METHOD FOR HYDRAULIC DESIGN OF THE GREATEST DEPTHS OF THE LOCAL WASHOUT HOLE OF THE CHANNEL BOTTOM IN THE TAIL WATER OF THE HYDROSYSTEM BY POST-JUMPING FLOW AND GREATEST WIDTHS OF THE CHANNEL SLOPE WASHOUT

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The proposed methods are applied to determine 1) time changes of a maximal depth of the pit of local wash-out Y_r and its limiting value Y_{rm} behind the horizontal water apron or the rear apron in the conditions of bed regime of the conjugation of pools in he case of a hydraulic jump occurring within the limits of the water apron; 2) the time corresponding to the intermediate t_1^* and stabilized t_1 configuration of the local wash-out pit; 3) a maximal lateral wash-out of the bed l in the downstream pool behind the water apron and the rear apron, i.e. in the local wash-out pit and as well as downstream, with still noticeable wave oscillations of the surface produced by the transformation of waves generated by a hydraulic jump; 4) an average value of the discharge of drift Q_{SL} washed away from the slopes by a longitudinal wave flow; 5) the volume of the ground W_S washed away from the slopes during the time t, its maximal value W_{Sm} and the time t_2 of stabilization of the slopes washed-out by waves.

The application area of the methods, the main restrictions, the notation used and a list of initial data needed for prediction calculation are discussed.

The task relating to the local washouts in the tail water of the hydrosystems regardless of essential practical importance of its engineering design can not be considered as finally and fully resolved. This mostly refers to the tasks relating to the depths of local washout hole of the bottom changing in time after shoring and bank (channel and canal slopes) washout. The mentioned circumstances together with insufficiently evident physical and hydraulic preconditions put into the existing methods for forecasting the local washout parameters with the stream flowing down from horizontal apron condition the necessity to improve the method for forecasting the main condition of the hydraulics of the local washouts and washout parameters, which also explains topicality of resolving the issue stated in the work [1]. The method for forecasting the increase of the greatest depths of the local washout hole in unconsolidated soil of the channel with post-jumping flow flowing from the apron depending on time and the slope washout parameters in the following areal of flying shoring by reducing theoretical base of the hydraulics to phenomenological method and forecasting correction coefficient by tests is drafted in it.

Comparison of the local washout hole parameters values determined by final calculation dependences described in the method with the same values obtained by other authors by means of independent tests and full-scale data provides quite reasonable interrelations. Particularly, the results of 78 tests and full-scale data were compared and the analysis made it evident that the obtained design formula is quite acceptable for forecasting the maximum depths of the local washout holes of actual units since the average square deviation of the design and test results does not exceed 18%.

The method is anticipated for the scientists and observers and designers involved in the field of designing hydraulic units.

1. Method Usage Field, Main Restrictions and Accepted Symbols

This method is used to determine the greatest y_r depths depending on time of the local washout hole of the channel bottom after horizontal downstream apron or the apron with hydraulic jump fully placed in the tail water within the downstream apron under the condition of mating bottom regime of the ponds, their boundary y_{rm} value, t_1^* and t_1 time periods required to achieve relevant depths of intermediate and stabilized forms of the local washout hole of the bottom towards the washout hole and under it by stream below it where the wave oscillation of the water surface caused by wave transformation generated by the jump is still noticeable, the greatest *l* width values of the channel slope washout, average Q_{SL} discharge of soil washed out from the slope by alongshore wave flow, W_S volume of the sediments washed out from the slope within the t time and its maximum W_{Sm} value and t_2 time period of the slope washout stabilization [1] (figures 1,2).

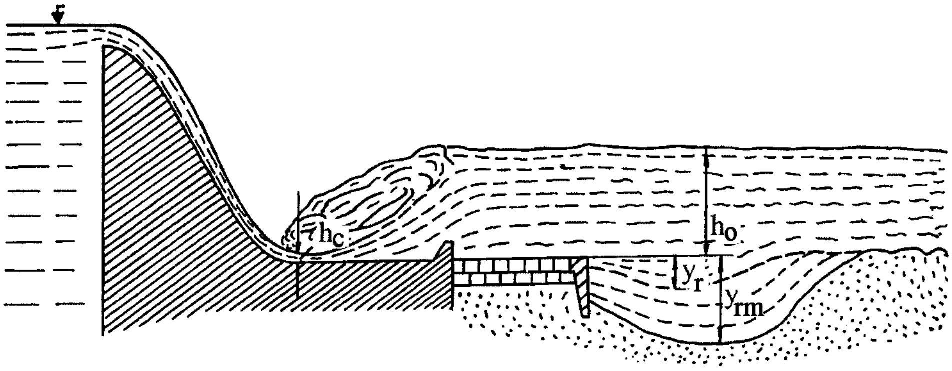

Figure 1. Graphic picture of the greatest depths of the local washout hole and their boundary (maximum) values

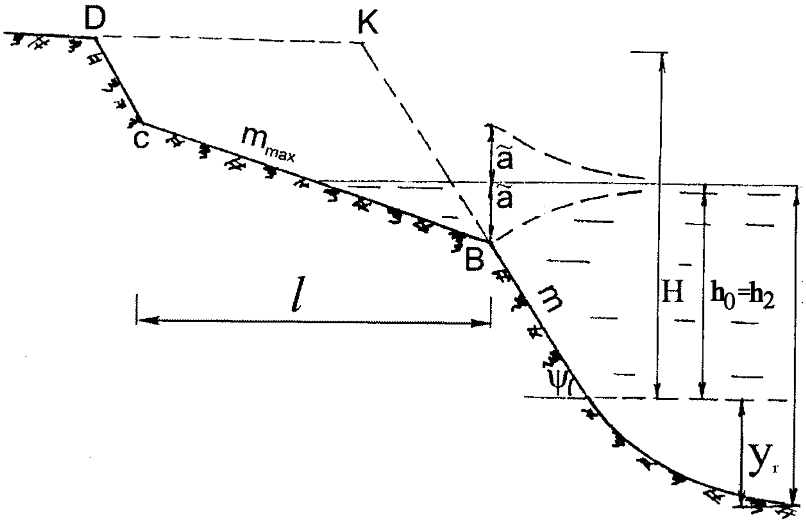

Figure 2. Diagram of configuration of the washed out slope stabilization

The method is acceptable when Froude number for the stream flowing from the shore after shoring in the tail water is less than 1. The other limitation to obtain it is the soil type composing the channel in the tail water. In particular, it is for estimating the local washout hole depths, the greatest channel slope washout widths, discharge of soil washed out from the slope, volumes of the washed out sediments on unconsolidated friable soil having low bonding coefficient composing the slope. In case of soils having high percentage of clay particle content and therefore having high value of bonding module, the given method is acceptable at the initial design stage for approximate estimation of the above parameters, in addition, the washout values will be excessive, i.e. the obtained parameters obtained by the calculation will be more than the true ones. The method is also acceptable when mating with bubbly flow bottom jump.

The following symbols are acceptable in basic calculation expressions:

y_{rm} - the greatest boundary (maximum) depth of the local washout hole;

h_0 - depth of the flow before commencing the washout of the channel bottom after the tail water apron;

v_0 - average flow velocity in the tail water;

v_1^0 - motionless (noneroding) velocity;

$\overline{\alpha}_{0,l}$ - correction of the number of flow motion running at the end of apron considering macropulsing;

y_r - the greatest depth of the respective local washout hole when passing t time from commencing the operation of the downstream apron;

W - respective hydraulic size of numerical value of average (meridian) size of sediment-granules of the soil composing the channel in the tail water;

t_1^* - numerical value of the time period required for achieving intermediate y_r^* depth of the local washout hole of the bottom;

t_1 - respective time value of stabilization of the local washout hole of the bottom;

l - the greatest width of the channel slope washout within the cross-section run at the shoring end in the tail water;

l_x - the greatest width of the channel slope washout within the cross-section x distance from the shore end;

Q_{SL} - value of average discharge of the soil (sediments) washed out from the channel slope by the alongshore wave flow within L distance from the shore end to the cross-section flowing down by stream where the wave amplitude becomes two lines less that the initial $\widetilde{a}_0$ amplitude;

W_S - soil volume washed out from the channel slope by the wave within the t time from commencing the process within L distance from the shore;

W_{Sm} - maximum soil volume washed out from the channel slope during practically stabilized form of the slope within L distance from the shore;

t_2- respective time value of practically stabilized channel slope configuration during the slope washout.

2. List of Initial Data Required for Estimations

When mating the ponds by bottom regime, in order to perform the estimations for determining the change of the greatest depths of the local washout hole after the downstream apron or the apron in the tail water in time and their boundary value, as well as the parameters of the washout hole and channel washout directed down towards the flow, it is necessary to have the following basic and initial data:

a) diagram of structural execution of the downstream apron and the apron; basic dimensions (longitudinal and vertical) of baffling units and the elements as well as the following respective hydraulic parameters of the design spilling discharges of the flow: specific gravity, values of kinetic energy correction (or correction of the motion number) at the final section of the tail water depth and jump (or at flow running point from the apron);

b) granulometric composition of the channel bottom and slope soil (sediment) in the tail water and if possible, local lens sizes of the fine-fraction sediment of the next apron plan and the values of their respective hydraulic sizes;

c) tail water plan within and structural decision of binding the downstream apron and the apron with other bordering elements (for instance, the case when the walls separating the dead parts of the spillway and downstream apron structures and the dams are present or absent, etc.).

***Note:* generally when designing the spillway and downstream apron structures, as a result of ordinary hydraulic design as well as with hydrological and geotechnical calculations and exploration, the majority of the above listed initial data are always available and so no additional information rather than generally used during the design is not required when executing the estimations for determining the local washout depths in the tail water by elaborated method.**

3. Method for Determining the Greatest Depths of the Local Washout Hole After Downstream Apron and Apron in the Tail Water

3.1. In mating the bottom regime by hydraulic jump, the greatest boundary (maximum) depth of the local washout hole on the area after the downstream apron and the apron is determined with the following dependence:

$$y_{rm} = 6h_0 \frac{\frac{v_0}{v_1^0}\left(\sqrt{\overline{\alpha}_{0,l}} - 0{,}548\right) - 0{,}271}{\frac{v_0}{v_1^0}\left(\sqrt{\overline{\alpha}_{0,l}} + 3{,}288\right) + 1{,}626}. \quad (1)$$

h_0 and v_0 values (flow depth and velocity at the end of the downstream apron) included in this expression in case of washing out with the flow running on the downstream apron without apron (l_0=0) are determined by normal hydraulic design, and

$$h_0 = h_2 - D. \quad (2)$$

Here h_2 is the second mated depth; D – depth of the downstream apron well (in case of the downstream apron wall backed up from the tail water $h_0=h_2$); $v_0 = \frac{q_0^*}{h_0}$, where q_0^* is specific discharge spilled during the most unfavorable condition of mated bond which has been determined by M. D. Chertousov or I. I. Agronski [2, 3] methods.

Note: **during operating the downstream apron holes, q_0^* specific discharge should be determined due to mixing water mass surrounded from the sides of the spilled discharge on the account of its numerical increase. In addition, Δq_0^* excess specific discharge can be calculated under the recommendations of A. S. Obrazovski and K. I. Rosinski [4, 5].**

v_1^0 value included in (1) dependence should be estimated by

$$v_1^0 = 1{,}2\sqrt{gd}\left(\frac{h_0}{d}\right)^{1/6} \tag{3}$$

where d is average diameter of soil particles composing the tail water.

It is recommended to determine correction value of α_0 motion amount after the hydraulic jump by the formula

$$\overline{\alpha}_0 = \frac{\overline{\alpha} + 2}{3}, \tag{4}$$

where $\overline{\alpha}$ kinetic energy correction after the jump is calculated by formula [6]

$$\overline{\alpha} = (1{,}7\sigma - 0{,}7)\left(0{,}85\frac{h_3}{h_1} + 0{,}25\right), \tag{5}$$

in which σ is jump sedimentation degree $\left(\sigma = \frac{h_4}{h_0}\right)$; and $h_3 = \sqrt[3]{\frac{q_0^{*2}}{g}}$ is critical depth; and h_4 and h_1 are respectively the flow depths in the tail water and a contracted section during q_0^* discharge.

In case there is l_0 long horizontal apron after the downstream apron, calculation is done again by (1) formula in which all the values except for $\overline{\alpha}_{0,l}$ are determined the way it is described above, and $\overline{\alpha}_{0,l}$ is determined by $\overline{\alpha}_{0,l} = \frac{\overline{\alpha}_l + 2}{3}$ dependence, where

$$\overline{\alpha}_l = \overline{\alpha} - (\overline{\alpha} - 1)\sqrt[3]{\frac{l_0}{2l_1}}. \tag{6}$$

Here l_1 is the downstream apron length equaling to the hydraulic jump length which we may determine from any well-known design dependence [2, 3, 6].

3.2. When having the aerated flow in the tail water (for instance, in case of the presence of the downstream apron after chute on which the flow aerated by well-known aeration criteria [2, 6, 7] and at the following point of the downstream apron, the air concentration achieves S_α value), calculation is done by the same succession and formula as given above, just h_0 and v_0 as well as l_1 jump length are calculated by [2, 6] method which is designed for preliminary design of pond mating in case of having aerated flow in the tail water.

3.3. Determination of the local washout hole dependence on time should be done by the following formula:

a. during washing out the bottom with the flow with increased turbulence ($\overline{\alpha}_0 > 1$) after the shore

$$y_r = y_{rm}\frac{1-\exp\left[-0{,}018\frac{Wt}{h_0+y_{rm}}\left(\frac{y_{rm}}{h_0}\right)^{2,5}\right]}{1-\frac{y_{rm}}{h_0+y_{rm}}\exp\left[-0{,}018\frac{Wt}{h_0+y_{rm}}\left(\frac{y_{rm}}{h_0}\right)^{2,5}\right]}. \qquad (7)$$

b. during the bottom washout by smoothly changing flow ($\overline{\alpha}_0 = 1$) running from the apron:

$$y_r = y_{rm}\frac{1-\exp\left[-3{,}63\cdot 10^{-3}\frac{Wt}{h_0}\left(\frac{y_{rm}}{h_0}\right)^{1,5}\left(1{,}67-\frac{v_1^0}{v_0}\right)\right]}{1-\frac{y_{rm}}{h_0+y_{rm}}\exp\left[-3{,}63\cdot 10^{-3}\frac{Wt}{h_0}\left(\frac{y_{rm}}{h_0}\right)^{1,5}\left(1{,}67-\frac{v_1^0}{v_0}\right)\right]}. \qquad (8)$$

3.4. t_1^* and t_1 numerical values of time periods required for achieving respective depths of the local washout hole of intermediate and stabilized form are determined by the following dependence:

$$t_1^* = \frac{h_0+y_{rm}}{0{,}018W}\left(\frac{h_0}{y_{rm}}\right)^{2,5}\ln\frac{y_{rm}\left(1-\frac{y_r{}^*}{h_0+y_{rm}}\right)}{y_{rm}-y_r{}^*}. \qquad (9)$$

$$t_1 = \frac{h_0+y_{rm}}{0{,}018W}\left(\frac{h_0}{y_{rm}}\right)^{2,5}\ln\left[100\left(1-\frac{y_{rm}}{h_0+y_{rm}}\right)\right]. \qquad (10)$$

y_{rm} in (7÷10) dependences is determined by (1) formula; h_0, v_0 and v_1^0– by the respective dependences provided in previous steps; W – respective hydraulic size of the average soil granule diameter in the tail water, m/sec, and t – time, counting of the seconds commences from the moment of spilling q_0^* discharge to the water outlet.

Note: **the elevation of the cement tooth deepening protecting from caving at the end of the shore should always be determined according to the assumption of achieving the boundary (maximum) value of the local washout hole, that is why (1) and (10) dependences, from practical viewpoint, are more important than (7÷9) dependences, although in forced skipping of flood discharge passing through the unfinished structures, (7) and (9) expressions allow to forecast safe duration of passing the flood discharge for shoring, which in number of cases may be essentially important.**

4. Method for Determining the Greatest Widths of the Channel Slope Washout After Downstream Apron and Apron in the Tail Water

4.1. The greatest width of the channel slope washout within the cross-section run at the shore end in the tail water, i.e. within the local washout hole is calculated by the following expression:

$$l = 2{,}77 \cdot 10^{-3} \frac{(h_2 - h_1)^2}{d}. \quad (11)$$

4.2. The following dependence is used for determining the stability of the beaches of large basins (seas, lakes, reservoirs) and canals:

$$l = 0{,}325 \frac{\tilde{a}^2}{d}. \quad (12)$$

4.3. The greatest width of the channel slope washout in the cross-section x distance far from the shore end is calculated by the following dependence:

$$l_x = 2{,}77 \cdot 10^{-3} \frac{(h_2 - h_1)^2}{d} \exp\left(-\frac{4\pi D x}{h_2 - h_1}\right). \quad (13)$$

In the (11-13) dependences h_1 and h_2 are respectively the first and the second mated depths of the hydraulic jump; d – average diameter of the beach forming soil granules ($d=d_{95\%}$); l – width of the beach washout; $\tilde{a}$ - amplitude of the wind-induced wave is determined by specific method provided in [8] work; $D=13{,}5\cdot10^{-5}$ - constant of the energy dissipation intensity.

4.4. The value of the average discharge of soil (sediment) washed out from the channel slope by the alongshore wave flow flowing down within the L distance from the shore end to the cross-section where the wave amplitude becomes two lines less than the initial $\tilde{a}_0$ amplitude is estimated by the following expression:

$$Q_{SL} = 4{,}3 \cdot 10^{-5} \frac{\lambda \tilde{a}_0^2}{m^{0,75}} \sqrt{\frac{g}{d}}. \quad (14)$$

4.5. The soil volume washed out from one channel slope within t time from the process commencement within L distance from the shore end is estimated by the following dependence:

$$W_S = 4{,}3 \cdot 10^{-5} \frac{\lambda \tilde{a}_0^2 t}{m^{0,75}} \sqrt{\frac{g}{d}}. \quad (15)$$

4.6. During washing out the slope, the value of time when the slope configuration gets practically stabilized form is estimated by the following dependence:

$$t_{2.} = \frac{N \cdot m_{max}^{0,75}}{\sqrt{gd}} \cdot 10^7 \ \text{[sec]}. \quad (16)$$

4.7. Maximum volume of the sediment washed out from one channel slope within L distance from the shore end in practically stabilized form (when $t=t_2$) is determined by the expression:

$$W_{sm} = 15\frac{N}{d}(h_2 - h_1)^3 . \quad (17)$$

in (16) and (17) expressions

$$N = 0,28(h_2 - h_1) - 58md + \left(1 - 202\frac{d}{h_2 - h_1}\right)(H - 1,28h_2 + 0,28h_1) . \quad (18)$$

in (14÷18) dependences λ is the wave length; m and m_{max} – respective slope coefficients before and after the washout; d – average diameter of the granules of soil composing the slope; H – height of trapezoid canal; g – acceleration of gravity force; definitions for h_1 and h_2 are given above.

Note: **a) as it is necessary to estimate the greatest widths of the channel slope washout in the tail water after the downstream apron and the apron within the local washout hole and below towards the stream where the wave oscillation of the water surface caused by the wave transformation generated by the hydraulic jump is still noticeable, for possible channel consolidation, proper selection of bridge (other) passages and roads along the channel, (11) and (13) dependences from practical viewpoint are more important than the (14÷17) dependences. However, average discharge of soil washed out from the channel slope within t time from the process commencement in practically stabilized form of the soil volume washed out from one channel slope by the waves and its maximum value when $t=t_2$ and determination of the values during stabilization may have particular practical importance in number of cases;**

b). Together with the design of the channel slope washout the design of the change of configuration of the lower depth part of the channel cross-section caused by partial sedimentation of soil particles to the bottom as a result of the slope washout where longitudinal flow velocities are minimum and due to which the conditions for the occurrence of under water accumulated bodies exist should be prepared too.

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