doi: 10.18720/MCE.76.10

Critical section and critical depth in open flows finding device

Устройство для нахождения критического сечения и критической глубины в открытых потоках

N.K. Yerzhanova,
M.Kh. Dulaty Taraz State University, Taraz, Republic of Kazakhstan
Zh.A. Mussin,
The Kazakh scientific research institute of water economy, Taraz, Republic of Kazakhstan
S.K. Dzholdasov,
M.Kh. Dulaty Taraz State University, Taraz, Republic of Kazakhstan
A.D. Altynbekova,
M.Kh. Dulaty Taraz State University, Taraz, Republic of Kazakhstan

Докторант Н.К. Ержанова,
Таразский государственный университет им. М.Х. Дулати, г.Тараз, Республика Казахстан
канд. техн. наук, ведущий науч. сотрудник Ж.А. Мусин,
КазНИИ водного хозяйства, г. Тараз, Республика Казахстан
канд. техн. наук, доцент С.К. Джолдасов,
Таразский государственный университет им. М.Х. Дулати, г.Тараз, Республика Казахстан
магистрант А.Д. Алтынбекова,
Таразский государственный университет им. М.Х. Дулати, г.Тараз, Республика Казахстан

Key words: flow rate; average speed; dynamic head; specific energy; spitzen scale; measuring needle; Pitot tube; stock; critical section; critical depth

Ключевые слова: расход потока; средняя скорость; динамический напор; удельная энергия; шпитцен-масштаб; мерная игла; трубка Пито; шток; критическое сечение; критическая глубина

Abstract. There is theoretically shown that pressure is equal to half of flow depth at state of speed flow, i.e .It is equal to half of critical depth. Knowing it, authors offer a device that is designed to finding critical section and critical depth in open flows which are defined by consecutive measurements of dynamic pressure and depth of flow by means of the device in various cross sections and section findings where the dynamic pressure is equal to a half of flow depth, and depth is critical depth, i.e. equality is observed. As a result of the use of such a device increases information density due to the direct determination of the critical section and the critical depth of flow and increase ease of operation.

Аннотация. В статье теоретически показывается, что при критическом состоянии потока скорости напор равен половине глубины потока, т.е. половине критической глубины. Авторами предлагается устройство предназначенное для нахождения критического сечения и критической глубины в открытых потоках, которые определяются путем последовательных замеров динамического напора и глубины потока с помощью устройства в различных поперечных сечениях и нахождения сечения, где динамический напор равен половине глубины потока, а глубина – критической глубине, т.е. равенство соблюдается. В результате применении такого устройства повышается информативность за счет возможности непосредственного определения критического сечения и критической глубины потока и повышение удобства эксплуатации.

Introduction

Finding the critical section and critical depth is necessary not only for estimation the flow state but also for the performance of a number of hydraulic calculations and analysis of the dimensionless coordinate research results. In addition, the critical depth is a unique function of speed and consumption, which enables to determine the velocity and flow rate of the fluid. For example, N.P. Lavrov and M.K. Toropov proposed a way for determining the water discharge at the head sections of the fleeting canals at a critical depth [1]. Consequently, the questions raised are of practical importance.

In hydrometric practice, as well as in the laboratory to measure the depth of the flow widespread measuring needle or Scale-Spitze, hydrometric tube piezometers [2-9]. It allows you to measure the level in the adjustment and calibration of flowmeters variable level.

The main part of the needle measuring rod is coated with it privileges. On the stock strengthened toothed strap and body are based on rack and vernier. Produce vernier reading on the moment of contact

Ержанова Н.К., Мусин Ж.А., Джолдасов С.К., Алтынбекова А.Д. Устройство для нахождения критического сечения и критической глубины в открытых потоках // Инженерно-строительный журнал. 2017. № 8(76). С. 106–114.

needle attached to the stem, or the liquid surface at the time of separation of the needle from the surface [10–16].

To fix the exact moment of contact dimensional needles used electro-contact way to display the time needle touch the liquid surface [2, 17].

Application dimensional needles can measure the level with great precision. Absolute error of measurement is almost independent of range. These advantage dimensional needles formed the basis for measuring the parameters of liquid flow in open flows. However, none of them is able to determine the critical section and a direct measurement of the critical depth.

Examine critical state of flow [18–25]. At the critical state of flow when h=hкр, and the specific energy section has a minimum value E = Emin, therefore,

$$\frac{dE}{dh} = 1 - \frac{\alpha Q^2}{g\omega^3}\frac{d\omega}{dh} = 1 - \frac{\alpha \upsilon^2}{g\omega}\frac{d\omega}{dh} = 0, \qquad (1)$$

where E – the specific energy of the cross section; Q – flow rate; ω – open area flow; h – the depth of the flow in the living section; g – acceleration of gravity; α – the coefficient of kinetic energy (Coriolis); *u* – the average speed in the living section.

Since $d\omega = bdh$ and $h = \frac{\omega}{b}$ equation (1) can be written as

$$\frac{dE}{dh} = 1 - \frac{\alpha \upsilon^2 b}{g\omega} = 1 - \frac{\alpha \upsilon^2}{gh} = 0, \qquad 2)$$

From here you can get

$$\frac{\alpha \upsilon^2}{2g} = \frac{h}{2} \qquad (3)$$

Equation (3) can be written in the parameter of kinetism $\alpha = 1$ how

$$\frac{\upsilon}{\sqrt{gh}} = 1 \qquad (4)$$

or $F_r = 1$ that meets the definition of a critical mode, i.e.,

$$F_r = \frac{\upsilon^2}{gh} = 1, \qquad (5)$$

Here

$$\upsilon^2 = gh, \qquad (6)$$

where F_r – froude number.

If both sides of (6), we multiply to $\frac{\rho}{2\gamma}$, we get

$$\frac{\rho \upsilon^2}{2\gamma} = \frac{\rho g h}{2\gamma} \text{ or } \frac{\upsilon^2}{2g} = \frac{h}{2} \qquad (7)$$

where ρ – density of the fluid; γ – the proportion of liquid.

This is the criteria for the critical state of flux, therefore, the critical state of flow rate pressure is equal to half the depth of the stream, i.e., half of the critical depth.

The purpose of the work is to increase the informative due to the possibility of finding the critical section and measuring the critical depth of the fluid flow, which is achieved by using a device, based on the equation of the dynamic head in the critical section of the flow half of its depth, which makes it is very easy to find the critical section of the liquid flow and measure the critical depth.

To achieve this objectives the following tasks:

– to conduct a theoretical analysis of the critical state of the open flow;

– select the conditions and justification devices for critical cross-section of the fluid flow and measuring the critical depth;

– collecting model to determine the critical cross-section of the fluid flow and measuring the critical depth;

– experiments on the measurement of critical depth;

– conclusions.

Materials and methods of research

A device is offered for finding critical section and critical depth in open flows. As a result of the application of such device the informative value increases due to the possibility of direct determination of the critical section, and critical depth of flow and flexibility in application increases too.

The goal is achieved by successive measurements of the dynamic pressure and flow depth using the device in different cross sections and finding the section where the dynamic pressure is half the depth of the flow and the depth - critical depth. This device performs the method of finding the critical section and measuring the critical depth in open flows. It contains measuring needle Pitot tube, the signal system in which the stem-dimensional needle designed for the measurement of fluid flow. It is equipped with two series-connected and arranged symmetrically with respect to the liquid surface of the same hinge diamonds, mounted one on top of the sleeve slid ably fitted on the rod, and the other - the lower part resting on the bottom of the channel. Wherein a portion of the vertical extension of a diagonal rod which is installed pitot tube, wherein the fluid level is fixed at the throat of the other dimensional position of the needle through rod rigidly connected to the first measuring needle, wherein the end of the needle is mounted on a level with the upper horizontal diagonal of the rhombus which effect mobility rhombuses constantly, regardless of the cross section will be located at a height $\frac{3}{2}h$ relative to the bottom of the channel. Two upper side of the lower extension of the rhombus are the two lower side of the top of the rhombus, constituting one unit with it, and their intersection point is fixed to the needle hub dimensional fixing fluid flow rate via a hinge whose axis is flush with the end of the needle. Horizontal diagonal rhombus are executed in the form of rods, one ends fixed to the left side hinges, and other moving freely on the sleeves mounted on the right side of the hinges. Two lower side of the lower rumba pulled an elastic member (spring) to prevent spontaneous alignment of the parties. Figure 1 is a schematic diagram of a device, Figure 2 – the same, as seen from the incident flow.

The device consists of two dimensional needles 1 and 2, the two articulated lozenges is the upper 3 and lower 4 forming the pantograph mechanism, the receiver of the velocity head in the form of a Pitot tube 5, consisting of a suction connection of the measuring tube, and the indicator 6. Measuring the needle 1 is rigidly fixed to the hub 7 is fixedly fitted on the guide rod 8, and is connected to the signaling device 6. On the rod 8 has two serially connected and arranged symmetrically with respect to the liquid surface of the rhombus hinge 3 and 4, one of which is fixed on the upper part of the sleeve 9 is movably fitted on the rod 8 and the other – the lower part rests on the bottom of the channel. The articulated lozenges 3 and 4 two upper sides 10 and 11 of the lower rhombus 4 are a continuation of the two lower sides 12 and 13 of the upper three rhombus, making them integral, and their intersection point is fixed to the hub 7 through a hinge 14, whose axis is at one measuring the level of the end of needle 1, and horizontal diagonals 15 and 16, made in the form of rods, one ends are fixed to the left side hinges 17 and 18 and the other ends are free to move along the sleeves 19 and 20 attached to the right side hinges 21 and 22. The lower side 23 and 24 of the lower rhombus tightened elastic member 4 (spring) 25.

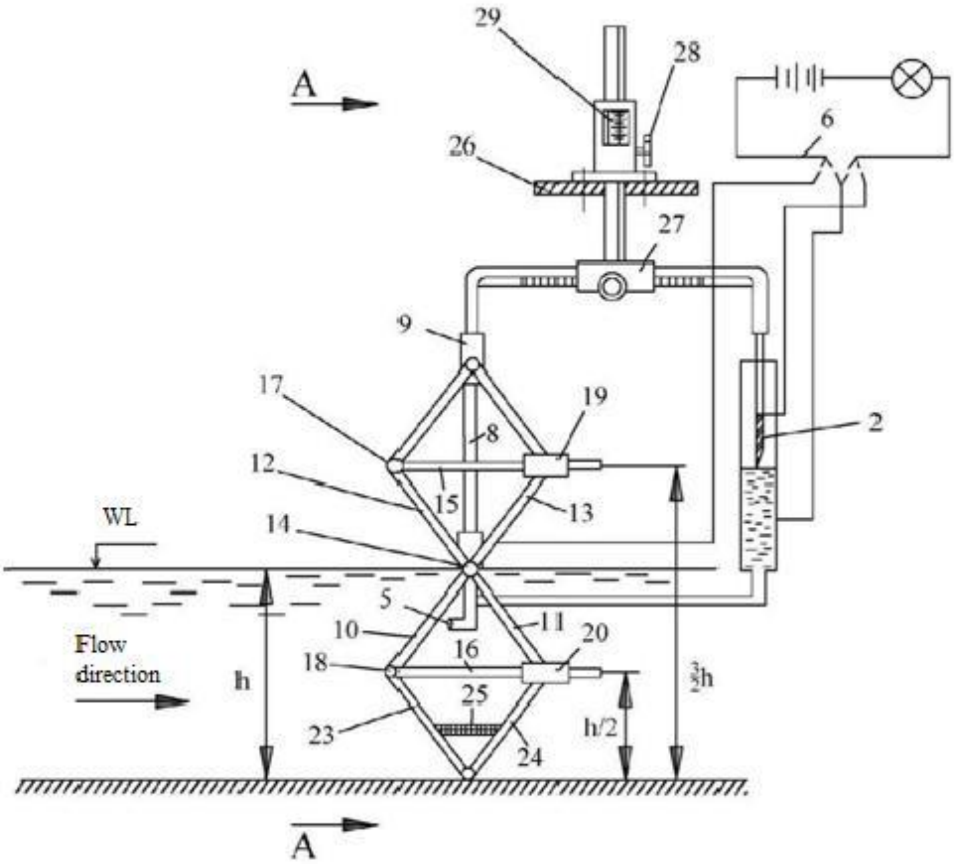

Figure 1. Schematic diagram of a device for measuring parameters of fluid flow in open flow

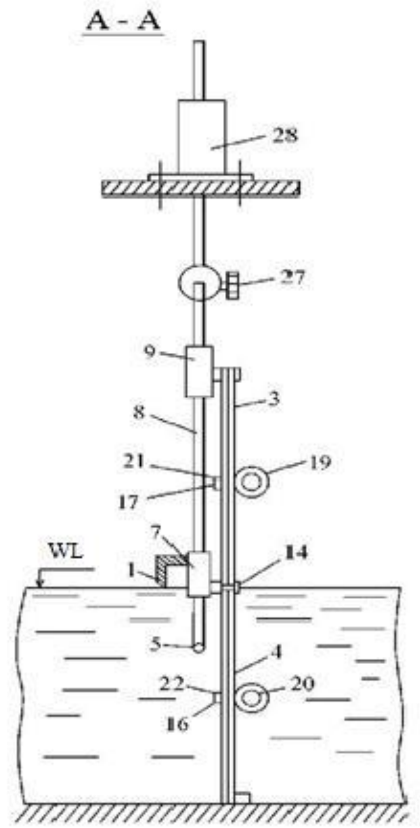

Figure 2. Device type from the incoming flow

On the lower part of the vertical diagonal rhombus 4, which is an extension rod 8, set Pitot tube 5 for measuring the mean dynamic pressure where the fluid level in the critical section is fixed dimensional needle 2 rigidly connected through the rod with measuring needle 1 is also connected to the signaler 6 wherein the needle tip is mounted flush with the upper horizontal diagonal of the rhombus 15 3, which by virtue of the mobility of rhombuses continuously and independently of the cross section will be located at a height of 3/2 h relative channel bottom. The entire installation is fixed on the bridge 26 and is moved horizontally by means of screws 27 and 28 coordinate mechanism. The critical depth is removed on a scale of 29.

Results and Discussion

For a channel of arbitrary shape in general form, it is solved by selection or graph analytical method, for the channel of the correct cross section, simple solutions are possible.

The well-known formulas are given for determining the critical depth for a channel of a regular section:

for a rectangular channel

$$h_{cr} = \sqrt[3]{\alpha \frac{q^2}{g}}, \tag{8}$$

where $q = \frac{Q}{b}$ – the specific consumption, i.e. flow per unit width of a rectangular channel.

for a trapezoidal channel, it is determined by the analytical method, proposed by Agroskin I.I., according to the formula

$$h_{cr.t.} = h_{cr} \frac{\sqrt[3]{1+2z_t}}{1+z_t}, \tag{9}$$

where $h_{cr} = \sqrt[3]{\alpha \frac{q^2}{g}}$ – the critical depth in a rectangular channel for a given flow rate (Q) and a width along the bottom (b); $z_т = mh_{кр.т}/b$ $z_t = mh_{cr.t.}/b$ – dimensionless ratio; $m = ctg\theta$ – slope coefficient of the trapezium.

The notation is introduced by $z_r = mh_{cr}/b$ for a rectangular channel and after some transformation, it is obtained from

$$z_r = \frac{z_t(1+z_t)}{\sqrt[3]{1+2z_t}}, \tag{10}$$

here $\frac{hcr.t}{h_{cr}} = \frac{z_t}{z_r}$.

Substituting different values of z_t, it can obtain from (10) the corresponding z_r and then the values of the ratio $h_{cr.t} = h_{cr}$.

for a triangular channel

$$h_{cr.tr} = \sqrt[5]{\frac{2\alpha}{g}\left(\frac{Q}{m}\right)^2}; \tag{11}$$

for a parabolic channel

$$h_{cr.par} = \sqrt[4]{\frac{27\alpha Q^2}{64gp}}, \tag{12}$$

where p – parabola parameter;

for a weir with a wide threshold, the critical depth of the flow is determined taking into account its curvature [20–22]

$$h_{cr.w} = \sqrt[3]{\frac{\alpha q^2}{g}} \cdot \sqrt[3]{1+\frac{ka}{\alpha}} = h_{cr}\sqrt[3]{1+\frac{ka}{\alpha}}, \tag{13}$$

where $\upsilon = \frac{1}{R_{av}}$ – the curvature of a trickle with dimension $[L]^{-1}$; $a = \upsilon h$ – the dimensionless curvature of the trickle; R_{av} – the value is calculated indirectly from the hydrodynamic pressure of the flow to the bottom; h – the depth of flow.

According to the dependencies shown above, the critical depth is determined analytically, and there is no direct determination of the critical section and the measurement of the critical depth using the device in any of the papers [21–25]. Direct measurement of the critical depth and the critical section in situ is not currently available.

There is described how the devise works and given an example of finding the critical depth. The device operates as follows.

Using 27 screws attached moves horizontally in the direction of flow. In the selected section using the screw 28 descends vertically setting up until the end of the needle 1 will not touch the surface of the liquid flow and not warning light at the first switch position. Then, the key signaling 6 is transferred to the second position and, if the warning light does not light up, the setting moves to the next position and the process is repeated as long as the warning light lights up in the second position of the key, which is fixed by contact dimensional needle 2 with the level of liquid in the tube Pitot 5. This will be the position of the critical section. On a scale with 29 divisions relieve the critical depth.

Essentially the process location of the critical section of flow is determined at equal velocity (dynamic) pressure of the fluid in millimeters of the column of fluid, such as millimeters of water column equal to half the depth of the liquid in the sectional view taken in the same units (millimeters). In other words, it must satisfy the relation

$$\frac{\rho \upsilon^2}{2} = \frac{\rho g h}{2}, \tag{14}$$

where $\frac{\rho \upsilon^2}{2}$ – speed pressure fluid in the flow; h – the depth of the flow in this section; ρ – density of the fluid; υ – velocity of liquid flow; g – acceleration of free fall.

If equality is not respected, the experiment was repeated in the other section to perform this equality, and in the case of compliance conclude according to the measured depth of the flow of critical value in this section, which is the critical section.

For example. Divide the flow - uneven. Rectangular tray at flow rates of 8.83 l/s, 13.37 l/s, 19.77 l/s. h_{cr} should be measured.

Consumption is 8.83 l/s. Installation is moved horizontally in the direction of flow until the first section by means of 27 screws. In the first section by means of screw 28 descends in the vertical installation position as long as one end of the needle 1 touches the liquid surface. Warning light switches in the first position of the key. Then, the key of signaling system translates to the second position - bulb does not light up. Installation is moved to the second section. The process is repeated. The warning light in the second position of key does not light up again. Move the installation to the third section. In this section the warning light at the second position of the key lights up, indicating the critical section. Measure the critical depth which is 5.22 cm and so on, the experiment is curried out when consumptions are 13.37 l/s, 19.77 l/s. The results of the experiments are given in the table.

Table 1. Measuring of critical depth

Tests	Section	Bottom mark	The level of fluid flow	The flow depth, cm	The warning light in the first key position	The warning light in the second switch position	Critical depth cm
1	2	3	4	5	6	7	8
1	1	14.21	19.86	5.65	Lights up	No lights	–
	2	14.00	19.40	5.40	–//–	–//–	–
	3	13.80	19.02	5.22	–//–	Lights up	5.22
2	1	14.02	21.34	7.32	Lights up	No lights	–
	2	13.80	20.82	7.02	–//–	–//–	–
	3	13.60	20.45	6.85	–//–	Lights up	6.85
3	1	13.80	23.12	9.32	Lights up	No lights	–
	2	13.49	22.50	9.01	–//–	–//–	–
	3	13.34	22.21	8.87	–//–	Lights up	8.87

Conclusions

1. Theoretical analysis of the critical state of the flow shows that in the critical state of the flow, the velocity head is equal to half the depth of the stream, i.e. half the critical depth.
2. In a rectangular cross section, where the condition $\frac{\rho\vartheta^2}{2} = \frac{\rho g h}{2}$ is observed, the measured flow depth corresponds to the critical value in this section, i.e. in the critical section.
3. The use of the device, based on the equality of the dynamic pressure in the critical flow cross section is half of its depth, allows you quite simply to find the critical cross-section of the fluid flow and measure the critical depth.
4. The device makes it possible to determine the critical section and critical depth flow by direct measurement in real conditions correspond to reality, no additional calculations, which increases the accuracy of determination of the critical depth and greatly reduces the time (if necessary measurement process is automated).

References

1. Lavrov N.P., Toropov M.K. Izmerenie raskhoda vody na golovnyh uchastkah bystrotechnyh kanalov [Measurement of water discharge at head sections of the fleeting canals]. *Meteorologiya i gidrologiya v Kyrgyzstane.* 2002. No. 2. Pp. 31–36. (rus)
2. Kosichenko N.V. Analiz izucheniya i utochneniya metodov svobodnogo rastekaniya potoka za beznapornymi vodopropusknymi otverstiyami [The analysis of studying and specification of methods of free spreading of a stream behind free-flow water throughput openings]. *Vestnik SGAU.* 2011. No. 9. Pp. 27–33. (rus)
3. Giancoli D.C. *Physics for Scientists & Engineers.* Third Edition. Prentice Hall. Upper Saddle River. New Jersey. 2000. 1024 p.
4. Liptak B. *Instrument Engineers' Handbook, Vol. 1: Process Measurement and Analysis.* CRC Press. 4 edition. 2003. 1920 p.
5. Biryukov B.V., Danilov M.A., Kivilis S.S. *Tochnyye izmereniya raskhoda zhidkostey* [Accurate measurement of liquid flow rate]. Moscow: Mashinostroyeniye. 1977. 144 p. (rus)
6. Kokhanenko N.V. Opredeleniye parametrov potoka na beskonechnosti, vdol' krayney linii toka i postoyannoy A [Determination of parameters of a stream on infinity, along the extreme line of current and permanent]. *Cherez innovatsii v nauke i obrazovanii k ekonomicheskomu rostu APK: materialy mezhdunar. nauch.– prakt. konf.* [Through innovations in science and education to the economic

Литература

1. Лавров Н.П., Торопов М.К. Измерение расхода воды на головных участках быстротечных каналов // Метеорология и гидрология в Кыргызстане. 2002. №2. С. 31–36
2. Косиченко Н.В. Анализ изучения и уточнения методов свободного растекания потока за безнапорными водопропускными отверстиями // Вестник СГАУ. 2011. № 9. С. 27–33.
3. Giancoli D.C. Physics for Scientists & Engineers. Third Edition. Prentice Hall. Upper Saddle River. New Jersey. 2000. 1024 p.
4. Liptak B. Instrument Engineers' Handbook, Vol. 1: Process Measurement and Analysis. CRC Press. 4 edition. 2003. 1920 p.
5. Бирюков Б.В., Данилов М.А., Кивилис С.С. Точные измерения расхода жидкостей. М.: Машиностроение, 1977.144 с.
6. Коханенко Н.В. Определение параметров потока на бесконечности, вдоль крайней линии тока и постоянной А // Через инновации в науке и образовании к экономическому росту АПК: материалы междунар. науч. – практ. конф. ДонГАУ: Персиановский. 2008. Т. 2. С. 198–200.
7. Коханенко Н.В., Баленко Е.Г., Ширяев В.В. Определение аналитической зависимости распределения глубин и скоростей вдоль продольной оси симметрии в задаче свободного растекания бурного потока // Изв. вузов. Сев.-Кавк. регион. Техн. науки. 2006. № 2. С. 14-16.

growth of the agro-industrial complex. Proceedings of international research and practical conference]. DonGAU. Persianovskiy. 2008. Vol. 2. Pp. 198–200. (rus)

7. Kokhanenko N.V., Balenko Ye.G., Shiryayev V.V. Opredeleniye analiticheskoy zavisimosti raspredeleniya glubin i skorostey vdol prodolnoy osi simmetrii v zadache svobodnogo rastekaniya burnogo potoka [Determination of the analytical dependence of the depth distribution and velocities along the longitudinal symmetry axis in the problem of free rapid flow]. *Izv. vuzov. Sev.Kavk. region. Tekhn. nauki.* 2006. No. 2. Pp. 14–16. (rus)
8. Kosichenko N.V., Mitsik M.F., Lemeshko M.A. Metod s ispolzovaniyem godografa skorosti primenitelno k raschetu parametrov burnogo dvukhmernogo potoka [Method using the velocity hodograph as applied to the parameter calculation of a turbulent two-dimensional flow]. *Matematicheskoye i kompyuternoye modelirovaniye yestestvennonauchnykh i sotsialnykh problem: sb. st. IV Mezhdunar. nauchn.tekhn. konf. molodykh spetsialistov, aspirantov i studentov* [Mathematical and computer modeling of natural and social problems: proceedings IV Intern. scientific-techn. conf. young specialists, post-graduate students and students]. Penza: Privolzhskiy Dom znaniy, 2010. Pp. 130–141. (rus)
9. Miller R.W. *Flow Measurement Engineering Handbook.* Second Edition. McGraw-Hill Publishing Compan.New York. NY. 1989.
10. Bobrovnikov G.N., Katkov A.G. *Metody izmereniya urovney* [Methods of level measurement]. Moscow. Mashinostroyeniye. 1977. 167 p. (rus)
11. Dedrick A.R., Clemmens A.J. Instrumentation for monitoring water levels. *Proc. Of Agri-Mation Conference and Exposition. ASAE.* Chicago. IL, 1986. Pp. 148–152.
12. Compton P.R., Kulin G. *A Guide to Methods and Standards for the Measurement of Water Flow.* Washington. National Bureau of Standards Special Publication 421. Institute for Basic Standards 1975. 97 p.
13. Grant D.M. *Open Channel Flow Measurement Handbook.* 1st edition, Lincoln. Instrument. Instrumentation Specialties Company. 1979.
14. Park J., Mackay S., Wright E. *Practical Data Communications for Instrumentation and Control.* IDC Technologies, 2003. 402 p.
15. Reynders D., Mackay S., Wright E. *Practical Industrial Data Communications. Best Practice Techniques.* IDC Technologies, 2005.
16. Bakshtanin A.M. *Gidravlicheskoye obosnovaniye metodov rascheta vodoboynykh kolodtsev s bokovym otvodom potoka* [Hydraulic study of the methods for the calculation of the stilling basin wells with a lateral diversion of flow]. PhD Thesis. Moscow. 2006. 154 p. (rus)
17. Kuphaldt T.R. *Lessons in Industrial Instrumentation* Version 0.2. 2008.
18. Andreyev A.Ye. Osobennosti upravleniya okolokriticheskimi potokami v nizhnikh byefakh nizkonapornykh vodopropusknykh sooruzheniy i otsenka yego effektivnosti [Management features of near-critical flows in the lower pools of low-head culverts and evaluation of its effectiveness]. *Gidravlika vodokhozyaystvennykh obyektov: Sb.nauchn.tr.:Trudy LPI* [Hydraulics of water management objects: Proceedings of LPI]. No. 424. Leningrad. 1983. Pp. 49–52. (rus)
19. Garanina Ye.B., Ponomarev N.K., Rabkova Ye.K. K voprosu o kinematicheskoy strukture otkrytykh potokov [To the question about the kinematic structure of open flows]. *Gidrotekhnicheskoye stroitelstvo.* 1995. No. 19. Pp. 30–33. (rus)
20. Gur'yev A.P., Khanov N.V., Yershov K.S. Vliyaniye planovogo rasshireniya vodosliva s gorizontal'noy vstavkoy na yego propusknuyu sposobnost' [Influence of planned expansion of a spillway with a horizontal insert on its bandwidth]. *Prirodoobustroystvo.* Moscow. 2010. No. 5.

8. Косиченко Н.В., Мицик М.Ф., Лемешко М.А. Метод с использованием годографа скорости применительно к расчету параметров бурного двухмерного потока // Математическое и компьютерное моделирование естественнонаучных и социальных проблем: сб. ст. IV Междунар. научн.-техн. конф. молодых специалистов, аспирантов и студентов. Пенза: Приволжский Дом знаний, 2010. С. 130–141.
9. Miller R.W. Flow Measurement Engineering Handbook. Second Edition. McGraw-Hill Publishing Compan.New York. NY. 1989.
10. Бобровников Г.Н., Катков А.Г. Методы измерения уровней. М: Машиностроение, 1977. 167 с.
11. Dedrick A.R., Clemmens A.J. Instrumentation for monitoring water levels // Proc. Of Agri-Mation Conference and Exposition. ASAE. Chicago. IL. 1986. Pp. 148–152.
12. Compton P.R., Kulin G. A Guide to Methods and Standards for the Measurement of Water Flow, Washington. National Bureau of Standards Special Publication 421. Institute for Basic Standards 1975. 97 p.
13. Grant D.M. Open Channel Flow Measurement Handbook. 1st edition, Lincoln. Instrument. Instrumentation Specialties Company. 1979.
14. Park J., Mackay S., Wright E. Practical Data Communications for Instrumentation and Control. IDC Technologies, 2003. 402 p.
15. Reynders D., Mackay S., Wright E. Practical Industrial Data Communications. Best Practice Techniques. IDC Technologies, 2005.
16. Бакштанин А.М. Гидравлическое обоснование методов расчета водобойных колодцев с боковым отводом потока: дис. канд. техн. наук. М., 2006. 154 с.
17. Kuphaldt T.R. Lessons in Industrial Instrumentation Version 0.2. 2008.
18. Андреев А.Е. Особенности управления околокритическими потоками в нижних бьефах низконапорных водопропускных сооружений и оценка его эффективности.// Гидравлика водохозяйственных объектов: Сб.научн.тр.: Труды ЛПИ № 424. Л., 1983. С. 49–52.
19. Гаранина Е.В., Пономарев Н.К., Рабкова Е.К. К вопросу о кинематической структуре открытых потоков // Гидротехническое строительство. 1995. № 19. С. 30–33.
20. Гурьев А.П., Ханов Н.В., Ершов К.С. Влияние планового расширения водослива с горизонтальной вставкой на его пропускную способность // Природообустройство. 2010. № 5. С. 42–46.
21. Гурьев А.П., Козлов В.Д., Ханов Н.В., Ершов К.С. Расчёт водосливов с переменной шириной пролёта в плане/ // Природообустройсво. 2010. № 3. С. 47–50.
22. Гурьев А.П., Хайруллин Р.А. Определение кинематических характеристик безнапорного потока в вертикально расположенных сопрягающих коленах // Природообустройсво. 2013. № 1. С. 42–50.
23. Ершов К.С. Формирование свободной поверхности потока на водосливе практического профиля криволинейного очертания с горизонтальной вставкой и непараллельными боковыми стенками // Природообустройсво. 2011. № 4. С. 51–54.
24. Бакштанин А.М. Теоретическое обоснование работы водобойного колодца с боковым отводом потока // Природообустройсво. Ч. III. «Гидротехническое строительство». 2008. № 5. С. 57–62.
25. Гурьев А.П. Совершенствование конструкции шахтного водосброса полигонального поперечного сечения // Сборник научных трудов «Известия ВНИИГ им. Б.Е.Веденеева». 2009. Т. 256. С. 35–45.

Pp. 42–46. (rus)

21. Guryev A.P., Kozlov V.D., Khanov N.V., Yershov K.S. Raschet vodoslivov s peremennoy shirinoy proleta v plane [Calculation of weirs with variable span width in a plan]. *Prirodoobustroysgvo.* Moscow. 2010. No.3. Pp. 47–50. (rus)
22. Gur'yev A.P., Khayrullin R.A. Opredeleniye kinematicheskikh kharakteristik beznapornogo potoka v vertikal'no raspolozhennykh sopryagayushchikh kolenakh [Definition of kinematic characteristics of a free-flow stream in vertically located interfacing knees]. *Prirodoobustroysgvo.* Moscow. 2013. No. 1. Pp. 42–50. (rus)
23. Yershov K.S. Formirovaniye svobodnoy poverkhnosti potoka na vodoslive prakticheskogo profilya krivolineynogo ochertaniya s gorizontal'noy vstavkoy i neparallel'nymi bokovymi stenkami [Formation of a free surface of a stream on a spillway of a practical profile of a curvilinear outline with a horizontal insert and nonparallel the side walls]. *Prirodoobustroysgvo.* Moscow. 2011. No. 4. Pp. 51–54. (rus)
24. Bakshtanin A.M. Teoreticheskoye obosnovaniye raboty vodoboynogo kolodtsa s bokovym otvodom potoka [Theoretical study of the stilling basin with side outlet flow. Nature conservation]. *Prirodoobustroysgvo.* Ch. III. «Gidrotekhnicheskoye stroitelstvo». 2008. No. 5. Pp. 57–62. (rus)
25. Gur'yev A.P. Sovershenstvovaniye konstruktsii shakhtnogo vodosbrosa poligonal'nogo poperechnogo secheniya [Improvement of the design of the spillway dug polygonal cross section]. *Sbornik nauchnykh trudov «Izvestiya VNIIG im. B.Ye.Vedeneyeva».* 2009. Vol. 256. Pp. 35–45. (rus)

Nurliza Yerzhanova,
+7(777)965-31-65; nurliza66@mail.ru

Zhassulanbay Mussin,
+7(726)242-55-40; musin_jasulan@mail.ru

Saparbek Dzholdasov,
+7(726)256-85-82; Arnur_68@mail.ru

Aliya Altynbekova,
+7(747)667-67-38; kleo-14@mail.ru

Нурлиза Киякбаевна Ержанова,
+7(777)965-31-65; эл. почта: nurliza66@mail.ru

Жасуланбай Аккаирович Мусин,
+7(726)242-55-40;
эл. почта: musin_jasulan@mail.ru

Сапарбек Куракбаевич Джолдасов,
+7(726)256-85-82; эл. почта: Arnur_68@mail.ru

Алия Досжанкызы Алтынбекова
+7(747)667-67-38; эл. почта: kleo-14@mail.ru

Ержанова Н.К., Мусин Ж.А., Джолдасов С.К., Алтынбекова А.Д. Устройство для нахождения критического сечения и критической глубины в открытых потоках // Инженерно-строительный журнал. 2017. № 8(76). С. 106–114.