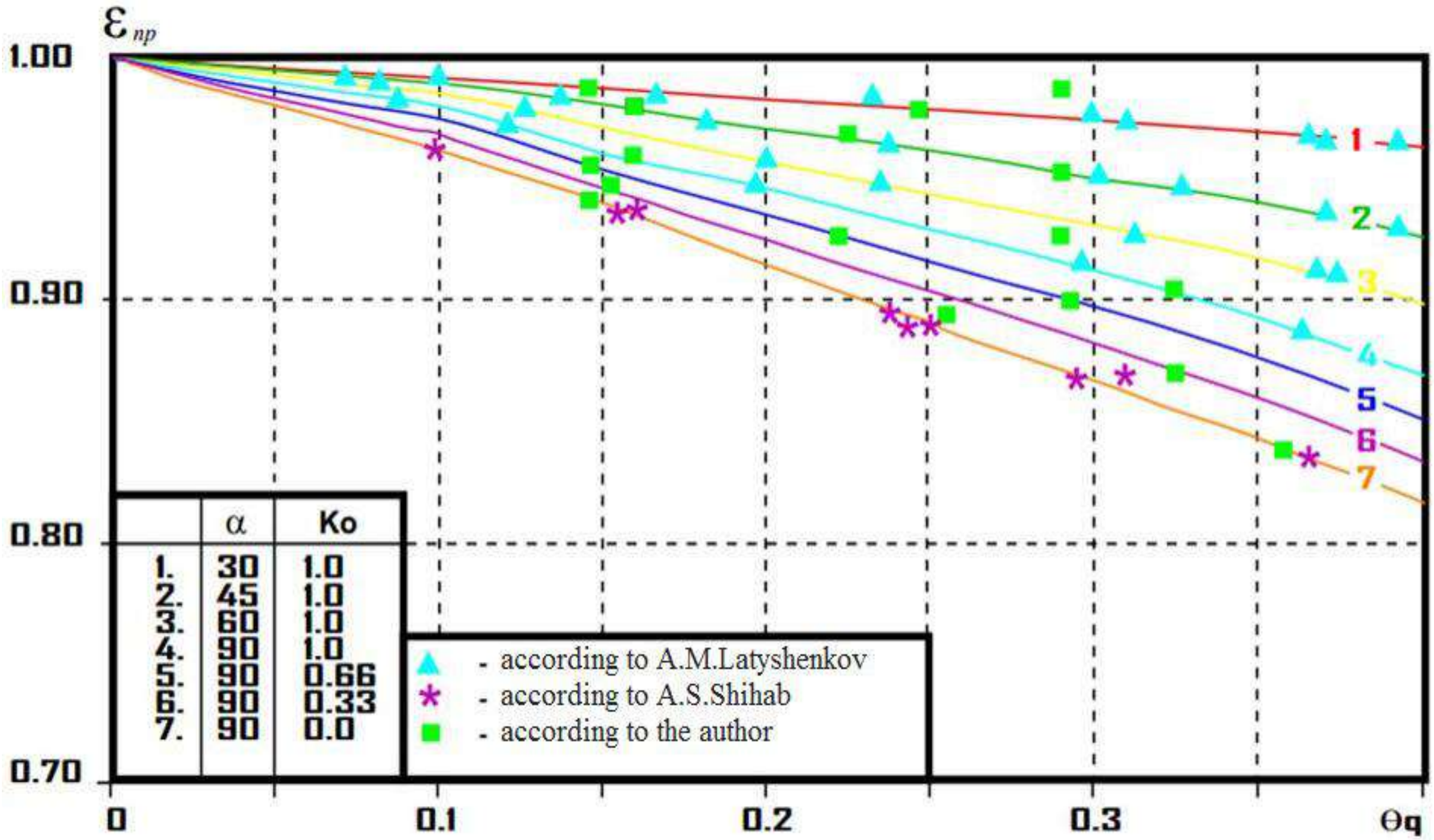

Fig.3.9. Dependency graphs $\varepsilon_{np} = f\,(\theta\,\mathrm{q}, \mathrm{Ko}, \alpha)$

3.3. Kinematic flow structure at transverse dams and-determination of the main planned flow sizes in the compression region

In everyday conditions, the trajectories of the surface and bottom stream jets are evenly distributed across the width, and no flow failure is observed. Under the influence of the structure, the flow structure changes (fig.3.10).

A noticeable change in the velocity field begins in the alignment located at some distance from the structure. The beginning of deformations of the flow velocity field does not coincide with the beginning of deformation of its free surface and is located closer to the structure. From this alignment, the velocity field changes downstream, both along the flow and in its cross-sections, the intensity of which increases with the approach to the structure. On the approach to the restriction area, the current velocity decreases at the bank to which the structure adjoins, and increases at the opposite bank. There is a deviation of the flow from the protected shore. The whirlpool zone formed in front of the dam is insignificant and weakly expressed.

In the area of tightness, near the upperedgeof the dam,the speed increases sharply. This is due to the large slope of the free water surface, which decreases with distance from the spur head. The maximum depth-averaged velocities in this alignment are located at the spur head.

Here, the maximum values are also reached by bottom velocities. Then there is a separation of the jet from the head and the formation of a whirlpool.

A large whirlpool borderson atransit stream,has aconstant water exchange with it, and receives energy from it for its circular movement. The small whirlpool formed behind the dam does not border on the transit stream.Water exchange occurs only with the large whirlpool. The flow velocities in a large whirlpool in the reverse flow section are significantly lower than the domestic speeds. Based on this, the whirlpool zone can be considered as a protection of the coast from the impact of high transit flow rates. On the border of a large whirlpool and a transit streamintense vortex formation is observed. Vortex zones occupy a small area of the flow mirror, so they can be ignored for theoretical solutions.

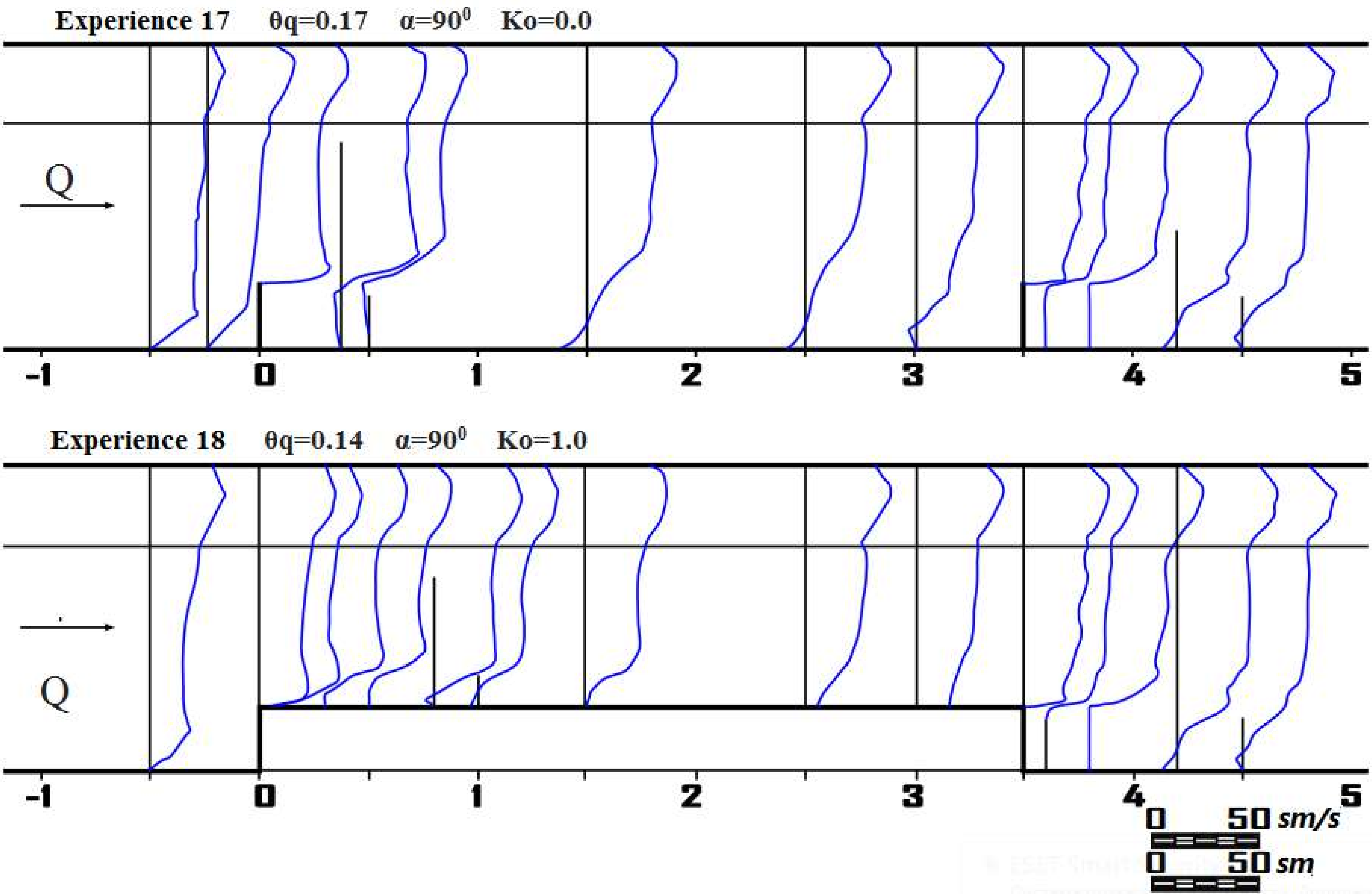

Fig.3.10. Experimental plots of local velocities

The velocity distribution in the compression region is characteristic of all separation flows. As a result of vertical and planned compression, the transit flow velocity from the constraint gate increases and reaches its maximum values in the compression line. Further in the direction of the current, the velocities decrease.

At low constraints, deformations of flow velocities are pronounced only in the floodplain. At the same time, the speed in the riverbed remains close to domestic ones.

From the target of the end of the whirlpool in the direction of the current, the area of velocity equalization is located. At the shore, which is adjacent to the structure, the speed in the direction of the current increases and at some distance approaching the household.

Analysis of the studies allowed us to conclude that the overall picture is similar to the scheme adopted in the theory of free turbulent jets [2]. The presence of the greatest transverse and longitudinal differences in depth and velocity in the compression region makes it difficult to theoretically establish the main planned flow sizes. As in the works of T.F.Avrova [3] and M.R.Bakiyev [9], we have limited ourselves to generalizing experimental studies in this area. This made it possible to consider the area of the flow deformed by the dam, which consists of the following hydraulic homogeneous zones (fig.3.11) [17]:

a) a weakly perturbed kernel with a width of-$b_Я$ (between the shore line that coincides with the x-axisand they$_1$ line).

b) intense turbulent mixing, width-b (between lines y_1 and y_2);

c) reverse currents, width -$b_H = Bl - b_я - b$; (between line y_2 and lineprotected coast).

The boundaries between zones are satisfactorily described by the following dependencies:

1. Boundary between a weakly perturbed core and a zone of intense turbulent mixing

$$\bar{y}_1 = 1 - (1 - EK)(x / lcc)^{3/4} \tag{3.9}$$

2. Boundary between the zone of intense turbulent mixing and the zone of reverse currents

$$\bar{y}_2 = 1 - 0.1(1 - EK)\left(x / lcc\right)^{3/4} \qquad (3.10)$$

3. Boundary between the transit flow and the whirlpool area

$$\bar{y}_3 = 1 - (1 - E)\left(x / lcc\right)^{3/4} \qquad (3.11)$$

4.Width of the intense turbulent mixing zone

$$\bar{b} = \bar{y}_2 - \bar{y}_1 = 0.90(1 - EK)\left(x / lcc\right)^{3/4} \qquad (3.12)$$

where $\bar{y}_1 = y_1 / b_o$;

y_1-ordinate of the boundary between a weakly disturbed core and a zone of intense turbulent mixing;

$\bar{y}_2 = y_2 / b_o$;

y_2-ordinateof the boundary betweenthe zone of intense turbulent mixing and reverse current zone;

$\bar{y}_3 = y_3 / b_o$;

y_3- ordinate of the boundary between the transit flow and the whirlpool

by region.

$\bar{b} = b/b_o$;

b-the width of the zone of intense turbulent mixing.

b_o - width of the flow in the narrowing area.

l_{cc} - length of the compression area.

x- distance to the design target from the dam head.

$E=b_T/b_o$ - planned compression ratio.

b_T - width of the transit flow.

$K=b_{яс}/b_T$- relative width of the core in the compressed section;

$b_{яс}$ -core flow width in compressed section.

The above formulas for determining the ordinates of zone boundaries are valid for constraints when the condition $B_p/b_o<EK$is satisfied. If this condition is not met, the increased specific flow rates of the riverbed affectthe location of the boundaries ofhydraulicall homogeneous zones. To account for the effect ofincreasedspecific

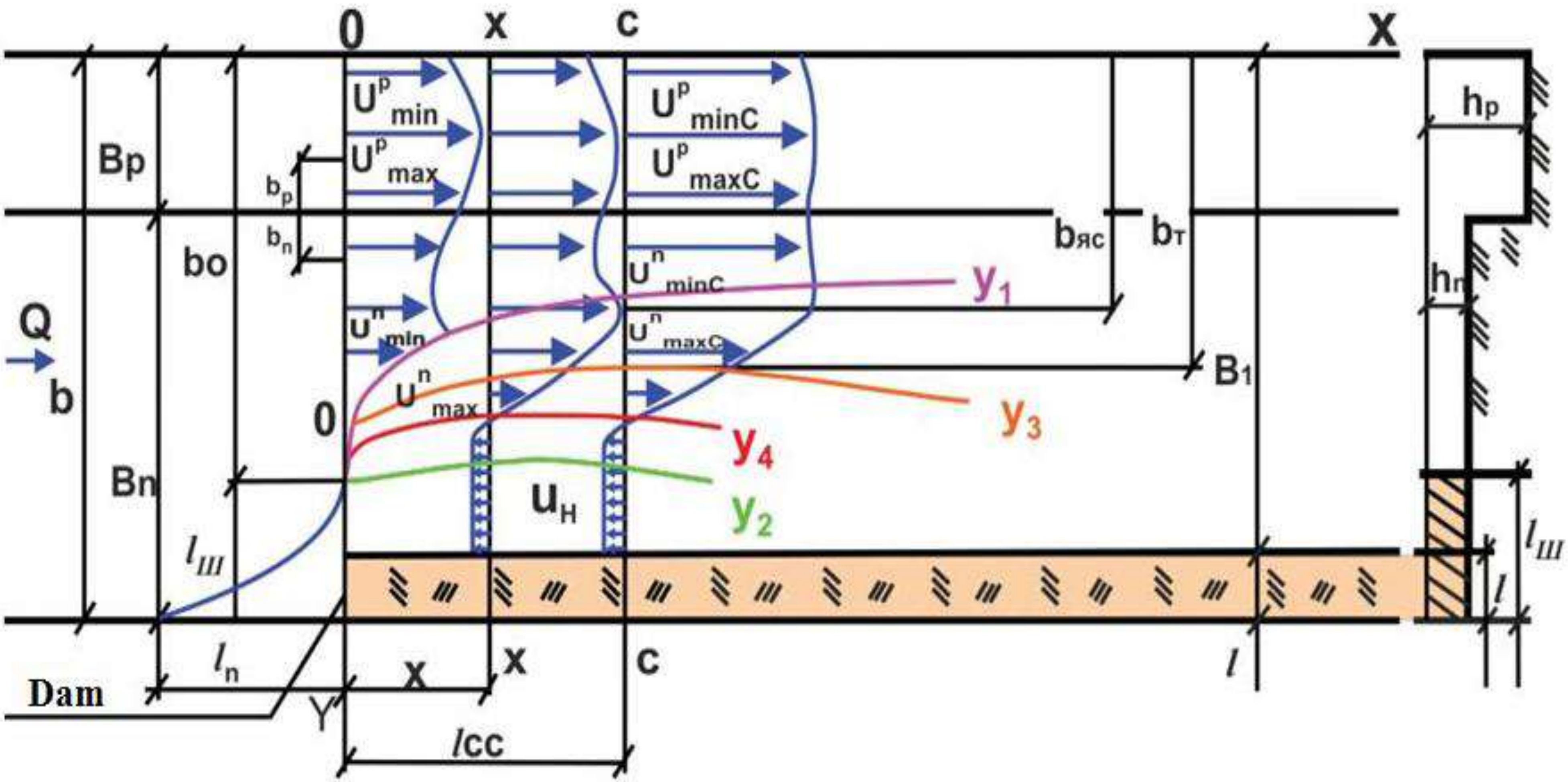

Fig.3.11. General flow diagram in the compression region

C-C-Compressed cross-section

y_1- Boundary between a weakly perturbed core and a zone of intense turbulent mixing

y_2-Boundary between a zone of intense turbulent mixing and a zone of reverse currents.

y_3- The boundary between the transit flow and the whirlpool area flow rates, the actual composite cross-section of the stream is replaced by an equivalent rectangular cross-section. Replacement is made on the condition that the domestic flow rate of the stream flows along a rectangular cross-section with a width $B_Ф = Q/(v_n h_n)$and a depth $h_n$with a speed v_n $(v_m, h_n$ – (average domestic speed and depth on the floodplain). For a fictitiousflow, the boundaries of hydraulically homogeneous zones are defined. After that, the position of the resulting curve in the flow with real boundaries is determined. The position of the curve segment located within the floodplain remains unchanged. In the channel, as if compressing the flowto its real size in the plan, we determine the position of curves in - the actual channel corresponding to similar curves in the fictitious channel. This is expressed by the following dependencies:

when $\bar{y} > \dfrac{B_p}{B_p + K_b(B_n - l_Ш)}$(curve segment on floodplain)

$$\bar{y} = K_b \frac{y - B_p\left(1 - \dfrac{1}{K_b}\right)}{B_p + K_b(B_n - l_Ш)}, \tag{3.13}$$

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$$y = [B_p + K_b(B_n - l_Ш)]\frac{\bar{y}}{K_b} + B_p\left(1 - \frac{1}{K_b}\right) \tag{3.14}$$

when $\bar{y} \le \dfrac{B_p}{B_p + K_b(B_n - l_Ш)}$(curve segment in the channel)

$$\bar{y} = y / B_p + K_b(B_n - l_Ш), \tag{3.15}$$

where from

$$y = \frac{\bar{y}}{B_p} - \frac{K_b}{B_p}(B_n - l_Ш), \tag{3.16}$$

where $K_b = \alpha_o h_p / h_n$is a coefficient that takes into account the non-uniformity of the distribution of division of unit costs to constraint (in the householdcondition);

$\alpha_o = \dfrac{v_p}{v_n}$ - coefficient of uneven distribution of displacement rates.

The values of E and K included in the dependences (3.7, 3.9...3.11) were

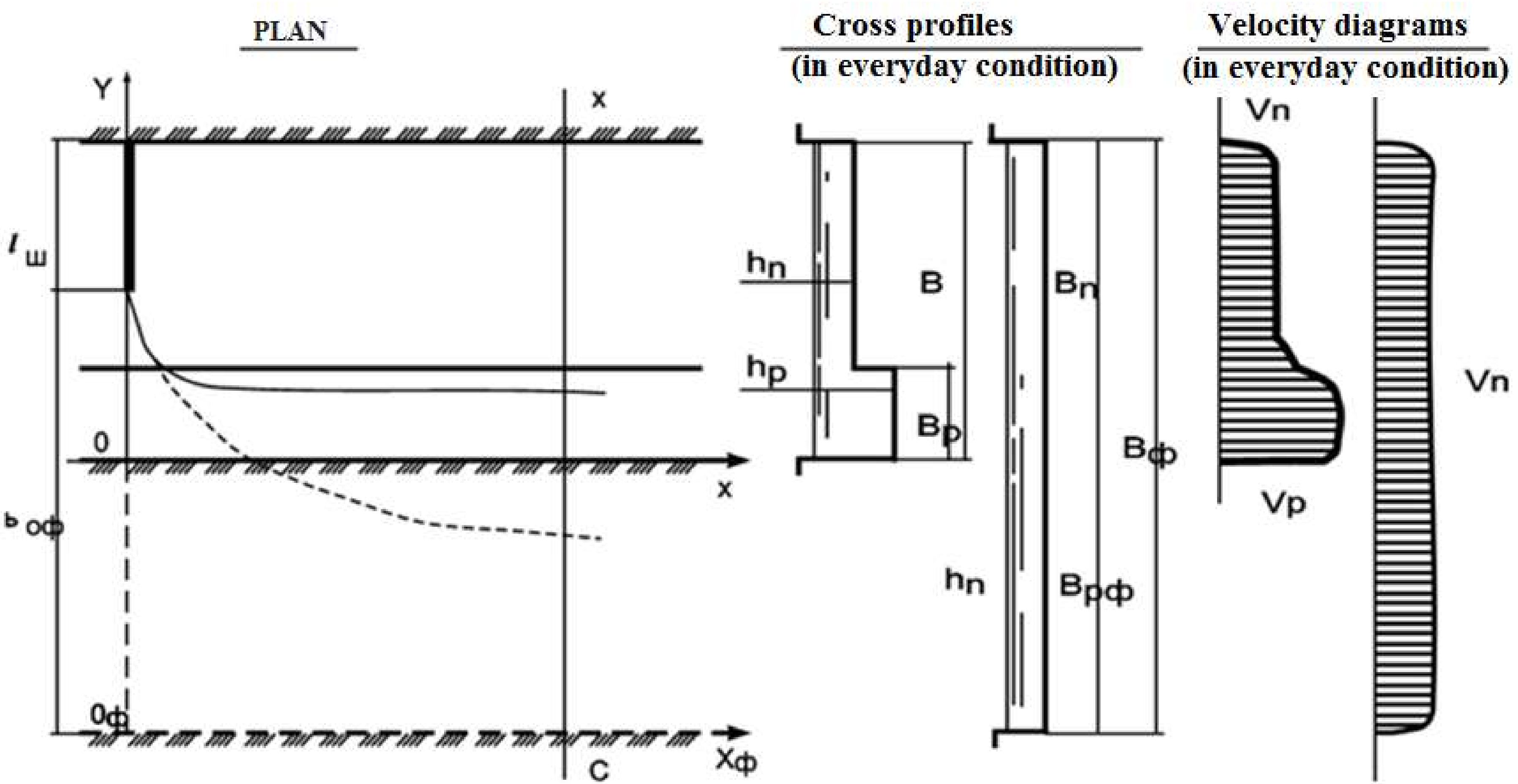


Fig.3.12. Calculation scheme for determining the position of the boundaries of hydraulic homogeneous zones at large degrees of constraint

_____ -zone boundary for actual flow

--------- -zone boundary for fictitious flow determined experimentally, which are shown in figures (fig.3.13-3.20) in the form of corresponding graphs. When analyzing these graphs, it can be seen that the coefficients *E* and *K* decrease with an increase in the degree of flow restriction in terms of flow rate and the angle of dam installation. As the width of the channel increases, the compression of the flow increases, which is more pronounced with greater flow constraints. Another factor that affects the values of *E* and *K* is the distance between them. As they interline distance decreases, the planned compression ratio decreases.

Based on processing the results of experimental studies, approximating equations are obtained for the analytical expression of the planned compression coefficient and the relative width of the core in the compressed section in the following form:

$$E = 1 - 0.35\Pi \tag{3.17}$$

$$K = 1 - 0.40\Pi, \tag{3.18}$$

where $\Pi = \theta_q^{0.85}\left(\frac{1-1.31\ \theta_q Ko}{\xi}\right)^{0.5}\left(1+\frac{\alpha}{180}\right)^{0.5}$;

$\theta_q = Q_{nep}/Q$ - degree of flow restriction by flow rate.

ξ=L/($l_n$ln+ll_H) - the relative distance between dams, taken in within 0..1.

A comparison of the results of other authorseis given in Table 3.1

Table 3.1

Planned compression ratio values $E=b_T/b_o$

θ_q flow constraint	Spur mounting angle	A.M. Latyshenkov [41] K_0= 1.0	A.K.S. Shihab [1] K_0=0.0	N.Rakhmatov[62]		Author	
				K_0	E	K_0	E
0.14	120	-----	0.87	0.0	0.89	0.0	0.92
	90	0.94	0.86	1.0	0.90	1.0	0.93
	45	0.96	0.88	1.0	0.92	1.0	0.93
0.16	120	-----	0.85	0.0	0.89	0.0	0.90
	90	0.93	0.83	1.0	0.91	1.0	0.92
	45	0.96	0.87	1.0	0.92	1.0	0.93
0.17	120	-----	0.81	0.0	0.89	0.0	0.90
	90	0.93	0.81	1.0	0.91	1.0	0.92
	45	0.96	0.85	1.0	0.92	1.0	0.92
0.20	120	-----	0.84	0.0	0.85	0.0	0.88
	90	0.90	0.83	1.0	0.88	1.0	0.91
	45	0.94	0.86	1.0	0.89	1.0	0.91
0.22	120	-----	0.82	0.0	0.86	0.0	0.88
	90	0.90	0.81	1.0	0.89	1.0	0.90
	45	0.94	0.84	1.0	0.89	1.0	0.91
0.25	120	-----	0.80	0.0	0.85	0.0	0.86
	90	0.88	0.79	1.0	0.88	1.0	0.89
	45	0.93	0.83	1.0	0.89	1.0	0.90
0.29	120	-----	0.81	0.0	0.80	0.0	0.84
	90	0.80	0.80	1.0	0.86	1.0	0.88
	45	0.89	0.82	1.0	0.87	1.0	0.89

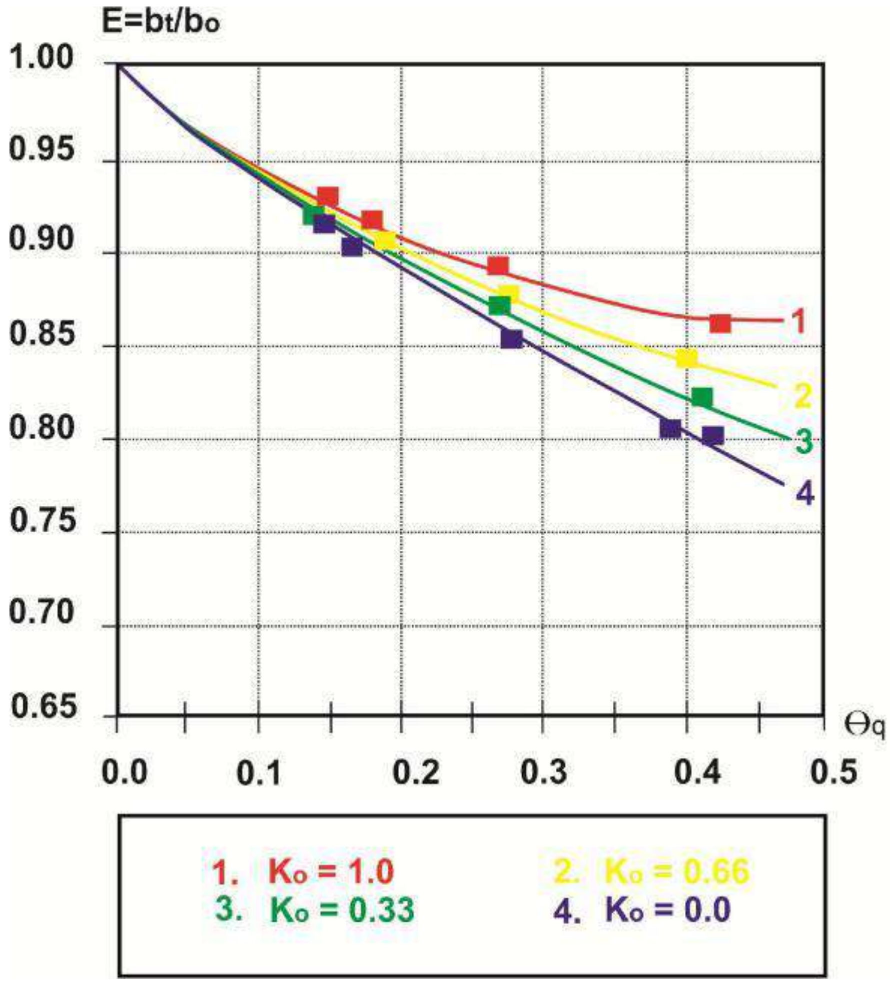


Fig.3.13. Dependency graphs $E=f(\theta q,Ko)$

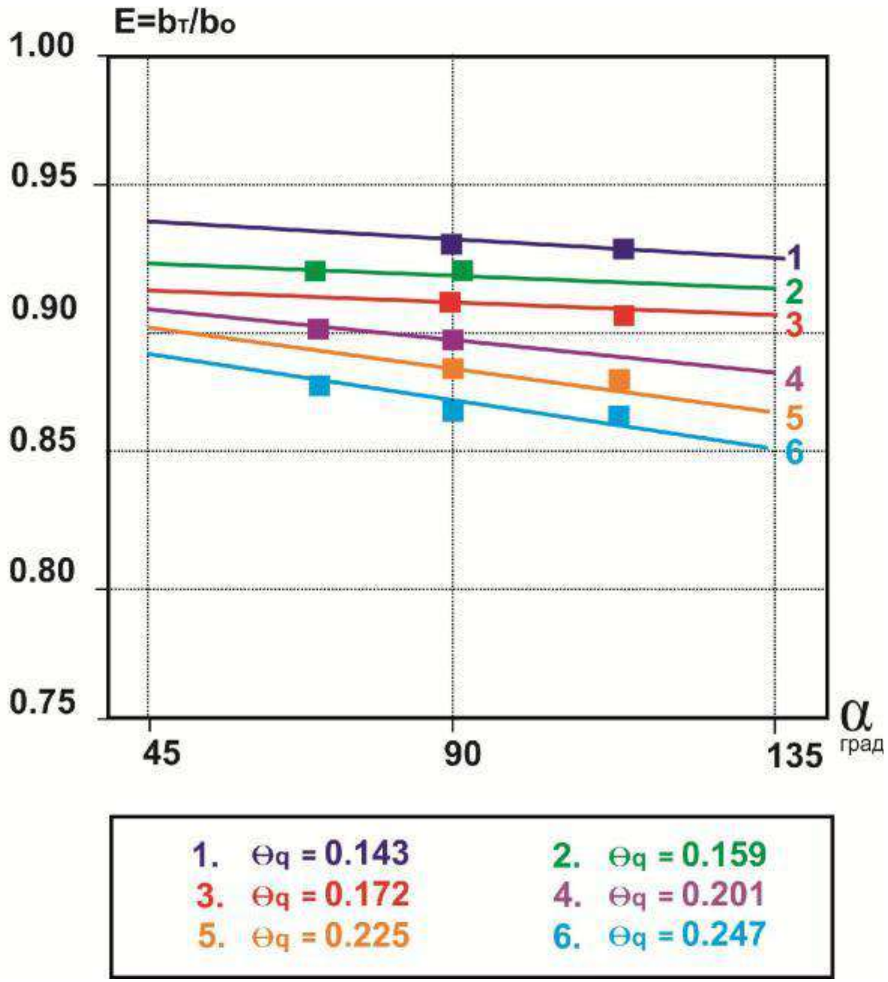


Fig.3.14. Dependency graphs $E=f(\alpha,\theta q)$

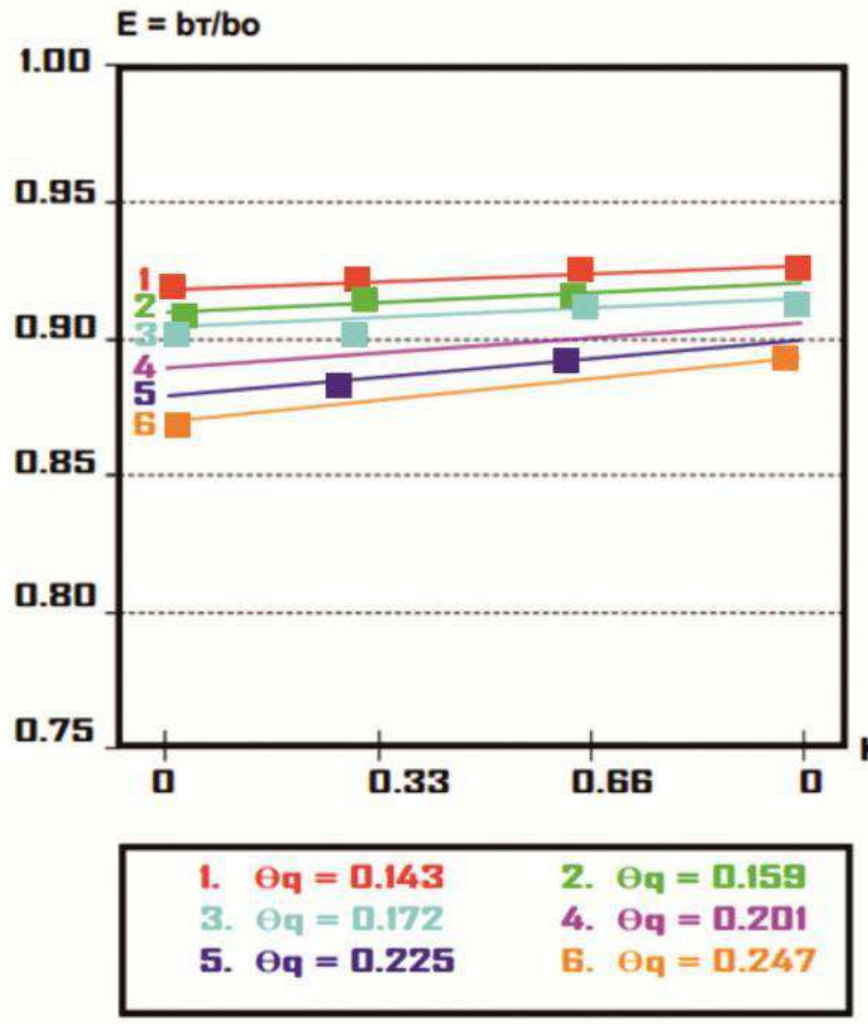


Fig.3.15. Dependency graphs *E=f(θq,Ko)*

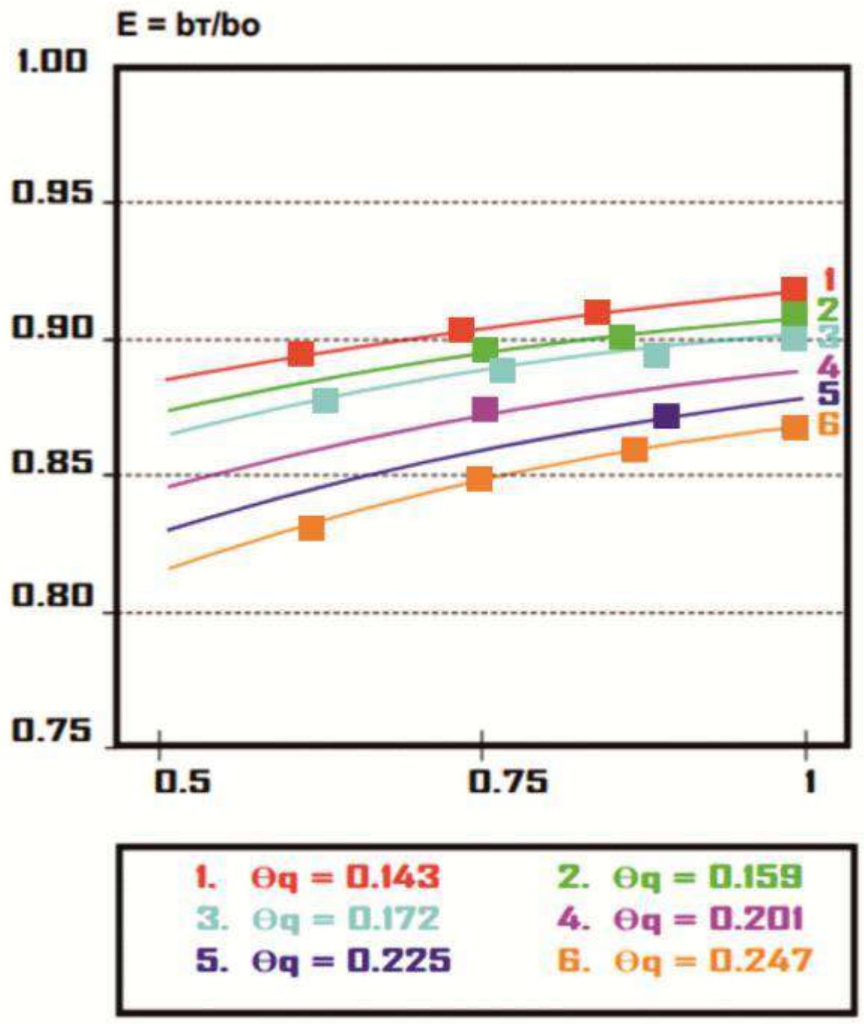


Fig.3.16. Dependency graphs *E=f(ξ,θq)*

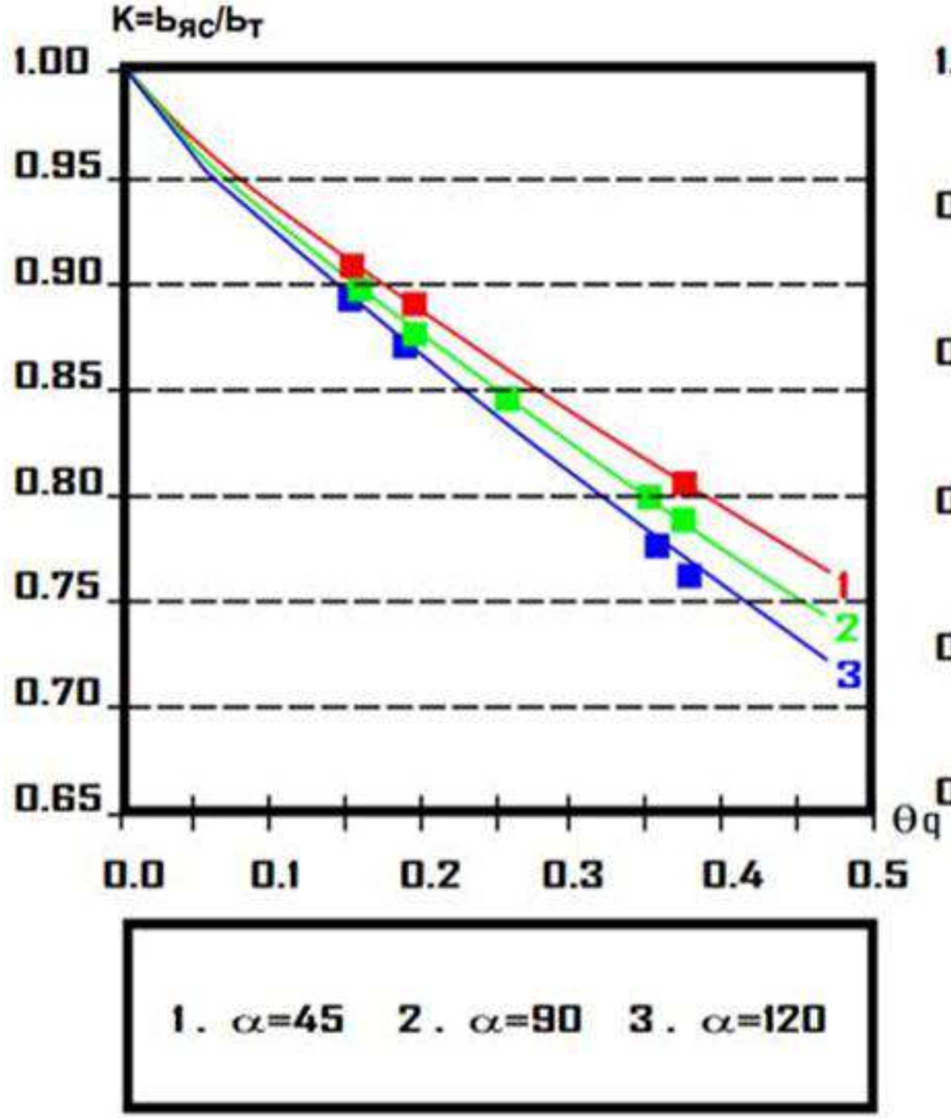


Fig.3.17. Dependency graphs *K=f(θq,α)*

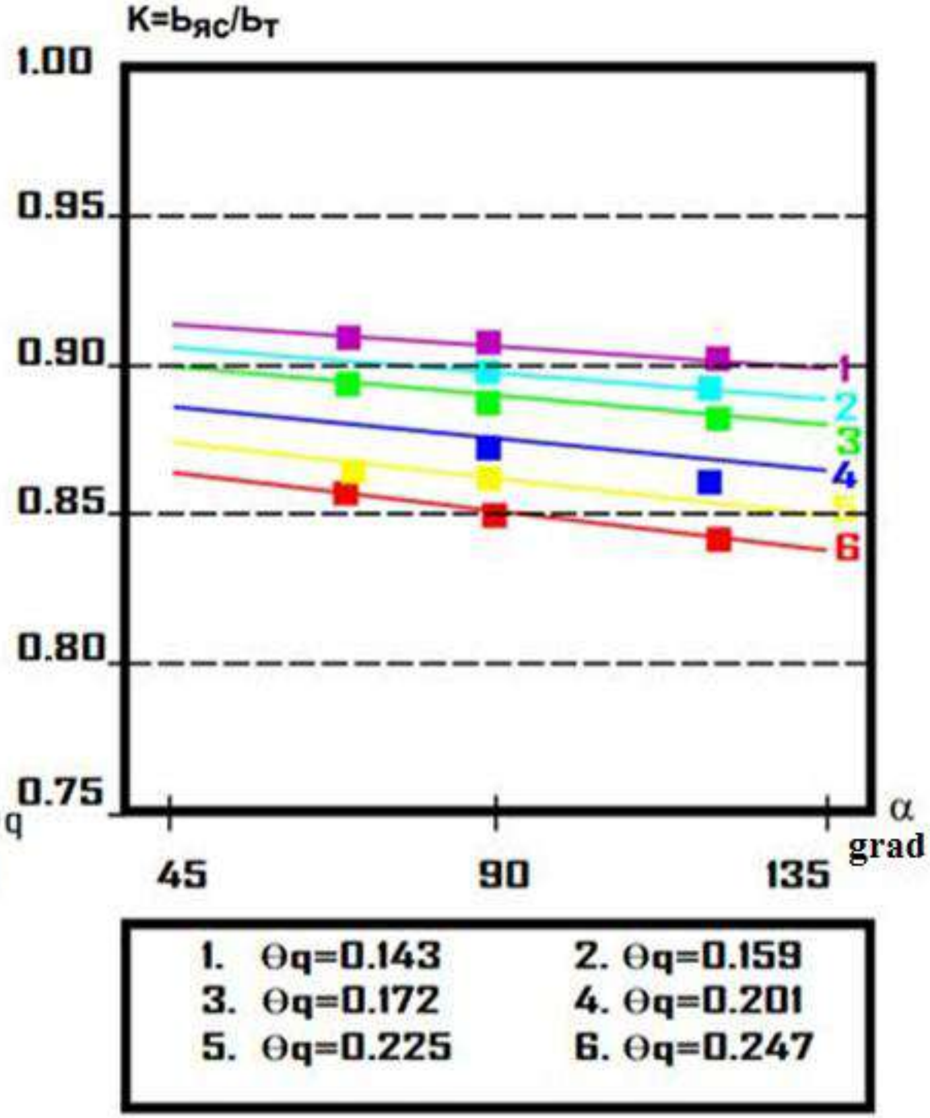


Fig.3.18. Dependency graphs *K=f(α,θq)*

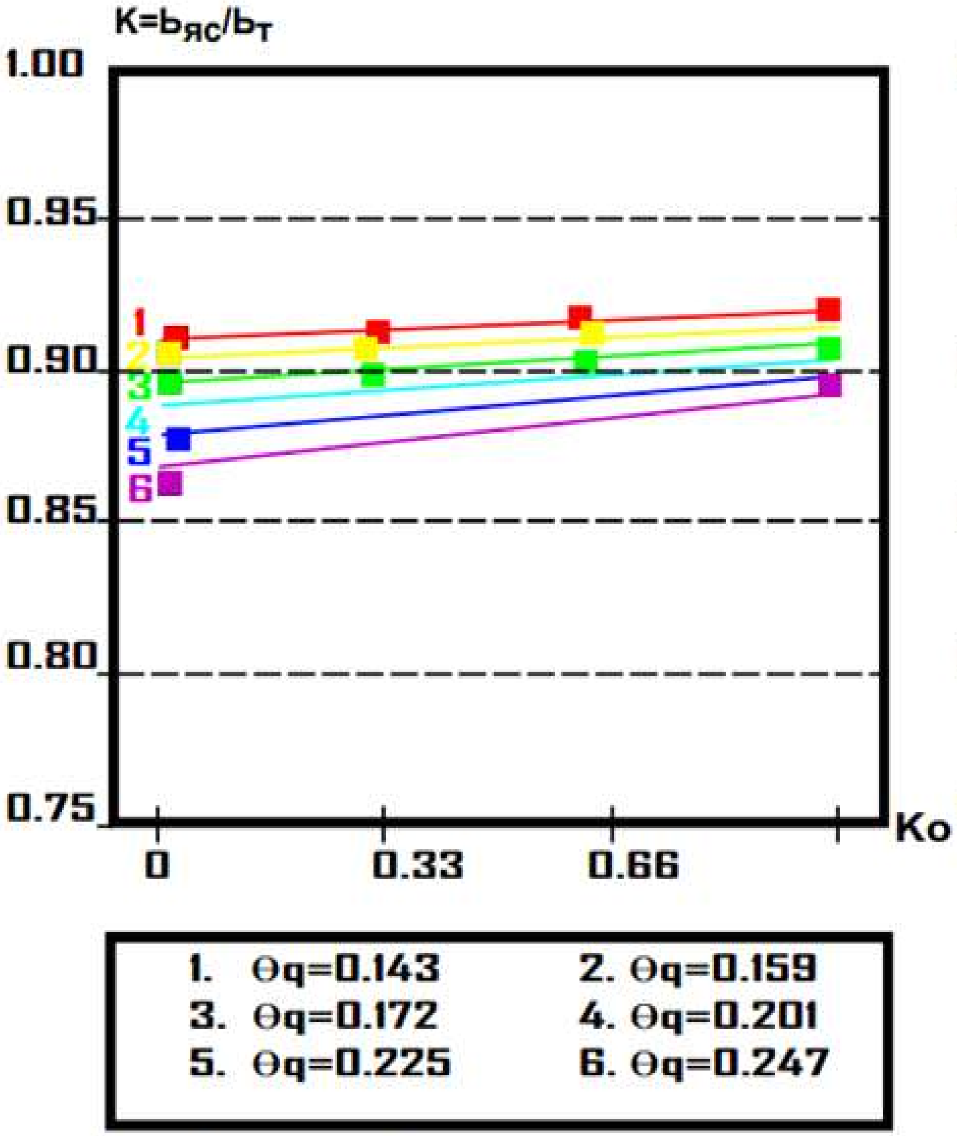


Fig.3.19. Dependency graphs *K=f(Ko, θq,)*

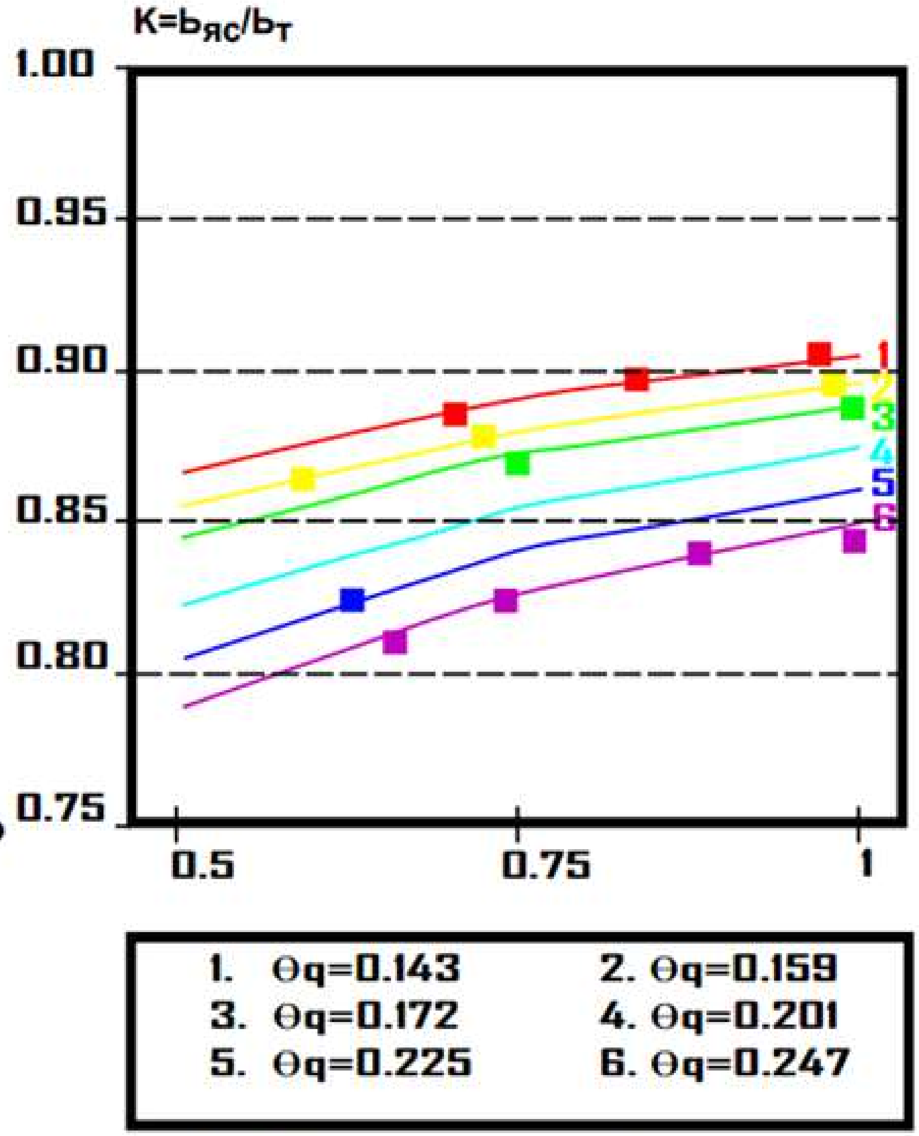


Fig.3.20. Dependency graphs *K=f(ξ,θq)*

3.4.Calculation of the velocity field in the compression region, taking into account the development of inter-dam floodplain space

3.4.1. Velocity distribution in the zone of a weakly perturbed core

Based on the results of studies (fig.3.21) and data from [1, 9], it is established that the velocity distribution in any alignment from the upper edge of the dam to the compressed section along the width of the core on the floodplain is satisfactorily described by the parabolic dependence(1.33) (fig.3.11). Where U_{max} is the velocity formed at the boundary weakly perturbedcore and zone of intense turbulent mixing; U_{min} is the velocity formed at the floodplain boundary of the zone of interaction between the channel and floodplain flows. Due to the fact that the relative minimum velocity in the core ($U_{min}/U_{min\ c}$) increases more intensively as it moves away from the constraint pack (fig.3.22) than the relative maximum velocity ($U_{max}/U_{max c}$)(fig.3.23), the plot of the velocity distribution in the compressed section is more uniform (fig.3.24) [80]:

$U_{\max c} \approx U_{\min c} \approx U_{ЯС}$, where $U_{ЯС}$- the average flow velocity in a weakly perturbed core in a compressed section on a floodplain.

The values of average velocities in the compressed section on the floodplain and in the riverbed are determined according to the formulas proposed by A.M.Latyshenkov [41]:

-in line $v_{pc}=v_p \beta_p$ (3.19)

-on the floodplain $U_{ЯС}= v_n\left(1+\alpha_o\left(\beta_p-1\right)\right)$, (3.20)

where v_p- the speed in the riverbed in the domestic state;

v_n- speed on the floodplain in the normal state.

β_p-coefficient of velocity increase in the channel part of the compressed sectioncalculated by formula (3.6) with drawing of referencepoints (fig.3.25) by various authors.

At the same time, the maximum speed in the riverbed (U_{pc}) according to M.R.Bakiyev is 2...8% higher than the average.Velocity distribution in the riverbed interaction zone and floodplain flows are calculated using the formula (2.6).

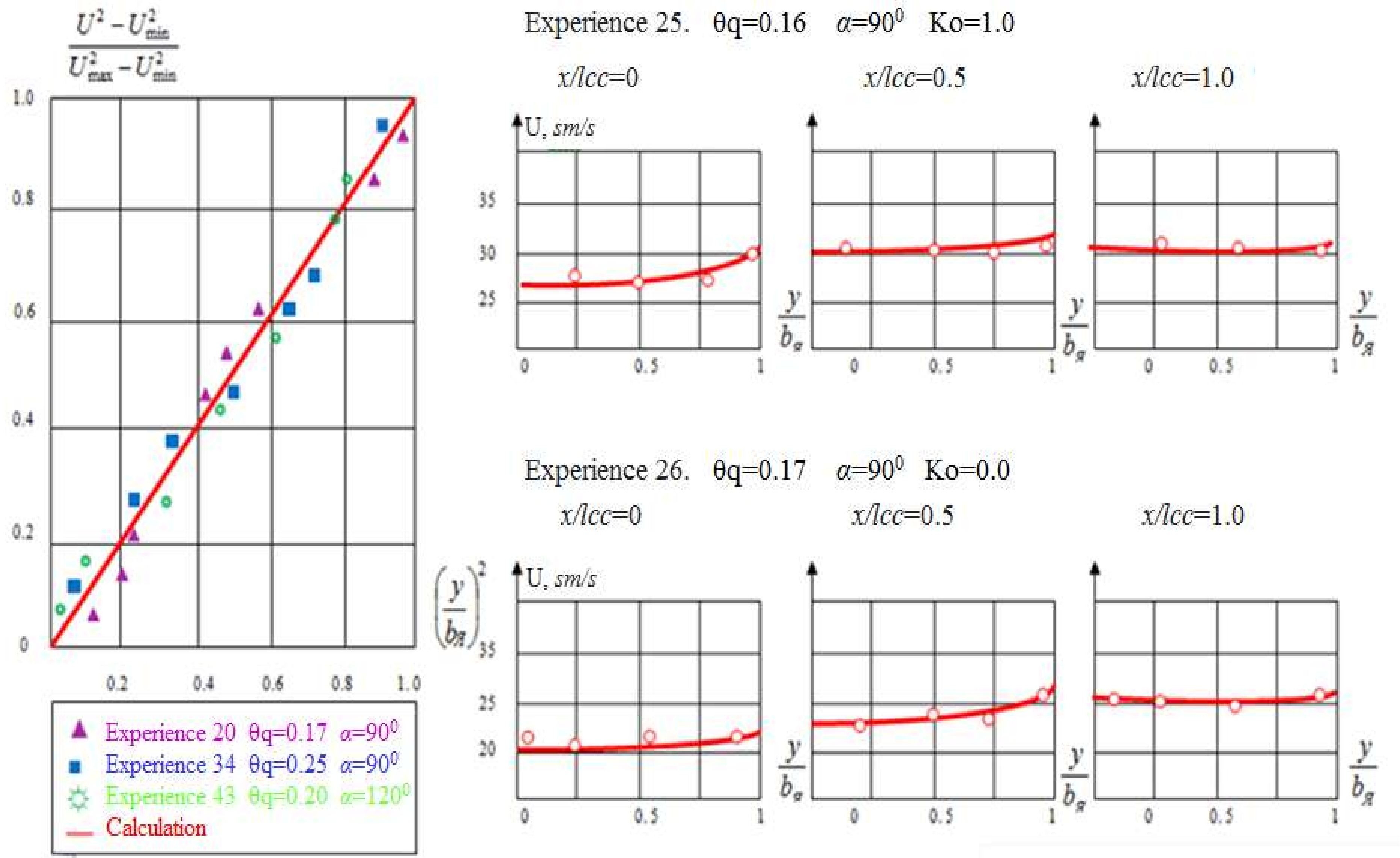


Fig.3.21. Comparison of experimental data and calculated velocity diagrams in the zone of a weakly disturbed core (compression region)

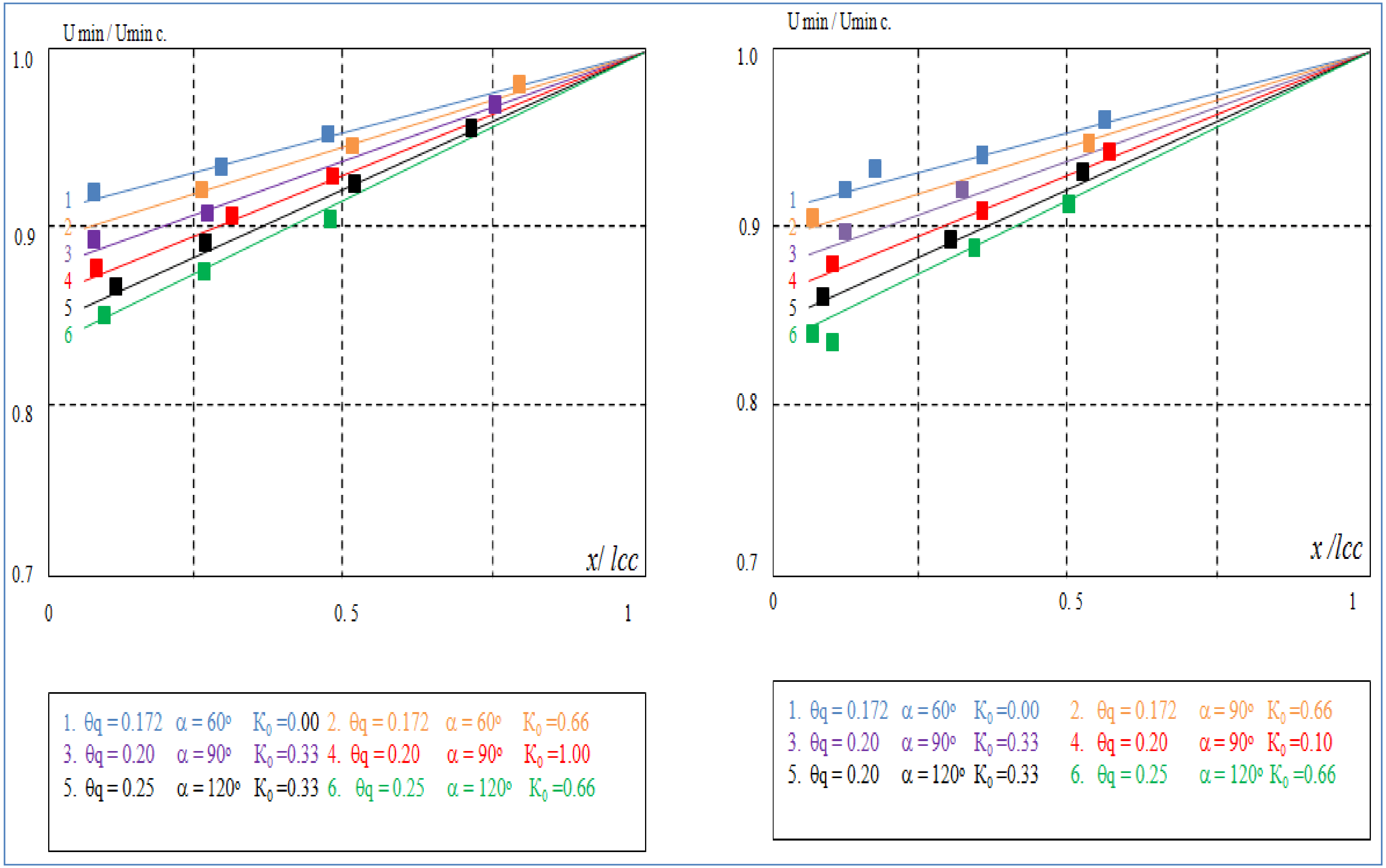
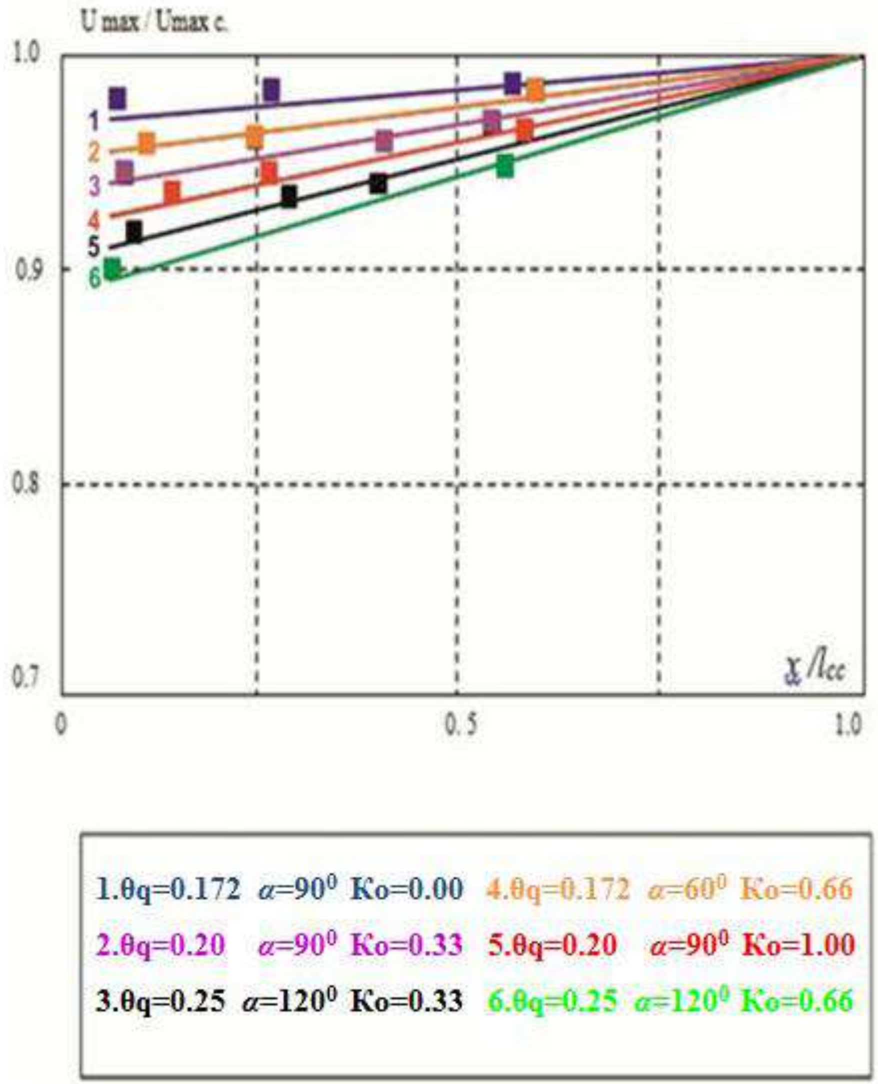


Fig.3.22. Graphs of changes in relative velocities in the compression region

A.On track

B.On the floodplain



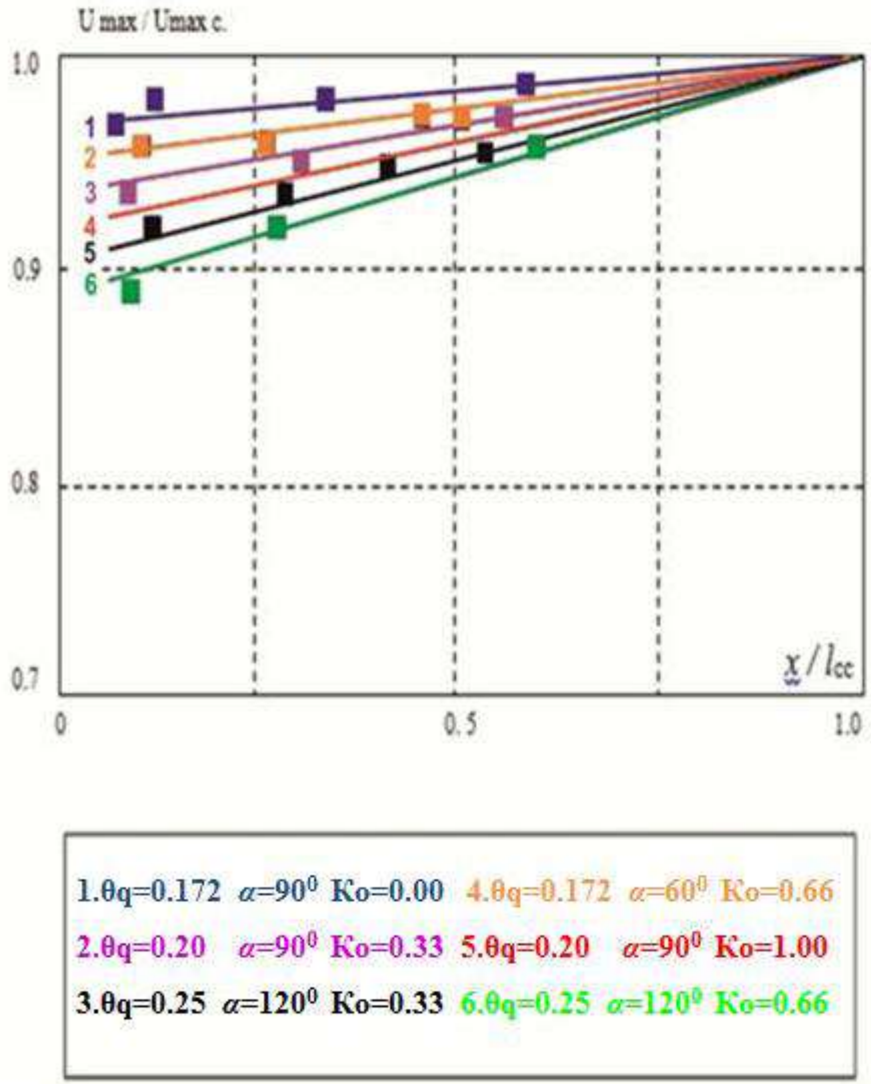


Fig.3.23. Graphs of changes in relative velocities in the compression region
A.On track
B.On the floodplain

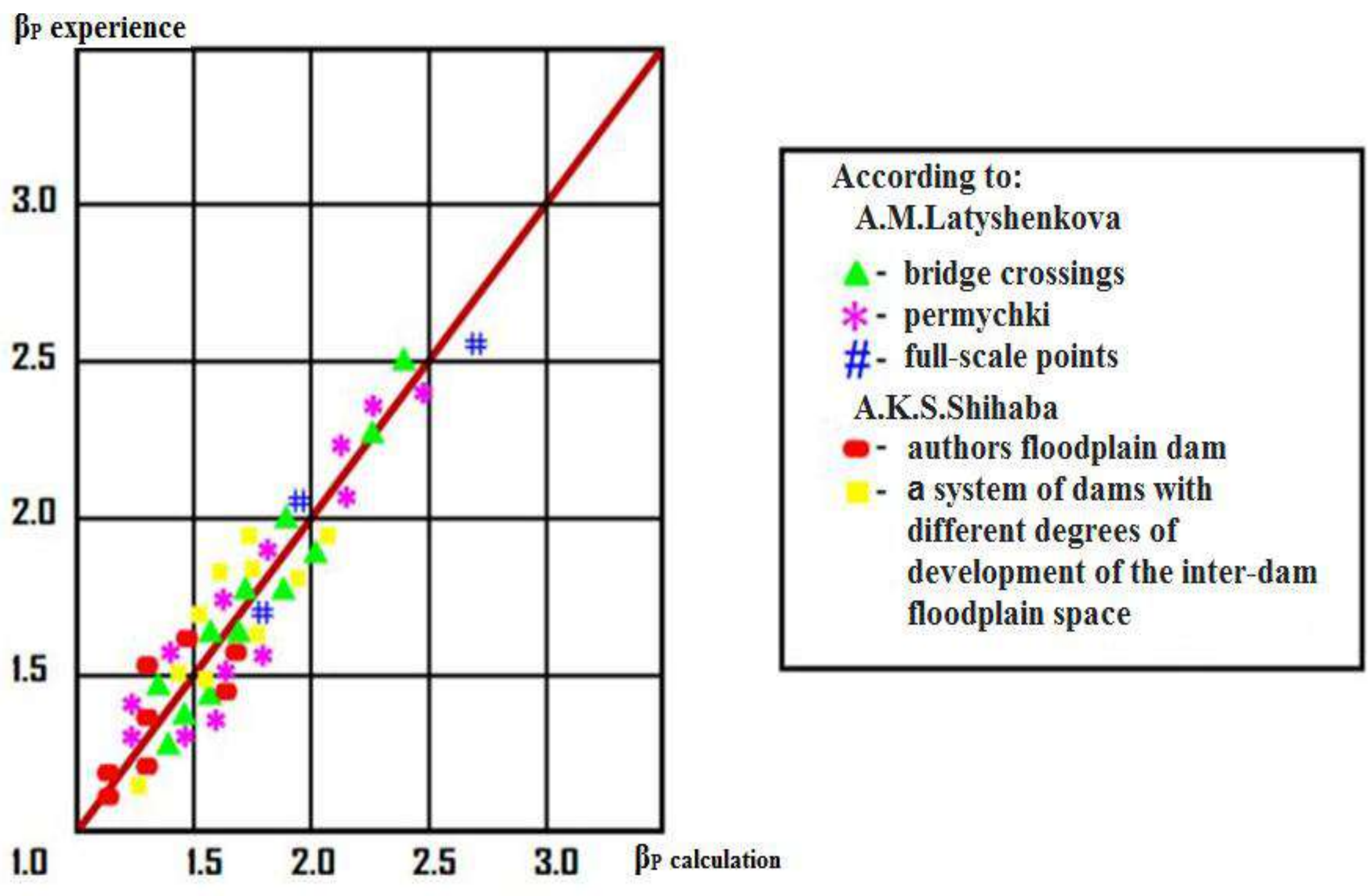


Fig.3.24. Comparison of experimental and calculated coefficient values β_P

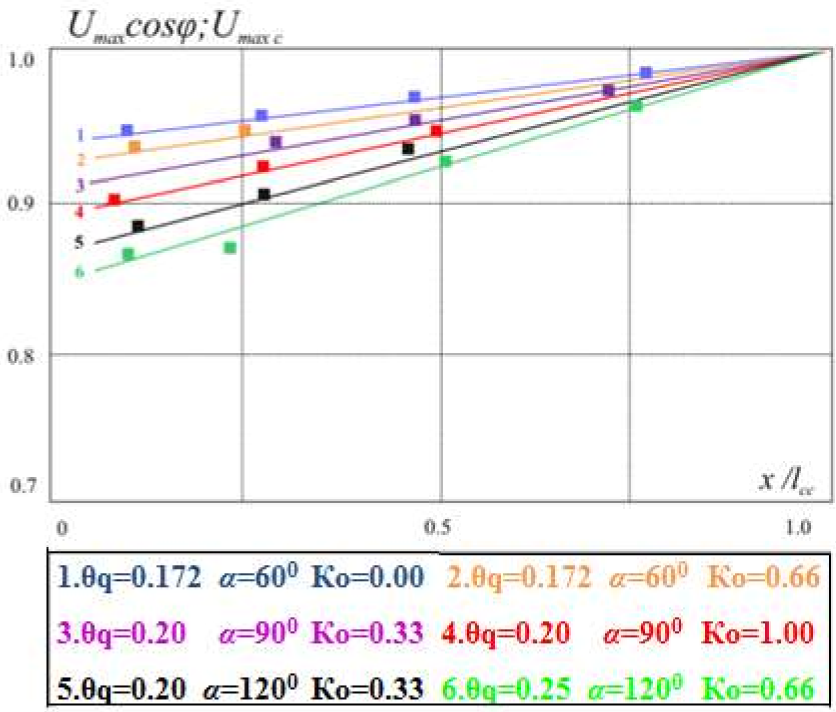


Fig.3.25. Graphs of changes in relative velocities in the compression region, taking into account the direction of the vector φ_{cp}. On the floodplain.

When constructing the velocity field in the zone of a weakly perturbed core, we use the following dependences;

- to determine the length of the velocity vector

$$U=\sqrt{U_{min}^2+(y/b_я)^2\left[U_{max}^2-U_{min}^2\right]} \tag{3.21}$$

-to determine the length of the longitudinal component of the velocity vector, taking into account the directionof the velocity vector φ_{cp} Schlichting-Abramovich (fig.26)

$$U_{np}=\sqrt{U_{min}^2+(y/b_Я)^2\left[(U_{max}\cos\phi_{cp})^2-U_{min}^2\right]} \tag{3.22}$$

- direction of the maximum velocity vector in the core area

$$cos\,\phi_{cp}=\frac{U_{np}}{U} \tag{3.23}$$

3.4.2. Velocity distribution in areas of intense turbulent mixing and reverse currents

Velocity distributioninthe turbulentmixing zone forthe compression region obeys the universal Schlichting-Abramovich dependence (fig.3.27):

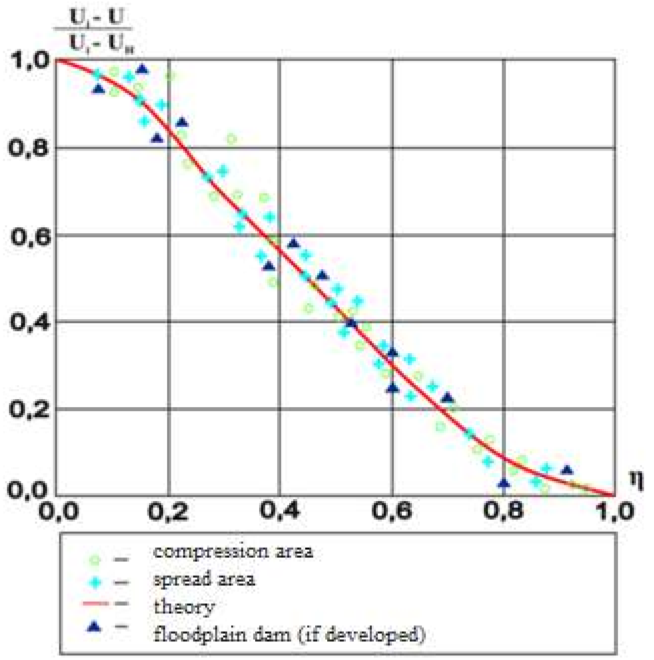


Рис.3.26. Dimensionless velocity profile in the turbulent mixing zone

$$(U_{\max}-U)/(U_{\max}-U_{н})=\left(1-\eta^{3/2}\right)^2, \qquad (3.24)$$

where $U_{\max}$ - the maximum velocity that is formed at the boundary between a weakly perturbed core and a zone of intense turbulent mixing.

U - velocity in the zone of intense turbulent mixing.

U_N - speed in the reverse current zone.

$\eta=(y_2-y)/(y_2-y_1)$ - relative ordinate of the point where U is defined.

Due to the small value of the reverse velocity - U_n, in the compression region, it was not possible to record the instruments in experiments. However, due to the increased flow ratesatthe boundary between the weakly perturbed coreandthe zone of intense turbulent mixing, a low-pressure region is formed, which causes intensive absorption of liquid from the zone of reverse currents into the transit flow. Replenishment of water consumption in the reverse current zone is possible only due to the amount of water flowing through the compressed cross-section, which proves the presence of a reverse velocity. The value of the return velocity in the compressed section is determined from the flow conservation equation written for the *C-C* gate and the gate where there is a domestic flow state (fig.3.24) [74]:

$$Q=b'_{ЯC}h_{pc}U_{pc}+b_p h_{pc}\int_{O}^{b_P}Udy+b_n h_{nc}\int_{b_P}^{b_e}Udy+b_{ЯC}h_{nc}U_{ЯC}+b_c h_{nc}\int_{Y_1}^{y_2}Udy+(B_n-b_n-b_{ЯC}-b_c-K_O l_{Ш}\sin a)h_{nc}U_{HC} \qquad (3.25)$$

where h_{pc}, h_{nc}-water depths in a compressed section in the channel and on the floodplain, respectively;

$b'_{ЯC}, b_{ЯC}$ - core widths in the compressedcross-section in the riverbed and onthe floodplain,respectively.

b_p, b_n - widths of the zonesof interaction of riverbed and floodplain streams in the riverbed and on the floodplain, respectively.

B_n - width of the floodplain.

b_C - width of the zone of intense turbulent mixing incompressed cross-section.

The velocity distribution is assumed in the zone of interaction of riverbed and floodplain flows according to the dependence(2.6), and in the zone of intense turbulent-mixing according to the dependence(3.24). After integration(3.25), we have:

$$Q = b'_{ЯC} h_{pc} U_{pc} + b_e h_{pc} U_{pc} (\phi_1 + m_{pc}\phi_2) + b_e h_{nc} U_{pc} (\phi_3 + m_{pc}\phi_4) + b_{ЯC} h_{nc} U_{ЯC} + \\ + b_c h_{nc} U_{ЯC} (0.55 + 0.45 m_{HC}) + (B_n - b_n - b_{ЯC} - b_c - K_O l_Ш \sin\alpha) h_{nc} U_{HC} \tag{3.26}$$

where $$\phi_1 = \frac{b_p}{b_e} - 0.8\left(\frac{b_p}{b_e}\right)^{2.5} + 0.25\left(\frac{b_p}{b_e}\right)^4 \tag{3.27}$$

$$\phi_2 = 0.8\left(\frac{b_p}{b_e}\right)^{2.5} - 0.25\left(\frac{b_p}{b_e}\right)^4 \tag{3.28}$$

$$\phi_3 = \left(1 - \frac{b_p}{b_e}\right) - 0.8\left[1 - \left(\frac{b_p}{b_e}\right)^{2.5}\right] + 0.25\left[1 - \left(\frac{b_p}{b_e}\right)^4\right] \tag{3.29}$$

$$\phi_4 = 0.8\left[1 - \left(\frac{b_p}{b_e}\right)^{2.5}\right] - 0.25\left[1 - \left(\frac{b_p}{b_e}\right)^4\right] \tag{3.30}$$

$$b_e = b_p + b_n;\ m_{pc} = U_{ЯC}/U_{pc};\ m_{нс} = U_{нс}/U_{ЯC}$$

Assuming $$K_1 = \phi_1 + m_{pc}\phi_2 \tag{3.31}$$

$$K_2 = \phi_3 + m_{pc}\phi_4 \qquad 3.32)$$

and dividing both sides of the equality by $b_o h_{nc} U_{ЯC}$, we get:

$$\frac{Q}{b_o h_{nc} U_{ЯC}} = \frac{U_{pc}}{U_{ЯC}}\left[\bar{b}'_{ЯC} \bar{h}_{pc} + \bar{b}_e \bar{h}_{pc} K_1 + \bar{b}_e K_2\right] + \bar{b}_{ЯC} + \\ + 0.55\bar{b}_c + 0.45\bar{b}_c m_{HC} + (\bar{B}_n - \bar{b}_n - \bar{b}_{ЯC} - \bar{b}_c - K_O \bar{l}_Ш \sin\alpha) m_{HC} \tag{3.33}$$

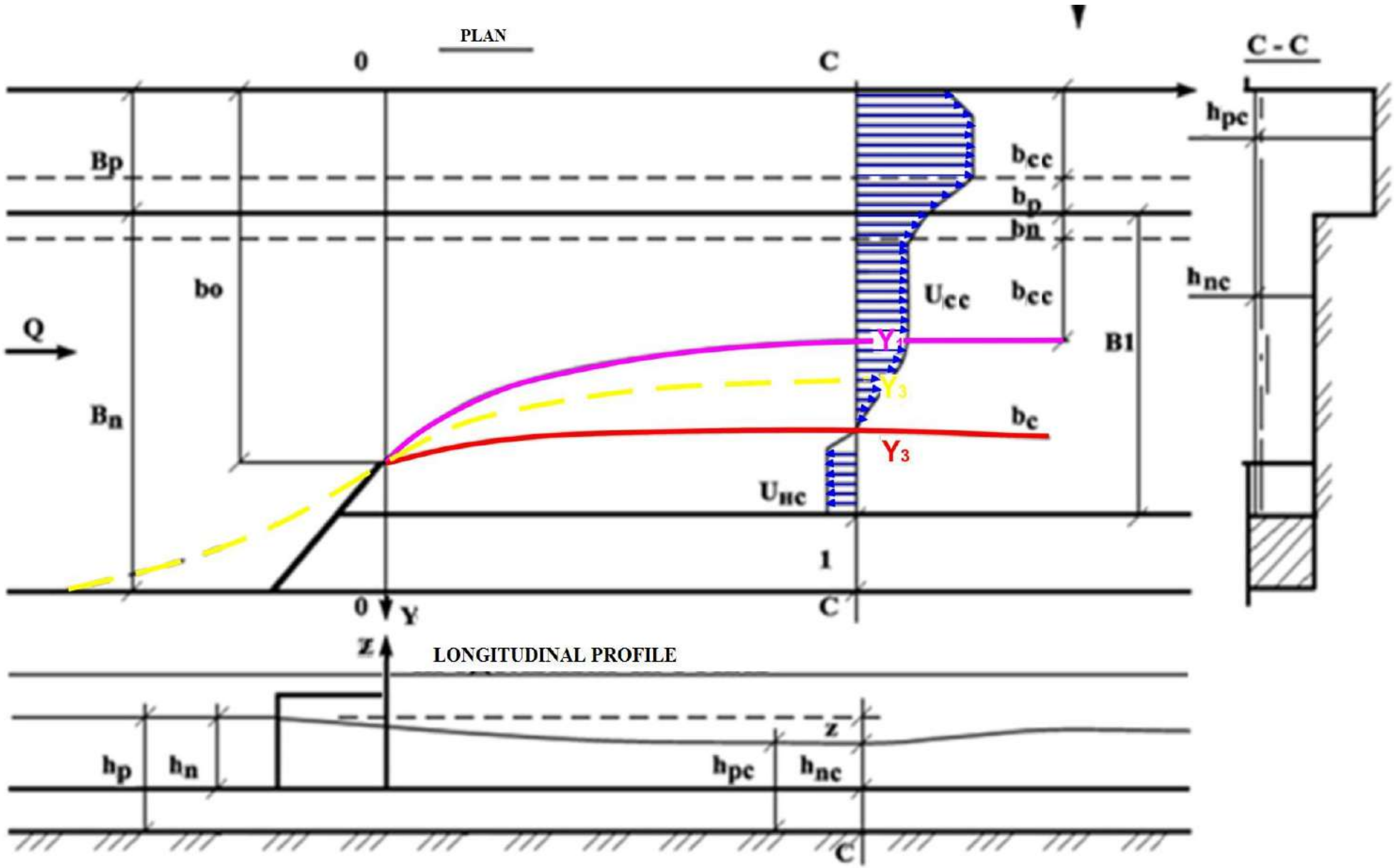


Fig.3.27.Design model of flow at contracted section

where $\bar{l}_{Ш} = l_{Ш} / b_o$; $\bar{h}_{pc} = h_{pc} / h_{nc}$; $\bar{B}_n = B_n / b_o$; $\bar{b}_e = b_e / b_o$;

$\bar{b}_n = b_n / b_o$; $\bar{b}_c = b_c / b_o$, $\bar{b}'_{яс} = b'_{яс} / b_o$.

Where do we get the law of change of relative inverse velocities in a compressed section, which has the form:

$$m_{нс} = \frac{U_{нс}}{U_{яс}} = \frac{\dfrac{Q}{b_o h_{nc} U_{яс}} - \dfrac{U_{pc}}{U_{яс}}\left[\bar{b}'_{яс}\bar{h}_{pc} + \bar{b}_e \bar{h}_{pc} K_1 + \bar{b}_e K_2\right] - \bar{b}_{яс} - 0{,}55\bar{b}_c}{\bar{B}_n - \bar{b}_n - \bar{b}_{яс} - 0{,}55\bar{b}_c - K_o \bar{l}_{Ш} Sin\alpha}; \qquad (3.34)$$

As can be seen from this relationship, an increase in the development of inter-dam floodplain space, all other things being equal, leads to an increase in reverse velocities in the compressed section.

Reverse speeds decrease rapidly as you approach the tightness-zone. Their values along the compression region can be approximately determined by the expression, proposed by M.R.Bakiev [9]:

$$U_{Hi} = U_{HC}(x / lcc)^2, \qquad (3.35)$$

where U_{Hi} – is the value of the inverse velocity in the alignment *i* with the abscissa *x*.

CONCLUSIONS of the CHAPTER III

Based on the experimental and theoretical studies carried out to study the influence of partial development of the inter-dam space on the hydraulic and kinematic characteristics of the regulated flow in the area of backwater and compression, the following conclusions can be drawn:

1. When installing a single dam and when the dam system is freely spreading, when $\xi = 1$ and when the absorption coefficient $Ko = 0$, the nature of the change in the level regime remains identical with the formation of backwater, areas of compression and spreading.

2. When installing a dam system, under the influence of the underlying dam, the depth behind the compressed section increases more intensively. The decrease ξ leads to an intensive increase in the depth of water in the spreading area, and when $\xi < 0.5$ the underlying dam falls into the whirlpool zone created by the first dam.

3.With an increase in the development coefficient, there is an equalization of water levels in the middle of the stream and at the opposite bank, and at the protected bank the water level decreases. When, $Ko = 0.5$ the connection between the dams disappears and they begin to work as single ones. When, $Ko = 1$ there is an abrupt rise in the water level behind the compressed section.

4.Graphical and analytical dependences are proposed fordetermining the length of the upper wateroflow zone and the compression region depending on the degree of flow θq, the angle of installation of the dam α, andthe coefficientof development of the inter-dam space Ko.

5.The backwater in front of the first dam is determined according to the recommendations of A.M.Lateyshenkov. At the same time, graphical dependencies are ε_{np} proposed to determine the area compression ratio $\varepsilon_{np} = f(\theta \text{q}, \text{Ko}, \alpha)$. An increase was established with ε_{np} increasing coefficient of development of the inter-dam floodplain space Ko, from $\varepsilon_{np} = 0.86$ at $Ko = 0$ to at $\varepsilon_{np} = 0.92$ at $Ko = 1$.

6.Analysis of the velocity field has shown, that the overall picture is qualitatively similar to that adopted in the theoryof turbulent jets with the formation of zones: weaklydisturbed poisonpa, intensive turbulent mixing,reverse currents, and the interaction of riverbed and floodplain flows.

To establishthe boundaries of these zones, analytical dependences are proposedthat depend on the planned compression coefficient E, the relative core K, the inter-dimensional space development coefficient Ko, and therelative distance from the constraint x / l_{cc}.

7.To determine E, K предло, graphical and analytical dependencesare used as functions of the flow θq, the relativeedistance between dikes ξ, the dike installation angle α, and the development coefficient Ko.

8. To determine E, K graphical and analytical dependencies are proposed as a function of flow θq constraint, relative spreading between dams ξ, dam installation angle α, and development coefficient Ko.

The increase Ko leads to an increase E and K.

8.The velocity distribution in the zone of a weakly perturbed core is satisfactorily described by the parabolic dependence proposed by M.R.Bakiev.Todetermine the nature of changes in the maximum and minimumvelocities along the lengthof the compression region, we propose graphical curves of maximuman $U_{\min}/U_{\min c} = f(\theta \text{q}, \alpha, \text{Ko})$ separately in the channel $U_{\max}/U_{\max c} = f(\theta \text{q}, \alpha, \text{Ko})$ and on the floodplain.

All other things being equal, an in $(\theta \text{q}, \alpha)$ crease Ko leads to a decrease in relative speeds.

9.We determine the magnitude of average velocities in a compressed section on the floodplain $U_{яс}$ and in the channel $V_{рс}$ using the formulas of A.M.Latyshenkov. The distribution of velocities in the zone of intense turbulent mixing obeys the Schlichting-Abramovich relationship.

10.To determine the reverse velocities in a compressed section, an analytical dependence is proposed, obtained by solving the flow conservation equation. As the analysis of the formula shows, an increase in the development of the inter-dam floodplain space, other things being equal, leads to an increase in reverse velocities in the compressed section.

CHAPTER IV.THEORETICAL STUDIESOF FLOW PATTERNS CONSTRAINED BY A SYSTEM OF DAMS BEHIND A COMPRESSED CROSS-SECTION, TAKING INTO ACCOUNT THE DEVELOPMENT OF INTER-DAM FLOODPLAIN SPACE

4.1. Experimental and theoretical studies

Asnoted in the previous chapters, theanalysis of experimental plots has shown that partial development of the interstitial floodplain space does not change the qualitative picture of the flow in the spreading area. This made it possible to consider the flow beyond the compressed cross-section, as in the works [1, 2, 3, 9, 10, 55, 62] consisting of the following hydraulically homogeneous zones:

- a weaklyperturbed kernel.
- intensive turbulent mixing;
- reverse currents.
- interaction of riverbed andfloodplain streams.

Experiments have shown that the hydraulic characteristics (width, depth, velocity) of the transit flow change in the spreading region due to the expansion of the flow, as well as under the action of external forces (bottom resistance, friction on the banks and at the edge of the whirlpool) [14].

It is experimentally established that in the zone of intense turbulent mixing, the velocity distribution obeys the universal Schlichting-Abramovich dependence written for the initial section of free turbulent jets:

$$(U_{ЯХ} - U)/(U_{ЯХ} - U_{H}) = \left(1 - \eta^{3/2}\right)^{2} \tag{4.1}$$

where U, U_{H} -average vertical flow velocities in the mixing zone and in the reverse flow zone, respectively;

η=(y_1--y)/(y_2-y_1) - relative coordinate of the vertical under consideration;

y_1, y_2 - coordinates of the inner and outer boundaries of the mixing zones;

y-coordinatesof the point under consideration;

y_2-y_1=b- width of the turbulent mixing zone $b=0,27x$at the initial section.

In the zone of interaction between the riverbed and floodplain flows, the velocity distribution is assumedby the formula (2.6)

Thus, the aim of theoretical research is to determine the law of velocity variation in the zone of a weakly perturbed core; the speed of reverse currents; the law of core width variation; the length of the water-gate zone and the depth of the flow at the end of the whirlpool of different roughness of the channel and floodplain, the presence of interactionsя taking into account the development of the interstitial floodplain space.

When solving problems, the following assumptions are made:

1.The problem is two-dimensional (flat).

2.Steady state flow mode.

3.It is assumed that the pressure distribution over the depth obeys the hydrostatic law, and the transverse pressure drop in the spreading zone is small.

1st calculated case (when b_{bx}>0)

A. To determine the velocity value in a weakly perturbed core in a riverbed, taking into account the development of inter-dam floodplain space, we use an integral relation that characterizes the law of conservation of momentum in the flow. The above equation is written for a liquid compartment bounded by the C-C and X-X sections, the bottom and lateral flow boundaries (fig.4.1):

$$\begin{aligned}&(B_p - b_p)h_{pc}U_{pc}^2 + h_{pc}\int_o^{b_p} U^2 dy + h_{pc}\int_{b_p}^{b_e} U^2 dy + b_{яс}h_{pc}U_{яс}^2 + h_{nc}\int_{y_1}^{y_2} U^2 dy + (B_n - b_n - b_{яс} - b_c - K_0 l_{Ш}\sin\alpha)h_{nc}U_{HC}^2 = \\ &= (B_p - b_p)h_{px}U_{px}^2 + h_{px}\int_O^{b_p} U^2 dy + h_{nx}\int_{b_p}^{b_e} U^2 dy + b_{ях}h_{nx}U_{ях}^2 + h_{nx}\int_{y_1}^{y_2} U^2 dy + (B_n - b_n - b_{ях} - b_x - K_0 l_{Ш}\sin\alpha)h_{nx}U_{HX}^2 + \\ &+ \int_0^x \int_0^{B_p} \frac{\lambda_p}{2} U^2 dydx + \int_0^x \int_0^{(B_n - K_0 l_{Ш}\sin\alpha)} \frac{\lambda_n}{2} U^2 dydx\end{aligned} \qquad (4.2)$$

where h_{px}, h_{nx} - the depth of water in the area of spreading in the riverbed and on the floodplain, respectively.

$b_{ЯX}$ - core width in the area of spreading in the channel;

b_X - width of the zone of intense turbulent mixing inthe spreading area.

To facilitate the solution, the water depth in the spreading area is assumed to be:

- in line $h_{px} = h_{pc} = h_p = Const = 0{,}5\ (h_{pc} + h_{p\sigma})$

-on the floodplain $h_{nx} = h_{nc} = h_n = Const = 0{,}5\ (h_{nc} + h_{n\sigma})$,

where $h_{p\sigma}$, $h_{n\sigma}$ - the domestic depth of the stream in the riverbed and on the floodplain, respectively.

The friction forces in the calculated section are calculated from the average velocities, taking into account the dependencies(3.19,3.20), we get:

$$\nu_{p*} = 0.5(U_{PC} + \nu_p) = 0.5\nu_p(\beta_p + 1) \tag{4.3}$$

$$\nu_{n*} = 0.5(U_{ЯC} + \nu_n) = 0.5\nu_n(2 + \alpha_0(\beta_p)) \tag{4.4}$$

The use of the universal Schlichting-Abramovich dependence (4.11) for the zone of intense turbulent mixing in equation (4.22) causes mathematical difficulties in integration. But M.A. Mikhalev [55] established that in the equation of momentum the reverse speed can be neglected if the condition is satisfied $-0.6 < (U_H / U_{ЯX}) < 0$ Considering the above, after integrating (4.22), we have [11]:

$$\begin{aligned}
&(B_p - b_p)h_p U_{pc}^2 + b_e h_p U_{pc}^2(\phi_5 + m_{pc}\phi_6 + m_{pc}^2\phi_7) + b_e h_n U_{pc}^2(\phi_8 + m_{pc}\phi_9 + m_{pc}^2\phi_{10}) + \\
&+ b_{ЯC} h_n U_{ЯC}^2 + 0.416 b_c h_n U_{ЯC}^2 = (B_p - b_p)h_p U_{px}^2 + b_e h_p U_{px}^2(\phi_5 + m_{px}\phi_6 + m_{px}^2\phi_7) + \\
&+ b_e h_n U_{px}^2(\phi_8 + m_{px}\phi_9 + m_{px}^2\phi_{10}) + b_{Яx} h_n U_{Яx}^2 + 0.416 b_X h_n U_{Яx}^2 + \\
&+ \frac{\lambda_p}{2}\nu_{p*}^2 B_{p^*} + \frac{\lambda_n}{2}\nu_{n*}^2\left(B_n - K_O l_Ш \sin\alpha - \frac{b_{Hc} + b_{Hx}}{2}\right)x
\end{aligned} \tag{4.5}$$

where $m_{px} = U_{Яx}/U_{px}$; $m_{pc} = U_{ЯC}/U_{pc}$;

$$\phi_5 = \frac{b_p}{b_e} - 1.6\left(\frac{b_p}{b_e}\right)^{2.5} + 1.5\left(\frac{b_p}{b_e}\right)^4 - 0.727\left(\frac{b_p}{b_e}\right)^{5.5} + 0.143\left(\frac{b_p}{b_e}\right)^7$$

$$\phi_6 = 1.6\left(\frac{b_p}{b_e}\right)^{2.5} - 2.5\left(\frac{b_p}{b_e}\right)^4 + 1.454\left(\frac{b_p}{b_e}\right)^{5.5} - 0.286\left(\frac{b_p}{b_e}\right)^7$$

$$\phi_7 = \left(\frac{b_p}{b_e}\right)^4 - 0.727\left(\frac{b_p}{b_e}\right)^{5.5} + 0.143\left(\frac{b_p}{b_e}\right)^7$$

$$\varphi_8 = 1 - \frac{b_p}{b_e} - 1.6\left[1 - \left(\frac{b_p}{b_e}\right)^{2.5}\right] + 1.5\left[1 - \left(\frac{b_p}{b_e}\right)^4\right] - 0.727\left[1 - \left(\frac{b_p}{b_e}\right)^{5.5}\right] + 0.143\left[1 - \left(\frac{b_p}{b_e}\right)^7\right]$$

$$\phi_9 = 1.6\left[1 - \left(\frac{b_p}{b_e}\right)^{2.5}\right] - 2.5\left[1 - \left(\frac{b_p}{b_e}\right)^4\right] + 1.454\left[1 - \left(\frac{b_p}{b_e}\right)^{5.5}\right] - 0.286\left[1 - \left(\frac{b_p}{b_e}\right)^7\right]$$

$$\phi_{10}=\left[1-\left(\frac{b_p}{b_e}\right)^4\right]-0.727\left[1-\left(\frac{b_p}{b_e}\right)^{5.5}\right]+0.143\left[1-\left(\frac{b_p}{b_e}\right)^7\right]$$

Assuming $K_3=\left(\phi_5+m_{pc}\phi_6+m_{pc}^2\phi_7\right)$; $K_4=\left(\phi_8+m_{pc}\phi_9+m_{pc}^2\phi_{10}\right)$;

$K_5=\left(\phi_5+m_{px}\phi_6+m_{px}^2\phi_7\right)$; $K_6=\left(\phi_8+m_{px}\phi_9+m_{px}^2\phi_{10}\right)$

and dividing both parts of the equation by $b_o h_p$ from (4.55), we get:

$$\begin{aligned}&U_{pc}^2\left(\bar{B}_p-\bar{b}_p+\bar{b}_e K_3+\bar{b}_e\bar{h}_n K_4+\bar{b}_{яс}\bar{h}_n m_{pc}+0.416\bar{b}_c\bar{h}_n m_{pc}^2\right)=\\&=U_{px}^2\left(\bar{B}_p-\bar{b}_p+\bar{b}_e K_5+\bar{b}_e\bar{h}_n K_6+\bar{b}_{ях}\bar{h}_n m+0.416\bar{b}_x\bar{h}_n m^2\right)+\\&+\frac{\lambda_p}{2}v_{p*}^2\frac{B_p x}{b_o h_p}+\frac{\lambda_n}{2}v_{n*}^2\left(B_n-K_O l_Ш\sin\alpha-\frac{b_{Hc}+b_{Hx}}{2}\right)\frac{x}{b_O h_p},\end{aligned}\tag{4.6}$$

where $\bar{b}_p=b_p/b_o$; $\bar{B}_p=B_p/b_o$; $\bar{b}_{яс}=b_{яс}/b_o$; $\bar{b}_p^*=b_p/b_e$;

$\bar{b}_{ях}=b_{ях}/b_o$; $\bar{b}_c=b_c/b_o$; $\bar{h}_n=h_n/h_p$

From where:

$$U_{px}=\sqrt{\frac{U_{pc}^2\left(\bar{B}_p-\bar{b}_p+\bar{b}_e K_3+\bar{b}_e\bar{h}_n K_4+\bar{b}_{яс}\bar{h}_n m_{pc}^2+0.416\bar{b}_c\bar{h}_n m_{pc}^2\right)-\frac{a_p\xi}{2}v_{p*}^2-\frac{a_n\xi}{2}v_{n*}^2\bar{h}_n}{\bar{B}_p-\bar{b}_p+\bar{b}_e K_5+\bar{b}_e\bar{h}_n K_6+\bar{b}_{Ях}\bar{h}_n m_{px}^2+0.416\bar{b}_x\bar{h}_n m_{px}^2}},\tag{4.7}$$

where $a_p=\frac{\lambda_p B_p}{h_p}$; $a_n=\dfrac{\lambda_n(B_n-K_o l_ш\sin\alpha-\frac{b_{нс}+b_{нх}}{2})}{h_n}$; $\xi=\frac{x}{b_o}$.

The law of change in the relative velocity of a weakly disturbed core in the riverbed, taking into account the partial development of the inter-dam floodplain space, has the form:

$$\frac{U_{px}}{U_{pc}}=\sqrt{\frac{\bar{B}_p-\bar{b}_p+\bar{b}_e K_3+\bar{b}_e\bar{h}_n K_4+F_1\bar{h}_n m_{pc}^2-R_a}{\bar{B}_p-\bar{b}_p+\bar{b}_e K_5+\bar{b}_e\bar{h}_n K_6+F_2\bar{h}_n m_{px}^2}},\tag{4.8}$$

where $R_a=\frac{a_p\bar{v}_p^2}{2}\xi+\xi\frac{a_n\bar{v}_n^2}{2}\cdot\bar{h}_n$; $\bar{V}_p=V_p/U_{pc}$; $\bar{V}_n=V_n/U_{pc}$

$F_1=\bar{b}_{яс}+0{,}416\bar{b}_c$; $F_2=\bar{b}_{ях}+0{,}416\bar{b}_x$;

B. The change in the velocity of a weakly perturbed core along the length of the spreading area in the floodplain, taking into account the partial development of-the intertidal space, is determined by a joint solution of the equation describing the law of conservation of momentum and the flow conservation equation written for the same gates. The flow conservation equation for gates *C-C* and *X-X* has the form:

$$\begin{aligned}&(B_p - b_p)h_{pc}U_{pc} + h_{pc}\int_O^{b_p} Udy + h_{nx}\int_{b_p}^{b_e} Udy + b_{ЯC}h_{nc}U_{ЯC} + \\ &+ h_{nc}\int_{y_1}^{y_2} Udy + (B_n - b_n - b_{ЯC} - b_c - K_o l_{Ш}\sin\alpha)h_{nc}U_{HC} = \\ &= (B_p - b_p)h_{px}U_{px} + h_{px}\int_o^{b_p} Udy + h_{nx}\int_{b_p}^{b_e} Udy + b_{яx}h_{nx}U_{яx} + \\ &+ h_{nx}\int_{y_1}^{y_2} Udy + (B_n - b_n - b_{яx} - b_x - K_0 l_{Ш}\sin\alpha)h_{nx}U_{Hx}\end{aligned} \tag{4.9}$$

Due to the small value of the return velocity in the compressed section, we assume that $U_{NS}=0$. Integrating (4.9), we obtain:

$$\begin{aligned}&(B_p - b_p)h_pU_{pc} + b_eh_pU_{pc}(\phi_1 + m_{pc}\phi_2) + b_eh_nU_{pc}(\phi_3 + m_{pc}\phi_4) + \\ &+ b_{ЯC}h_nU_{ЯC} + 0.55b_ch_nU_{ЯC} = (B_p - b_p)h_pU_{px} + b_eh_pU_{px}(\phi_1 + m_{px}\phi_2) + \\ &+ b_eh_nU_{px}(\phi_3 + m_{px}\phi_4) + b_{Яx}h_nU_{Яx} + 0.55b_xh_nU_{Яx}\end{aligned} \tag{4.10}$$

Dividing the resulting equality by b_oh_p, after the transformation, we get:

$$\frac{U_{px}}{U_{pc}} = \frac{\bar{B}_p - \bar{b}_p + \bar{b}_e K_1 + \bar{b}_e \bar{h}_n K_2 + \bar{h}_n m_{pc}\left(\bar{b}_{яс} + 0.55\bar{b}_c\right)}{\bar{B}_p - \bar{b}_p + \bar{b}_e K_7 + \bar{b}_e \bar{h}_n K_8 + \bar{h}_n m_{px}\left(\bar{b}_{яx} + 0.55\bar{b}_x\right)} \tag{4.11}$$

where $K_7 = \phi_1 + m_{px}\phi_2$; $K_8 = \phi_3 + m_{px}\phi_4$.

The joint solution of (4.8) and (4.11) gives:

$$A_1m_{px}^2 + A_2m_{px} + A_3 = 0 \tag{4.12}$$

where $A_1 = Ф_1^2 Б_3 - D_1P_1^2$; $A_2 = Ф_1^2 Б_2 - 2M_1D_1P_1$; $A_3 = Ф_1^2 Б_1 - D_1M_1^2$;

$$D_1 = \bar{B}_p - \bar{b}_p + \bar{b}_eK_3 + \bar{b}_e\bar{h}_nK_4 + F_1\bar{h}_nm_{pc}^2 - R_a$$

$$P_1 = \bar{b}_e\phi_2 + \bar{b}_e\bar{h}_n\phi_4 + \bar{h}_nF_3; \qquad Ф_1 = \bar{B}_p - \bar{b}_p + \bar{b}_eK_1 + \bar{b}_e\bar{h}_nK_2 + \bar{h}_nF_4m_{pc};$$

$$M_1 = \bar{B}_p - \bar{b}_p + \bar{b}_e\phi_1 + \bar{b}_e\bar{h}_n\phi_3; \quad Б_1 = \bar{B}_p - \bar{b}_p + \bar{b}_e\phi_5 + \bar{b}_e\bar{h}_n\phi_8;$$

$$Б_2 = \bar{b}_e\phi_6 + \bar{b}_e\bar{h}_n\phi_9; \ Б_3 = \bar{b}_e\phi_7 + \bar{b}_e\bar{h}_n\phi_{10} + \bar{h}_nF_2; \ F_3 = \bar{b}_{яx} + 0.55\bar{b}_x; \ F_4 = \bar{b}_{яс} + 0.55\bar{b}_c;$$

Equation (4.12) is used to determine the law of change in the relative velocity of a weakly disturbed core along the spreading area on a floodplain, taking into account the partial development of the inter-dam floodplain space.

The value of the return velocity U_{Hx} in the whirlpool zone, taking into account the partial development of the interstitial floodplain space, is determined from the flow conservation equation (4.9) written for the sections *C-C* and *X-X* (fig.4.1).

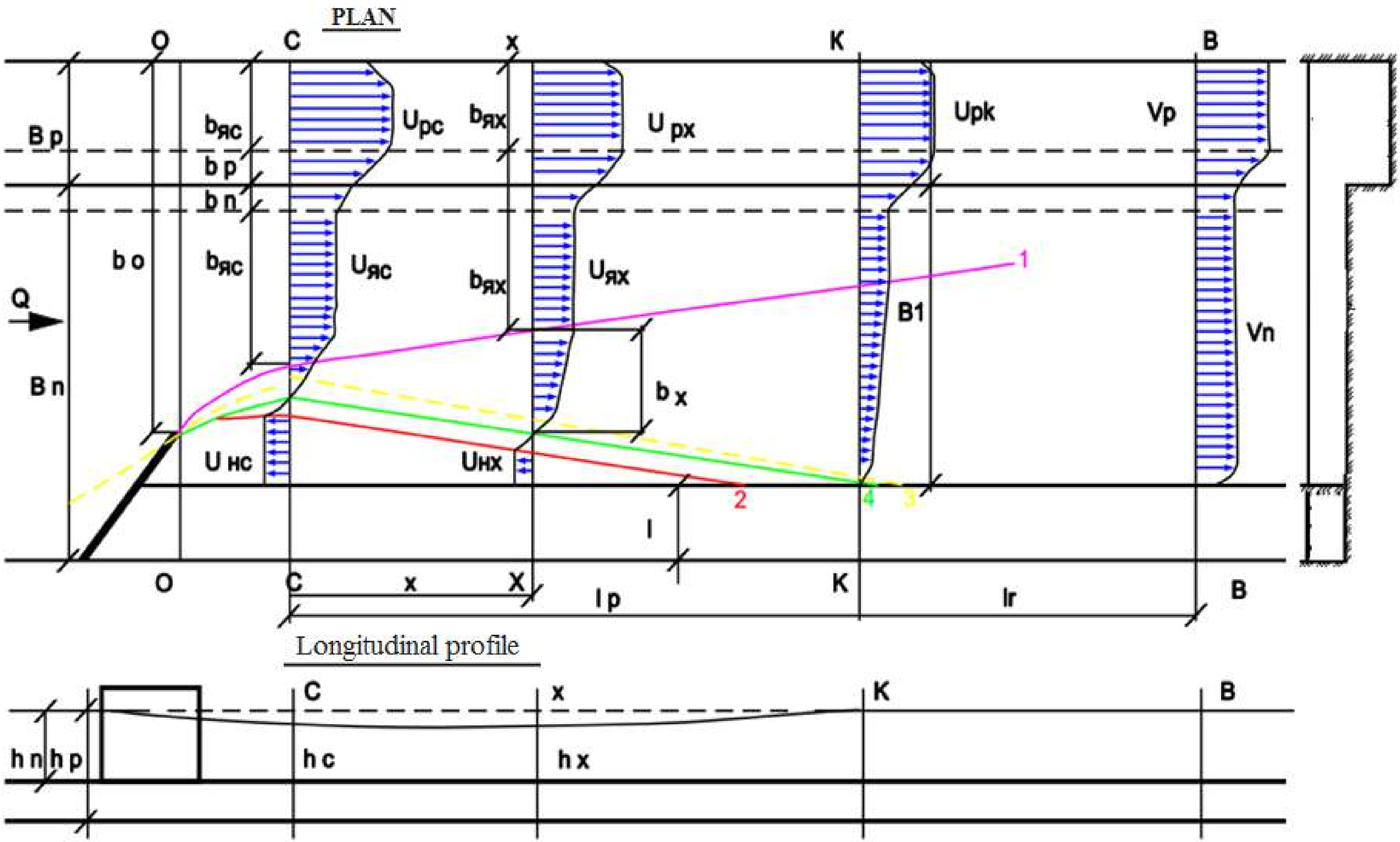


Fig. 4.1. Calculation scheme of flow spreading behind a compressed cross-section during partial development of the interphase space

Taking the velocity distribution in the zone of intense turbulent mixing according to dependence (4.1) and in the interaction zone according to (2.6)after integration, we obtain:

$$
\begin{aligned}
&\left(B_p - b_p\right)h_p U_{pc} + b_e h_p U_{pc}\left(\phi_1 + m_{pc}\phi_2\right) + b_e h_n U_{pc}\left(\phi_3 + m_{pc}\phi_4\right) + b_{ЯC} + \\
&+ b_c h_n U_{pc}\left(0.55 + 0.45 m_{Hc}\right) + \left(B_n - b_n - b_{Яc} - b_c - K_0 l_{Ш} \sin\alpha\right) h_n U_{Hc} = \\
&= \left(b_p - b_p\right) h_p U_{px} + b_e h_p U_{px}\left(\phi_1 + m_{px}\phi_2\right) + b_e h_n U_{px}\left(\phi_3 + m_{pn}\phi_4\right) + b_{Яx} h_n U_{Яx} + \\
&+ b_x h_n U_{px}\left(0.55 + 0.45 m_{Hx}\right) + \left(B_n - b_n - b_{Яx} - b_x - K_0 l_{Ш} \sin\alpha\right) h_n U_{Hx},
\end{aligned}
\tag{4.13}
$$

where $m_{Hx} = U_{Hx} / U_{Яx}$.

Dividing both sides of the equality by $U_{Яx} b_O h_p$, after the transformations we have:

$$
\begin{aligned}
&\frac{Upc}{U_{Яx}}\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_1 + \bar{b}_e \bar{h}_n K_2\right) + \frac{U_{Яc}}{U_{Яx}}\left(\bar{b}_{Яc}\bar{h}_n + \bar{b}_c\left(0.55 + 0.45 m_{Hc}\right)\right) + \frac{U_{Hc}}{U_{Яx}}\bar{b}_{Hc}\bar{h}_n = \\
&= \frac{1}{m_{px}}\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_7 + \bar{b}_e K_8\right) + \bar{b}_{Яx}\bar{h}_n + 0.55\,\bar{b}_x\bar{h}_n + 0.45\,\bar{b}_x \bar{h}_n m_{Hx} + m_{Hx}\bar{b}_{Hx}\bar{h}_n \quad ,
\end{aligned}
\tag{4.14}
$$

$$
\bar{b}_{Hx} = \left(B_n - b_n - b_{Яx} - b_x - K_0 l_ш \sin\alpha\right) / b_O.
$$

Hence, the law of change in the relative velocity of the reverse current over a compressed cross-section, taking into account the partial development of the inter-dam floodplain space, has the form:

$$
m_{нх} = \frac{\dfrac{U_{pc}}{U_{ях}} \cdot Б_4 + \dfrac{U_{яс}}{U_{ях}} \cdot Б_5 + \dfrac{U_{нс}}{U_{яс}} \cdot \bar{b}_{нс}\bar{h}_n - \dfrac{Б_6}{m_{px}} - \bar{h}_n(\bar{b}_{ях} + 0{,}55\bar{b}_x)}{\bar{h}_n(\bar{b}_{нх} + 0{,}45\bar{b}_x)}
\tag{4.15}
$$

where $Б_4 = \bar{B}_p - \bar{b}_p + b_e K_1 + \bar{b}_e \bar{h}_n K_2$; $Б_5 = \bar{b}_{яс}\bar{h}_n + \bar{b}_c(0{,}55 + 0{,}45 m_{нс})$; $Б_6 = \bar{B}_p - \bar{b}_p + \bar{b}_e K_7 + \bar{b}_e K_8$

2nd calculated case (whena b_{yx}=0)

A. From the equation describing the law of conservation of momentum in the flow, we determine the velocity value in a weakly disturbed core, taking into account the partial development of the inter-dam floodplain space. The equation written for gates *C-C*and *X-X*will have the form:

$$
\begin{aligned}
&(B_p - b_p)h_{pc}U_{pc}^2 + h_{pc}\int_o^{b_p} U^2 dy + h_{nc}\int_{b_p}^{b_e} U^2 dy + (B_n - b_n - b_{Hc} - \\
&- K_o l_{Ш} \sin\alpha)h_{nc}U_{Hc}^2 + h_{nc}\int_{y_1}^{y_2} U^2 dy + b_{Hc}h_{nc}U_{Hc}^2 = (B_p - b_p)h_{px}U_{px}^2 + h_{px}\int_o^{b_p} U^2 dy + \\
&+ h_{px}\int_o^{b_e} U^2 dy + (B_n - b_n - b_{Hx} - K_o l_{Ш} \sin\alpha)h_{nx}U_{Hc}^2 + h_{nx}\int_{y_1}^{y_2} U^2 dy + b_{Hx}h_{nx}U_{Hx}^2 + \\
&+ \int_o^x\int_o^{B_p} \frac{\lambda_p}{2} U dy dx + \int_o^x \int_o^{(B_n - K_o L_{Ш}\sin\alpha)} \frac{\lambda_n}{2} U dy dx
\end{aligned} \tag{4.16}
$$

Taking into account the assumptions and simplifications, as in the 1st calculated case after integration (4.16), we have:

$$
\begin{aligned}
&(B_p - b_p)h_p U_{pc}^2 + b_e h_p U_{pc}^2(\phi_5 + m_{pc}\phi_6 + m_{pc}^2\phi_7) + b_e h_n U_{pc}^2(\phi_8 + m_{pc}\phi_9 + m_{pc}^2\phi_{10}) + \\
&+ 0.416(B_n - b_n - b_{Hc} - K_o l_{Ш} \sin\alpha)h_n U_{Яc}^2 = (B_p - b_p)h_n U_{px}^2 + b_e h_n U_{px}^2(\phi_5 + m_{px}\phi + \\
&+ m_{px}^2\phi_7) + b_e h_n U_{px}^2(\phi_8 + m_{px}\phi_9 + m_{px}^2\phi_{10}) + 0.416(B_n - b_n - b_{Hx} - K_o l_{Ш} \sin\alpha)h_n U_{Яx}^2 + \\
&+ \frac{\lambda_p}{2}\nu_{p*}^2 B_{p*} + \frac{\lambda_n}{2}\nu_{n*}^2(b_n - K_o l_ш \sin\alpha - \frac{b_{Hc} + b_{Hx}}{2})x
\end{aligned} \tag{4.17}
$$

Dividing both parts of the equation by $b_o h_p$ from (4.17), we obtain:

$$
\begin{aligned}
&U_{pc}^2(\bar{B}_p - \bar{b}_p + b_e K_3 + \bar{b}_e \bar{h}_n K_4 + 0.416 b_{Tc}\bar{h}_n m_{pc}^2) = \\
&= U_{px}^2(\bar{B}_p - \bar{b}_p + \bar{b}_e K_5 + b_e h_n K_6 + 0.416 \bar{b}_{Tx}\bar{h}_n m_{px}^2) + \\
&+ \frac{\lambda_p}{2}\nu_{p*}^2 \frac{B_p x}{b_o h_p} + \frac{\lambda_n}{2}\nu_{n*}^2(B_n - K_o l_ш \sin\alpha - \frac{b_{Hc} + b_{Hx}}{2})\frac{x}{b_o h_p}
\end{aligned} \tag{4.18}
$$,

where $\bar{b}_{TC} = \dfrac{B_n - b_n - b_{Hc} - K_O l_ш \sin\alpha}{b_O}$; $\bar{b}_{Tx} = \dfrac{B_n - b_n - b_{Hx} - K_O l_ш sin\alpha}{b_O}$.

Hence, the law of change in the relative velocity of a weakly perturbed core in the riverbed, taking into account the partial development of the inter-dam floodplain space for the second calculated case, has the form :

$$
\frac{U_{px}}{U_{pc}} = \sqrt{\frac{\bar{B}_p - \bar{b}_p + \bar{b}_e K_3 + \bar{b}_e \bar{h}_n K_4 + 0.416\bar{b}_{Tc}\bar{h}_n m_P^2 - R_a}{\bar{B}_p - \bar{b}_p + \bar{b}_e K_5 + \bar{b}_e \bar{h}_n K_6 + 0.416\bar{b}_{Tc}\bar{h}_n m^2}} \tag{4.19}
$$

B. The change in the velocity of the core in the floodplain along the spreading area, taking into account the partial development of the inter-basin floodplain space, is determined by a joint solution of equation(4.16) and the equation of conservation of flow. The flow conservation equation written for the C-C and X-X gateshas the form:

$$\left(B_p - b_p\right)h_{pc}U_{pc} + h_{pc}\int_O^{b_p} Udy + h_{nc}\int_{b_p}^{b_e} Udy + \left(B_n - b_n - b_{Hc} - K_o l_ш \sin a\right)h_{nc}\int_{y_1}^{y_2} Udy + b_{Hc}h_{nc}U_{Hc} =$$
$$= \left(B_p - b_p\right)h_{px}U_{px} + h_{hx}\int_O^{b_p} Udy + h_{nx}\int_{b_p}^{b_e} Udy + \left(B_n - b_n - b_{Hx} - K_o l_ш \sin a\right)h_{nx}\int_{y_1}^{y_2} Udy + b_{Hx}h_{nx}U_{Hx} \quad (4.20)$$

integrating (4.20), I got:

$$\begin{aligned}&\left(B_p - b_p\right)h_p U_{pc} + b_e h_p U_{pc}\left(\phi_1 + m_{pc}\phi_2\right) + b_e h_n U_{pc}\left(\phi_3 + m_{pc}\phi_4\right) + \\ &+ 0.55\left(B_n - b_n - b_{Hc} - K_o l_ш \sin\alpha\right)h_n U_{Яc} = \left(B_p - b_p\right)h_p U_{px} + \\ &+ b_e h_p U_{px}\left(\phi_1 + m_{px}\phi_2\right) + b_e h_n U_{px}\left(\phi_3 + m_{px}\phi_4\right) + \\ &+ 0.55\left(B_n - b_n - b_{Hc} - K_o l_ш \sin\alpha\right)h_n U_{Яx}\end{aligned} \quad (4.21)$$

Dividing equality(4.21) by$b_o h_p$after transformation, we have :

$$\frac{U_{pc}}{U_{px}} = \frac{B_p - b_p + b_e K_7 + b_e h_n K_8 + 0.55 m_{pc} b_{Tc} h_n}{B_p - b_p + b_e K_1 + b_e h_n K_2 + 0.55 m_{px} b_{Tx} h_n} \quad (4.22)$$

The joint solutionof (4.19) and(4.22) gives:

$$A_{21}m_{px}^2 + A_{22}m_{px} + A_{23} = 0 \quad (4.23)$$

where $A_{21} = Ф_2^2 Б_{23} - D_2 P_2^2$, $A_{22} = Ф_2^2 Б_{22} - 2M_2 D_2 P_2$, $A_{23} = Ф_2^2 Б_{21} - D_2 M_2^2$

$$D_2 = \bar{B}_p - \bar{b}_p + \bar{b}_e K_9 + \bar{b}_e \bar{h}_n K_{10} + F_1 \bar{h}_n m_{pc}^2 - R_a$$

$$P_2 = \bar{b}_e \phi_2 + \bar{b}_e \bar{h}_n \phi_4 + \bar{h}_n F_3$$

$$Ф_2 = \bar{B}_p - \bar{b}_p + \bar{b}_e K_1 + \bar{b}_e \bar{h}_n K_2 + \bar{h}_n F_4 m_{pc} \quad M_2 = \bar{B}_p - \bar{b}_p + \bar{b}_e \phi_1 + \bar{b}_e \bar{h}_n \phi_3$$

$$Б_{21} = \bar{B}_p - \bar{b}_p + \bar{b}_e \phi_3 + \bar{b}_e \bar{h}_n \phi_8;\ Б_{22} = \bar{b}_e \phi_6 + \bar{b}_e \bar{h}_n \phi_9;\ Б_{23} = \bar{b}_e \phi_7 + \bar{b}_e \bar{h}_n \phi_{10} + \bar{h}_n F_2$$

Equation (4.23) is used to determine the law of change in the relative velocityin the core on a floodplain along the spreading area, taking into account the partial development of the intertidal space.

B. The value of the return velocity U_{Hx} in the whirlpool zone in the spreading area, taking into account the partial development of the inter-dam floodplainspace, is determined from the flow conservation equation written for the cross section *X-X*and the target, where the household flow parameters are preserved:

$$Q = \left(B_p - b_p\right)h_{px}U_{px} + h_{hx}\int_O^{b_p} Udy + h_{nx}\int_{b_p}^{b_e} Udy + \left(B_n - b_n - b_{Hx} - K_o l_ш \sin a\right)h_{nx}\int_{y_1}^{y_2} Udy + b_{Hx}h_{nx}U_{Hx} \quad (4.24)$$

After integrating (4.24), we obtain :

$$Q=\left(B_p-b_p\right)h_pU_{px}+b_eh_pU_p\left(\phi_1+m_{px}\phi_2\right)+b_eh_nU_p\left(\phi_3+m_{px}\phi_4\right)+$$
$$+\left(B_n-b_n-b_{Hx}-K_ol_{Ш}\sin\alpha\right)h_n\left(0.55+0.45m_{Hx}\right)U_{Яx}+b_{Hx}h_nU_{Hx}\quad , \tag{4.25}$$

where $m_{Hx}=U_{Hx}/U_{Яx}$.

Dividing both sides of the equality by $U_{Яx}b_Oh_p$, after conversion, we have:

$$\frac{Q}{U_{Яx}b_Oh_p}=\frac{U_{px}}{U_{Яx}}\left(\bar{B}_P-\bar{b}_p+\bar{b}_e\,K_7+\bar{b}_e\,\bar{h}_n\,K_8\right)+\left(0.55+0.45m_{Hx}\right)\bar{b}_{Tx}\,\bar{h}_n+\bar{b}_{Hx}\,\bar{h}_n\,m_{Hx} \tag{4.26}$$

Hence the law of change in the relativevelocity of the reverse current over a compressed cross-section, taking into account the partial development of the inter-dam floodplain space:

$$m_{HX}=\frac{\dfrac{Q}{U_{ЯX}b_Oh_P}-\dfrac{U_{PX}}{U_{ЯX}}\left(\bar{B}_P-\bar{b}_P+\bar{b}_e\,K_7+\bar{b}_e\,\bar{h}_n\,K_8\right)-0.5\bar{b}_{TX}\,\bar{h}_n}{\bar{h}_n\left(0.45\bar{b}_{TX}+\bar{b}_{HX}\right)} \tag{4.27}$$

The alignment of the velocity plot starts from the end of the whirlpool (*K-K*), and at the distance l_r in the *B-B* alignment (fig.4.11) the velocity over the entire width of the flow becomes constant and equal to the maximum. The length of this region is determined from the integral relation that characterizes the law of conservation of momentum in the flow. The equation written for a liquid compartment bounded by sections *K-K* and *X-X*has the form:

$$\left(B_p-b_p\right)h_pU_{pK}^2+h_p\int_O^{b_P}U^2dy+h_n\int_{b_P}^{b_e}U^2dy+b_{ЯK}h_{nc}U_{ЯK}^2+h_n\int_{Y_1}^{y_2}U^2dy=$$
$$=\left(B_p-b_p\right)h_pU_{px}^2+h_p\int_O^{b_P}U^2dy+h_n\int_{b_P}^{b_e}U^2dy+b_{Яx}h_{nx}U_{Яx}^2+h_n\int_{y_1}^{y_2}U^2dy+$$
$$+\int_O^x\int_O^{B_p}\frac{\lambda_p}{2}Udydx+\int_O^x\int_O^{(B_n-K_Ol_Ш\sin a)}\frac{\lambda_n}{2}Udydx\quad , \tag{4.28}$$

where $b_{Яx}$- the width of the core in the velocity equalization region.

b_X- width of the zone of intense turbulent mixing in the velocity equalization region;

U_{pK}- channel speed in the *K-K* alignment.

We calculate the friction forces in the calculated area from the household speeds.

The velocity distribution in the zone of intenseturbulent-mixing in the region of velocity equalization is satisfactorily described by the universal Schlichting-Abramovich dependence:

$$(U_Я - U)/(U_Я - U_{\min}) = \left(1-\eta^{3/2}\right)^2,$$

where $U_{\min}$ - the velocity formed on the floodplain near the protected shore.

After integrating(4.27) we have:

$$\begin{aligned}&\left(B_p - b_p\right)h_pU_{pK}^2 + b_eh_pU_{pK}^2\left(\phi_5 + m_{pK}\phi_6 + m_{pK}^2\phi_7\right) + b_eh_nU_{pK}^2\left(\phi_8 + m_{pK}\phi_9 + m_{pK}^2\phi_{10}\right) +\\ &+ b_{ЯK}h_nU_{ЯK}^2 + 0.584b_Kh_nU_{ЯK}^2 = \left(B_p - b_p\right)h_PU_{px}^2 + b_eh_pU_{px}^2\left(\phi_5 + m_{pr}\phi_6 + m_{pr}^2\phi_7\right) +\\ &+ b_eh_nU_{px}^2\left(\phi_8 + m_{pr}\phi_9 + m_{pr}^2\phi_{10}\right) + b_{Яx}h_nU_{Яx}^2 + b_{Яx}h_nU_{Яx}^2\left(0.584 - 0.268m_r + 0.684m_r^2\right) +\\ &+ \frac{\lambda_p}{2}v_p^2B_px + \frac{\lambda_n}{2}V_n^2\left(Bn - K_ol_Ш \sin\alpha\right)x\end{aligned} \quad (4.29)$$

where $m_{pr} = U_{Яx}/U_{px}$; $m_{pK} = U_{ЯK}/U_{pK}$; $m_r = U_{\min}/U_{Яx}$.

Assuming $K_9 = \phi_5 + m_{pK}\phi_6 + m_{pK}^2\phi_7$, $K_{10} = \phi_8 + m_{pK}\phi_9 + m_{pK}^2\phi_{10}$, $K_{11} = \phi_5 + m_{pr}\phi_6 + m_{pr}^2\phi_7$

$K_{12} = \phi_8 + m_{pr}\phi_9 + m_{pr}^2\phi_{10}$, $K_{13} = 0.584 - 0.268m_r + 0.684m_r^2$

and dividing both parts of the resulting equality by b_Oh_p from (4.29), we get:

$$\begin{aligned}&U_{pк}^2\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_9 + \bar{b}_e \bar{h}_n K_{10} + \bar{b}_{Як} \bar{h}_n m_{pк}^2 + 0.584\bar{b}_к \bar{h}_n m_{pк}^2\right) =\\ &= U_{px}^2\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_{11} + \bar{b}_e \bar{h}_n K_{12} + \bar{b}_{Яx} \bar{h}_p m_{px}^2 + \bar{b}_x \bar{h}_n K_{13}m_{px}^2\right) +\\ &+ \frac{\lambda_p}{2}\nu_p^2\frac{B_px}{b_oh_p} + \frac{\lambda_n}{2}\nu_n^2\left(B_n - K_ol_ш \sin\alpha\right)\frac{x}{b_oh_p}\end{aligned} \quad (4.3030)$$

where

$\bar{b}_{Як} = b_{Як}/b_O$; $\bar{b}_к = b_к/b_o$.

Taking $x=l_r$ lr and substituting the corresponding velocity values, we have:

$$\begin{aligned}&U_{pк}^2\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_9 + \bar{b}_e \bar{h}_n K_{10} + \bar{b}_{Як} \bar{h}_n m_{pк}^2 + 0.584\bar{b}_к \bar{h}_n m_{pк}^2\right) -\\ &- \nu_{pк}^2\left(\bar{B}_p - \bar{b}_p + \bar{b}_e K_{11} + \bar{b}_e \bar{h}_n K_{12} + \bar{b}_{Яx} \bar{h}_n m_{px}^2 + \bar{b}_x \bar{h}_n K_{13}m_{px}^2\right) =\\ &= \frac{l_r}{b_o}\left(\frac{\lambda_p}{2}\nu_p^2\frac{B_p}{h_P} + \frac{\lambda_n}{2}\nu_n^2\left(B_n - K_ol_ш \sin\alpha\right)/h_p\right)\end{aligned} \quad (4.31)$$

Finally, the relative length of the area where the velocity equalization occurs, taking into account the partial development of the inter-dam floodplain space:

$$\frac{l_r}{b_o}=\frac{D_2^{'}-\frac{V_p^2}{U_{pk}^2}\left[Б_7+(\overline{b}_{як}+\overline{b}_к)\overline{h}_{пб}m_{рб}^2\right]}{\frac{a_p\overline{V}_p^2}{2}+\frac{a_n\overline{V}_n^2}{2}\overline{h}_{пб}^2} \tag{4.32}$$

where $D_2^{'}=\overline{B}_p-\overline{b}_P+\overline{b}_eK_9+\overline{b}_e\overline{h}_{пб}K_{10}+(\overline{b}_{як}+0{,}584\overline{b}_к)\overline{h}_{пб}m_{рк}^2$

$Б_7=\overline{B}_p-\overline{b}_p+\overline{b}_eK_{11}+\overline{b}_e\overline{h}_{пб}K_{12}$; $m_{рк}=U_{пк}/U_{рк}$; $m_{рб}=V_n/V_p$; $\overline{h}_{рб}=h_{пб}/h_{рб}$;

$a_p=\frac{\lambda_pB_p}{h_p}$; $a_n=\frac{\lambda_n(B_n-K_ol_ш\sin\alpha)}{h_{пб}}$

To determinethe length of the whirlpool zone beyond the compressed cross-section, we use the recommendations of I.V.Lebedev [46]:

$$L_p=\frac{B_l-b_T}{tg\phi}, \tag{4.33}$$

where L_p- the length of the whirlpool over the compressedcross-section ;

In$_l$ -the total width of the stream.

b $_T$-width of the transit stream.

ϕ-the angle of inclination of the whirlpool chord to the shoreline,xwhich characterizesthe intensity of flow spreading.

$$tg\phi=a\frac{\lambda\beta\theta_\Omega}{1g\frac{1}{1-\theta_\Omega}}, \tag{4.34}$$

where λ -coefficient of hydraulic friction.

$\beta=B_1/R$-relative stream width.

R-hydraulic radius.

θ_Ω t -coefficient of flow constraint over the area ε_{np}.

a-theht coefficient that depends on the characteristics of the channel $(\lambda\beta)$and its degree of constraint at $\lambda\beta>2.5\ldots3$ a=0.01+0.056θ_Ω

when $\lambda\beta<2.5\ldots3$ a=0.075/$\lambda\beta$ (4.35)

Inthe spreading region, an increase in the width of the channel leads to anequalization of the velocity field,sothe boundaries ofhydraulically homogeneous zones change. According to the theory of turbulent jets [2], the change in the width of a weakly perturbed core is described by the linear dependence:

$$b_{Яx} = b_{Яc} - C_1 x; \; b = b_c + C_2 x \tag{4.36}$$

However, with an increase in the development coefficient (Ko), the angular coefficient C decreases with respect to the value accepted in the theory of turbulent jets.N.Rakhmatov[62] suggests determining the valueof the angular coefficientby the formula:

$$C_1 = 0{,}11 - 0{,}048Ko \tag{4.37}$$

$$C_2 = 0{,}27 - 0{,}03Ko$$

$$C = C_1 + C_2$$

Comparison of calculated and experimental values of the velocity field and planned flow sizes gives satisfactory results.

Direct calculations show that an increase in the development coefficient from 0 to 0.66 leads to an increase in reverse velocities in the compressed section by 2.3 times, which are much higher than non-erasable velocities. Increasing Ko from 0 to 0.5 leads to a 42% reduction in the length of the vortex zone beyond the compressed section L_b. Therefore, it is recommended to fix a new shoreline or build a new spur between dams with a coefficient of 0.5 development.

In the dissertation, Appendix 1 shows calculation algorithms with a numerical example for the Amu Darya River section, and Appendix 2 shows computer programs "Calculation of the planned size of a stream constrained by a floodplain dam, taking into account the development of inter-dam space".

CONC LUSIONS OF CHAPTER IV

The flow alongthe stream behind the compressed crosssection occurs under the influence of external forces, the dam structure and the hydraulic regime of the river. It has been experimentally establishedo that the velocity distribution in this region occurs alongothe axis of the ohr and with turbulentjets: a weakly disturbed core, turbulent mixing, reverse currents,and the interactionofflood and channel flows.

1. Theoretically, taking into account the influence of the hourly development of interstellar space, it is established:

- speed in the riverbed, on the floodplain, as well as reverse speeds in the whirlpool zone;

-the length of the recoveryareadepends on the planned flow size at the end of the vortex zone, the friction forces, and the development coefficient.

2. The length of the whirlpool zone is determined the formula of I.V.Lebedev.

3. An increase in the development coefficientleads to a change in the boundariesof hydraulically homogeneous zones.

With an increase Ko, the angularexpansion coefficient decreases,which is taken into accountaccording to the recommendations of N. Rakhmatov.

5.The solution of the problem is also obtained for the caseof highpressures, when the width of the core on thefloodplainis equal to zero.

CHAPTER V. EXAMPLE OF CALCULATION OF A FLOODPLAIN DAM TAKING INTO ACCOUNT PARTIAL DEVELOPMENT OF INTER-DAM SPACE

Table 5.1

Initial parameters

№	Description	Symbol	Unit of measurement	Amount
1	2	3	4	5
1	Discharge, including those in channel and floodplain	Q	m^3/sec	4360
		Q_p	m^3/sec	2700
		Q_n	m^3/sec	1660
2	Channel width	B_p	m	360
3	Floodplain width	B_n	m	850
4	Flow velocity at natural state in floodplain	V_{cs}	m/sec	0,98
5	Flow velocity at natural state in channel	V_{fs}	m/sec	1,50
6	Flow depth at natural state in channel	h_{cs}	m	5.0
7	Flow depth at natural state in floodplain	h_{fs}	m	2.0
8	Height of prominence between channel and floodplain		m	3.0
9	Dam length	$l_ш$	m	450
10	Dam installation angle	α	$degree$	60^0
11	Area, occupied by dam at natural state	ω_{per}	$h_{fd}\, l_s \, sin\alpha$	779.4
12	Discharge for the part of floodplain blocked by dam	Q_{per}	$\omega_{per}\, V_{nб}$	763.8
13	Extent of contraction for discharge	θ_q	Q_{per}/Q	0.175
14	Froude's number at natural state in channel	Fr_{cs}	$\frac{V_{cd}^2}{gh_{cd}}$	0.046
	in floodplain	Fr_{fs}	$\frac{V_{fd}^2}{gh_{fd}}$	0.049
15	Floodplain area reclamation coefficient	Ko	$\frac{l}{l_s \sin\alpha}$	0.5

5.1. Planned flow sizes

5.1.1. The length of the upper whirlpool zone is determined by the dependence of(3.2) or according to the schedule (fig. 3.6)

$$\frac{l_n^2}{\omega_{nep}} = 95.7 Fr^{0.1}\theta q^{-0.126}\left(\alpha/180^0\right) = 95.7\times 0.049^{0.1}\times 0.175^{-0.126}(60^0/180^0) = 29.5$$

$$l_n^2 = 29.5\times 779.4 = 22998 m^2, \quad l_n = 151.7 m.$$

5.1.2. The length of the compression region is determined by the formula

$$l_{cc}/b_o = \left[(1{,}92K_o + 6{,}95)\theta_q^2 + (0{,}6K_o - 6{,}2)\theta_q\right]\sin(\pi+\alpha) =$$
$$= \left[(1{,}92\times 0{,}5 + 6{,}95)0{,}175^2 + (0{,}6\times 0{,}5 - 6{,}2)0{,}175\right]\sin(180+60) = 0{,}682$$

$$l_{cc} = 0{,}682\times 820{,}3 = 559{,}8m$$

$$b_o = B_p + B_n - l_ш \sin\alpha = 360 + 850 - 450\times 0{,}866 = 1210 - 389{,}7 = 820{,}3m.$$

5.1.3. The planned compression ratio and transit flow width are determined by the graphs (fig.3.13, 3.14) or by the formula (3.16)

$E = b_T/b_o = 0{,}91$ from where $b_T = 0{,}91\times 820{,}3 = 746{,}5\,m$

5.1.4. The relative width of the core in the compressed section is found from the graph (fig. 3.17, 3.18)

$K = B_{яс}/b_T = 0{,}9$ from where $B_{яс} = 0{,}9\times 746{,}5 = 671{,}8m.$

5.1.5. The boundaries of hydraulically homogeneous zones are set according to the dependencies (3.8, 3.9, 3.10, 3.11)

when $x/l_{cc} = 0{,}5$ $x = 279.9m$

a) the boundary between a weakly perturbed core and a zone of intense turbulent mixing

$$\bar{y}_1 = 1-(1-0{,}91\times 0{,}9)(0{,}5)^{3/4} = 0{,}886;\ y_1 = \bar{y}_1\times b_o = 0.886\times 820.3 = 726.8m$$

b) the boundary between the zone of intense turbulent mixing and the zone of reverse currents

$$\bar{y}_2 = 1-0{,}1(1-0{,}91\times 0{,}9)(0{,}5)^{3/4} = 0{,}988;\ y_2 = \bar{y}_2\times b_o = 810{,}5m$$

c) the boundary between the transit flow and the whirlpool area

$$\bar{y}_3 = 1-(1-0{,}91)(0{,}5)^{3/4} = 0{,}95;\ y_3 = \bar{y}_3\times b_o = 0{,}95\times 820{,}3 = 779{,}3m$$

d) width of the intense turbulent mixing zone

$b = y_2 - y_1 = 810.5 - 726.8 = 83.7$

The calculation results are summarized in Table 5.2

Table 5.2

Boundaries of hydraulically homogeneous zones

x *m*	*e*	*K*	y_1 *m*	y_2 *m*	*b* *m*	y_3 *m*
0,0	0,91	0,9	820,3	820,3	0,0	820,3
279,9	0,91	0,9	726,8	810,5	83,7	779,6
559,8	0,91	0,9	671,8	804,7	132,9	746,5

5.2. Backwater and water depth in the compressed section

5.2.1. According to the schedule (fig.3.9) we find the spatial compression coefficient E_{pr}=0.94

5.2.2.We find the coefficient of velocity increase in the compressed section by the formula (3.6)

$$\beta_p = 1 + \frac{763{,}8}{2700}\frac{360\times 5}{360\times 5 + 0{,}94(360\times 5 + 920{,}6)} = 1 + \frac{763{,}8\times 1800}{2700\times 4357{,}4} = 1 + 0{,}12 = 1{,}12$$

5.2.3. Find the coefficient of uneven speed distribution in the household condition

$$\alpha_o = \frac{1{,}5}{0{,}98} = 1{,}53$$

5.2.4. Finding the relative flow rate of the riverbed

$\tau = 2700/4360 = 0{,}619$

5.2.5. Calculate the coefficient that takes into account the redistribution of velocities in the riverbed and on the floodplain in section C-C using the formula (3.5)

$$K' = (1{,}12 - 1)(1 + 0{,}619 - \frac{0{,}619}{1{,}53}) = 0{,}146$$

5.2.6. Influence of the shape of the velocity plot in a compressed section on the change in the amount of movement (according to 3.4)

$$D=\frac{2\times0{,}146(1800+850\times2/1{,}53}{1800+0{,}94\times920{,}6}=\frac{850{,}0}{2665{,}4}=0{,}31$$

5.2.7. Backwater in the riverbed

$$Z_p=0{,}31\times\frac{1{,}05\times1{,}5^2}{2\times9{,}81}=0{,}04m$$

5.2.8. Dam root support дамбы

$$Z_n=Z_p+il_n=0{,}04+0{,}00025\times151{,}7=0{,}04+0{,}04=0{,}08m$$

5.2.9. Differential pressure

$$Z=0{,}04+0{,}00025(151{,}7+559{,}8)=0{,}22m$$

5.2.10. Water depth in the maximum backwater alignment

$$H_p=5+0{,}04=5{,}04m;\ H_n=2+0{,}04=2{,}04m$$

5.2.11. Gof lubin of water in compressed section

$$H_{сжр}=5{,}04-0{,}22=4{,}82m;\ H_{сжп}=2{,}04-0{,}22=1{,}82m$$

5.3. Calculation of the velocity field in the compression region

5.3.1. Average velocities in the compressed cross-section in the riverbed and on the floodplain according to the formula (3.19, 3.20)

$$V_{pc}=1{,}5\times1{,}12=1{,}68\,m/s;\ U_{яс}=0{,}98[1+1{,}53(1{,}12-1)]=1{,}16\,m/s$$

then the maximum and minimum speed in the riverbed and on the floodplain

$$U^p_{\max c}=1{,}05\times V_{pc}=1{,}05\times1{,}68=1{,}76\,m/s;$$

$$U^n_{\max c}=1{,}05\times U_{яс}=1{,}05\times1{,}16=1{,}2\,m/s;$$

$$U^p_{\min c}=0{,}96\times V_{pc}=0.96\times1{,}68=1{,}6\,m/s;$$

$$U^n_{\min c}=0{,}96\times U_{яс}=0{,}96\times1{,}16=1{,}11\,m/s.$$

5.3.2. Calculation of changes in relative velocities along the compression region is found from the graphs of Figures (3.22, 3.23), and the longitudinal component is found from the graph (3.26)

The calculation results are summarized in Table 1.3

Table 5.3.

Calculation of changes in relative velocities along the compression region

x m	$\frac{x}{l_{cc}}$	in the riverbed		in the floodplain		in the riverbed		in the floodplain		in the floodplain	
		$\frac{U_{\min}}{U_{\min c}}$	$U_{\min}$ m/s	$\frac{U_{\min}}{U_{\min c}}$	$U_{\min}$ m/s	$\frac{U_{\max}}{U_{\max c}}$	$U_{\max}$ m/s	$\frac{U_{\max}}{U_{\max c}}$	$U_{\max}$ m/s	$\frac{U_{\max}\cos\varphi}{U_{\max c}}$	$U_{\max}\cos\varphi_{cp}$ m/s
0.0	0.0	0.9	1.44	0,9	1,0	0,95	1,67	0,96	1,15	0,93	1,12
279,9	0,5	0,95	1,52	0,98	1,07	0,98	1,73	0,98	1,18	0,96	1,15
559,8	1,0	1,0	1,6	1,0	1,11	1,0	1,76	1,0	1,2	1,0	1,2

5.3.3. We find the widths of the zones of interaction between riverbed and floodplain streams according to the dependencies (2.3, 2.5, 2.7)

$$b_p/2 = 1{,}4\times 5/2 - 1{,}4 = 2{,}1;\ b_p = 4{,}2m.$$

$$b_n/2 = 5/2 - 1{,}0 = 1{,}5;\ b_n = 3{,}0m.$$

$$b_e/2 = 2{,}4\times 5/2 - 2{,}4 = 3{,}6;\ b_e = 7{,}2m.$$

5.3.4. The velocity distribution in the zone of a weakly disturbed core within the floodplain is found from the dependences (3.20, 3.21, 3.22) and we assume the following notation:

$$M = U_{\max}^2 - U_{\min}^2;\ Б = (y/b_я)^2\times M;\ N = (U_{\max}\cos\varphi_{cp})^2 - U_{\min}^2;\ P = (y/b_я)^2\times N$$

$$b_{яо-о} = b_o - B_p - b_n = 820{,}3 - 360 - 3 = 457{,}3m;$$

$$b_{яс} = y_p - B_p - b_n = 671{,}8 - 360 - 3 = 308{,}8m$$

The calculation results are summarized in Table 5.4

5.3.5. Reverse velocities in a compressed cross-section are calculated from the dependencies (3.33). For this purpose, we first find the parameters by (3.26)

$$\phi_1 = \frac{4{,}2}{7{,}2} - 0{,}8\left(\frac{4{,}2}{7{,}2}\right)^{2,5} + 0{,}25\left(\frac{4{,}2}{7{,}2}\right)^4 = 0{,}612 - 0{,}2076 = 0{,}404$$

$$\phi_2 = 0{,}8\left(\frac{4{,}2}{7{,}2}\right)^{2,5} - 0{,}25\left(\frac{4{,}2}{7{,}2}\right)^4 = 0{,}179$$

$$\phi_3 = \left(1 - \frac{4{,}2}{7{,}2}\right) - 0{,}8\left(1 - \left(\frac{4{,}2}{7{,}2}\right)^{2,5}\right) + 0{,}25\left(1 - \left(\frac{4{,}2}{7{,}2}\right)^4\right) = 0{,}0456$$

Table 5.4

Calculation of velocities in the zone of a weakly disturbed core on a floodplain

$\frac{x}{l_{cc}}$	$\left(\frac{y}{b_я}\right)^2$	U_{max}^2	U_{min}^2	M	Б	$U_{min}^2+Б$	U m/s	$(U_{max}\cos\varphi_{cp})^2$	N	P	U_{min}^2+P	U_{np} m/s	$\cos\varphi=\frac{U_{np}}{U}$	φ°
	0.0				0.0	1.0	1.0			0.0	1.0	1.0	1.0	0^0
0.0	0.25	1.3225	1.0	0.32	0.08	1.08	1.04	1.25	0.258	0.063	1.06	1.03	0.99	8^0
	1.0				0.32	1.32	1.15			0.25	1.25	1.12	0.974	13^0
	0.0				0.0	1.15	1.07			0.0	1.15	1.07	1.0	0^0
279.9	0.25	1.3924	1.1449	0.24	0.06	1.21	1.1	1.32	0.17	0.0425	1.19	1.09	0.992	7^0
	1.0				0.24	1.39	1.18			0.17	1.32	1.15	0.975	12^0
	0.0				0.0	1.23	1.11			0.0	1.23	1.11	1	0^0
559.8	0.25	1.44	1.2321	0.21	0.05	1.28	1.13	1.44	0.21	0.0525	1.28	1.13	1	0^0
	1.0				0.21	1.44	1.2			0.21	1.44	1.2	1	0^0

$$\phi_4 = 0,8\left(1-\left(\frac{4,2}{7,2}\right)^{2,5}\right) - 0,25\left(1-\left(\frac{4,2}{7,2}\right)^{4}\right) = 0,5924 - 0,2200 = 0,3724$$

$$m_{pc} = 1,16/1,68 = 0,69$$

$$K_1 = 0,404 + 0,69\times 0,179 = 0,53;\ K_2 = 0,0456 + 0,69\times 0,3724 = 0,302$$

then

$$\bar{h}_{pc} = h_{pc}/h_{pc} = 4,82/1,82 = 2,65; \qquad \bar{B}_n = B_n/b_o = 850/820,3 = 1,036;$$

$$\bar{b}'_{яс} = b'_{яс}/b_o = 355,8/820,3 = 0,434; \qquad l_ш = l_ш/b_o = 450/820,3 = 1,55;$$

$$\bar{b}_{яс} = b_{яс}/b_o = 308,8/820,3 = 0,38; \qquad \bar{b}_e = b_e/b_o = 7,2/820,3 = 0,0088;$$

$$\bar{b}_c = b_c/b_o = 132,9/820,3 = 0,162; \qquad \bar{b}_n = b_n/b_o = 3/820.3 = 0.0037.$$

$$m_{нс} = \frac{\dfrac{4360}{820,3\times 1,82\times 1,16} - \dfrac{1,68}{1,16}\left[0,434\times 2,65 + 0,0088\times 2,65\times 0,53 + 0,0088\times 0,31\right] - 0,38 - 0,55\times 0,162}{1,036 - 0,0037 - 0,38 - 0,55\times 0,162 - 0,5\times 0,55\times 0,866} = -0,96$$

$$U_{нс} = -0,96\times 1,16 = -1,11\, m/sek$$

when $K_o = 0$

$$m_{нс} = \frac{0,312}{1,036 - 0,473} = \frac{0,312}{0,563} = -0,554;\ U_{нс} = -0,554\times 1,16 = -0,64\, m/s$$

if $K_o = 0,33$. $m_{нс} = \dfrac{0,312}{1,036 - 0,63} = \dfrac{0,312}{0,406} = -0,77;\ U_{нс} = -0,84\, m/s$.

if $K_o = 0,5$ $m_{нс} = \dfrac{0,312}{0,325} = -0,96;\ U_{нс} = -1,11\, m/s$.

when $K_o = 0,66$ $m_{нс} = \dfrac{0,312}{1,036 - 0,249} = \dfrac{0,312}{0,406} = -1,25;\ U_{нс} = -1,45\, m/s$.

As can be seen from the calculations, an increase in the development coefficient leads to an increase in reverse speeds, which may exceed the permissible speeds for erosion. In this case, it is necessary to fix a new shoreline or arrange additional spurs between existing dams.

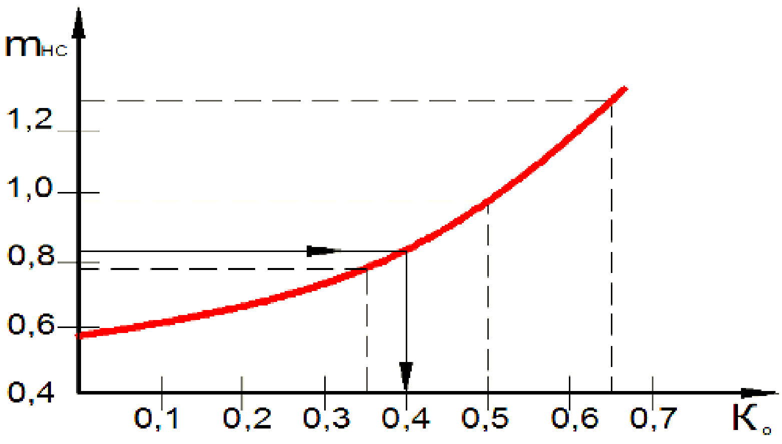


Fig. 5.1. Graph $m_{нс} = f(K_o)$

5.3.6. Reverse velocities on the length l_{cc} are calculated from the dependencies (3.34)

if $x/l_{ш} = 0{,}5$, $U_н = -1{,}11 \times (0{,}5)^2 = -0{,}28\, m/s$

5.3.7. The velocity distribution in the turbulent mixing zone is calculated from (3.23), denoting $U_{max} - U_н = \Delta U$

The calculation results are summarized in Table 1.5.

Table 5.5.

Velocity distribution in the turbulent mixing zone $K_o = 0{,}5$

x m	b m	$y_2 - y_1$	η	$f(\eta)$	U_{max} m/s	U_H m/s	ΔU m/s	$\Delta U f(\eta)$ m/s	ΔU m/s
279,9	83,7	0	0	1,0	1,18	-0,28	0,9	0,9	-0,28
		21,0	0,25	0,76				0,68	0,50
		42,0	0,50	0,42				0,38	0,70
		63,0	0,75	0,12				0,108	0,9
		83,7	1,0	0,0				0,0	1,18
559,8	132,9	0	0	1,0	1,20	-1,11	0,9	0,09	-1,11
		0,33	0,25	0,76				0,07	1,13
		66,5	0,5	0,42				0,04	1,16
		100,0	0,75	0,12				0,01	1,19
		132,9	1,0	0,0				0,0	1,20

5.4. Calculations of flow spreading over a compressed cross-section, taking into account the development of inter-dam floodplain space

5.4.1. The length of the whirlpool zone beyond the compressed cross-section is determined by the formula (4.34). For this purpose, we pre-calculate

a) coefficient of hydraulic friction

$$\frac{1}{\sqrt{\lambda_p}} = 4\lg\frac{5{,}0}{0{,}5} + 4{,}25 = 20{,}25 \quad \lambda_p = 0{,}00244$$

$$\frac{1}{\sqrt{\lambda_n}} = 4\lg\frac{2,0}{0,5} + 4,25 = 18{,}16 \quad \lambda_n = 0{,}00287$$

where is the relative roughness?

$$\Delta = 1{,}4 \times d_{cp}^{0,75} = 1{,}4 \times (0{,}25)^{0,75} = 0{,}50mm;$$

$$\lambda = \frac{\lambda_p + \lambda_n}{2} = \frac{0{,}00244 + 0{,}00287}{2} = \frac{0{,}0053}{2} = 0{,}00265$$

b) relative width of the stream (at K_o=0)

$$\beta = \frac{1210}{\dfrac{850\times 2 + 360\times 5}{850 + 360 + 2 + 5 + 3}} = \frac{1210}{2,876} = 420,7$$

c) coefficient of flow restriction by area

$$\theta_\Omega = \frac{\omega_n}{\Omega} = \frac{779,9}{360\times 5 + 850\times 2} = 0,223$$

d) coefficient

$$a = 0{,}075/1{,}24 = 0{,}06$$

e) then the angle of inclination of the chord to the coastline

$$tg\varphi = 0{,}06 \times \frac{0{,}00265 \times 420{,}7 \times 0{,}223}{\lg\dfrac{1}{1 - 0{,}223}} = 0{,}136$$

f) when K_o=0

$$L_b = \frac{B - b_T}{tg\varphi} = \frac{1210 - 746{,}5}{0{,}136} = \frac{463{,}5}{0{,}136} = 3408m$$

g) at K_o=0.5

$$L_b = \frac{B - K_o l_ш \sin\alpha_ш - b_T}{tg\varphi} = \frac{1210 - 164{,}8 - 746{,}5}{0{,}33} = \frac{268{,}7}{0{,}136} = 1976{,}0m$$

In other words, the length of the whirlpool zone is reduced by almost 42%.

h) distance between dams (K_o=0)

$$L = b_o + l_ш \cos\alpha_ш + l_{cc} + L_b = 151{,}7 + 559{,}8 + 450\cos 60^0 + 3408 = 4345m$$

i) taking into account the $L_{erosion}$=0,5L=0,5*4345=2172,5 m

5.4.2. Change in the width of the slightly disturbed core in the floodplain according to the recommendations of G.N.Abramovich (4.36)

when K_o=0,0.

$$b_{яx} = 308{,}8 - C_1 \times x;\ C_1 = C - 0{,}048 \times K_o$$

when K_o=0.5

$$C_1 = 0{,}11 - 0{,}048 \times 0{,}5 = 0{,}11 - 0{,}0{,}24 = 0{,}086;\ b_{яx} = 308{,}8 - 0{,}086 \times x$$

when $x = 100m$

$$b_{яx} = 308{,}8 - 0{,}086 \times 100 = 300\ m;$$

when $x = 500m$

$$b_{яx} = 308{,}8 - 0{,}086 \times 500 = 265{,}8m;$$

when $x = 1000m$

$$b_{яx} = 308{,}8 - 0{,}086 \times 1000 = 222{,}8м;$$

when $x = 2000m$

$$b_{яx} = 308{,}8 - 0{,}086 \times 2000 = 136{,}8m;$$

$$\frac{U_{nc}}{U_{pc}} = \frac{1{,}26}{1{,}68} = 0{,}69;\ \frac{U_{nб}}{U_{pб}} = \frac{0{,}98}{1{,}5} = 0{,}65.$$

5.4.3. We will first accept (4.3, 4.4)

$$h_{px} = 0{,}5(h_{pc} + h_{pб}) = 0{,}5(4{,}82 + 5) = 4{,}91m;$$

$$h_{nx} = 0{,}5(h_{nc} + h_{nб}) = 0{,}5(1{,}82 + 2) = 1{,}91m;$$

$$V_{p*} = 0{,}5(U_{pc} + V_{pб}) = 0{,}5(1{,}82 + 1{,}5) = 1{,}59m/s;$$

$$V_{n*} = 0{,}5(U_{nc} + V_{nб}) = 0{,}5(1{,}16 + 0{,}98) = 1{,}07m/s.$$

5.4.4. Hydraulic friction coefficients in the spreading area

$$\frac{1}{\sqrt{\lambda_p}} = 4\lg\frac{4{,}91}{0{,}5} + 4{,}25 = 20{,}22;\ \lambda_p = 0{,}00245.$$

$$\frac{1}{\sqrt{\lambda_n}} = 4\lg\frac{1{,}91}{0{,}5} + 4{,}25 = 18{,}58;\ \lambda_n = 0{,}0029.$$

5.4.5. Relative velocity according to (4.12)

$$A_1 m_{px}^2 + A_2 m_{px} + A_3 = 0$$

let's first calculate

$\overline{B}_n = 306/820{,}3 = 0{,}439;$ $\overline{b}_p = 4{,}2/820{,}3 = 0{,}0051;$

$\overline{b}_{яс}^{'} = b_{яс}^{'}/b_o = 355{,}8/820{,}3 = 0{,}434;$ $\overline{b}_{яс} = 308{,}8/820{,}3 = 0{,}376;$

$\overline{b}_p^* = 4{,}2/7{,}2 = 0{,}583;$ $\overline{b}_e = b_e/b_o = 7{,}2/820{,}3 = 0{,}0088;$

$\overline{b}_c = b_c/b_o = 132{,}9/820{,}3 = 0{,}162;$ $\overline{h}_n = 1.91/4.91 = 0.389;$

$\overline{b}_{ях} = b_{ях}/b_o$

when $x = 100m$ $\overline{b}_{ях} = 300/820{,}3 = 0{,}366;$

when $x = 1000\,m$ $\overline{b}_{ях} = 222{,}8/820{,}3 = 0{,}2716;$

when $x = 2000\,m$ $\overline{b}_{ях} = 136{,}8/820{,}3 = 0{,}1668;$

when $x = 2807\,m$ $\overline{b}_{ях} = 67{,}4/820{,}3 = 0{,}082$

using the formulas

$$\varphi_5 = \frac{b_p}{b_e} - 1.6\left(\frac{b_p}{b_e}\right)^{2.5} + 1.5\left(\frac{b_p}{b_e}\right)^{4} - 0.727\left(\frac{b_p}{b_e}\right)^{5.5} + 0.143\left(\frac{b_p}{b_e}\right)^{7} =$$
$$= 0{,}583 - 1{,}6(0{,}583)^{2{,}5} + 1{,}5(0{,}583)^4 - 0{,}727(0{,}583)^{5{,}5} + 0{,}143(0{,}583)^7 = 0{,}306$$

$$\varphi_6 = 1.6\left(\frac{b_p}{b_e}\right)^{2.5} - 2.5\left(\frac{b_p}{b_e}\right)^{4} + 1.454\left(\frac{b_p}{b_e}\right)^{5.5} - 0.286\left(\frac{b_p}{b_e}\right)^{7} =$$
$$= 1{,}6(0{,}583)^{2{,}5} - 2{,}5(0{,}583)^4 - 1{,}454(0{,}583)^{5{,}5} - 0{,}286(0{,}583)^7 = 0{,}193$$

$$\varphi_7 = \left(\frac{b_p}{b_e}\right)^{4} - 0.727\left(\frac{b_p}{b_e}\right)^{5.5} + 0.143\left(\frac{b_p}{b_e}\right)^{7} =$$
$$= (0{,}583)^4 - 0{,}727(0{,}583)^{5{,}5} + 0{,}143(0{,}583)^7 = 0{,}235 - 0{,}0374 = 0{,}081$$

$$\phi_8 = \left(1 - \frac{b_p}{b^x}\right) - 1{,}6\left[1 - \left(\frac{b_p}{b^x}\right)^{2{,}5}\right] + 1{,}5\left[1 - \left(\frac{b_p}{b^x}\right)^{4}\right] - 0727\left[1 - \left(\frac{b_p}{b^x}\right)^{5{,}5}\right] + 0{,}143\left[1 - \left(\frac{b_p}{b^x}\right)^{7}\right] =$$
$$= 1 - 0{,}583 - 1{,}6\left[1 - 0{,}583^{2{,}5}\right] + 1{,}5\left[1 - 0{,}583^4\right] - 0{,}727\left[1 - 0{,}583^{5{,}5}\right] + 0{,}143\left[1 - 0{,}583^7\right] =$$
$$= 0.0083$$
$$\phi_9 = 1{,}6\left[1 - 0{,}583^{2{,}5}\right] - 2{,}5\left[1 - 0{,}583^4\right] - 1{,}454\left[1 - 0{,}583^{5{,}5}\right] + 0{,}286\left[1 - 0{,}583^7\right] = 0{,}0746$$
$$\phi_{10} = \left[1 - 0{,}583^4\right] - 0{,}727\left[1 - 0{,}583^{5{,}5}\right] + 0{,}143\left[1 - 0{,}583^7\right] = 0{,}334$$

$$F_1 = 0{,}376 + 0{,}416 \times 0{,}162 = 0{,}443; \quad F_4 = 0{,}376 + 0{,}55 \times 0{,}162 = 0{,}465;$$

$$\Phi = 0{,}439 - 0{,}0051 + 0{,}0088\times 0{,}53 + 0{,}0088\times 0{,}389\times 0{,}31 + 0{,}389\times 0{,}465\times 0{,}69 =$$
$$= 0{,}5696 - 0{,}0051 = 0{,}5645$$

by $Б_1 = \overline{B}_p - \overline{b}_p + \overline{b}_e\phi_5 + \overline{b}_e\overline{h}_n\phi_8;$

$$Б_1 = 0{,}439 - 0{,}0051 + 0{,}0088\times 0{,}306 + 0{,}0088\times 0{,}389\times 0{,}0083 = 0{,}4417 - 0{,}0051 = 0{,}4366$$

by $Б_2 = \overline{b}_e\varphi_6 + \overline{b}_e\overline{h}_n\varphi_9 = 0{,}0088\times 0{,}193 + 0{,}0088\times 0{,}389\times 0{,}0746 = 0{,}00196$

by

$$Б_3 = \overline{b}_e\varphi_7 + \overline{b}_e\overline{h}_n\varphi_{10} + \overline{h}_n F_2 =$$
$$0{,}0088\times 0{,}00071 + 0{,}0088\times 0{,}389\times 0{,}334 + 0{,}389(\overline{b}_{ях} + 0{,}416\overline{b}_x) = 0{,}0081 + 0{,}389(\overline{b}_{ях} + 0{,}416\overline{b}_x)$$

nri K_o=0

$$a_p = \frac{\lambda_p B_p}{h_p} = \frac{0{,}00245\times 360}{4{,}91} = 0{,}1796;\ a_n = \frac{\lambda_n B_n}{h_n} = \frac{0{,}0029\times 850}{1{,}91} = 1{,}291$$

nriK_o>0

$$a_n = \frac{\lambda_n (B_n - K_o l_ш \sin\alpha - \dfrac{b_{нс}b_{нх}}{2}}{h_n} = \frac{0{,}0029\times(850 - 0{,}5\times 450\times 0{,}866 - \dfrac{210{,}5 + 210{,}5 - 0{,}16x}{2}}{1{,}91} =$$
$$= \frac{0{,}0029(444{,}6 + 0{,}08x)}{1{,}91};$$

where

$$b_{нс} = B_n - b_n + b_{яс} - b_c K_o l_ш \sin\alpha_ш = 850 - 3{,}0 - 308{,}8 - 132{,}9 - 0{,}5\times 450\times 0{,}866 = 210{,}5\,m$$

$$b_{нх} = b_{нс} - 0{,}16x = 210{,}5 - 0{,}16x;\ B_n = 850 - 194{,}9 - 105 = 550m;$$

$$\lambda_n = \frac{0{,}0029\times 550}{1{,}91} = 0{,}835$$

$$\overline{V}_{p^x} = V_{p^x} / U_{рк} = 1{,}59/1{,}68 = 0{,}95;\ \overline{V}_{n^x} = V_{n^x} / U_{пк} = 1{,}07/1{,}68 = 0{,}64;$$

$$R_a = \frac{01796\times 0{,}95^2}{2}\xi + \xi\frac{0{,}0029(444{,}6 + 0{,}08x)}{1{,}91}\frac{0{,}64^2}{2}0{,}389 =$$
$$= 0{,}08\xi + 0{,}00012(444{,}6 + 0{,}08x)\xi;$$

where $\overline{h}_n = h_n / h_p = 191/4{,}91 = 0{,}389$

$$P_1 = 0{,}0088\times 0{,}179 + 0{,}0088\times 0{,}389\times 0{,}3724 + 0{,}389\times F_3 =$$
$$= 0{,}0029 + 0{,}389\times(b_{ях} + 0{,}55\times b_x)$$

$$M_1 = 0{,}439 - 0.0051 + 0{,}0088\times 0{,}5643 + 0{,}0088\times 0{,}389\times 0{,}0456 =$$
$$= 0{,}4442 - 0{,}0051 = 0{,}439$$

by $K_3 = \left(\varphi_5 + m_{pc}\varphi_6 + m_{pc}^2\varphi_7\right) = 0{,}307 + 0{,}69\times 0{,}193 + 0{,}69^2\times 0{,}081 = 0{,}478$

$$K_4 = \left(\varphi_8 + m_{pc}\varphi_9 + m_{pc}^2\varphi_{10}\right) = 0,0083 + 0,69 \times 0,0746 + 0,69^2 \times 0,389 \times 0,334 = 0,219$$

$$D_1 = \bar{B}_p - \bar{b}_p + \bar{b}_e K_3 + \bar{b}_e \bar{h}_n K_4 + F_1 \bar{h}_n m_{pc}^2 - R_a =$$

$$= 0,439 - 0,0051 + 0,0,0088 \times 0,478 + 0,0088 \times 0,389 \times 0,219 +$$

$$+ 0,443 \times 0,389 \times 0,69^2 - R_a = 0,521 - R_a$$

$$b_x = b_c + Cx$$

$$R_a = 0,08\frac{100}{820,3} + 0,00012(444,6 + 0,08 \times 100)\frac{100}{820,3} = 0,0098 + 0,0066 = 0,0164$$

when $x = 500m$

$$R_a = 0,08\frac{500}{820,3} + 0,00012(444,6 + 0,08 \times 500)\frac{500}{820,3} = 0,0488 + 0,0354 = 0,084$$

when $x = 1000\,m$

$$R_a = 0,08\frac{1000}{820,3} + 0,00012(444,6 + 0,08 \times 1000)\frac{1000}{820,3} = 0,0098 + 0,0066 = 0,174$$

Mixing zone width

$$b_x = b_c + Cx$$

where $C_2 = 0,27 - 0,03K_o = 0,27 - 0,015 = 0,255$

where $b_x = b_c + 0,255x = 132,9 + 0,255x$

if $x = 100\,m$. $b_x = 132,9 + 0,255 \times 100 = 158,4m$; $\bar{b}_x = 0,193$; $\bar{b}_{яx} = 0,366$

when $x = 500\,m$ $b_x = 132,9 + 0,255 \times 500 = 260,4m$; $\bar{b}_x = 0,317$; $\bar{b}_{яx} = 0,324$

when $x = 1000\,m$ $b_x = 132,9 + 0,255 \times 1000 = 387,9m$; $\bar{b}_x = 0,473$; $\bar{b}_{яx} = 0,2716$.

when $x = 100\,m$

$$A_1 = 0,5645^2 \times \left[0,00185 + 0,389(0,366 + 0,416 \times 0,193)\right] -$$
$$- (0,521 - R_a)\left[0,0029 + 0,389(0,366 + 0,55 \times 0,193)\right]^2 = 0,0384$$

$$A_2 = 0,5645^2 \times 0,00196 - 2 \times 0,439 - (0,521 - R_a)\left[0,0029 + 0,389(0,366 + 0,55 \times 0,193)\right] =$$
$$= -0,082$$

$$A_3 = 0,5645^2 \times 0,4366 - (0,521 - R_a)(0,439)^2 = 0,1393 - 0,0973 = 0,042$$

$$0,0384m^2 + 0,082m + 0,042 = 0$$

$$m_{1,2} = \frac{-0,082 \pm \sqrt{(-0,082)^2 - 4 \times 0,0384 \times 0,042}}{2 \times 0,0384} = \frac{0,082 \pm \sqrt{0,00025}}{0,0768} = \frac{0,082 \pm 0,0158}{0,0768};$$

$$m_{px_1}=\frac{0{,}082+0{,}0158}{0{,}0768}=\frac{0{,}0978}{0{,}0768}=1{,}27;\ m_{px_2}=\frac{0{,}082-0{,}0158}{0{,}0768}=\frac{0{,}0662}{0{,}0768}=0{,}86.$$

5.4.6. The relative velocity in the riverbed is found by (4.8)

$$\frac{U_{px}}{U_{pc}}=\sqrt{\frac{0{,}521-0{,}0169}{0{,}439-0{,}0051+0{,}0088\times K_5+0{,}0088\times 0{,}389K_6+F_2\times 0.389\times 0.86^2}}=0{,}94$$

where $F_2=0{,}366+0{,}416\times 0{,}193=0{,}446$

by $K_5=\left(\phi_5+m_{px}\phi_6+m_{px}^2\phi_7\right)$ and $K_6=\left(\phi_8+m_{px}\phi_9+m_{px}^2\phi_{10}\right)$

$$K_5=0{,}306+0{,}86\times 0{,}193+0{,}86^2\times 0{,}081=0{,}532;$$

$$K_6=0{,}0083+0{,}86\times 0{,}0746+0{,}86^2\times 0{,}334=0{,}319;$$

$$U_{px}=0{,}94\times 1{,}68=1{,}58\,m/s.$$

$$\frac{U_{яx}}{U_{px}}=0{,}86;\ U_{яx}=0{,}86\times 1{,}58=1{,}34\,m/s.$$

5.4.7. The speed of reverse currents is determined by (4.15). Previously, we find

$$\bar{b}_{нс}=b_{нс}/b_o=210{,}5/820{,}3=0{,}257;$$

$$\bar{b}_н=\bar{B}_п+\bar{b}_п-\bar{b}_{яx}-\bar{b}_x-K_o\bar{l}_ш\sin\alpha=1{,}036-0{,}0037-0{,}366-0{,}193-0{,}5\times 0{,}549\times 0{,}866=0{,}235;$$

$$Б_4=0{,}439-0{,}0051+0{,}0088\times 0{,}53+0{,}0088\times 0{,}389\times 0{,}31=0{,}44;$$

$$Б_5=0{,}376\times 0{,}389+0{,}162\left[0{,}55+0{,}45\times(-0{,}96)\right]=0{,}165;$$

$$Б_6=0{,}439-0{,}0051+0{,}0088\times 0{,}558+0{,}0088\times 0{,}366=0{,}442;$$

$$K_7=0{,}404+0{,}86\times 0{,}179=0{,}558;$$

$$K_8=0{,}0456+0{,}86\times 0{,}3724=0{,}366;$$

$$m_{нx}=\frac{\frac{1{,}68}{1{,}34}\times 0{,}44+\frac{1{,}16}{1{,}34}\times 0{,}165+\frac{-1{,}11}{1{,}16}\times 0{,}257\times 0{,}389-\frac{0{,}442}{0{,}86}-0{,}389(0{,}366+0{,}55\times 0{,}193)}{0{,}389(0{,}235+0{,}45\times 0{,}193)}=-0{,}784$$

$$\frac{U_{нx}}{U_{яx}}=-0{,}784;\ U_{нx}=-0{,}784\times 1{,}34=-1{,}05\,m/s.$$

5.4.8. The velocity distribution in the zone of intense turbulent mixing in the floodplain is based on the dependence

$$\frac{U_{яx}-U}{U_{яx}-U_н}=(1-\eta^{1{,}5})^2$$

We denote $\Delta U = U_{яx} - U_{н}; \eta = \frac{y_2 - y}{y_2 - y_1} = \frac{y_2 - y}{b_{яx}}; \; f(\eta) = (1 - \eta^{1,5})$

The calculation results are summarized in Table 5.6.

Table 5.6.

Velocity distribution in the zone of intense turbulent mixing on the floodplain

x m	b m	$y_2 - y_1$	η	$f(\eta)$	$U_{яx}$ m/s	U_H m/s	ΔU m/s	$\Delta U f(\eta)$ m/s	ΔU m/s
100	158,4	0	0	1,0	1,34	-1,05	0,29	0,29	-1,05
		39,6	0,25	0,76				0,22	1,12
		79,2	0,50	0,42				0,12	1,22
		118,8	0,75	0,12				0,035	1,30
		158,4	1,0	0,0				0,0	1,34

Based on the calculation data, we construct the velocity field of the flow deformed by a system of floodplain dams during partial development of the floodplain space (fig.5.2)

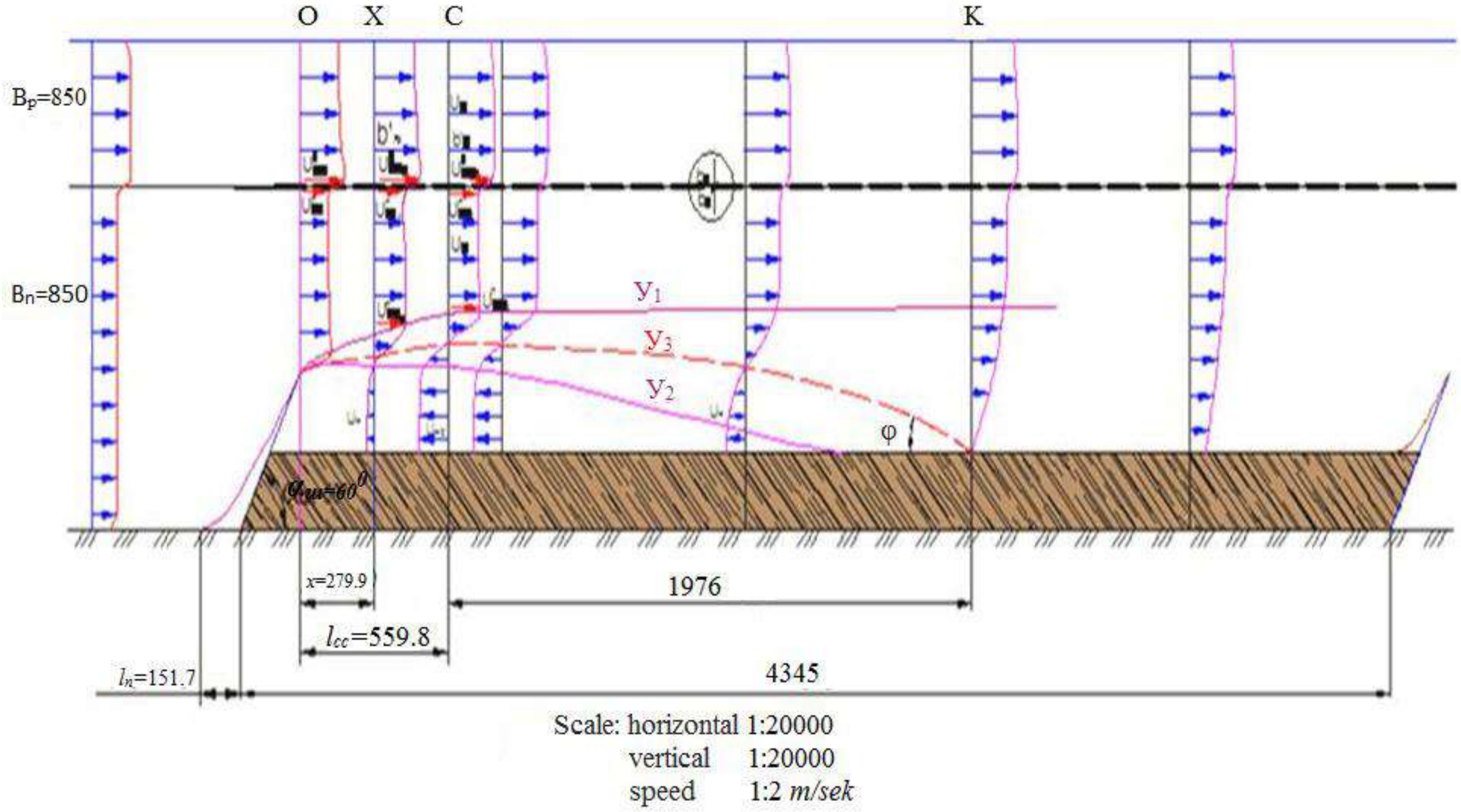


Fig. 5. 2. Calculated velocity plot

Computer program for calculating the planned dimensions of the flow constrained by a floodplain dam, taking into account the development of the inter-dam space

The program solves the problem of calculating the boundaries of homogeneous zones in the compression region, the length of the eddy zone in the headwaters, the compression and spreading regions.

The described block makes it possible to calculate with sufficiently high accuracy the distances between transverse floodplain dams, taking into account the development (siltation) of the inter-dam space.

The program provides the following functions: input of initial data; calculation of planned flow sizes; issuance of results.

The program is used to solve problems in the field of river hydraulic engineering

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Globalization;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace Irrigatsiya_Programma
{
public partial class First_calculation : Form
    {
public First_calculation()
        {
InitializeComponent();
        }
        List<double> x_0_q = new List<double>();
```

```
    double q_one = 0.0, q_two = 0.0, q_tree = 0.0, b_one
= 0.0, b_two = 0.0, v_one = 0.0,
    v_two = 0.0, h_one = 0.0, h_two = 0.0, l_one = 0.0,
l_two = 0.0, alfa = 0.0, alfa_rad, w = 0.0, q_nep = 0.0,
    theta = 0.0, f_one = 0.0, f_two = 0.0, k_o = 0.0, l_n
= 151.7, l_cj, d_cj;
            //5.1
    double P, E, K;
            //5.1

    double res_l_n_wnep, res_l_shtrix, res_b_0, res_b_t,
res_b_ya, res_x, res_y_1,
                 res_y_2, res_y_3, res_b;
            //5.2
    double alfa_0;
    double E_np, omega, g = 9.81, i = 0.00025;
    double gamma_p, gamma_n, delta, gamma, betta,
omega_full, per, theta_omega, a_koef, tan_fi, L_b, L, L_p;
    int m;

    private void First_calculation_Load(object sender,
EventArgs e)
            {
    this.Size = new Size(440, 741);
                textBox1.KeyPress += textBox1_KeyPress;
textBox1.Size = new Size(162, 26);
                textBox2.KeyPress += textBox1_KeyPress;
textBox2.Size = new Size(162, 26);
                textBox3.KeyPress += textBox1_KeyPress;
textBox3.Size = new Size(162, 26);
                textBox4.KeyPress += textBox1_KeyPress;
textBox4.Size = new Size(162, 26);
                textBox5.KeyPress += textBox1_KeyPress;
textBox5.Size = new Size(162, 26);
                textBox6.KeyPress += textBox1_KeyPress;
textBox6.Size = new Size(162, 26);
                textBox7.KeyPress += textBox1_KeyPress;
textBox7.Size = new Size(162, 26);
                textBox8.KeyPress += textBox1_KeyPress;
textBox8.Size = new Size(162, 26);
                textBox9.KeyPress += textBox1_KeyPress;
textBox9.Size = new Size(162, 26);
                textBox10.KeyPress += textBox1_KeyPress;
textBox10.Size = new Size(162, 26);
```

```
                textBox11.KeyPress += textBox1_KeyPress;
textBox11.Size = new Size(162, 26);
                textBox12.KeyPress += textBox1_KeyPress;
textBox12.Size = new Size(162, 26);
                textBox13.KeyPress += textBox1_KeyPress;
textBox13.Size = new Size(162, 26);
                textBox14.KeyPress += textBox1_KeyPress;
textBox14.Size = new Size(162, 26);
                textBox15.KeyPress += textBox1_KeyPress;
textBox15.Size = new Size(162, 26);
                textBox16.KeyPress += textBox1_KeyPress;
textBox16.Size = new Size(162, 26);
                textBox17.KeyPress += textBox1_KeyPress;
textBox17.Size = new Size(162, 26);
                textBox18.KeyPress += textBox1_KeyPress;
textBox18.Size = new Size(162, 26);
                textBox26.KeyPress += textBox1_KeyPress;
textBox26.Size = new Size(162, 26);
            }



    private void button1_Click(object sender, EventArgs
e)
            {
                x_0_q.Add(0);
                x_0_q.Add(0.5);
                x_0_q.Add(1);

                panel_5_1.Visible = true;
                panel_5_2.Visible = false;
    this.Size = new Size(815, 741);


    try
                {
    Double.TryParse(textBox1.Text, out q_one);
    Double.TryParse(textBox2.Text, out q_two);
    Double.TryParse(textBox3.Text, out q_tree);
    Double.TryParse(textBox4.Text, out b_one);
    Double.TryParse(textBox5.Text, out b_two);
    Double.TryParse(textBox6.Text, out v_one);
    Double.TryParse(textBox7.Text, out v_two);
    Double.TryParse(textBox8.Text, out h_one);
```

```
Double.TryParse(textBox9.Text, out h_two);
Double.TryParse(textBox10.Text, out l_one);
Double.TryParse(textBox11.Text, out l_two);
Double.TryParse(textBox12.Text, out alfa);
Double.TryParse(textBox13.Text, out w);
Double.TryParse(textBox14.Text, out q_nep);
Double.TryParse(textBox15.Text, out theta);
Double.TryParse(textBox16.Text, out f_one);
Double.TryParse(textBox17.Text, out f_two);
Double.TryParse(textBox18.Text, out k_o);
Double.TryParse(textBox26.Text, out d_cj);

FirstCalculation();
SecondCalculation();
ThirdCalculation();

                textBox22.Text =
Math.Round((Decimal)res_l_n_wnep, 3,
MidpointRounding.AwayFromZero).ToString();
                textBox24.Text =
Math.Round((Decimal)res_l_shtrix, 3,
MidpointRounding.AwayFromZero).ToString();
            }
catch (Exception ex)
            {
MessageBox.Show(ex.Message);
            }
        }

private void textBox1_KeyPress(object sender,
KeyPressEventArgs e)
        {
if (!char.IsControl(e.KeyChar) &&
!char.IsDigit(e.KeyChar) && (e.KeyChar != ','))
            {
e.Handled = true;
            }

            // only allow one decimal point
if ((e.KeyChar == ',') && ((sender as
TextBox).Text.IndexOf(',') > -1))
            {

e.Handled = true;
```

```
                }
            }



     void FirstCalculation()
            {
     alfa_rad = alfa * Math.PI / 180;

                //P ningformulasi
                P = Math.Pow(theta, 0.85) * Math.Pow(1 - 1.31 * theta * k_o, 0.5) * Math.Pow(1 + alfa / 180, 0.5);

                //E va K koefsentlarqiymatinitopish
                E = 1 - 0.35 * P;
     K = 1 - 0.4 * P;

            //5.1.1 The length of the upper whirlpool zone is determined according to the dependence (3.2) or according to the graph (Figure 3.6)

     res_l_n_wnep = Math.Sqrt((95.7 * Math.Pow(f_two, 0.1) * Math.Pow(theta, -0.126) * (alfa / 180)) * w);

     //5.1.2 The length of the compression region is determined by the formula
     res_b_0 = b_one + b_two - (l_two * Math.Sin(60 * Math.PI / 180));
     res_l_shtrix = (((1.92 * k_o + 6.95) * Math.Pow(theta, 2) + (0.6 * k_o - 6.2) * theta) * Math.Sin(3.14 + alfa * 3.14 / 180)) * res_b_0;

     //5.1.3.  The  planned  compression  ratio  and  transit flow width are determined by the graphs (Fig. 3. 12,3. 13) or by the formula (3.16)
     res_b_t = E * res_b_0;
     //5.1.4. We find the relative width of the core in the compressed section from the graph (Fig.3. 16, 3.17)
     res_b_ya = K * res_b_t;

      //5.1.5. The boundaries of hydraulically homogeneous zones are set according to the dependencies (3.8, 3.9, 3.10, 3.11)
```

```
     res_x = x_0_q[0] * res_l_shtrix;

                //result y bir
                res_y_1 = (1 - (1 - E * K) *
Math.Pow(x_0_q[0], 0.75)) * res_b_0;

                //result y ikki
                res_y_2 = (1 - 0.1 * (1 - E * K) *
Math.Pow(x_0_q[0], 0.75)) * res_b_0;

                //result y uch
                res_y_3 = (1 - (1 - E) *
Math.Pow(x_0_q[0], 0.75)) * res_b_0;

                //result b = y2-y1
     res_b = res_y_2 - res_y_1;

                    Text_x_0.Text =
Math.Round((Decimal)x_0_q[0], 3,
MidpointRounding.AwayFromZero).ToString();
     text_X.Text = Math.Round((Decimal)res_x, 3,
MidpointRounding.AwayFromZero).ToString();
     text_E.Text = Math.Round((Decimal)E, 3,
MidpointRounding.AwayFromZero).ToString();
     text_K.Text = Math.Round((Decimal)K, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_Y_1.Text =
Math.Round((Decimal)res_y_1, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_Y_2.Text =
Math.Round((Decimal)res_y_2, 3,
MidpointRounding.AwayFromZero).ToString();
     text_B.Text = Math.Round((Decimal)res_b, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_Y_3.Text =
Math.Round((Decimal)res_y_3, 3,
MidpointRounding.AwayFromZero).ToString();

             }

     void SecondCalculation()
             {
     alfa_rad = alfa * Math.PI / 180;
```

```
                //P ningformulasi
                P = Math.Pow(theta, 0.85) * Math.Pow(1 -
1.31 * theta * k_o, 0.5) * Math.Pow(1 + alfa / 180, 0.5);

                //E va K koefsentlarqiymatinitopish
                E = 1 - 0.35 * P;
    K = 1 - 0.4 * P;

            //5.1.1 The length of the upper whirlpool zone
is determined according to the dependence (3.2) or
according to the graph (Figure 3.6)
    res_l_n_wnep = Math.Sqrt((95.7 * Math.Pow(f_two, 0.1)
* Math.Pow(theta, -0.126) * (alfa / 180)) * w);

    //5.1.2 The length of the compression region is
determined by the formula
    res_b_0 = b_one + b_two - (l_two * Math.Sin(60 *
Math.PI / 180));
    res_l_shtrix = (((1.92 * k_o + 6.95) *
Math.Pow(theta, 2) + (0.6 * k_o - 6.2) * theta) *
Math.Sin(3.14 + alfa * 3.14 / 180)) * res_b_0;

    //5.1.3. The planned compression ratio and transit
flow width are determined by the graphs (Fig. 3. 12,3. 13)
or by the formula (3.16)
    res_b_t = E * res_b_0;

    //5.1.4. We find the relative width of the core in
the compressed section from the graph (Fig.3. 16,
3.17)res_b_ya = K * res_b_t;

    //5.1.5. The boundaries of hydraulically homogeneous
zones are set according to the dependencies (3.8, 3.9,
3.10, 3.11)
    res_x = x_0_q[1] * res_l_shtrix;

                //result y bir
                res_y_1 = (1 - (1 - E * K) *
Math.Pow(x_0_q[1], 0.75)) * res_b_0;

                //result y ikki
                res_y_2 = (1 - 0.1 * (1 - E * K) *
Math.Pow(x_0_q[1], 0.75)) * res_b_0;
```

```
                //result y uch
                res_y_3 = (1 - (1 - E) *
Math.Pow(x_0_q[1], 0.75)) * res_b_0;

                //result b = y2-y1
    res_b = res_y_2 - res_y_1;

                    Text_x_01.Text =
Math.Round((Decimal)x_0_q[1], 3,
MidpointRounding.AwayFromZero).ToString();
                    text_X1.Text =
Math.Round((Decimal)res_x, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_E1.Text = Math.Round((Decimal)E,
3, MidpointRounding.AwayFromZero).ToString();
                    text_K1.Text = Math.Round((Decimal)K,
3, MidpointRounding.AwayFromZero).ToString();
                    text_Y_11.Text =
Math.Round((Decimal)res_y_1, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_Y_21.Text =
Math.Round((Decimal)res_y_2, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_B1.Text =
Math.Round((Decimal)res_b, 3,
MidpointRounding.AwayFromZero).ToString();
                    text_Y_31.Text =
Math.Round((Decimal)res_y_3, 3,
MidpointRounding.AwayFromZero).ToString();

            }

    void ThirdCalculation()
            {
    alfa_rad = alfa * Math.PI / 180;

                //P ningformulasi
                P = Math.Pow(theta, 0.85) * Math.Pow(1 -
1.31 * theta * k_o, 0.5) * Math.Pow(1 + alfa / 180, 0.5);

                //E va K koefsentlarqiymatinitopish
                E = 1 - 0.35 * P;
    K = 1 - 0.4 * P;
```

```
            //5.1.1 The length of the upper whirlpool zone
is determined according to the dependence (3.2) or
according to the graph (Figure 3.6)

    res_l_n_wnep = Math.Sqrt((95.7 * Math.Pow(f_two, 0.1)
* Math.Pow(theta, -0.126) * (alfa / 180)) * w);

     //5.1.2 The length of the compression region is
determined by the formula

    res_b_0 = b_one + b_two - (l_two * Math.Sin(60 *
Math.PI / 180));
    res_l_shtrix = (((1.92 * k_o + 6.95) *
Math.Pow(theta, 2) + (0.6 * k_o - 6.2) * theta) *
Math.Sin(3.14 + alfa * 3.14 / 180)) * res_b_0;

    //5.1.3. The planned compression ratio and transit
flow width are determined by the graphs (Fig. 3. 12,3. 13)
or by the formula (3.16)
    res_b_t = E * res_b_0;

    //5.1.4. We find the relative width of the core in
the compressed section from the graph (fig.3. 16, 3.17)
    res_b_ya = K * res_b_t;

    //5.1.5. The boundaries of hydraulically homogeneous
zones are set according to the dependencies (3.8, 3.9,
3.10, 3.11)
    res_x = x_0_q[2] * res_l_shtrix;

                //result y bir
                res_y_1 = (1 - (1 - E * K) *
Math.Pow(x_0_q[2], 0.75)) * res_b_0;

                //result y ikki
                res_y_2 = (1 - 0.1 * (1 - E * K) *
Math.Pow(x_0_q[2], 0.75)) * res_b_0;

                //result y uch
                res_y_3 = (1 - (1 - E) *
Math.Pow(x_0_q[2], 0.75)) * res_b_0;
```

```
                //result b = y2-y1
    res_b = res_y_2 - res_y_1;

                Text_x_02.Text =
Math.Round((Decimal)x_0_q[2], 3,
MidpointRounding.AwayFromZero).ToString();
                text_X2.Text = Math.Round((Decimal)res_x,
3, MidpointRounding.AwayFromZero).ToString();
                text_E2.Text = Math.Round((Decimal)E, 3,
MidpointRounding.AwayFromZero).ToString();
                text_K2.Text = Math.Round((Decimal)K, 3,
MidpointRounding.AwayFromZero).ToString();
                text_Y_12.Text =
Math.Round((Decimal)res_y_1, 3,
MidpointRounding.AwayFromZero).ToString();
                text_Y_22.Text =
Math.Round((Decimal)res_y_2, 3,
MidpointRounding.AwayFromZero).ToString();
                text_B2.Text = Math.Round((Decimal)res_b,
3, MidpointRounding.AwayFromZero).ToString();
                text_Y_32.Text =
Math.Round((Decimal)res_y_3, 3,
MidpointRounding.AwayFromZero).ToString();
            }



    private void button2_Click(object sender, EventArgs
e)
            {
                panel_5_1.Visible = true;
                panel_5_2.Visible = true;
    this.Size = newSize(1163, 741);


//5.4.1. The length of the whirlpool zone behind the

compressed section is determined by formula (4.77), for

this we first calculate

// where is the relative roughness

    delta = 1.4*Math.Pow(d_cj,0.75);
```

```
//a) coefficient of hydraulic friction

     gamma_p =Math.Pow((1/(4 * Math.Log10(h_one*1000 /
delta) + 4.25)),2);
     gamma_n = Math.Pow((1/(4 * Math.Log10(h_two*1000 /
delta) + 4.25)),2);

     gamma = (gamma_p + gamma_n) / 2;

     omega_full = b_one * h_one + b_two * h_two;
     per=b_one + b_two + h_one + h_two + h_one - h_two;
     //б) относительная ширина потока (при Ko=0)
     betta = (b_one + b_two) / (omega_full / per);

     theta_omega = w / omega_full;

     if (gamma * betta < 2.5)
                 {
     a_koef = 0.075 / (gamma * betta);
                 }
     else if (gamma * betta > 2.5)
                 {
     a_koef = 0.01 + 0.056 * theta_omega;
                 }

     tan_fi = (a_koef * (gamma * betta * theta_omega)) /
(Math.Log10(1 / (1 - theta_omega)));

     L_b = (b_one + b_two - k_o * l_two *
Math.Sin(alfa_rad)-res_b_t)/tan_fi;

                 L = res_b_0 + l_two * Math.Cos(alfa_rad)
+ res_l_shtrix + L_b;

     L_p = 0.5 * L;

     textBox_K.Text = Math.Round((Decimal)delta, 3,
MidpointRounding.AwayFromZero).ToString();
     textBox_D.Text = Math.Round((Decimal)gamma, 5,
MidpointRounding.AwayFromZero).ToString();
                 textBox27.Text =
Math.Round((Decimal)gamma_p, 5,
MidpointRounding.AwayFromZero).ToString();
```

```
                 textBox28.Text =
Math.Round((Decimal)gamma_n, 5,
MidpointRounding.AwayFromZero).ToString();
                 textBox29.Text =
Math.Round((Double)tan_fi, 3,
MidpointRounding.AwayFromZero).ToString();
     textBox_Z_p.Text = Math.Round((Decimal)betta, 3,
MidpointRounding.AwayFromZero).ToString();
     textBox_Z_n.Text = Math.Round((Decimal)theta_omega,
3, MidpointRounding.AwayFromZero).ToString();
     textBox_Z.Text = Math.Round((Double)L_b, 3,
MidpointRounding.AwayFromZero).ToString();
     textBox_H_P.Text = Math.Round((Double)L, 3,
MidpointRounding.AwayFromZero).ToString();
     textBox_H_n.Text = Math.Round((Double)L_p, 3,
MidpointRounding.AwayFromZero).ToString();
        }
```

dam calculation

Calculation of the planned dimensions of the flow constrained by a floodplain dam, taking into account the development of the inter-dam space

Designate	Unit	Quantity
Q	m^3/sek	4360
Q_p	m^3/sek	2700
Q_n	m^3/sek	1660
B_p	m	360
B_n	m	850
$V_{нб}$	m /sek	0,98
$V_{рб}$	m /sek	1,50
$h_{рб}$	m	5,0
$h_{нб}$	m	2,0
l_n	m	3,0
$l_ш$	m	450
α	grad	60
$\omega_{пер}$	$h_{нб}\, l_ш Sin\alpha$	779,4
$Q_{пер}$	$\omega_{пер} V_{нб}$	763,8
θ_q	$Q_{пер}/Q$	0,175
$Fr_{рб}$	$V^2_{рб}/gh_{рб}$	0,046
$Fr_{нб}$	$V^2_{рб}/gh_{нб}$	0,049
Ko	$l/l_ш \sin\alpha$	0,5
d_{cp}	mm	0,25

Result 1 | Result 2 | About the program

dam calculation

Calculation of the planned dimensions of the flow constrained by a floodplain dam, taking into account the development of the inter-dam space

Designate	Unit	Quantity
Q	m^3/sek	4360
$Q_р$	m^3/sek	2700
$Q_п$	m^3/sek	1660
$B_р$	m	360
$B_п$	m	850
$V_{пб}$	m/sek	0,98
$V_{рб}$	m/sek	1,50
$h_{рб}$	m	5,0
$h_{пб}$	m	2,0
$l_п$	m	3,0
$l_ш$	m	450
α	grad	60
$\omega_{пер}$	$h_{пб}\, l_ш Sin\alpha$	779,4
$Q_{пер}$	$\omega_{пер} V_{пб}$	763,8
θ_q	$Q_{пер}/Q$	0,175
$Fr_{рб}$	$V_{рб}^2 / gh_{рб}$	0,046
$Fr_{пб}$	$V_{рб}^2 / gh_{пб}$	0,049
Ko	$l/l_ш \sin\alpha$	0,5
$d_{ср}$	mm	0,25

Result 1 | Result 2 | About the program

Planned flow sizes

$x/l_ш$	0	0,5	1
x m	0	280,351	560,701
E	0,914	0,914	0,914
K	0,901	0,901	0,901
y_1 m	820,289	734,115	675,362
y_2 m	820,289	811,671	805,796
b m	0	77,556	130,434
y_3 m	820,289	778,131	749,388

dam calculation

Calculation of the planned dimensions of the flow constrained by a floodplain dam, taking into account the development of the inter-dam space

Designate	Unit	Quantity
Q	m^3/sek	4360
Q_p	m^3/sek	2700
Q_n	m^3/sek	1660
B_p	m	360
B_n	m	850
$V_{пб}$	m/sek	0,98
$V_{рб}$	m/sek	1,50
$h_{рб}$	m	5,0
$h_{пб}$	m	2,0
l_n	m	3,0
$l_ш$	m	450
α	grad	60
$\omega_{пер}$	$h_{пб}\, l_ш Sin\alpha$	779,4
$Q_{пер}$	$\omega_{пер}\, V_{пб}$	763,8
θ_q	$Q_{пер}/Q$	0,175
$Fr_{рб}$	$V^2_{рб}/gh_{рб}$	0,046
$Fr_{пб}$	$V^2_{рб}/gh_{пб}$	0,049
Ko	$l/l_ш \sin\alpha$	0,5
$d_{ср}$	mm	0,25

Result 1 | Result 2 | About the program

Planned flow sizes

$x/l_{сс}$	0	0,5	1
x m	0	280,351	560,701
E	0,914	0,914	0,914
K	0,901	0,901	0,901
y_1 m	820,289	734,115	675,362
y_2 m	820,289	811,671	805,796
b m	0	77,556	130,434
y_3 m	820,289	778,131	749,388

lengths of whirlpool zones

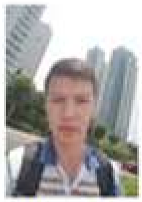
Δ	0,495
λ	0,00265
λ_p	0,00243
λ_n	0,00287
$tg\varphi$	0,153
β	421,771
θ_Ω	0,223
L_k	1740,847
l_n	151,347
l_{cc}	560,701
L	3346,837
L_p	1673,418

dam calculation

Bakiev Masharif Ruzmetovich

Khaitov Kholmurod Jamardovich

Yakubov Kuvonchbek Tazhibaevich



Kumakov Muminjon Komiljon son

The program solves the problem of calculating the boundaries of homogeneous zones of the compression region, the length of the eddy zone in the upper pool, the compression and spreading regions.The described block makes it possible to calculate with sufficiently high accuracy the distances between transverse floodplain dams, taking into account the development (siltation) of the inter-dam space. The program provides the following functions: input of initial data; calculation of planned flow sizes; issuance of results. The program is used to solve problems in the field of river hydraulic engineering.

back

ELEKTRON HISOBLASH MASHINALARI UCHUN YARATILGAN DASTURNING RASMIY RO'YXATDAN O'TKAZILGANLIGI TO'G'RISIDAGI

GUVOHNOMA

СВИДЕТЕЛЬСТВО ОБ ОФИЦИАЛЬНОЙ РЕГИСТРАЦИИ ПРОГРАММЫ ДЛЯ ЭЛЕКТРОННЫХ -ВЫЧИСЛИТЕЛЬНЫХ МАШИН

O'ZBEKISTON RESPUBLIKASI INTELLEKTUAL MULK AGENTLIGI
АГЕНТСТВО ПО ИНТЕЛЛЕКТУАЛЬНОЙ СОБСТВЕННОСТИ РЕСПУБЛИКИ УЗБЕКИСТАН

№ DGU 05651

Ushbu guvohnoma O'zbekiston Respublikasining «Elektron hisoblash mashinalari uchun yaratilgan dasturlar va ma'lumotlar bazalarining huquqiy himoyasi to'g'risida»gi Qonuniga asosan quyidagi EHM uchun dasturga berildi:

Настоящее свидетельство выдано на основании Закона Республики Узбекистан «О правовой охране программ для электронно-вычислительных машин и баз данных» на следующую программу для ЭВМ:

Дамбалар оралиғини ўзлаштиришни инобатга олган ҳолда поймадаги дамба билан сиқилган оқим ўлчамларини ҳисоблаш
Расчет плановых размеров потока стесненного пойменной дамбой с учетом освоения междамбного пространства

Talabnoma kelib tushgan sana:
Дата поступления заявки: **07.08.2018**

Talabnoma raqami:
Номер заявки: **DGU 2018 0630**

Huquq egasi(egalari):
Правообладатель(и): **Тошкент ирригация ва қишлоқ хўжалигини механизациялаш муҳандислари институти, UZ**
Ташкентский институт инженеров ирригации и механизации сельского хозяйства, UZ

Dastur muallif(lar)i:
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программы **Бакиев Машариф Рузметович, Ҳайитов Холмурод Жамардович, Якубов Кувончбек Тажибаевич, Кумаков Муминжон Комилжон ўғли, UZ**

O'zbekiston Respublikasi elektron hisoblash mashinalari uchun dasturlar davlat reestrida 13.09.2018 yilda Toshkent shahrida ro'yxatdan o'tkazilgan.

Зарегистрирован в государственном реестре программ для электронно-вычислительных машин Республики Узбекистан, в г. Ташкенте, 13.09.2018 г.

Bosh direktor
Генеральный директор **А. Файзуллаев**

INTELLEKTUAL MULK AGENTLIGI

Conclusion

Based on the theoretical and experimental studies conducted on thee topic "Calculation of floodplain dams taking into account partial development of inter-dam space", the following conclusions are made.

1.The affinity of the velocity distribution in the zone of interaction between floodplain and channel flows is experimentally substantiated, and the regularities of changes in the width of the zone on rivers with a one-sided floodplain are established in the presence of partial development of the interstitial floodplain space. As a result, the correspondence of the main provisions of the theory of turbulent jets and experimental studies is proved.

2. Partial development of the interstitial space with unilateral restriction of the flow by a system of floodplain dams leads to a sharp change in the hydraulic regime of the regulated channel, a backwater zone is formed in the upper stream, areas of compression and spreading of the area, and a velocity field in the lower stream. As a result, it became possible to forecast a new line of protected bank on rivers with a one-sided floodplain.

3. The influence of the flow constraint degree θq, the dike installation angle α, the Froude Fr, and the development coefficient Ko on the length of the upper whirlpool zone and the compression region was experimentally established. Graphical and analytical dependencies have been developed to determine the distance between dams in the system.

4. The validity of using the method of A.M.Latyshenkov for calculating the backwater is experimentally proved. At the same time, graphical dependencies are proposed to determine the compression ratio over the area ε_{np}. An increase ε_{np} was found with an increase in the coefficient of development of the interstitial floodplain space Ko, from $\varepsilon_{np} = 0.86$ in the absence of development $Ko = 0$, to $\varepsilon_{np} = 0.92$ in the case of full development $Ko = 1$. As a result, the purpose of marking the top of the dam is justified, taking into

account the development of inter-dam space, in order to prevent water overflow over the ridge.

5. The boundaries of hydraulically homogeneous zones in the compression region are established, for the determination of which graphical and analytical dependences are proposed on the planned compression E, the relative width of the core on the floodplain K, the coefficient of development of the interstitial space Ko, as well as the relative distance from the constraint line x/l_{cc}. All other things being equal, increasing Ko from 0 to 1.0, E increases from 0.77 to 0.86.

6. The validity of using M. R. Bakiev's parabolic dependence for calculating velocities in the compression region is experimentally proved. To determine the parameters of the formula, graphical dependences $U_{min}/U_{minc} = f(\theta \mathrm{q}, \alpha, \mathrm{Ko})$, from which it follows that an increase in the development coefficient leads to a decrease in relative speeds. As a result, it became possible to predict the boundaries of the washout at the head of the dam and, accordingly, the boundary of the bottom attachment.

7. A method for calculating reverse velocities in a compressed section has been developed. At the same time, it was found that an increase in the development coefficient to 0.66 leads to an increase in reverse velocities by 2.3 times, which may exceed the permissible speeds for erosion. Increasing Ko from 0 to 0.5 leads to a 42% reduction in the length of the vortex zone beyond the compressed section L_b. The developed calculation method makes it possible to predict the need for fixing a new shoreline or installing additional spurs between existing dams.

8. Theoretically, using the main provisions of the theory of turbulent jets, a method for calculating velocities in the channel U_p, on the floodplain U_n, in reverse currents U_H in the spreading and recovery zone is developed. As a result, it became possible to develop a new plan for the riverbed re-regulation scheme for over-regulated sections of rivers.

9. The main results formed the basis of recommendations that made it possible to introduce into production during protective and regulatory works on the Amu Darya River in the area of water intake to the Karshi Main Canal with an annual economic effect of 12,780 thousand soums per year. A calculation algorithm and a computer program were developed, which made it possible to determine the distances between dams.

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