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Hydrology

Some Issues of Hydraulic Modelling of Cohesive (Structural) Debris Flows

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Decrease of the linear measurements of constructions in laboratory conditions under high viscosity medium influence requires also to decrease working body of the prototype, i.e. to change real mass of cohesive debris flow by the body of less viscosity. The adaptive often-used numbers for cohesive debris flows in hydraulics (Reynolds, Froude, Strouhal, Euler, Weber, Ilyushin, Hedstrom) are introduced in the paper. The example of modelling of coherent debris flow (with core flow) to conduct laboratory investigations are introduced in the paper. *© 2020 Bull. Georg. Natl. Acad. Sci.*

Cohesive debris flow, modelling, adaptation of hydraulic numbers

The decrease of linear measurements of the construction under the influence of high-viscosity media in laboratory conditions requires to study working characteristics of debris flows. The above-said indicates the necessity of changing the working body of the prototype, i.e. to change the real mass of cohesive debris flow by the less viscosity body that is not necessary while investigating the issues connected with testing of the constructions under influence of water flow on them.

If the flow circulation in hydraulic laboratories occurs by means of usual centrifugal pumps, at circulation of the model working medium of cohesive debris flows (or changing working bodies) different types of installations are required. For this purpose so-called shaking water sink with two basins at the ends started to be applied in the laboratories. The testing model (construction) can be located at any place of the depending on the character of the task (on the samples of the cohesive debris flow taken straight from the prototype of the testing object) [1].

As the investigations showed the change of prototype by modelling body for continuous observation of dynamic processes under laboratory conditions is required to research modelling of cohesive debris flows. To model cohesive structural flows first of all it is necessary to adapt the main (known) hydraulic numbers for cohesive debris flows.

Below some hydraulic numbers (criteria) adapted for cohesive (structural) debris flows are introduced [2-5].

1) The critical Reynolds number:

$$\mathrm{Re} = \frac{VH}{\nu}, \qquad (1)$$

V – average flow velocity;

H – depth of the flow;

ν – kinematic coefficient of viscosity.

Average cross-section velocity of cohesive (structural) debris flow is as follows [4,5]:

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

$$f(\beta) = \frac{\beta}{2}\left(\beta^2 - 1\right) + \frac{1}{3}\left(1 - \beta^3\right), \tag{3}$$

$\beta = \frac{h_0}{H}$ – relative depth of the flow;

h_0 – depth of the core (structural part) of the flow [6];

$$h_0 = H\left(3\frac{V}{V_0} - 1\right), \tag{4}$$

$V_0 = V_{\max}$ – velocity of the flow core (structural part);

g – accelerated gravity forces.

Taking into account (2) and (3) the critical Reynolds number will be:

$$R_e = \frac{giH^3 f[\beta]}{\nu^2}. \tag{5}$$

2) The Froude number:

$$F_r \frac{V^2}{gH}. \tag{6}$$

The Froude number for cohesive debris flows taking into account (2) and (3) will be

$$F_r = \frac{gi^2 H^3 f(\beta)^2}{\nu^2}, \tag{7}$$

At $F_r \langle 1$ – tranquil flow;

$F_r \rangle 1$ – rapid flow.

$F_r = 1$ – critical state of the flow when energy characteristics at which the specific energy of the given discharge and form of the cross-section reach minimal value (e.g. critical depth, critical gradient).

In that case taking into account (2) critical depth:

$$H_{кр} = \sqrt[3]{\frac{\nu^2}{gi_{кр} f(\beta)^2}} \;. \tag{8}$$

And critical gradient:

$$i_{кр} = \frac{\nu^2}{gH_{кр}{}^3 f(\beta)^2}. \tag{9}$$

Thus, as is seen from (8) and (9), critical depth and critical gradient for rectangular river bed, together with the other parameters, depend on the square of the coefficient of kinematic viscosity of cohesive debris flow.

3) The Strouhal Number:

$$Sh = \frac{H}{Vt}. \tag{10}$$

For cohesive debris flow:

$$Sh = \frac{\nu}{tgiHf(\beta)}. \tag{11}$$

4) The Euler Number

$$E_u = \frac{\Delta P}{\rho V^2}. \tag{12}$$

For cohesive flow:

$$E_u = \frac{\Delta P \nu^2}{\rho g^2 i^2 H^4 f(\beta)^2}, \tag{13}$$

ρ - flow density,

ΔP - pressure (stress).

5) The Weber Number:

$$W_e = \frac{V^2 H \rho}{\sigma}. \tag{14}$$

for cohesive flow:

$$W_e = \frac{g^2 i^2 H^4 f(\beta)^2 H \rho}{\nu^2 \sigma}. \tag{15}$$

6) The Ilyushin Number:

$$U = \frac{\tau_0 H}{\mu V}. \tag{16}$$

For cohesive debris flow:

$$U = \frac{\tau_0 H \nu}{\mu giH^2 f(\beta)}, \quad 17)$$

where μ is the coefficient of dynamic viscosity.

7) The Hedstrom Number expresses the product of the Ilyushin criterion by the Reynolds number:

$$H_e = UR = \frac{\tau_0 H^2 \rho}{\mu^2}, \tag{18}$$

where μ is the coefficient of dynamic viscosity; $\tau_0 = \tau$ is the yield stress what is expressed by shear strength.

We multiply the numerator and the denominator (18) by the density ρ. Then we get:

$$H_e = \frac{\tau_0 H^2}{\nu^2 \rho}. \tag{19}$$

Taking into account $\nu = \frac{\mu}{\rho}$ and that $\frac{\tau_0}{g} = T^2 = gh_0 i$ (has the value of dynamic velocity), then instead of the expression (19) we have:

$$H_e = \frac{T^2 H^2}{\nu^2} = \frac{gh_0 i H^2}{\nu^2}. \tag{20}$$

Designating the corresponding parameters of the nature and model by the indexes "H" and "m", we assume that $g_H = g_m$. Then instead of (20), we have:

$$\frac{h_H i_H H_H^2}{\nu_H^2} = \frac{h_m i_m H_m^2}{\nu_m^2}. \tag{21}$$

From which it *follows that*

$$\frac{\nu_H}{\nu_m} = \frac{H_H}{H_m}\sqrt{\frac{h_H i_H}{h_m i_m}} . \tag{22}$$

In the case when the gradient in prototype and on the model is the same, i.e. $i_H = i_m$, then instead of (22) we have:

$$\frac{\nu_H}{\nu_m} = \frac{H_H}{H_m}\sqrt{\frac{h_H}{h_m}} . \tag{23}$$

While modelling the phenomenon it is necessary also to check the value of "critical velocity" (K_C) of the working prototype of the body to provide structural regime in the laboratory water sink. For this purpose we must use Esman parameter [7].

$$E = \frac{2V\rho}{\tau_0} . \tag{24}$$

Structural regime will take place if E<1000. Then we can write:

$$V_{kc} = \sqrt{\frac{E}{2}}\sqrt{\frac{\tau_0}{\rho}} = 22{,}4\sqrt{\frac{\tau_0}{\rho}} . \tag{25}$$

Dependence (25) prompts critical value of the velocity above which structural regime in clayey solutions is not observed. Given dependences (22) and (23) with account of (25) allow us to model the process of high density flows observing structural regime of motion in the laboratory conditions.

Choosing the model medium, the given dependences dictate both geometric and dynamic parameters of the flows with high viscosities. Clayey solution with different concentrations can be used as the model. Laboratory equipment to provide the corresponding investigations and circulation on the model i.e. continuous supply of clayey solution by means of the corresponding pumps should be used. The process of interaction of the flow and construction must be observed.

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