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INFLUENCE OF THE BOTTOM SILLS ON THE FLOW SCOURING CAPACITY ON THE FOOTHILL AREAS OF THE RIVERS

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Abstract. The regulation of riverbeds with the help of hydrotechnical constructions is one of the most widespread flood protection methods used on the rivers of the Ukrainian Carpathians. Analysis of a priori information (results of field observations, normative and design documentation) determined the range of changes in the main hydraulic parameters of the water flow and the size of the bottom sills. The purpose of hydraulic studies was to study the influence of bottom sills on the flow scouring capacity on the foothill areas of the rivers during floods. The theoretical studies of the flow scouring capacity were carried out according to the Nikitin's recommendations.

During the execution of the experiments, for each height of the bottom sills set corresponding costs and bottom slope, which provides received, according to the scheduling matrix Froude number and full-supply depth. In order to test the suitability of the Nikitin's recommendations for our conditions were met the experimental investigation of sediment particles stability from the existing factors in the case where the flat-bottomed flume decorated with a cement-sand mortar.

Investigation of the influence of the acting factors on the diameters of sediment particles resistant to erosion was carried out at a Froude number equal to 0,8 and a full-supply depth of 0,15 m for the case where the bottom was finished with a cement-sand mortar.

Analysis of the laboratory studies results has shown that the installation of the bottom sills to an increase in the flow depth and, accordingly, to a decrease in the diameter of the sediment particles forming the bottom, that is, the eroded flow capacity before the bottom sills.

The results of laboratory studies have made it possible to determine the effect of the bottom sills on the change in the flow depth ahead of them and on its erosive capacity.

The results obtained are basic for the development of a methodology for the designing bottom sills to stop deep erosion on the foothill areas of the rivers.

Keywords: foothill areas of the rivers, bottom sills, flow scouring capacity, resistant to erosion particles bottom.

Introduction. Stream regulation using hydrotechnical regulation structure is one of the most common methods of flood protection used on the rivers of the Ukrainian Carpathians [1]. Stream regulation issues have been closely examined by V.F. Talmaza, A.N. Kroshkin, Y.I. Kaganov, I.I. Kirienko, A.E. Shchodro, L.A. Shynkaruk, etc.

Submountain rivers are located at the rivers' outlet from mountains and are characterized by the fact that they have a variable water regime, which can lead to significant river's course deformations. Such river reaches have longitudinal bottom slopes in the range of 0.002 ... 0.01 and are characterized by a large roughness coefficient. The flow depths during flooding reach 3.0 ... 6.0 m and more, and speeds – 3.0 ... 7.0 m/s. Froude numbers vary in the range of 0.2 ... 0.8 [2-4].

Bottom sills are anti-mudflow, correctional and anti-erosion hydrotechnical regulatory structures used to reduce eroded bottom processes on rivers during the passage of floods [2].

Bottom sills can be monolithic and packaged. Monolithic ones are built in the form of retaining wall made from concrete, stone concrete, or concrete with few reinforcements. Packaged constructions are made from concrete with few reinforcements. In addition, there are gabion sills with figural under layer and stone-brush sills with fascine masonry.

As previous experience of bottom sills building shows, they are usually built in 1.0-4.0 m height. The reason is I.I. Kherkheulidze's recommendations, who said that it is economically unviable to build massive structures above 4...5 m. With increasing height, it is more difficult to ensure the structure stability and the downstream protection from erosion.

The aim of hydraulic research is observation of bottom sills impact on submountain river's ability to erode during a flood, and improvement of existing methods of hydraulic calculation of parameters of bottom sills in the submountain rivers.

Research methods. Methods of physical and mathematical modeling of hydraulic elements, the kinematic structure of the stream flow and its ability to erode were applied using mathematical planning of the experiment. The physical parameters of the flow were studied using standard and sufficiently approved methods. We also used methods of computer statistical processing of the obtained experimental results to confirm the adequacy of analytical models.

To solve the raised problems, theoretical and experimental studies of uniform and non-uniform parameters (in the presence of bottom sills) of steady-state water movement, its ability to erode, depending on the main factors: Froude number, normal depth of stream and bottom roughness were performed. Such studies can be fully performed in laboratory conditions only, and, unlike in-field studies (in field conditions), they allow experiments to be carried out in a wider range of changes in the operating factors of the water stream, the size of the bottom sills, etc. In addition, the accuracy of experiments in laboratory conditions is much higher than in natural conditions.

Experimental hydraulic studies were carried out in the laboratory of Hydraulic Engineering Department at the National University of Water and Environmental Engineering (NUWM) in a mirror tray [6]. The total length of the tray is 38.8 m, the width is 1.0 m, and the height of the side walls is 1.0 m (Fig. 1).

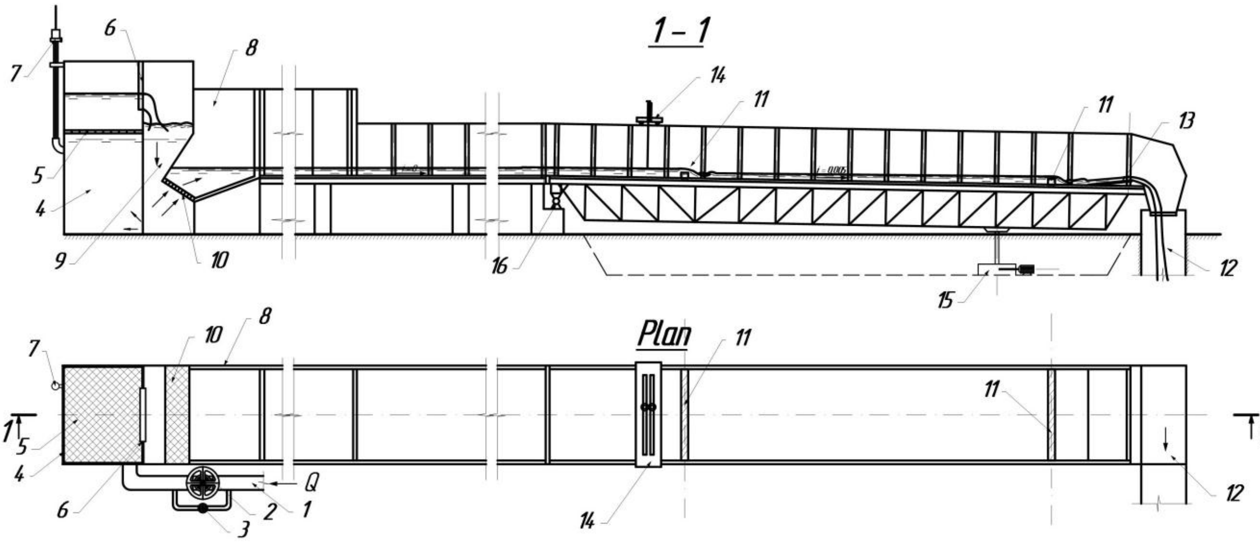

Fig. 1. Scheme of experimental facility:
1 – pipeline to feed water into the tray; 2 – valve for coarse regulation of water flow; 3 – valve for precise regulation of water flow; 4 – pressure tank; 5 – wood grating for flow energy dissipation in the pressure tank; 6 – measured triangular weir; 7 – piezometer of measuring triangular weir; 8 – mirror tray; 9 – stilling pool; 10 – wood grating for flow energy dissipation during entrance to the mirror tray; 11 – drain trench; 12 – tilting gate to ensure normal depth; 13 – carriage with a tap and a spinner; 14 – tray bias device (screw jack); 15 – rotating joint; 16 – bottom sill

The tray consists of two sections. First section (fixed) with a length of 23.2 m has zero slope of the bottom. Second section (mobile) with a length of 15.6 m is placed on a metal truss, which rests on a hinge at the support and, with the help of lifts, can change the bottom slope. The side walls of the tray are made of glass. Fixed section is connected with mobile one with special waterproofing rubber. The water was supplied to the tray through a pipeline from a pressure tank of the hydrotechnical laboratory. Water flow was controlled using a measured triangular weir. After the spillway, the water passed through a quencher system, which ensured a uniform water flow into the tray. At the end of the tray, a metal tilting gate is arranged in order to control the depth of the flow.

On the mobile section of the tray, we covered a bottom with a cement-sand grout (rigid model) or with crumbs or rubble (eroded models) of the corresponding fraction depending on the type of roughness of the bed bottom, which was subject to modeling. In the study of hydraulic structures, their models were arranged in a tray in the form of rectangular wooden beams, the height of which was taken according to the research conditions.

Theoretical research of stream's ability to erode was performed according to recommendations of I.K. Nikitin [7]. A diagram of the flow force impact on the proportion of incoherent bottom accretions under the action of the water flow and a diagram of maximum instantaneous velocities is shown in Fig. 2. The share is affected by its own weight G, the horizontal component F_x and the vertical – F_y due to the flow. The most unstable particles of the layer will be those that are less deep into the bottom, and whose height is almost equal to the distance d from the bottom.

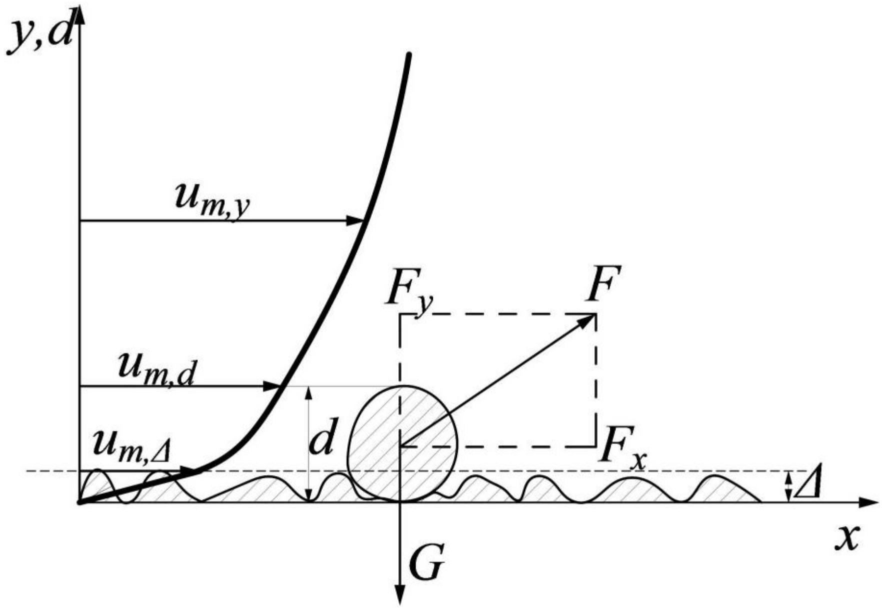

Fig. 2. The scheme of power influence of the flow on the share of inconsistent bottom accretions and the diagram of maximum instant velocities $(u_{m,y})$

The moment of disruption by the flow of upper sediment layer particles will be the beginning of the bottom erosion. On the basis of experimental studies [7], it was shown that the movement of accretions of different size occurs when:

$$\frac{\omega_{cm}}{u_{m,d}} = 0{,}42\,, \tag{1}$$

which is called the criterion of stability of noncohesive accretions, where ω_{st} – the hydraulic fracturing of particles in diameter d_{st}, that are in a critical state because of flow forces action, mps; $u_{m,d}$ – maximum instantaneous velocity at the height of the vertices of these particles, mps.

Hydraulic particle size of accretions is determined by the formula of V.M. Honcharov [8, 9]:

$$\omega = \sqrt{\frac{2g(\rho_ч - \rho_в)d}{1{,}75\rho_в}}\,, \tag{2}$$

where $\rho_ч$ – particle density, g/cc; $\rho_в$ – water density, g/cc, d – particle diameter, m.

The value of $u_{m,d}$ is determined by the:

$$u_{m,d} = u_d + 3\sqrt{\left(\overline{u'}\right)^2_{m,d}} , \tag{3}$$

where u_d – averaged velocity at the height of particle vertices with a diameter of d, mps; $\sqrt{\left(\overline{u'}\right)^2_{m,d}}$ – longitudinal pulsation velocity at the height of particle vertices with a diameter of d, mps.

For the near-wall layer $0 \le d \le \Delta$, the average velocity u_d is determined by:

$$u_d = u_{*\delta}\, Re_{*\delta\,\infty} \frac{d}{\Delta} , \tag{4}$$

where $u_{*\delta}$ – dynamic velocity, mps, $Re_{*\delta\,\infty}$ – two-layer model parameter of I.K. Nikitin; Δ – estimated height of roughness protrusions, m.

For a turbulent core $\Delta \le d \le h$, the average velocity u_d is determined by:

$$u_d = u_{*\delta}\, Re_{*\delta\,\infty} \left(1{,}15\, lg \frac{d}{\Delta} + 1{,}5 - 0{,}5 \frac{\Delta}{d} \right). \tag{5}$$

The condition of the erosion-resistance of the stream composed of incoherent bottom accretions with hydraulic size ω has the form of:

$$\frac{\omega}{u_{m,d}} > 0{,}42 . \tag{6}$$

Usually, the stream consists of particles of different sizes. Under the action of the stream, firstly, the smallest particles begin to move. Rest of accretions creates erosion pavement of the bottom. The flow regime at which the erosion pavement is created can be determined by dependency (6).

On Fig. 3, there is a scheme of areas of accretions, resistant and nonresistant to erosion.

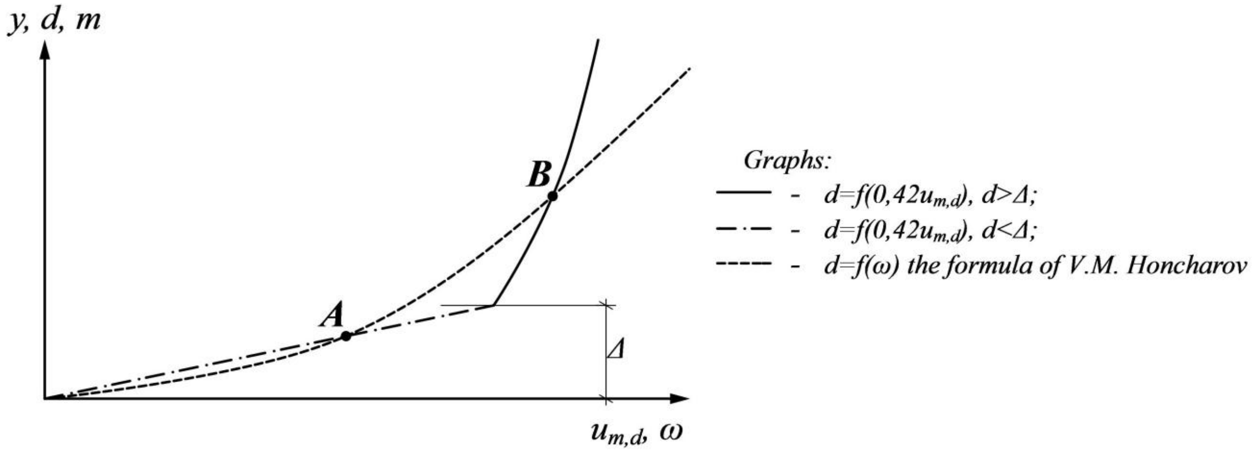

Fig. 3. Scheme of areas of accretions, resistant and nonresistant to erosion

Fig. 3 shows diagrams $d = f\left(0{,}42u_{m,d}\right)$ and $d = f(\omega)$. The points of intersection of these graphs $f\left(0{,}42u_{m,d}\right) = f(\omega)$ correspond to the diameters of the particles, which are resistant to erosion. Particles whose diameter is less than the diameter, which corresponds to p. *A*, and larger than the diameter in p. *B*, will also be resistant. Particles of accretions whose diameters have an intermediate value can be eroded.

Results. The conditions of hydraulic research of bottom sills effect on the distribution of accretions that are resistant to erosion by diameter, depending on the structure of the water flow and the height of bottom sills in natural conditions (model) are given in Fig. 1.

Figure 1 – Conditions of experimental hydraulic research (for model at scale $M=40$)

Factors		Levels of variation			Interval of variation
Natural look	Coded look	-1	0	+1	
Style of model's bottom finish	X_1	Cement-sand grout	chips (grade 3-8 mm)	cobble (grade 5-20 mm)	-
Froude code Fr	X_2	0.2	0.5	0.8	0.3
Normal depth h, m for reconstruction (for model)	X_3	0.075 (3.0)	0.1125 (4.5)	0.150 (6.0)	0.0375 (1.5)
Bottom sill height p, m for reconstruction (for model)	X_4	0.04 (1.6)	0.08 (3.2)	0.12 (4.8)	0.04 (1.6)

During the experiments, for each height of the bottom sills, the corresponding costs and bottom bows were established, which ensured that Froude numbers and normal depths were taken according to the planning matrix.

In order to verify the suitability of the recommendations of I.K. Nikitin experimental studies were carried out on the stability of accretions' particles from the operating factors in the case when the bottom of the tray is finished with a cement-sand grout. The conditions of the experiment, the output and statistical processing of the results [10] are given in Fig. 2.

Figure 2 – Matrix for researching the resistance of accretions' particles to erosion and statistical processing of experimental data

Natural values of factors			Height of bottom sill, p	Input parameters			Diameters o accretions that are resistant to erosion, $d_{cm,д}$
Style of bottom's finish	Fr	h		Diameters of accretions that are resistant to erosion, $d_{cm,m}$	Median fall diameter, max. ins. speed $\omega = 0,42u_{m,d}$	Intersection point on graphs	
		m	m	m	mps		
1	2	3	4	5	6	7	
CSG	0,80	0,15	0,04	0,0053	0,312	p.*B* (fig. 4)	0,0057
			0,12	0,0019	0.185	p.*C* (fig. 4)	0,0023

Statistical analysis			
Reproducibility dispersion $S_в^2 \cdot 10^6$	Dispersion of adequacy $S_a^2 \cdot 10^6$	Estimated value of Fisher's criterion F_p	Table value of Fisher's criterion at 95% level of confidence probability and degree of freedom ($f_в = 5$, $f_a = 5$)
m^2	m^2		
0,167	0,360	2,16	5,1

The research of active factors impact on the particle diameters of accretions that are resistant to erosion was performed with a Froude number of 0.8 and a normal flow depth of 0.15 m for the case when the bottom was finished with a cement-sand grout.

Experimental studies to determine the diameter of resistant accretions carried out as follows. In tray, that was finished with cement-sand grout, with stream, which parameters corresponded to the terms of the experiment plan (Fig. 2), 7 m away from the sill, we scattered the soil (a mixture of sand and gravel), which included particles of different diameters. The particles of soil, resistance of which was less than the stream's ability to erode, was carried out beyond the tray. The soil fractions remaining on the bottom of the tray were dried and sifted through lab sieve (ТУ 23.2.2068-89) after the experiment.

The diameter of the sieve head, the total balance of which was not less than 95% of the sieved mass of soil, was taken for the minimum diameter of the accretions resistant to erosion.

Fig. 4 shows graphs $y = f(0{,}42u_{m,d})$ in case, when bottom of the tray is finished with cement-sand grout, with uniform motion and with the arrangement of bottom sills (height: p = 0,04 m and p = 0,12 m). Also, Fig. 4 shows graphs of the dependence of the hydraulic size of the accretions' particles on their diameter by the formula of Honcharov (2). The ordinates of the points of intersection of the named graphs correspond to the diameters of the particles of accretions that create the bottom of the tray.

In a uniform motion, the diameter of the particles of accretions should be not less than 0.016 m (p. A), with the installation of a bottom sills in height p = 0.04 m, the diameter of the particles of accretions, that create bottom finishing, decreases and should be not less than 0.0053 m (p. B), and at sills height p = 0.12 m – not less than 0.0019 m (p. C).

Graphs analysis in the Fig. 4 represents that the arrangement of the sills leads to increase of depth of the stream and, in accordance with the decrease in the diameter of the particles of accretions, forming the bottom finishing, which means that the stream's ability to erode decreases before the bottom sills.

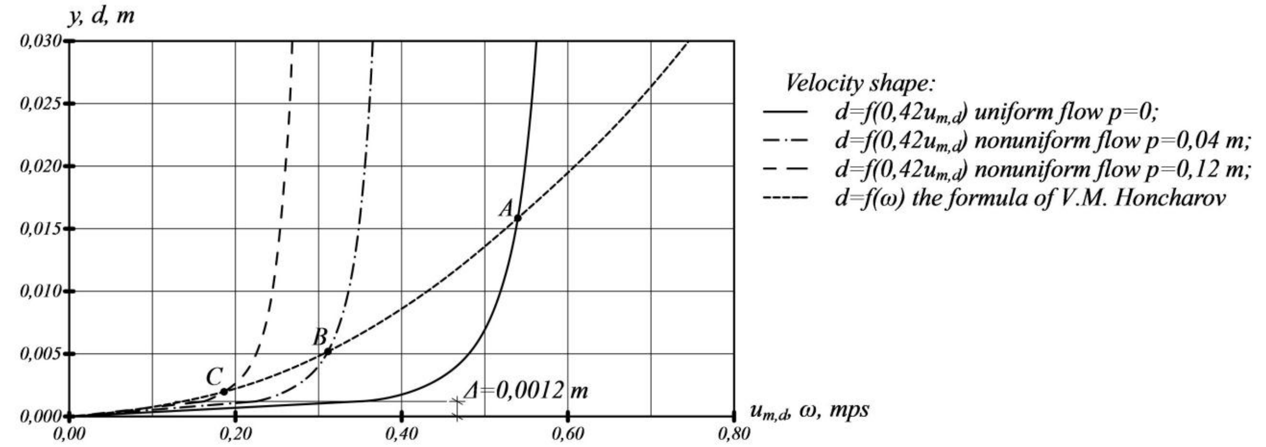

Fig. 4. Conditions of particles of accretions resistance with a diameter *d* near the bottom of the tray are finished with cement-sand grout at the installation of bottom sills with a height p = 0.04 m and p = 0.12 m and with uniform motion

Summary:

1. On the basis of analysis of a priori information (results of field observations, normative and project documentation) a range of changes in the basic hydraulic parameters of the water stream and the size of the bottom sills was determined.

2. The results of laboratory researches made it possible to determine the impact of the bottom sills on the change in the stream depth in front of them and on its erosion potential.

3. The obtained results are fundamental for the development of a methodology for designing the bottom sills in order to stop the deep erosion on submountain rivers.

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ВЛИЯНИЕ ДОННЫХ ПОРОГОВ НА РАЗМЫВАЕМУЮ СПОСОБНОСТЬ ПОТОКА НА ПРЕДГОРНЫХ УЧАСТКАХ РЕК

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Аннотация. Регулирование русел с помощью гидротехнических регуляционных сооружений является одним из распространенных методов противопаводковой защиты, используемых на реках Украинских Карпат. На основе анализа априорной информации (результатов натурных наблюдений, нормативной и проектной документации) был определен диапазон изменения основных гидравлических параметров водного потока и размеров донных порогов. Целью гидравлических исследований было изучение влияния донных порогов на размываемых способность руслового потока на предгорных участках рек при прохождении наводнений и паводков. Теоретические исследования размываемой способности потока выполнялись согласно рекомендациям И.К. Никитина.

Во время выполнения экспериментов, для каждой высоты донного порога устанавливали соответствующие расходы и поклоны дна, которые обеспечивали принятые согласно матрицы планирования, числа Фруда и нормальные глубины. С целью проверки пригодности рекомендаций И.К. Никитина для наших условий были выполнены экспериментальные исследования устойчивости частиц наносов от действующих факторов для случая, когда дно лотка отделано цементно-песчаным раствором.

Исследование влияния действующих факторов на диаметры частиц наносов устойчивых к размыву выполнялись при числе Фруда равном 0,8 и нормальной глубине потока – 0,15 м для случая, когда дно было отделано цементно-песчаным раствором.

Анализ результатов лабораторных исследований показал, что устройство порогов приводит к увеличению глубины потока и соответственно к уменьшению диаметра частиц наносов, формирующих отмостку дна, то есть размываемых способность потока перед донным порогом уменьшается. Результаты лабораторных исследований позволили определить влияние донных порогов на смену глубины потока перед ними и на его размываемую способность. Полученные результаты являются базовыми для разработки методики проектирования донных порогов с целью прекращения глубинной эрозии на предгорных участках рек.

Ключевые слова: предгорные участки рек, донный порог, размываемых способность потока, устойчивые к размыву наносы.

ВПЛИВ ДОННИХ ПОРОГІВ НА РОЗМИВНУ СПРОМОЖНІСТЬ ПОТОКУ НА ПЕРЕДГІРСЬКИХ ДІЛЯНКАХ РІЧОК

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Анотація. Регулювання русел за допомогою гідротехнічних регуляційних споруд є одним з поширених методів протипаводкового захисту, що використовуються на річках Українських Карпат. На основі аналізу апріорної інформації (результатів натурних спостережень, нормативної та проектної документації) було визначено діапазон зміни основних гідравлічних параметрів водного потоку і розмірів донних порогів. Метою гідравлічних досліджень було вивчення впливу донних порогів на розмивна спроможність руслового потоку на передгірних ділянках річок при проходженні повеней і паводків. Теоретичні дослідження розмивної спроможності потоку виконувалися відповідно до рекомендацій І.К.Нікітіна.

Під час виконання експериментів, для кожної висоти донного порога встановлювали відповідні витрати і уклони дна, які забезпечували прийняті відповідно до матриці планування, числа Фруда і нормальні глибини. З метою перевірки придатності рекомендацій І.К.Нікітіна для наших умов були виконані експериментальні дослідження стійкості частинок наносів від діючих факторів для випадку, коли дно лотка оброблено цементно-піщаним розчином.

Дослідження впливу діючих факторів на діаметри частинок наносів стійких до розмиву виконувалися при числі Фруда рівному 0,8 і нормальній глибині потоку - 0,15 м для випадку, коли дно було оброблено цементно-піщаним розчином.

Аналіз результатів лабораторних досліджень показав, що влаштування порогів призводить до збільшення глибини потоку і відповідно до зменшення діаметра частинок наносів, що формують вимощення дна, тобто розмивна спроможність потоку перед донним порогом зменшується. Результати лабораторних досліджень дозволили визначити вплив донних порогів на зміну глибини потоку перед ними і на його розмивну спроможність. Отримані результати є базовими для розробки методики проектування донних порогів з метою припинення глибинної ерозії на передгірних ділянках річок.

Ключові слова: передгірські ділянки річок, донний поріг, розмивна спроможність потоку, стійкі до розмиву наноси.

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