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Determining the Properties of Hyperconcentrated Flow

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Abstract: On the basis of theoretical studies and taking into account variation of the soil rheological characteristics, it was determined in the given article, that when the equivalent depth of the cohesion is equal to the depth of the flow, then the movement of the debris-flow mass is not occurred, and by changing the angle of internal friction, i.e., by its increasing, the speed of flow is reduced. It was found that a sharp jump-type variation in the free surface of cohesive debris flow occurs not only due to the dam failures that have originated as a consequence of the debris-flow storages and debris-flow mass, but always, when the flow proceeds from the rough mode to calm.

Keywords: Debris flow, Natural disasters, Hyperconcentrated flow, Hydraulic reclamation facilities, Hydraulic jump.

I. INTRODUCTION

In the context of sustainable development of the population, the damage caused by natural disasters is an issue of global importance. According to the World Conference on Natural Disasters, the number of accidents, causing great economic losses (which is 1% and more of a Gross Domestic Product), in 1962-1992 years in the world are increased by 4.1 times, the number of victims – by 3,5 times, and the number of deaths – by 2,1 times [1].

Worldwide strong influence of catastrophic debris-flows are periodically experienced by many settlements, farmlands, roads, oil and gas-pipeline route, hydraulic reclamation facilities, mining and tourist complexes, etc. The range of natural hazards covers the mountain and foothill regions where settlements are located that are characterized by a complex geological situation. The negative socio-economic, demographic and environmental impacts identified as a result of the impact of debris flows, cover all areas of human activity [2, 3].

Formation of floods, feature of their dynamics and conditions of movement on the debris cones, distinguishability among other phenomena, selection and adaptation of the design model of motion, require a special approach and proper selection of design schemes for solving individual problems [4, 5, 6, 7].

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II. Proposed Methodology

According to the statement of the practice of engineering problems, among the parameters in the equations a special place occupies by the critical depth, consequently, for its calculation, when the real depth of the debris-flow is equal to H, we use the energy equation:

$$\varepsilon = h\left(1-\frac{h_0}{h}\right)\varphi + \frac{\alpha V^2}{2g} \tag{1}$$

or

$$\varepsilon = h + \frac{\alpha V^2}{2g} - h(1-\varphi) - h_0\varphi. \tag{2}$$

In the equation (2), determination of the h_0 value is based on the method of creepage of planar surfaces, i.e. shear stress equation is:

$$P = \frac{\gamma h^2}{2}\left(1-\frac{h_0}{h}\right)^2 \varphi. \tag{3}$$

Since as, pressure force value $P = \gamma h_{b.G.}\omega$ and, accordingly, $h_{b.G.} = h/2$. In that case, when $B = 1, \omega = h$, we may write:

$$\frac{\gamma h^2}{2} = \frac{\gamma h^2}{2}\left(1-\frac{h_0}{h}\right)^2 \varphi. \tag{4}$$

With the simplification of the equation (4) and solution of the quadratic equation towards h_0, we will get:

$$h_0 = h\frac{\sqrt{\varphi}-1}{\sqrt{\varphi}} \tag{5}$$

If we consider h_0 in (2) equation, we will get:

$$\varepsilon = h - h(1-\varphi) - h\varphi\frac{\sqrt{\varphi}-1}{\sqrt{\varphi}} + \frac{\alpha V^2}{\varphi} \tag{6}$$

By differentiating the equation (6), we will get:

$$\frac{d\varepsilon}{dh} = d\left(h + \frac{\alpha V^2}{2g}\right) - \frac{1-\varphi}{\varphi}\frac{dh}{dh} - \frac{\sqrt{\varphi-1}}{\sqrt{\varphi}}\frac{dh}{dl} \tag{7}$$

And finally we will get:

$$\frac{d\varepsilon}{dh} = -\frac{\alpha Q^2}{g\omega^3}B + \varphi\left(1-\frac{h_0}{h}\right) \tag{8}$$

When the energy of cross-section is minimum, i.e. $\frac{d\varepsilon}{dh} = 0$, then:

$$\frac{\alpha Q^2}{g\omega^3}B = \varphi\left(1-\frac{h_0}{h}\right) \tag{9}$$

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Equation (9) coincides with the water flow equation.
By transforming and simplifying the equation (9), we will receive equation for calculation of critical depth:

$$h_{cr}^{\ 3} - h_0 h_{cr}^{\ 2} - \frac{\alpha q^2}{g\varphi} = 0 \qquad (10)$$

Estimated equation of critical depth, presented in the given form, can be obtained using the momentum equation that indicates the accuracy and appropriateness of the use of this model.
According to the above mention, when the velocity of the wave is equal to the flow movement velocity, the process can be examined as a jumping phenomenon. Transition from the rough mode to calm, or vice versa, is conducted by means of a hydraulic jump. During the movement in the open debris-flow channels, as in classical hydraulics and in this case we are faced with different flow conditions: rough, calm and critical.
Similar phenomena may occur in cohesive debris-flow processes. This splitting is not of a formal nature, and with a certain accuracy determines whether the assignment of the boundary conditions. In addressing these objectives, it is necessary to: build and analyze the free surface of flow motion, compute the energy disruption systems, estimate flow motion modes, determine the flow characteristics arising in consequence of failure of dams created by debris-flow storages and landslides, determine the critical height, velocity, flow rate and other parameters.
In the case of movement of a cohesive debris-flow, the flow state can be described by the following equation:

$$\frac{\alpha Q^2}{g\omega^3} B \gtreqless T \qquad (11)$$

Where: T is a dimensionless parameter and during the year it equals to 1.

$$T = \varphi\left(1 - \frac{h_0}{h}\right) \qquad (12)$$

In our case, T looks like:

Where: φ is a coefficient and depends on the angle of internal friction of the debris-flow;
h_0 - equivalent depth of coherency;
α - Coriolis factor;
Q - Flow rate of coherence debris-flow;
B,ω - width of the free surface and the area of cross-section
g - acceleration of gravity.

Determination of critical characteristics of cohesive debris-flow is presented below.
The differential equation of one-dimensional unsteady motion of coherent debris-flow has a discontinuity in the event, when the derivative $\frac{dh}{dl} = \infty$ and the denominator is 0. In such case, the following equation is relevant to the discontinuity of a flow:

$$\frac{\alpha Q^2}{g} = \frac{\omega_{cr}^{\ 3}}{B}\varphi\left(1 - \frac{h_0}{h_{cr}}\right) \qquad (13)$$

Similarly to the hydraulics of Newtonian fluids, in the case of critical state, the condition determining the critical depth is represented by the equation (13), which can also be represented graphically (see Figure 1).
In the equation (13), when $h = h_{cr}$ and the right side is equal to 1, i.e.:

$$\varphi\left(1 - \frac{h_0}{h_{cr}}\right) = 1 \qquad (14)$$

and the solution towards h_0 will be looked like:

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$$h_0 = -h_{cr}\frac{1-\varphi}{\varphi} \qquad (15)$$

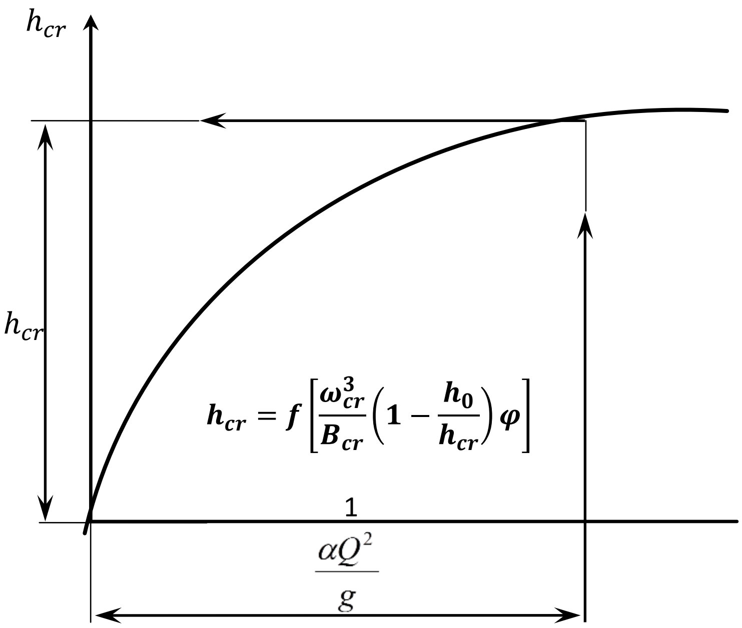

Fig. 1. $h_{cr} = f\left[\frac{\omega_{cr}^3}{B_{cr}}\left(1-\frac{h_0}{h_{cr}}\right)\varphi\right]$ graph

From equation (15) it is clear that the equivalent depth of the coherency is in the opposite direction. Its value is a function of rheological properties, as in the coherence debris-flow cohesion is c, angle of internal friction is φ and volume weight is γ, then equation for calculation of critical depth will be looked like:

$$h_{cr} = -\frac{2c}{\gamma}\frac{\sqrt{\varphi}}{1-\varphi} \qquad (16)$$

According to the above mentioned, in the equation (13), when the left side is equal to 1, than the equation for calculation of critical depth will be looked like:

$$h_{cr} = \frac{1}{\varphi}\sqrt[3]{\frac{\alpha q^2}{g}} + h_0 \qquad (17)$$

If we will consider equation (17) in the equation (15), the equation for calculation of the height of flow passage will be looked like:

$$h_0 = -\sqrt[3]{\frac{\alpha q^2}{g}}\frac{1-\varphi}{\varphi} \qquad (18)$$

When evaluating the conditions of movement of debris-flow on the transition sites, its critical characteristics acquire a special significance. In order to evaluate the critical characteristics, particularly, during determination of the critical depth, flow energy equation may be used, which is represented by the equation (10). Using Cardano's formulas, approximate solution of equation (10) will be as follows:

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$$h_{cr}=\sqrt[3]{\frac{\alpha q^2}{2g\varphi}\left[1+\frac{2g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3+\sqrt{1+\frac{4g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3}\right]\left(1+\sqrt[3]{\frac{1+\frac{2g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3-\sqrt{1+\frac{4g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3}}{1+\frac{2g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3+\sqrt{1+\frac{4g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3}}}\right)} \quad (19)$$

In the equation (19), when φ=1, $\beta=0$ and $h_0=0$, it became similar to the equation for calculation of the critical depth of water:

$$h_{cr}=\sqrt[3]{\frac{\alpha q^2}{g}} \quad (20)$$

In a case of equality of water and debris flow rates, when $q_{df}=q_w$, the equation (19) will be looked like:

$$\frac{h_{cr.df}}{h_{cr.w}}=\sqrt[3]{\frac{1}{2\varphi}\left[1+\frac{2}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3+\sqrt{1+\frac{4\varphi}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3}\right]\left(1+\sqrt[3]{\frac{1+\frac{2}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3-\sqrt{1+\frac{4\varphi}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3}}{1+\frac{2}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3+\sqrt{1+\frac{4\varphi}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3}}}\right)} \quad (21)$$

If we will consider the definition:

$$K=\frac{2}{27}\left(\frac{h_0}{h_{cr.w}}\right)^3 \quad (22)$$

The equation for calculation of critical depth will be:

$$h_{cr.df}=h_{cr.w}\sqrt[3]{\frac{1}{2\varphi}\left(1+K+\sqrt{1+2K}\right)}\left(+\sqrt[3]{\frac{\left(1+K-\sqrt{1+2K}\right)}{\left(1+K+\sqrt{1+2K}\right)}}\right) \quad (23)$$

In the presented equation (23), the member $\left(1+\sqrt[3]{\frac{\left(1+K-\sqrt{1+2K}\right)}{\left(1+K+\sqrt{1+2K}\right)}}\right)$ has a small value and in a case of its ignoring, the equation for calculation of critical depth will be:

$$h_{cr.df}=K\sqrt[3]{\frac{\alpha q^2}{g}} \quad (24)$$

where:

$$K=\sqrt[3]{\frac{1}{2\varphi}\left[1+\frac{2g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3\right]+\sqrt{1+\frac{4g\varphi}{\alpha q^2}\left(\frac{h_0}{3}\right)^3}} \quad (25)$$

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III. CONCLUSION

According to the implemented methodology, we have obtained that the sharp jump-type variation in the free surface of cohesive debris flow occurs not only due to the dam failures that have originated as a consequence of the debris-flow storages and debris-flow mass, but always, when the flow proceeds from the rough mode to calm.

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