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Debris flow channel processes and determination of the lateral compression ratio

I. Kruashvili[1], W. Loiscandl[2], I. Inashvili[1], K. Bziava[3], M. Himmelbauer[2]

[1]Georgian Technical University, Tbilisi, Georgia, e-mail: iraklikruashvili@yahoo.com; i.inashvili@gtu.ge

[2]University of Natural Resources and Life Sciences, Vienna, Austria, e-mail: willibald.loiskandl@boku.ac.at; margaritahimmelbauer@boku.ac.at

[3]Ts. Mirtskhulava Water Management Institute of Georgian Technical University, Tbilisi, Georgia, e-mail: k.bziava@gtu.ge

Debris flow channels are characterized by a number of characteristics that are affected on the steady flow (with the uniform velocity). The problem deepens and becomes more abrupt in a case where the control of the debris flow in the waterway is carried out by using engineering measures. Particularly, compression of the debris flow by means of lateral structures causes its lateral deformation and occurrence of wave motion. By using the abovementioned, both the stability of channel processes and potential occurrence of deformation acquire special significance in matters of studying the stability of steady flow (debris-flow). In order to assess the stability of the debris flow and for forecasting the probable lateral compression, considering the rheological characteristics, we have derived the equation for computing the correlation between debris flow depth and wave depth, and lateral compression.

debris flow, stability of channel, wave motion.

Процессы в селевых руслах и определение коэффициента бокового сжатия

И. Круашвили[1], В. Лоискандл[2], И. Инашвили[1], К. Бзиава[3], М. Химмельбауэр[2]

[1]Грузинский технический университет, Тбилиси, Грузия, e-mail: iraklikruashvili@yahoo.com; i.inashvili@gtu.ge

[2]Венский университет природных ресурсов (BOKU), Вена, Австрия, e-mail: willibald.loiskandl@boku.ac.at; margaritahimmelbauer@boku.ac.at

[3]Институт водного хозяйства им. Цотне Мирцхулава грузинского технического университета, Тбилиси, Грузия, e-mail: k.bziava@gtu.ge

Селевые русла характеризуются рядом особенностей воздействия на транзитный поток. Проблема осложняется и становится более интенсивной, когда регулирование селевого потока в канале осуществляется инженерными методами. В частности, регулирование селевых потоков поперечными сооружениями приводят к деформации потока и возникновению волнового движения. Исходя из вышесказанного, при изучении устойчивости транзитного потока, особое внимание заслуживают стабильность русловых процессов и деформация русла. В статье, с целью прогнозирования устойчивости селевого потока и бокового сжатия, учитывая реологические характеристики, получены расчетные модели соотношения глубины селя к глубине волны, а также уравнение бокового сжатия потока.

селевой поток, устойчивость канала, волновое движение

Within the problematic of sustainable development of national economy, the debris flow occupies a special place among the natural disaster. According to the confirmed monitoring materials, often, morphometry of the debris flow waterway beds is inappropriately linked to the hydraulic parameters of flow. The fact is caused by both the deformations of waterway beds and failure of the shoreline infrastructure.

Despite the numerous scientific articles [*Makkaveev, Konovalov, 1940; Kruashvili et al., 2014a,b; Kukhalashvili, 2014*] that are dedicated to the above mentioned problem, perfect (completed) engineering (construction) norms and rules for hydraulic and hydrological computing of such type flows are still weak or totally absent in the practice. It is necessary to mention the fact that each waterway - it would be debris flow waterway or waterway, is characterized by the singularity of interaction with flow. Debris flow waterway is stabilized, when the merger of union between its morphometric and hydraulic elements of flow complies with the certain criteria.

Detection of the basic laws of interaction between the channel-bed and flow and processing their theory and computation issues, recently take a special place.

Dilemma, that was arisen regarding the interaction of riverbed and flow, has put a question to scientists to identify those laws that are emerged during the interaction of flow and structure, however the hydraulic issues related to the hyper-concentrated flows, which occupies a special place among the the natural disaster, partly left without attention.

Wave motion, which occurs in various waterways and reservoirs, is formed by different reasons and causes the various nature of motion, but it should be noted that the wave motion theory is related to the potential fluid motion, wherein the initial fluid motion is calmed.

Wave motion, the velocity of wave propagation in the determined fluid depth depends on the height h of this fluid and wavelength. When the wavelength is much bigger than its height, then the propagation velocity of its ridge (crest) can be defined by the equations derived by Lagrange, Saint-Venant or other authors.

It is known that the determination of the possibility of wave origin is closely related to the establishment of the stable criteria of uniform flow motion.

In addition, the stable motion problems are related to those unsolvable mathematical difficulties that have not been overcome yet. However, scientists from different countries at different times where repeatedly returning to study given problem and trying at least partially resolved and generated those criteria that would allow us to take in advance into account the possibility of generating of wave motion in the waterways. Since the first half of the 19th century flows were divided into two types: "quiet" and "storm" flow [*Boussinesq, 1877*].

Saint-Venant was divided flow into two types: a quiet and storm flows, but mentioned gradation of flow types where insufficient due to the frequent change of one type of flow into another or vice versa [*Vedernikov, 1946*]. V. Vedernikov made a significant contribution towards the assessment of uniform motion stability; proposed criterion by him has a number of advantages above other criteria. Using his criterion attention is drawn to the shape of a bed that will significantly impact the ability of the regime of a possible motion.

Criterion of stability of uniformly motion turbulent flow derived by T. G. Voynich-Syanozhentskiy, as the author points out, only 10% does not match in reality to the recent regime [*Voinovich, Shvarts, 1946*].

It is necessary to mention researches for the big-slope channels conducted by the specialists Thorsky G.N., Tilp P.J., Haggman P.C. From the US Bureau of Reclamation, this once again proved the great urgency of the given problem in a large undulating flows and the need for further study [*Thorsky et al., 1967*].

When the debris flow channels are formed by means of solid sediments that were moved by the debris flow, in a case on existence of regulation structures in it, it is necessary to know both bearing capacity of channel and feasible optimum value of cross-section compression of debris flow. In addition, it is necessary to consider the possible variation of shapes and sizes of debris-flow during expansion or narrowing of debris-flow channel, which is the reason of appearance of available channel deformation processes.

The task acquires a particular interest in a case, when the lateral compression of debris flow, which moves with stationary steady velocity, may occur due to the improper installation of bridges, located on the debris-flow channels and cross (transverse) regulation structures.

Lateral compression above the critical value can cause loss of both the stability of debris-flow movement regime and specific development of debris-flow channel deformation. Given problem gaining a special interest during assessment of stability of debris-flow and decision of regulation processes.

During the selection of particular regulation measures it should be considered not the average velocity, but the velocity of wave movement, because it causes (wave movement velocity) both the continuous and stepped variation of debris-flow channel morphometry.

According to the study about the influence of water wave flow movement on the erosion processes, which was conducted by Academician O. Natishvili, it was found that the value of average velocity of water flow, which moves as a wave type flow, increases by 1,5 times [*Natishvili et al., 2014*]. According to the mentioned, it is obvious, that inconsideration of wave movement may cause a high error both in channel processes and during assessment of quantitative deformations of actual channel section.

Debris flow, which was occurred due to the narrowing section of channel, is evaluated by the Low of quantity of motion, and its flow rate is equal to the multiplication of its velocity by depth. Cancelation of debris-flow narrowing causes the drop down of the debris-flow wave crest up to the minimum energy and flow takes place to the opposite direction against the debris-flow. When the initial velocity is equal toV_0, lowering of the wave crest height H up to its final depth h=h_k takes place. In this case, for the calculation of the motion velocity of wave decreasing, we may use the following equation [*Makkaveev, Konovalov, 1940*]:

$$V = V_0 \pm 2\sqrt{gH} \mp 2\sqrt{gh} \qquad (1)$$

In a case, when the wave flow spreads in the opposite direction and the initial velocity V_0 is equal to zero:

$$V = -\sqrt{2gH} + 2\sqrt{gh} \qquad (2)$$

Thus, specific debris flow rate:

$$q = Vh = \left(-2\sqrt{gH} + 2\sqrt{gh}\right)h \qquad (3)$$

A similar equation for commutating the debris-flow rate can be derived according to the wave parameters obtained due to the flow narrowing, when the debris-flow bed is inclined to the ratio plot of the motion α with angle and the wave height is important. In this case, velocity of wave spreading is equal:

$$C = \sqrt{gh\left(1-\frac{h_0}{h}\right)\varphi\cos\alpha}\left(1+\frac{3}{4}\frac{\Delta h}{h}\frac{1}{\left(1-\frac{h_0}{h}\right)\xi}\right), \qquad (4)$$

Where
C - Velocity distribution of wave (m/s);
g - Gravitational acceleration (m/s^2)
h_0 - Equivalent depth appropriated to the coherence (m);
h - Depth of the moving flow, when $h_{cr}=h$ (m);
Δh - Wave height of the moving flow (m);
φ - Coefficient representing the function of angle of internal friction (Dimensionless).

When the height of the wave is insignificant:

$$C = \sqrt{gh\left(1-\frac{h_0}{h}\right)\varphi\cos\alpha}, \qquad (5)$$

In a case of equaling the rheological characteristics to zero, i.e., when h_0=0 and φ=1,0 velocity of wave distribution matches to the velocity of water wave distribution:

$$C = \sqrt{gh\cos\alpha}. \qquad (6)$$

In a case of a significant depth of wave, equation for calculation of debris-flow rate will be looked like:

$$q = h\sqrt{gh\left(1-\frac{h_0}{h}\right)\varphi\cos\alpha}\left(1+\frac{3}{4}\frac{\Delta h}{h}\frac{1}{\left(1-\frac{h_0}{h}\right)\varphi}\right). \qquad (7)$$

When the Δh height of wave is insignificant:

$$q = h\sqrt{gh\left(1-\frac{h_0}{h}\right)\varphi\cos\alpha}. \qquad (8)$$

In a case of equaling the rheological features and channel plane to 0:

$$q = h\sqrt{gh}. \qquad (9)$$

Division of flow depth by initial area is available by equating (3) and (4) equations and can be expressed by:

$$\frac{h}{H} = \frac{4}{2+\sqrt{\left(1-\frac{h_{00}}{h}\right)\varphi\cos\alpha}\left(1+\frac{3}{4}\frac{\Delta h}{h}\frac{1}{\left(1-\frac{h_0}{h}\right)\varphi}\right)}. \qquad (10)$$

When the wave height is insignificant and α=0, the division is equal to $\frac{h}{H}=\frac{4}{9}$ and it matches with the value of division of water flow depth by its initial depth value.

During the regulation of debris-flow, when its cross section is narrowing or enlarging, disruption of the flow structure and mode change is occurred, i.e., due to the lateral deformation, stretch takes place in the compressed section of debris-flow. Due to the compression, relative value of stretch of debris-flow, when α=0, can be expressed:

$$\frac{\Delta h}{h}=\frac{2\sqrt{\left(1-\frac{h_0}{h}\right)\varphi}+\left(1-\frac{h_0}{h}\right)\varphi}{4}. \tag{11}$$

When the rheological features h_0=0 and φ=1, then the division $\frac{\Delta h}{h}=\frac{3}{4}$.

(11) equation describes the relative characteristic of the hyper-concentrated flow deformation. Particularly, by the range of change value $\frac{\Delta h}{h}$. Division of the lateral deformation with the longitudinal deformation can be determined by the following equation:

$$\mu=\frac{\frac{\Delta B}{B}}{\frac{\Delta h}{h}}, \tag{12}$$

Where:
μ is the Poisson's ratio;
ΔB – lateral compression of the flow (m);
B – flow width (m);
Δh – value, expressing the stretch of flow (m);
h – flow depth (m).

In order to describe the tension in the arbitrarily chosen point in the debris-flow body, can be described based on the main tensions:

$$\frac{\sigma_2}{\sigma_1}=\frac{\mu}{1-\mu}. \tag{13}$$

Relation between the principal stresses for the debrisflow mass, which can be introduced by the rheological characteristics, can be expressed by the following equation:

$$\frac{\sigma_2}{\sigma_1}=\left(1-\frac{h_0}{h}\right)\varphi. \tag{14}$$

In a case of equating (14) and (13) equations, the equation, computing ratio of the division of cross deformation by longitudinal deformation, can be transformed as following:

$$\mu=\frac{\left(1-\frac{h_0}{h}\right)\varphi}{1+\left(1-\frac{h_0}{h}\right)\varphi}. \tag{15}$$

Fig. 1 illustrates ratio of the division of cross deformation by longitudinal deformation, when the rheological characteristics vary within the certain range.

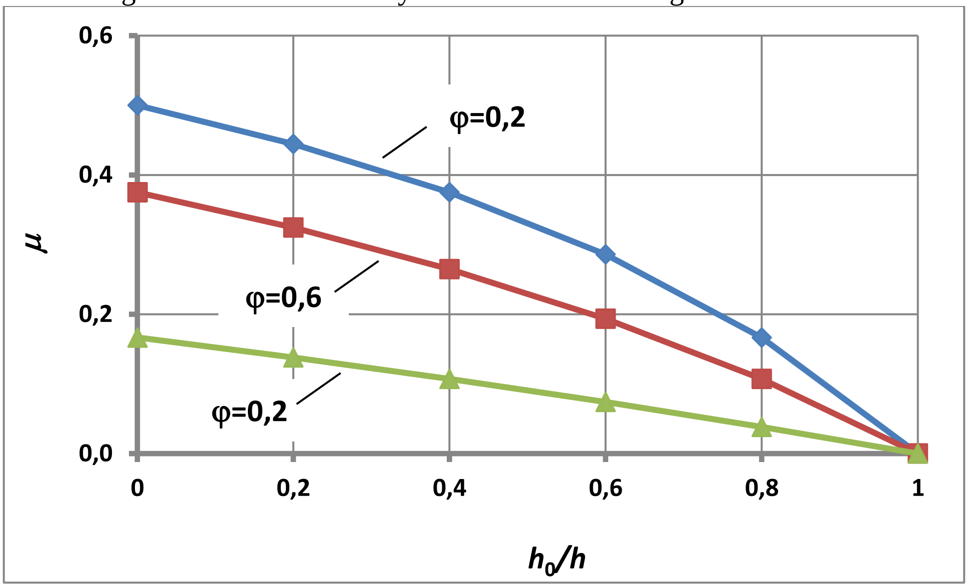

Fig. 1. Relation of ratio of the division of cross deformation by longitudinal deformation with its *C* coherency and φ coefficient of internal friction

In a case of Newtonian fluids, i.e. in the (15) equation, when h_0=0 and φ=1,0, then μ=0,5.

$$\frac{\Delta B}{B} = \mu \frac{2\sqrt{\left(1-\frac{h_0}{h}\right)\varphi + \left(1-\frac{h_0}{h}\right)\varphi}}{4}. \qquad (16)$$

If we mark the value of lateral compression of the flow by *n* and consider the value μ in (16) equation, we will get:

$$n = \frac{\left(1-\frac{h_0}{h}\right)\varphi}{1+\left(1-\frac{h_0}{hh}\right)\varphi} \frac{2\sqrt{\left(1-\frac{h_0}{h}\right)\varphi + \left(1-\frac{h_0}{h}\right)\varphi}}{4}. \qquad (17)$$

Figure 2 illustrates the relation between the variation range of the lateral compression ratio and rheological characteristics and presented by the graphical relationship

$$n = f\left(\mu, {}^{h_o}\!/_{h}, \varphi\right)$$

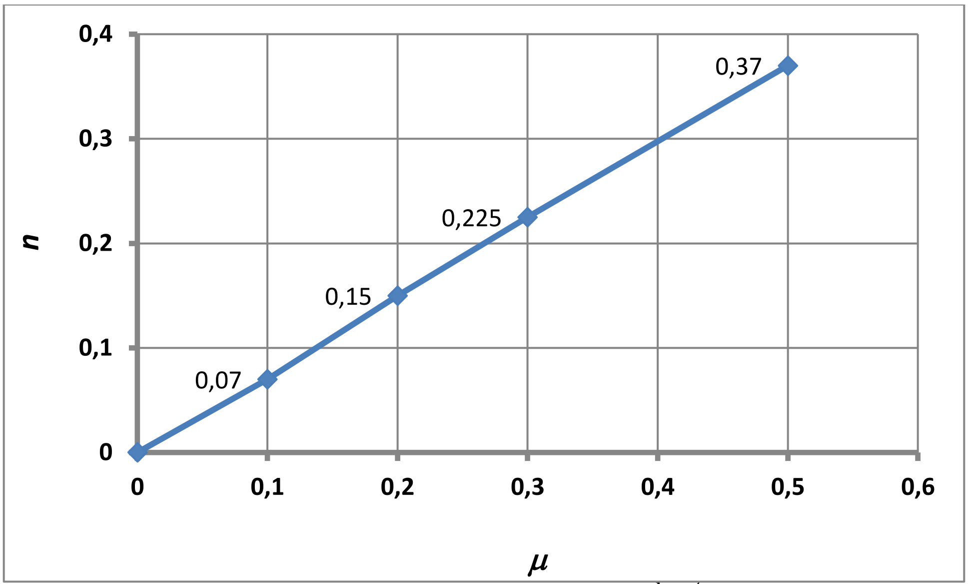

Fig. 2. Relation of lateral relative deformation of debris-flow, when h_o/h =0 and angle of internal friction φ=1,0.

Graphical relationship shows, that when rheological characteristics equal to zero and disruption of debris-flow stability is starting, the critical value of lateral compression $n = \frac{3}{4}\mu$, i.e., *n*=0,37. Obtained result is in normative convergence with the results obtained by the researches conducted on the water flow. During the regulation of water flow by means of cross structure, the graphical value of n is equal to 0,33.

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