Development of the debris flow control elastic barrage design methodology

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Abstract: In this paper, we present the debrisflow regulatory barrages innovative construction specifications. By evaluating the dynamic nature of debrisflows we determine the methodology of building debris flow regulating constructions and specific elements in said constructs. By taking in mind the river bed and its topographical parameters, we determine debrisflow regulatory elastic barrages geometrical size and we mapped out its designs specific example. By assessing the maximum discharge of the debrisflow, we determine its, dynamical, influence metrics, which in practice helps us assess the constructions reliability and risks of it being rendered unusable by the aforementioned factors.

Keywords: debrisflow reliability, risk, design, debris flow elastic barrage

Introduction

The existence of rheological different flows and complex configuration of watercourses in nature complicates the effectiveness of regulatory measures applied

during disasters. Due to the expected risk regulation and movement regime, it is important to adapt effective innovative mathematical models to this natural phenomenon (Mirtskhulava, 1975).

In the case of known debris flow ratio and watercourses bed shape, flow stability can be fully described based on a cross-sectional energy curve. Considering the non-prismatic shape of the watercourse bed, the stationary mode of motion is almost ruled out, and a different depiction of the variable stability corresponds to the positive slope of the watercourse (Beruchashvili, 1979).

New construction of elastic barrage

Creating an effective complex structure guarantees the maintenance of ecological equilibrium and stability in the environment, meaning that the creation of such barrages, where the stiffness of the structures in relation to the impact force of the flow is minimized and the shape of the structural elements of the structure and construction dimensions are specified, would be most effective (Gagoshidze, 1970). The methodology for assessing the impact of a disaster on a structure depends on its anomaly. Therefore, the effectiveness of the structure compared to the existing one should be distinguished by the impact on the flow, both in the vertical and horizontal plane. In addition, different types of construction elements and elasticity significantly improves energy dissipation (Gavardashvili et al., 2020).

In addition to the above, the arrangement of different types of flows in innovative watercourses can lead to risks when selecting structural elements, which complicates the possibilities of applying the new calculation methodology.

The paper proposes an innovative elastic barrage design with copyright and a patent (Fig. 1).
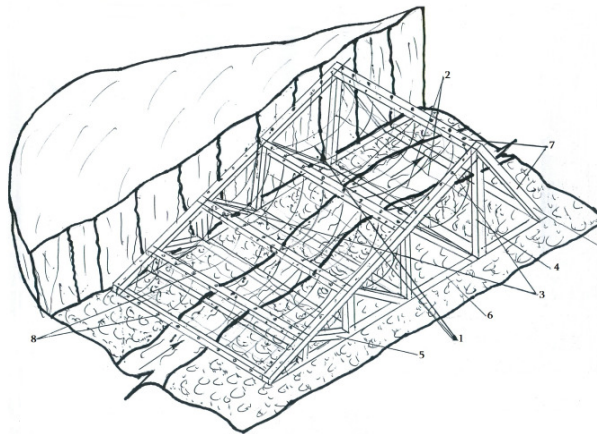

Fig. 1. Debris flow control elastic barrage (*own study*)

Unlike barbed wire structures, the innovation of the elastic barrier is presented in a constructive solution. It is made of triangular prisms connected by stems of equal height, which are placed in the bed of the mudslide.

The construction is presented in the form of sections. The hanging pressure surface is made of ropes and has a curved elastic mesh. According to the direction of the current, the height of the prism stems increases and is represented as a springboard. The size and length of the cross-section of the structure depends on the strength and structure of the debris flow. The structure is shown in Figure 1. The arrangement of the constituent elements given in # 1 is as follows: Triangular prisms (3), Triangular prism bases (4), Prism base heights (5), Prism grips (6), Attachment holes (7) or nets may be arranged in these places. Hanging hooks – longitudinal (1) and transverse (2) elastic ropes.

The height of the structure increases in the upstream direction, while the magnitude of the gap in the vertical plane varies according to the sections. The layout of the structural elements of the presented structure and the possibility of their calculation in the form of diagrams are given in Figures 2 and 3.
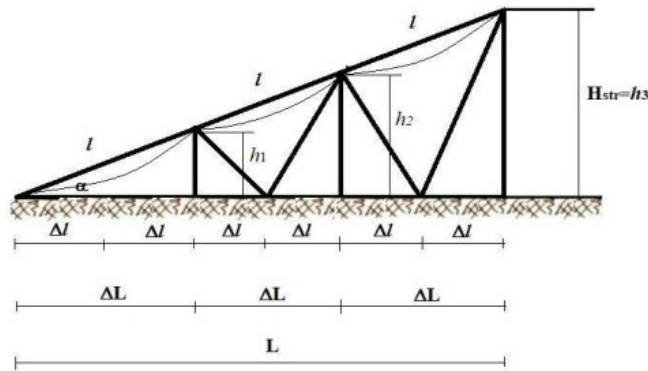

Fig. 2. Longitudinal cross-section of the Debris Flows controlling elastic barrier (*own study*)
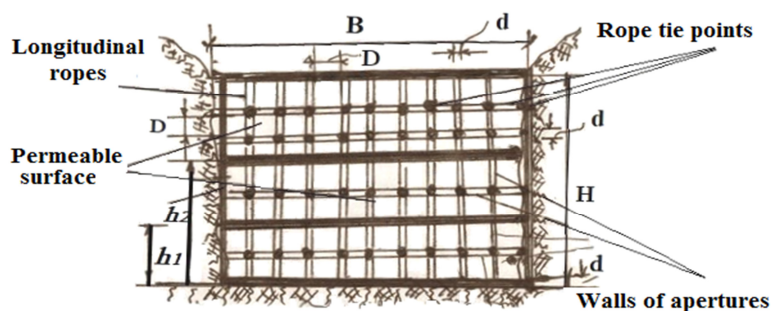

Fig. 3. Cross-section of debris flow watercourse (*own study*)

The permeable surface created by the ropes is rectangular, the cross-sectional area of which does not change with the height of the structure and is constant: the cross-sectional area of the structure is related to the debris flow capacity and hydraulic characteristics of the flow (Gavardashvili et al., 2020).

The flow force affecting the structures takes place through the permeable surface of the first part of the net. The rectangular shape of gaps and linear shape of the grooves makes it possible to ensure optimal energy dissipation (Takahashi, 2007; Vinogradov, 1980). The key advantage of using this structure over the existing structures is its multiple usability (It is not a one-time-use construction).

Completely new approaches and calculation methodologies are used when selecting the structural elements of debris flow control structures. Because of the elasticity of the pressure surface of a structure, when the width B of the bed is equal and the impact of the flow occurs across its entire surface, to ensure structural stability, the height is taken to be equal to half of its width $H_{konc} = B/2$. The number and length of sectors created by prisms are obtained equal to each other on the surface of the bed channel to increase stability $\Delta L_1 = \Delta L_2 =,.....,\Delta L_n$:

The length of the structure when the height is equal to H:

$$L = \frac{H}{\sin \alpha} \tag{1}$$

The length of the structure depends on the number of sections N

$$L = N\Delta L \tag{2}$$

Structure height in relation to sector lengths

$$H = \sin \alpha N\Delta L \tag{3}$$

Limits for changing the ratio of the height of the structure to the length of the structure

$$\frac{1}{6} \leq \frac{H}{L} \leq \frac{5}{18} \tag{4}$$

The angle of inclination to the base of the structure is based on the principle of flow conduit

$$\alpha = \left(11 \div 13\right) \tag{5}$$

Lengths of grids to be hung in sections of the structure ℓ

$$\ell = \Delta L + \Delta h = \Delta L\left(1 + tg\alpha\right) \tag{6}$$

The width of the structure d when the width of the cross-section of the ropes and the distance between the ropes are known D

$$B = nd + (n-1)D \qquad (7)$$

Structure height H, when its value is equal to $B/2$

$$H = \frac{nd + (n-1)D}{2} \qquad (8)$$

The number of ropes along the length

$$n = \frac{1}{2} \cdot \frac{B+2D}{d+D} \qquad (9)$$

Number of ropes on the width

$$n = \frac{B+D}{d+D} \qquad (10)$$

The thickness of the deaf part depends on the height and width

$$d^* = nd \qquad (11)$$

Area of the permeable part of the structure

$$\omega_{fer.} = (n-1)D \cdot \frac{(n-1)D}{2} = \frac{(n-1)^2}{2} D^2 \qquad (12)$$

The total area of the structure in the cross-section

$$\omega = \frac{\left[nd + (n-1)d \right]^2}{2} \qquad (13)$$

Structure permeability coefficient

$$K = \frac{\omega_{fer.n}}{\omega} = \frac{\left(1 - \dfrac{d}{B}\right)^2}{\left(1 + \dfrac{d}{D}\right)^2} \qquad (14)$$

Because the relative magnitude d/D is very small and has almost no effect on the permeability of the structure, the permeability coefficient can be determined by the formula (Gavardashvili et al., 2019a):

$$K = \frac{1}{\left(1 + \dfrac{d}{D}\right)^2} \tag{15}$$

During the dynamic impact of the debris-flow, when the rope length is equal to the height of the structure, the volumetric weight of the debris flow is equal to γ, ω – live cross section area [m^2]; V – flow velocity; α – the angle of inclination to the base of the structure; Π – the angle of internal friction; h_0 – linked equivalent depth [m]; H – depth of flow [m]; α^* – velocity variable coefficient (Gavardashvili et al., 2019b):

$$P_1 = \frac{\gamma \omega V^2}{g} \sin \alpha\, f(m) \tag{16}$$

where:

$$f(m) = \frac{16 - \left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2}{\left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2} \tag{17}$$

The magnitude of the force acting on the permeable structure (Iordanishvili & Sokhadze, 1974):

$$P_2 = \frac{\gamma \omega V^2}{g} \sin \alpha\, f(m) \tag{18}$$

Permeability coefficient

$$\frac{\omega_1}{\omega} = K = \frac{P_2}{P_1} = \frac{1}{\left(1 + \dfrac{d}{D}\right)^2} \tag{19}$$

Accordingly, the force acting on the permeable structure

$$P_2 = \frac{\alpha \omega V^2 \sin \alpha}{g} \frac{1}{\left(1 + \dfrac{d}{D}\right)^2} f(m) \tag{20}$$

To estimate the magnitude of the impact force on the piercing and deaf grasp, we provide the graphical relationship $P_2 / P_1 = f\left(K, \dfrac{d}{D}\right)$ (Fig. 4).
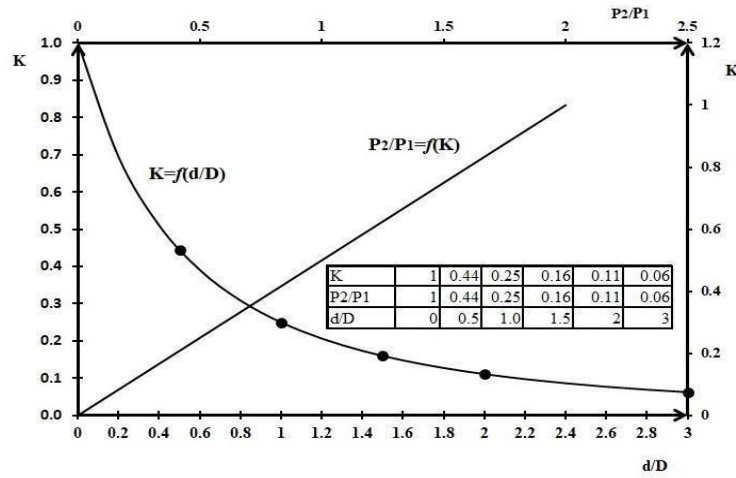
Fig. 4. The relative magnitude of the force acting on the permeable and deaf structures (P_2/P_1) dependency graph with permeability and rope d – diameter permeability D in relationship to the width ratio (*own study*)

The peculiarities of the flow motion substantiated by O. Natishvili should be taken into account when discussing the impacts on the floodplain (Natishvili et al., 1995; Natishvili & Tevzadze, 2007; Natishvili & Kruashvili, 2015). When a mudslide moves through the gradient layer and the heart, in such a case the condition of the flow motion is provided by the ratio of the equivalent depth of the link to the full height of the flow and it must be less than 0.67 (Yano & Daido, 1985); $h_0/H < 0.67$ otherwise the flow does not move.

It is estimated, the magnitude of the dynamic force on the proposed structure based on the specific assumptions. When $B = 10$ m, depth of passage in the flow watercourses $H = 5$, flow velocity $V = 5$ m/s, volume weight $\gamma = 2000$ Kg/m^3, internal friction angle $\Pi = 30°$, diameter of transported stone $D_{max} = 0.4$ m, rope diameter $d = 0.01$ m, $D_{min} = 0.2$ m and the equivalent depth of the link $h_0 = 3.0$ m, accordingly $\dfrac{h_0}{H} = \dfrac{3.0}{5} = 0.6$. Based on the dynamic model of the debris flow, the magnitude of the impact force coefficients.

$$f(m) = \frac{16 - \left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2}{\left(\alpha^3 + 4\alpha\sqrt{\alpha}\right)\left(2 + \sqrt{\alpha}\right)^2} \tag{21}$$

Striking force corrector m the magnitude of the coefficient in relation to the rheological characteristics α is expressed in terms of the magnitude of the coefficient and its significance (Kruashvili et al., 2016):

$$a = \left(1 - \frac{h_0}{H}\right) tg^2\left(45^0 - \frac{\phi}{2}\right) \tag{22}$$

A graph is given to simplify the calculation of the debris flow correction force (Fig. 5).
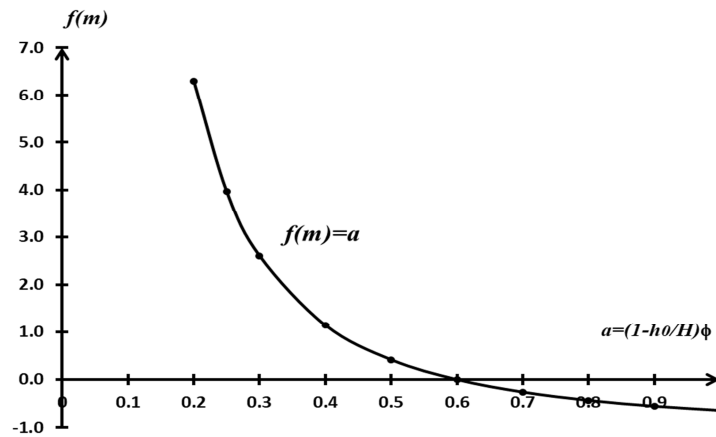

Fig. 5. Graph describing the debris flow strike force correlation coefficient in relation with the rheological features (*own study*)

The magnitude of the force acting on the structure – $P = f(m)\dfrac{\gamma\omega V^2}{g} =$

$$= \frac{2000 \cdot 5 \cdot 10 \cdot 5^2}{9.8} \cdot 4.2 = 10714.2 \text{ TN}.$$

Presented permeability coefficient of the structure, when $d = 5$ cm and $D = 40$ cm – $K = \dfrac{1}{\left(1 + \dfrac{5}{40}\right)^2} = 0.79$

Length of the structure – $L = \dfrac{H}{\sin\alpha} \dfrac{5}{\sin 12^0} = 24.03$ m

The number of sections of a structure is taken from its stability and when the number $N = 3$ section length – $\Delta L = 24 \cdot 3 = 8.0$ m.

The lengths of the grid made of ropes are taken in the longitudinal direction of the structure according to the formula (6), and the length of the grid of the structure is taken between the sectors – $\ell = \Delta L(1 + tg\alpha) = 8.0(1 + tg12^0) = 9.7 \approx 10$ m.

Permeable surface mesh dimensions D is taken as equal to the maximum stone diameter. In our case $D = 40$ cm, and the diameter of the rope $d = 5$ cm.

Number of ropes in sections by length $- n_1 = \dfrac{\ell + 0.4}{0.4 + 0.05} = \dfrac{9.7 + 0.4}{0.45} = 22.0$ pc

The number of ropes in the section in width $- n_2 = \dfrac{B + D}{d + D} = \dfrac{10 + 0.4}{0.05 + 0.4} = 23.0$ pc

Number of ropes on the structure with a length of 10 m $- N = N(n_1 + n_2) = 3(23 + 22) = 135.0$ pc

Power acting on the permeable structure $- P_2 = KP_1 = 10714.2 \times 0.79 = 8464.2$ kN

Number of structures $- N = \dfrac{P}{P - P_2} = \dfrac{10714.2}{10714.2 - 8464.2} = \dfrac{10714.2}{2250} \approx 4.76$ pc

The ratio of the diameter of the rope to the length of the permeability is given by the ratio of the impact force on the permeable structure to the impact force on the deaf structure (Fig. 6).
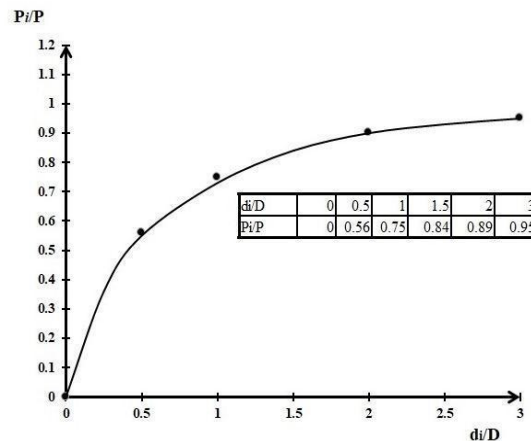

di/D	0	0.5	1	1.5	2	3
Pi/P	0	0.56	0.75	0.84	0.89	0.95

Fig. 6. Schedule of change of striking force in case of change of deaf part of the structure $(P_i/P) = f(d_i/D)$ (*own study*)

The neutralization of the striking force by the structure is of particular importance in determining the number of structures for specific cases. The number of structures is related to the permeability coefficient and its size $N = 1/K$. The relationship between the number of structures and the permeability coefficient is given in the form of a graph (Fig. 7).
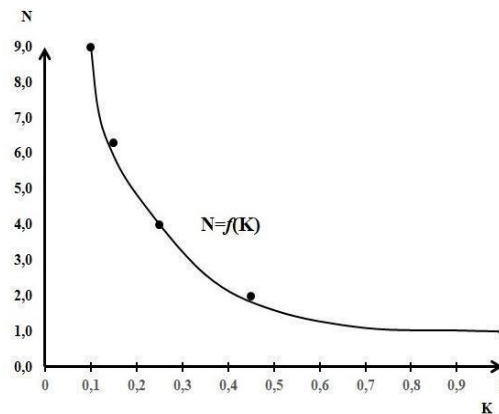
Fig. 7. Dependence of structure number on permeability coefficient (*own study*)

According to the graph when the deafness rate is $K = 0.21$. The number of structures is equal to 4.76. In this case, 5 structures are required to neutralize the impact force, as for the diameter of the rope, its reduction increases the coefficient of permeability, while the structural dimensions of the other elements of the structure remain unchanged.

Conclusion

Innovative approaches to barrage calculation have been adopted using the new calculation methodology and the use of selected models. Based on the selection of optimal permeability measures, a specified methodology for the number of structures is established.

Acknowledgements

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