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Hydrology

Forecast of Avalanche and Monoclynal Wave Debris Flow Movement

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ABSTRACT. Criterial correlation for prediction of the occurrence of avalanche movement of cohesive debris flow in the water flow riverbed is suggested. Simultaneous start of several alluvial heaths in erosive incision causes sudden increase of hydraulic parameters of debris flow and the occurrence of monoclynal wave on free surface of the flow. Methods of calculation of hydraulic parameters of monoclynal wave with the account of non-newtonian nature of the debris flow are worked out. *© 2015 Bull. Georg. Natl. Acad. Sci.*

Key words: *debris flow, avalanche, disaster.*

In 2014, at night of the 20-21st of August in Daryal gorge near the border of Georgia and Russia natural disaster took place. Landslide descended on the road. It happened exactly on the same part of the road, which suffered from disaster in May 2014. A part of Devdorak glacier slid from Kazbek. As a result, a huge avalanche of cohesive debris flow was formed. It traveled to Daryal gorge on the Georgian territory, covered riverbed of r. Terek, destroyed a part of Georgian Military Road and formed huge blockages on it. The Georgian Military Road was closed for traffic for about a month. The pipeline providing Armenia with gas was ruined during the hazard. Herewith general methods of avalanche motion prediction and definition of dynamic parameters of monoclynal wave in cohesive debris flows are presented.

1. Debris Flow Avalanche Movement

The main factors necessary to know for characteristics of debris flows avalanche movement are velocity and place of stoppage. These two opposite problems are very important for design and calculation of anti-debris constructions. In order to establish the boundaries of debris flow dangerous zone impact on the environmental trigger levels of debris flow must be determined. Criterial correlation of avalanche movement will give the opportunity to predict conditions of occurrence of debris movement at any certain point of water flow.

Avalanche debris movement is very disastrous, because all the debris mass sediments rush down from erosive incision with great velocity down the slope. Analogues processes are very difficult for tak-

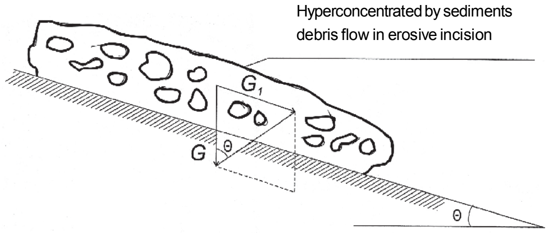

Fig 1.1 Longitudinal profile of debris mass in erosive incision.

ing photos from. However, one of such processes was registered in the works of the Georgian Geological Scientific Institute. One of the members of the expedition G. Kharaishvili could take photos of the complete process of the avalanche debris flow movement. Such phenomenon can often be observed after earthquake, when debris mass in the erosive incision stays in the ready state for "sliding". Still this phenomenon cannot be called a flow. It is a movement of a definite volume of debris mass.

To solve the problem we want to describe the behaviour of the whole piece of broken mass and observe the change of the velocity up to full stop on the alluvial fan of water breakage of debris character.

In Fig. 1.1 a longitudinal profile of the debris mass in the erosive incision is presented. We shall guide the movement of the whole or significant part of its mass.

The equation of equilibrium of the above mass in the erosive incision will be:

$$G_1 - F_1 - G_2 = 0 \tag{1.1}$$

where $G_1 = \gamma w \sin\theta$; γ – specific weight of deposited debris mass; w – general bulk of the whole debris mass in the erosive incision; θ – angle of the bottom gradient of erosive incision to horizon; $i = \sin\theta$ – gradient of the erosive incision bottom; F_1 – inertial force; G_2 – tractive resistance force.

As debris mass is "quasisolid" body, it does not subordinate to Coulon laws regarding to two solid bodies friction, but it subordinates to sliding of "abnormal" non-newtonian liquid on contact surface (debris mass) in stream flow solid body. In the given case friction force depends on viscousity coefficient and velocity between the layers of moving flow, which on the contact surface of the flow and riverbed sticks to the guiding banks and to the bottom of the water flow. Debris mass friction in the riverbed water flow is often debris friction on the surface of the already sedimented debris mass. On those parts, where there are no fresh segments of debris mass the waterbed way is smoothed out by the head part of debris, on which it slides further on. Roughness of water flow has little impact on the τ value, if irregularities are small and caves are not filled with debris sediments. However, at great roughness the friction must enlarge at the time of filling it (smoothing out) with debris mass. In this case, when the debris is "quasisolid" body, friction force depends on viscousity and velocity of the sliding between the layers of moving flow. That is why instead of $Mg\cos\theta$ we shall introduce the resistance force in the form of "abnormal" liquid $G_2 = \tau\Omega$ as the force of tangential stress. Substituting the corresponding values into (1.1) we get:

$$\frac{dV}{dt}\rho w = \rho g w i - \tau\Omega, \tag{1.2}$$

where, in fact, τ is the average value of tangential stress, and Ω is the contact area of debris flow with riverbed water flow (not depending on the form of the riverbed cross section).

After not complex transformations and integration (1.2) we get:

$$V_2 - V_1 = ig\left(1 - \frac{\tau\Omega}{\gamma w i}\right)(t_2 - t_1), \tag{1.3}$$

where V_2, V_1 are velocities in neighbouring sites, respectively; t_2, t_1 – time of the water flow movement on a separate part (between sites).

Dependence (1.3) must be used to each straight line part of the way sequentially, beginning with erosive incision for which initial velocity $V = V_0 = 0$ including alluvial fan. On each following part initial velocity is equal to the velocity, which we get at the end of the previous part, though some loss of the velocity is possible on the way curves.

For approximate evaluation of appearance of avalanche movement occurrence the gradient must be averaged on the whole length up to the place of debris stop according to the following criteria (1.4), i.e. to predict avalanche debris movement. Place of debris stop can be defined according to the methods in [1]. Avalanche debris movement is quite rare phenomenon. Still while designing antidebris constructions one should check the possibility of occurrence of avalanche debris movement in water flow. Below, we introduce the criterial dependence,

$$1 > \frac{\tau\Omega}{\gamma wi}, \qquad (1.4)$$

which will make it easier to predict the possibility of occurrence of avalanche debris movement.

In the opposite case, when $1 < \frac{\tau\Omega}{\gamma wi}$, the avalanche debris movement will not occur.

2. Investigation of Monoclynal Wave in Cohesive Debris Flows

Sharp increase of movement parameters of the formed cohesive debris flow is usually connected with the process of combination of several heaths from erosive incisions in upper reaches of alluvial water flow, where due to different reasons of geodynamic meteorological, topographic and other characters, the sediments of rock deposits are accumulated. Under the influence of water medium on them, such as, atmospheric precipitations, melted snow, ground waters, etc., the cohesive debris flows are often formed [2-4] usually characterized by wave movement. The mechanism of such phenomenon is the following: at combination of several erosive incisions side inflows into the main alluvial flow the debris joins alternately, which covers above the previous flow.

It should be noted, that while travelling downslope along the deformed surface of water flow, the head part of debris flow is partially used for smoothing the roughness of the riverbed surface, both on bottom and its slopes. Then the body of the debris flow following the front part moves already by the smoothed riverbed increasing its velocity up to “uniform” motion regime.

Due to sharp increase of hydraulic parameters of the flow in the form of“monoclynal” (single) wave [5], travelling down the slope with constant velocity the disaster of overflow of debris through access construction may occur.

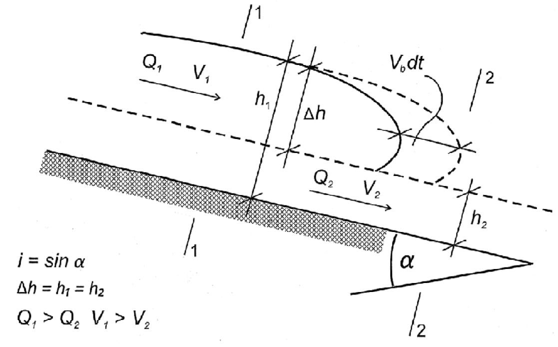

Fig. 2.1 The scheme for analysis of sharp increase of hydraulic parameters of debris flow movement.

Such wave is a prototype of flash flood wave, which represents special form of unsettled movement, when the form of wave has stable profile, contours of which do not change in time; the “uniform” forward movement is characterized by the following distinctive features:

a) position of wave fronts at different moments of time are identical to each other;

b) velocity of wave front translation is bigger, than the average velocity;

c) wave profile is transferred with constant velocity.

In Fig. 2.1 the scheme of sharp increase of hydraulic parameters of debris flow in the form of monoclynal wave is presented.

Designate over Q_1; w_1; V_1; h_1; Q_2; w_2; V_2; h_2 discharge, the area of live section, velocity and deepness of the flow with corresponding indexes in sites before ($1 \div 1$) and after the wave ($2 \div 2$) with “uniform” motion. Velocity of monoclynal wave $V_b > V_1 > V_2$. Due to the stable profile and volume of the wave its front will carry away constant discharge $(V_b - V_1)w_1$ and leave in upper flow constant discharge $(V_b - V_2)w_2$, that is due to continuity of the flow $(V_b - V_1)w_1 = (V_b - V_2)w_2$, from where:

$$V_b = \frac{V_1\omega_1 - V_2\omega_2}{\omega_1 - \omega_2} = \frac{Q_1 - Q_2}{\omega_1 - \omega_2} \qquad (2.1)$$

Dependence (2.1) will give the possibility to judge about velocity of wave spread, when the flow moves in uniform regime before and after its front. It is clear that, when $V_1 = 0$ and $w_1 = 0$, $V_b = V_2$.

Assume that cross section of the riverbed has square form, then from (2.1) we get:

$$V_b = \frac{V_1 h_1 - V_2 h_2}{h_1 - h_2} = \frac{V_1 h_1 - V_2 h_2}{\Delta h}, \tag{2.2}$$

where Dh = $h_1 - h_2$ is the height of the wave crest. Out of (2.2) we define

$$V_1 = \frac{V_b h_1 - V_b h_2 + V_2 h_2}{h_1}. \tag{2.3}$$

Dependence (2.3) gives the possibility to judge about flow velocity in site 1 ÷ 1 when the wave occurs before site 2 ÷ 2 on the surface of uniformly moving flow with average in section velocity V_2 and depth h_2.

Let us consider the case $V_1 > V_2$ and $h_1 > h_2$.

As the velocity of debris flow between the sites 1 ÷ 1 and 2 ÷ 2 increases due to the wave, then motion quantity per time unit is equal to the product of mass and change of the velocity, also per time unit, i.e.:

$$F = \rho_c \left(V_b - V_2\right) h_1 \left(V_1 - V_2\right). \tag{2.4}$$

where r_c is the density of alluvial mass.

Taking into account that force is equal to difference of hydrostatic pressures in the sites we get:

$$F = \gamma_c \frac{h_1^2}{2} - \gamma_c \frac{h_2^2}{2}. \tag{2.5}$$

Comparing the dependencies (2.4) and (2.5) and considering $g_c = r_c \cdot g$ we have:

$$\left(V_b - V_2\right) h_1 \left(V_1 - V_2\right) = \frac{g}{2}\left(h_1^2 - h_2^2\right). \tag{2.6}$$

Considering (2.3) after transformations instead of (2.6) we can write:

$$V_b = \sqrt{\left(h_1 + h_2\right)} + V_2 \tag{2.7}$$

or

$$V_b = C + V_2, \tag{2.8}$$

where C is the velocity of dynamic wave distribution in cohesive alluvial mass, which includes that part of tension, which is necessary to overcome the so-called gradient of resistance to the motion, i.e.:

$$C = \sqrt{\frac{g}{2}\left(h_1 + h_2\right)}. \tag{2.9}$$

On the other side [6, 7]:

$$C = \sqrt{g h_1 \cos\theta_1}. \tag{2.10}$$

where q_1 is ultimate value of surface gradient to the bottom of water flow at which cohesive alluvial mass of definite depth and given concentration begins to move at the same angle of gradient of the water flow bottom of cohesive debris flow and reaching definite depth less than at the motion stops its movement. In fact this is one of the cases of occurrence of reological (non-newtonian) nature (initial resistance to shift $t_0 > 0$) of these flow types. Usually for non-newtonian liquids at $q_1 = 0$ and cos$q_1 = 1$.

Comparing (2.9) and (2.10) we can get necessary minimal value of h_1 for occurrence on free surface of progressive flow in the sites (2.2) with depth h_2 monoclynal wave with constant velocity V_b. Then

$$h_1 = \frac{h_2}{2\cos\theta_1 - 1}. \tag{2.11}$$

In opposite case the expressed front of "monoclynal" wave with constant velocity V_b will not be formed and it will not take a complete form of "faded" wave analogously to wave hydraulic jump, which is often observed in newtonian liquids.

At combined solution of (2.2) and (2.10) we have:

$$\left(V_1 - V_2\right)^2 = \frac{g}{2}\left(h_1 + h_2\right)\frac{\Delta h^2}{h_1^2} \tag{2.12}$$

The dependence expresses correlation between initial and final velocities on the one hand and the depth of monoclynal wave on the other hand.

Substituting (2.9) and (2.12) and considering (2.10) we can get:

$$V_1 - V_2 = \sqrt{\frac{g\cos\theta_1}{h_1}}\Delta h. \tag{2.13}$$

At a sudden stop of the flow in the site 2 ÷ 2, i.e. $V_1 = V$ and $V_2 = 0$ from (2.13) it follows:

$$V = \sqrt{\frac{g}{2}\left(h_1 + h_2\right)}\frac{\Delta h}{h_1} \tag{2.14}$$

or taking into account (2.9)

$$V = C\frac{\Delta h}{h_1} \tag{2.15}$$

Then height of the wave will be:

$$\Delta h = \frac{Vh_1}{C} = \frac{Vh_1}{\sqrt{gh_1 \cos\theta_1}}. \tag{2.16}$$

At last it should be noted that in order to consider any form of the flow section (not only at square, but any incorrect) one can use methods from [6, 7, 8], where characteristics of waterbed section are changed by expression $\frac{HB}{3} = I$, where I is the moment of torsion inertia at thickness (depth) H and width B.

ჰიდროლოგია

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