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Hydrology

Waves in Debris Flows

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ABSTRACT. Mixture of structural debris flow is considered in the form of quasicontinuum. Wave phenomena are treated in the limits of one-dimensional problem. The processes of motion of long, continuous, dynamic and monoclinal waves are investigated. The problems of stability of initial uniform motion of debris flow in steep gradient beds are analyzed. Attention is paid to the increase of wave at inlet of pressureless flow in the pressure construction. *© 2007 Bull. Georg. Natl. Acad. Sci.*

Key words: *debris flow, continuous waves, dynamic waves, monoclinal waves, stability criterion, waveforming.*

Having recently become frequent, natural cataclysms, such as debris flows, made us remember about the necessity of perfection of hydraulic calculation methods for antidebris flows hydrotechnic constructions located in mountain and foothill regions.

By their nature, waves can be two- or three-dimensional. However, to solve the engineering problem description of the wave process in the limits of one-dimensional problem is assumed to be more convenient. Similar approach, on the one hand, partially decreases accuracy of the obtained results, on the other hand, it expands the operative possibility of application of the dependencies obtained in such a way for solving a series of problems that can satisfy practical requirements with enough accuracy.

The results given below are mainly based on the description of wave process from hydraulic (i.e. one-dimensional) point of view, when definite indices of wave are considered only in one direction (mean on free cross-sectional area velocity) – in the direction of translational stream.

There are many different types of waves in nature. In this work we shall deal with three most important: continuous, dynamic (shock) and monoclinal [1,2].

Powerful debris flows are formed mainly in the erosion incisions. Formed mixture moves along the waterflow bed in the form of structural mudstone or turbulent stream.

Structural debris flow is the most dangerous, as it can easily break obstacles such as bridges, main constructions of hydropower stations and irrigation systems, doing a lot of harm to roads and populated areas.

Structural debris flow consists of rock fragments, broken-stone ballast, plant remains mixed with mud. Such flow includes 80-90% (in mass) of hard material and 10-20% water (in structural state). Density of such mixture 1.8–2.3 t/m^3, moving medium – plastic stone-muddy conglomerate.

Continuous waves occur every time, when one set (stationary) value of motion parameters gradually passes into the other set value because of smooth change of outlay (also depth) with absence of dynamic effects connected with inertia and impulses. This quasi-stationary phenomenon is always observed when gravitation forces are gradually balanced by resistance forces. Then the velocity of a continuous wave will be [1]

$$V_b = V + \omega \frac{\partial V}{\partial \omega} \tag{1}$$

where V, ω are mean on free cross-sectional velocity and area of free cross-sectional flow up to wave initiation.

Velocity of structural debris flow at uniform motion [1]:

$$V = \frac{giH^2}{\nu} f(\beta) \quad (2)$$

where: ν is kinematical viscosity coefficient, i is gradient of waterflow bottom, $\beta = \frac{h}{H}$ relative depth, h – depth of the debris flow core, H – full depth of debris flow.

$$f(\beta) = \frac{\beta}{2}(\beta^2 - 1) + \frac{1}{3}(1 - \beta^2)\,. \quad (3)$$

For beds with straight angle cross-section taking into account (2) instead of (1) we shall get:

$$V_b = \frac{3giH^2}{\nu} f(\beta)\,. \quad (4)$$

Comparing (4) and (2) we get that velocity of the continuous wave is three times more than mean on the cross-section debris flow velocity.

Considering that structural debris flow mixture at definite depth does not move even on slope surface, i.e. it does not run off, then the velocity of dynamic wave can be expressed by dependence [2]:

$$C = \sqrt{gH\cos\theta_1}\,, \quad (5)$$

where θ_1 is limiting value of the slope of waterflow bottom, at which debris flow mixture of certain depth and given concentration begins to replace.

Instability in structural debris flows occurs, if the velocity of continuous one-dimensioned waves V_b exceeds the velocity of dynamic waves C, spread on the surface of the flow, i.e. $V_b > V + C$.

Inserting into this inequality (2), (4), (5) and taking into consideration that $i = \sin\theta$, where θ is the angle of the slope for hydraulic flow in relation to horizontal surface, we shall get the condition of instability:

$$\frac{VH}{\nu} f(\beta) > \frac{1}{4}\frac{\cos\theta_1}{\sin\theta}\,, \quad (6)$$

where $\theta_1 \leq \theta$. Left part (6) is Reynolds number for structural debris flow. Dependence (6) characterizes instability of one-dimensional long waves in structural debris flow stream.

Instability in the considered case will be observed in the form of sharply expressed waves commensurable in sizes with depth of uniformly moving flow, which is observed in nature.

For waterflow $f(\beta) = \frac{1}{3}$ and instead of (6) we have $\frac{VH}{\nu} > \frac{3}{4}\frac{1}{\sin\theta}$. In this case instability will be observed in the form of rolling waves on slope surface, as it happens during heavy rain on slope parts of the streets.

The increase of debris flow parameters is usually connected with the process of confluence of several debris flow sources from erosion incision in upper waterbeds forming “monoclinal” (single) wave. After passage of monoclinal wave all the antidebris flow constructions are in an extreme situation.

Basing on the known laws of mechanics and taking into account (5) the height of monoclinal wave can be prognosticated [2]

$$\Delta h = \frac{VH}{\sqrt{gH\cos\theta_1}}\,. \quad (7)$$

Series of theoretical and experimental investigations describe the questions of stability of uniform flow in beds with big gradients not containing debris. Debris significantly influence conditions of stability of water flow. Sometimes it happens that waves having great amplitude appear in these quick flows and debris carrying stream flows over the canals walls, while uniform stream having the same quantity of water and drifts would have flown in the borders of the canal [3, 4]. Analysis shows that depending on debris concentrations, their hydraulic grain size, density etc., debris carrying flow by level of its stability can be more or less than equivalent of water flow or similar to it.

In [5] there is considered the problem of uniform motion stability of structural stream on fast flows and critical relation for prognostification of wave formation on the surface of structural debris flow is obtained:

$$\frac{1}{F_{r_0}} > \left(\frac{2\omega_0}{B_0 H_0}\right)^2, \quad (8)$$

where F_{r_0}, ω_0, B_0, H_0 are correspondingly Froude number, free cross-section area, width and general depth of primary uniform motion of the flow before loss of stability.

Comparing (8) with analogous criterial conditions of debris carrying flows [3,4] we can conclude that waves on the free surface of structural debris flows are formed at relatively small velocities compared with those equivalent (on discharge) to water flows with drifts.

Among numerous antidebris flow constructions [6] the most widely spread are bridge passways over mountain debris water flows. Suddenly formed structural debris flow with discharge exceeding the ability of the underbridge space breaks over the upper inlet part of the construction as the result of which in the upper pool a reverse wave of increase (reverse effect works) is formed. Likewise phenomenon is observed due to imperfect methods of elaboration of hydraulic parameters of structural debris flow.

Below we present the methods of establishing the dynamic parameters of reverse one-dimensional wave front of structural debris flow increase in a straight angle canal at its inlet into the truct of construction (Fig.), in case if the underbridge space does not provide passage of the stream.

Assuming that the front of the reverse wave occurring at moment t_1 under the influence of the flow in the inlet part of underbridge space will move up the stream with velocity C and at the moment t_2 will be at the distance $(t_2–t_1)C = \Delta t\times C$ from cross-section 1 - 1. Mass flowing at the same period of time from the side of cross-section 0 - 0 in volume between cross-section 2 - 2 and 1 - 1 with velocity V_0 for bed with straight angle cross-section on a unit of width at depth h_0 will be $m_0=\rho h_0V_0\Delta t$. Mass of the reverse wave with increased height Z moving from the side of cross-section 1 - 1 up the flow to cross-section 2 - 2 will be $m_0=\rho ZC\Delta t$. Mass flowing out for the time Δt from volume between cross-sections 2 - 2 and 1 - 1 and flowing into gallery will be $m_r=\rho h_rV_r\Delta t$. Then all the mass of debris flow mixture for the time Δt in the indicated volume

$$m = \rho\Delta t(V_0h_0 + ZC - h_rV_r)\,, \tag{9}$$

where ρ is the density of flow (debris flow mixture), V_r – mean on cross-section velocity of flow in the gallery at pressure motion; h_r – height of the gallery.

It is assumed that the width of the galleries is equal to the width of entering bed.

Supposing that in dam sites 1 - 1 and 2 - 2 pressure on the depth subordinates to hydrostatic law [5], impulse of the force F will be:

$$F\Delta t = \gamma\Delta t\left(\frac{h_0^2}{2} - \frac{H^2}{2}\right), \tag{10}$$

where γ is specific gravity of debris flow mixture.

As $H=h_0+Z$, expression (10) can be written in the following way:

$$F\Delta t = -\gamma\Delta t\left(h_0Z + \frac{Z^2}{2}\right). \tag{11}$$

Applying the law of motion quantity to compartments 1 - 1 and 2 - 2 we shall have $m(V_r-V_0)=F\Delta t$ or with account (9) and (11)

$$(V_0h_0 + CZ - V_rh_r)(V_r - V_0) = -g\left(h_0Z + \frac{Z^2}{2}\right). \tag{12}$$

On the other hand, discharge of flow per unit of the bed's width and gallery, which enters the construction is:

$$q_0 = q_r + q_b \tag{13}$$

where discharge in the gallery $q_r=V_rh_r$ is the consumption of reverse wave of increase $q_b=CZ$ and $q_0=V_0h_0$.

Then discharge of the reverse wave will equal:

$$CZ= V_0h_0- V_rh_r. \tag{14}$$

Inserting (14) into (12) we get:

$$\frac{gZ^2}{2} + gh_0Z + K = 0\,, \tag{15}$$

at the solution of which the depth of reverse wave of increase

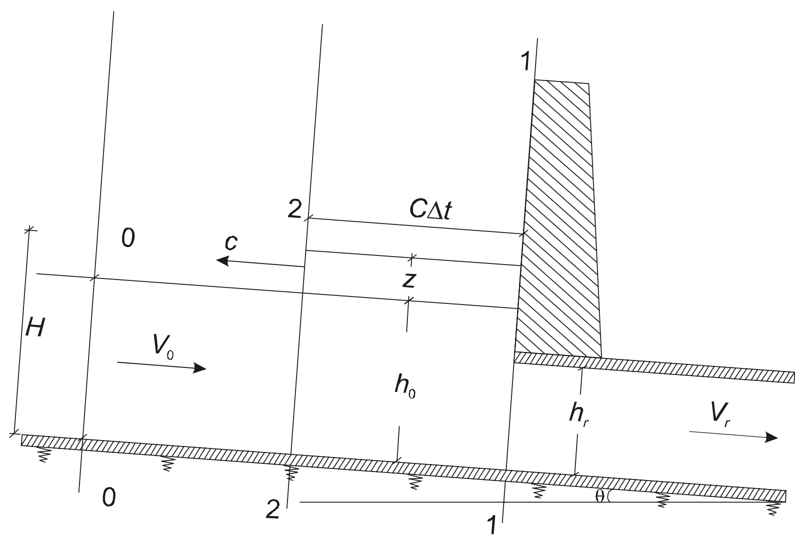

Fig. The scheme of estimation of head water wave at inlet of structural flow into the gallery.

$$Z = -\frac{gh_0 \pm \sqrt{g^2 h_0^2 - 2Kg}}{g}, \quad (16)$$

where

$$K = 4(V_r^2 h_r - V_0 V_r h_0). \quad (17)$$

Knowing Z, it is not difficult from (14) to define velocity of relative replacement of reverse wave front of increase:

$$C = \frac{V_0 h_0 - V_r h_r}{Z}. \quad (18)$$

Velocity of debris flow at pressure motion in the gallery can be defined according to methods from [7].

The suggested dependencies with some approximation can be spread and in the case of any beds with correct cross-section under symbol h it should be understood $\frac{\omega}{B}$, where ω is the area of free cross-section flow before wave motion occurred, and B is the mean width of the bed.

Taking into consideration any form of the bed's cross-section (not only correct one) it is possible to use methods from [7], where characteristics of cross-section of bed of any incorrect form are changed by the expression $H^3 \cdot \frac{B}{3} = I$, where I is the moment of inertia of girder rolling of straight angle cross-section at the width H and B.

ჰიდროლოგია

ტალღები ღვარცოფულ ნაკადებში

ო. ნათიშვილი

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ბმული ღვარცოფი წარმოდგენილია კვაზიკონტინიუმის ფორმით. ტალღური მოვლენები განხილულია ერთგანზომილებიან გარემოში. ყურადღება გამახვილებულია გრძელ უწყვეტ, ნახტომისებურ და მონოკლინური სახით ტალღების გადაადგილების პროცესებზე. გაანალიზებულია ნაკადის მძაფრი თანაბარი სიჩქარით მოძრაობის მდგრადობის პირობები დიდი ქანობის მქონე კალაპოტებში. გათვალისწინებულია უდაწნეო ნაკადის დაწნევიან ნაგებობებში შესვლისას ტალღის წარმოქმნის შესაძლებლობა.

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