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SOLID SEDIMENTS MOVEMENT REGULATING INNOVATIVE DEBRIS FLOW ELASTIC BARRAGE

Givi Gavardashvili[1,2], Eduard Kukhalashvili[1,2], Natia Gavardashvili[2]

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[1]*Tsotne Mirtskhulava Water Management Institute of Georgian Technical University*
[2]*Ecocenter for Environmental Protection the Organization in Category of Consultative Status with the Economic and Social Council (ECOSOC) of UN, I. Chavchavadze Ave. 60-b, 0179, Tbilisi, Georgia, E-mail:* givi_ gava@yahoo.com

ABSTRACT: Field-scientific and expeditionary studies were carried out in the White Aragvi river catchment basin in order to predict and regulate the movement of solid fractions on erosive-debris flow type rivers in the mountain landscapes of Georgia. Based on the above-mentioned research, the main hydrological, hydraulic, and energy characteristics of the movement of solid fractions in Mountain Rivers were determined.
In order to regulate the volume of solid fractions transported by the debris flow, the possibilities of forceful impact on the structures are evaluated, and the reporting relationships for their evaluation are derived.
The nature of the change of the lateral expansion coefficient during the movement of solid fractions in the river bed with the link currents is determined, and the possibilities of the change of the flow regimes and the movement in the channel are clarified by keeping the stationarity intact.
Based on the theoretical and field-scientific studies, a methodology was developed, using which the working project of the rainwater catchment and debris flow regulating elastic dam was implemented.
In the village of Kvemo Mleta, Dusheti municipality, in the riverbed of the river Mletis Khevi, 1650 m above sea level, an innovative construction of an Elastic debris flow-regulating barrage has been constructed, the scientific novelty of which is certified by Georgian patent certificate.

KEY WORDS: solid fractions, transport, debris flow, flow energy indicators.

1. INTRODUCTION

The Georgian military road, starting from Tbilisi and running to Larsi for almost 170 km, is a mountainous and piedmont landscape where natural disasters such as floods, water erosion of mountain slopes, debris flows, landslides, snow avalanches, and mountain slope collapses are active every year (Fig. 1). This area is the catchment basin of the rivers Aragvi (Black Sea basin) and Tergi (Caspian Sea basin), which is often called the natural laboratory of origin of natural disasters.

The Aragvi River in the territory of Georgia flows as four different rivers: Tetri Aragvi, Shavi Aragvi, Pshavis Aragvi and Khevsuretis Aragvi. Presently, the catchment basin with the most active natural disasters is the erosiove-mudflow basin of the Mleta River gorge, the right tributary of the Tetri Aragvi River. This very basin is the object of our scientific study (see Fig. 2), where floods occur at least 4 times a year.

Figure 1 Geographic location of the study object

Figure 2 View of the talus train filled with sediments of the Mleta River gorge

The debris flows formed in the Mleta River gorge channel often block the Tetri Aragvi Riverbed (Fig. 3), thus forming a natural barrier with a micro-reservoir. In case of critical parameters, the water mass disrupts this barrier, and solid fractions, together with the mudflow mass, flow towards the Zhinvali reservoir, thus reducing the lifetime of the Zhinvali HPP.

Besides, the debris flows formed in the Mleta River gorge channel put the St. Georgia Church of Mleta dated 1876 at the risk of destruction (Fig. 4), and the local population of Kvemo Mleta (Dusheti Municipality, Georgia) is also in danger.

Figure 3 Debris flow formed in the Mleta River gorge channel blocked the Tetri Aragvi Riverbed

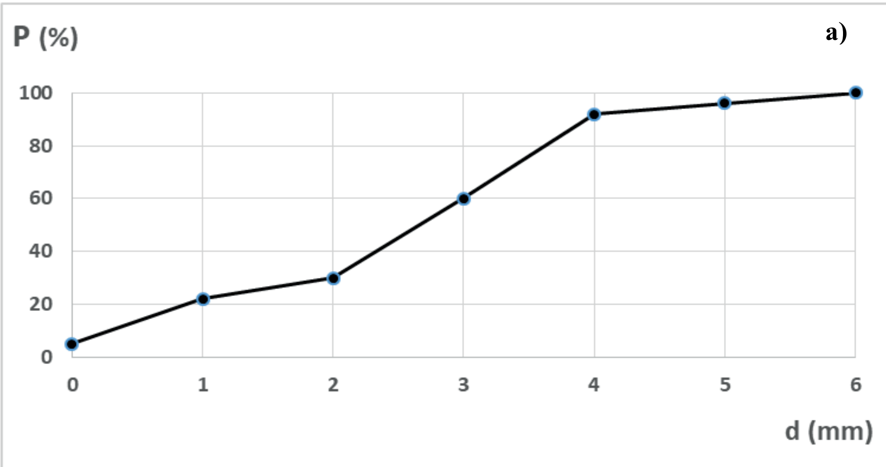
Figure 4 Yard of the Church of Mleta covered with debris flow mass and solid fractions

Following the above-mentioned, regulation of the Mleta gorge channel, the right tributary of the Tetri Aragvi, is of great strategic importance for Georgia, as sediment accumulation in the riverbed through the facility is the only engineering and technical solution for stabilizing the riverbed.

2. FINDINGS OF THE 2020-2022 FIELD EXPEDITION STUDIES IN THE MLETA RIVER GORGE CHANNEL

In order to determine the amount of solid sediment transported by a debris flow, field expedition studies were conducted, and it was found that the average diameter of solid fractions transported by the flow varied between 15 and 45 cm (Fig. 5). As for the content of fine-grained fractions in the debris flow mass and conglomerates encountered in the riverbed, their grain-size curves are given in Fig. 6.

Figure 5 General view of solid sediment transported to the Mleta River gorge channel by the debris flow



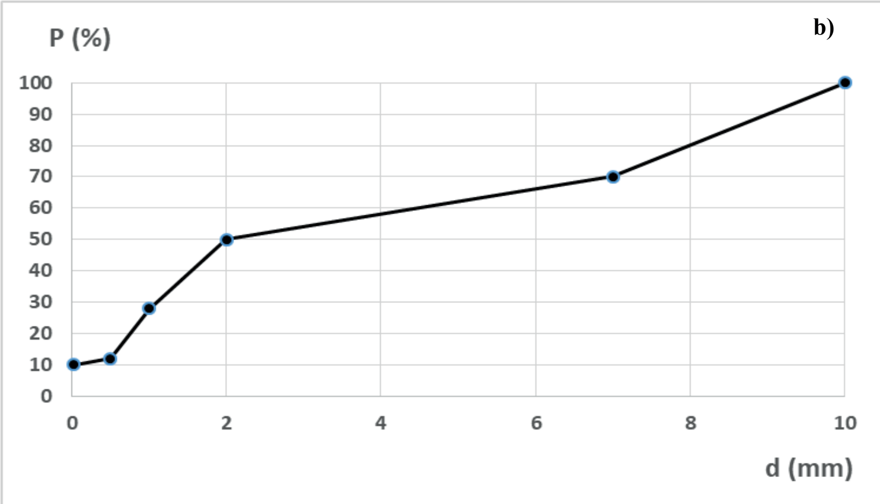


Figure 6 Grain-size curves of solid fractions accumulated in the Church yard: a) fine-grain fractions, b) conglomerates

In order to determine the main geological characteristics of the solid fractions transported from the erosive gullies of the Mleta gorge and accumulated on the talus train of the riverbed, 5 samples of eroded solid particles and soil collapsed from the left slope were taken on site, whose parameters are given in Table 1.

Table 1

Main geological characteristics of solid sediments

Sample no.	Altitude asl (m)	Coordinates		Bed slope (i)	Volumetric weight (t.force/m^3)	Density (t/m^3)	Angle of internal friction (°)
		X	Y				
1	2	3	4	5	6	7	8
First	1740	42421113	44490809	0,225	1,88	0,192	15°
Second	1785	42420526	44499444	0,242	1.89	0,193	15°
Third	1795	42420439	44499194	0,258	1.92	0,196	14°
Fourth	1807	42420232	44498986	0,276	1,94	0,197	14°
Fifth	1811	42420180	44498684	0,292	1,98	0,202	13°

As a result of the analysis of theoretical and field studies, an empirical dependence was recorded, which calculates the specific discharge of solid fractions formed in the River Mleta gorge channel and transported by flood or turbulent flow (q_{sd}).

By considering the main characteristics of the riverbed, the dependence will be as follows (q_{sd}):

$$q_{sd} = 0{,}2\ C\ i^{1{,}13} \cdot h^{1{,}5}\left(K/\bar{d}\right)^{0{,}35} \quad (\text{m}^2/\text{s}) \qquad (1)$$

Where: C is the Chezy coefficient (m0,5/s), i is the slope of the Mleta riverbed, h is the average depth of the current (m), K is the height of sediment swells on the bottom of the riverbed (m), $\bar{d}$ is the average diameter of solid fractions transported by the flow (m), 0,15< $\bar{d}$ <0,45 (m).

3. DEBRIS FLOW REGULATION ELASTIC BARRAGE TO REGULATE THE MOVEMENT OF SOLID FRACTIONS IN THE RIVERBED

In order to regulate the movement of solid fractions in mountain rivers, an innovative debris-flow regulation elastic barrage was designed at the Tsotne Mirtskhulava Water Management Institute of Georgian Technical University. The priority of the scientific and technical aspects of this innovation is certified by Georgian Patent (Georgian Patent No. GE P 2020 7068).

In order to work out the design methods for the structure, a large-scale laboratory simulation of the laboratory model of the debris flow regulation elastic barrage was carried out at the above-mentioned scientific-research institute, when the flow loaded with sediment was moving inside a hydraulic channel. The laboratory experiments will be conducted on the turbulent flow movement inside the hydraulic channel.

Fig. 7 shows the debris flow regulation elastic barrage during the laboratory tests, with the following modeling similarity parameters taken into account: dynamic similarity (*Fr = ident*), geometrical similarity (bed slope *i = ident*), sediment movement (V_{water} / $V_{sediments}$ = *ident*), bed resistance coefficient (Chezy coefficient *C = ident*).

Figure 7 Debris flow regulation elastic barrage during the laboratory tests

The dynamic impact of the flow on the innovative debris flow control structure is calculated with the following dependence:

$$P_1 = \frac{\gamma \omega V^2}{g} \sin \psi \ f(m), \quad (\mathrm{N/m^2}) \tag{2}$$

Where γ is the volume weight of the debris flow (N/m^3); ω is the area of the effective cross-section (m^2); V is the flow velocity (m/s); ψ is the gradient angle to the structure base (^{0}); ψ is the internal friction coefficient and equals to:

$$\psi = tg^2\left(45^0 - \frac{8}{2}\right); \tag{3}$$

Where h_0 is the equivalent depth of cohesiveness (m); H is the depth of current (m); a is the coefficient $(1 - h_0 / H)\psi$. $f(m)$ is the coefficient, and depends on the rheological properties of the debris flow:

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

The innovative debris flow control structure is a bearing frame made of a metal structure with steel details. Considering the technical characteristics of the structure, a point foundation was selected for it, and waterproof concrete W8, Class B25, made with Portland cement, was used for the foundations. The structure, which is in contact with the ground and the river's filtration current, is waterproofed with up-to-date insulating materials. The bearing structure of the anti-debris flow control barrage, as a single spatial system, is designed for permanent and temporary dynamic loads. The calculation was performed with the software „Lira Sapr 2019" (License Number 1/7165).

The detail project is developed in accordance with normative documents effective in the territory of Georgia: Concrete and reinforced concrete structures (03.01.-09); Building Foundations (DN 02.01-08); Building climatology (DN 01.05-08); SNiP 2.01.07.85 Loads and Impacts; SNiP II-23-81: Steel structures; SNiP 2.03.11-85: Protection of structures against corrosion. The calculation results are given in Figure 8.

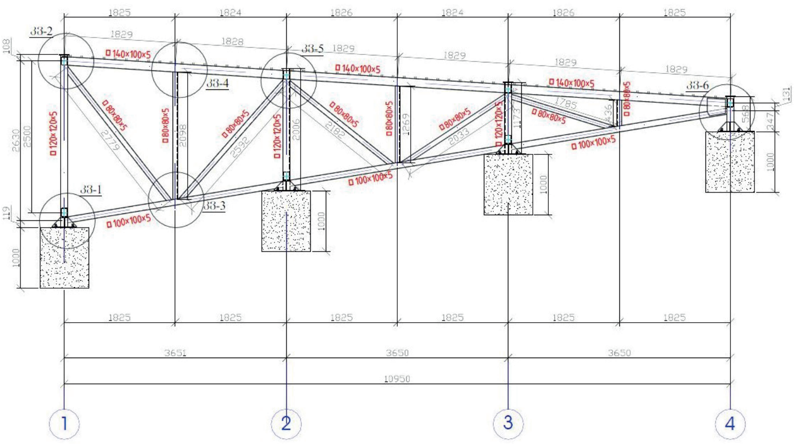


Figure 8 Longitudinal section of the debris flow regulation structure

The volume of solid fractions accumulated in the headrace of the debris flow regulation elastic barrage is calculated as a function of time according to the following dependence:

$$W_t / W_T = \left[0{,}90 + 0{,}10\left(\bar{d}/\Delta\right)^{1{,}51}\right] (t/T)^{2{,}34}, \quad (5)$$

Where: W_t is the volume of solid fractions retained by the structure at a given moment of time (m^3), W_T is the total volume of fractions retained at the headrace of the structure (m^3); ($W_T = q_{sd}.B.T$), (m^3), B - width of the river bed (m); Δ is the permeability factor of the structure, t is the elementary time period (min), T is the time of complete filling of the structure with sediments in its headrace (min). There are metal cables suspended from the steps of the structure to make the barrage open-end by providing square holes (0.15 x 0.15 (m^2). According to the design data, the structure carries water mass with solid fractions less than 0.15 m to the tailrace, while the solid fractions greater than 0,15 m remain in the headrace of the structure.

Based on the theoretical, laboratory, and field studies conducted, in order to regulate the solid fractions in the Mleta riverbed at 1600 m asl, in October 2022 an experimental model of the debris flow regulation elastic barrage was built by us, and the debris flow formed in May 2023 filled the first step of the structure with solid fractions. The general view is given in Figure 9.

View of the structure before the debris flow passage

View of the structure after the debris flow passage

Figure 9 General view of the debris flow regulation elastic barrage regulating solid fractions

The expedition and field scientific studies and their analysis in the headrace of the elastic debris flow control barrage have yielded the following results: the structure contained the debris flow mass together with solid fractions in the headrace along a 30-m section, the volume of which is 112 m^3, and the height of the debris flow mass at the first step of the structure was 1.0 m (Fig. 10).

The weight of the largest stone transported by the debris flow and retained in the headrace of the structure was 1.19 tons. The riverbed slope was 15° in the headrace of the structure before the debris flow passage in the riverbed, and the slope of the longitudinal profile of the surface of the debris flow mass accumulated in the headrace of the structure after the debris flow passage decreased by 4° to 11°.

Figure 10. Debris Flow Regulation Elastic Barrage in the Mleta River Gorge (June, 2023)

4. CONCLUSION

Based on the theoretical, laboratory, and field scientific studies conducted under the financial support of the grant project of the Shota Rustaveli National Science Foundation of Georgia "Debris flow regulation elastic Barrage" in 2020 – 2023, the following basic conclusions can be drawn:

- An innovative design of a debris flow regulation elastic barrage, the priority of which is confirmed by a Georgian patent, has been developed to stabilize mountain riverbeds;
- In order to effectively regulate sediments in riverbeds, laboratory experiments were conducted on the model of the debris flow regulation elastic barrage, when two-phase flows loaded with sediment of different diameters were flowing in the hydraulic channel;
- Based on the conducted experiments, the methodology as well as hydrological and hydraulic calculations of turbulent debris flows were worked out and used to develop a working design of the debris flow regulation elastic barrage;
- By using the working design, an experimental structure of the debris flow regulation elastic barrage was installed in the Mleta riverbed in September and October 2022;
- In May 2023, turbulent mudflow was formed in the Mleta River gorge bed, and the flow affected the experimental model of the debris flow regulation

elastic barrage with a dynamic impact force. The structure did not collapse and has been operable to date, proving its reliability.

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