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DEVELOPMENT OF THE METHOD OF ANALYSIS FOR DETERMINING THE COORDINATES OF TERMINAL SURFACE OF MUDFLOW SEDIMENTS

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It is necessary to determine the amount of sediment deposits in upper bay during the operation of the facility to calculate the height of the mudflow protection dam. According to already known geometric characteristics of the channel, this kind of storage is conditioned by the position of the upper surface of the mudflow sediments. After filling the mudflow protection rim before construction, the channel transformations are practically almost completed. A stabilized surface is established which becomes the new bed of the channel. Our aim is to determine the position of this surface. Theoretical solution for predicting the parameters of vertical channel transformations and the boundary conditions of this problem are used in this article. The studies carried out allow us to suggest a method for calculating the coordinates of the terminal surface of mudflow sediments. In a wide range of changes in the initial characteristics of the watercourse, numerous examples are calculated by this method. The analysis of the results allows us to assess the influence of parameters determining the process of formation of the terminal surface of sediment deposits.

Key words: channel transformations, flow, facilities, bay, sediment deposits.

Introduction

The rivers of the mountain zone are distinguished by a large seasonal discrepancy in the flow consumption and during the period of spring flood a significant part of the annual flow passes through their channels. As a result many leats of the mountain foothill zone in relation with mudflow are quite risky. Vertical channel transformations predominate in such kind of rivers which are quite actively developing in their lowland areas due to sediment deposition washed away from the slopes of the catchment basin. Channel transformations are relatively activated when water work facilities are built on waterways. Particularly for the protection of settlements, communication routes and other facilities, mudflow protection dams and dams of various designs and materials are quite widely used: solid ones made of concrete, reinforced concrete and masonry, perforated ones - made of metal and grids [1,2,3] (Fig. 1). The process of sediment accumulation at the upper bay of these facilities is completed over time and the upper surface of sediments is practically stabilized (Fig. 2). Establishing its position is an important condition for determining the amount of accumulations and, therefore, for calculating the size of a mudflow protection facility. Many studies are devoted to constructive varieties [1,2] and methods for calculating these facilities [4,5].

Fig. 1 Cascade of mudflow protection facilities: downside monolithic – made of reinforced concrete, upside– made of collected metal constructions.

When modeling channel transformations [6,7,8] occurring at river facilities [4,9], a reliable assessment of the factors determining this process is important. Sediment waste [10,11], energy loss, the speed of moving particles of soil [12] and the dimensions of the initial characteristics of the watercourse are considered to be significant ones among them [13]. The disadvantages in these parameters automatically pass to the developed model. A number of works analyzed and indicated the operational imperfections of existing mudflow protection facilities and the main disadvantages in the methods for calculating the parameters of their characteristic [8,14].

Conflict setting and set of methodology

It is supposed that a mudflow protection dam with a height of H_n and a width along the crest of B_n was established in a trapezoidal mudflow channel. The initial longitudinal slope of the channel at the facility site is - i_P, the bed coordinate is - Z_P, and the channel width is b_P (Figs. 3 and 4).

During operation at the upper bay of the facility sediment is deposited flowing along the stream. Practice shows that with the filling of the rim before the construction, the started channel-forming unsteady process will calm down over time [2,14,15]. As a result of this transformation, a new, stable bed is established on a certain section of the channel before the facility (surface s-s in Fig. 2). The nature of the movement of subsequent flows flowing on this surface will practically be steady. The ultimate goal of the hydraulic calculation of the mud-protection facility is to establish a dam of such height ($H_П$) at which the whole amount of sediment entering the structure during operation is deposited at the upper bay. Obviously, besides the initial geometrical characteristics of the channel, the position of the terminal surface s-s has a great influence on the amount of deposits. After filling the upper bay to the indicated surface, a non prismatic channel is formed in front of the structure characterized by the coordinate of the bed Z and width b (Figs. 3 and 4).

Due to the lack of scientifically justified methods for calculating mudflow holding facilities, significant discrepancies often arise between project and operational values of these pointed parameters. This significantly reduces the effectiveness of mudflow protection activities [3,4].

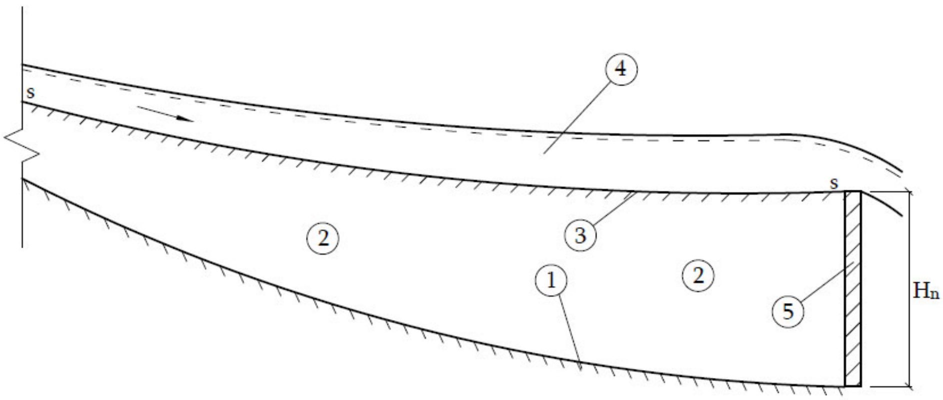

Fig. 2 Longitudinal cutting of upper bay of the facility full of sediments
1-initial bed of channel, 2-mudflow sediment deposits,
3-new bed after stabilizing process (surface s-s),
4-site of movement, 5-mudflow holding facility

In this article we aimed at developing the analytic method for establishing the coordinate of upper and stable surface of mudflow sediments.

Research results

The task is a special case of the general problem of channel transformations. Based on the analysis and assessment of the main factors determining this process, the authors have developed a mathematical model for the stable stage of vertical channel transformations [8]. By a joint solution of the basic equations of hydrodynamics of sediment flows with patterns of sediment consumption, energy loss and soil characteristics etc. a universal dimensionless equation is suggested. It is applicable for all types of tasks concerning this problem.

$$\frac{d\bar{z}}{d\bar{x}} - \frac{1}{a\beta_0}\left(\frac{a-1}{\bar{b}^{(2a-1)/a}} + \frac{Fr_0}{\bar{b}^{(a+2)/a}}\right)\frac{d\bar{b}}{d\bar{x}} = i_0\,\bar{d}_{OT}^{1/3}\,\bar{b}^{(4a-10)/3a}, \qquad (1)$$

where β_0 – is relation of channel width to depth of bed, Fr_0 – is the number of Froud, d_{OT} – is average diameter of channel forming ground, a – is the indicator according to variety of structures of sediment waste, a= 2,7…4,5; i_0 – is the slope of channel section where the bed movement or sediment deposits are absent (the section is immediately in front of the zone of sediments). The positive direction of coordinates x is accepted to be against the flow and point of calculation is crest of the dam (Fig. 3). The linear scale of limitlessness is taken the width of b_0 channel on the section of which longitudinal slope is equal to i_0 [13].

The correct establishment of the boundary conditions of the problem has a decisive influence on the validity and reliability of the final solutions. In the tasks of forecasting channel transformations, it is advisable to use the regularity of changing the width of a new channel as a given condition. A joint solution of the selected regularity with equation (1) will allow us to establish the final terminal position and other parameters for the final and stable stage of the channel-forming process. In our task one of two options of the following can be used as a boundary condition:

- Regulation of decreasing (increasing) the width of b up the flow starting from boundary dimension of B_n (width of dam) is accepted due to the condition of smoothly changing movement (Fig. 4);
- Regulation of change of width is considered to be the condition according to which the boundary lines of flow and side walls of new channel coincide, i.e. the change of width is dictated by cross form of the channel (Fig. 5).

In present work the developments are given for further cases.

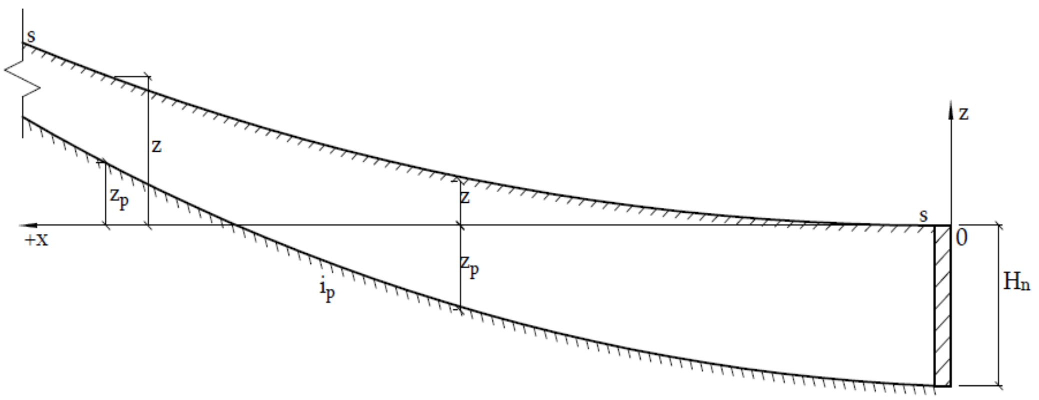

Fig. 3 Calculated scheme of stable stage of channel transformations

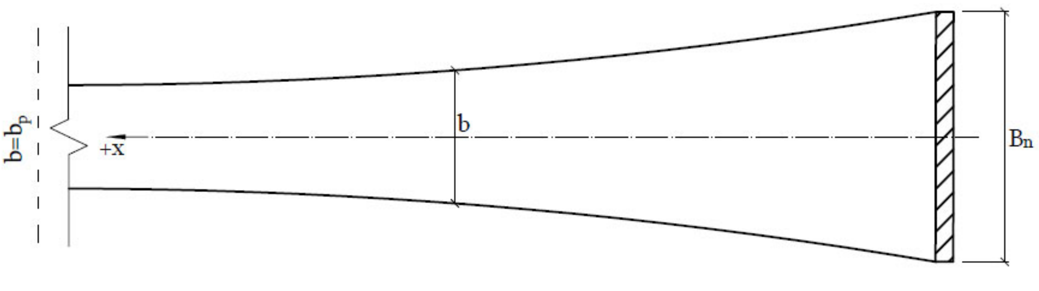

Fig. 4 Calculated scheme of smoothly drafting of upper bay over the surface s-s

Choosing the initial point of coordinates of crest of dam, we can (Fig. 2,3,4)

$$b = b_P + 2m(z - z_P), \tag{2}$$

where m – is coefficient of outflow of side walls of the channel equal to $m = ctg\varphi$ (Fig. 5).

Channel curve may be admitted as constant relating to small parts, therefore, according to Fig. 3 we can write

$$z_P = i_P\, x - H_n\,. \tag{3}$$

In case of chosen system of calculation of coordinates of upper bay sediment z always has positive sign, the coordinate of initial bed of channel z_p in interval $0 \le x < \frac{H_n}{i_P}$ is negative and in interval $x > \frac{H_n}{i_P}$ - is positive.

On the site of channel transformations the regulation of channel curve i_P is admitted as linear. For other forms of relief of bed it is easy to calculate other regulations.

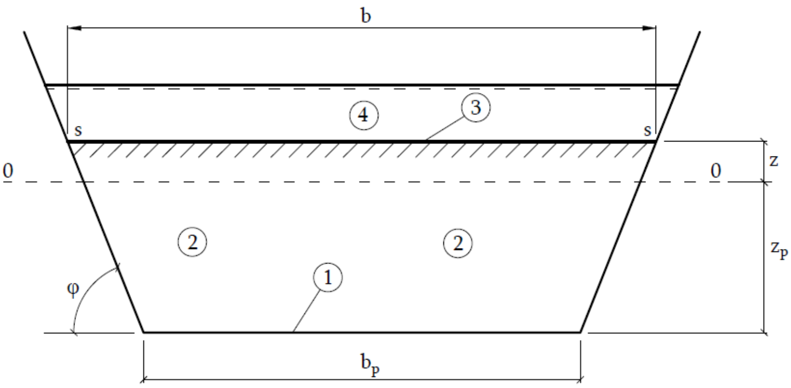

Fig. 5 Cross section of upper bay after stabilization of channel processes
1-initial bed of channel, 2-mudflow sediment deposits,
3-new bed after stabilization process (surface s-s), 4-site of movement

According to expression (3) the regulation (2) is written in dimensionless form as

$$\bar{b} = \bar{b}_P + 2m\left(\bar{z} + \bar{H}_n - i_P\, \bar{x}\right). \tag{4}$$

In the initial point between width of b_P and B_n we have

$$\bar{b}_P = \bar{B}_n - 2m\bar{H}_n\,. \tag{5}$$

The boundary conditions of the task are

- In case of $\bar{x} = 0$, we have $\bar{z} = 0$, $\bar{z}_P = \bar{H}_n$ and $\bar{b} = \bar{B}_n$,
- And in case of $\bar{x} = \frac{H_n}{i_P}$, we have $\bar{z}_P = 0$ and $\bar{b} = b_p + 2m\bar{z}$.

From equation (4) we have

$$\frac{d\bar{b}}{d\bar{x}} = 2m\left(\frac{d\bar{z}}{d\bar{x}} - i_P\right) . \qquad (6)$$

The analysis of expression (6) shows that depending on the meaning of curves $\frac{d\bar{z}}{d\bar{x}}$ and i_p the sign of derivative can be both positive and negative. The first case means that new channel formed in front of the facility against the flow (x) widens. Consequently, the surface of sediment deposits will be deleted form initial bed of the channel. In the second case the new contra flow channel narrows and, consequently, these two surfaces will be closer (Fig. 3,4).

According to dimension, the equation (1) has the following form

$$\frac{d\bar{z}}{d\bar{x}}\left[1+\frac{2m}{a\beta_0}\left(\frac{a-1}{\bar{b}^{(2a-1)/a}}+\frac{Fr_0}{\bar{b}^{(a+2)/a}}\right)\right] = i_0\,\bar{d}_{OT}^{1/3}\,\bar{b}^{-(4a-10)/3a} + \frac{2m}{a\beta_0}\left(\frac{a-1}{\bar{b}^{(2a-1)/a}}+\frac{Fr_0}{\bar{b}^{(a+2)/a}}\right)i_P , \qquad (7)$$

It is easy to assume that endless dimension of channel forming ground in front of the facility $\bar{d}_{OT}$ and more than 1/3 degree is closer to one. In this case

$$\frac{d\bar{z}}{d\bar{x}} = \frac{i_0\,\bar{b}^{-(4a-10)/3a} + \frac{2m}{a\beta_0}\left(\frac{a-1}{\bar{b}^{(2a-1)/a}}+\frac{Fr_0}{\bar{b}^{(a+2)/a}}\right)i_P}{1+\frac{2m}{a\beta_0}\left(\frac{a-1}{\bar{b}^{(2a-1)/a}}+\frac{Fr_0}{\bar{b}^{(a+2)/a}}\right)} . \qquad (8)$$

So, based on the universal equation describing vertical channel transformations for the problem studied, a linear differential equation (8) is derived. Its joint solution with the boundary condition (4) makes it possible to establish the coordinates of the final and stabilized surface of sediment deposits for any initial characteristics of flow, channel and structure. For various conditions close to nature, a number of numerical examples were calculated using the developed methodology. A wide range of changes in the initial parameters inside characterizes the diversity of mountain-foothill streams (the Froude number varies in the range 2 ... 6, the ratio β_0 - 6…18, the relation of slope m-0,5…1, the channel slope coefficient i_0 and i_p – between the interval of 0,01…0,06, indicator of degree a - 3 ... 4.5). In the MATHCAD environment appropriate algorithm has been compiled for calculations according to equation (8) and the boundary condition (4). At the same time, the initial condition of the problem was established: when x = 0, b = B_{Π}.

The analysis of the results of calculations show that, besides the slopes i_0 and i_P the indicator of degree *a.* has significant influence on the form and surface position s-s. It takes into account the structural diversity of the formulas according to the waste of sediments. Indeed, the change of number of Froude Fr_0 and relation β_0 have significant influence on final result. In Table 1 and 2 the results of calculations for two dimensions of indicator *a* are shown. On the basis of these results the graphs of change of dimensionless coordinates of channel bed before and after channel transformations are given (Fig.6). According to the results given in tables and graphs we observe certain variance between the coordinates of surface sediments obtained in the dimensions of *a = 3* and *a= 4.* The analysis of calculated data shows that those formulas in which sediment possibility is proportional 3,3 ...3,7 to speed degree are more acceptable.

Table 1

Calculated dimensions of the coordinates of channel bed before and after channel transformations:

$a = 3;\ \beta_0 = 12;\ Fr_0 = 5;\ i_0 = i_p = 0{,}03$

x	0	10	20	30	40	50	60	70	80
z	0,00	0,26	0,52	0,78	1,04	1,30	1,57	1,84	2,11
z_p	-1,50	-1,20	-0,90	-0,60	-0,30	0,00	0,30	0,60	0,90

Table 2

Calculated dimensions of the coordinates of channel bed before and after channel transformations:

$a = 4;\ \beta_0 = 12;\ Fr_0 = 5;\ i_0 = i_p = 0{,}03$

x	0	10	20	30	40	50	60	70	80
z	0,00	0,40	0,79	1,23	1,66	2,14	2,61	3,13	3,65
z_p	-1,50	-1,20	-0,90	-0,60	-0,30	0,00	0,30	0,60	0,90

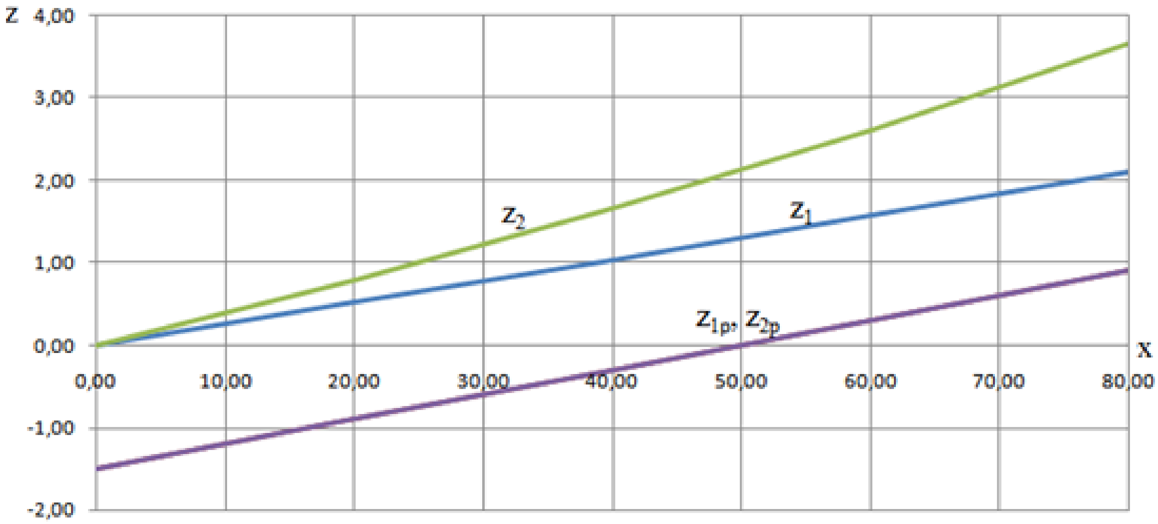

Fig. 6 Graphs of change of dimensionless coordinates of channel bed and surface of sediment deposits Z_{1P} and Z_{2P} - initial coordinates of channel bed; Z_1 - calculated coordinates of terminal surface (new channel) in case of a = 3; Z_2 - the same in case of a = 4.

Testing was done on field objects to assess the reliability of the developed method. We used the results of studies carried out at the mud-protection facilities installed on the watercourses Akzhar (Kazakhstan) [2] and Katsotsk (Armenia) [16] for this purpose. In the first case, the dam is perforated built up with precast reinforced concrete elements. The height of the dam is $H_п$ =10 m. the width along the crest is $B_п$ =30 m. In the second example there is a monolithic concrete dam of 8 m height and 55 m width. During operation the upper bays of both mudflow protection dams were almost full. Calculations are performed for the indicated examples using the developed method. The results obtained are opposed to data from field studies.

During 1979-1981 along the water flow of River Akzhar 18 mudflows passed with a maximum flow rate of Q = 45 m^3/s [2]. The following channel characteristics were obtained as a result of measurements: the natural slope in the interval 0 <x <250 m is equal to i_p = *0,08* and in case of x > 250 m - i_p = *0,1* and in case of slope i_0 = *0, 04;* on the sites with the slopes i_p and i_0 the widths of the channel are respectively equal to b_p = 3,5 m; b_0 = 4,5 m, the slope coefficient of the side walls of the channel is m = 0.75. After filling the mudflow reservoir on characteristic sections the coordinates of the final and stabilized surface of the mudflow deposits were also measured (Table 3).

Table 3

Measured coordinates of surface sediments in upper bay of River Akzhar

x (м)	0	33	100	200	262	285	385	410
z (м)	10,0	11,8	17,0	24,0	28,1	31,0	38,4	41,0

For calculations of developed method the initial parameters are given in dimensionless form. In this case we take the scale of dimensionlessness the value of width b_0 = 4,5 m. the following dimensions of initial parameters are used: $H_п$ =2,22 ; $B_п$ = 6,67; b_p = 0,78; i_p =0,08, when 0< x < 250 m and i_p= 0,1 when x> 250 m; i_0 = 0,04 ; m = 0,75; Fr_0 = 3; β_0 = 6. Two dimensions are chosen for indicator *a* in calculations: 3 and 4. The results of calculations are shown in Table 4.

Table 4

Calculated dimensionless coordinates of surface sediments

a=3									
x	0	14	28	42	56	67	78	89	100
z_1	0,0	0,77	1,51	2,24	2,94	3,99	5,08	6,17	7,28
a=4									
x	0	14	28	42	56	67	78	89	100
z_2	0,0	1,13	2,26	3,39	4,53	5,25	5,89	6,54	7,38

On the basis of the results of calculations and field data the graphs of change of dimensionless coordinates of channel bed of upper bay of the Akzhar before and after channel transformations are set as follows (Fig.7).

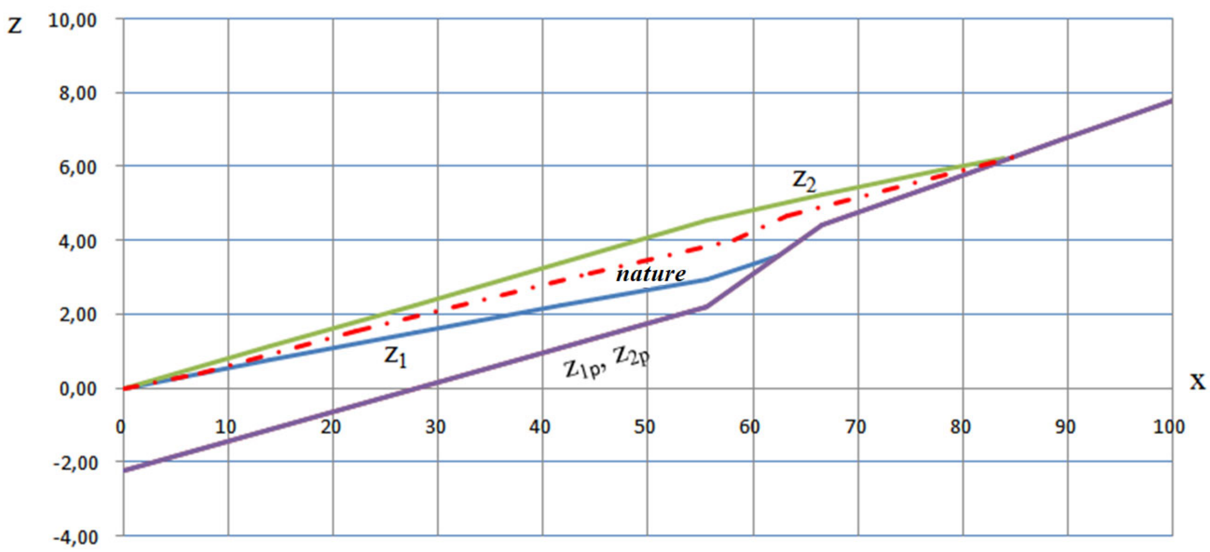

Fig. 7 The graphs of change of dimensionless coordinates of channel bed and surface sediments in upper bay of the dam on River Akzhar
Z_{1P} and Z_{2P} - position of initial channel bed, Z_1 - calculated surface of sediment deposits (new bed of channel) in case of a = 3; Z_2 – the same in a = 4; position of factual surface of sediment deposits is shown by dotted line

Analogue studies are also conducted for mudflow protection facilities built on the Katsotsk. There are the following initial characteristics of channel [16]: natural slope on the dam is equal to - $i_p = 0,11$; slope i_0 = 0, 03; width of the channel with slopes i_p and i_0 are respectively equal to b_p = 4,3 m; b_0 = 5,5 m; the coefficient of the slope of side walls - m=3,3. In case of full mudflow reservoir the coordinates of terminal and stabilized surface of mudflow deposits are measured.

Table 5

Measured coordinates of surface sediments deposited in upper bay of the dam of River Katsotsk

x (м)	0	15	26	46	76	116	130
z (м)	8	8,8	9,7	10,9	13,6	15,3	16,2
b (м)	55	43	32	24	17	14	10

In the calculations we use the following dimensionless values of initial parameters: $H_п$ =1,45; $B_п$ = 10; b_p = 0,64; m = 3,3; i_p = 0,11; i_0 = 0,03; Fr_0 = 5; β_0 =10. For the indicator *a* the values of 3 and 4 are also chosen. The results of calculations are given in Table 6.

According to the results of calculations and field data the graphs of changing dimensionless coordinates of channel bed in upper bay of the dam on the Katsotsk are given before and after channel transformations (Fig. 8).

Table 6

Calculated dimensionless coordinates of surface sediments

a=3					
x	0,0	7,50	15,0	22,5	30,0
z_1	0,0	0,38	0,75	1,16	1,81
a=4					
x	0.00	7.50	15.00	22.50	30.00
z_2	0.00	0.71	1.39	2.03	2.63

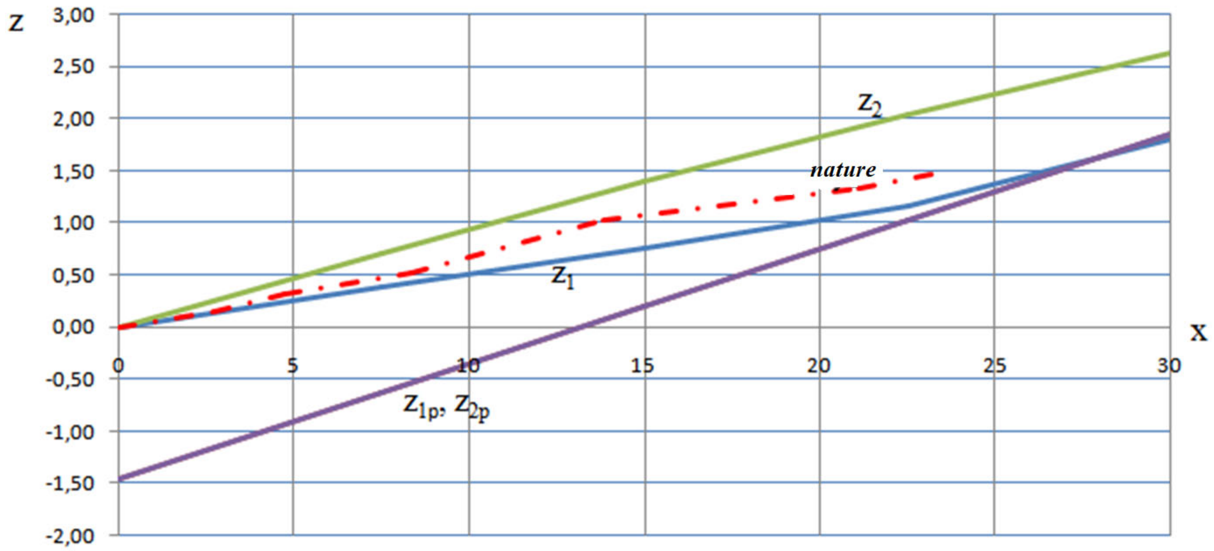

Fig. 8 The graphs of change of dimensionless coordinates of channel bed and surface deposits in upper bay of the Katsotsk
Z_{1P} and Z_{2P} - position of initial channel bed, Z_1 –calculated surface of mudflow sediments (new bed of the channel) in case of a = 3; Z_2 – in the same in case of a = 4; position of factual surface of deposits in given by dotted line

The analysis of the graphs of field examples also states the conclusion on significant impact of the dimension of indicator *a* on the position of terminal surface of mudflow deposits. It shows that the correct choice of formulas on the waste of sediments has important meaning. As the confrontation of calculated and field data shows during the calculation of channel transformations at mudflow protection facilities for *a* the interval 3,3 …3,7 is more applicable. Along with the factor the impact of curve of two sections of channel i_p and i_0 is also notable.

Conclusion

Factors determining the process of channel transformations occurring in front of the mudflow protection facilities are taken into account in the suggested method. The results of calculations carried out in a wide range of changes in the initial parameters of the channel and flow revealed the main factors determining the position of the terminal and stable surface of mudflow deposits. This conclusion was also confirmed by comparing field data to the results of calculations where a fairly good coincide was observed. These results allow us to suggest the developed method for determining the amount of sediment deposits in projecting of mudflow protection facilities, dams and barrages.

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ՍԵԼԱՎԱՅԻՆ ԿՈՒՏԱԿՈՒՄՆԵՐԻ ՎԵՐԻՆ ՄԱԿԵՐԵՎՈՒՅԹԻ ԿՈՈՐԴԻՆԱՏՆԵՐԻ ՈՐՈՇՄԱՆ ՏԵՍԱԿԱՆ ՄԵԹՈԴ

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Հակասելավային պատնեշի բարձրության հաշվարկը կատարվում է կառուցվածքի շահագործման ընթացքում վերին բիեֆում կուտակված բերվածքների ծավալով: Հունի

երկրաչափական հայտնի բնութագրերի դեպքում այդ ծավալը պայմանավորված է սելավային կուտակումների վերին մակերևույթի դիրքով: Կառուցվածքի դիմացի սելավապահ ծավալը բերվածքներով լցվելուց հետո հունային ձևափոխությունները գործնականում դադարում են: Հաստատվում է կայունացած մակերևույթ, այսինքն հունի նոր հատակ: Նպատակ է դրված որոշել այդ մակերևույթի դիրքը: Աշխատանքում օգտագործվել են ուղղաձիգ հունային ձևափոխությունների պարամետրերի կանխատեսման տեսական լուծումները և տվյալ խնդրի եզրային պայմանները: Կատարված մշակումները հնարավորություն են տվել առաջարկել սելավային կուտակումների վերջնական մակերևույթի կոորդինատների հաշվարկի մեթոդ: Ջրահոսքերի ելքային բնութագրերի փոփոխման լայն տիրույթում տվյալ մեթոդով հաշվարկվել են թվային օրինակներ: Ստացված արդյունքների վերլուծությունը հնարավորություն է տալիս գնահատել սելավային նստվածքների մակերևույթի ձևավորման գործընթացը պայմանավորող պարամետրերի ազդեցությունը:

Բանալի բառեր. հունային ձևափոխություն, հոսանք, կառուցվածք, բիեֆ, բերվածքների կուտակում:

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АНАЛИТИЧЕСКИЙ МЕТОД ОПРЕДЕЛЕНИЯ КООРДИНАТ КОНЕЧНОЙ ПОВЕРХНОСТИ СЕЛЕВЫХ ОТЛОЖЕНИЙ

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Расчет высоты противоселевой плотины проводится по объему наносов, отложившихся в ее верхнем бьефе в течении срока службы сооружения. При известных геометрических характеристиках русла этот объем обусловлен положением верхней поверхности селевых отложений. После заполнения селезадерживающего объема перед сооружением русловые преобразования практически завершаются. Устанавливается стабилизированная поверхность, являющаяся новым дном русло. Поставлена цель определить положение этой поверхности. В работе использованы теоретическое решение по прогнозу параметров вертикальных русловых преобразований и краевые условия данной задачи. Проведенные разработки позволили предложить метод расчета координат конечной поверхности селевых отложений. В широком диапазоне изменения исходных характеристик водотока по данному методу рассчитаны численные примеры, в том числе для эксплотируемых сооружений. Анализ полученных результатов расчетов позволяет оценить влияния параметров, обуславливающих процесс образования конечной поверхности селевых отложений.

Ключевые слова: русловое преобразование, поток, сооружение, бьеф, отложение наносов.

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